The Ecotourism Snorkeling Industry and Hawai'i Reef Soundscapes: An Exploratory Study

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Abstract

Coral reefs have distinctive soundscapes consisting primarily of reef associated fish, with most sounds resulting from various behaviors of said species. Ecotourism, particularly through snorkeling in coral reefs, can affect behavior in fish, therefore potentially altering the soundscape. Four different reefs across the western coast of Hawai'i were assessed both acoustically and visually through periodical deployment of a HydroMoth and a GoPro. Reefs were selected based on the amount of snorkelers present, ranging from none to high (over 16 visually identified). Recordings were analyzed in RavenPro and VLC Media Player to identify species, create a count of instances of biophony, and a count of instances of anthrophony. Results indicated that the sites with higher amounts of anthrophony instances correlated with a higher amount of snorkelers present, but there were no correlations between amount of biophony and presence of snorkelers. This research serves as an exploratory study and aims to lay the groundwork for future research with interest in the correlations between snorkeler presence and reef soundscape by describing potential patterns observed and identifying common reef associated fish sounds.

Keywords: Ecotourism, marine soundscape, reef associated fishes

Introduction

Hawaiian coral reefs are defined by high biodiversity, with 276 reef associated taxa identified across the Hawaiian Archipelago, and 17%-55% of those species being endemic (Friedlander et al., 2020). Therefore, the unique composition of ichthyphony creates a similarly unique ambient soundscape across Hawaiian coral reefs (Kaplan et al., 2017). Identification of ichthyphony in various fish species is a somewhat recent topic of study. In 2014, one study created a library of ichthyacoustics from coral reefs on the western coast of Hawai'i Island, which resulted in the documentation of 85 sounds produced by 45 different species, or about 47% of all species observed throughout the course of the study (Tricas and Boyle, 2014). Identification of species that create sound is incredibly relevant and important in order to develop the soundscapes of coral reefs. Sounds are often correlated with different behaviors, including foraging, feeding, competition over resources such as nesting sites, space, or food, and reproductive activities, including courtship, nest defense, and spawning. (Tricas and Boyle, 2014). In addition to acoustics produced by reef dwelling fish, many coral reef soundscapes are also saturated with anthropogenic sounds, which are observed to have a negative effect on the general soundscape. One study reports that during COVID-19, when ship traffic was greatly reduced, the Hapuna Bay coral reef experienced a one decibel (dB) increase in the intensity of fish calls (Duane et al., 2021). The impact of noises also depended on the species and its developmental stage, mobility, and/or acoustic sensitivity, and may impact ability to communicate, reproduce, forage, and conduct other natural behaviors (Ferrier-Pagès et al., 2021). Most research identifying the negative effects of anthrophony on the reef soundscape

are primarily focused on impacts of machine produced sound, such as from sailing vessels and vehicles. Thus far, the impact of human-produced sound, especially in relation to the ecotourism snorkeling industry, remains a subject of lesser interest compared to studies focusing on other forms of anthrophony.

Tourism, especially ecotourism, contributes the most to Hawai'i's GDP, accounting for 17.7% in 2022 (DBEDT Research Division, 2024). Snorkeling, a huge component of ecotourism, is a massive industry, with the recreational value in 2004 being $281 million, making up 78% of the net benefits of coral reefs for the economy (Cesar and Beukering, 2004). In 2001, 14,640 snorkeling trips occurred, with 91.5% of trips consisting of primarily non-locals, or tourists (Cesar and Beukering, 2004). Therefore, coral reefs often experience large amounts of snorkeling activity, with the majority of trips involving tourists, who often have less experience and knowledge about reefs and reef associated fish than residents. Reefs already experience severe degradation in part due to tourism, but little research has been done to determine if excessive sound production from tourists is also responsible for alterations in this habitat. The goal of this study is to explore whether or not snorkelers have an impact on coral reef soundscapes, specifically ichthyphony, in Hawai'i, and if the impact differs with the amount of snorkelers present at the reef. To accomplish this, acoustic and visual data was collected at four locations across the western coast of Hawai'i Island, with each location categorized based on the amount of snorkelers present at the site. It is hypothesized that the location with the highest number of snorkelers present will correlate with a soundscape with lowest amount of ichthyphony and highest anthrophony.

