Hanauma Bay Social Carrying Capacity Survey (Year 4)
2021/2022 Annual Report

For:
City and County of Honolulu
Parks and Recreation Department
Hanauma Bay Nature Preserve
Honolulu, Hawai‘i

Location:
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Prepared for:
City and County of Honolulu: Parks and Recreation
Hawai‘i Board of Land and Natural Resources

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Executive Summary

During the annual period from May 2021 through January 2022, all contractual work plan tasks were completed. Interview questions were developed and survey design was initiated following institutional certification and approval. Previous studies on the carrying capacity of Hanauma Bay have been annotated and compiled to summarize the findings. A list of 28 survey questions were established to determine the social carrying capacity of Hanauma Bay and visitor perceived experience. As required by law, the University of Hawai‘i follows government regulations on the protection of research subjects. These regulations apply to all interviews conducted within the purview of the University. In compliance with this program, online training courses from the Collaborative Institutional Training Initiative Training Program were completed. These included topics in research, ethics, and compliance. Approval of research questions was obtained from the Institutional Review Board prior to initiation of interviews. Survey questions were distributed in two time periods, a summer and winter dataset, to allow for seasonal differences. In July and August of 2021, over the course of 10 days, 340 surveys were collected from visitors to the Hanauma Bay Nature Preserve. The same survey method was repeated in December of 2021 and January of 2022 where 344 survey responses were collected over the course of nine days. Visitors surveyed were mainly non-local (87%) with 68% first time visitors. Visitors were mostly female (55%) and the most common age group was between 16-30 years old (45%). English was the primary language for 89% of visitors. The majority of visitors were White (51%) or Asian (33%) and 80% of visitors came from the U.S. mainland. A Bachelor’s degree was the most common level of education (39%) among visitors and the majority of visitors (57%) had an annual income over $90,000/yr. Visitors were most excited to see different types of fishes (48%). 83% of visitors said they were satisfied with the marine life they experienced. The majority of visitors (74%) observed others contacting the reef one or more times. This was verified by a simultaneous study (Murphy 2021) similarly showed that one in every two snorkelers contacted the reef in the Keyhole and Backdoor sectors. Channel and Keyhole were the most used sectors of the Bay comprising 94% of all visitors and Channel alone comprised 57% of all snorkelers in the Bay. The most popular activity was relaxing or sunbathing on the beach (55%). The Channel sector had the highest number of visitors for each of the three activities: standing in water, swimming/snorkeling, and on the beach. The main activity that attracted visitors to Hanauma Bay was snorkeling (88%) however 14% of visitors had never snorkeled before. Nearly half of the visitors (49%) did not think Hanauma Bay could accommodate more visitors. Conversely, 57% of visitors did not believe the number of guests negatively affected their experience. The majority of visitors queried about crowding did not believe there were too many people in the water (54%) or on the beach (53%) during their visit. The educational video was considered effective at providing useful information to 84% of visitors whereas the SeaGrant kiosk was only considered effective to 51% of visitors. The entrance fee into the Bay was considered appropriate by 75% of visitors, some of which were residents or military who were exempt. Factors that may influence responses to the surveys were also explored. Daily weather measurements were recorded, and beach count photos were obtained hourly along with box office counts to determine usage and distribution of visitors at the Bay.

Introduction

The Hanauma Bay Nature Preserve (HBNP) has long been an extremely popular tourist attraction in the state of Hawai‘i. Following designation as Hawai‘i’s first Marine Life Conservation District (MLCD) in 1967, the Bay has continued to see a high number of annual visitors (Lankford 2005). In some locations, researchers have documented a greater number of visitors within MPAs than in nearby unprotected areas (Gonson et al. 2017). In 1975, the HBNP was receiving half a million visitors annually, approximately 1,370 daily visitors. Half a million annual visitors were considered a sustainable number of visitors in the Hanauma Bay Beach Park Development Plan of 1977. By 1988, this number had increased to nearly 4 million annual visitors or 10,000-12,000 daily visitors (Vieth & Cox 2001). This extreme increase of visitors brought detrimental effects to the Bay through reduced visibility from sedimentation and decreased water quality (Gardner 1999). Similarly, the high number of visitors caused large amounts of freshwater input into the Bay from the beach showers, causing increases of bacteria and pollution (Brock & Kam 2000). High numbers of annual visitors to the Bay prompted changes, made to prevent further ecosystem declination.

One way to promote a healthy ecosystem in the Bay is to decrease the number of visitors coming to Hanauma Bay. Prior to efforts by the City and County of Honolulu to further limit visitors to protect marine resources in the late 1980s, over 3 million visitors a year entered the Bay (http://www.honolulu.gov/parks-hBay.html). User fees were established in 1990 for visitors and commercial tours while also limiting the number of tour buses allowed into the HBNP (Brock & Kam 2000). In 1990, the number of visitors had decreased to 8,000 daily (Gardner 1999). 1995 was the first year that non-resident visitors were charged an entrance fee which would be used for management of the Bay and research (Mak & Moncur 1998). Increased management and the application of user fees effectively brought the daily number of visitors down to 6,808 by 1999 (Vieth & Cox 2001; Clark 2016). By 2000, it was reported that the number of daily visitors decreased further to 3,210, just above a quarter of the record high number of visitors to the Bay in 1988 (Brock & Kam 2000). The user fee has increased over the years from $5.00 in 2016, $7.50 in 2017, $12.00 in 2020, and currently to $25.00 as of January 2022. In 2017, HBNP had 842,439 annual visitors, approximately 2,300/day, comprised of both tourists and residents. To assist in strategic management, valid information on the user experience, impacts on the marine environment and facility capacity was acquired.

The COVID-19 pandemic brought unprecedented changes to Hanauma Bay. This unique opportunity to assess changes in the absence of visitors for a nine-month period was unparalleled in Hanauma Bay’s history. Reopening accommodated State of Hawai‘i COVID restrictions, limiting the number of visitors when the Bay reopened on 2 December, 2020. The ability to provide controlled visitor access to vulnerable and unique locations can offer opportunities for ocean conservation (Wanger 2001). The visitor capacity was 750 visitors per day beginning 2 December 2020 and extending through 27 April 2021, a quarter of counts prior to the COVID closure. The current online reservation system used during the summer survey period (July-

August 2021) was launched on 26 April 2021 to reduce traffic on Kalanianaole Highway and provide a more organized and sustainable system of entry. In December 2021 to reduce the number of no-show visitors and scalpers, the online reservation system implemented a payment requirement when reserving an online time slot at Hanauma Bay. For a one-month period from 28 April through 27 May, 2021, the capacity was raised to 1,050 daily visitors. On 28 May 2021 the capacity was subsequently increased to 1,400/day. When comparing the usage prior to and following the COVID restrictions, this equates to a 69% reduction in visitors. According to box office counts, May 2019 had 64,459 visitors, a daily average of 2,479. May 2021 was the first full month implementing the online reservation system with 25% of slots left open for walk-ins. May 2021 had 19,689 visitors, a daily average of 903. The numbers of daily visitors have nearly returned to pre-COVID numbers. July 2021 saw the highest attendance since reopening at just over 48,000 monthly visitors for a daily average of 2,088. HBNP is also encouraging more residents to utilize the Bay. Historically, Hanauma Bay has seen decreases in the number of local residents visiting the Bay. 32% of visitors were locals in 1977 and only 13% by 1990 (Reynolds 1990). The May 2019 box office counts showed 90% non-locals (80% adults 10% children) and 5.8% locals (5% adult and 0.8% children). May 2021 showed a slight shift in favor of locals with 85% non-locals (75% adult 10% children) and 10% locals (8% adult 2% children). Winter survey results show an increase with 74% non-locals and 15% local. More recent policy changes have improved "*kama'aina*" usage. Hawai'i residents can bypass the reservation system and enter the Bay free of charge between 6:45-9:00 am Wednesdays to Sundays.

As a means of understanding perceived visitor experience, a social carrying capacity study was initiated in May 2021. The National Park Service defines the social carrying capacity as "the type and level of visitor use that can be accommodated while sustaining acceptable resources and social conditions that complement the purpose of the park" (National Park Service 1997). Social carrying capacity examines the number and distribution of visitors determined through visitor perception of recreational experiences. Surveys are often comprised of multiple components including demographics, visitor satisfaction, and overall experiences (Needham et al. 2008; Gonson et al. 2017). Outcomes of social carrying capacity studies are based solely on perceived visitor experience from an individual perspective. Expectations may not be met for a variety of reasons, including prior bias of number of users, weather, or expected marine life.

Perceptions of crowding are a key component of social carrying capacity surveys and overcrowding is an important factor to consider when managing an area as popular as Hanauma Bay (Chen & Teng 2016). After concerns about the Bay were raised in 1989, the first visitor satisfaction survey utilizing a questionnaire was distributed in 1990 (Hanauma Bay Case Study 1989; Reynolds 1990). Crowding was the main complaint from two thirds of visitors at Hanauma Bay in 1990 (Reynolds 1990). At that time, there were over 10,000 daily visitors.

Education of visitors is another key component of social carrying capacity studies with the belief that more educated visitors will be better stewards of the protected area (Needham et al 2008). Interpretation and recreational learning were two methods believed to be most effective at Hanauma Bay (Komatsu & Liu 2007). The educational spillover effect proposed by van

Beukering & Cesar (2004) suggests that successful education will lead to reef stewardship at other locations outside where it was initially learned, transferring responsible behavior to extended areas. A social carrying capacity study was initiated by Wanger (2001) with a focus on educational materials and their effectiveness on visitor behavior at Hanauma Bay. Coral trampling was recorded based on volunteer and visitor's observations. Coral trampling can be extremely detrimental to coral reefs and the health of the marine ecosystem (Rodgers & Cox 2003). There was higher observed trampling on days the educational exhibits were closed at Hanauma Bay suggesting that educational material was having a positive effect on visitors' behavior (Wanger 2001).

A similar study to the current Hanauma Bay social carrying capacity study was conducted in 2005. Visitor satisfaction and perceived crowding at Hanauma Bay was recorded by visitors both entering and leaving from 2000-2002 (Lankford 2005). It was observed that visitors were more likely to be satisfied after snorkeling and seeing marine life, but more likely to mention overcrowding when on the beach (Lankford 2005). The carrying capacity based on that study was estimated to be 3,200 daily visitors and any increases beyond this limit correlates to decreased visitor satisfaction (Lankford 2005).

Hanauma Bay has experienced high levels of human use over the past 50 years. To address areas of management concern related to visitor capacity, the prior biological carrying capacity study and the present social carrying capacity study will provide research data to develop adaptive management and educational strategies that integrate both the marine biota and the visitor usage.

Projected scope of work details from project work plan

Semi Annual Report	**Task/Activity**	**Anticipated Results**
May - October	Task 1: Social survey development ● Acquiring certifications for human studies ● Development of question list ● Data collection method Task 2: Projected scope of work details from project plans ● Summer surveys Task 3: Project updates on task and data collected ● Summer survey completion	● Social Survey questions list established ● Collaborative Institutional Training Initiative (CITI) and Institutional Review Board (IRB) certifications acquired for surveys ● Summer month surveys completed at the Bay.

