MARINE MAMMAL COURSE BOOK

BOCAS DEL TORO, PANAMA

UNIVERSITY OF VERMONT

2019

Instructors

Laura J. May-Collado, Instructor

Field Assistants

Heather Daszkiewicz (Awarded in 2015 the Mostly likely to become a Dolphin Scientist! 4 years later she is a Dolphin Scientist!)

Betzi Perez (Betzi is a Panamanian scientist awarded the Hardcore Award by me 😊 for her ambitious doctoral thesis and her determination)

To both Heather and Betzi thank you for your support and for inspiring this new generation of scientists. I appreciate the time you dedicated to this course and the students.

Our Captains

Eric Brown

STRI

Demetrio

STRI

To both Demetrio and Eric thank you for keeping us save! You are an integrative part of our research team, without your support and participation we would not be able to achieve our goals.

UVM Dolphin Pod

Meredith Maloney

For her the best immune system received the Snotbot Award

Amanda Jones

For the best shirt collection received the Bruce Mate Award

Kahlia Gonzales (a.k.a. Kathlia)

For her leadership in PhotoID received the Randy Wells Award and the Maui Award

Carly Sarbacker

For the Best Species Presentation and her love for manatees received the John Reynold's III Award

Mikayla Kass

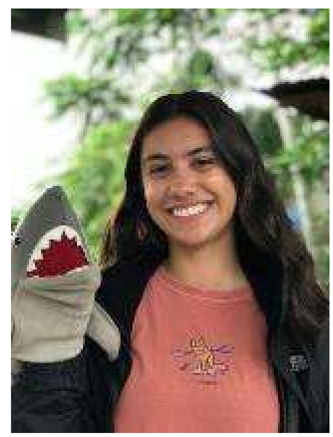
For her adaptation and behavioral plasticity skills received the Mary Jane West-Eberhard Award

Summer Barnes

For her independence, drive and initiative received the Asha de Vos Award

Emma Shapera

For her highly acrobatic boat dives received the Natalia Molchanova Award



Alyssa Neuhaus

For her survival skills in the face of a bad laryngitis received the Maria Mitchell Bravery Award

Hannah Hutchens

For the best fun fact species presentation received the Bill Nye Award

Rachel DuBrul

For her outgoing and charming personality received the Congeniality Award and the Boteros Award

Maddy Tregenza

For her chill attitude received the Moxie Award and the Marie and the Marie Tharp Award for her future in Oceanography

Emma Gimbrere

For her endless curiosity, drive, and great science communication skills received the David Attenborough Award

Matt Herberg

For being so inspired by this field experience we grant you the Excellency Meme Award

James Grant

For his passion for photography and awesome animals' pics during this course received the National Geographic Award

Natalie Davis

For her love and compassion of Bocas street dogs received the Humane Society Award

Katie Hollenberg

For her perseverance and assistance in cataloguing oceanic dolphins received the Betzi Perez Award

Photo by James Grant (of course) of a dolphin playing a tree branch.

To my Dolphin Pod, you represent the new generation of nature film makers, nature photographers, science communicators, veterinarians, and scientists! Thank you for taking this course, I have learned so much from you. I end this course so inspired by each one of you. Thank you, for letting me share with you my passion for marine life. I hope that by putting you in the shoes of field marine biologists and by taking you to a place that contrast in culture, economy, and conservation needs to yours, you get a better understanding of the task lays ahead of us in terms of conservation. Stay passioned and join the movement to protect our oceans.

See you in the fall!

Syllabus

BIO 296 (4 credits)

Marine Mammal Biology

CE Study Abroad Course in Panama

UVM Summer Mon. May 27 to 30 @ UVM; June 1-15 @ Bocas del Toro Panama, 2019

Instructors	Instructor
Laura J. May-Collado, Ph.D.	Heather Daszkiewicz
lmaycoll@uvm.edu	hdaszkie@gmail.com

Pre-requisites: Undergraduate junior or senior levels. BCOR 102, BCOR12 or WFB 150.

Course Description:

Marine mammals are not just beautiful and charismatic; they also share a remarkable evolutionary history that led them back (independently) to the ocean millions of years ago. The return to the sea involved a number of dramatic modifications in their anatomy, physiology, and communication. Ecologically, these animals play crucial roles as top predators, keystone species, and ecosystem engineers. For example, large whales contribute to nutrient cycling in the oceans through their poop and carcasses. For these reasons scientists are concern about how population declines of whales can potentially disrupt how nutrients are made available to nutrient poor waters. In terms of conservation, aquatic mammals are top conservation priorities among mammals. One species is already functionally extinct, the Yangtze river dolphin and several others are at the brink of extinction (e.g., the Vaquita and Mediterranean monk seals, Northern Right Whales). Whaling, overexploitation of their food supplies by fisheries, and habitat lost due to pollution (e.g., plastic, metals, noise) and climate change are among the factors threatening these animals.