Materials and Methods

Study Sites

Four sites were used for the study, conducted at four different reefs across the western coast of Hawai'i Island, HI, USA. Sites were categorized into four categories based on the amount of snorkelers present at the location. To determine the number of snorkelers, a visual survey was conducted upon arrival at the site and included all snorkelers currently observable in the water. The categories include high presence ('H'), with 16 or more snorkelers observed, medium presence ('M'), with 6-15 snorkelers observed, low presence ('L'), with 1-5 snorkelers observed, and control ('C'), with no snorkelers observed. Due to the exploratory nature of the study, there was one site per category; therefore, sites will be referred to as their category for clarification. At each site, two plots were also recorded. A plot was defined as the point where recording equipment was deployed and the surrounding five meters circumference. Plots were selected at a distance of 20 meters (m) or more away from each other in order to gain a better understanding of the entire reef and avoid any possible replicates in the dataset.

The high presence site ('H') was located at Kahalu'u Beach Park, which is a publically accessible snorkeling site. Upon arrival, approximately 35 snorkelers were noted. Exact counts are unavailable due snorkelers diving and surfacing frequently. Recording occurred on January 13th, 2025, between 11:50 and 12:48 HST (Hawai'i Standard Time). Plot 1 (HP1) was located at 19.5796, -155.9673. Recording started at 11:50 and concluded at 12:07, with the equipment placed on a sandy substrate between two stony coral heads. Plot 2 (HP2) was located at 19.5791, -155.9666. Recording started at 12:33 and concluded at 12:48, with the equipment placed on a sandy substrate close to a stony coral head.

The medium presence ('M') and low presence ('L') sites were located at two different reefs at Kaloko-Honokōhau National Historical Park. 'M' had approximately 12 people visually identified upon arrival. Recording occurred on January 16, 2025, between 15:00 and 16:00. Only one plot was recorded due to

time constraints. MP1 was located at 19.4017, -156.0133.

Recording started at 15:23 and concluded at 15:38. The recording equipment was located on a sandy substrate with only sparse, dead coral heads nearby. 'L' had approximately 3 people visually identified upon arrival. Recording occurred on January 16, 2025, between 13:00 to 14:30. LP1 was located at 19.4003, -156.0140. Recording began at 13:14 and concluded at 13:29, with the equipment placed on rocks near a steep ledge. Equipment was frequently moved due to strong waves. LP2 was located at 19.4003, -156.0139. Recording started at 13:53 and conducted at 14:08, with the equipment located on a sand with many rocks, but few coral heads. At this plot, recording was not conducted with the researcher in the water due to unsafe wave conditions.

The control site ('C') was recorded at Hawai'i Ocean Science and Technology (HOST) Park. Though there were people standing nearby along the shore and in the water (around two meters into the water), there were no snorkelers upon arrival. Recording occurred on January 16, 2025, between 11:00 and 12:00 HST. CP1 was located at 19.4254, -156.0257. Recording occurred between 11:04 and 11:19, with the equipment deployed on a sandy bottom between many lava rocks and a few coral heads. CP2 was located at 19.4253, -156.0256. Recording occurred between 11:38 and 11:53, with the equipment deployed on a sandy bottom with some lava rocks nearby.

Data Collection Protocol

A HydroMoth, a modified version of an AudioMoth which is used for marine environments, was used for recording. The sampling frequency was set to 48 kHz, as sounds over this frequency were highly unlikely to occur within the reef, and a bit rate was set to the default setting. The device was set to record continually for about 15 minutes, then pause for one second, then repeat this cycle. This ensured the creation of unique audio files for ease during analysis. The HydroMoth was sealed in a waterproof container with a 1.5 m fishing line and bobber attached in order to locate the device after deployment. A small rock was strapped to the device in order to weigh it down so that it would rest on the reef floor. A GoPro camera was also utilized in order to gain footage of the species in range to allow for more effective identification. The camera was sealed in a waterproof container and was set to record continuously.

