Keepers of the Reef: *Chelonia mydas* and The Ecological Implications of Tourism Interactions in Kāne‘ohe Bay

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Abstract: Throughout history, eco-tourism has been used to foster relationships between the natural environment and general public, however it is only truly beneficial when performed in a non-consumptive manner. The term "non-consumptive" is similar to that of "take," meaning no pursuit, harm, or harassment. However, even the term harassment can be species specific, and therefore research-based evidence is crucial in defining this context-dependent term. Kāneʻohe Bay has quickly become a hot-spot for eco-tourism, as snorkel tours deploy in designated recreational areas daily, but with little to no regulations for tourist-wildlife interactions. Due to its charismatic value, green sea turtles (*Chelonia mydas*) in Hawai'i are frequently subject to such interactions with only loose guidelines to protect them. To validate the ecological importance of *C. mydas,* examine the effects of tourism-based interactions, and reveal the need to safeguard this valuable species from consumptive eco-tourism, observational surveys and quadrat sampling methods were performed in high-tourism and low-tourism (control) sites within Kāneʻohe Bay. After surveying 9 reefs in total, we found that while higher tourism rates did not affect distribution or exhibited behavior type, they did cause significantly lower rates of flee response (mean=4.17%), revealing that these turtles are habituating to tourism interactions over time in comparison to control turtles (mean=95.24%). Additionally, after photographing 12 sleeping coves, all three coral types were found to be significantly different in presence/absence counts when comparing coves with areas adjacent, with Fungia being 26.8x more likely in a cove than adjacent. At all reefs, no *Acanthophora* or *Hypnea* spp. cover was found through CoralNet analysis, which may be due to the non-significance in distribution. These results reveal not only the crucial role *C. mydas* play in coral reef ecosystems, but also the detrimental effects which result from repeated, unregulated tourism interactions. Further research regarding the consumptive manner of non-regulated eco-tourism in Kāneʻohe Bay is therefore crucial.

Keywords: Eco-tourism, Chelonia mydas, Non-consumptive tourism, Behavioral observations,

Snorkeling, Coral reefs

INTRODUCTION

Historically, eco-tourism has been commonly used to create a connection with our natural environment and the general public. However, the practice of eco-tourism is only beneficial to the wildlife itself when it is executed in a non-consumptive manner (Landry & Taggart, 2010). The term "non-consumptive" itself is context-dependent, and for that reason many areas of eco-tourism have difficulty in clearly defining it. This vagueness is mirrored in the lack of specific federal or state regulations for in-water tourism interactions, specifically in the case of Hawai'i's green sea turtle (*Chelonia mydas*) population (Meadows, 2004; NOAA Fisheries, n.d.). The answer to defining non-consumptive tourism, and therefore implementing clear and useful regulations, lies in research-based evidence. While previous studies show that tourism-based disturbances impact the behavior of immature *C. mydas* (Griffin et al., 2017), this trend has yet to be examined in the mature population of *C. mydas* present on O'ahu.

Kāne'ohe Bay has quickly become a hot-spot for in-water tourism, and the population of *C. mydas* residing there are therefore frequently subject to tourism-based human interactions. With multiple boats holding snorkeling cruises per day, it is crucial that the potential adverse effects of such interactions are further examined. As consumers of invasive algae such as *Acanthophora* spp. and *Hypnea* spp. (Wabnitz et al., 2010) and potential ecosystem engineers by altering reef structure to create sleeping coves, *C. mydas* contribute toward reef resilience and diversity. However, a change in natural behavior caused by tourism-based disturbances, could result in increased predation and inefficient energy expense (Hayes et al., 2017). As well, these disturbances could cause habituation in *C. mydas*, which could in turn reduce avoidance towards predators such as sharks (Griffin et al., 2017). Due to their heavy influence on reef health and resilience, adverse population effects due to decreased predation avoidance could ultimately lead to the deterioration of Kāne‘ohe**’s** patch reefs, consequently effecting the delicate communities that live there.

This study sought to examine the critical role of *Chelonia mydas* in Hawaiian patch reef ecosystems, and the effects non-regulated tourism interactions may be having on this species. We had 5 main hypotheses when examining the ecological role of *C. mydas* and the implications of tourism: 1.) Frequent tourism use alters the distribution of C. mydas in Kāne‘ohe Bay. 2.) Frequent tourism interactions cause a change in the exhibited behaviors of C. mydas. 3.) Frequent tourism use causes a decrease in flee response rates due to habituation. 4.) C. mydas alter coral type distribution within their patch reef communities by producing sleeping coves. 5.) C. mydas serve as bio-controllers in their communities by consuming invasive algae. We tested these hypotheses in Kāne‘ohe Bay, by conducting observational surveys of sea turtle behavior in patch reefs with a heavy tourism presence, and those with a light tourism presence. Additionally at the same patch reefs, quadrat surveys were performed to compare the biodiversity within the sleeping coves of *C. mydas* with that of the area adjacent. Using substrate quadrats on a 6 meter transect at the same patch reefs, relative abundances of invasive algae (*Acanthophora* and *Hypnea* spp.) were assessed using CoralNet, with the purpose of further quantifying the important role of *C. mydas* within their ecosystem. By conducting this study, we have provided research-based data which could be useful when forming future eco-tourism legislation—a crucial step in the road to non-consumptive “use” of wild species.