	Task 4: Preliminary analysis of survey data	
Annual Report	**Task/Activity**	**Results**
December - May	Task 1: Projected scope of work details from project plans • Winter survey completion Task 2: Project updates on task and data collection Task 3: Analysis of survey data • Compare summer and winter surveys data • Analyze total data from all responses	• Winter survey session completed at the Bay • Winter data analyzed • Final data analysis comparing summer and winter survey data

Social Survey Development: Certifications, Question Development, and Data Collection

Survey

Numerous social surveys have been conducted at the HBNP since its establishment as a Marine Life Conservation District. Social carrying capacity surveys are important to gauge visitor satisfaction and make potential changes to accommodate the opinions of visitors. Social surveys are recommended to be performed annually and in different seasons for effective management (Reynolds 1990). This survey was divided into a summer and winter period to accommodate the variation in visitors to the HBNP during both time points.

All surveys were conducted at the HBNP on the island of O‘ahu. Prior to conducting surveys, an application was submitted to the University of Hawai‘i Human Research Program (HRP) and the Institutional Review Board (IRB) for certifications. Interview questions were submitted to the board for approval to work ethically with human subjects. A Collaborative Institutional Training Initiative (CITI) certification was obtained prior to initiation of surveys stating that all surveys and data collected would be used ethically and within the scope of the project.

The social carrying capacity study consists of three components: (1) visitor exit survey, (2) daily weather observations, and (3) hourly beach count photos.

A voluntary survey made up of 27 questions (24 multiple choice and 3 open ended) was offered to guests as they exited the park after visiting the beach (Appendix A). A temporary canopy to provide shade and protection from the elements was set up near the walking path exit adjacent to the Hanauma Bay gift shop where all patrons must exit. As guests passed the tent

they were asked to complete a voluntary, confidential survey about their experience in the Bay. This haphazard survey design was biased toward visitors willing to stop and against those with small children or subsequent engagements. The questions covered five subject categories: demographics, facilities, visitor usage, marine life, and overall experience including educational tools (Appendix A). These demographics were included to better understand the visitor population present at the HBNP and efficacy of educational materials. Facilities questions were included to establish adequacy of facilities compared to the number of visitors. Visitor usage questions were developed to assess the perceived visitor usage and admission rate value. Marine life provided an understanding of what initially attracts visitors to the Bay. Overall experience and educational tools provided insight into the effectiveness between demographics, of signage and educational material. On average, the survey took visitors 3-5 minutes to complete and was administered through Google Forms via four Samsung tablets. No more than 50 surveys were collected in a single day to ensure the majority of the data was not from a single time point. The first 150 surveys were paper copies that were distributed due to technical issues with the tablets. There were no changes to the survey distribution method during this time. These forms were digitalized and combined with the rest of the online survey data.

Daily Weather Observations

Weather observations were taken at the beginning of each survey day prior at the start of visitor surveys; however major changes in weather throughout the day were recorded. Cloud cover, wind and presence/absence of rainfall were all recorded using visual observations.

Beach Count Photos

Photos of the entire beach were taken from the same upper facility lookout at the top of every hour using an iPhone camera. Photos were then edited to divide each section of the Bay into four zones; Backdoor, Keyhole, Channel, and Witches Brew. Division of each territory went from the reef edge where the waves break to the end of each beach section where the sand ended (Figure 1). Beach count photos were included to observe the activity of visitors at Hanauma Bay and to determine heavily trafficked areas during surveys. The three categories recorded included standing in the water, swimming/snorkeling, and on the beach. The difference of swimming and standing in the water was based on the horizontal or vertical orientation of the visitors and distance from shore.

Completion of surveys

A total of 684 surveys were collected and analyzed during the annual survey period. 340 surveys were collected in the summer sample period of July-August 2021 and 344 surveys were collected throughout the winter sampling period of December 2021 - January 2022. These tasks were performed over the course of a one-month period on each of the days the Bay was open to the public (Wednesday-Sunday) for a total of 10 survey sessions (10 days) in the summer and 10 survey sessions (9 days) in the winter. Survey days were distributed across the month. This data provides insight on how many people are visiting the Bay, their location, and the activity engaged in. The survey questions provide background on the demographic population at Hanauma Bay and the overall experience during the visit. All surveys and data were uploaded to

Google Forms where data was imported from the responses. Graphs were generated from the data using Google Forms and Excel.

A total of 62 beach count photos have been annotated to include the number of people in each sector of the Bay with 28 beach count photos in the summer and 34 beach count photos in the winter and their activity (Figure 1). Table 2 shows the most common activity was on the beach and the most common area for people to gather was in the Channel sector. Channel and Keyhole contained 94% of all visitors. The Channel sector comprised 57% of all visitors to the Bay with 55% of these visitors on the beach. 27% of total visitors to the Bay were observed swimming or snorkeling and the highest sector for this activity was the Channel. The most popular activity for visitors according to the beach count photos was on the beach. 55% of all visitors to the Bay were observed on the beach during the hourly beach count photos. The Channel sector was consistently the most used sector for all activities in both the summer and winter time periods. The only exception was in the summer period when Keyhole had the majority of people standing in the water.

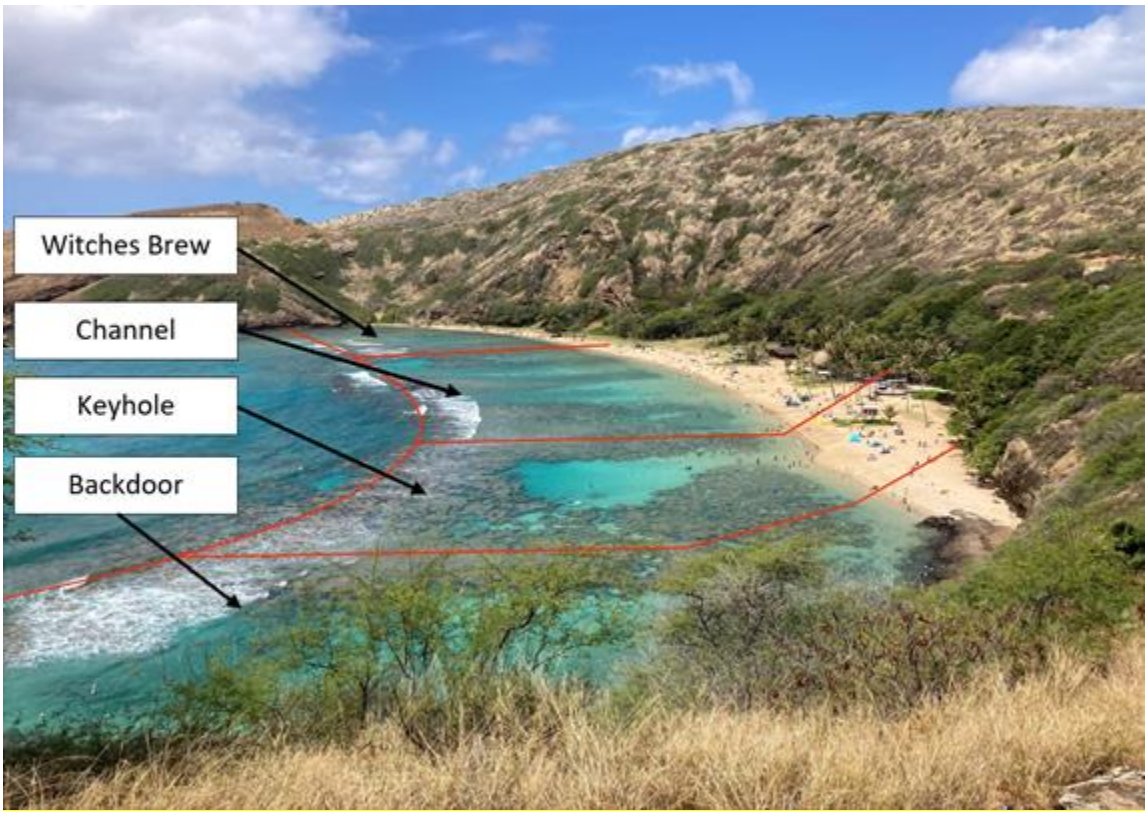

Figure 1. Photograph of Hanauma Bay divided into four sectors taken from the upper lookout.

Table 1. Total number of people in each sector separated by observed activity combined for summer and winter surveys.

	In water standing	**Swimming/Snorkeling**	**On beach**	**Total**
Witches Brew	41	49	100	190
Channel	1,547	2,274	4,708	8,529
Keyhole	1173	1,548	2,872	5,593
Backdoor	78	109	502	689
Total	2,839	3,980	8,182	15,001

Analysis of survey data

Demographics

From data collected in the summer and winter sessions, graphs were generated based on visitor response. There was a total of 684 responses across both time points. The first seven questions of the survey looked at the demographics of visitors to the Bay. These questions establish background information on personal details and comprehension of information presented through educational videos and signage.

Question 1: What is your age?

The highest percentage of visitors who responded to the survey were between 16-30 years old (45%). The rest of the age groups in descending order were 31-45 (32%), 45+ (20%), and 0-15 (3%) (Figure 2a). This distribution is somewhat expected where younger to middle aged people are the most frequent visitors to the Bay. Visitors aged 0-15 will likely be accompanied by an adult and would either not stop to take the survey, or the adults would take the survey and input their own age.

Question 2: What gender do you identify as?

There were more female (55%) than male (44%) visitors to the Bay who answered the survey. Only 1% identified themselves as non-binary or non-conforming and less than 1% answered as transgender or preferred not to answer (Figure 2b).

Question 3: Please specify your race.

The main ethnicities visiting Hanauma Bay were White (51%) and Asian (33%). Native Hawaiians and other Pacific Islanders only made up 1% of visitors at the Bay (Figure 3). Some visitors selected multiple entries such as White and Asian which accounts for the categories that

make up 1% of Figure 3. During the survey periods, Japanese visitors did not return in previous numbers once Covid 19 travel restrictions were lifted. These percentages will likely shift once visitors from Japan return.

Question 4: What is your primary language?

English was the primary language for 89% of visitors. The next highest languages were Chinese (2%), Spanish (2%), and Korean (2%). When comparing these percentages to question #7 about place of residency, most of the travelers come from the U.S. mainland, thus, English would likely be the highest percentage, with the absence of Japanese visitors.

Question 5: What is the highest degree or level of education you have completed?

The most common level of education among visitors to the Bay was a Bachelor's degree (39%) and the second highest was a Master's degree (30%). The rest of the education levels in descending order are High school (16%), PhD or higher (9%), Trade school (3%), some high school (2%), and prefer not to answer (1%).

Question 6: Which of the following represents your annual household income before taxes?

The annual household income of visitors to the Bay was on the higher side of the survey options. The majority of visitors at the Bay (57%) had an income of $90,000 or higher, which was the highest category listed on the survey. The second highest percentage (20%) was the second highest income level on the survey of $60,000-$90,000. Only 13% of visitors had an income of $30,000-$60,000 and 10% of visitors had an income less than $30,000.

Question 7: Are you a resident of Hawai‘i?

Only 13% of visitors were from O‘ahu or a neighbor island while 80% of visitors were from the U.S. mainland. The majority of the 13% of visitors from Hawai‘i were from O‘ahu and less than 1% were from neighboring islands. Less than 1% of visitors indicated they were from Japan. 7% of visitors selected the "Other" category suggesting that they are international travelers not from Japan.