When the plot was reached, the researcher would deploy the HydroMoth on the reef floor for a period of five minutes. This time allowed

Figure 1: Location of plots within different sites, control plots (red, CP1 and CP2), low plots (yellow, LP1 and LP2), medium plot (green, MP1), and high plots (blue, HP1 and HP2), in Hawai'i, HI, USA, created with Google Earth.

sea life to acclimate to the equipment in order to avoid damage to equipment or organisms. During this acclimation period, the depth was measured using a PVC pipe with 0.5, 1.0, and 1.5 m marked approximately to the best of the recorder's ability. Coordinates were taken using Google Maps. After the acclimation period concluded, the recording period began and lasted for approximately 10 minutes, with the start and end time of the HydroMoth noted. The GoPro camera was also deployed and held by the researcher who floated nearby and pointed at the HydroMoth and the surrounding area. At the end of the recording period, all equipment was removed from the water and notes were made and recorded with Epicollect5, including external temperature, observed snorkelers, and any notes and observations recorded with Epicollect5.

Files were offloaded from corresponding equipment and uploaded in the forms of WAV files and video, for the HydroMoth and GoPro, respectively. HydroMoth recordings were visualized in RavenPro 1.6 and the corresponding video was viewed using VLC Media Player. A contrast of 48, a brightness of 67, a FFT of 2048, and the color scheme of copper was utilized in RavenPro. Ten seconds were displayed horizontally and 2 kHz vertically. For each plot, a 60 second interval was randomly taken for further analysis. In each 60 second interval, the amount of anthrophony and biophony were recorded on RavenPro. Each entry in the selection table was annotated with sound type (anthropogenic or biological), source, and description. GoPro footage was analyzed similarly, with the 10 minute clip analyzed for number of species observed, number of individuals per species, and amount of snorkelers recorded. Individuals were counted every time it appeared on video, unless it was obvious that it was the same individual coming back in frame. Species identification was verified first through visual appearance, then secondly through the use of local field guides (Hoover).

Results

MP1 had the lowest amount of biophony instances recorded, with 16 instances, while LP2 had the highest amount recorded, with 99 instances (Table 1). 'M' had the lowest overall amount of biophony recorded, while 'L' had the highest overall amount recorded (Fig. 2). CP1 and LP1 had the most types of biophony (distinct sounds) recorded, with six types per site, while CP2, HP1, and HP2 had the least amount, with three types per site (Table 1). 'L' had the highest overall biophony type count, with an average of five between LP1 and LP2, while 'H' had the least amount, with an average of three between HP1 and HP2 (Table 1).

'H' had the highest amount of anthrophony, with an average of 3.5 instances across both plots, with HP1 having 7 total instances (Fig. 2). 'C' had the lowest amount of anthrophony, with an average of 0 instances across both plots (Fig. 2).

Based on GoPro video identification, four plots were able to have species visually identified: LP1, MP1, HP1, and HP2. Based on the available data, HP1 had the highest biodiversity based on taxonomic family, with approximately five families identified, while LP1 and MP1 had the lowest, with three families identified per plot (Table 2). MP1 had the most sightings, with 62 individuals identified, while LP1 had the least, with only 5 individuals identified (Table 2). Species belonging to *Diadematidae* and *Acanthuridae* were the most abundant across all plots, with *Diadematidae* being identified in all plots and *Acanthuridae* in three of the four plots (Table 2).

Discussion

Due to the exploratory nature of this study, few correlations can be drawn from the data; however a positive trend may exist between increased snorkeler presence and increased anthropogenic noise, though this trend should

Table 1: Numbers of biophony and anthrophony counts from a random 60 second sample from each recording based on snorkeler presence type and locations in Hawai'i, USA, recorded between January 13 and January 16, 2025.