METHODS

Study site

Surveys were conducted in the central and lower northwestern regions of Kāne‘ohe Bay on O’ahu, Hawai’i (Figure 1). For each high-tourism site, there was a closely adjacent control site

(Reefs #12, #13, #41, #43, #44) to avoid spatial skew. High-tourism areas (Reefs #8, #14, #15, #39) were determined by Hawaii Code R. § 13-256-73. Therefore, we had four study sites in total: high tourism central, low tourism central, high tourism lower-northwestern, and low tourism lower-northwestern. Analyzation methods of any field photos were performed remotely at a later time.

Tourism-based disturbance

Data examining the effect of tourism-based disturbances on *C. mydas* was collected via observational surveys. During each survey, which had a duration of 15 minutes and was replicated twice, divers swam the perimeter of the designated patch reef, recording any data unto an underwater slate and maintaining an even pace to ensure consistent methods. Start times of each survey were noted via a waterproof watch. If a turtle was spotted, the exhibited initial behavior and movement type was recorded. The approximate life stage of each turtle was estimated and recorded via carapace size, with a carapace of less than 0.8 meters signifying a juvenile and greater than 0.8 meters signifying an adult. Sex of the turtle was also recorded, which was estimated by typical tail length procedures (male tails protruding far beyond the carapace, and female tails appearing much shorter in comparison, barely extending past the carapace or being covered entirely) utilized in many previous studies (Jensen et al., 2018; Thomson et al., 2015). If the turtle was sedentary when spotted, one diver made an approach to a distance of approximately 2-3 meters. Whether a flee response was exhibited by the turtle within the next 60 seconds following the approach was then recorded. Observed turtle counts for each reef were compared using a Multi-way ANOVA test, comparing distribution both by region and tourism rate. Observed initial behavior type counts were compared using a Fisher's test, comparing only by tourism rate. Flee response rates were calculated as a relative percentage for each reef. These percentages were then compared using another Multi-way ANOVA test, comparing by both region and tourism rate.

Sleeping Coves

If a sedentary turtle produced a flee response, leaving behind the sleeping cove they were observed in, we then examined the cove itself. Using a Go-Pro Hero, photos were taken of the cove itself, along with the areas adjacent to the cove (above, below, left, right). If any areas adjacent were missing or insufficient due to natural reef shape or patch reef damage, they were not photo'd. The specific area adjacent (above OR below OR left OR right) chosen for comparison to the proximal sleeping cove was randomly chosen when all field photos were later analyzed. Upon analyzation, presence/absence counts of each observed coral type were recorded for both the cove and area adjacent. Presence/absence counts between cove and area adjacent were then compared using Fisher's tests, with a separate test for each coral type.

Invasive Algae

Data regarding the relative abundance of invasive algae (*Acanthophora* and *Hypnea* spp.), was planned to be obtained from the invertebrate substrate group (Kristina and Emily). Their group conducted three transects at each reef. Transects were 6 meters in length, with 12 quadrats which were 50 centimeters by 50 centimeters in size. Photos were taken of each quadrat, and CoralNet was later used to analyze these photos for any *Acanthophora* or *Hypnea* spp. cover. It was intended to further analyze this data via a Pearson correlation test, comparing algal cover of each species by observed turtle counts for each reef.

RESULTS

Turtle distribution and behavior in Kāne‘ohe Bay

In total, we had 50 encounters with C. mydas across the 9 reefs surveyed throughout our study, with 38 encounters taking place within low tourism sites, and 12 encounters taking place within high tourism sites. Using a Multi-Way ANOVA, distribution was found to be non-significantly different, both by region ($p = 0.077$) and tourism rate ($p=0.650$), refuting Hypothesis 1. As seen in Figure 2, turtles were most frequently observed within the LLNW region (n=32), and least frequently observed within the LC (n=10). HC (n=8) and HLNW (n=5) had intermediate observation counts. Reef #43 had the highest observed turtle count (n= 17). No turtles were observed at Reef #15 (Table 1; Figure 2).

Four total behavior types were observed during our surveys: swimming, sleeping, basking, and cleaning. When observation counts for each behavior type were compared by tourism rate (region was excluded as a factor since distribution by region was non-significant) using a Fisher's test, differences were found to be non-significant ($p=0.1291$), refuting Hypothesis 2. The LLNW region had the most diverse behavior, with all four types being observed there (Figure 3). In comparison, the LC region was least diverse, with only one behavior type (sleeping) being observed. Sleeping was the most frequently observed behavior (n=23). Basking (n=6) was only observed at Reef #44 and cleaning (n=1) at Reef #43, both residing within the LLNW region.

