

Foraging behavior and dietary preferences of *Chelonia mydas* based on coastal benthic cover and nutritional composition of macroalgae on windward O‘ahu, Hawai‘i

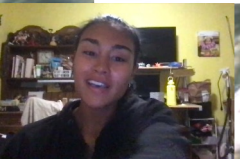
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Chelonia mydas

- Hawaiian Green Sea Turtle-Honu
- Distinct **recovering** population in HI
 - (Balazs & colleagues)
 - Threatened ESA status
 - Threats: bycatch, vessel strikes, hunting, loss of nesting habitat, climate change
- Biological transporter of nutrients + energy
- Herbivore - Recent diet shift to invasive algae
- Bahr et al. 2018 paper (on turtle foraging of *Gracilaria salicornia*) was the inspiration for our study



Question

Does the *C. mydas* diet reflect habitat-specific algal abundance or diet preference?

Approaches:

- Benthic composition of foraging habitat
- Behavioral patterns and frequency
- Nutritional composition of consumed species
- Preference for algal species



Study Area within O‘ahu



Study Sites within Kāneʻohe Bay and Kailua Bay



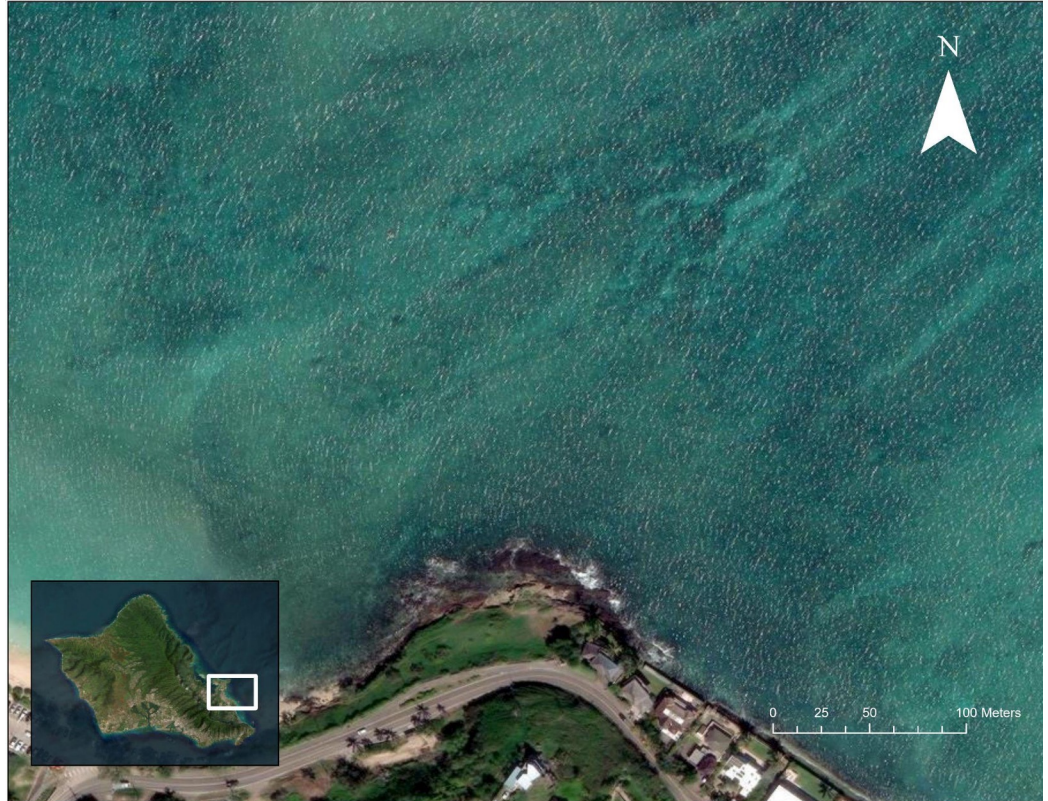
Kāneʻohe Bay - Moku o Loʻe

- 60 km²
- Largest bay in Hawaiian Archipelago
- Sheltered, on windward/Koʻolau side
- Barrier and patch reef ecosystem
- Moku o Loʻe
 - Home to HIMB
 - Well-studied biota
 - Algal-dominated
 - Marine Protected Area



Kailua Bay - Alāla Point

- 5 km²
- Isolated littoral zone
- Fringing reef ecosystem
- Alāla Point located at south end of Kailua Bay
 - Common turtle foraging site



Benthos



Acanthophora spicifera

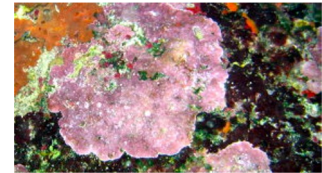


Laurencia nidifica



Turbinaria ornata

Gracilaria salicornia



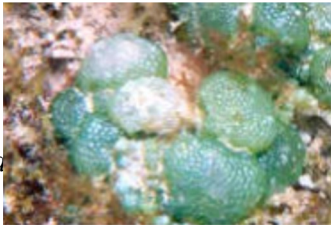
Crustose Coralline Algae (CCA)

Sargassum spp.

Red Algae



Halimeda discoidea



Dictyosphaeria versluisii



Caulerpa taxifolia

Green Algae



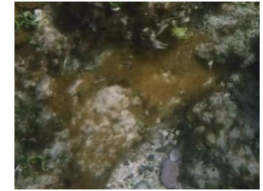
Padina spp.



Dictyota acutiloba



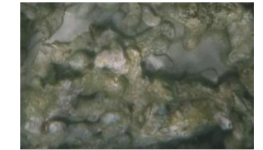
Turf



Sarcothelia edmondsoni



Silt



Rubble



Sand

Lyngbya majuscula

Brown Algae

Herbivorous Fish



Paige Cloninger

Acanthurus blochii



© Keoki Stender

Acanthurus dussumieri



© Keoki Stender

Zebrasoma flavescens



Mackenzie Theilmann

Acanthurus triostegus



© Keoki Stender

Ctenochaetus strigosus



© Keoki Stender

Zebrasoma velifer



© Keoki Stender

Scarus psittacus



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Chlorurus spilurus

Grazers

Browsers

Scrapers

Introduction



Fish Herbivory

- Overall reef health
- Prevents shifts to algal-dominated reefs
- Competition

Hypothesis:

