COURSE-BASED UNDERGRADUATE RESEARCH EXPERIENCE: LIFE SCIENCE SCHOLAR PROGRAM (BIOL 096)

Spring 2021

A special semester studying the impact of COVID-19 lockdowns on marine communities

PHOTO BY JAMES GRANT (UVM)

Course Instructor Laura J May-Collado, Ph.D.

Meeting Time: Tuesday 10:05 & 11:05 p.m. in 217A Marsh Life Science Bldg

LSS-LASP PROGRAM - Laura J May-Collado, Ph.D. (lauramay-collado.com)

I know this semester was hard, because well science is hardwork! I hope this semester gave you a demonstration about what it means to be a scientist. Good science takes time, involves failure, independent thinking, troubleshooting, discussions, re-evaluations, and yes frustration. Good science is always challenging at different levels, from collecting the data to its analysis and writing. Although hard, science opens the posibilites for understanding and discovery and that's what I love about science.

"Science may be a career for some, but for most of us it is also a calling, a calling to uncover the beauty that lies hidden in the remarkable biology of organisms..." Dr. Leticia Aviles, Behavioral Ecology Scientist.

Thank you for a fantastic year! You were all fantastic students and I wish you the best in your future careers.

Prof. Laura J May-Collado

Impact of COVID-19 Regulations on Bottlenose Dolphin (*Tursiops truncatus)* Presence in Bocas del Toro, Panama

Liam Kelliher[1], Julia Murray[2], and Liam Keefe[1]

[1]University of Vermont Department of Biological Sciences, Burlington, Vermont 05405, United States

[2]University of Vermont Department of Psychological Sciences, Burlington, Vermont 05405, United States

Abstract

Previous research has described the habitat of bottlenose dolphins in Dolphin Bay, Panama as stressful. Dolphins are targeted by multiple tour-boats on a daily basis. Bottlenose dolphins rely on sound to communicate, localize prey, and navigate. Previous work has shown the impact of tour-boats and associated anthropogenic noise on their communication. In this project, we examine dolphin acoustic presence before and during the COVID-19 lockdowns in Panama. We generated a presence-absence matrix of dolphin and boat detections for data collected using autonomous underwater recorders in 2018 and 2020. We hypothesize that a decrease in boat traffic following COVID-19 regulations will directly lead to an increase in dolphin frequency in Dolphin Bay. Our results indicate that there is a direct correlation between anthropogenic traffic and dolphin acoustic frequency. This research will provide marine ecologists with a better understanding of the impact that unregulated boat traffic has on dolphin populations and inform ongoing conservation efforts.

Keywords: whistles, resident population, boat traffic, dolphin behavior, cetacean.

1. Introduction

Sound is a foundational aspect of any terrestrial or oceanic environment, and animals are typically accustomed to dealing with certain levels of noise. However, anthropogenic domination over every environmental niche on the planet has impacted the amount of sound in different environments. In areas of high anthropogenic boat traffic, such as Bocas del Toro, species are forced to adapt to a consistently high level of sound emanating through their environment.

Bottlenose dolphins (*Tursiops truncatus*) rely on sound to navigate, locate prey, and socialize (Kassamali-Fox et al., 2020). Previous work has found that dolphin acoustic signals can be masked by boat engines, as they overlap in frequencies disrupting their ability to obtain information from conspecifics and their environment (May-Collado and Wartzok 2008). Furthermore, anthropogenic traffic has been shown to be detrimental to groups where calves are present (Guerra et al., 2014). While the acoustic impact of anthropogenic traffic on bottlenose dolphins has been well studied, little has been researched in regard to how populations respond when acoustic stressors are almost entirely removed from their environment.

Resident bottlenose dolphins of Dolphin Bay, Panama live in a small population that shows high levels of site fidelity (May-Collado et al. 2017). Their predictable behavior has made them a target of the largest dolphin watching tour boat industry in Panama (Sitar et al., 2016). In

Dolphin Bay, dolphin foraging, and social activities are significantly impacted by anthropogenic traffic (Kassamali-Fox et al., 2020). On top of this, mothers and calves are consistently separated due to these high levels of noise (May-Collado et al., 2015). The consistent antagonization of this population by the dolphin-watching industry generates high levels of stress in individual organisms (Perez-Ortega et al. 2021).

Here we examine the acoustic presence of bottlenose dolphins in Dolphin Bay using autonomous underwater recorders deployed before and during the COVID-19 pandemic. We hypothesize that a decrease in boat traffic following COVID-19 regulations will directly lead to an increase in dolphin acoustic presence in Dolphin Bay. This research will provide marine ecologists with a better understanding of the impact that unregulated boat traffic has on dolphin populations and inform ongoing conservation efforts.

2. Material and Methods

2.1 Study Site

This research was conducted in Dolphin Bay, Bocas del Toro, Panama (Fig. 1). Dolphin Bay is found in the archipelago of Bocas del Toro, on the Caribbean coast of Panama. The area is characterized by mangrove islands and exceptionally clear water that can reach sixty feet in depth (May-Collado et al., 2015). Additionally, Dolphin Bay is home to a resident dolphin community of about 40 dolphins (May-Collado et al., 2017). These dolphins are genetically isolated and show high levels of male and female philopatry (Barragan-Barrera et al., 2017). (Kassamali-Fox et al., 2019), showed that their predictability in this area has fueled a dolphin-watching activity that leads to aggressive interactions. Although regulations are in place, the high number of boats and lack of compliance to regulations often results in disruptive interactions (Kassamali-Fox et al., 2019, Sitar et al., 2016) and is thought to be driver of high calf mortality (May-Collado et al., 2019).

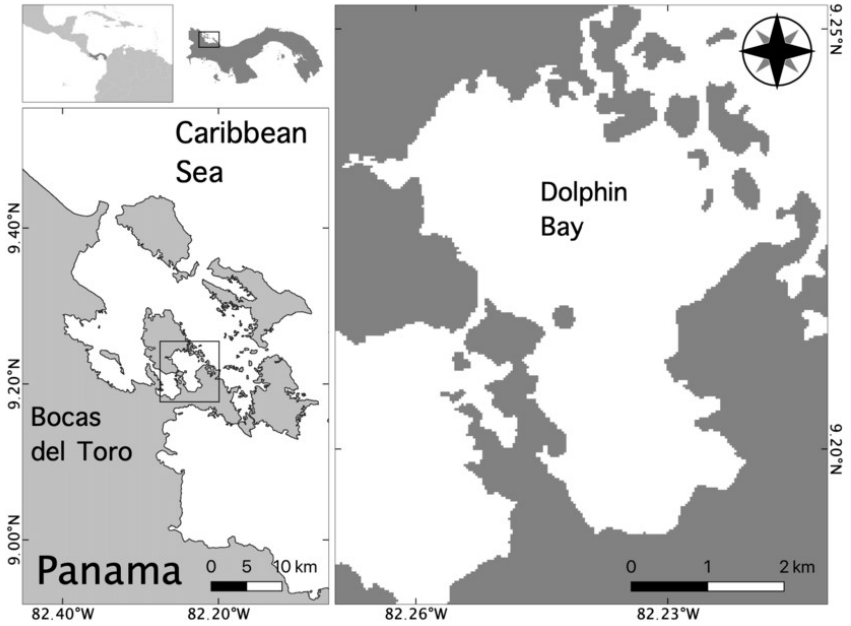

Figure 1. A visual depiction of Dolphin Bay, Panama, and surrounding geographical features.

2.2. Recordings

To study the impact of COVID-19 lockdowns and dolphin presence at Dolphin Bay a Soundtrap 300 SD (frequency range 20 Hz-150 kHz ±3dB; self-noise of less than sea-state in the bandwidth 100 Hz-2 kHz, and sensitivity of -203 dB re V/µPa) recorder (Fig. 2) was deployed at 15 m location within the dolphin main habitat (9.23N / -82.24W). This location is characterized by a muddy bottom and is also the site where most dolphin-tour boat interactions occur. The recorder was programmed to record the soundscape for 10 minutes of every hour from September to November in 2020. Recordings were uploaded to the RFCxArbimon online platform for storage and inspection. A spectrogram was opened in Arbimon with a fast Fourier transform (FFT) size of 1,024 points, an overlap of 50%, and using a 512-sample Hann window.

2.3 Data Analysis

We selected 10 days per month to be analyzed, and from these days we examined the first minute of 10 minutes of each hour to determine presence (1) and absence (0) of dolphin sounds (whistles, echolocation clicks, burst sounds, etc.) and boat noises. The matrix will then be compared to presence-absence data from 2018 to determine if, during the COVID-19 lockdown, boat activity declined and if that led to an increase in dolphin acoustic presence. Data visualization was done in JMP 14. (SAS Institute, NC, United States). An ANOVA analysis was used to determine if the number of 1-min files with dolphins and boats varied before and during COVID-19 lockdowns.

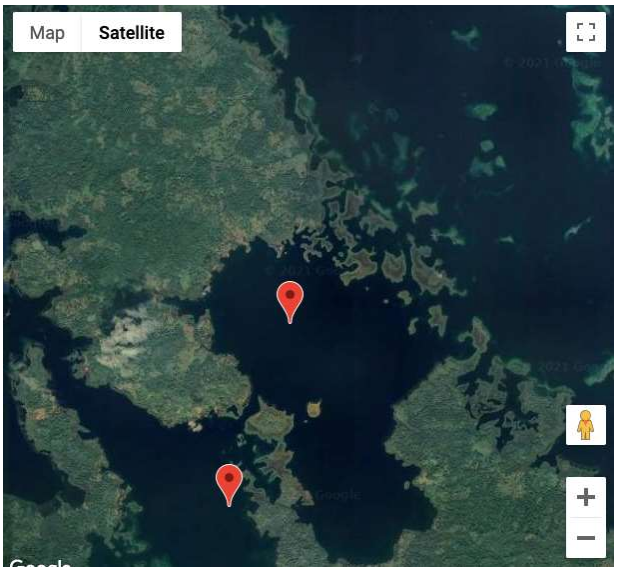

Figure 2. *The location of the Soundtrap 300 SD that was used to record acoustic data in Dolphin Bay.*

3. Results

A total of 7,200 1-min files were analyzed (n_{2017}=99, n_{2018}=171, n_{2020}=761. After accounting for differences in recording samples we found a significant decrease in boat presence in Dolphin Bay (F Ratio=71.3, df=2, p<0.0001, Fig. 3) and significant increase in dolphin detections in 2020 (F Ratio=272, df=2, p<0.0001, Fig. 4). We also found a significant decrease in dolphin detections throughout the day during 2018 (F Ratio=201, df=2, p<0.0001, Fig. 5) and in that same year an increase in tour-boat presence (F Ratio=62, df=2, p<0.0001, Fig. 6).

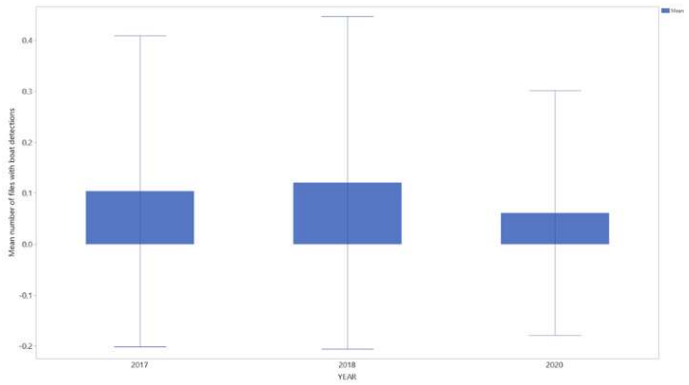

Figure 3. Mean number of 1-min files with boat detections by year at Dolphin Bay, Panama.

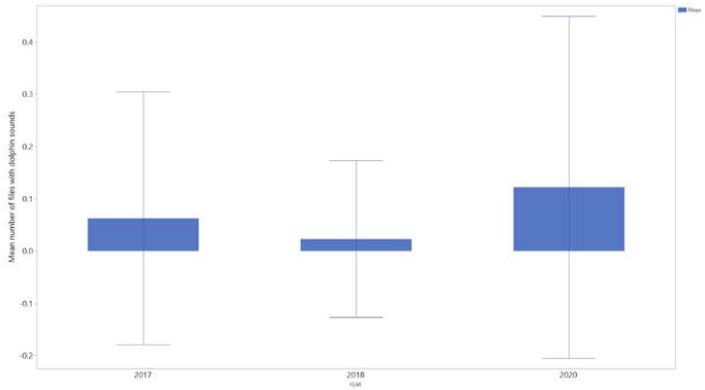

Figure 4. Mean number of 1-min files with dolphin detections by year at Dolphin Bay, Panama.