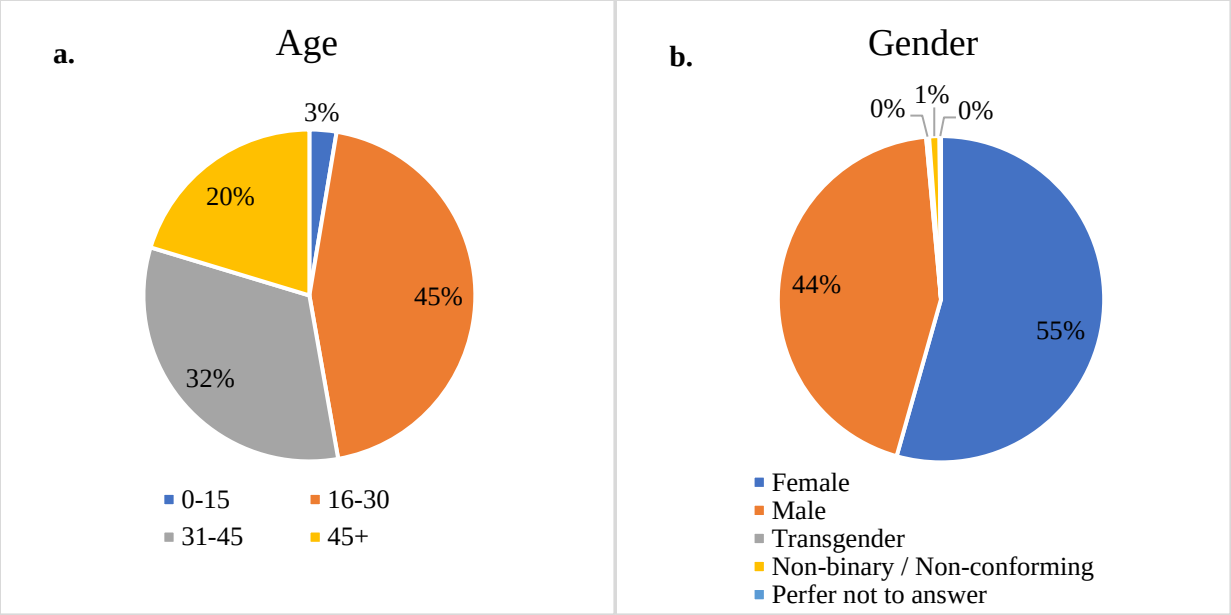

Figure 2. Age (**a.**) and gender (**b.**) of visitors at Hanauma Bay in percent of total across summer and winter surveys.

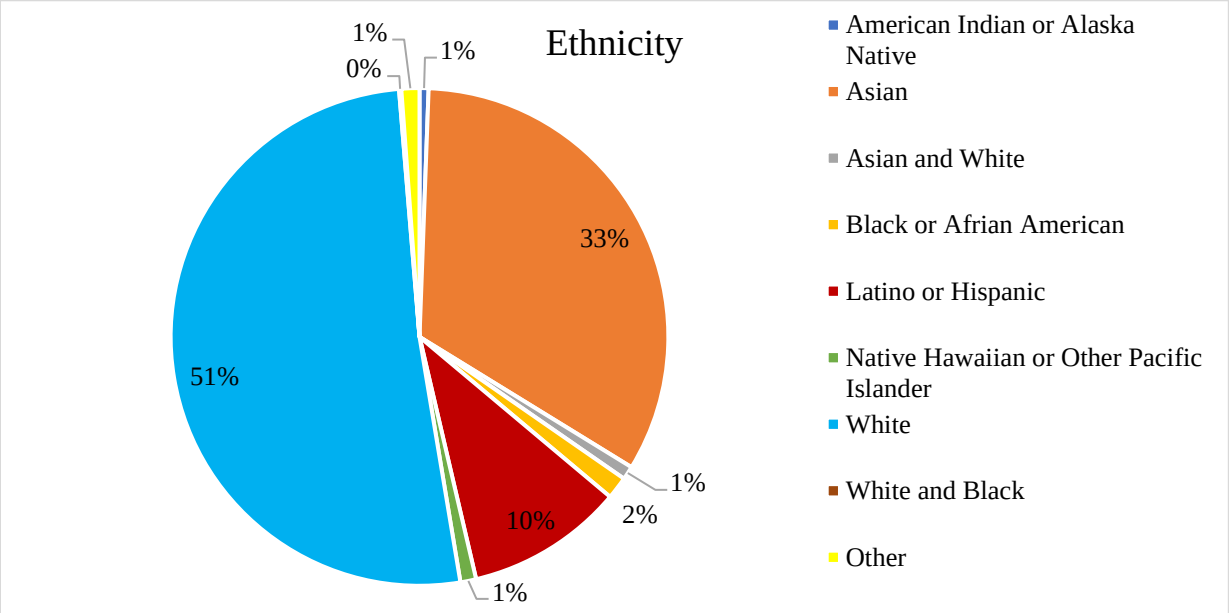

Figure 3. Ethnicities of visitors at Hanauma Bay in percent of total across summer and winter surveys.

Marine Life

Question 19: How satisfied were you with the marine life you experienced today?

Satisfaction questions were based on a scale of 1 (very dissatisfied) to 5 (very satisfied). The majority of visitors indicated they were very satisfied (46%) or satisfied (37%) with the marine life they experienced. This was the first visit for 52% of visitors thus, no prior preconception of marine life biased over half of the responses except from other areas. Neutral responses comprised 11% of visitor responses and 6% said they were either dissatisfied (5%) or very dissatisfied (1%).

Question 20: Of all the marine life at Hanauma Bay, which were you most excited to see?

Of the 684 surveys distributed across both time points, there were a total of 1108 responses to question 20. The survey allowed visitors to select multiple options indicating that many users selected multiple choices instead of what they were solely most excited to see. When comparing the percentages of the visitor responses, most visitors were excited to see different types of fishes (48%). The next highest marine life was coral reefs (20%), followed by sea turtles (18%), and lastly monk seals (14%). Unless venturing outside the inner reef flat, the coral reef is underdeveloped suggesting visitors' perception of coral reefs is skewed or limited. Turtles and monk seals are limited at Hanauma Bay and were not experienced by the majority of respondents.

Question 21: On a scale of 1-4, how would you rate the quality of the Bay's natural resources?

This question had similar satisfaction levels as question 19 asking about the quality of the marine life. Using the scale of 1-4, 43% of visitors indicated the quality of the Bay's natural resources were ideal and 44% indicated it was mostly ideal (3). Only 11% of visitors thought the quality of the Bay's natural resources were less than ideal (2) and 2% thought it was not ideal at all (1). Response is likely biased by comparing prior travels to tropical regions with HBNP.

Question 22: How many times did you observe others touch, stand on, or bump the reef?

The majority of people said they noticed others contacting the reef 1-4 times (44%) and only 26% said they never saw anyone touch the reef (Figure 4). Visitors observed 17% of people contacting the reef 5-9 times, 6% of people 10-14 times, and 7% of people 15 or more times. The levels of contacting the reef varied with the observer and could be an intentional grabbing of the reef to maneuver or an accidental touch of the fins on the reef. Contacting the reef should be avoided whether accidental or intentional and the amount of contact can be related to the effectiveness of the mandatory educational video shown to visitors as they enter the Bay. Results of the study (Murphy 2021) on reef contact is attached as an appendix. We designed this study to determine the number of times reef contact was made by visitors in the Backdoor and Keyhole sectors. Both sectors combined, comprised approximately 42% of visitors to the Bay and 42% of snorkelers in the water. Results from this study show there is a direct relationship between visitor density and frequency of contact with the reef (Murphy 2021). Out of 327 snorkelers 168 reef disturbances were documented (51%) however only 3% of these were directly on a coral colony. The number of reef disturbances was lower than what visitors observed in this study (74%). The highest number of snorkelers and reef disturbances were in the nearshore Keyhole sector with grabbing the reef as the highest disturbance (Murphy 2021).

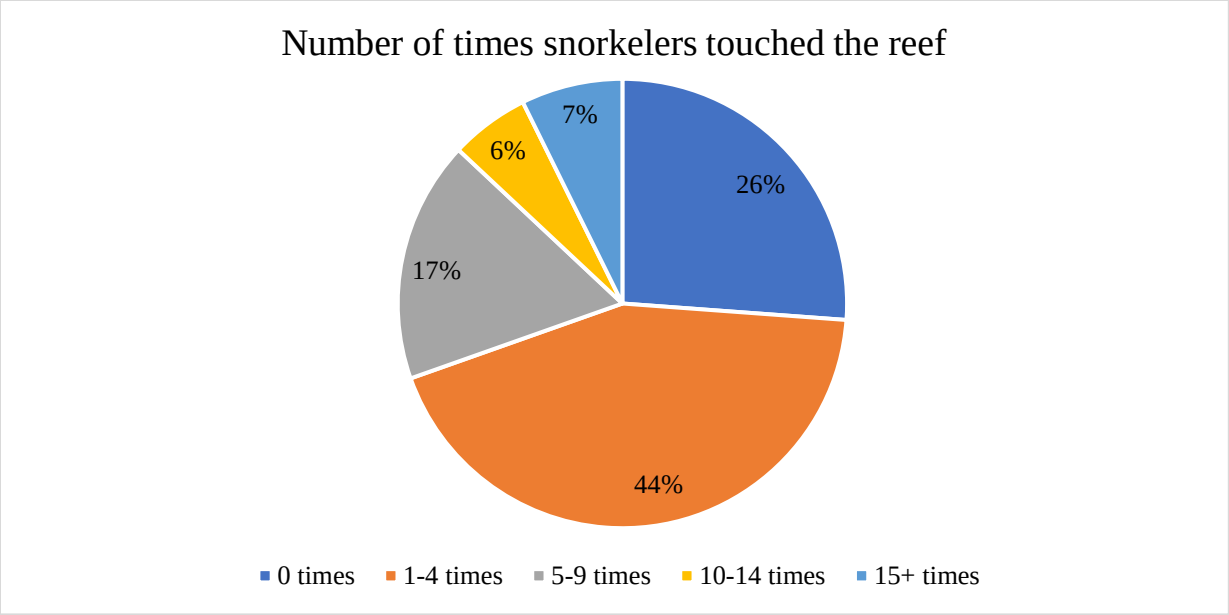

Figure 4: Number of times visitors saw another person touch, bump, or hit the reef in percent of total.

Overall Experience

Visitors were queried on perception of crowding. The box office counts were used to compare actual numbers with perceptions. From the reopening in December 2020 until January 2022, Hanauma received 429,425 visitors (https://www.honolulu.gov/parks-hBay/home.html). The summer months sampling period in July and August 2021 reported a total of 60,163 visitors while the winter sampling period in December 2021 and January 2022 reported 57,433 visitors, a slight 4% difference. When compared to 2019, when Hanauma was last open for a full year, the number of visitors is well below the pre-COVID numbers.

Question 8: Have you visited Hanauma Bay before today?

The majority of visitors who answered the survey had not been to Hanauma Bay prior to this visit (52%).

Question 9: What was your primary reason for visiting Hanauma Bay today?

The main reason for visitors to visit Hanauma Bay was snorkeling (88%). Visitors came for the beach or to sunbathe (7%) and 3% to swim in the Bay. A few visitors indicated “other” for their primary purpose for visiting (2%). Question 20 indicated the marine life that visitors most wanted to see was a variety of fishes, therefore snorkeling would be the primary purpose for visiting the Bay.