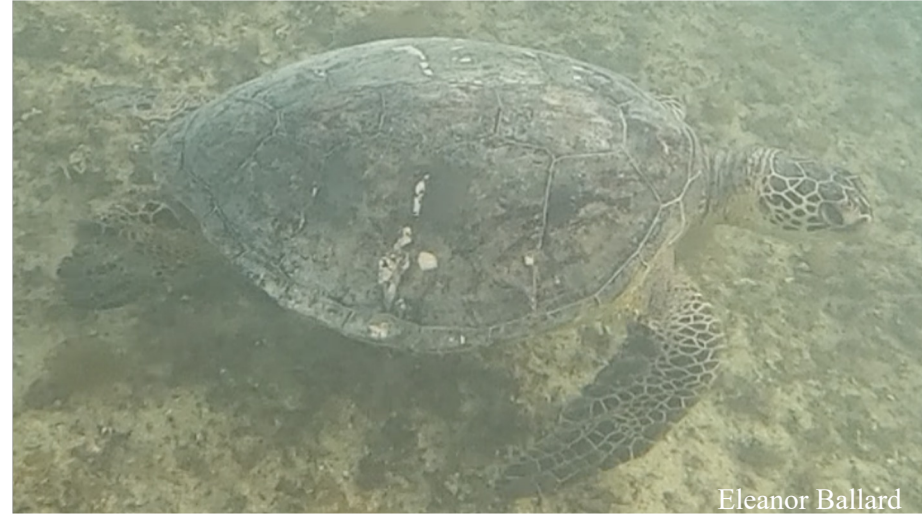
There will be an inverse relationship between herbivorous fish abundance and algal cover



Faith Gilman

Behavioral Patterns

- Common behaviors: migration, nesting, and resting
- Alāla Point presents a unique study site for foraging behaviors



Hypothesis:

Hawaiian green sea turtles spend the majority of time at Alāla Point foraging.

Dietary Preference

- Rapid increase in the abundance of non-native algal species in Kāneʻohe Bay and at Alāla Point over past 50 years
- Previous studies on *C. mydas* shift in diet to invasive algal species
 - Bahr et al. 2018
 - BIOL 403 2022 study on Moku o Loʻe and Alāla Point

Hypothesis:

Turtles will have a dietary preference for specific algal species regardless of algal abundance.

Turtle preference



VS.

Algal Abundance



Nutritional Composition

- 50 different algal species in *C. mydas* diet
 - Diet dominated by red algae
 - Generally, red algae are high in carbohydrates
 - Most algae are low in lipids
- Important for recovering population



Hypothesis:

Green sea turtles at Alāla Point and Kāneʻohe Bay prefer red algae with high levels of carbohydrates over more abundant algal species.

A large sea turtle is swimming in clear, greenish water. The turtle is positioned on the right side of the frame, facing left. Its head is slightly above the water surface, and its front flippers are extended downwards. The water is bright and clear, with some light reflections on the surface. The background shows a rocky seabed covered in green algae or coral.

Methods

Fish and Benthic Methods

- Thirty 15 m belt-transects for each site
- Perpendicular from shore
- Fish size class (TL)
 - 0-5 cm
 - 5-10 cm
 - 10-15 cm
 - 15-30 cm
- Photographs for benthic composition were taken 1 m above
- Uploaded to CoralNet
- Statistical analysis: Linear



Behavioral Methods

- Behavioral patterns of Hawaiian green sea turtles
 - 0730 to 1330
 - 10 minute (600 sec) surveys
 - 3.1 m distance from turtle

- The duration (sec) of each behavior into percentage:

$$\text{Frequency of behavior (\%)} = \frac{\text{Number of sec behavior is performed}}{600 \text{ sec}} \times 100$$



Definitions of *C. mydas* behaviors

Behavior	Definition
<i>Foraging</i>	Turtle attempts to bite vegetation on substrate or debris in the water column, or vegetation is clearly visible in the mouth and the jaw motion is up and down (Francke et al. 2013).
<i>Surfacing</i>	Turtle is at the surface or breaches the water surface. Open mouth or expulsion of bubbles may be visible (Francke et al. 2013).
<i>Aggressive Social Interaction</i>	Turtle engages in mouth gaping displays, biting, or chasing behavior with another turtle (Thomson et al. 2015).
<i>Non-Aggressive Social Interaction</i>	Turtle engages in approaching, following, body/flipper contact, or nuzzling behaviors with another turtle (Thomson et al. 2015).
<i>Defecation</i>	Visible expulsion of feces from the turtle.
<i>Swimming</i>	Turtle moves away from a stationary position at a particular location to another stationary point (Thomson et al. 2015).
<i>Other</i>	All other observed behaviors. Descriptions of “other” classified behaviors were recorded and described.

Nutritional Composition Methods

~ Kāneʻohe Bay

- Gut contents, Brunson (2020)
 - Esophageal lavage technique & necropsies



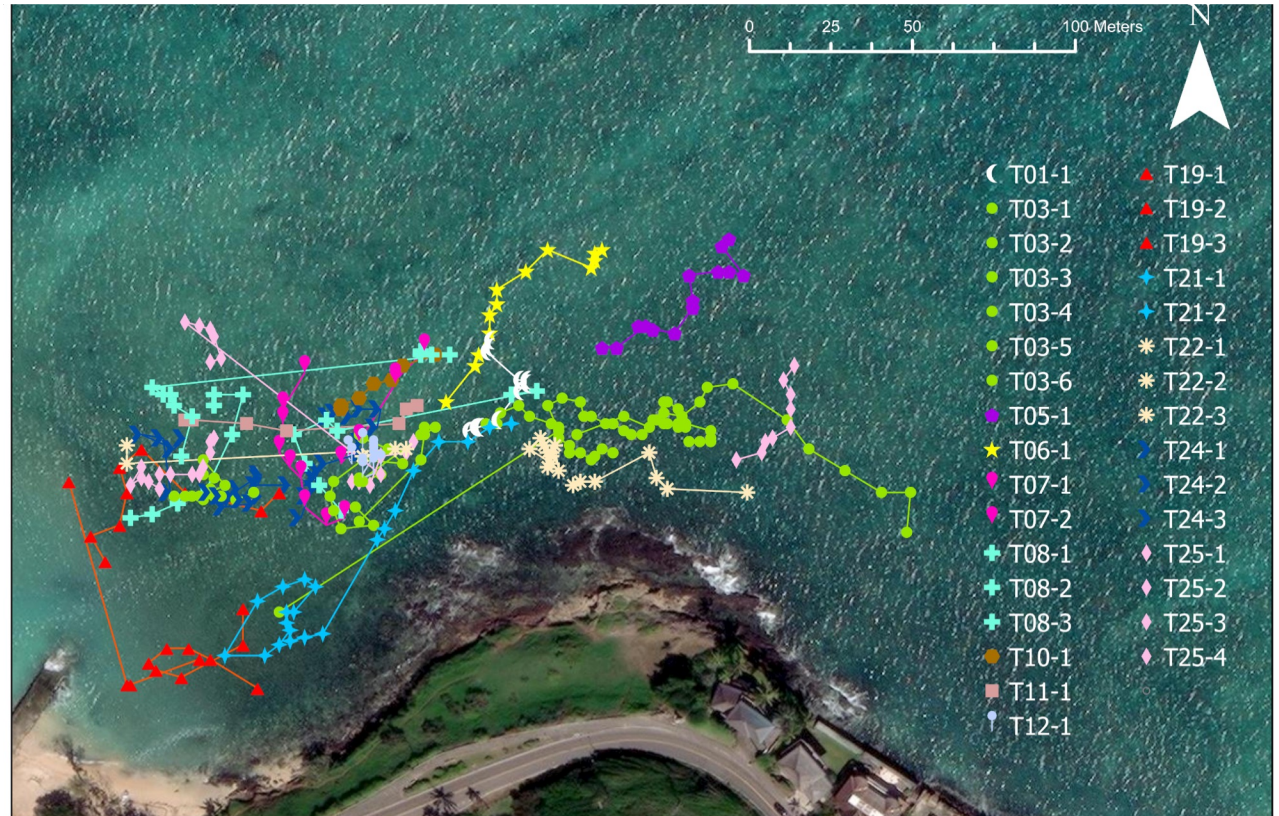
Preference and Nutritional Composition Methods ~ Alāla Point