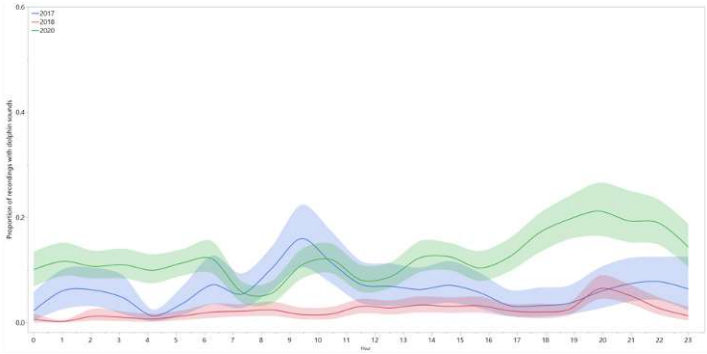

Figure 5. Proportion of 1-min files with dolphin detections by year at Dolphin Bay, Panama.

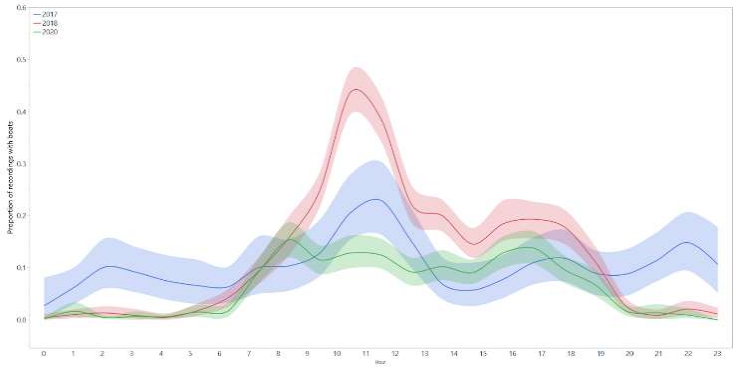

Figure 6. Proportion of 1-min files with boat detections by year at Dolphin Bay, Panama.

4. Discussion

Our results indicate that although bottlenose dolphins are acoustically present in both 2017/2018 (no regulations) and 2020 (COVID-19 regulations), they were detected significantly more frequently when government regulations were placed on the dolphin-watching industry in 2020. These results corroborate the previously described impact of tour-boats on dolphins' acoustic behavior and presence (May-Collado and Wartzok 2008, Perez-Ortega et al. 2021) and habitat use (social and foraging activities) (Kassamali-Fox et al., 2020) at Dolphin Bay. Although only ten days of the three months chosen in 2020 were analyzed, our results showed a decrease of 4 times the presence of boats and a doubling in dolphin presence in Dolphin Bay during 2020. Similar trends in acoustic behaviors following COVID-19 regulations have been found in animals that live in urban areas. For example, a recent study in San Francisco area reveals that birds lowered the frequency and amplitude of their acoustic signals during COVID-19 lockdowns as traffic decreased (Derryberry et al. 2020).

Another important observation is that the boats detected in 2020 within Dolphin Bay are transport and personal boats. Therefore, in addition to a decrease in boat presence, there was also a shift on the type of boat activity and level of interaction with dolphins. Perez-Ortega et al. (2021) showed that when dolphins are in the presence of transport boats their acoustic behavior does not change, and several previous studies have shown how dolphin acoustic behavior changes drastically in the presence of tour-boats (Christiansen et al., 2005; Cope-Mattson et al., 2005; Lusseau, 2006). We propose that these drastic changes in their soundscapes allowed dolphins to increase their use of Dolphin Bay. While previous studies studied how dolphin's behavior changes in the presence of the research boat and tour boats (Guerra et al., 2014; Sitar et al., 2016; Kassamali-Fox et al., 2020; May-Collado et al., 2014), our study provides a unique comparison between normal and lockdown boat-presence, clearly showing the impact of anthropogenic traffic on bottlenose dolphin presence.

Our results contribute to ongoing conservation efforts to remove the global dolphin-watching industry, as a significant number of scientific studies have exemplified the negative impact this industry has on the cetaceans it was built around. This study warrants further exploration in the examination of how dolphin populations recover behaviorally when anthropogenic stressors are removed from their environment, as conservation efforts continue to push for the removal of the

dolphin-watching industry. Our results can also be used as a platform for enforceable action to take place in terms of regulating dolphin tour-boat activity in Dolphin Bay. Due to the clear correlation between anthropogenic traffic frequency and the acoustic behavior of bottlenose dolphins, the Panamanian government can use our data to tighten restrictions on this industry. Some of these regulations should restrict aggressive following maneuvers, the amount of hours tour-boats can be in the Bay, and the decibel range of the boats' motors. It is important that the government enforces these regulations, otherwise they will be overwhelmingly ignored by this industry.

Acknowledgments

This paper is dedicated to Laura May-Collado in gratitude for her work on the study of cetaceans, specifically in Central America. She has consistently inspired students with her dedication at the University of Vermont, whether it be through her Life Science Scholars Program or advanced biology classes. We also thank her for her consistent feedback throughout our entire research process and the writing of this manuscript, as without her guidance and tutelage we would have struggled to overcome the inherent obstacles of conducting research.

Reference List

Sitar, A., May-Collado L.J., Wright, A.J., Peters-Burton, E., Rockwood, L., Parsons, E.C.M.. (2016). "Boat operators in Bocas del Toro, Panama display low levels of compliance with national whale-watching regulations," Elsevier Oceanogr. Ser.

Barragán-Barrera, D. C., May-Collado, L. J., Tezanos-Pinto, G., Islas-Villanueva, V., Correa-Cárdenas, C. A., and Caballero, S. (2017). "High genetic structure and low mitochondrial diversity in bottlenose dolphins of the Archipelago of Bocas del Toro, Panama: A population at risk?," PLoS One, 12.

Christiansen, F., Lusseau, D., Stensland, E., and Berggren, P. (2005) "Effects of tourist boats on the behavior of Indo-Pacific bottlenose dolphins off the south coast of Zanzibar," Endanger. Species Res, 11, 91-99

Cope-Mattson, M., Thomas, J. A., St. Aubin, D. (2005). "Effects of Boat Activity on the Behavior of Bottlenose Dolphins (Tursiops truncatus) in Waters Surrounding Hilton Head Island, South Carolina," Aquatic Mammals, 31, 133-140

Guerra, M., Dawson, S. M., Brough, T. E., and Rayment, W. J. (2014). "Effects of boats on the surface and acoustic behaviour of an endangered population of bottlenose dolphins," Endanger. Species Res, 24, 221–236.

Kassamali-Fox, A., Christiansen, F., May-Collado, L. J., Ramos, E. A., and Kaplin, B. A. (2020). "Tour boats affect the activity patterns of bottlenose dolphins (Tursiops truncatus) in Bocas del Toro, Panama," PeerJ.

Kassamali-Fox, A., Christiansen, F., Quinones-Lebron, S., Rusk, A., May-Collado, L. J., and Kaplin, B. (2015). "Using Markov chains to model the impacts of the dolphin watching industry on the dolphin community of Dolphin Bay, Bocas del Toro, Panama," Int Whaling Commission.

Lusseau, D. (2006). "The Short-Term Behavior Reactions of Bottlenose Dolphins to Interactions with Boats in Doubtful Sound, New Zealand," Marine Mammal Science, 22, 802-818.

May-Collado, L. J. (2020). "Coastal Resources of Bocas del Toro, Panama: Tourism and Development Pressures and the Quest for Sustainability: edited by D. O. Suman and A. K. Spalding," Coast Manage, 48, 232–233.

May-Collado, L. J., Quiñones-Lebrón, S. G., Barragán-Barrera, D. C., Palacios, J. D., and Gamboa-Poveda, M. (2014). "The dolphin watching industry of Bocas del Toro continues impacting the resident bottlenose dolphin population," International Whaling Commission.

May-Collado, L. J., Quiñones-Lebrón, S. G., Barragán-Barrera, D. C., Palacios, J. D., Gamboa-Poveda, M. P., and Kassamali-Fox, A. (2015). "The Bocas del Toro's dolphin watching industry relies on a small community of bottlenose dolphins: implications for management," International Whaling Commission, SC/66a/WW/10 Rev 1.

May-Collado, L. J.1,2, Barragán-Barrera, D. C.3, Quiñones-Lebrón, S. G.1, & W. Aquino-Reynoso (2012). "Dolphin watching boats impact on habitat use and communication of bottlenose dolphins in Bocas del Toro, Panama during 2004, 2006-2010," SC/64/WW2 1-8.

Perez-Ortega, B., Daw, R., Paradee, B., Gimbrere, E., May-Collado, L.J. (2021). "Dolphin-Watching Boats Affect Whistle Frequency Modulation in Bottlenose Dolphins," Frontiers in Marine Science, 8, 102.

Peters, K. J., Parra, G. J., Skuza, P. P., and Möller, L. M. (2012). "First insights into the effects of swim-with-dolphin tourism on the behavior, response, and group structure of southern Australian bottlenose dolphins," Marine Mammal Science, 29(4), E484-E497.

Humpback Whale Singing Activity Did Not Change During Covid-19 Lockdowns

Claudia Pollock, Ely Remes, and Chloe Pay
University of Vermont Department of Biological Sciences, Burlington, Vermont 05405, United States

Abstract
Humpback whales are one of the many diverse species that inhabit the Cano Island, Biological Reserve. Humpback whales communicate acoustically and have different song types for mating, common, or alternative. COVID-19 regulations have significantly decreased the amount of boat traffic at Cano island. It is predicted that a decrease in human traffic will most likely result in an increased humpback whale activity in that area because there will be less human noise pollution which most likely scares off many creatures. There was no significant difference between the mean detection of whales and the mean detection of boats between 2019 and 2020. However, the trend of the detections changed. In 2019, when boats were more active, the amount of whale calls decreased. In comparison, in 2020, there appeared to be an increase in the number of boats at later hours in the night. Our results support the idea that when there is a general time where the boat traffic increases, this leads to a decrease in the detection of whales during those hours.

Key Words: Humpback Whales, Ocean(s), COVID-19, Acoustics, Impacts, Boat Traffic

1. Introduction
Humans have impacted the environment in various negative ways that have caused changes to ecosystems and environments. Among these are changes to the acoustic environment due to human made noise pollution (Curovic *et al.*, 2021). Humans contribute noise pollution to several different ecosystems, both on land and in the sea. Oceans are becoming increasingly more noisy environments as commercial shipping, oil drilling, military-related activities, tourism, and an overall increase in ocean traffic have become more prevalent (Firestone and Jarvis, 2007).

Many marine organisms rely on sound to communicate and obtain information from their environment. Sounds allow animals to exchange information, form and maintain social relationships, navigate their surroundings (National Geographic, 2021). This is because in seawater sound travels farther than in air, allowing these animals to communicate over long distances. Unfortunately, noise from human activities can also reach farther away and mask important biological signals (Curovic *et al.*, 2021), such as those produced by humpback whales. Humpback whales males sign in breeding areas to attract female and competing with other males, and past research have found that boat presence can impact humpback whales singing activity (Weilgart,2008).

Here we use data from passive acoustic monitoring efforts during COVID-19 lockdowns to study the impact of boat traffic on the singing activity of humpback whales at Caño Island, Biological Reserve in Costa Rica. Caño Island is an important breeding ground for humpback whales migrating from the antarctica peninsula (Chereskin et al. 2019). We hypothesized that whale singing activity will vary before and during Covi-19 lockdowns. We predicted with a decrease in boat traffic during Covid-19 there will be an increase on humpback whale's presence throughout the day.

2. Materials and Methods

2.1 Study Site

The research for this study was conducted in the Caño Island Biological Reserve in Costa Rica (8°42′22.1″N 83°53′23.1″W). This reserve is an important breeding area for southern humpback whales migrating from the Antarctica Peninsula (Chereskin et al. 2019).

Figure 1. Jardín Isla de Caño. The blue location dot is the marker for the small island where the passive acoustic monitor is being collected.

2.2 Recordings

A Soundtrap 300 SD (frequency range 20 Hz-150 kHz ±3dB; self-noise of less than sea-state in the bandwidth 100 Hz-2 kHz, and sensitivity of -203 dB re V/µPa) recorder was deployed at 25 m in September 2019 and September 2020 at Jardin, a location with sandy ocean floor, at a sampling rate of 48kHz and 16 bit. In 2019, was programmed to record for 5 minutes every 30 minutes, and in 2020 for the first 15 minutes of every hour. These recordings were then uploaded to the Arbimon RFCx online platform for remote access.

3. Results

Overall, there are no significant differences in the mean detection of humpback whale songs and boats between years ($p>0.05$). However, there was more variation in whale song detection in 2019 than in 2020. While in 2020 whale song were detected equally throughout the day, in 2019 there was decrease in whale signing activity between 5 a.m. and 12 p.m., this the time where regularly tour boats arrive to the island. Interestingly, more boats were detected at late hours, which could indicate the presence of fishing boats near the protected area.