The effects of tourism-based disturbances

Out of the 50 total encounters, 31 turtles were sedentary upon initial observation. One sedentary turtle could not be approached, due to the shallow depth at the part of the reef he was occupying to bask. Therefore, 30 turtles were approached to test our flee response hypothesis, with 10 occurring in high tourism sites, and 20 occurring in low tourism sites. Flee response rate for the HC region (8.335%) had a relatively large standard deviation of 11.79 (Figure 4). When compared using a Multi-way ANOVA, flee response rates were found to have a non-significant difference by region (p=0.395), but significant difference by tourism rate (**p=0.00077**), supporting Hypothesis 3. High tourism sites had a mean flee response rate of 94.29%, and low tourism sites of 5.56% (Table 2). As shown in Figure 4, LC had the highest flee response rate (100%), while HLNW had the lowest (0%).

Sleeping coves

By utilizing the sedentary turtles who fled from their sleeping coves, we were able to photograph the substrate of 12 sleeping coves altogether. All three coral types, Finger (**p=0.00000074**), Fungia (**p=0.0028**), and Rice (**p=0.014**), were found to be significantly different in observation count when comparing coves against areas adjacent, supporting Hypothesis 4. According to the provided odds ratio, Fungia was 26.8x more likely to be in a cove than adjacent to a cove. As seen in Figure 5, Finger (n=10) and Rice (n=4) coral were never observed within a cove.

Invasive Algae

Upon CoralNet analyzation of the 27 total substrate transects, we found no detection of *Acanthophora* or *Hypnea* spp. cover. Therefore, no data analysis regarding invasive algae was performed, and no conclusion was reached regarding Hypothesis 5.

DISCUSSION

Turtle distribution and behavior in Kāneʻohe Bay

As contributors toward reef resilience, there is much to be lost when C. mydas begin leaving areas of high tourist activity to seek reefs of lower tourism use. Fortunately, our study found that tourism rate is not currently affecting *C. mydas* distribution in Kāneʻohe Bay. However, a lack of change in distribution due to tourism rate could be due to the habituation trend revealed by our flee response data. If turtles at high-tourism reefs become accustomed to human disturbances, they may not see such disturbances as a reason to vacate high-tourism patch reefs. Region was also found to have an insignificant effect on distribution, supporting previous evidence of the widespread distribution of this species throughout Kāneʻohe Bay (Brill et al., 1995). However, the p value of 0.077 could be considered marginally significant, and therefore further research regarding the effects of region on distribution should be considered. With more sampling, it is possible this value could have reached significance, however from the results of our dataset region affecting distribution cannot be considered a definitive trend. The LLNW region had the highest count of observed turtles, and while this trend was non-significant, the slight observed regional preference could be due to the unique basking and cleaning sites observed in this region, however further research is needed to provide a conclusive explanation. There were no turtles observed at Reef 15, despite it being a relatively diverse and healthy reef. Many factors could influence this trend, such as its close proximity to the channel (and therefore boat traffic) or food availability, and therefore further research is needed to come up with a definitive explanation.

Tourism rate was also found to have an insignificant effect on initial observed behavior type, contradicting previous trends seen in immature *C. mydas* or other turtle species (Smulders et al., 2020; Papafitsoros, n.d.; Hayes et al., 2017). However, due to the constraints of this study, tourists were not actively present when surveys were conducted. Our capstone dive team only consisted of around 5 people, and it is possible that more drastic behavioral changes would have been observed if larger snorkel groups (consisting of 20+ people) were present. Additionally, exhibited behaviors were only compared on a spatial scale, not a temporal scale. Since only initial behaviors were observed, it is possible that if observed over-time, a more significant trend in behavioral changes due to human interaction would have been witnessed. Further research examining these context-dependencies should be considered.

Cleaning was only observed at Reef #43 and basking at Reef #44, revealing that certain reefs may serve as specialized behavior sites. The LLNW region was the most diverse in behavior, while the LC region was least diverse. This may be due to the low sample size for the LC region, compared to the higher sample size in the LLNW. Additionally, this could be due to the specialized behavior sites which were present in the LLNW and not observed in the other three regions. Sleeping was found to be the most frequent behavior, which contradicts previous evidence that adult turtles forage throughout the day without many breaks (Enstipp et al., 2016). Therefore, further research examining this trend is needed.