- 10 minute survey periods
- Recorded bites tallied for each algal species the turtle swallowed
- Proportion of consumed algal species calculated
- Overall proportions of carbohydrates, proteins, lipids calculated for each site
- Nutritional composition - One-way ANOVA & Kruskal-Wallis



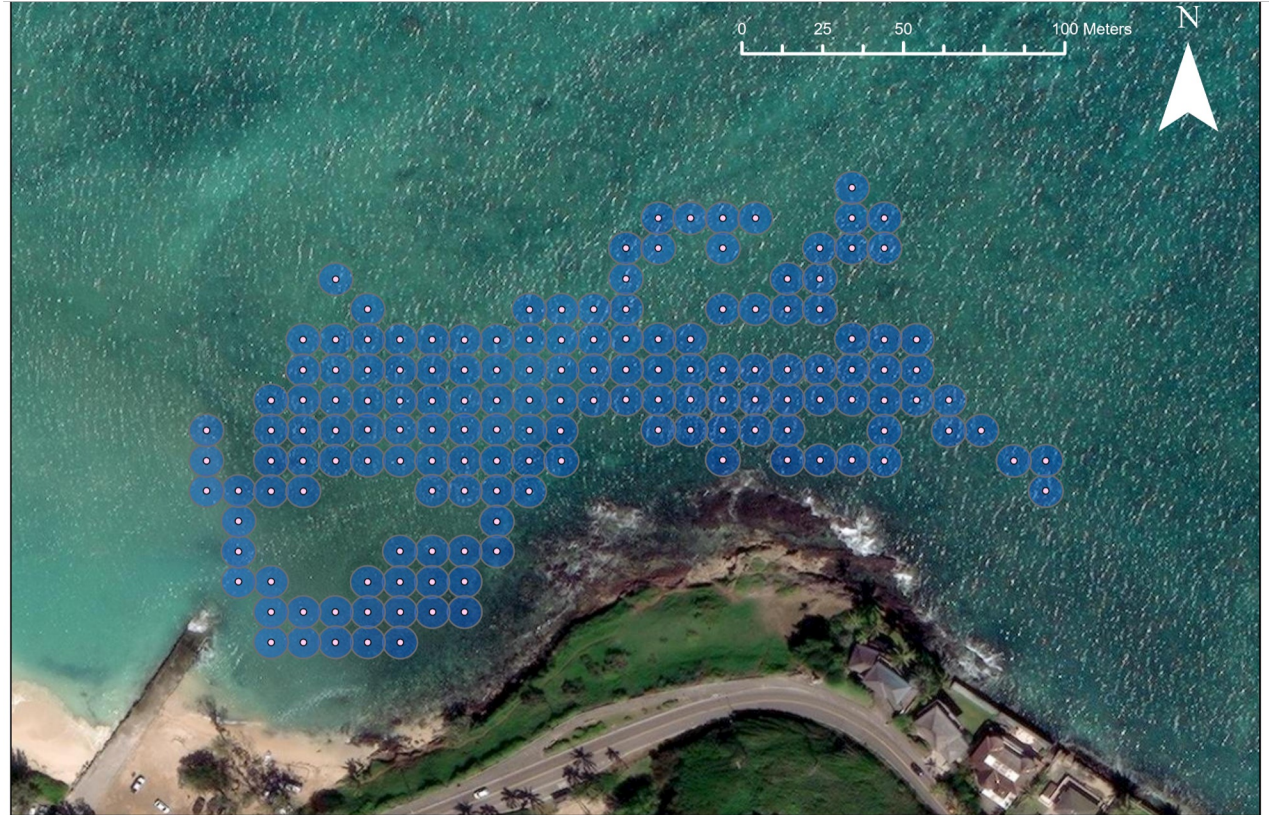
Diet Preference Pathing Methods

- 10 minutes survey period (same as bite surveys)
- Used Apple Watch Ultra GPS for points
- Imported points to ArcGIS
- Used to generate map for benthic photos



Benthic Cover Assessment Methods

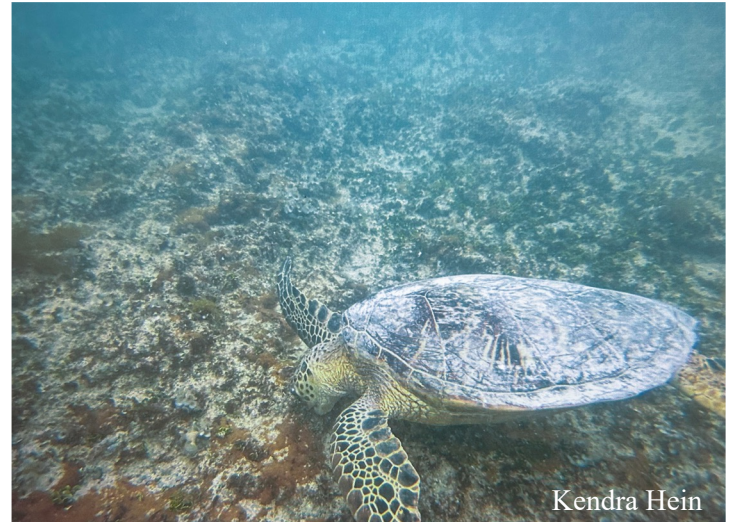
- 155 survey sites for benthic cover
- 50 points annotated at each site using CoralNet to assess benthic cover
- Used grid to interpolate coverage to make abundance maps




Statistical Analysis for Turtle Diet Preference

- A chi-square test assesses expected vs. observed values
 - Expected: benthic composition (%)
 - Observed: bites of algae per turtle (%)
- 14 surveys of the overall 9 turtles were selected for chi-square

$$X^2 = \sum \frac{(\text{Observed value} - \text{Expected value})^2}{\text{Expected value}}$$

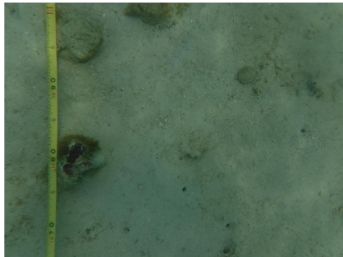


A large sea turtle, likely a hawksbill, is shown swimming underwater. The turtle is positioned in the center-right of the frame, moving towards the left. Its head is lowered towards the seabed, which is covered in coral and green algae. The turtle's shell is a mix of brown and grey, with a distinct pattern of scutes. Its flippers are spread out, showing a brown and white pattern. The water is clear, and the lighting is natural, suggesting a shallow reef environment.