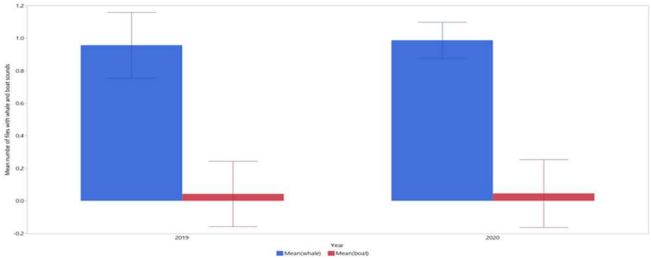

Figure .2. Mean number of 1-min files with boat and whale sounds. The bars represent the standard deviation by year.

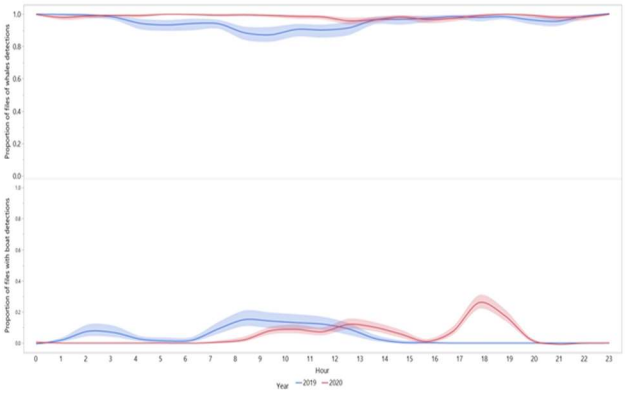

Figure 3. Proportion of recordings with whales' detections (top) and boat detections (bottom) by time of the day.

4. Discussion

Our results show that overall, the mean number of whale and boat detections did not change significantly. We did find a trend that in 2019, when tour boats presence peaked, humpback whale song detections decreased. In 2020, such declines in whale song detection did not occur. Sawyer Miller-Bottoms (CURE, 2021) found that during 2020 noise levels there was a significant decrease in boat presence and associated noise levels, particularly at low frequencies at Caño Island.

Although we did not find significant differences in whale song activity during Covid-19 there is a trend towards an increase whale singing. This is likely the result of a small sample size in our study. Several studies in this year CURE projects found an impact of Covid-19 lockdowns. For example, Kelliher et al. (2021) found that bottlenose dolphins in Bocas del Toro, Panama increased in acoustic activity during Covid-19 lockdowns and Wilson (2021) also found a trend in humpback whale singing activity in Panama.

Noise pollution is an important factor impacting whale communication (Curovic *et al.*, 2021). As things go back to normal, it is important to continue monitoring this population to see how the likely increase of boat traffic will impact whale presence and acoustic levels. The correlation found in this study between boat presence and whale presence could be used in argument to increase restrictions on boat travel in this area to protect the humpback whale species as well as other species in this marine community. The correlation between boat presence and whale presence can be extended even father to other marine communities where noise a

Acknowledgements

This paper is dedicated to Laura May-Collado in gratitude for her work and research done on humpback whales in Central America. Through her guidance as a mentor to the University of Vermont's Life Science Scholars, she has enabled us to be able to perform our research and has helped us along with every step of the way. Without her dedication to us, her students, our research would never have found the momentum it needed.

Reference List

Caño Island Biological Reserve, Go Visit Costa Rica (**2021**).

Caño Island Diving, Dive The World (**2021**).

Chereskin, E., Beck, L., Gamboa-Poveda, M., Palacios-Alfaro, J. Monge-Arias, R., Chase, A., Coven, B., Guzmán, A., McManus, N., Neuhaus, A., O'Halloran, R., Rosen, S., May-Collado, L. (**2019**). *"Song structure and singing activity of two separate humpback whales populations wintering off the coast of Caño Island in Costa Rica"* J. Acoust. Soc. Am. 146.

Curovic, L; Jeram, S; Murovec, J; Novakoic, T; Rupnik, K; Prezelj, J (**2021**). *"Impact of*

COVID-19 on environmental noise emitted from the port", Science of the Total Environment, 756:144147.

Jeremy Firestone 2 & Christina Jarvis 3 (**2007**). Response and Responsibility: Regulating Noise Pollution in the Marine Environment, Journal of International Wildlife Law & Policy, 10:2, 109-152.

National Geographic Education Encyclopedic Entry, Noise Pollution, National Geographic (**2021**).

Weilgart, L.S. (**2008**). The Impact of Ocean Noise Pollution on Marine Biodiversity.

Kassamali-Fox, A., Christiansen, F., May-Collado, L. J., Ramos, E. A., and Kaplin, B. A. (**2020**). *"Tour boats affect the activity patterns of bottlenose dolphins (Tursiops truncatus) in Bocas del Toro, Panama,"* PubMed.

Perez-Ortega, Betzi., Daw, Rebecca., Paradee, Brennan., Gimbrere, Emma., May-Collado, Laura. J. (**2021**). *"Dolphin-Watching Boats Affect Whistle Frequency Modulation in Bottlenose Dolphins,"* Frontiers in Marine Science.

Chereski, E., LJ., Beck, L., Gamboa-Poveda, M., Palacios-Alfaro, J. D., Monge-Arias, R., Chase, A. R., Coven, B. M., Guzman, A., McManus, N., O'Halloran, R. A., Neuhauss, A. P., Rosen, S. G., and L. J. May-Collado. (**2019**). *"Song structure and singing activity of two separate humpback whales populations wintering off the coast of Caño Island in Costa Rica,"* JASA Express Letters.

Humpback Whale's Use of Breeding Ground near Coiba Contreras off the Pacific Coast of Panama

Quinn Chapman, Dagny Keltner, and Hannah Larose
University of Vermont Department of Biological Sciences, Burlington, Vermont 05405, United States

ABSTRACT

Humpback whales from northern and southern hemispheres annually migrate to Central America to breed. Previous research suggests the possibility of temporal and geographical overlap between these two breeding whale populations. To test this hypothesis, male song activity was used as an indicator of humpback whale presence during both whale population breeding seasons. Autonomous underwater recorders were deployed near Coiba Contreras Island in Panama from August 2020 to December 2020 and at Isla Canal from January to March of 2018 and generated a presence-absence data matrix of male humpback whales' songs to determine if there is temporal overlap. We expect detections of southern whales from August of November and northern whales from November to February. The period of overlap is expected to be mid-end of November. If there is overlap, we should expect to have songs present throughout this period our results show that humpback whale song detections occur throughout the year at Coiba and Isla Canal, suggesting there is potential for temporal overlap between populations. Furthermore, Southern Hemisphere whales' song detection increased in July, reaching its peak in September, and then decreased dramatically until October where it plateaued. A second peak of song detections occurred in November which is consistent with the arrival of Northern Hemisphere whales. Future studies should analyze the song structure of songs detected in November to determine if both populations are present at the same time in this area. This research will provide key information of when both whale populations are present in this area, and of the potential connectivity across hemispheres. Additionally, this research can be used to revise boat traffic patterns to mitigate the negative impacts boats can have on humpback whales.

Key Words: Bioacoustics, soundscape, RFCxArbimon, courtship song, Megaptera novaeangliae

1. Introduction

Megaptera noveangilae, more commonly known as the humpback whale, completes seasonal migration between feeding and breeding grounds in different groups across the world. Two distinct populations, the Northern Hemisphere humpbacks and the Southern Hemisphere humpbacks are no exception when it comes to preforming this trek. Specifically, the Southern Hemisphere humpback populations leave their feeding grounds near the Antarctic and migrate to their breeding grounds in Central America between the months of July through October. Conversely, the Northern Hemisphere humpback population retire from their northern latitude feeding ground and arrive to their equatorial breeding grounds in December and staying until April (Clapham, 2001).

Previous research suggests a possibility of temporal and geographical overlap between these two breeding whale populations. One study that originally inquired into relationship between water temperature and the migration of wintering Southern Hemisphere humpbacks off Central America, found evidence supporting this hypothesized overlap. Throughout the course of the

research, it was found there was a period of spatial overlap between Southern and Northern Hemisphere populations off the Panama coast (Rasmussen *et al.*, 2007). One hypothesized explanation for this overlap is a mutual dependence on this location for its stable temperatures and protective environment for newborn calves between the Southern and Northern populations (Brodie, 1977; Lockyer, 1981). Additionally, the presence of shared genetic traits between the two populations suggests there is a "trans equatorial exchange" (Medrano-Gonzalez L., 2001). It is this discovery of gene flow in addition to a persistent presence of humpback whales throughout the course of year in Central American waters (Rasmussen *et al.*, 2007) that serves as strong indication for a period of overlap between these two populations.

This research will continue to build upon what little knowledge is currently known about daily humpback whale song detection for humpback whale populations during breeding season off the coast of Panama. Additionally, either the presence or absence of a temporal overlap between Southern and Northern Hemisphere humpback whales. Our team hypothesized that a large group of Southern Hemisphere humpback whales will be detected from the months of August – November, followed by a smaller group of Northern Hemisphere humpback whales detected between the months of November and February. Similarly, it was hypothesized that the month of November, is when a period of overlap between the two populations would occur. To test this hypothesis, we utilized male song activity as indicators of humpback whale presence during both whale populations' respective breeding seasons at Coiba Contreras and Isla de Canal. This research will firstly serve to provide a more detailed picture as to when each population is present at their frequented breeding grounds. However, on a broader scale, by identifying the presence or absence of these whales this will contribute to the study of humpback whale population connectivity across hemispheres.

2. Materials and methods

2.1 Study site

This study took place in Isla Contreras as well as Isla de Canal, which make up just two of the 38 islands within Coiba National Park, a protected area of over 400,000 acres in the Gulf of Chiriquí off the Pacific coast of Panama (Fig. 1). This area is an important breeding area for Southern and Northern Hemisphere humpback Whales (Gretchen H. Steiger, 1991; Rasmussen *et al.*, 2007). Southern humpback whales migrate from the Antarctica Peninsula and the Fuegian Archipelago in Chile Panama (June - September) and the Northern humpback whales migrate from California and Oregon (December - April) (Gretchen H. Steiger, 1991; Calambokidis, 2000; Rasmussen *et al.*, 2007) The International Whaling Commission (1998) estimated that annually 2,000 Southern Hemisphere and 450 Northern Hemisphere humpbacks make the journey to these tropical waters to give birth and mate. Using the complex and stereotypic courtship song of the Male humpback, either the presence or absence of humpback whales was able to be indicated.

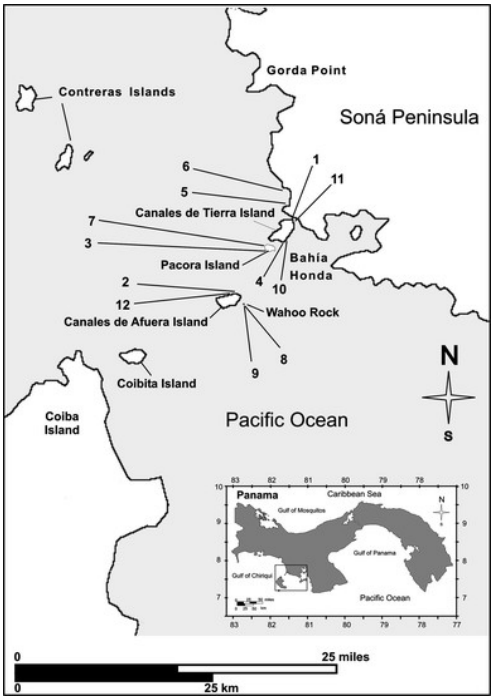

Figure 1. Study site in Panama's Coiba National Park, Coiba Contreras located in the upper left-hand corner (Dominici-Arosemena & Wolff, 2006).

2.2 Soundscape sampling

A Soundtrap 300 SD (frequency range 20 Hz-150 kHz ±3dB; self-noise of less than sea-state in the bandwidth 100 Hz-2 kHz, and sensitivity of -203 dB re V/µPa) recorder was deployed at 25 m at a location near Contreras Island (7.77N/-81.75 W) and Isla del Canal (7.68N/-81.61 W) which are characterized by large boulders and sandy bottom. The recorder was programmed to record the soundscape for 10 minutes every hour from August to December 2020 in Contreras and for 5 minutes every 30 minutes in Isla Canal from January to March 2018. Data from Recordings were uploaded and opened in RFCxArbimon an online platform (https://arbimon.rfcx.org/) and a spectrogram was generated using a fast Fourier transform (FFT) size of 512 points, an overlap of 50%, and using a 512-sample Hann window.