Plot Info	CP1	CP2	LP1	LP2	MP1	HP1	HP2
Location	Kaloko	Kaloko	Historic Park	Historic Park	National Historic Park	Kaloko	Kahalu'u Beach Park
HOST Park	National	National	Hono-kōhau	Kaloko	National	Historic Park	Kahalu'u
Collection (m/d/y)	1/16/2025	1/16/2025	1/13/2025	1/13/2025	1/16/2025	1/16/2025	1/16/2025
Date of Data	1/16/2025	Date of Data	1/16/2025	Date of Data	1/16/2025	Date of Date	1/16/2025
Presence Type	Low (1-5)	Control (0)	Control (0)	Low (1-5)	Medium (6-15)	High (16+)	High (16+)
Depth (m)	0.50	0.50	1.60	0.75	1.50	1.20	0.75
Biophony Instance	55	41	52	99	16	43	21
Biophony Types	6	3	6	4	4	3	7
Anthrophony Instances	0	0	1	0	1	0	3

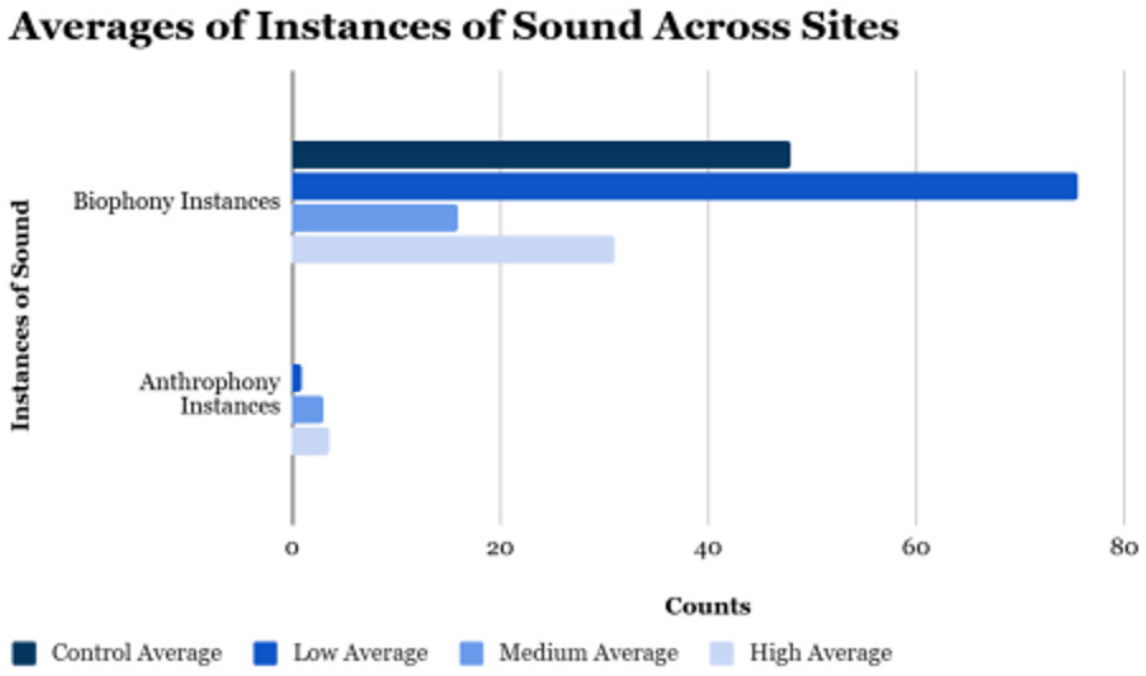

Figure 2: Averages of occurrences of sounds (anthropogenic or biological) across plots of all sites. Collected in Hawai'i, HI, USA, between January 13 and January 16, 2025.

Table 2: Abundance of various reef associated families from LP1, MP1, HP1 and HP2, identified using GoPro footage. Recorded between January 13, 2025, to January 16, 2025.

Genus	LP1	MP1	HP1	HP2	Species Included
Acanthuridae	2	0	2	3	*Z. flavescens, A. olivaceus, A. triostegus*
Zanclidae	2	0	0	2	*Z. cornutus*
Pomacentridae	1	3	1	5	*E. caeruleus*
Mullidae	0	5	8	0	*P. pleurostigma*
Tetraodontidae	0	1	0	0	*A. meleagris*
Labridae	0	0	2	0	
Chaetodontidae	0	0	4	0	*C. quadrivittatus*
Balistidae	0	0	6	1	Unknown
Total	5	62	36	17	

be researched in greater depth in the future. The site with the highest amount of anthropogenic noise recorded was HP1 and, when taking the average of the plots, 'H' has the highest amount of anthrophony recorded. Kahaluʻu Beach Park, the location of 'H', is a popular snorkeling spot that frequently has a high number of people both in the water and around the park. Most of the anthrophony identified from the HydroMoth recordings were the result of snorkelers, most commonly coming from snorkeling gear or people speaking. Additionally, Kahaluʻu Beach Park is located next to a major road and is used for other ecotourism activities, such as beachgoing and surfing, which may have added to the high amount of anthrophony. As mentioned, the small amount of data recorded means that future researchers should continue to research this trend to ensure credibility.