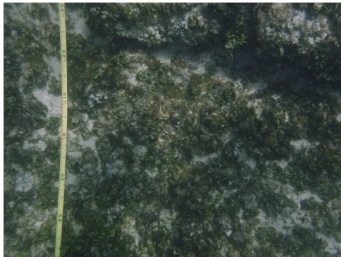
Results

Benthic Composition Results

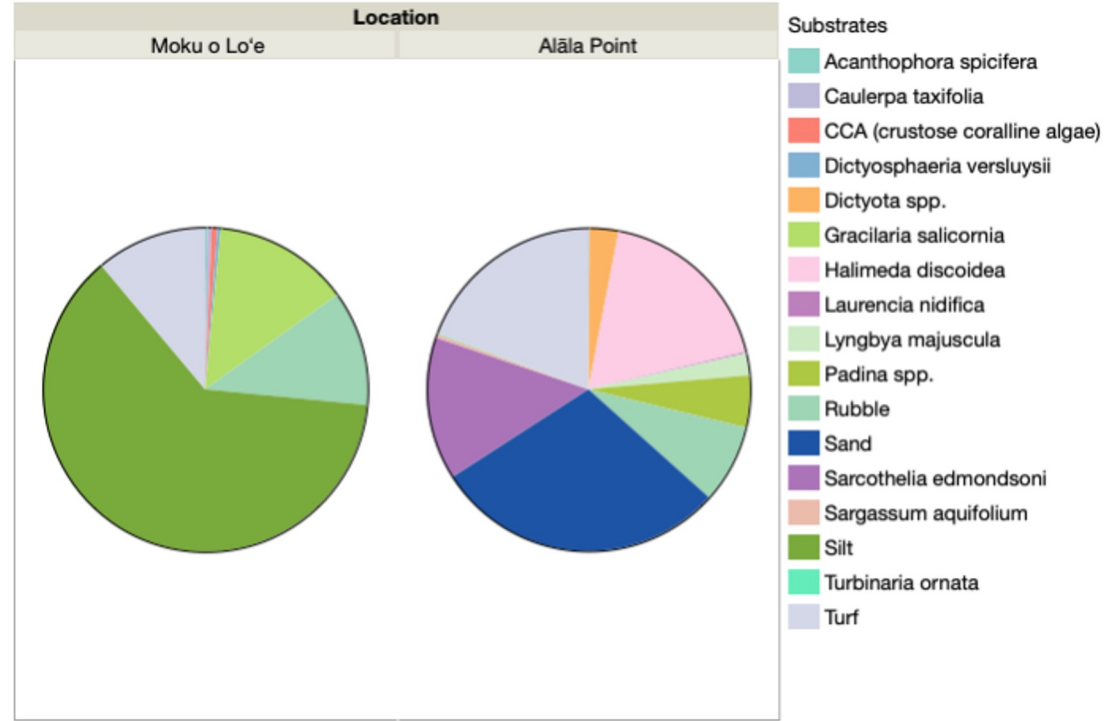
- Moku o Lo‘e dominated by:
 1. silt (57.9%)
 2. *Gracilaria salicornia* (12.6%)
 3. turf (10.3%)
- Alāla Point dominated by:
 1. sand (28.6%)
 2. turf (18.9%)
 3. *Halimeda discoidea* (17.9%)



Moku o Lo‘e



Alāla Point



Herbivorous Fish Results

- Most abundant herbivorous fish:
 - *Scarus psittacus* around Moku o Lo'e
 - *Acanthurus triostegus* at Alāla Point