2.3 Data analysis

The first 10 days of provided recordings from each month were inspected. Specifically, the first ten minutes of each hour from 12:00 am to 11:00 pm were analyzed for either the presence or absence of *Megaptera noveangilae's* courtship song under the "Species Presence Validation" tab in Arbimon. Each recording was scored presence (1) and absence (0) of humpback whale male songs for each 1-min file (Fig. 2). This information was then used to determine changes in singing activity by time of day and month, and whale breeding population.

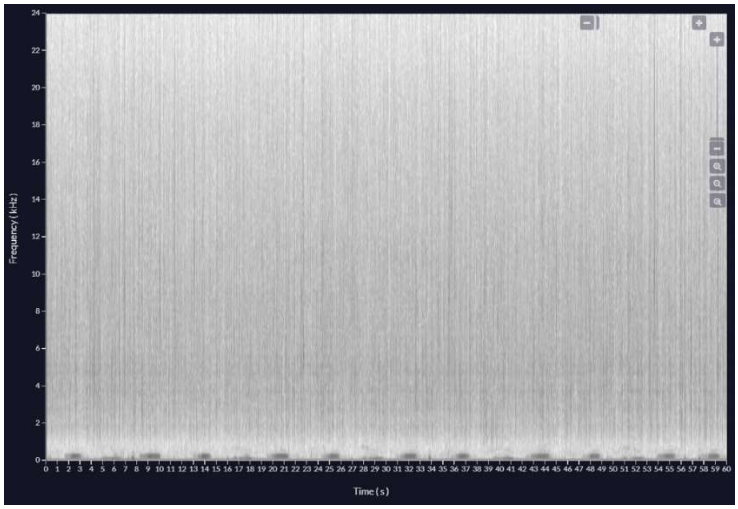

Figure 2. Example of *Megaptera noveangilae*'s courtship song over 60 second period in Coiba Contreras, Panama.

3. Results

A total of 200 hours (about 1 week 1 and a half days) of recording time were analyzed. 30 hours were from Isla de Canal in 2018 and 170 hours (about 1 week) from Contreras Island in 2020. After accounting for differences in recording effort, our results show that humpback whale songs were detected from August to March in the study sites (Fig. 3). The Southern Hemisphere humpback whales had a peak of activity in September, with a recorded average proportion of 0.45 1-minute files possessing songs. A second peak of activity was found in November when Northern Hemisphere humpback whales begin to arrive to the area, with a recorded average proportion of 0.30 1-minute files containing songs. Notably, the month of October which encompasses the time between these two populations respective departure and arrival exhibited a mean proportion of 0.20 1-minute files with songs present.

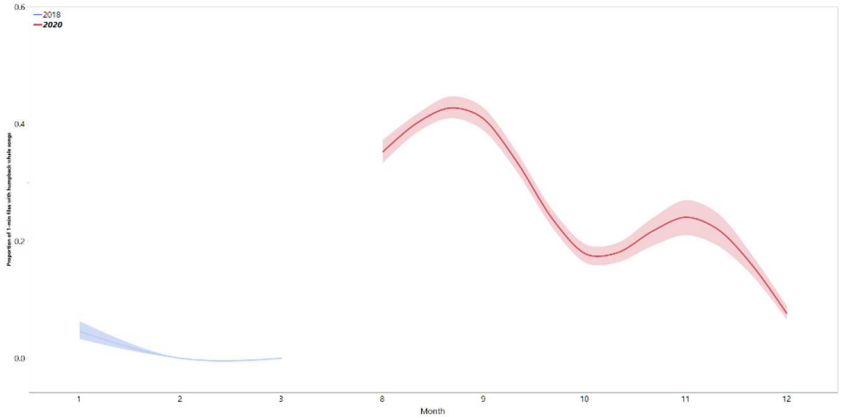

Figure 3. Proportion of 1-minute files with humpback whale songs from January to March of 2018 in Isla de Canal (blue) and August to December 2020 in Coiba Contreras (red).

4. Discussion

Our results provide evidence supporting a potential temporal and geographical overlap of Northern Hemisphere and Southern hemisphere humpback whale populations during the month of October. The presence of northern humpback whales arriving in the months of November and December are consistent with the timing of the migration of humpback whales from the northern pacific to the Central America region (Ryan *et al.*, 2019). The presence of southern humpback whales arriving in the southern winter months of July and August are also consistent with the timing of the migration of humpback whales from the southern pacific to the same Central America region (Guzman and Felix, 2017).

The arrival and departure times suggested through the presence absence data reveal migration patterns that are consistent with previous studies which suggested that northern hemisphere whales and southern hemisphere whales overlap geographically in middle-pacific regions. Geographical migration patterns tracked through genetic tagging of humpback whales identified DNA from skin samples at many different study sites in the middle pacific region (Palsbøll *et al.*, 1997) of whales from both the northern pacific and the southern pacific suggesting that both groups occupied the same geographical area. Another study done using photo ID data through satellites tracked groups of whales from both the southern pacific and the northern pacific to the same regions of the middle pacific near the Coiba region (Acevedo and Smultea, 1995). These, as well as many other previous studies using photo ID technology support the hypothesis of both groups of whales occupying the same region in the pacific but could not confirm if the timing of arrival and departure in the area allow for overlap between the two groups.

This is the first research study that uses soundscape data to confirm the geographical overlap of both groups of humpback whales in the middle pacific region. Our results also suggest that, in addition to occupying the same region of the middle pacific, both groups occupied the Coiba region at the same time. This is supported by the absence of a gap in the presence of humpback sounds between the departure of southern whales and the arrival of northern whales suggesting an overlap in populations. Although two different study sites were used in this investigation, the presence-absence data collected supports the hypothesis that there is significant overlap between northern and southern groups of humpback whales in the Coiba Contreras region off the coast of panama. This information is integral to the study of interactions between distinct groups of whales as it provides a basis for the time and place that these interactions may occur which can be applied to future studies. Furthermore, this research provides insight into the migration patterns of northern and southern humpbacks and can be used by boat transporters and other industries that make up boat traffic to decrease boat contact with humpback whales. Humpback whales can be negatively impacted when boats interfere with their calls, or physically harmed if a boating vessel strikes and injurers them. Now, new laws and regulations have further support to be put in place to protect humpbacks from boats and ships using this research.

Acknowledgements

This manuscript is dedicated to our fellow aspiring scientists, who we hope will retain their curiosity and continue to question the world around them through a fine-tuned scientific lens. We would specifically like to thank to Dr. Laura May-Collado for her unwavering technical and

logistical support, as well as her guidance throughout our research and writing processes. Additionally, we would like to thank Dr. May-Collado for her feedback that improved this manuscript.

References and Links

Acevedo, A., and Smultea, M. A. (**1995**). "First Records of Humpback-Whales Including Calves at Golfo-Dulce and Isla-Del-Coco, Costa-Rica, Suggesting Geographical Overlap of Northern-Hemisphere and Southern-Hemisphere Populations," Mar Mammal Sci **11**, 554-560.

Andrews-Goff, V., Bestley, S., Gales, N. J., Laverick, S. M., Paton, D., Polanowski, A. M., Schmitt, N. T., and Double, M. C. (**2018**). "Humpback whale migrations to Antarctic summer foraging grounds through the southwest Pacific Ocean," Sci Rep-Uk **8**.

Ashe, E., Wray, J., Picard, C. R., and Williams, R. (**2013**). "Abundance and Survival of Pacific Humpback Whales in a Proposed Critical Habitat Area," Plos One **8**.

Brodie, P. F., Harrison, R.J (**1977**). "Form, function and energetics of cetecae: a discussion," Academic Press: New York **3**, 5-58.

Calambokidis, J. (**2000**). "Reproductive Rates of Humpback Whales off California," Mar Mammal Sci **16**, 220-239.

Clapham, P. (**2001**). "Why Do Baleen Whales Migrate? A Response to Conrkeron and Connor," Mar Mammal Sci **17**, 432-436.

Gretchen H. Steiger, J. C., Richard Sears, Kenneth C. Balcomb, James C. Cubbage (**1991**). "Movement of Humpback Whales Between California and Costa Rica " Marine Mammal Science **7**, 306-310.

Guzman, H. M., and Felix, F. (**2017**). "Movements and Habitat Use by Southeast Pacific Humpback Whales (*Megaptera novaeangliae*) Satellite Tracked at Two Breeding Sites," Aquat Mamm **43**, 139-155.

Lockyer, C. H. a. B., S.G (**1981**). "The Migration of Whales," Society for Experimental Biology Cambridge University **13**, 105-137.

Medrano-Gonzalez L., B., C.S., Robles-Saavedra, M.R., Murrell, J., Vasquez-Cuevas, M.J., Congdon, B.C., Calambokidis, J., Urban-Ramirez, J., Florez-Gonzalez, L., Olavarria-Barrera, C., Aguayo-Lobo, A., Nolasco-Sot0, J., Juarez-Salas, S. A., and Villavicencio-Llamosas, K (**2001**). "Trans-oceanic population genetic structure of humpback whales in North and South Pacific," Memorial Queensland Museum **47**, 465-479.

Palsbøll, P. J., Allen, J., Bérube´, M., Clapham, P. J., Feddersen, T. P., Hammond, P. S., Hudson, R. R., Jørgensen, H., Katona, S., Larsen, A. H., Larsen, F., Lien, J., Mattila, D. K., Sigurjónsson, J., Sears, R., Smith, T., Sponer, R., Stevick, P., and Øien, N. (**1997**). "Genetic tagging of humpback whales," Nature **388**, 767-769.

Rasmussen, K., Palacios, D. M., Calambokidis, J., Saborio, M. T., Dalla Rosa, L., Secchi, E. R., Steiger, G. H., Allen, J. M., and Stone, G. S. (**2007**). "Southern Hemisphere humpback whales wintering off Central America: insights from water temperature into the longest mammalian migration," Biology Lett **3**, 302-305.

Rosenbaum, H. C., Maxwell, S. M., Kershaw, F., and Mate, B. (**2014**). "Long-Range Movement of Humpback Whales and Their Overlap with Anthropogenic Activity in the South Atlantic Ocean," Conserv Biol **28**, 604-615.

Ryan, J. P., Cline, D. E., Joseph, J. E., Margolina, T., Santora, J. A., Kudela, R. M., Chavez, F. P., Pennington, J. T., Wahl, C., Michisaki, R., Benoit-Bird, K., Forney, K. A., Stimpert, A. K., DeVogelaere, A., Black, N., and Fischer, M. (**2019**). "Humpback whale song occurrence reflects ecosystem variability in feeding and migratory habitat of the northeast Pacific," Plos One **14**.

Valdivia, C. A., Pacheco, A. S., Felix, F., Haase, B., Rasmussen, K., Santillan, L., Alcorta, B., and Silva, S. (**2017**). "Movements and Timing of Humpback Whales (*Megaptera novaeangliae*) Within the Breeding Region of the Eastern South Pacific," Aquat Mamm **43**, 324-330.

Behavior of Humpback Whales Wintering off Las Marias, Panama, in Relation to the Lunar Cycle

Hayley Norton, Megan O'Connor, Franny Oppenheimer
University of Vermont, Department of Biology

Abstract

Previous research has found evidence that the interaction between phases of the moon and time of day influence male humpback whale singing behavior. Humpback whales are thought to be acoustically active at night and shift to visual competitive tactics during the day. Here we study the potential influence of moon phases and time of day on the singing activity of humpback whales at Las Marias, an important breeding area in Panama. We use data collected from passive acoustic monitoring efforts in this area and generated a presence-absence matrix of song detections for Marias from October to December 2020 noting time of day and moon phase. Our results show that at Las Marias, male humpback whales mean singing activity increases during the first quarter and waxing to full moon phases. Based on previous studies we hypothesize that there will be a decrease in singing activity from first to last quarter. This study will provide a better understanding of the acoustic behavior of male humpback whales in this breeding ground.

Key Words: singing activity, Cetacea, songs, temporal variation.

Introduction

Humpback whales spend warmer months foraging at high latitudes where there's a higher amount of prey and migrate in the colder months to breed in the tropics (where prey is limited). Las Marias, Panama, part of the Coiba marine park and considered a UNESCO World Heritage Site, is a hub for Humpback breeding (*Smith*). The area's climate is defined as "tropical rainforest" (*mindat.org*), which means that temperatures range from 21 to 30° C throughout the year with a 77-88% humidity and an average yearly rainfall of 80-400 inches (*Private Islands*), making it the ideal warm-water place for humpback breeding. Humpback mating behavior includes singing, as well as competitive displays among reproductive males (*Yakovsky*)- acoustic behavior of humpbacks, specifically of breeding stock group whales off of Cano Island in Costa Rica, has been studied previously, and has been shown to peak during the breeding month of October and during the midday to midnight hours. (*Chereskin et. all, 2019*) Using these results, we can assert that acoustic behavior will change throughout the year and throughout each day; we think it may also change throughout the lunar cycle.