There are no apparent correlations between biophony and snorkeler presence, which could be attributed to a few reasons. One such is the difference in reef compositions between the sites. Though coral was present at all sites, the abundance of live coral changed dramatically across the sites, with 'H' having the most and 'M' having the least, though reef associated species were identified at each site. Abundance of coral is correlated with a higher amount of reef associated species and a higher amount of individual fish in the area, which was apparent at HP1 and HP2 (Bell and Galzin, 1984). This may have impacted the abundance of species at 'H'. Secondly, though sites had relevant species present, the composition of species differed across the sites, often dramatically. This could have altered the soundscape for each site. Therefore, it is important to identify which of these species are known to produce sound and, if they do, under what conditions they do so.

Sounds of Observed Families

Acanthuridae

There were three observed species belonging to this family: *Z. flavescens*, the yellow tang (lauʻipala), *A. olivaceus*, the orange-band

surgeonfish (na'ena'e), and *A. triostegus*, the convict tang (manini). Some members of this family are known to produce sound, primarily during agonistic behaviors (Lobel et al., 2010). Specific frequencies and durations are largely unknown, but *A. bahianus* is known to produce sound between 150-4,700 Hz and for around 100 milliseconds (ms) (Lobel et al., 2010). This family was found at all plots except for MP1. Further study on sounds produced by *A. bahianus* would be of interest, especially due to the yellow tang's abundance in most coral reefs throughout the Hawaiian archipelago.

Zanclidae

There was one observed species belonging to the *Z. cornutus* family, the Moorish idol (kihikihi). This species is known to produce single pulsed sounds and longer trains that range from 176 to 520 Hz and last around 30 to 102 ms (Tricas and Boyle, 2014). They produce these sounds during aggressive acts and courtship behaviors (Tricas and Boyle, 2014). In addition, they also produce pulsed sounds ranging from 200 to 566 Hz during both courtship and agonistic behaviors, with the latter typically directed toward common conspecifics, a species often belonging to the family *Acanthuridae* (Tricas and Boyle, 2014). Moorish idols were observed at LP1 and HP1 and, in the case of HP1, would have been in the range of other species, most notably *Acanthuridae*. This may indicate that ichthyphony produced by Moorish idols may have only occurred in HP1 due to the presence of other species, but further research is required.

Diadematidae

E. calamaris, the double spined urchin (wana), was observed across all sites. In previous studies, sound has been detected coming from large aggregations of *D. setosum* which, although not a Hawaiian species, provides insight into the relevant species (Soars et al., 2016). Species from this family are known to produce wide frequency bands, ranging from 400 Hz to over 20,000 Hz (Soars et al., 2016). However, due to the often low frequency of the sound produced, it can be difficult to differentiate these from the sounds of snapping shrimps, which is the major producer of biophony in ocean soundscapes, particular in shallow areas, and are known to obscure sounds of other species (Au and Banks, 1998). Therefore, though *Diadematidae* are present throughout all measured plots, assessing soundscapes with use of *Diadematidae* would be difficult.

Mullidae

The only observed species belonging to *Mullidae* was *P. pleurostigma*, the sidespot goatfish (moano). Goatfish are known to produce sounds associated with reproductive behaviors, such as courtship, spawning, and nest defense, with males producing both single pulses and train sounds at low frequencies when observed chasing females in courtship (Tricas and Boyle, 2014). It is unknown if this species in particular produces sound. Reproductive behavior was not observed on the footage, which could contribute to the low amount of biological noise recorded in MP1 (Tricas and Boyle, 2014).