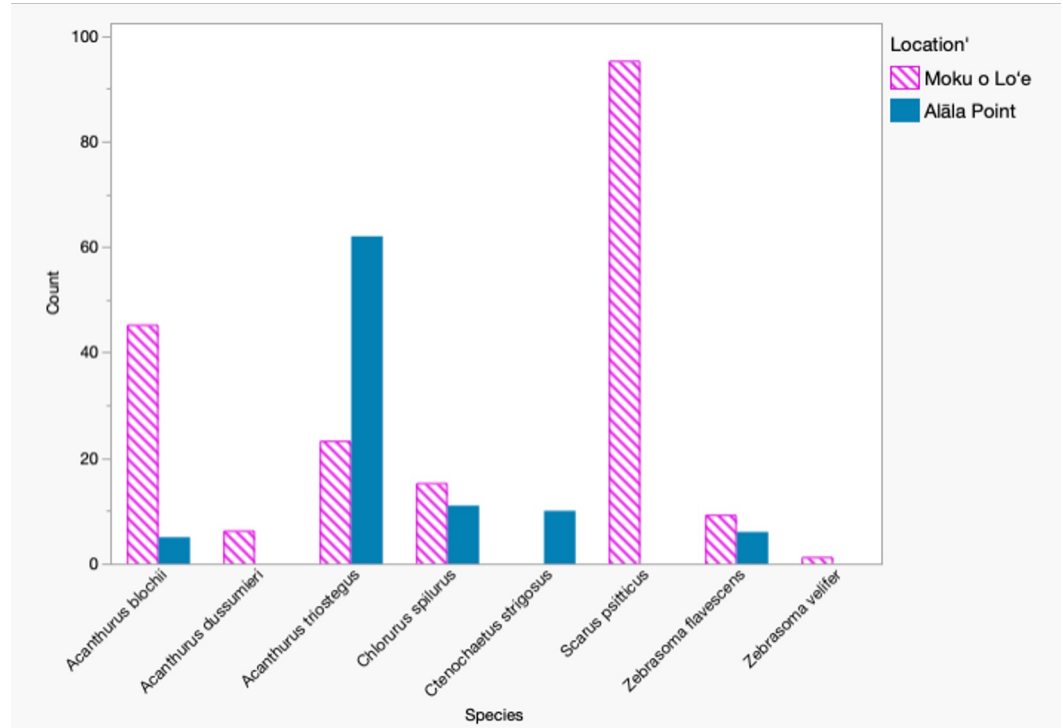
Scarus psittacus

Uhu



Acanthurus triostegus

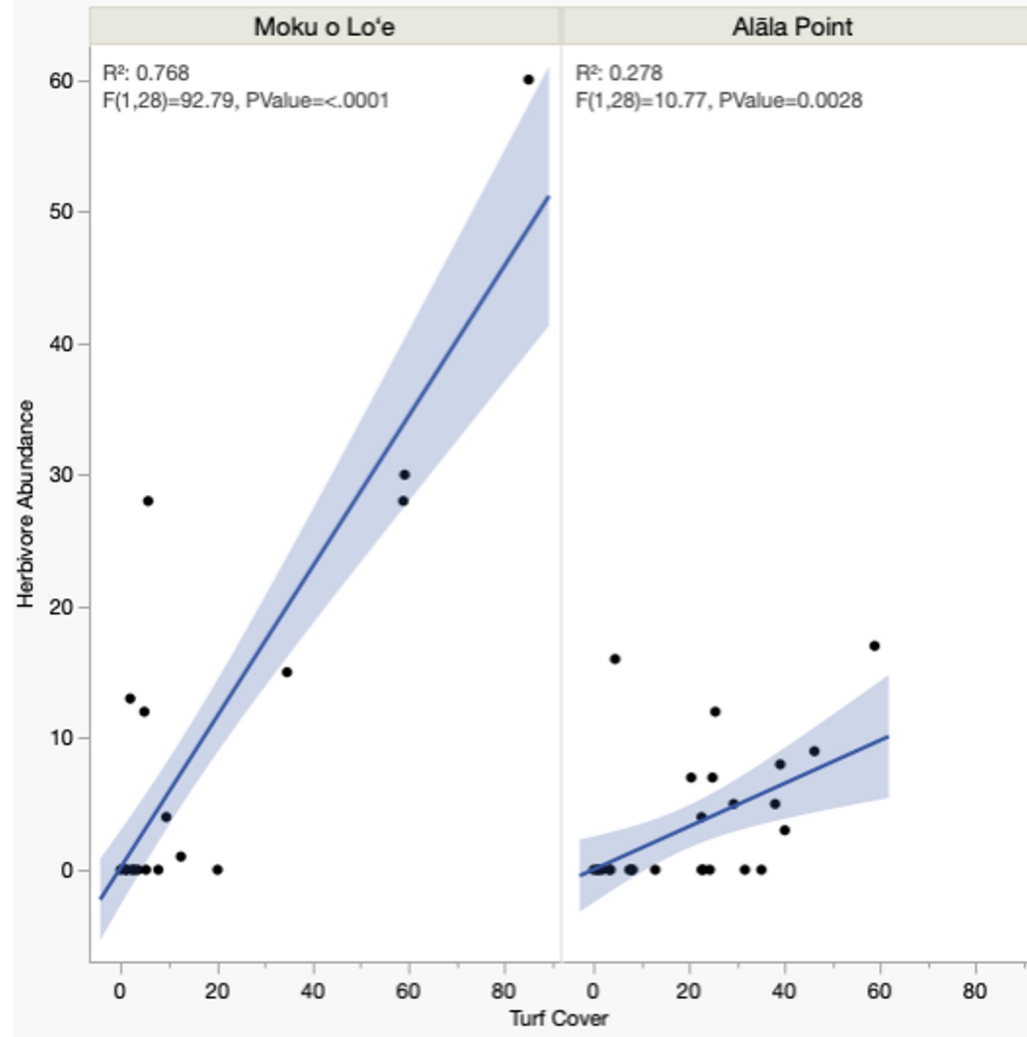
Manini



Results

(Turf Cover vs. Herbivorous Fish Abundance)

- At Moku o Lo'e
 - Statistically significant **positive** relationship
- At Alāla Point,
 - Statistically significant **positive** relationship
 - Does not represent the best fit of the data

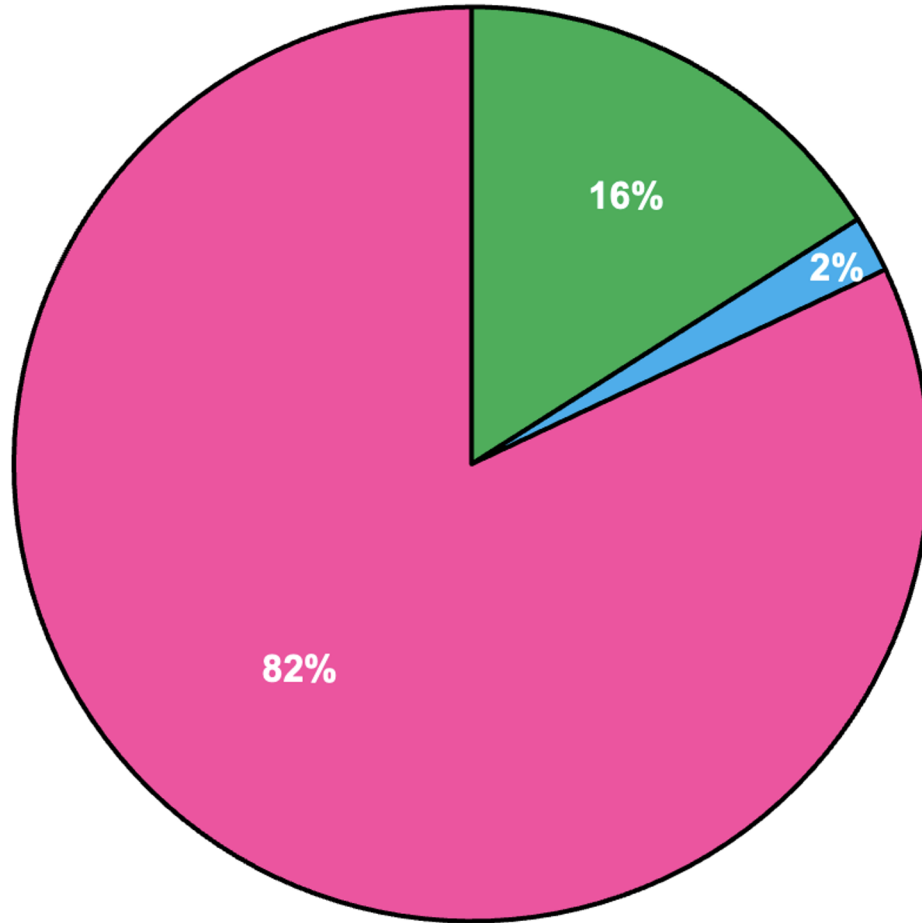


Behavioral Results

■ Foraging ■ Surfacing ■ Swimming

Percent of time spent on behaviors for all surveyed turtles at Alāla Point between July and August 2023