The effects of tourism-based disturbances

Within their natural environment, the instinctual flee responses from danger exhibited by green sea turtles are crucial to their survival. Repetitive human disturbances can cause habituation, decreasing those innate flee responses, and sometimes leading to a decrease in overall predation avoidance. The relatively large standard deviation for flee response rate in the HC region is most likely due to small sample size and could have been reduced with further sampling, which also would have provided more consistency in high vs low tourism flee interaction counts. Using a Multi-way ANOVA, we found that while region did not affect flee response rate, tourism rate had a very strong effect, causing extremely low flee rates at high-tourism reefs. This reveals *C. mydas* in high tourism areas are habituating to tourism-related disturbance, in comparison to control turtles who had extremely high flee rates. Not only is this concerning due to potential predator avoidance, but additionally seemingly "calm" turtles may exhibit physiological signs of stress which were not measured in this study, such as cortisol levels or heart rate (Culik et al., 1990). To avoid habituation, and potential decreased predation avoidance, alteration of tourism-use sites in Kāneʻohe Bay is proposed. Nearing 100%, flee response rates in low-tourism areas reveal that enforceable distance regulations are crucial in protecting non-habituated individuals of this species from unnecessary energy expense, supporting previous evidence (Griffin et al., 2017; Meadows, 2004).

Ecological value of sleeping coves

According to the intermediate disturbance hypothesis, diversity within an environment peaks when the environment endures disturbances of intermediate frequency and intensity. When evaluated using multiple Fisher's tests, turtles were found to significantly alter the distribution of coral types within their patch reef communities when forming their sleeping coves. By disturbing and altering the physical state of the reef, they create small, shaded pockets of available substrate perfect for colonization by Fungia. This trend of cove preference by Fungia supports previous evidence that these corals prefer shade in shallow reef habitats (Goffredo & Chadwick-Furman, 2000). These results reflect the critical ecological role of *C. mydas* since, as eco-engineers, they may promote overall community diversity (Yeakel et al., 2020) within reef eco-systems.

Invasive algae consumption by *C. mydas*

A large factor contributing toward levels of reef resilience is overall algal cover, and therefore the ability of the coral to photosynthesize. Invasive algal species *Acanthophora* and *Hypnea* have quickly overtaken Hawaiian reefs and have consequently been utilized by *C. mydas* as a food source (Wabnitz et al., 2010; Russell & Balazs, 2009). Through CoralNet analysis, we found no evidence of *Acanthophora* or *Hypnea* spp. cover in Kāneʻohe Bay. This may be due to consumption by the evenly distributed green sea turtles in Kāneʻohe Bay. Additionally, this may be caused by previous removal projects which have occurred in recent years (Neilson et al., 2014). Although no definitive trend was found due to a lack of data, previous studies with evidence of *C. mydas* as invasive algae consumers (Wabnitz et al., 2010; Russell & Balazs, 2009) further support the need to protect this species, as through protecting this species, you protect the overall health of patch reefs.

Potential for future research

Our results confirm both the negative effects unregulated eco-tourism holds for *C. mydas*, and the ecological value that could be lost due to these adverse side effects. However, due to the constraints of this project, there is ample room for expansion unto this research. Expanded research with further sampling could be used to evaluate distribution by region and examine factors that could be causing distribution to vary by region. Such factors could include the specialized behavior sites which were observed in our study. The utilization of the sites themselves could also be further examined, by revisiting the reef and testing if the specialized behaviors occur at these specific sites over a larger temporal scale.

Further investigation could also be conducted regarding the effects of tourism on exhibited behavior, since our observational surveys did not take place at the same time as snorkel tours. While tourism interactions may not have long-lasting effects on behavior, it is possible its behavioral effects are immediate and brief in duration. Therefore, conducting surveys while snorkel tours are actively deployed, not deployed, and as well at control reefs could allow for short-term effects to be further examined.

Additionally, further examination of habituated turtles could be useful in evaluating current stress levels during human interactions, since they do not externally indicate stress via a flee response. Measuring variables such as cortisol levels or heartrate would allow stress to by evaluated on a physiological level.

Due to the time constraints of our research, examining tagged coves over a longer temporal scale could reduce current context dependencies, such as who came first: the turtle or the cove? Such research would also allow for nesting site fidelity to be examined, and enable us to determine if coves are occupied by the same resident turtle, or varying residents. As well, how the morphology of sleeping coves changes over time could be assessed.

Future research regarding invasive algal cover could be especially useful, since our study collected no conclusive data. By expanding to more reefs such as #34, which had highest *Acanthophora* cover in 2014 (Neilson et al., 2014), a more definitive trend may be reached.

CONCLUSION

In conclusion, eco-tourism has great potential, but regulations backed by research-based evidence are the only way to have it be non-consumptive and non-harmful. This study reveals that although current tourism in Kāneʻohe Bay does not affect distribution or behavior type, it is consumptive, as it alters the natural behavior of *C. mydas* by causing habituation towards human disturbances. Furthermore, it reveals that human interactions with non-habituated turtles typically enact a flee response, which may be energetically expensive for this ectotherm species (Bennett, 1994). *C. mydas* serve crucial roles as eco-engineers in Kāneʻohe Bay, and therefore promote overall reef diversity (Yeakel et al., 2020). The results of this study are useful in arguing for better protection of *C. mydas*, specifically for in-water tourist interactions, by revealing aspects of their ecological value and the long-term effects of repeated, unregulated tourist interactions. Enforceable distance regulations and alteration of designated tourism-use sites in Kāneʻohe Bay could better protect its green sea turtle population (Landry & Taggart, 2010).