As the moon rotates around the earth and the earth rotates around the sun, the moon is visible to earth in different fractions, called phases. When the moon is directly between the earth and sun it appears dark: this is the new moon. When the earth is between the sun and moon, the moon is bright and reflects sunlight: this is the full moon. Transitioning from the new moon to the full moon is called waxing and transitioning from the full moon to the new moon is called waning: the visible moon takes different identifiable shapes during these times (crescent, gibbous, quarter) (*National Geographic*). *Light* is a limiting factor in humpback mating displays; a female can't judge what she can't see, and these displays are necessary to gain a female's attention (*Morell*). Changes in moon phase cause differences in moonlight available and could therefore affect humpback behavior.

In this study, we evaluated the presence of humpbacks in Las Marias using audio recordings from a span of three months. We analyzed 10 days each from October, November, and December of 2020, months in which the population of humpbacks is present after their southward migration (*Fisheries*). We then compared these dates to the lunar cycle and analyzed the apparent effects of the lunar cycle on mating behavior. We hypothesized that lunar phases with the lightest, i.e. waxing to full moon, full moon, and waning to third quarter, would promote the most whale activity - the vocal portion of what is otherwise a visual behavior. We expected to see files from those phases having the most recorded whale presence.

Materials and Methods

A. Study Site

This took place in Las Marias, located within the archipelago of Islas Secas in the Gulf of Chiriquí, Panama. This location is characterized by its designation as a "tropical rainforest' with high temperatures, consistently elevated humidity, and a high rate of yearly rainfall as well as a sandy bottom and presence of large boulders. This area is also an important breeding area for Southern Hemisphere humpback whales that migrate every year from the from the Antarctica Peninsula and the Fuegian Archipelago in Chile Panama (months) (*Palacios-Alfaro et all, 2012*) In this breeding area humpback whale males sing stereotypic and complex songs that act as a means of communication with other whales. As Las Marias acts as a breeding area for humpback whales, the songs heard in the recordings were characterized as courtship songs, specifically sung to attract and communicate with female humpback whales. Male humpback whale songs are the most common source of acoustic behavior that is observed in breeding areas such as Las Marias (*Dunlop et all, 2007*).

B. Recordings

A Soundtrap 300 SD (frequency range 20 Hz-150 kHz ±3dB; self-noise of less than sea-state in the bandwidth 100 Hz-2 kHz, and sensitivity of -203 dB re V/µPa) recorder was deployed at 25 m a location near Isla Maris (lat7.993/long-82.071) characterized by large boulders and sandy bottom. The recorder was program to record the soundscape for 10 minutes every hour from October to December 2020. Data from Recordings were uploaded and open in RFCxArbimon an online platform (https://arbimon.rfcx.org/) and a spectrogram was generated using a fast Fourier transform (FFT) size of 512 points, an overlap of 50%, and using a 512-sample Hann window.

C. Data Analysis

The first 10 days from each month (October 16-26, November 10-20, and December 1-11) were selected and the first 10 recorded minutes of each hour were inspected, scoring for presence (1) and absence (0) of humpback whale male songs and boats for each 1-min file. Along with determining the presence of humpback whale male songs we were able to score the songs as courtship-specific songs. To determine if lunar phases and tides influence male singing activity, we obtained information from the new moon to waxing gibbous phases of October, the waning crescent to waxing crescent phases of November, and the full moon to waning crescent phases of December (*Moon Phases 2021*). These days provided data occurring during each phase of the lunar cycle.

Results

A total of 110.9 h of acoustic time was analyzed between October and December of 2020. Whale presence was detected during each lunar cycle over the course of all three months, with varying consistencies of presence depending on each phase of the lunar cycle (Fig. 1). The first quarter and waxing to full moon phases showed the most consistent presence of humpback whales over time with a value increasing to 1 and remaining until the end of the lunar phase. The waning to last quarter showed the least whale presence over the course of the monthly lunar phases, with a maximum presence of 0.2 during the phase. The new moon showed an initial high volume of whale presence with a value of 1, however its value decreased to 0 near the end of the phase. The last quarter had varying degrees of presence throughout its phase, as did the waxing to 1st quarter. The waning to new moon phase showed a consistent intermediate presence value between 0.5-0.7 for its entire phase.

The mean number of files is equal to the sum number of files containing whale song per lunar phase divided by the total number of files containing whale song.
The lunar phase with the greatest mean number of files with whale songs was waxing to 1st quarter (~4 files), followed by waxing to full moon (~3 files) and waning to new moon (~3 files), followed by first quarter (~1 file), last quarter (~0.75 file), waning to last quarter (~0.5 file), and new moon (~0.5 file) (*Figure 1*).

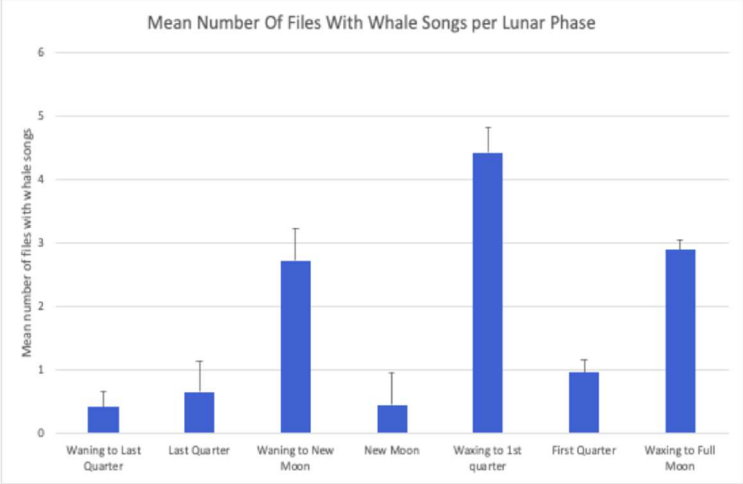

Figure. 1. Mean number of 1-min sound files with humpback whale song detection by lunar phase at Las Marias, Panama in October, November, and December of 2020 vs corresponding Lunar Phase

Discussion

We find that humpback whale singing activity increases in three moon phases: waning to new moon, waxing to 1st quarter, and waxing to full moon. These moon phases had significantly more whales than the other phases examined in the months from which data was collected.

This could be since light is not the most prevalent factor in the mating ritual - Humpback mating behavior includes singing an elaborate male breeding display, as well as competitive displays

among reproductive males. All males within a population share a common set of songs and patterns and these songs gradually change over the months, and many scientists think that a higher level of acoustic activity could indicate that the male vocal display might be the more important mating behavior (Sousa-Lima & Clark, 2008). This could also be since the times we studied had more of those phases than others, especially in November and October. Northern whales are spotted in Panama in (a lesser number) between December and April, and southern whales are found (in a larger number) between July and October, which could be the reason as to why more presence was noticed within the months of November and October than December because many of the southern whales had left. Humpback whales come from both the Southern Hemisphere (July to October with over 2,000 whales) and the Northern Hemisphere (December to March about 450 whales along Central America) to Panama (and Costa Rica) (Chereskin et al. 2019). These factors of migration and light not being as much of a limiting factor are our main predications as to why there was more presence during those three specific moon phases.

This research raises other questions around the mating behavior of humpback whales: if light is not as important for mating behavior, why are their specific phases with dramatic increases in acoustic data? What other behaviors might be critical for humpback mating? To determine that the data we gathered was not just a fluke, or impacted by temporary factors, we would like to analyze audio recording from multiple other months and years. That way, we could consider any shifts in behavior due to changes in temperature, pH, and resources. We would also then be able to assess other causes of the spike in acoustic behavior during the waning to new moon, waxing to first quarter, and waxing to full moon. It may also be useful to study mating behavior in other areas and potentially in different conditions (climate, pH, etc.), to assess the overall importance and commonality of certain aspects of the behavior overall - for example, do only some populations require light for their rituals to function?

Acknowledgments
We would like to thank our advisor, Dr. Laura May-Collado, for her wonderful mentorship and guidance on this project, and for proofreading this manuscript. Thanks also to our colleagues in LSS CURE for their unwavering support, and to Conservation International and University of Vermont for the original funding for this study.

Reference List

Chenoweth, E. M., Hill, D. F., & Gabriele, C. (n.d.). Tidal Influences on humpback whale habitat selection near headlands (pp. 280-289, Rep.).

Dunlop, R. A., Noad, M. J., Cato, D. H., and Stokes, D. (2007). " The social vocalization repertoire of east Australian migrating humpback whales (Megaptera novaeangliae)," (J. Acoust. Soc. Am. 122, 2893–2905).

Erbe, C., Marley, S. A., Schoeman, R. P., Smith, J.N., Trigg, L. E., Embling, C. B. (2019) The Effects of Ship Noise on Marine Mammals - A Review. (Front. Mat. Sci. 6:606).

Chereskin, E., Beck, L., Gamboa-Poveda, M.P., Palacios-Alfaro, J.D., Monge-Arias, R.,

Chase, A.R., Coven, B.R., Guzmán, A.G., McManus, N.W., Neuhaus, A.P., O'Halloran, R.A., Rosen, S.G., May-Collado, L.J., (2019). "Song structure and singing activity of two separate humpback whales populations wintering off the coast of Caño Island in Costa Rica" , (J. Acoust. Soc. Am.146 , EL509-EL515).

Friday, September 28. “Studying Humpback Whales in Panama.” Center For Ocean Life, (2018).

National Geographic Society. Cause and effect: Tides. (2012).

National Geographic Society. Tide. (2019).

Private Islands, las Marias Panama, Central America Usd 3,000,000.00 Inquire Now. mindat.org, and the Hudson Institute of Mineralogy. “Las Marías, Provincia De Herrera, Panama.” Mindat.org

“Moon Phases 2021 – Lunar Calendar for Panama, Panama.” Timeanddate.com, (1970)

Palacios-Alfaro, J. D., Martinez-Fernandez, D., Sanchez-Godinez, C., and Venegas, R. (2012). “ Distribution and behavior of humpback whale (Megaptera novaeangliae Borowski, 1781) (Breeding BSG), in southern Pacific of Costa Rica,” (International Whaling Commission, Report No. SC/64/SEP16).

Smith, J.M.B. “Tropical Rainforest.” Encyclopædia Britannica, Encyclopædia Britannica, Inc.

Sousa-Lima, R., Clark, C. Modeling the effect of boat traffic on the fluctuation of humpback whale singing activity in the Abrolhos National Marine Park, Brazil, (Can Acoustics, 2008).

Yavorski, K. “How Do Dolphins Mate?”, (2019), Sciencing, Leaf Group Ltd. / Leaf Group Media

Soundscapes of a Marine Community Before and During COVID-19 Lockdowns

Grace E. Thompson[1], Kaitlyn A. Zoller[1], Solomon C. Snuggerud[1], Katharine E. Roberts[1]
[1]University of Vermont Department of Biology, Burlington, Vermont 05405

ABSTRACT
Noise from human activities in the ocean have increased by about 3.3 dB per decade. Given that many marine species rely on sound for several biologically important activities (e.g., feeding, reproduction, navigation) scientists are concerned about the impact of an increasingly noisy ocean. The Covid-19 lockdowns have provided a unique opportunity to study the impact of anthropogenic noise on marine communities. This study uses data from passive acoustic monitoring in two nearby locations within the Archipelago of Chiriquí in Panama from August 2017 and 2020 to study changes in boat and biological noise levels before and during the Covid-19 lockdowns. We hypothesize that during Covid-19 lockdowns a reduction in boat presence will result in an increase of biological sound sources. Our results show that dolphin and fish detections significantly increased during Covid-19 lockdowns, but no significant differences were found with humpback whale song and snapping shrimp detections. This study can provide an alternative to marine community health assessments which can improve preservation of ecosystem function.