The goal of this course is to introduce you to the biology of aquatic mammals, their habitats, the communities that rely on them economically, and to get students involved in field research. The course is primarily for advance undergraduates but graduate and sophomores can enroll with permission from the instructor. I want to enfasize that **this is not a recreational course** you will spend **8 hours or more at day** participating in boat surveys collecting field data on behavior, acoustics, and abundance. Days are hot and humid, and our boats have a small roof not enough to cover everyone. Students that register for this course must have a serious commitment to the course. Often there is a misconception that the dolphins will 'perform' as dolphins in aquaria or that students will be swimming with them. That's not how research on marine mammals works! Studying dolphins can be tedious, they can be hard to find, and once you do they might have other plans and swim away within seconds; and NO we do not swim with dolphins in this course, we want to reduce our impact as much as possible.

The first week of classes we will meet via zoom an online connection tool. During this lectures student will be introduced to basics on the biology marine mammals and to the methods that will be used during our surveys. On June 1st we'll head down to Panama, and on June 2nd we will flight to my study site in the Archipelago of Bocas del Toro where we will make our home at Bocas Marine Station of the Smithsonian Tropical Research Institute located in the main island, Isla Colon. I have been studying dolphins in Bocas for almost 16 years, we know almost every single animal and how they relate to each other. This population is at risk of extinction and your participation in this course will contribute to generate biological information to designed management strategies that help protect this dolphin population and their habitat.

Learning goals of this course:

1. Learn about the evolution, ecology, and behavior of marine mammals in tropical waters of Panama.
2. Observe the conservation treats that these animals face every day and brainstorm about the what can be done to protect them.
3. To offer the opportunity to learn about the challenges and efforts that take to study these animals in their natural environment.
4. Engage students in all aspects of marine mammal research: literature reading and discussion, asking questions, collecting, processing, and analyzing data, learning how to interpret analytical results and how to communicate the results.
5. Learn that science is not about eureka moments! Good science takes time, involves failure, troubleshooting, discussions, re-evaluations, and yes frustration. Good science is always challenging at different levels, from collecting the data to its analysis.
6. Learn that not all research projects are equal! Different questions, systems, or species will require different approaches. My research is field based so is bound to be limited by replication, sample size, lack of controls (because there are impossible to have!), logistics! However, field based projects are essential for our understanding of our biological world, and are often the spark for more sophisticated and controlled studies.

Grading: Lecture: 1000 pts

Assigments	**Points**	**Due Data**
3 Online Assigments	150 (each 50)	May 27-29
Blogging	50	Assigned in the field
Species Presentation	50	Assigned in the field
Participation/actitude/responsibility/initiative	250	
Research Project • Proposal • Manuscript Draft • Manuscript Final • Oral presentation	 100 100 100 100	 June 4 June 13 June 14 June 14
Outreach Activities	100 pts	

Assignments: Each day after lectures there will be an assignment in blackboard consisting of 3-4 questions related to the topics of the day. Each assignment is due that same day @ mid-night.

Blogging: Communicating our science to the public is a fundamental aspect of the life of any scientist, but particularly of field biologists working with charistmatic species that play an important role in the economy of local communities. Each student will be assigned a day of field experience to blog about. The post will be posted in the course Blog in English and Spanish, and it will be shared in several social media sources to reach a broad audience.

Species Presentation: Each student has an assigned species (list will be posted in BB). This assignment consists of two parts: a 2-page written summary on the biology of the species (5%) and a 5 min presentation in class (5%, 3 PowerPoint slides maximum!). The summary and presentation must have information about

- Global distribution and preferred habitat and diet
- Social organization (social or solitary, group size, type of society etc.)
- Behavior (communication i.e., acoustic, foraging i.e., strategies and adaptations,
- Reproduction i.e. litter size, mating system)
- Conservation status (i.e., IUCN status, threats, conservation efforts)
- Any new cool discovery or fact about this species that you want to share.
- The written summary must be turn on the day of your presentation.