APPENDICES

Figures

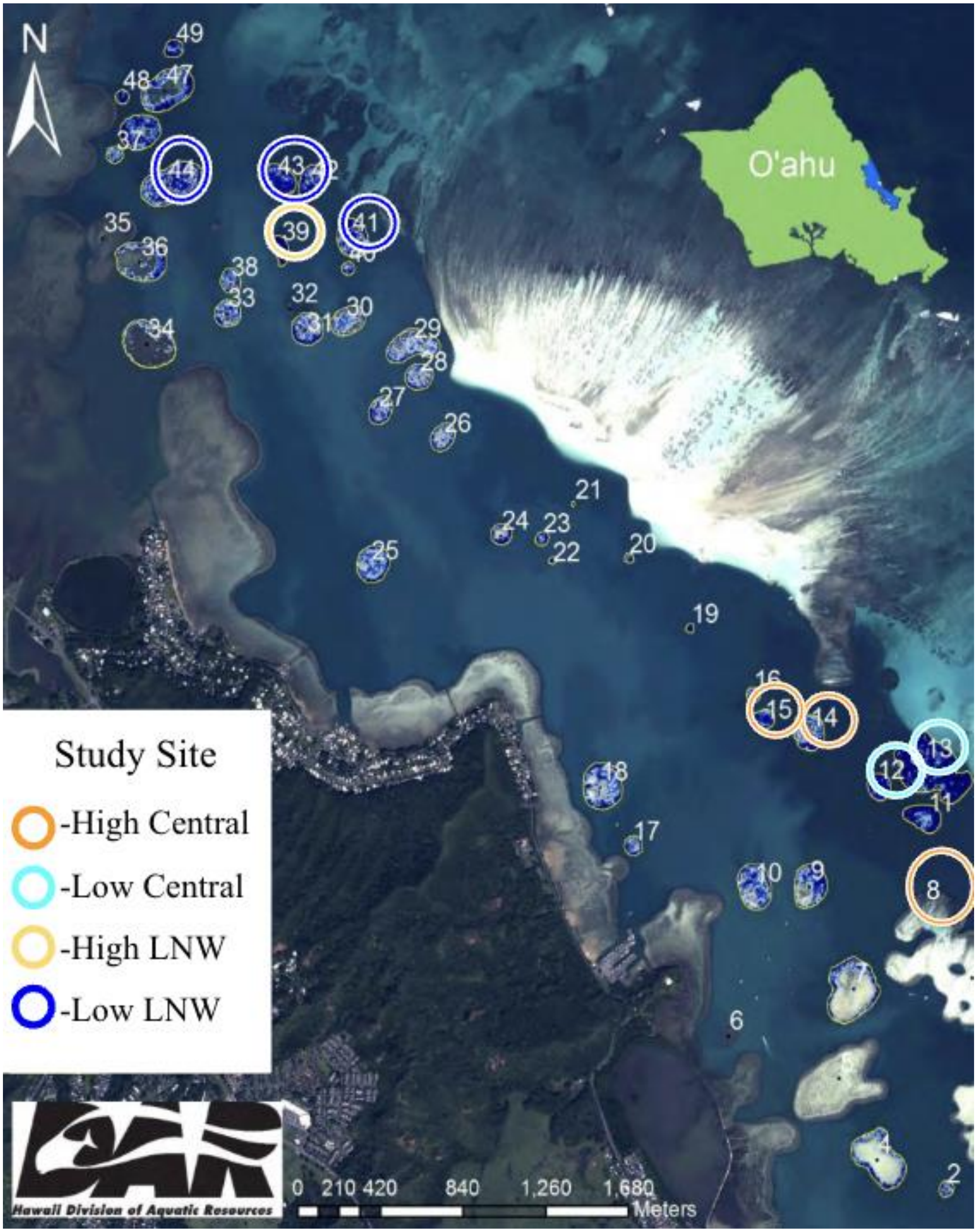

Figure 1. Map of Kāne'ohe Bay with Numbered Patch Reefs. Provided key indicates the four study sites, with a high and low tourism site for each of the two regions. Image utilized from Neilson et al., 2014.