Question 10: How many times have you snorkeled in your lifetime?

While snorkeling was the primary purpose for many of Hanauma's visitors during these time periods (88%), 63% of visitors had only previously snorkeled 1-20 times. Since the majority of visitors were from the U.S. mainland, this could indicate that while the visitor's current visit to Hanauma Bay may not have been their first snorkeling experience, it is likely that the visitors had only recently started snorkeling. The next highest percentage (14%) represented visitors who had never been snorkeling before. Similarly, 14% of visitors had frequently snorkeled (20-50 times) and only 9% of visitors had snorkeled more than 50 times.

Question 11: Hanauma Bay could have accommodated more visitors today without affecting my experience.

When visitors were queried if Hanauma Bay could accommodate more visitors, 49% either disagreed (37%) or strongly disagreed (12%) (Figure 5). Neutral responses comprised 25% of visitor's responses and 26% either strongly agreed (7%) or agreed (19%) that the Bay could accommodate more visitors. Despite Hanauma receiving lower numbers of visitors due to COVID-19, visitors indicate that if the number of daily visitors increased, user satisfaction would decrease.

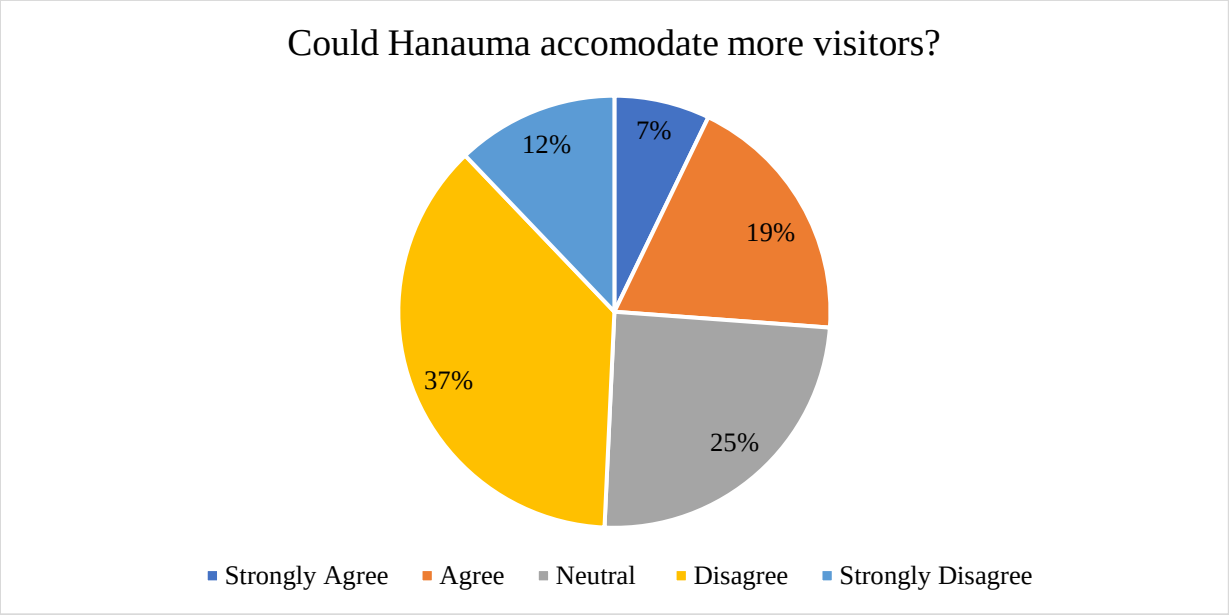

Figure 5. Responses on visitor accommodation at Hanauma Bay in percent of total.

Question 12: The number of guests at Hanauma Bay negatively impacted my experience today.

When asked if the number of people at the Bay negatively affected their experience, 57% either disagreed (44%) or strongly disagreed (13%) (Figure 6). A larger percent of visitors (30%) was neutral. Only 14% of visitors agree (11%) or strongly agree (3%) that the current number of visitors negatively affected their experience. Nearly half of the respondents believe HBNP cannot accommodate more people however, only 14% believed the number negatively impacted their experience.

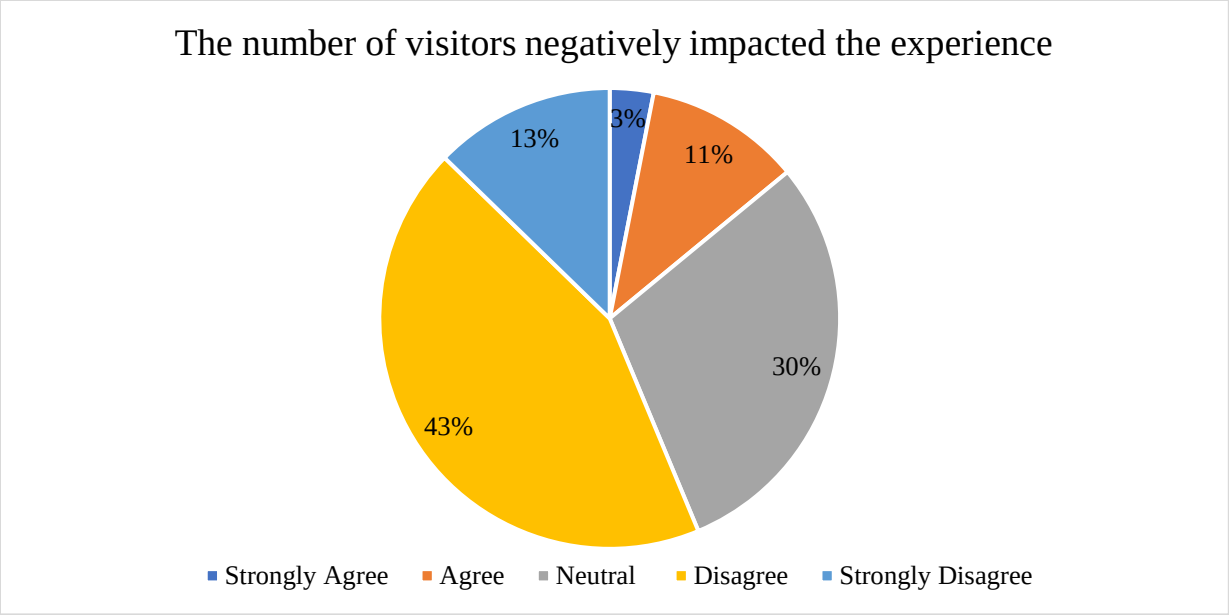

Figure 6. Visitor's opinion on the number of people at Hanauma Bay in percent of total.

Question 13: There were too many snorkelers in the water during my visit.

The hourly beach count photos said 27% of all recorded people were in the water snorkeling (Table 2) and question 9 stated that 88% of visitors came to Hanauma to snorkel. Despite these factors, 54% of visitors disagreed (45%) or strongly disagreed (9%) that there were too many snorkelers in the water (Figure 7). Nearly one third (31%) of visitors indicated they were neutral and 15% indicated they agreed (12%) or strongly agreed (3%) that there were too many snorkelers in the water.

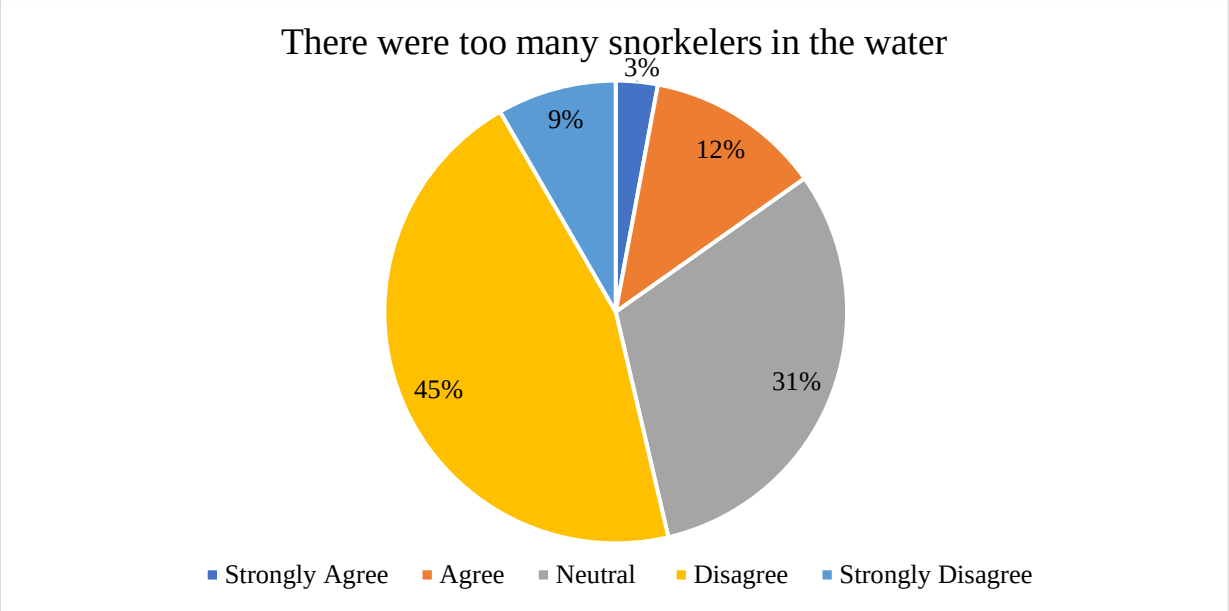

Figure 7. Visitor opinion on the number of snorkelers in the water in percent of total.

Question 14: There were too many visitors on the beach during my visit.

Similar to question 13, the hourly beach count photos showed that the majority of visitors to Hanauma Bay (55%) were on the beach at the time of the hourly beach counts. Even though 55% of visitors were on the beach, 53% either disagreed (45%) or strongly disagreed (8%) that there were too many people on the beach (Figure 8). Similar to previous questions on perceived crowding, 30% of visitors were neutral and 17% either agreed (13%) or strongly agreed (4%) that there were too many people on the beach.