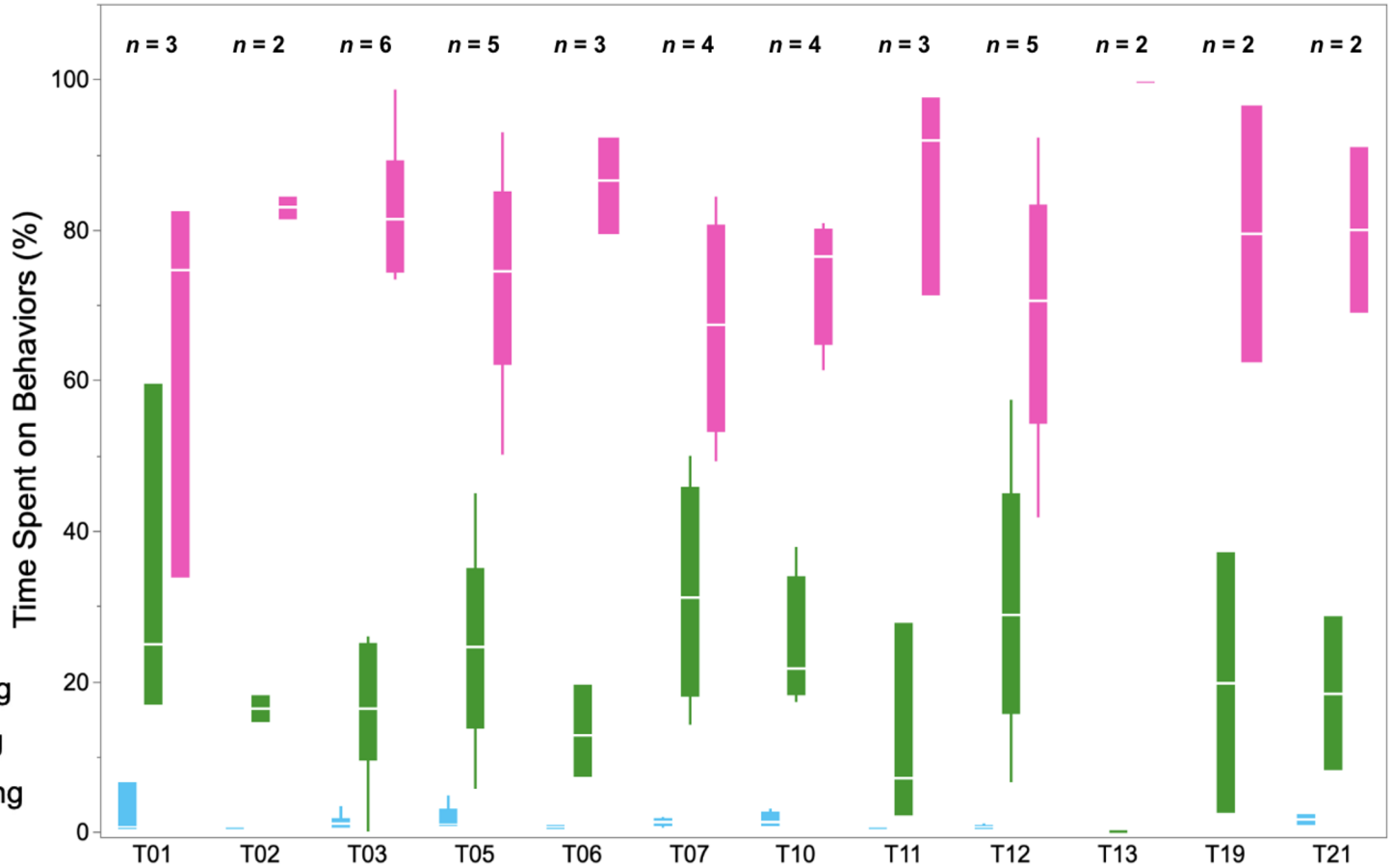
$n = 25$



Behavioral Results

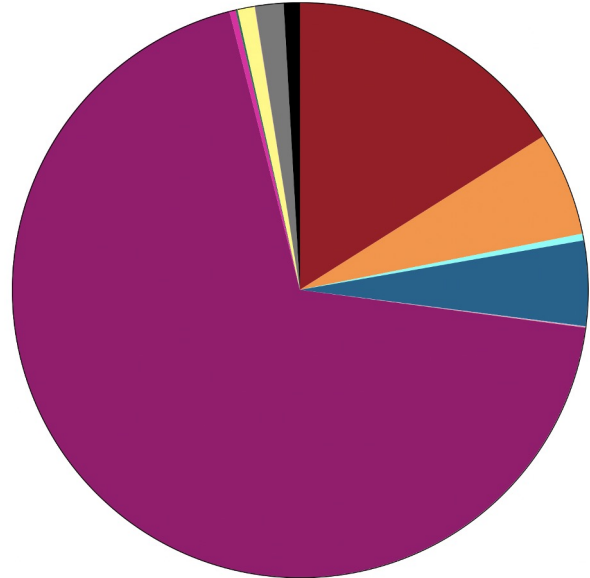
Time spent on behaviors (%) for individual turtles surveyed more than once ($n > 1$) at Alāla Point between July and August 2023. Surveys (n) of individual turtles were recorded on different days