Keywords: mammal activity, acoustic ecology, boat traffic, Chiriquí archipelago, marine ecology

1. Introduction
Because light attenuates rapidly with depth in marine ecosystems, many marine organisms use sound for communication, navigation, and localization of food. For example, male humpback whales sing in breeding areas to attract females and compete with males by producing stereotypic and complex songs (Dunlop et al., 2007). Their songs are within human hearing range, ranging from 0.03 kHz to 8 kHz (Madin, 2012). Dolphins produce a variety of high frequency sounds that include echolocation clicks for the purpose of locating prey and navigating that range from 40 kHz to 150 kHz, as well as whistles and bursts for communication, that range from 0.2 kHz to 30 kHz (Madin, 2012). Fish produce pulses that differ in the types of sounds created, the duration, and the repetition of the sounds. These sounds are typically low in frequency; around 0.2 kHz (Amorim, 2006). The sounds that fish produce are used to find and compete for mates, intraspecific competition, defense of habitats, and to make distress calls (Amorim, 2006). Snapping shrimp are ocean-dwelling crustaceans that make noise using a large claw. The sounds that snapping shrimp produce are loud snaps that have frequencies that range from tenths of kHz to above 200 kHz (Bohnenstiehl et al., 2016). Noise from human activities in the ocean has increased by about 3.3 dB per decade (Frisk, 2012). Boat traffic from tour boats and container boats used for the shipments of goods contribute to the increasing noise levels in the ocean. As the number of boats traveling in the ocean increases, the noise contributed from these vessels also increases. The noise contributed to the marine soundscape masks the biological signals made by marine organisms and thus impacts these marine organism's food location, distress calls, navigation, communication, and mate attraction and competition.

The islands of Islas Secas and Secas Pargo are located close together in the Chiriquí archipelago off the coast of Panama and are part of a private, protected tourism site. Islas Secas and Secas Pargo are home to a variety of marine organism species, such as humpback whales (Rasmussen et al. 2007), dolphins (May-Collado et al. 2009), snapping shrimp, and a variety of sound-producing fish species (Benfield et al. 2008). The COVID-19 pandemic introduced restrictions on travel as well as country-wide lockdowns in many countries during 2020 and forced many people to stay at home which resulted in significantly lower noise levels in many parts of the world. A study found a significant reduction of noise levels in mainly urban areas that resulted in observations of increased bird songs and animal sounds (Manzano, 2021). This trend was observed in marine settings as well. Due to Covid-19 restrictions of movement and changes in human consumption of products, decreases in boat traffic were observed in 70.2% of Exclusive Economic Zones, with April being the peak month for declines observing a 1.4% decrease in boat traffic. Boats used for leisure were observed to have larger and longer lasting decreases in activity during the first 6 months of 2020 (March, et al., 2021). This decrease in boat traffic corresponded to an overall decrease in noise from boat travel in the world's oceans. The Covid-19 pandemic provides a unique opportunity to study the soundscape at conditions that are close to natural conditions for the organisms.

Given that many marine species rely on sound for several biologically important activities (e.g., feeding, reproduction, navigation) scientists are concerned about the impact of an increasingly noisy ocean due to human-related traffic, such as boats. This study uses data from passive acoustic monitoring in two nearby locations within the Archipelago of Islas Secas in Panama in August 2017 and August 2020 to study changes in boat and biological noise levels before and during the Covid-19 lockdowns. In this study, we assessed the impact of human boat activities on the marine soundscape of Islas Secas and Islas Pargo. Our goal was to analyze the impact of high volumes of human boat traffic on the activity levels of marine animals present in the Islas Secas archipelago region. We hypothesized that the activity of the marine animals present would decrease in the presence of boat travel.

2. Materials and Methods

A. Study Site

This study took place in the archipelago of Islas Secas on the Gulf of Chiriquí, off the Pacific coast of Panama. Islas Secas and Islas Pargo, the two locations that were studied, are two of the four major islands in the archipelago. The waters of the Gulf of Chiriquí range from an average temperature of 72 degrees Fahrenheit, or 22.2 to 33.3 degrees Celsius. The climate is particularly warm all year as the temperature doesn't drop below 69 degrees Fahrenheit, or 20.6 degrees Celsius. The humidity ranges from 5% to 95%, and the climate is considered to be quite humid. The area is prone to large amounts of rainfall year-round, with the percentage of rainfall during the months of April to November being 51% (Average Weather in Chiriqui, Panama, 2016).

Islas Secas is home to a diversity of microhabitats including sandy and rocky bottom, and coral reefs. Several species of marine organisms are observed in this area including humpback whales that migrate every year from the Chile and the Antarctica Peninsula to this area to reproduce (Rasmussen et al. 2007), pantropical spotted dolphins and bottlenose dolphins (May-Collado et al. 2009), several species of sonorous fish and snapping shrimp (Benfield et al. 2008).

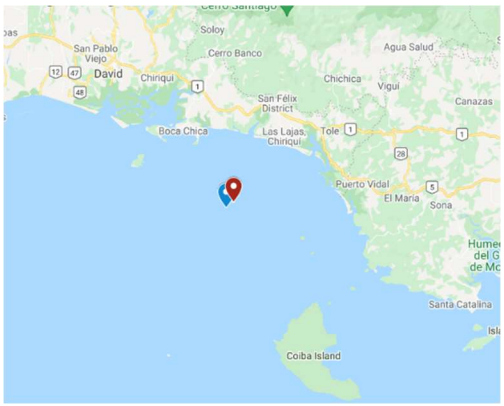

Figure 1: Map of study sites in the Archipelago of Islas Secas, located off the coast of Panama (7.9820° N, 82.0312° W)

B. Recordings

A Soundtrap 300 SD (frequency range 20 Hz-150 kHZ ±3dB; self-noise of less than sea-state in the bandwidth 100 Hz-2 kHz, and sensitivity of -203 dB re V/µPa) recorder was deployed at 25 m in Pargo (7.9582° N, 82.0519° W) from July to the end of September 2020 and in Secas (7.9783° N, 82.0276° W) in August 2017. In Islas Secas, the recorder was programmed to record the soundscape continuously in a 24-hour cycle at a sampling rate of 48 kHz. From these recordings a 1-minute sample was manually selected every 10 minutes. In Pargo, the recorder was programmed to record the soundscape for 10 minutes every hour, also at a sampling rate of 48 kHz.

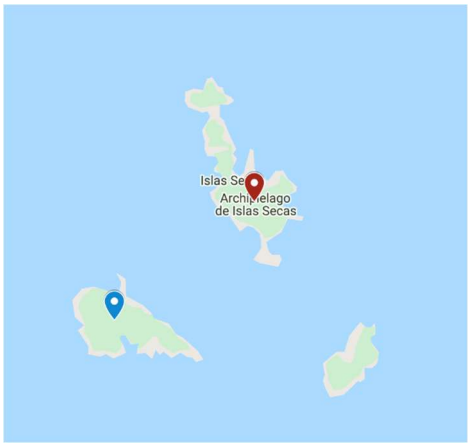

Figure 2: Soundtrap 300 SD recorder placements in the Archipelago of Islas Secas, Pargo located (7.9582° N, 82.0519° W) Secas located (7.9783° N, 82.0276° W)

C. Data Analysis

The 1-minute recordings were uploaded to the RFCx Arbimon platform for the inspection of the presence (1) and absence (0) of boats, humpback whale, dolphin, fish, and snapping shrimp

sounds. We selected 10 days in August 2017 and 10 days in August 2020. The dates inspected were August 1st – 5th 2017, and August 17th – 21st in the location Islas Secas. These dates were inspected by analyzing the first 5 minutes of each hour in the day. August 1st - 5th 2020, and August 17th – 21st 2020 in the location Secas Pargo were also inspected. These dates were inspected by analyzing the first 10 minutes of each hour in the day. Data visualization was done in JMP 14. (SAS Institute, NC, United States). An ANOVA analysis was used to determine if the number of 1-min files with whale, dolphins, fish, shrimp, and boats varied before and during Covid-19 lockdowns.

3. Results

A total of 18,200 1-min files were analyzed from 2017 and 5, 999 1-min files from 2020. After accounting for differences in sampling effort we found significant increase in the mean number of humpback whales (F Ratio=60, df=1, p<0.0001), dolphins (F Ratio=7,467, df=1, p<0.0001), fish (F Ratio=14,904, df=1, p<0.0001), and snapping shrimp detections (F Ratio=669.7, df=1, p<0.0001) during the Covid-19 lockdowns (see Fig.2).The mean number of boat detections increased in 2020 (F Ratio=60.3, df=1, p<0.0001).

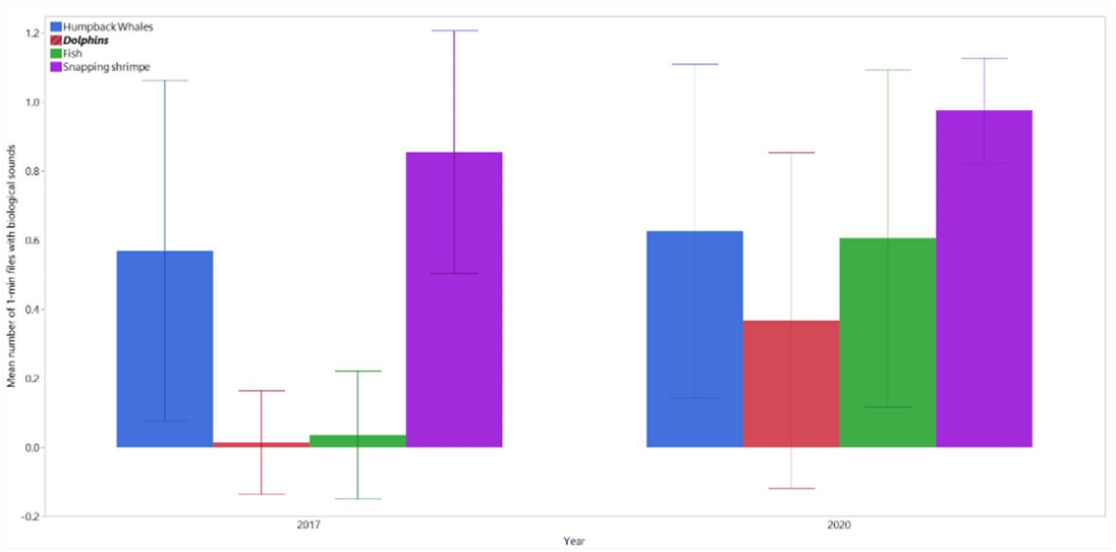

Figure 3. Mean number of 1-min files with biological sound sources before and during Covid-19 lockdowns in the archipelago of Islas Secas, Panama

4. Discussion

This study found that the mean activity of dolphins and fish increased, whereas the mean activity of humpback whales and snapping shrimp did not change significantly, between August 2017 and 2020 at the Archipelago of Chiriquí. Interestingly a study done in Coiba National Park, located in the Gulf of Chiriquí found not significant differences in boat presence between 2017 and 2020 in an area close to Islas Secas and Secas Pargo (Hodson, 2021).
Our study finds that humpback whale and snapping shrimp acoustic presence was unaffected by the increase in boat activity, but dolphins and fish were more detected. Our study area is an important nursing area for mother humpback whales and their newborns (Rasmussen et al., 2007) and male singing activity is lower than in neighboring areas such as Cano Island in Costa

Rica (May-Collado pers.comm. 2021). This could explain why we did not find any significant difference between years. Interestingly, a study in Cano Island found an increase in humpback whale singing activity (Durant, 2021), and a study found that whales contributed more to the soundscape in Cano Island during Covid-19 than in previous years (Miller-Bottoms, 2021). The study by Miller-Bottoms also found that in normal years noise levels were concentrated a low frequency, as it has been reported by other studies (Frisk, 2012). Low frequencies are used by both humpback whales and fish. The decrease in noise at low frequencies might explain the increase in detection of fish sounds which are often soft and very low in frequency (Amorim, 2006). Finally, that we found more dolphin detections than in previous years, suggesting that in the absence of human activity, dolphins may have been closer to the coast where our recorders were able to capture their high frequency sounds.

The results from this study are significant in that they are essential in informing the public, governments, and various advocacy groups about the impacts of noise from human activities on marine wildlife. This study was among the first study that was able to be conducted at relatively natural conditions due to travel restrictions from the Covid-19 pandemic, thus these results can be used to inform future analysis of the impact of human marine traffic on marine ecosystems. These results, as well as the results from other studies, could be used to help reshape boating policy and lead to better regulation of tourist destinations for whale watching, as well as other human activities that are centered around marine wildlife. Studies like this need to be continued so the effects of noise on marine wildlife can become better understood in order to ensure the preservation of the marine habitat and that industries such as the whale watching industry are regulated in such a manner so that their activities do not cause harm to marine ecosystems.

Acknowledgements
We would like to thank Laura J. May-Collado, PhD, Kristin Rasmussen, MSc, and their colleagues for providing the 1-minute sound recordings from their data collection that allowed us to conduct the analysis of said data. We would also like to thank Laura J. May-Collado, PhD for her help with writing the manuscript and guidance during this research project.

References

Amorim, M. C. (**2006**). "Diversity of sound production in fish," Communication in Fishes **1**, 71-105.

Amrein, A. M, Guzman, H. M., Surrey, K. C., Polidoro, B., and Gerber, L. R. (**2020**). "Impacts of Whale Watching on the Behavior of Humpback Whales (*Megaptera novaeangliae*) in the Coast of Panama," Front Mar Sci **7**,601277.