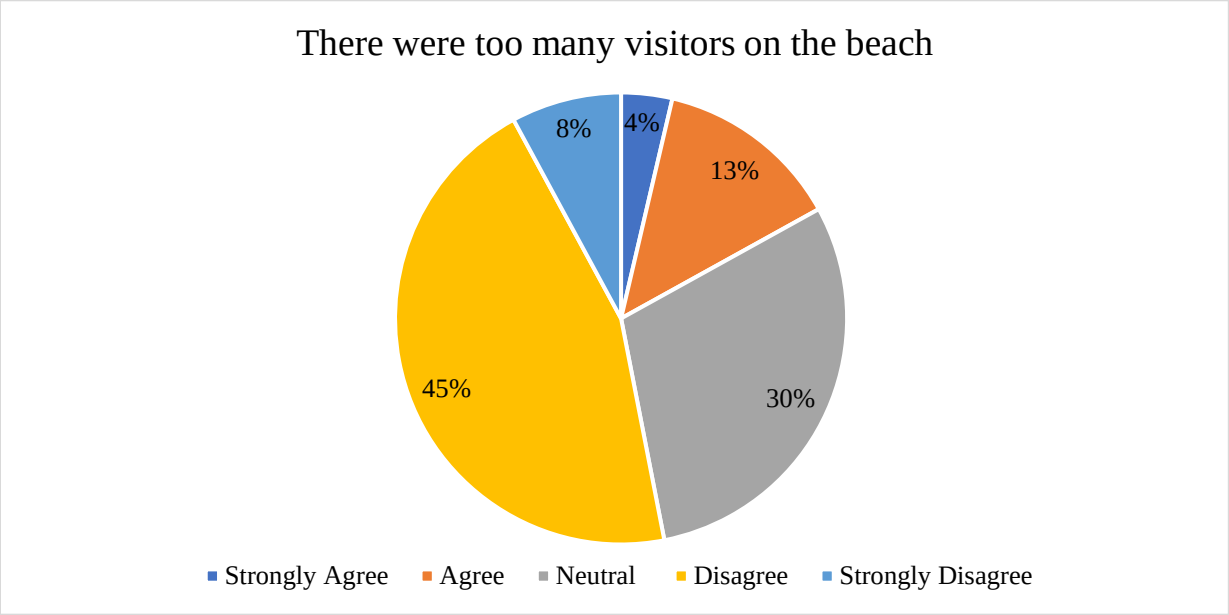

Figure 8. Respondents' opinion on the number of people on the beach in percent of total.

Question 23: How effective was the educational video at providing useful information?

The majority (84%) of visitors agree (45%) or strongly agree (39%) that the educational video was effective at providing useful information. Only 11% were neutral and 5% disagree (4%) or strongly disagree (1%) that it is effective. Even though the majority of people said the video was effective, there were still 74% of visitors that said they saw someone touch the reef one or more times.

Question 24: How effective was the SeaGrant Kiosk (down at beach level) at providing useful information?

The SeaGrant kiosk was viewed as less effective than the educational video at providing useful information. Only 51% of visitors agree (25%) or strongly agree (26%) that it was useful while 34%, the largest percentage, were neutral. Compared to the educational video, a higher number of people (15%) disagree (10%) or strongly disagree (5%) that the kiosk provides useful information. One reason the SeaGrant kiosk may not be as effective is that it is not a mandatory resource for visitors. All visitors to the Bay must watch the video and pass through the theater

before entering the Bay, however the sea grant kiosk is centrally located at the bottom of the Bay and may not be visible by visitors going directly to the Keyhole or Backdoor sectors of the Bay. It is likely that the reason the neutral category is highest for this question is because many people did not utilize the SeaGrant kiosk and therefore had no opinion on its effectiveness.

Question 27: From your experience, was the admission fee an appropriate amount?

Approximately 75% of visitors agreed in some way that the fee was appropriate. This was an open-ended question so visitors could elaborate, eliciting a wide variety of responses. The 75% of visitors that supported the admission fee were counted based on having a "Yes" in their response indicating they thought the fee was an appropriate amount, or any comment indicating they believed the price to be fair. The remaining responses either believed the price was too high or their responses were neutral. Of the 75% of visitors who supported of the fee, 6% of the responses indicated they were military or residents who said that they supported the fee because they were exempt. Visitors who identified themselves as residents of Hawai'i comprised 13% of the survey population. There was no specific question to identify military however they likely identified themselves as a resident. Excluding the percentage of locals, there is still 62% of non-resident visitors that support the current fee. Another opinion among 11% of visitors was the fee was high but believed to be fair to support conservation. The remaining 13% of responses believed the fee was too expensive.

Recommendations

Recommendations are based on the responses to the survey questions. These surveys were conducted as HBNP reopened following the COVID-19 closure. This population may not be representative of previous years. Many international travelers were limited by COVID travel restrictions and therefore the population at Hanauma Bay was mainly from the United States. These visitors are culturally different than Japanese visitors and crowd perceptions are strongly dependent on prior experience and population of place of residence. When screening the mandatory video, headsets are available in multiple languages for international travelers to comprehend the information.

- The majority of visitors (69%) have either a Bachelor's or Master's degree. This higher education level may present an opportunity to educate the visitors further through interactive exhibits or more in-depth educational videos in the dominant languages.
- HBNP has been effective in increasing the number of locals and their accessibility. The resident population doubled since the new regulations took effect. The management strategy has been successful in allowing resident access with early entry, bypassing the reservation system and waiving of video viewing and entry fees. Management should be commended for this success. To enhance this accomplishment, community outreach to disseminate this information may be useful in reaching a larger user population. One further step to consider may be increasing the early entry period on Saturdays and Sundays to include resident families engaged in work and school activities on weekdays. Access for school groups is currently difficult to obtain. Facilitating admission and

encouraging use of underutilized sectors such as Witches Brew and Backdoors will alleviate any increase in resource use.

- Based on the results of this social carrying capacity survey, the majority of users surveyed are satisfied with their experience at HBNP and the current entry fees. Satisfaction level may increase further with the return of visitors from Japan. An overwhelming number of visitors were highly satisfied with the natural resources at the Bay. Familiarity with fishes can enhance their experience. Educational activities can include a Junior Marine Biologist certificate, similar to the Junior Park Ranger at the National Parks.

- Disperse users among other activities. These may include non-fee based controlled nature hikes, children's programs, ocean films etc. All activities will provide education about the Hawaiian ecosystem or history.

- Place educational information signs along the sidewalk leading up to the ticket windows so visitors have another chance to become familiar with the reef environment while they wait in line for tickets. Signs should include information on the living reef environment and step-by-step instructions on how to enter the Bay and proceed with snorkeling. Provide signs in both English and Japanese and other languages common to visitors. Cover sidewalk to provide shade for visitors and signs. If sidewalks are covered before entering the park and information in present, visitors will have another opportunity to understand how they can help protect the natural resources within HBNP and themselves.

- Create an informational webpage and resources for visitors to reference prior to arriving at the Bay. Include research that is ongoing and supported by their entry fee. (Ex. https://dlnr.hawaii.gov/ecosystems/nars/maui/ahihi-kinau-2/)

- Educational materials and displays should include information on climate change (CC) impacts on coral reefs with clear direction and fun activities on actions to reduce carbon. The National Parks Service has a CC response strategy, action plan, and regional policies and strategies that include science, adaptation, mitigation, and communication.

- Place informational signs with interactive displays within the education center describing ongoing research within the Bay: CRAMP, recruitment modules, biological carrying capacity study. Knowing about ongoing research will educate visitors, enrich their experience, and increase the likelihood of coral reef protection.

Budgetary Spending

Description	Awarded	Total Expended	Available Balance
Social Carrying Capacity of the Hanauma Bay Nature Preserve	60,000		
Project Date: 05/01/2021-04/30/2022			
A. Salaries and Fringe	50,249	40,628	12,093
B. Total Materials and Supplies Costs	**6,545**	8,989	**-6,003**
C. Indirect Costs 10%	**6,000**	6,000	**00**
D. Total Direct and Indirect Costs	**60,000**	55,617	4,383

Literature Cited

Brock, R., & Kam, A. (2000). Carrying capacity study for the Hanauma Bay nature preserve: final report. *Honolulu: Department of Parks and Recreation*. Carrying Capacity Study for the Hanauma Bay Nature Preserve Final Report

Chen, C. L., & Teng, N (2016). Management priorities and carrying capacity at a high-use beach from tourists' perspectives: A way towards sustainable beach tourism. *Marine Policy 74*:213–219.

Clark, A. M. (2016). Hawaii's Sustainable Marine Tourism Challenges and Opportunities. Hawaii Division of Aquatic Resources PowerPoint Presentation.

Gardner, E. A. (1999). A Victim of Its Own Success: Can User Fees Be Used to Save Hanauma Bay. *Ocean & Coastal LJ*, *4*, 81.

Gonson, C., Pelletier, D., Alban, F., Giraud-Carrier, C., & Ferraris, J. (2017). Influence of settings management and protection status on recreational uses and pressures in marine protected areas. *Journal of Environmental Management*, 200:170–185.

Hanauma Bay Beach Park Development Plan (1977)

Hanauma Bay Case Study (1989)

http://www.honolulu.gov/parks-hBay.html

Komatsu, M. & Liu, J. (2007). Cross-cultural Comparison Between Japanese and Western Visitors for the Effectiveness of the Hanauma Bay Education Programme. Tourism Recreation Research, 32:3, 3-12,

Lankford, S., Inui, Y., Whittle, A., Luna, R., & Tyrone, D. (2005). Sustainability of coastal/marine recreation: Modeling social carrying capacity for Hanauma Bay, Hawaii. University of Hawaii.

Mak, J., & Moncur, J. E. (1998). Political economy of protecting unique recreational resources: Hanauma Bay, Hawaii. *Ambio*, 217-223.

Murphy, S.K. (2021). Assessing human-induced coral reef disturbances from visitors at Hanauma Bay Nature Preserve. Undergraduate global environmental science thesis submitted to the University of Hawai‘i at Manoa.

National Park Service (1997) The Visitor Experience and Resource Protection (VERP) Framework: A handbook for planners and managers. U. S. Department of the Interior, National Park Service, Denver Service Center. 102pp.

Needham, M. D., Tynon, J. F., Ceurvorst, R. L., Collins, R. L., Connor, W. M., & Culnane, M. J. W. (2008). Recreation carrying capacity and management at Pupukea Marine Life Conservation District on Oahu, Hawaii. Final project report for Hawaii Division of Aquatic Resources, Department of Land and Natural Resources. Corvallis: Oregon State University, Department of Forest Ecosystems and Society. 104pp.

Reynolds, E. (1990, May). Hanauma Bay baseline users survey. In *Proceedings of the 1990 Congress on Coastal and Marine Tourism* (Vol. 1, pp. 106-116).

Rodgers, K. S. & Cox. E. F. (2003). The effects of trampling on Hawaiian corals along a gradient of human use. *Biological Conservation 112*:383–389.

van Beukering PJH, Cesar HSJ. 2004. Ecological economic modeling of coral reefs: evaluating tourist overuse at Hanauma Bay and algae blooms at the Kihei coast, Hawai'i. Pac Sci 58(2): 243-260.

Vieth, G. R., & Cox, L. J. (2001). Sustainable Use Management of Hanauma Bay. *Department of Natural Resources and Environmental Management*, CTAHR—July 2001 (2 p.).

Wanger, J.R. (2001). Interpretive Education as a Conservation Tool at Hanauma Bay Nature Preserve, Hawaii. Master of Arts in Geography. University of Hawaii. 123p.

Appendix A

Hanauma Bay Survey Questions

1. ***What is your age?***
   0-15

   16-30

   31-45

   45+

   Prefer not to answer

2. ***What gender do you identify as?***
   Female

   Male

   Transgender

   Non-binary/non-conforming

   Prefer not to answer

3. ***Please specify your race.***
   American Indian or Alaska Native

   Asian

   Black or African American

   Native Hawaiian or Other Pacific Islander

   Latino or Hispanic

   White

   Other_____

4. ***What is your primary language?***
   English

   Japanese

   Other _____

5. ***What is the highest degree or level of education you have completed?***
   Some high school

   High school

   Bachelor's degree

   Master's degree

   PhD or higher

Trade school

Prefer not to answer

6. ***Which of the following represents your annual household income before taxes?***
   Less than $30,000

   $30,000 to $60,000

   $60,000 to $90,000

   $90,000 or higher

7. ***Are you a resident of Hawai‘i?***
   Yes, I live on O‘ahu.