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Participation/actite/responsibility/initiative: Students will be assigned a number of responsibilities during this course including bringing equipment from the lab to the field, and materials for the outreach activities. Once in the field students are expected to be ready to go to the field at the appointed time, collect field data as indicated in the research protocol (see BB), participate in cleaning the boat and the lab, participate in every boat-survey, show initiative and responsibility during data collection, and respect the rules of established by your instructor, STRI, and UVM. Students are expected to comply with UVM Code of Academic Integrity, as requested by Dr. May-Collado and the rules of Smithsonian Tropical Research Institute. **Students are required to participate in all course activities**. **No drug or alcohol is allowed in this course.**

Independent Research Project

Students can work individually or in groups. However, expectations will be higher for group projects. We expect students to develop questions that are answerable within the time frame of this course. We expect students to take charge of their independent

projects, be independent and resourceful readers of scientific literature related to their

projects and demonstrate initiative in learning the programs that can help them

address their research questions. Databases and other resources Dr. May-Collado behavioral, photoID, and spatial data for bottlenose dolphins (to use this data we will sign a MOU agreement). Dr. May-Collado acoustic data for several cetaceans (to use this data we will sign a MOU agreement).

I. Proposal: 1 page.

a. Background to problem with citations of papers or other sources that document the information you are presenting. This background should include the

- Observations that lead to your question or hypothesis.
- Purpose and scope - Statement of the purpose of your paper.
- Hypothesis and testable prediction (s)
- Significance: How does your project advance knowledge on this field? How does your project benefits society?

b. Materials and Methods - What type of data have you found and what additional data are you going to try to find? How will the data you collect be analyzed to address your

objectives, questions or hypothesis? It is important to make it clear how the scientific

method will be used to test or address either your hypothesis or the predictions you

expect if the hypothesis is true.

c. **Expected outcomes**
d. **Research Plan -** Schedule of steps to be accomplished with deadline dates.
e. **Literature Cited -** Full reference to the papers cited in the introduction and materials and methods sections. Use format from Journal of Marine Mammal Science

f. **You will turn in an electronic version to both Laura and Heather**

II. Manuscript: length depends on each project

The manuscript must follow the Journal of Marine Mammal Science (MMS) format that you can read here: https://www.marinemammalscience.org/journal/guide-for-authors/. The first submission is not synonymous of an 'incomplete draft' we expect a complete manuscript in format of MMS. After figures, tables, and stats are done I recommend writing a short version of the abstract. What this does is to provide focus and a framework to write the complete draft. Save every version of your draft separately for you to see your own progress. I recommend that you read your paper over carefully and see if you can find mistakes or identify ways in which your paper could be improved. As you write keep track of the references and write the Literature Cited section as you are writing the paper rather after you are finished. Electronic submission to both instructor and TA. **The draft if due on June 13**. You will received feeback from me, after addressing fully my review the final manuscript is due **on June 14.**

III Oral Presentation

We will use traditional oral presentation format. You will have 10 minutes, 8 minutes for your presentation, and 2 minutes for questions for your presentation on **June 14**. Please upload the presentation in the assigned laptop in the lab in the following format: PowerPoint (PPT or PPTX), standard definition, 4:3 ratio. Please embed any videos or audio within the presentation. Also include ALL videos & audio files in a separate folder on your thumb drive. This will enable us to correct any problems on site.

Course Materials

a. There is not textbook in this course. Scientific Literature and Resources related to the topics of the course will be uploaded to Blackboard prior the beginning of the course.
b. Lectures will be available in Blackboard under Course Materials
c. Dolphin'fins Catalog: Please download from Blackboard-Course Materials
d. Install the following Software prior going to the field:
    - Socprog compiled (free download) (not available in mac).
        - http://whitelab.biology.dal.ca/SOCPROG/social.htm
        - http://whitelab.biology.dal.ca/SOCPROG/Manual.pdf
    - Audacity both platforms Mac and Windows free download.
        - https://www.audacityteam.org/download/
    - JMP or SPSS download from UVM software services.
    - Word: Excel, Power Point, Word also available for student in UVM software services.

Instructors Bios:

Laura J. May-Collado: Native of Costa Rica. She has over 20 years of experience working with marine mammals. She earned her master's degree at University of Costa Rica and her Ph.D. at Florida International University. She is currently a Research Associate at the University of Vermont in the Department of Biology, and has coordinated Field Biology courses for OTS in the past. Website: lauramay-collado.com

Heather Daszkiewicz : She is American biologists that has work with dolphins and sea turtles in the past three years in Florida. She earned her B. Sc. at University of Vermont, and took this marine mammal field course in 2015.