Australian Government: Department of Water, Agriculture, and the Environment. "Whales, dolphins and sound." https://www.environment.gov.au/marine/marine-species/cetaceans/whale-dolphins-sound

Benfield, S., Baxter, L., Guzman, H., and Mair, J. (**2008**). "A comparison of coral reef and coral community fish assemblages in Pacific Panama and environmental factors governing their structure," Journal of the Marine Biological Association of the United Kingdom **88**,1331-1342.

Bohnenstiehl, D.R., Lillis, A., and Eggleston, D.B. (**2016**). "The Curious Acoustic Behavior of Estuarine Snapping Shrimp: Temporal Patterns of Snapping Shrimp Sound in Sub-Tidal Oyster Reef Habitat," PLoS ONE **11**, 1.

Dunlop, R.A., Noad, M.J., Cato, D.H., and Stokes, D. (**2007**). "The social vocalization repertoire of east Australian migrating humpback whales (*Megatptera novaeangliae*)," J Acoust Soc Am **122**, 2893-2905

Durant, G. (**2021**). "How does Covid-19 lockdown impact boating and Humpback whale (*Megaptera novaeangliae*) singing activity?" CURE Course Spring 2021.

Frisk, G.V. (**2012**). "Noiseonomics: The relationship between ambient noise levels in the sea and global economic trends," Sci Rep **2**, 437.

Hodson, A.M. (**2021**). "Impacts of Covid-19 Regulations on the Soundscape of Marine Communities within Coiba National Park." CURE Course Spring 2021.

Kassamali-Fox, A., Christiansen, F., May-Collado, L. J., Ramos, E. A., and Kaplin, B. A. (**2020**). "Tour boats affect the patterns of bottlenose dolphins (Tursiops truncatus) in Bocas Del Toro, Panama," PeerJ **8**, 8804.

Madin, K. (**2012**). "Frequency Ranges of Marine Animal Sounds: For selected animals likely to be in or near Cape Cod coastal waters," Woods Hole Oceanographic Institution https://www.whoi.edu/oceanus/feature/frequency-ranges-of-marine-animal-sounds/

Manzano, J.V., Pastor, J.A.A., Quesada, R.G., Aletta,F., Oberman, T., Mitchell, A., and Kang, J. (**2021**) "The "sound of silence" in Granada during the COVID-19 lockdown," Noise Mapping **8**, 16-31.

March, D., Metcalfe, K., Tintoré J., Godley, B. (**2021**). "Tracking the global reduction of marine traffic during the COVID-19 pandemic," Nat Commun **12**, 2415.

May-Collado, L.J. Chapter 42: Marine Mammals. 2009. In Marine Biodiversity of Costa Rica, Central America. Edited by Wehrmann, I. and J. Cortes. Springer Verlag Academic Press.

Miller-Bottoms, S. (**2021**). "Ambient noise levels of a protected marine community in Costa rica before and during Covid-19," CURE Course Spring 2021.

Rasmussen, K., Palacios, D. M., Calambokidis, J., Saborio. M.T., Dalla Rosa, L., Secchi, E. R., Steiger, G. H., Allen, J. M., and Stone, G. S. (**2007**). "Southern Hemisphere humpback whales wintering off Central America: insights from water temperature into the longest mammalian migration," Bio Lett **3**, 302-305.

Weather Spark. "Average Weather in Chiriqui, Panama." https://weatherspark.com/y/16722/Average-Weather-in_Chiriqu%C3%AD-Panama-Year-Round

Whale and Dolphin Conservation, Inc. "Humpback Whale: Megaptera novaeangliae." https://us.whales.org/whales-dolphins/species-guide/humpback-whale/?gclid=CjwKCAiAjeSABhAPEiwAqfxURR3vHTvmFCxi5nVvmu_Ro2-ZMtmTYWbaK8G1Csp1aOIouSsvbfepqxoCmHoQAvD_BwE

The Impact of Covid-19 Lockdowns on Bottlenose Dolphin and Toadfish Occurrence in Almirante Bay, Panama

Peyton Dunphy[1], Elizabeth Hynes[1], and Juliana Bouchard[1]
[1]University of Vermont, Department of Biology, Burlington VT, 05405 USA

Abstract

Covid-19 lockdowns resulted in a decline of global traffic density, resulting in a unique opportunity to study the impacts of boat noise on sonorous marine organisms. Here we study potential changes in bottlenose dolphins, toadfish, and boat presence before and during Covid-19 lockdowns in Almirante Bay, Panama. Almirante Bay is home to taxi and ferry companies that provide access to various islands in the archipelago of Bocas del Toro and is a major port for export of produce. We generated a presence-absence matrix of sound detections from bottlenose dolphins, toadfish, and boats using acoustic data collected with autonomous underwater recorders on a 24-hour cycle. We hypothesize that during Covid-19 lockdowns there will be a decline in boat traffic density resulting in an increase in detection rate of dolphins and toadfish. Our results found a significant decrease in taxi-boats during the Covid-19 lockdowns, an increase in toadfish acoustic presence, but no significant differences were found in dolphin acoustic detections. However, we did find that all sound sources did vary significantly throughout the data between years. The results of this study demonstrate the negative impacts of boat traffic (and associated) noise to the acoustic activity of marine organisms. This research will provide marine ecologists with an increased understanding of the impacts of boat traffic on bottlenose dolphins and toadfish, which will inform conservationists on the benefits of designing policies to regulate boating.

Key Words: boat traffic, acoustic analysis, anthropogenic noise, communication, soundscape

1. Introduction

With human noise pollution increasing by about 3.3dB per decade, the ocean ecosystems directly face the consequences (Frisk, 2012). However, in the wake of the Covid-19 pandemic, lockdowns have been placed causing a decline in global traffic density (Oguzoglu, 2020). This decrease in travel can have a positive effect on the ocean ecosystem by decreasing the sound pollution present in our oceans. In response to the Covid-19 pandemic, the boat traffic has been limited to that of government and necessary transport boats for resources (Huveneers et al., 2021). With Almirante Bay being a key port to accommodate exports, boat traffic may still be present throughout the pandemic (Thompson, 2016).

When considering the changing noise pollution levels present in these ecosystems, it is important to understand the impact this alteration has on the marine organisms. The scientific community has placed an increased focus on using soundscape analysis to determine the health of the ecosystem (Linseth, 2018). Since other senses, such as sight, are limited underwater, sound is the major sense used by aquatic species, as it travels in any direction and can vary in frequency (Laura J. May-Collado et al.). In turn, sound plays a key role in the lives of marine organisms as it provides communication, navigation, and the location of food. Soundscape patterns that

emerge noisy, meaning numerous organisms are heard, showcase a more diverse and healthier ecosystem (Lobel, 2013). In Almirante Bay, the sonorous species present include bottlenose dolphins (*Tursiops truncatus*) and toadfish (*Amphichthys cryptocentrus*), which help form the soundscape of the bay (Thomas A. Wake et al., 2013). Bottlenose dolphins' sounds have been found to be concealed by the sounds produced by boat engines, as they share similar frequencies (May-Collado and Wartzok, 2008). Toadfish can face a negative impact from boat noise, as the sound produced by the boat impairs the fishes' auditory sensitivity, which is essential to the toadfish in attracting mates and during agnostic encounters (Vasconcelos et al., 2007). These interactions of the natural soundscape and human noise pollution can be detrimental to the marine species present. Research done through recordings will allow for the entire soundscape composition to be seen. This availability of all occurring sounds led us to explore the effects of human disruption, through boats, on the biodiversity of the health of the ecosystem in Almirante Bay. These results can then be compared prior to and during the Covid-19 pandemic, to track changes that occurred.

The occurrence of the pandemic and resulting lockdowns, create a unique opportunity to study the impact of boat noise on sonorous marine organisms. In our research, we study the acoustic presence of bottlenose dolphins, toadfish, and boats before and during the Covid-19 lockdown in Almirante Bay, Panama. The sounds were obtained using autonomous under water recorders that were utilized before and after the pandemic. We hypothesize that during the Covid-19 lockdown there will be a decline in boat traffic density causing an increase in the detection rate of bottlenose dolphins and toadfish. This research will allow for marine ecologists to better understand the effects of boat traffic, and other sources of noise pollution, on the marine species.

2. Materials and Methods

2.1 Study Site

This study took place in Almirante Bay in the Archipelago of Bocas del Toro, Panama (Figure1.). Almirante Bay is characterized by warm temperatures ranging from 72 to 86 degrees Fahrenheit and densely populated coral reefs (Berry et al., 2013). The Bay is abundant in nutrients, chlorophyll, and zooplankton, making it a desirable habitat for a rich diversity of marine organisms including bottlenose dolphins and toadfish (Cramer, 2013). The area is home to a rich diversity of marine organisms including bottlenose dolphins and toadfish. Their habitat overlaps with taxi boats routes, that run from 6 a.m. to 6 p.m. every 30 min each way between mainland and taxis run, (Perez et al., 2021).

Bottlenose dolphins and toadfish were selected as the subjects of this study because of their vocalness, which can be used to measure the effects of anthropogenic noises on their behavior and health. An increase in noise pollution can reduce the probability of the marine animals detecting signals, which reduces their range of communication. To compensate, the animals may increase the level of their own calls, by making their signals longer or more redundant, or by waiting to signal until noise is reduced. Some sound exposures may be loud enough to make it more difficult for an animal to perform its regular functions., causing them to avoid the human sound sources (Tyack, 2008). Depending upon the consistency of exposure to these disturbances, the marine animals of the affected ecosystems can endure severe health issues such as hearing

loss and stress responses that result in physiological costs. By listening to the noises produced by the sonorous bottlenose dolphins and toadfish, we are able to examine how human activity is affecting the overall health of the marine ecosystem's inhabitants as well as their communication and presence.

2.2. Recordings

A Soundtrap 300 SD (frequency range 20 Hz-150 kHz ±3dB; self-noise of less than sea-state in the bandwidth 100 Hz-2 kHz, and sensitivity of -203 dB re V/µPa) recorder was deployed at 12 m depth in Almirante (9.289N, -82.332 W) from February to April 2019 and from July 9th through the 13th in 2020 (Fig. 1). Recordings were uploaded and open in RFCxArbimon an online platform (https://arbimon.rfcx.org/) and a spectrogram was generated using a fast Fourier transform (FFT) size of 512 points, an overlap of 50%, and using a 512-sample Hann window. To determine if Covid-19 lockdowns resulted in an acoustic change of toadfish and dolphin acoustic presence in Almirante Bay we selected the first five days of February, March, and April of 2019 as well as a week (July 9-13) in July of 2020 and inspected the 10 minutes of each hour of recording available. During this process, we scored presence (1) and absence (0) of boats, dolphins, and toadfish sounds for each 1-min file.

2.3 Data analysis

Data visualization was done in in JMP 14. (SAS Institute, NC, United States). An ANOVA analysis was used to determine if the number of 1-min files with dolphins, toadfish, and boats varied before and during Covi-19 lockdowns.

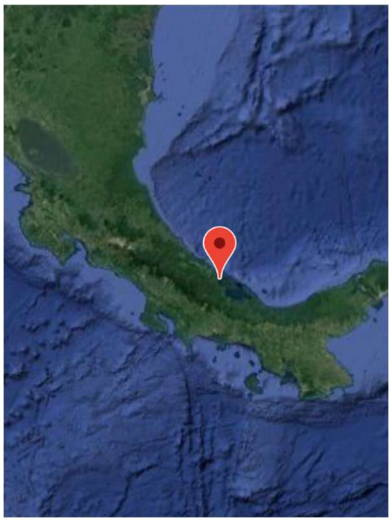

Figure 1. Location of the Almirante Bay in the Province of Bocas del Toro, Panama (9.289N/-82.332W).

3. Results

A total of 360 hours of acoustic time were analyzed from February 2019-April 2019 and 24 from July 2020 during the Covid-19 lockdowns. We found a significant decrease in taxi-boat detections in 2020 than in 2019 (F Ratio=17.4, df=1, p<0.0001, Fig.2). Dolphin sound detections did not vary significantly between years (p>0.005, Fig.2), but toadfish detections were significantly higher in 2020 than in 2019 (F Ratio=52.6, df=1, p<0.0001, Fig.2).