   Yes, I live on a neighboring island.

   No, I am from the mainland US.

   No, I am from Japan.

   No, I am from (fill in the blank) _____

8. ***Have you visited Hanauma Bay before today?***
   Yes

   No

9. ***What was your primary reason for visiting Hanauma Bay today?***
   Snorkel

   Beach / Sunbathe

   Swim

   Other_____

10. ***How many times have you snorkeled in your lifetime?***
    0 times

    1-20 times

    20-50 times

    50+ times

<u>For the following statements, please tell me your level of agreement.</u>

11. ***Hanauma Bay could have accommodated more visitors today without affecting my experience.***
    Strongly agree
    Agree
    Neutral
    Disagree

Strongly disagree

12. ***The number of guests at Hanauma Bay negatively impacted my experience today.***

Strongly agree

Agree

Neutral

Disagree

Strongly disagree

13. ***There were too many snorkelers in the water during my visit.***

Strongly agree
Agree
Neutral
Disagree
Strongly disagree

14. ***There were too many visitors on the beach during my visit.***

Strongly agree
Agree
Neutral
Disagree
Strongly disagree

15. ***How would you describe the number of facilities provided at Hanauma Bay? Check one box for each facility.***

Bathrooms	(Adequate□	Not adequate□	Did not use□)
Showers	(Adequate□	Not adequate□	Did not use□)
Trash cans	(Adequate□	Not adequate□	Did not use□)
Water fill stations	(Adequate□	Not adequate□	Did not use□)
Snorkeling gear rental	(Adequate□	Not adequate□	Did not use□)
Gift Shop	(Adequate□	Not adequate□	Did not use□)
Food/Concessions	(Adequate□	Not adequate□	Did not use□)

16. ***Did you use the upper level facilites located near the entrance of the park? Please select all that apply.***

Picnic tables

Bathrooms

Overlook

Lawn

None

For the following statements, please tell me your level of satisfaction.

17. ***Overall, how satisfied were you with the number of safety personnel (lifeguards)?***
    Very satisfied

    Satisfied

    Neutral

    Dissatisfied

    Very Dissatisfied

18. ***How satisfied were you with vehicle parking at Hanauma Bay?***
    Very satisfied
    Satisfied
    Neutral
    Dissatisfied
    Very Dissatisfied
19. ***How satisfied were you with the marine life you experienced today?***
    Very satisfied
    Satisfied
    Neutral
    Dissatisfied
    Very Dissatisfied
20. ***Of all the marine life at Hanauma Bay, which were you most excited to see?***
    Different types of fish

    Coral/reef

    Sea turtles

    Monk seals

21. ***On a scale of 1-4, how would you rate the quality of the Bay's natural resources?***
    1 – ideal conditions

    2 – average, could improve

    3 – less than average

    4 – not ideal, deteriorating

22. ***How many times did you observe others touch, stand on, or bump the reef?***
    0 times

    1 – 4 times

    5 – 9 times

    10 – 14 times

    15+ times

For the following statements, please indicate the level of effectiveness.

23. How effective was the educational video at providing useful information?

Extremely effective

Effective

Neutral

Not effective

Didn't understand it

24. How effective was the SeaGrant Kiosk (down at beach level) at providing useful information?

Extremely effective

Effective

Neutral

Not effective

Didn't understand it

Didn't see it

25. ***Would you revisit Hanauma Bay based on your experience today? Why or why not?***

26. ***Did Hanauma Bay not meet, meet or exceed your expectations today? Why or why not?***

27. From your experience, was the admission fee an appropriate amount?

Any other thoughts about Hanauma Bay or your experience? Please provide any comments below:

Appendix B

Assessing human-induced coral reef disturbances from visitors at Hanauma Bay Nature Preserve. A thesis submitted to the global environmental science division in partial fulfillment of the requirements for the degree of Bachelor of Science in global environmental science. December 2021. Shannon Keala Murphy

ABSTRACT

It has been noted in many research papers that regions with high snorkeling and diving activity damages coral reef ecosystems. I investigated the effects of visitor snorkeling density, and the number of times snorkelers physically disturbed the reef. Four plots were designated for bimonthly monitoring, where the number of snorkelers entering each plot and their interaction with the reef was recorded. Coral health was qualitatively observed, and the surface area of the coral tissue was quantitatively measured. My results show a direct relationship between snorkeling density and the number of disturbances. However, there is no evidence of visitor density and coral health impairment. There was no coral breakage or abrasions from snorkelers during the data collection period, possibly a result of low coral cover across the Bay, limited branching morphology, and/or species with high skeletal strength due to historical disturbances from higher water motion and extensive visitors. Corals in each of the plots experienced tissue loss mainly from preexisting lesions or tissue damage; the causation of the previous coral injury is unknown. Future management actions in Hanauma Bay could limit the number of visitors and occurrence of reef disturbances to potentially reduce tissue loss and promote coral recruitment.

RESULTS

3.1 The Number of Snorkelers and Reef Disturbances

A total of 327 snorkelers were observed in all the plots combined, with the highest visitation in KN (n= 144). The lowest snorkeler count was in BF (n= 23) and BN and KF had intermediate values (n= 67, n= 93), respectively. Over the study period, 168 reef disturbances were documented, < 5 of the disturbances were directly to coral heads and the rest of the disturbances were to the other substratum. Most disturbances occurred in KN (n= 65) followed closely by KF (n= 61) (table 1). Grabbing was the most common category of reef disturbance and was three times higher than the other categories. The second highest reef disturbance was standing (fig. 3).

In the 30-minute survey period, KN experienced the highest snorkeling density and reef contacts (fig. 4). However, the proportion of snorkelers to reef disturbances was highest for KF (66%) followed by BF (61%) making the relative frequency of reef contacts to snorkelers swimming through the plot highest for KF and BF. Although BF had the lowest visitation rate, more than half the snorkelers entering the plot contributed to a reef disturbance (table 1).

Table 1. Comparison of the number of visitors separated by plot and corresponding reef disturbance categories. FD = frequency of disturbance, is separated by plot and reef disturbance category. The percentage of visitor contact by plot was calculated from the total frequency of disturbance divided by the total number of visitors.

Plot	Number of Visitors	Stand	Sit	Kick	Grab	Body Graze	FD by plot	Visitor Contact Percent (%)
BF (1)	23	0	0	2	10	2	14	60.87
BN (2)	67	4	3	2	17	2	28	41.79
KF (3)	93	12	5	8	28	8	61	65.59
KN (4)	144	11	7	11	31	5	65	45.14
FD by category	327	27	15	23	86	17		

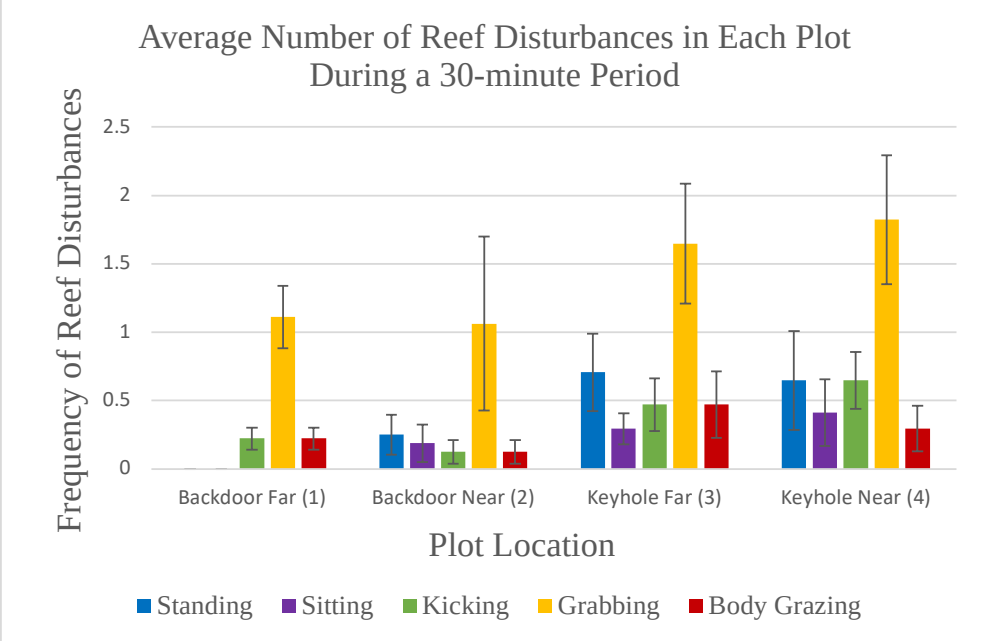

Figure 3. Frequency of reef disturbances averaged over a 30-minute survey period categorized by reef disturbance and plot location. Standard error is included.

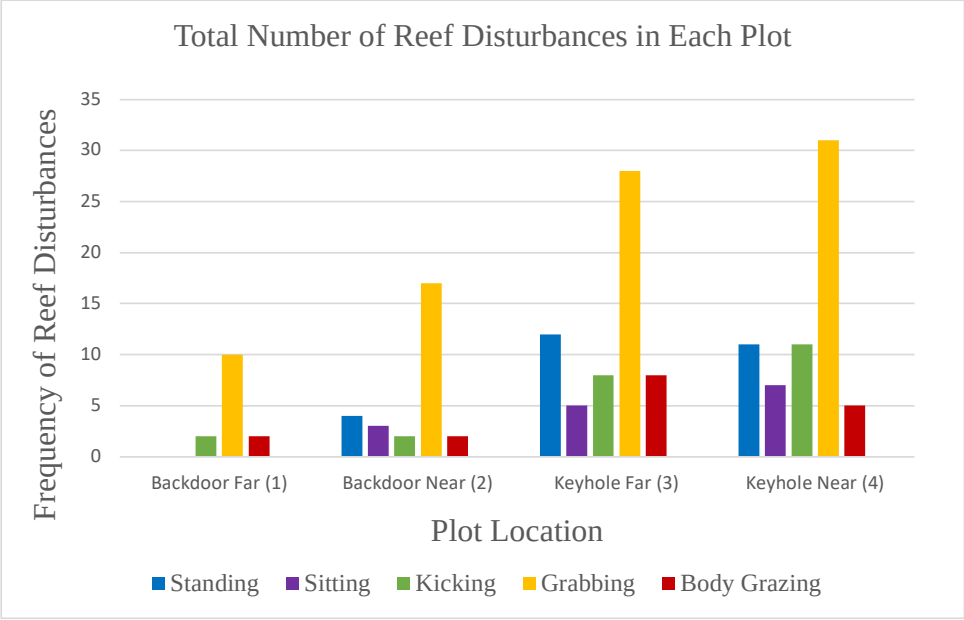

Figure 4. Total frequency of reef disturbances over entire data collection period categorized by reef disturbance and plot location.

3.2 Coral Health Documentation and Images

From the initial survey before Hanauma Bay was reopened to the public, corals were observed to identify preexisting dead branches and pink tissue regions, which are indicators of stress. Prevalent dead branches were recorded on corals A, D, E, F, H, I, N, and O (see Appendix for coral photos).