- Surfacing
- Foraging
- Swimming



Nutritional Composition Results

Gracilaria salicornia highest in Kāneʻohe Bay Point

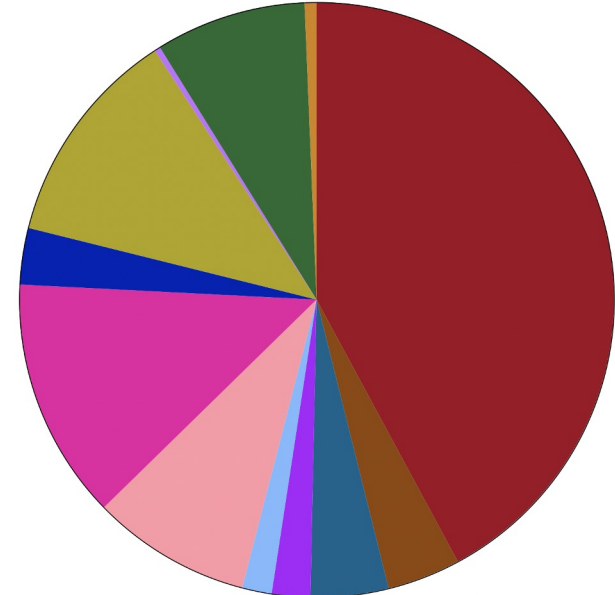


12.6% benthos

Acanthophora spicifera highest in Alāla



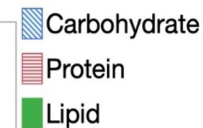
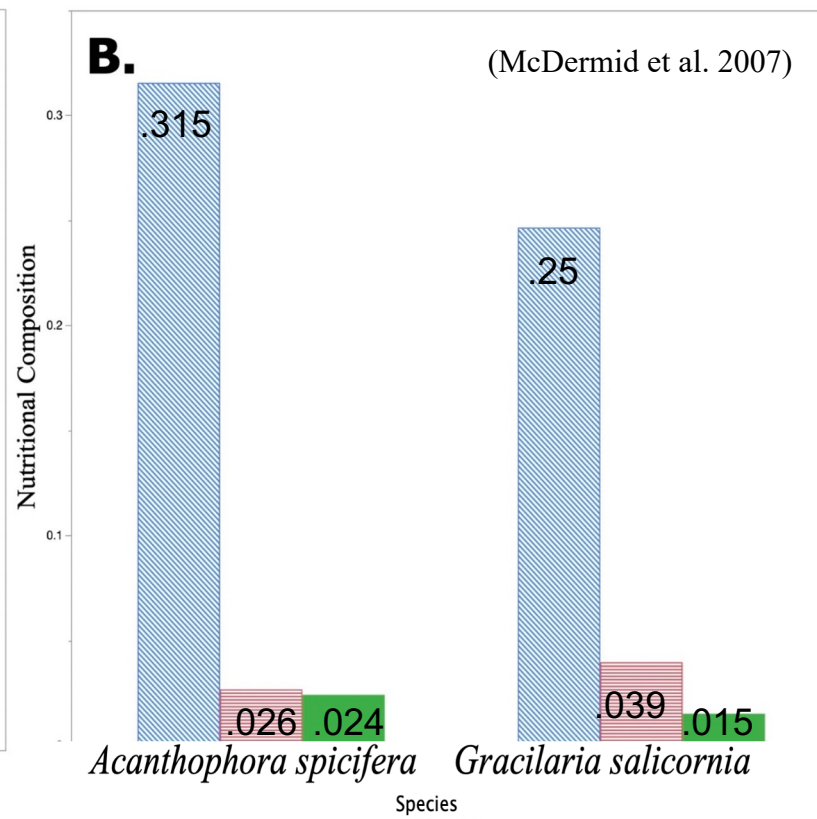
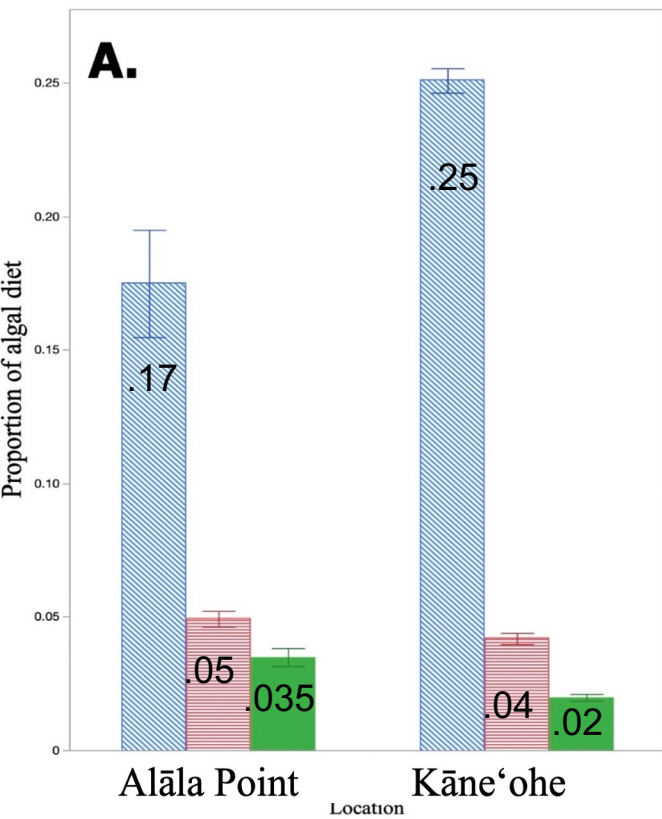
- *Acanthophora spicifera*
- *Amansia glomerulata*
- *Dasya iridescens*
- *Gracilaria salicornia*
- *Asparagopsis taxiformis*
- *Bryopsis*
- *Cladophora* sp.
- *Codium*
- *Dictyosphaeria versluysii*
- *Dictyota acutiloba*
- *Halimeda* sp.
- *Halophila* sp.
- *Laurencia nidifica*
- *Lyngbya majuscula*
- *Neomeris* sp.
- *Padina* sp.
- *Pterocladiaella capillacea*
- *Sargassum* sp.
- *Sphacelaria novae-hollandensis*
- *Turbinaria ornata*
- *Ulva* sp.
- Unknown
- Unknown Algae



6.4% benthos

Nutritional Composition Results

	p-Value
Carbohydrates	0.0003
Proteins	0.1213
Lipids	<.0001



Dietary Preference Statistics

Nine turtles were observed with multiple replicates resulting in 14 total samples selected for chi-squared analysis



Algae species	Total Bites (%)	Benthic Composition (%)	Chi-squared value
<i>Acanthophora spicifera</i>	44.8	>	229.496
<i>Halimeda discoidea</i>	13.8	=	0.334
<i>Dictyota acutiloba</i>	9.7	>	10.932
<i>Lyngbya majuscula</i>	7.6	<	3.299
<i>Padina</i> spp.	6.2	=	0.251
<i>Laurencia nidifica</i>	5.5	>	28.426
<i>Codium edule</i>	4.8	>	248.461
<i>Dasya iridescens</i>	2.4	>	446.731
<i>Dictyosphaeria versluysii</i>	2.1	>	2.702
<i>Asparagopsis taxiformis</i>	1.4	>	292.135
<i>Sarcothelia edmondsoni</i> *	1.4	<	11.831
<i>Neomeris</i> sp.	0.3	=	3.029
<i>Caulerpa taxifolia</i>	0.0	=	0.052
<i>Sargassum aquifolium</i>	0.0	=	0.219
Other (abiotic)	0.0	<	42.348
Total			1320.247

Individual Turtle Dietary Preferences at Alāla Point



Turtle ID	Top Eaten Algae	Bites (%)
T03	<i>Acanthophora spicifera</i>	44.4
T05	<i>Acanthophora spicifera</i>	65.0
T07	<i>Lyngbya majuscula</i>	41.7
T08	<i>Acanthophora spicifera</i>	47.4
T19	<i>Acanthophora spicifera</i>	71.4
T21	<i>Acanthophora spicifera</i>	51.4
T22	<i>Codium edule</i>	30.0
T24	<i>Acanthophora spicifera</i>	47.7
T25	<i>Acanthophora spicifera</i>	77.4

A large sea turtle, likely a hawksbill, is shown swimming in clear, greenish water. The turtle is positioned on the left side of the frame, facing right. Its shell is a mix of brown and tan with distinct scutes. The water is a uniform, slightly hazy green. A semi-transparent grey rectangular box is overlaid on the right side of the image, containing the word "Discussion" in a white, serif font.

Discussion

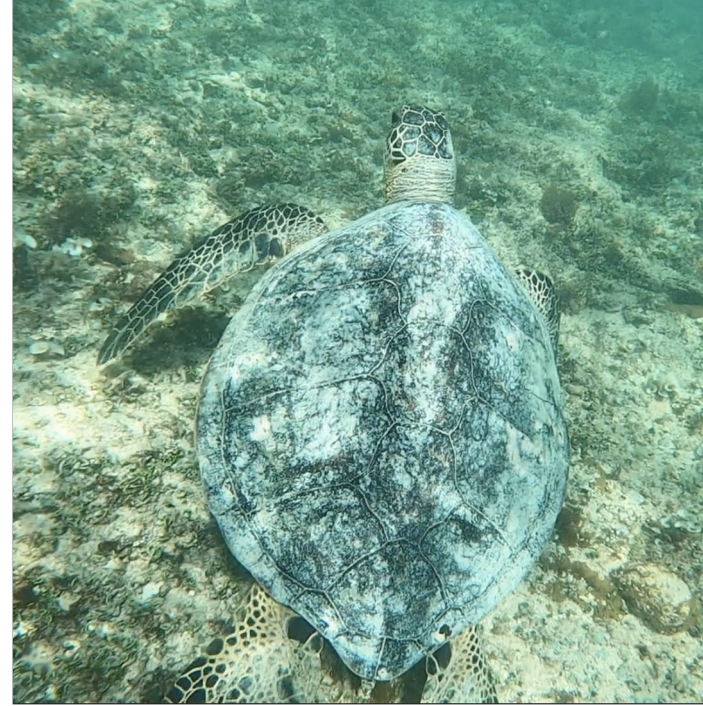
Herbivory

- Abundance of herbivorous fish increased as turf cover increased at Moku o Lo'e
- At Alāla Point, percent cover of turf did not explain abundance of herbivorous fish
- No take marine reserve may be reason for higher abundance at Moku o Lo'e
- Percent cover of *Gracilaria salicornia* consistent with Bahr et al. 2018 study