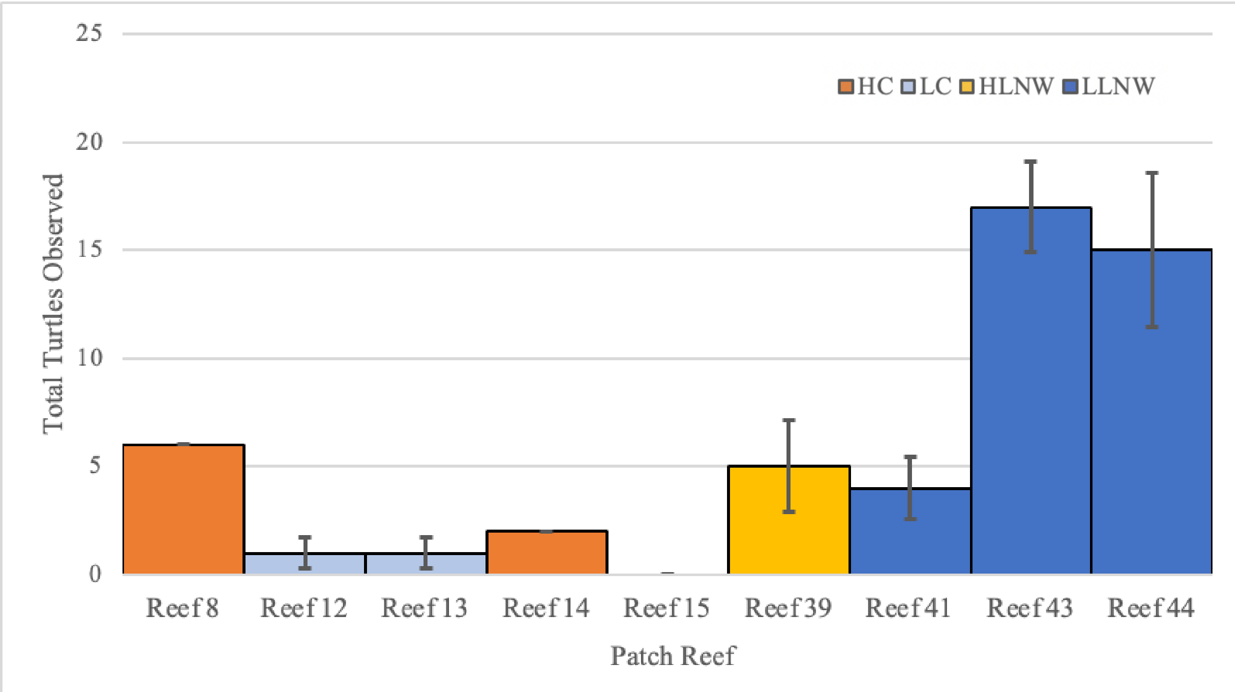

Figure 2. Total Turtle Observation Counts by Patch Reef, Compared by Study Site. Reef 12 and 13 both had standard deviations of 0.71, Reef 39 of 2.12, Reef 41 of 1.41, Reef 43 of 2.12, and Reef 44 of 3.54. Reefs 8 and 14 had no deviation. LLNW had the highest number of observed turtles, while LC had the lowest. No turtles were observed at Reef 15.