Throughout the survey period, most corals either lost tissue surface area or remained unchanged (table 2). The one exception is coral M that increased in tissue surface area based on ImageJ

measurements (fig 7). 12 of the 42 data points are unavailable due to photographic error (table 2). The tide difference and slight misplacement of the lock in the images distorted the scale.

Some specific examples of tissue loss are found from coral J and K. Coral J was bleached on May 30th, 2021, resulting in major tissue loss on the top of the coral head (fig. 5). Coral K developed tiny algal specks first noticed on April 4th, 2021. As time progressed, more tiny algae settled on the coral head. By the final survey, a colony of algae was noticeable (Appendix fig. A.12).

Figure 5. (Left): Coral J bleached between May 16th (Survey #9) and May 30th (Survey #10). Only the top portion of the coral experienced discoloration. (Right): Coral J revisited on June 13th (Survey #11), two weeks following the initial assessment. Turf algae settlement was observed succeeding tissue mortality.

Table 2. Determining the change in living coral tissue surface area from the first survey on December 4, 2020 (Survey #0) and the last survey on September 26, 2021 (Survey #17) in cm^2. Δ SA = the change in surface area. A positive change in surface area indicates coral growth and a negative change in surface area indicates tissue loss. Some values are not applicable due to photographic error. Standard error (SE) values are in cm^2.

Coral Identification	Coral Reference Letter	Survey #0 SA [cm^2] ± SE	Survey #17 SA [cm^2] ± SE	Δ SA [cm^2] ± SE
BF1001	A	283.209 ± 16.29	234.014 ± 3.56	-49.195 ± 16.67
BF1002	B	655.709 ± 12.08	586.255 ± 15.57	-69.454 ± 19.71
BF1003	C	1303.139 ± 7.71	1219.844 ± 5.76	-83.295 ± 9.62
BF1004	D	N/A	N/A	N/A
BF1005	E	927.345 ± 38.34	928.630 ± 4.55	1.285 ± 21.12
BF1006	F	352.079 ± 20.15	324.527 ± 4.70	-27.553 ± 20.66
BF1007	G	N/A	N/A	N/A
KF3001	H	216.760 ± 4.35	218.909 ± 2.19	2.148 ± 6.40
KF3002	I	213.809 ± 16.46	138.295 ± 4.69	-75.514 ± 16.60
KF3003	J	N/A	N/A	N/A
KF3004	K	N/A	N/A	N/A
KF3005	L	N/A	N/A	N/A
KF3006	M	525.572 ± 19.46	587.979 ± 4.69	62.407 ± 20.01
KF3007	N	156.024 ± 4.66	153.81 ± 3.66	-2.214 ± 5.92
KN4001	O	281.318 ± 8.11	268.492 ± 0.31	-12.826 ± 8.11

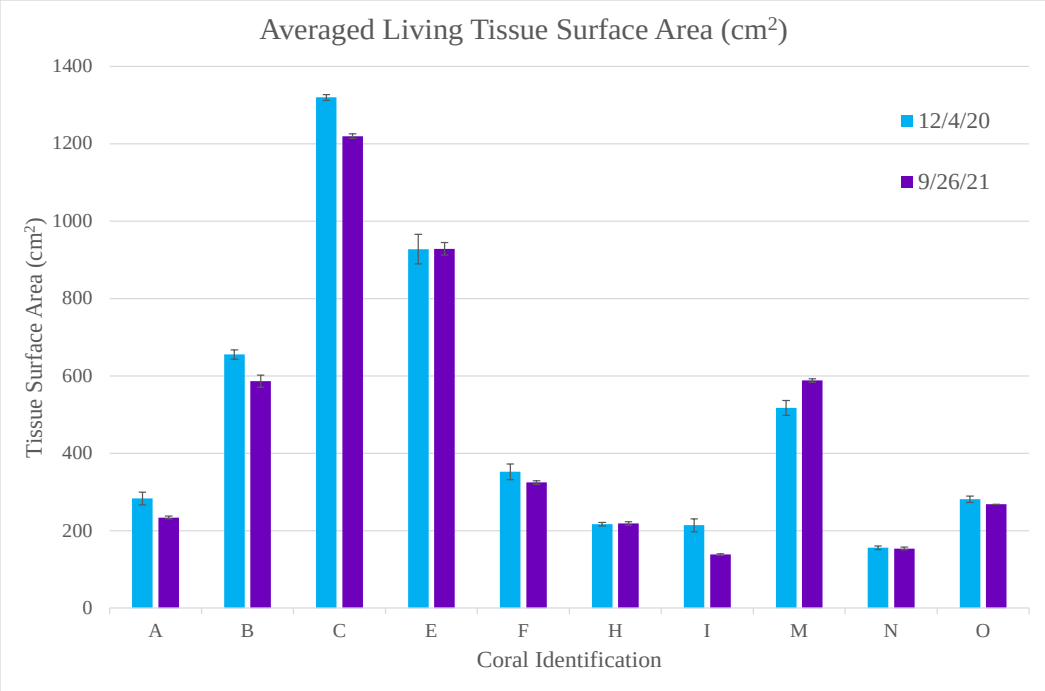

Figure 6. Averaged living tissue surface area (cm^2) from the first survey on 12/04/20 (Survey #0) compared to the last survey on 09/26/21 (Survey #17). Standard error bars are in cm^2.

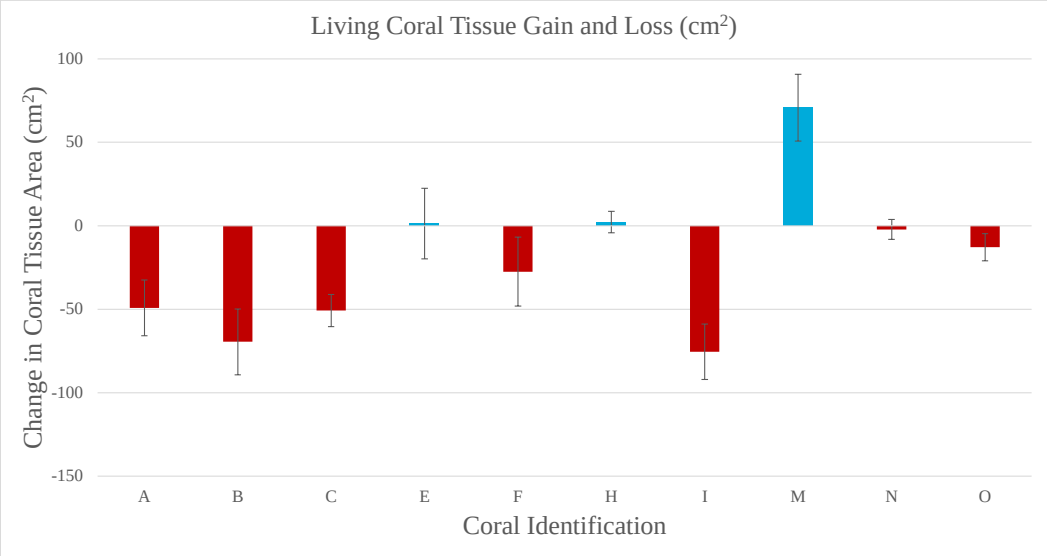

Figure 7. The change in tissue surface area (cm^2) from the first survey on 12/04/20 (Survey #0) compared to the last survey on 09/26/21 (Survey #17). The blue bars indicate tissue growth, and the red bars indicate tissue loss. Standard error bars are in cm^2.

3.3 Natural vs. Anthropogenic Disturbances

Biological disturbances were detected in the initial survey. All coral colonies surveyed had noticeable fish bites except corals F, G, L, and O. Coral I had dead tissue below the branch tips most likely from a burrowing organism (see Appendix for images). As data collection progressed, there were no obvious abrasions, broken branches, or lesions caused by snorkelers. It is possible that more snorkelers touched the surveyed corals, but the contact did not result in any noticeable injury.

In comparison to the outer reef (OR), corals in OR experienced the same biological disturbances of fish bites, turf algae, and sediment-covered branches. The abiotic stressors occurring in the inside reef of Hanauma Bay apply to the outside reef as well.

4.0 DISCUSSION

4.1 The Number of Snorkelers and Reef Disturbances

The total number of visitors and reef disturbances was highest for KN followed by KF, BN, and BF. A total of 327 snorkelers contributed to 168 reef disturbances in the 9-month survey period, which equates to a ratio of approximately one disturbance for every two snorkelers. Less than 3% of the disturbances were directly to a coral colony and the rest of the contact was to the substratum (bare reef, macroalgae, or crustose coralline algae). It is plausible that snorkelers noticed me with a clipboard underwater and altered their behavior to be more cautious with directly touching the corals. The results of high disturbance to the reef does not show much of an effect because most of the substratum is rock, algae covered sediment, or crustose coralline

algae. Since most of the reef appears “dead”, identifying the effects from physical contact to the substratum is limited.

The high visitation and reef disturbance rate occurred in KN because most people enter and exit the water at this location. A similar pattern of high trampling near water-entry points in popular tourist destinations was found in the Red Sea reef flats (Leujak and Ormond, 2008). KN is located next to a large sand patch where many snorkelers put on their equipment. For some, it is their first time using a mask and fins. As the visitors are comfortable wearing their gear, they swim over to the close reef sections nearshore where the KN plot is located.

The far shore plots of Backdoor and Keyhole Lagoon had the highest disturbance to visitor proportion. This may be the result of higher wave action and turbidity closer to the fringing reef. Snorkelers may be more likely to grab onto the reef in stronger ocean conditions, regardless of snorkeling experience.

Grabbing was the most common reef disturbance and was documented three times as often as the other categories of physical contact. Based on observations, grabbing was a method for snorkelers to move over the reef without scraping their knees or legs from kicking, especially during low tide. The second highest disturbance was standing on the reef. Standing was mainly intentional as a method for snorkelers to locate each other if separated. Other disturbances included kicking, which occurred mostly during low tide since the fins add additional length to the snorkeler’s legs. Body grazing was observed when snorkelers moved across an extremely shallow reef shelf and their entire body was submerged on top of the reef. Another observed behavior of snorkelers was sitting on the reef, especially with high winds and swell. The water motion would toss snorkelers putting them in a sitting position on the reef. This may be an effect of inexperienced snorkeling.

An additional category of reef disturbance found in the literature is sedimentation via resuspending sand as snorkelers kick (Leujak and Ormond, 2008; Giglio et al., 2016; Harriot et al., 1997; Rouphael and Inglis, 1997; Luna et al., 2009). Sedimentation was not included in data collection because the plots were only located over reef substrate. There is a possibility that some corals on the edge of the reef shelf, including A and H, are subject to higher sedimentation rates due to snorkelers kicking sand. Since both of those corals were found with sediment-covered dead branches from the time of the initial survey, the resulting effects of increased sedimentation after reopening of the Bay could not be determined. The reef disturbance of increased sediment load smothers the tissue layer and reduces coral growth and reproduction (Hawkins and Roberts, 1994; Neil, 1990; Webler and Jakubowski, 2016). Additionally, the high sedimentation across Hanauma Bay can limit coral recruits for future colony growth. Sediment resuspension in Hanauma Bay can be correlated to visitor density and snorkeling activity because the mean clarity was 5.9 meters clearer during COVID-19 closures than on the public days (Severino et al., 2020).