Tetraodontidae

A. meleagris, the golden puffer (kōkala) was the only observed species within this family and was identified at MP1. Though swim bladder vibrations occur as a secondary mechanism within this family, there is no known sound production to come from either this family or *A. meleagris* (Rice et al., 2022). This, coupled with the low presence across the sites indicates that this species would be of little use for understanding the soundscape composition of coral reefs.

Balistidae

Various species of triggerfish (humuhumu) were observed, though further identification could not be completed due to the quality of the video recording. Three different species

of triggerfish are known to make sound while exhibiting agonistic behaviors during social interactions, with sounds ranging from short thump-like pulses, longer rasp-like pulses (both recorded from *M. niger*), single pusles, and pulse trains (recorded from both *S. bursa* and *Z. auromarginatus*) (Tricas and Boyle, 2014). These sounds can occur during behaviors such as territory defense, agonistic changes, and nest-guarding behaviors, exhibited by females only. Triggerfish sounds likely appeared on recordings.

Labridae

Labridae, particularly parrotfish, are well known for their sound production. Various genera of parrotfish are known to produce a distinctive biting sound when feeding and are often an important indicator of reef health as they feed on coral rock. Increased feeding activity was associated with decreased macroalgal cover, and therefore an increase in the density of new coral recruits (Tricas and Boyle, 2021, and Mumby et al., 2007). The species identified at HP1, *T. duperrey*, the saddle wrasse (Hīnālea Lauwili), is known to produce two types of pulse trains, with the Type I being indicative of spawning and courtship and Type II indicating just courtship (Boyle and Cox, 2010). Similarly to other species identified in the recordings, due to the low amount of wrasse spotted on video, it was unlikely that courtship and spawning behavior was captured auditorily, though this could be helpful in future studies.

Chaetodontidae

Chaetodontidae are well known for having sounds produced during social interactions, and are known to have two primary mechanisms of production: a tail slap that stimulates the lateral line and ear, and a head bobbing motion, producing a pulsing sound which stimulates the swim bladder and ear (Tricas and Boyle 2015). The two species identified in this family, *C. quadrimaculatus*, fourspot butterflyfish (lauhau), and *H. diphreutes*, schooling bannerfish (pāpā), are not specifically known to produce sound, but it is likely they do so based on other species in the family. This family would be a good indicator of coral reef soundscape due to their abundance in the reefs as well as if confirmation of sound production occurs in the future.

By understanding the contexts in which different ichthyological families and species produce sound and if they produce sound at all, future research on this subject can be more clearly conducted. By targeting reefs with similar ichthyological compositions, a better understanding of the changes in the soundscape could be identified.

This study remained limited due to many factors, including unsafe conditions preventing recording, limited sample size, limited time in collecting data, and last minute restructuring. One particular issue was that the GoPro would not remain stationary on the ocean floor and required the recorder to hold it during the entire recording period. Therefore, the observer contributed to the anthropogenic noise in each site where GoPro footage was recorded. However, despite the setbacks, this research may serve as an exploratory study on snorkeler presence and anthrophony interacting with coral reef soundscapes. With a more concrete dataset and a small redesign of the experimental procedure, correlations could be more clearly identified. When conducting potential follow up studies, research should be conducted so that site variation is temporal, not physical. By remaining at one site with a fluctuating amount of snorkelers in the reef from day to day, a better understanding of the changes of that specific soundscape could be identified. This would also allow the species composition in the reef to remain relatively consistent, despite changes tidally and seasonally. The author advises that, if further research were to be conducted, it should occur at Kahalu'u Beach Park, with monitoring occurring at three or more plots at the site at least twice per week. This could allow further clarification of potential correlations between

snorkeler presence, anthrophony, and biophony in the coral reef soundscapes. If interest arises, all materials can be found here: https://cornell.box.com/s/3d5xsabr7a9t0n5ec7cs70jfuibrvb7m.

Acknowledgments

I would like to thank the instructors of NTRES 3152, including Dr. Larissa Sugai, Dr. Ben Gottesman, and especially Dr. Aaron Rice. Additionally, I would like to thank students who aided in field work collection, including Janet Reddy, Cecilia Wagner, Kay Williams, and Gabrielle Pryor. Thanks Jeep Crew!

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