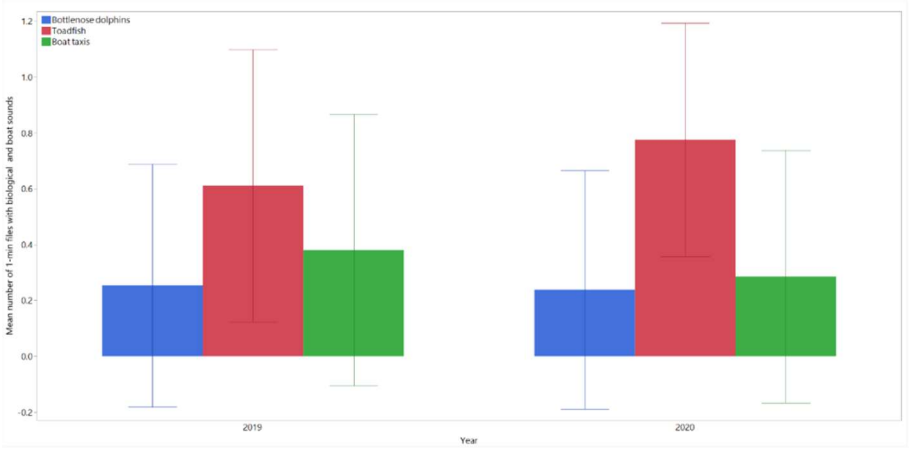

Figure 2. Mean number of 1-min files with sound detections for dolphins, toadfish, and boats in 2019 (pre-covid lockdowns) and 2020 (during covid-lockdowns).

Although there were not significant differences in the overall mean number of dolphin detections between years, we did find a significant difference in the distribution of dolphin detections throughout the day (F Ratio=31.6, df=1, p<0.0001). Figure 3 shows that in 2019 most dolphin detections happen from 7 p.m. to 4 a.m. while in 2020 there were three peaks of dolphin detections at 5 a.m., between 11 a.m. and 4 p.m., and from 7 to 10 p.m. We also found significant difference in the distribution of toadfish detections throughout the day between years (F Ratio=54.5, df=1, p<0.0001). Figure 4 shows the toadfish detections increased during daytime in 2020. Finally, the presence of boats throughout the day also varied significantly (F Ratio=18.3, df=1, p<0.0001, Fig.5).

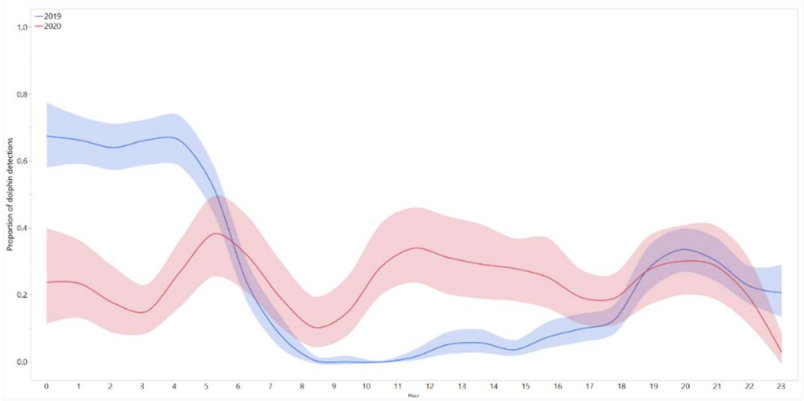

Figure 3. Proportion of 1-minute files with dolphin sounds over a 24-hour period in 2019 and 2020 at Almirante Bay.

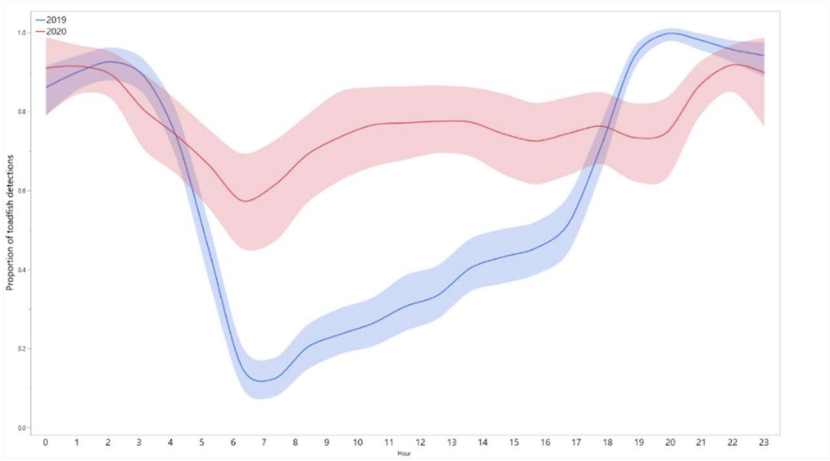

Figure 4. Proportion of 1-minute files with toadfish sounds over a 24-hour period in 2019 and 2020 at Almirante Bay.

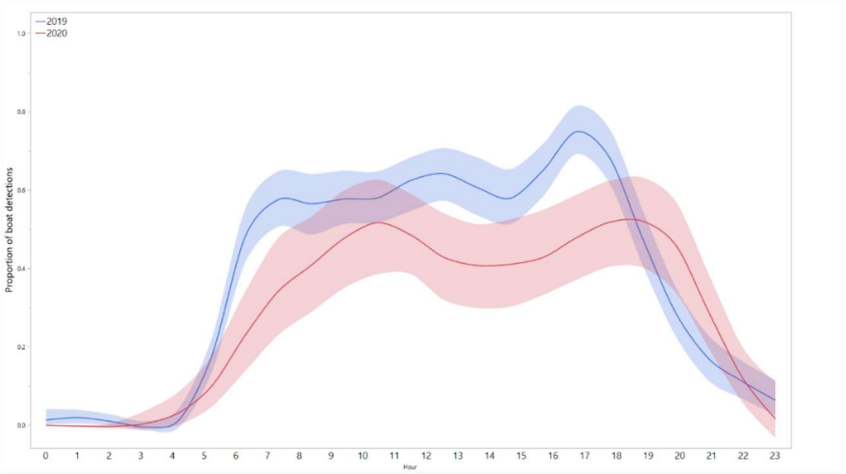

Figure 5. Proportion of 1-minute files with boat over a 24-hour period in 2019 and 2020 at Almirante Bay.

4. Discussion

Our results find that although boat traffic did not notably increase as we had originally predicted, there was an increase in the detection rates of bottlenose dolphins and toadfish from pre-Covid lockdowns to Covid lockdowns. Although the study only had five days of data during the time of the Covid-19 pandemic, our results show that bottlenose dolphin and toadfish presence does increase even when a slight decrease in anthropogenic sounds occur. A study conducted in the Kvarnerić region produced similar results, also concluding that boating is a large contributor to underwater noise and as a result may be negatively impacting the quality of the coastal habitats causing a decline in dolphin abundance (Rako et al., 2013).

During the analysis of our recordings, it was noted that boat traffic did not particularly increase from pre to post lockdown periods. There are two main types of boats that travel in Almirante Bay, including taxi boats and commercial boats. Taxi boats are crucial in the transportation of

individuals between the islands of the archipelago, while the commercial boats are needed to deliver necessary exports. The Covid-19 lockdowns shut down many nonessential businesses, and due to the necessity of exports, commercial boats could not completely stop running during the pandemic. As a result, the main source of decrease in the boat traffic detections comes from a decline in taxi boats as transporting tourists is not as essential as the transportation of food and other goods. Even with this minor decrease in the boat traffic noise, there was an increase in toadfish and bottlenose dolphin detection rates. However, toadfish presence increased more drastically from the decrease in boat traffic than bottlenose dolphin presence did. Perez-Ortega et al. (2021) showed that due to taxi boat's consistency in maintaining schedules and pre-established routes, they cause less disruptive interactions with dolphins. As a result, the acoustic behavior of bottlenose dolphins in the presence of transport boats does not change dramatically, which would explain the less drastic change in dolphin presence with boat presence decreasing, in contrast to toadfish, which are heavily impacted by boat noise. From a previous CURE study, it was found that male toadfish use acoustic communication to attract females, making their calls critical to their reproductive success (Gagne, 2019). Gagne found that boat noise can degrade toadfish calls, and in an attempt to avoid the masking of their acoustic communication, toadfish change the frequency of their calls. With boat traffic decreased, it is likely that toadfish presence increased during the daytime as the decreased noise pollution allowed them to expand the hours at which their calls would be heard, increasing their chances of reproductive success.

Our results contribute to ongoing conservation efforts to preserve the toadfish and bottlenose dolphin populations of Panama. As sonorous species such as toadfish and bottlenose dolphins are vital in indicating the health of marine communities, it is necessary to monitor their acoustic contributions to soundscapes. With the decrease in boat traffic noise and the resulting increase in toadfish and bottlenose dolphin noise, this study supports the conclusion that designing policies for the regulation of boat traffic is essential to preserving these species in Almirante Bay. Due to the strong correlation between anthropogenic traffic frequency and the acoustic behavior of toadfish and bottlenose dolphins, marine ecologists can use our data to push for conservation efforts to preserve these sonorous species. Such conservation efforts may include limiting the hours in which commercial boats and taxi boats can travel in the bay or designing specific pre-established routes for the boats that would interfere with the bottlenose dolphin and toadfish the least.

Acknowledgments

We would like to thank Laura May-Collado for her mentorship during our research process. Without her extensive knowledge, feedback, and dedication to this research our project would not have been possible. We would also like to extend a thank you to those who have collected the data for this project, as well as the University of Vermont Course-based Undergraduate Research Experience program, which provided us the opportunity to complete this research.

References

Berry, K.L.E., Seemann, J., Dellwig, O., Struck, U., Wild, C., and Leinfelder, R.R. (2013). "Sources and Spatial Distribution of Heavy Metals in Scleractinian Coral Tissues and Sediments from the Bocas del Toro Archipelago, Panama," Environ Monit Assess 185, 9089–9099.

Cramer, K. L. (2013). "History of Human Occupation and Environmental Change in Western and Central Caribbean Panama," Bulletin of Marine Science 89(4), 955- 982(28).

Gagne, E. K. (2019). "Boat Traffic in Bocas Del Toro, Panama Associated with Selection for Lower and Louder Toadfish (Amphichthys Cryptocentrus) Calls," CURE: Soundscapes and Behavior Research (BIOL 188-A).

Huveneers, C., Jaine, F.R.A., Barnett, A., Butcher, P. A., Clarke, T. M., Currey-Randall, L. M., Dwyer, R. G., Ferreira, L. C., Gleiss, A. C., Hoenner, X., Ierodiaconou, D., Lédée, E.J.I., Meekan, M. G., Pederson, H., Rizzari, J. R., van Ruth, P.D., Semmens, J. M., Taylor, M. D., Udyawer, V., Walsh, P., Heupel, M. R., and Harcourt, R. (2021). "The Power of National Acoustic Tracking Networks to Assess the Impacts of Human Activity on Marine Organisms during the COVID-19 Pandemic," Elsevier 256,108995.

Lindseth, A.V., Lobel, P.S. (2018). "Underwater Soundscape Monitoring and Fish Bioacoustics: A Review," Fishes 3(3), 36.

Lobel, P. S., and Lobel, L. K. (2013). "Stalking Spawning Fishes," American Academy of Underwater Sciences.

May-Collado, L.J, Campos-Cerqueira, M., and Aide T. M. "How Can Audio Recordings Improve Tropical Biodiversity Conservation?" Learn Gala.

May-Collado, L J., and Wartzok, D. (2008). "A Comparison of Bottlenose Dolphin Whistles in the Atlantic Ocean: Factors Promoting Whistle Variation," Journal of Mammalogy 89(5), 1229-1240.

Oguzoglu, U. (2020). "COVID-19 Lockdowns and Decline in Traffic Related Deaths and Injuries," IZA Institute of Labor Economics, 2-17.

Perez-Ortega, B., Daw R., Paradee, B., Gimbrere, E., and May-Collado L. J. (2021). "Dolphin-Watching Boats Affect Whistle Frequency Modulation in Bottlenose Dolphins," Front. Mar. Sci. 8, 618420.

Rako, N., Fortuna, C., Holcer, D., Mackelworth, P., Nimak-Wood, M., Pleslić, G., Sebastianutto, L., Vilibic, I., Wiemann, A., and Picciulin, M. (2013). "Leisure Boating Noise as a Trigger for the Displacement of the Bottlenose Dolphins of The Cres–Lošinj Archipelago (Northern Adriatic Sea, Croatia)," Elsevier 68, 77-84.

Thompson, P. (2016). "Live and dead coral cover on three reefs and public perceptions of degradation around Almirante Bay, Bocas del Toro," Independent Study Project (ISP) Collection, 2488.

Tyack, P. L. (2008). "Implications for Marine Mammals of Large-Scale Changes in the Marine Acoustic Environment," Journal of Mammalogy 89(3), 549-558.

Vasconcelos, R. O., Amorim, M. C.P., and Ladich, F. (2007). "Effects of Ship Noise on the Detectability of Communication Signals in the Lusitanian Toadfish," J. Exp. Biol. 210(12), 2104-2112.