4.2 Coral Health Documentation and Images

Most corals from the initial survey had dead branches, discoloration of tissue, and algal growth. The cause of the preliminary damage is unknown due to a lack of historical photo documentation. In general, tissue loss progresses from a tissue lesion, followed by macroalgae

settlement then, algae mortality, and sedimentation deposition. This specific progress was observed with coral C during the 4th survey in February. One branch tip bleached to a light grey color without evidence of any physical damage. The branch continued to decline with subsequent surrounding coral branches following. The lack of noticeable damage leaves the cause of tissue loss unknown, suggesting potential internal injuries or damage from burrowing organisms or pathogens (Rodríguez-Villalobos et al., 2015). In other words, a single coral branch bleached and the section below the branch also became covered in sediment, therefore, it could have been targeted by another organism. Tissue loss for *Pocillopora meandrina* has been documented previously in Hanauma Bay. Some of the tissue degeneration is by *Drupella cornus* (corallivorous snail) but the other instances have unknown sources (Walton, 2003 Dissertation).

The bright pink portions of some coral branches indicate coral stress (Bongiorni and Rinkevich, 2005). Researchers believe the pink coloration is from a loss of coral tissue and zooxanthellae, or it is from pathogens inducing the pigmentation (D'Angelo et al., 2012). During a stress event, the zooxanthellae are removed from the coral polyps and the tissue is no longer pigmented by the *Symbiodinium* spp. dinoflagellates (Jones et al., 1998; Curran and Bernard, 2021). Instead, chromoproteins, non-fluorescent photopigments in the tissues, show through the tissue now devoid of symbionts (Donà, 2019 Dissertation). The chromoproteins may be used as photoprotection for the zooxanthellae in high light environments (D'Angelo et al., 2012).

Other researchers link the pink pigmentation to coral diseases such as pink-line syndrome (D'Angelo et al., 2012). Pink-line syndrome is a disease that appears pink between living and dead tissue, induced by fungi and a cyanobacterium, *Phormidium valderianum* (Ravindran and Raghukumar, 2006). The process of pink-like syndrome infiltration proposed by Ravindran and Raghukumar (2006), beings with cyanobacterium settlement on the coral host. *P. valderianum* increase carbon dioxide concentrations around the coral polyps by respiration, causing the zooxanthellae to escalate photosynthesis production. The photosynthate is utilized by the zooxanthellae to grow, rather than diverting the sugars to the coral host. In return, the coral loses its portion of photosynthate, which hinders growth and calcification. The weakened coral host, acidic environment, and higher carbon dioxide concentrations degenerate the coensacral tissue, turning the polyp tissue pink (Ravindran and Raghukumar, 2006).

The pink pigmentation on *P. meandrina* is potentially a symptom of stress from environmental and biological factors through the expression of chromoproteins (Bongiorni and Rinkevich, 2005), or it is the product of disease (Ravindran et al., 2015). In either case, the pink patches found on numerous corals surveyed in Hanauma Bay such as A, D, H, M and O are likely to bleach due to the degeneration of coral tissue and/or expulsion of zooxanthellae (see Appendix for coral images). However, a few of the pink branches were present over the entire survey period and bleaching associated with pink pigment regions was not observed. Therefore, those coral colonies are maintaining a state of stability and equilibrium. If the corals are exposed to further environmental stress, bleaching is likely to occur. If the coral remains resistant to bleaching, the zooxanthellae may once again repopulate the coral, returning the brown coloration.

The coral identified as J was recorded as bleached five months into the data collection. The week before the May 30th survey, Hanauma Bay experienced an extreme tidal change from -0.5 ft to 2.5 ft. During the lowest tide interval, the top portion of the coral may have been only a

few inches underwater and the strong irradiance has been linked to bleaching (Jokiel and Brown, 2004). It is probable that the nearby corals did not experience any bleaching due to genetic differences or varying symbiont clades that are more resilient (Pettay and Lajeunesse, 2009; Morikawa and Palumbi, 2019).

Coral K had minute algal growth across the coral head. The cause of the algae infiltration is unidentifiable as well as the algal species. Obtaining coral tissue samples could give insight into the susceptibility of the coral head to algal settlement.

A few ImageJ measurements were not included in the surface area analysis due to photographic error. Some photo distortion occurred from tide differences and water movement and the misplacement of the lock altered the reference scale. However, qualitative observations from the first and last photos show most corals either losing tissue or remaining unchanged. The only corals with growth potential from the photos are B, E and L. The initial photos documented white branch tips, but later images show full brown tissue, which may indicate growth. One method of coral growth is through primary calcification, or skeletal extension at the coral tips (Fang et al., 1989). It is possible that primary calcification was rapid, and the zooxanthellae had yet to settle in the polyps.

4.3 Natural vs. Anthropogenic Disturbances

There were no documented coral breakage or new lesions from human disturbances. Although there were many reef contacts and high visitor numbers, low coral cover may explain why most of the corals remained untouched. For example, the KN plot is 25 m^2 and the only living coral in the plot (coral O), occupies approximately 0.03 m^2, representing <1% coral cover. However, if snorkelers notice a coral on the reef shelf, they may want to swim near it. It is plausible that visitors are more cautious with their behavior near a coral colony rather than the reef substrate that appears as rock. Hence, there was no indication of physical damage inflicted by humans.

Corals in the outside reef were documented with similar patterns as the inside reef: dead branches, fish bites, and heavy sediment load. Many corals offshore may be subject to heavy sedimentation due to extreme turbidity and waves that break along the reef shelf. The degraded coral health conditions could also be a product of other regional-scale stressors.

5.0 CONCLUSION

5.1 The Number of Snorkelers and Reef Disturbances

I hypothesized that high visitor activity in the nearshore plots would result in the most coral damage from physical contact. My hypothesis was not substantiated by the results since corals at all stations experienced tissue loss. Tissue loss was not evident as an outcome of human disturbance when compared with results from the offshore reference station. However, one of the nearshore plots, KN, had the highest visitation and reef disturbance frequency and very low coral coverage. Although the evidence for human disturbance is limited, previous human contact could have caused the current tissue damage noticed in the initial survey. Additionally, anthropogenic reef interactions may prohibit coral growth, reproduction, and larval settlement (Richmond,

1993; Mora et al., 2016). This is evident in Hanauma Bay, since limited coral growth and recruitment was observed for *Pocillopora meandrina*.

The far shore plot in Keyhole Lagoon had the second highest visitation and reef disturbances. It is reasonable to assume that many snorkelers entered the ocean from Keyhole Lagoon and swam over the near shore reef, then proceeded to swim to the far shore plot. Overall, few snorkelers visited Backdoor Lagoon. Only in instances when some snorkelers ventured to the East side of the Bay did other snorkelers follow.

The ratio of one disturbance for every two snorkelers is based on the daily visitor cap. In December of 2020, Hanauma Bay only allowed 720 visitors to enter the park, but this increased to 1000 daily visitors in April of 2021. If the daily entrance increases to pre-covid conditions of 3,000 people per day, the occurrence of reef disturbances is anticipated to triple along with physical contacts directly to coral colonies.

5.2 Management Actions for Hanauma Bay

Since 2002, all visitors entering Hanauma Bay are required to watch a 9-minute educational video as a part of a conservation plan (Hanauma Bay History, HanaumaBay- StatePark.com). The video describes the importance of coral reefs, safety measures, and establishes the prohibition of touching or taking any marine life. Despite precautionary measures of the education team and staff at Hanauma Bay, there are still high numbers of reef contacts. Most reef disturbances occur as a product of poor snorkeling techniques (Harriot et al., 1997; Giglio et al., 2016; Luna et al., 2009; Webler and Jakubowski, 2016). Therefore, it is recommended for first-time snorkelers to remain in the sandy patches of the Bay along reef shelfs where they can still view fishes and coral. The education staff can convey this message to visitors and adapt it as a park regulation.

The data represents only 2.5% of the total time Hanauma Bay is open per month. Therefore, the number of snorkelers entering each plot and the number of reef disturbances are likely to be significantly higher. It is possible that during the other 97.5% of the time, snorkelers contacted coral colonies, but the strong skeletal structure is the reason for unnoticeable lesions or abrasions. If that is the case, the morphology, robust branch structure, size, and density of the coral (Rodgers et al., 2003) could explain why *Pocillopora meandrina* is one of the only remaining coral species present on the inside reef of Hanauma Bay. Based on the results of Severino et al. (2020), expanding the number of daily visitors is likely to increase sediment resuspension. Moreover, physical reef disturbances from visitors are only a part of the narrative of coral degradation in the Bay. The combination of physical disturbance (Lamb et al, 2014), high bacteria levels (Richmond, 1993), sunscreens (Danovaro et al., 2008), and runoff (Richmond, 1993) can cause poor coral health. Impaired health of corals in Hanauma Bay may limit future coral recruitment and affect the survival of other marine life in the nature preserve that depend on coral reefs (Bonin et al., 2009; Hourigan et al.,1988). Evidence of coral degradation can reduce tourist visitation and impact visitor expectancy (Le et al., 2019; Coghlan and Prideaux, 2009). The objective is to mitigate current human disturbances in Hanauma Bay, not to promote stressors to the marine life residing there by increasing visitor capacity and reef contacts.

A tide-gauge placed in the water at Hanauma Bay would be useful. Direct physical contact could be limited by prohibiting snorkeling once the tide reaches below a threshold of 0.7 ft (fig. appendix A.1). Lifeguards located in the four stands or volunteers can regulate this activity and communicate with snorkelers via loudspeakers across the beach. During this period of low tide, snorkeling can remain along the reef shelves in sandy patches located in Backdoor Lagoon, Keyhole Lagoon, and Sandman's patch. Snorkelers will still be able to view marine organisms along the shelf.

Another way minimize reef contacts is designating a meeting location if members lose contact in the ocean. Having this information in the educational video and at the *SeaGrant* kiosk on the beach can limit purposeful reef disturbances, especially sitting and standing on the substratum. If a snorkeler needs to locate their group, they need to first move to sandy seafloor to stand.

Hanauma Bay can experience rough conditions throughout the year and snorkelers need to be cautious during times of high wind and swell. The increased water motion throughout the Bay can cause snorkelers to grab onto the reef to stabilize. During these circumstances, lifeguards should decide if visitors are limited to snorkeling along the reef shelf as in the low tide circumstance.

Future studies need to investigate the patterns of dead coral branches and associated reasons through examining zooxanthellae density, protein expression, and various genomic techniques. *Pocillopora meandrina* tissue loss has been studied in the Bay previously, but the causation of tissue decline is still unknown (Walker, 2003 Dissertation). Tissue sampling of coral branches with pink pigmentation will help determine the microbial consortium of disease and if the coloration is strictly from chromoproteins. In the case of coral disease, determining the causation of the pathogen infiltration is an important aspect of minimizing tissue loss. Additional sedimentation and coral recruitment research may be a crucial part of coral recovery.

Pocillopora meandrina is a candidate under the Endangered Species Act. All coral species should be protected across O‘ahu and especially at Hanauma Bay Nature Preserve where visitors can learn about their importance and act accordingly. Corals face the effects of many global stressors that are predicted to increase. It is also important to control regional-scale impacts of human contact with the reef. If the goal is to maintain the current conditions for Hanauma Bay, the least managers can do is keep visitor counts the same. The new information provided in this study can allow managers to more fully understand human contact consequences to develop strategies to reduce them.