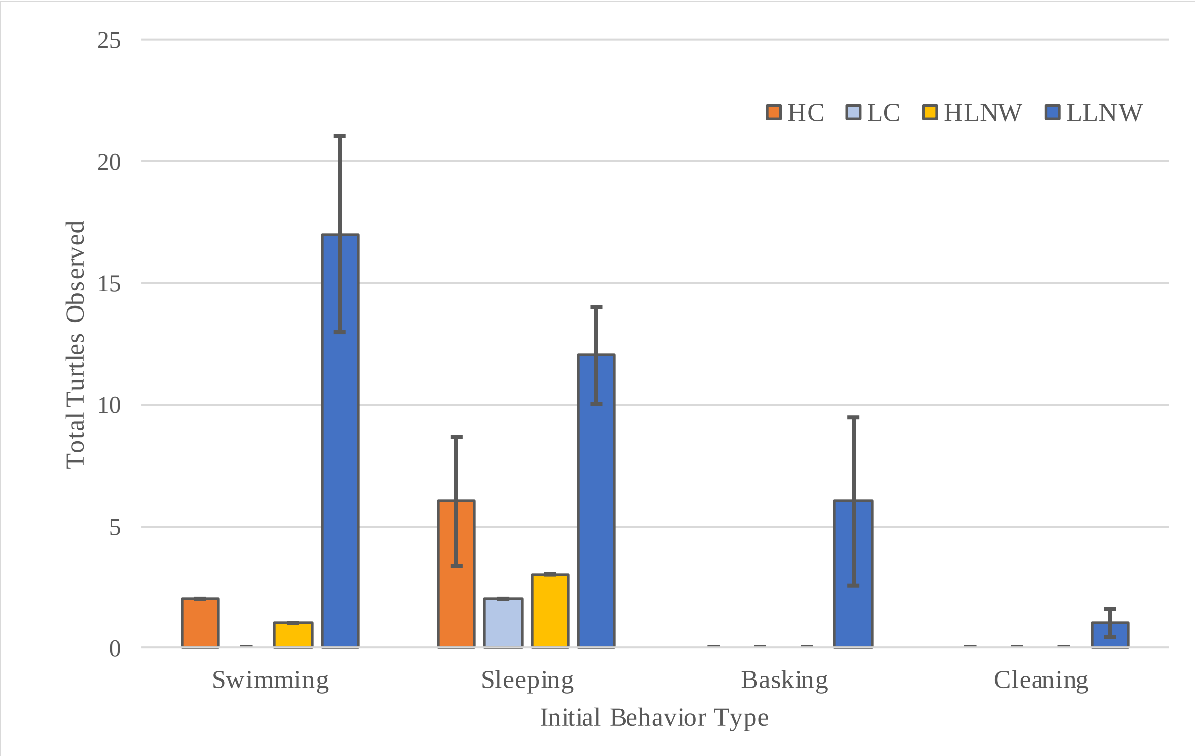

Figure 3. Total Turtle Observation Counts for Each Observed Behavior Type, Compared by Study Site. Within LLNW, swimming had a standard deviation of 4.04, sleeping of 2, basking of 3.46, and cleaning of 0.577. For HC, sleeping had a standard deviation of 2.65, and swimming had no deviation. For both LC and HLNW, there were no standard deviations for all behavior types. LLNW had the most variety of observed behaviors, while LC had the least variety. Basking and cleaning were only observed in LLNW.

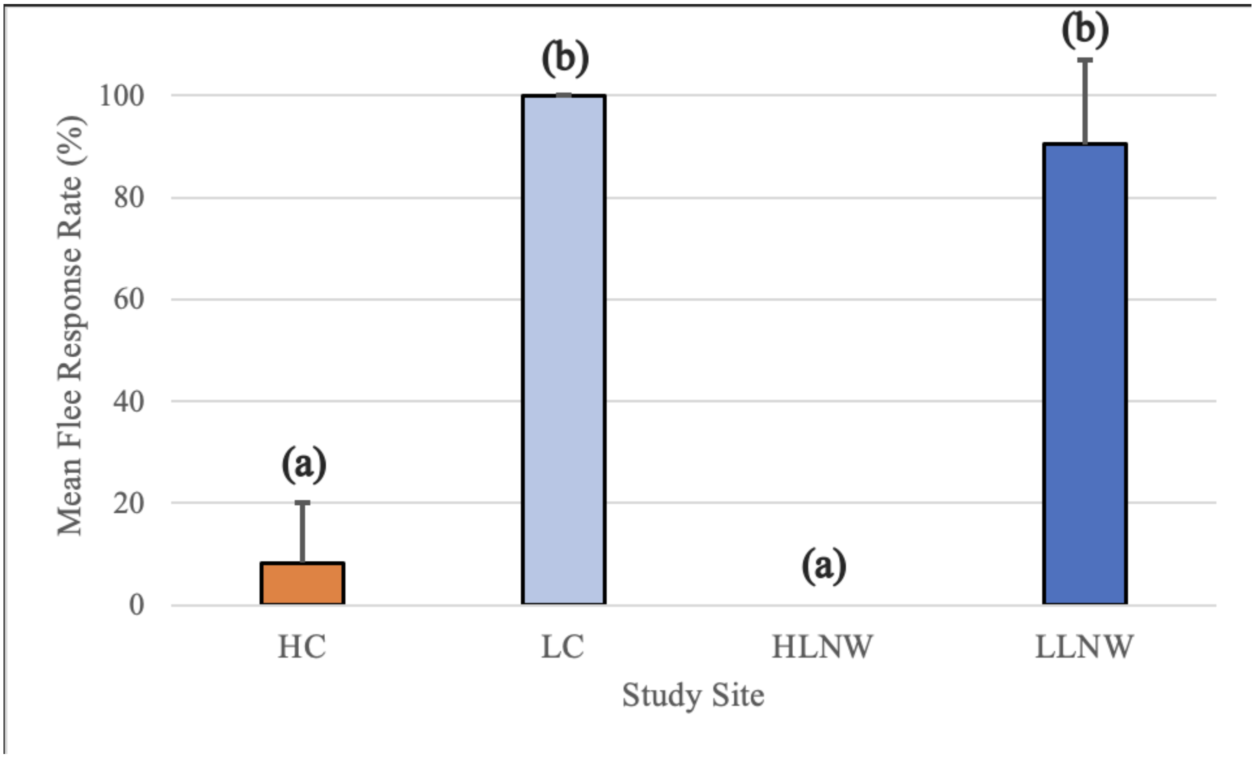

Figure 4. Mean Flee Response Rates, Calculated as a Percentage, for Each Study Site. The labels (a) and (b) were used to convey a non-significant relationship. Bars with opposing letters, therefore, were significantly different from one another. HC had a standard deviation of 11.79, LLNW of 16.49, and LC had no standard deviation. A standard deviation for HLNW was non-applicable due to limited sampling. HC had a mean flee response rate value of 8.335%, LC of 100%, HLNW of 0%, and LLNW of 90.48%. LC had the highest flee response rate, followed by LLNW, then HC, then HLNW.