Behavior

- Hypothesis is rejected
 - Majority of time at Alāla Point was spent swimming
- Limitations:
 - Age and sex of observed turtles
 - Morning & afternoon hours
- Future studies:
 - Invasive techniques to identify age/sex
 - Expands analysis
 - Assess temporal changes in behaviors of green sea turtles individuals throughout a day and over a year



Eleanor Ballard

Nutritional Composition

- Proportion of carbohydrates outweighed proportion of proteins and lipids in the mean algal diet
- Food selection relates to nutrient and energy intake (McDermid et al. 2007)
 - Carbohydrates provide glucose
- The closest match to each observed algal genus was made for each site
- Proportions calculated from bites and wet mass
- Difference in sample sizes

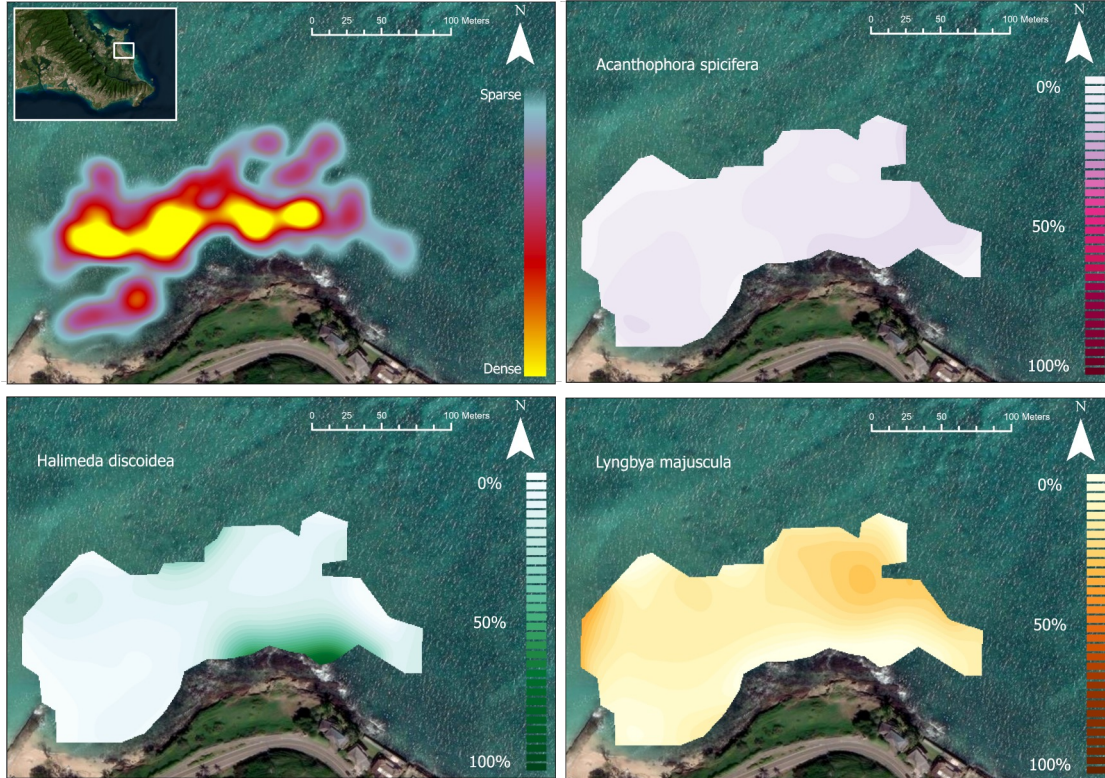


Nutritional Composition

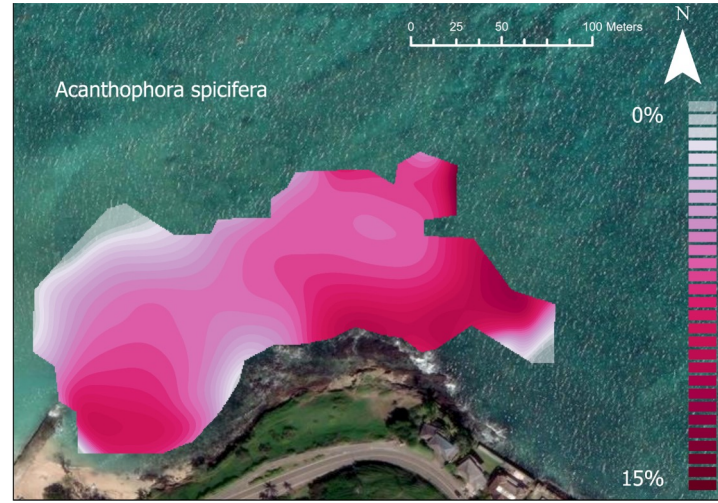
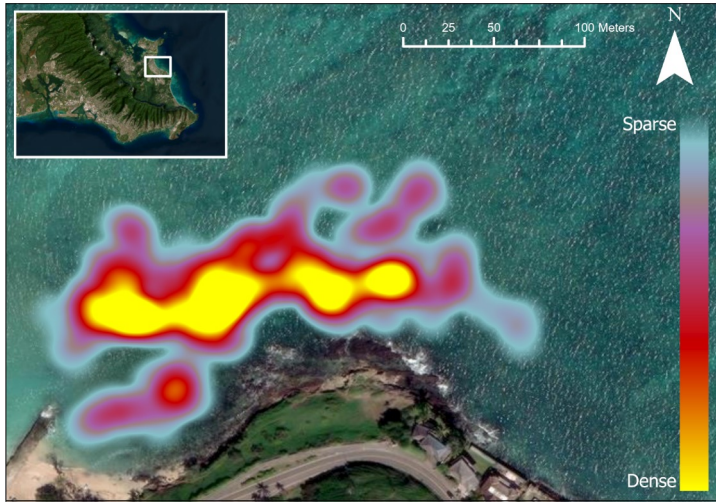
- 11 species from Alāla Point and 10 species from Kāneʻohe had known nutritional composition values
- Unable to calculate energy budget due to lack of site-specific information on common algae species
 - bites/wet mass vs. ash-free dry weight
- Determining full, diurnal representation of the Hawaiian green sea turtle diet



Dietary Preference



- Foraging Density Heatmap
- % benthic cover by algae



Intense grazing seen with other terrestrial and marine herbivorous species:



Dedicated to Shandell Brunson

We would like to thank the late Shandell Brunson for her dedication and love of sea turtle research with NOAA Fisheries and as a master's student in the School of Life Sciences at the University of Hawai'i at Mānoa.



Acknowledgments

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Questions?