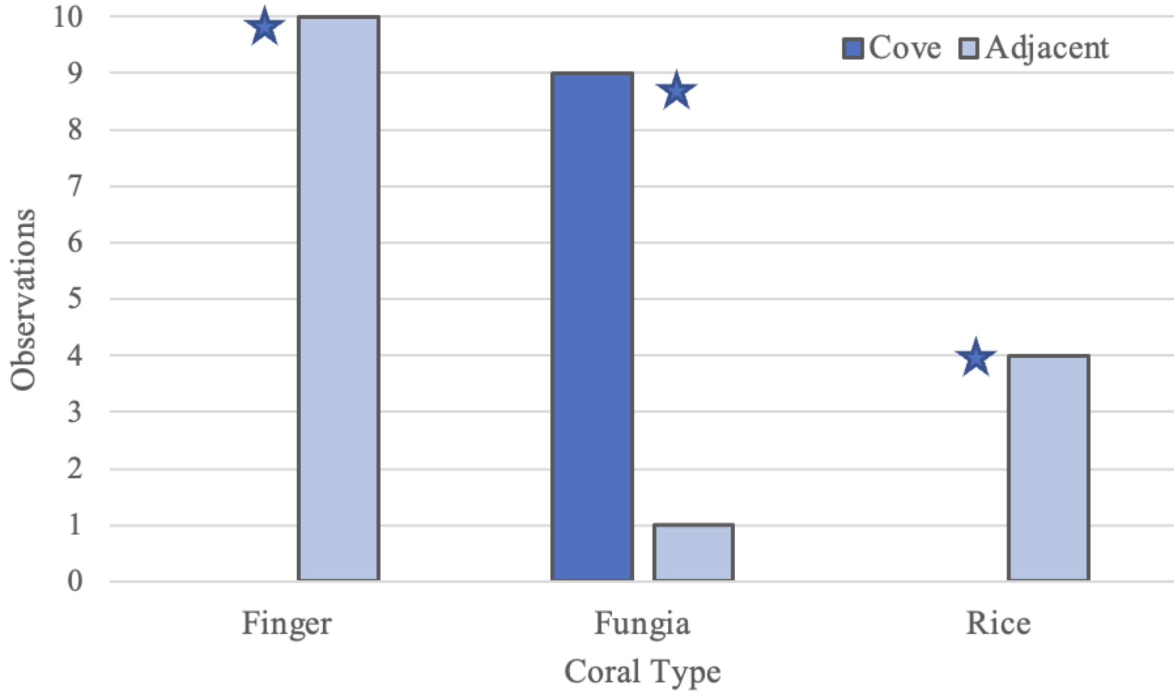

Figure 5. Observation Counts for Each Coral Type, Within Coves and Areas Adjacent. Star symbols were used to convey significance between cove and adjacent. Finger and Fungia were both observed 10 times total, while rice was only observed 4 times total. Finger and rice coral were never observed within a cove.

Tables

Table 1. Total Turtles Observed at Each Patch Reef, and the Correlating Study Site. HC had 8 total turtles observed, LC had 2, HLNW had 5, and LLNW had 36.

Patch Reef	Study Site	Total Turtles Observed
Reef #8	HC	6
Reef #12	LC	1
Reef #13	LC	1
Reef #14	HC	2
Reef #15	HC	0
Reef #39	HLNW	5
Reef #41	LLNW	4
Reef #43	LLNW	17
Reef #44	LLNW	15

Table 2. Flee Response Rates Exhibited at Each Patch Reef, and the Correlating Study Site. HC had a mean flee response rate of 8.335%, LC of 100%, HLNW of 0%, and LLNW of 90.48%.

Patch Reef	Study Site	Flee Response Rate (%)
Reef #14	HC	0
Reef #8	HC	16.67
Reef #41	LLNW	100
Reef #43	LLNW	71.43
Reef #44	LLNW	100
Reef #13	LC	100
Reef #12	LC	100
Reef #39	HLNW	0

Meta-data

Field	**Example**	**Description**
Date	20423	Date of survey (mmddyy)
Reef#	32	Number of patch reef survey was conducted on (#)
Transect#	1	Number of transect (replicate)
SurveyStart	09:43	Start time of the 15 min survey (hh:mm)
Sex_of_Turtle	Male	Biological sex of turtle (determined by tail length) (Male/Female)
Initial_Behavior	foraging	Type of behavior turtle is performing when initially spotted (Foraging/Sleeping/Swimming)
Movement_type	sedentary	Type of movement turtle is performing when initially spotted (Sedentary/Mobile)
Life_Stage	adult	Current life stage of observed turtle (estimated by carapace size) (Juvenile/Adult)
Flee_Response	Yes	If the turtle was initially sedentary, did it flee within 30 sec from diver when approached? (Yes/No)
CoralType_Sleeping Cove	Fungia, Finger	Coral types found within the sleeping cove (Fungia/Rice/Lobe/Cauliflower/Finger)
Coral Type_Adj_Sleeping Cove	Rice, Cauliflower	Coral types found in the area adjacent to the sleeping cove (Fungia/Rice/Lobe/Cauliflower/Finger)

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