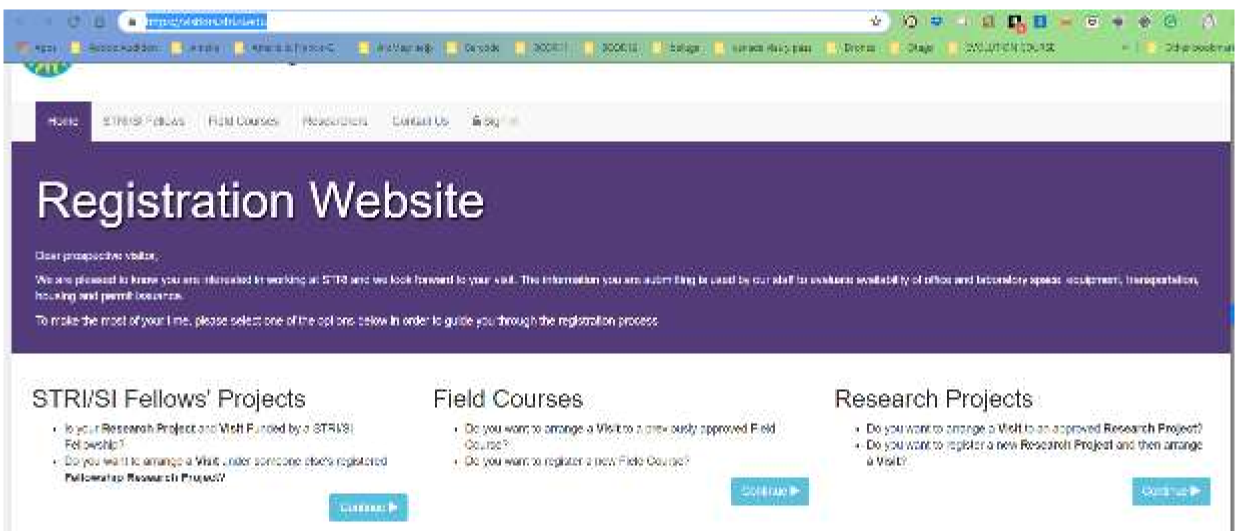
Invited Guess Betzi Perez: Native of Panama. She has over a decade of experience on marine mammal research. She is currently developing her doctoral thesis on this dolphin population studying the effect of engine noise on stress and reproduction.

Getting ready for Bocas

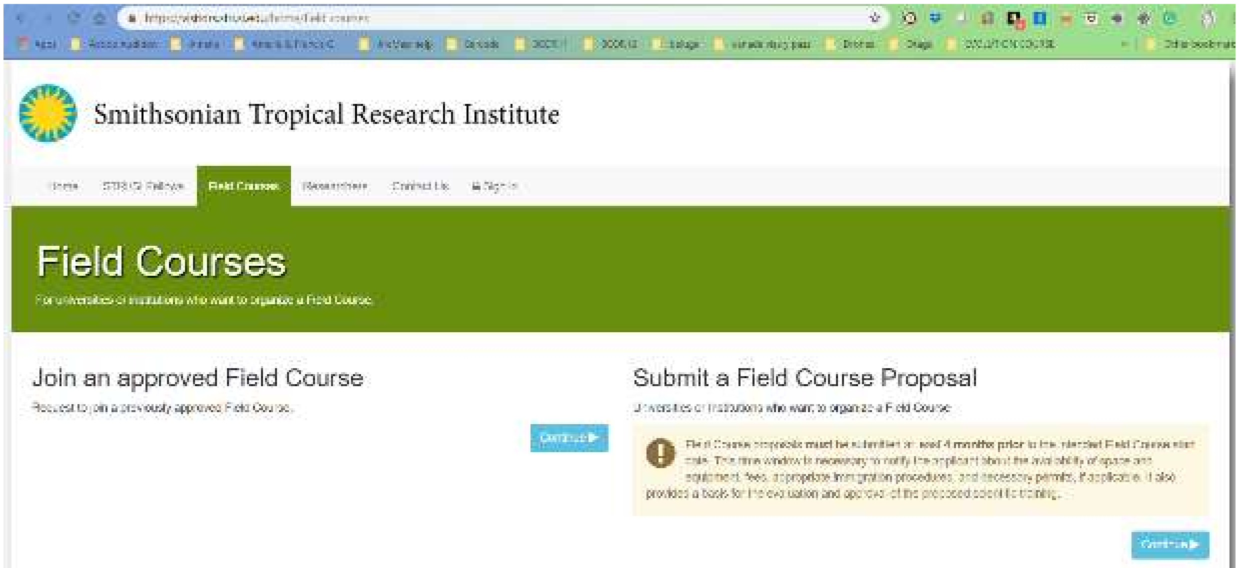
1. Register at Smithsonian Tropical Research Institute (STRI)

Please go to https://visitors.stri.si.edu/

Under field courses click continue. You are arranging a visit under an approved field course.



Click Join an approved Field course

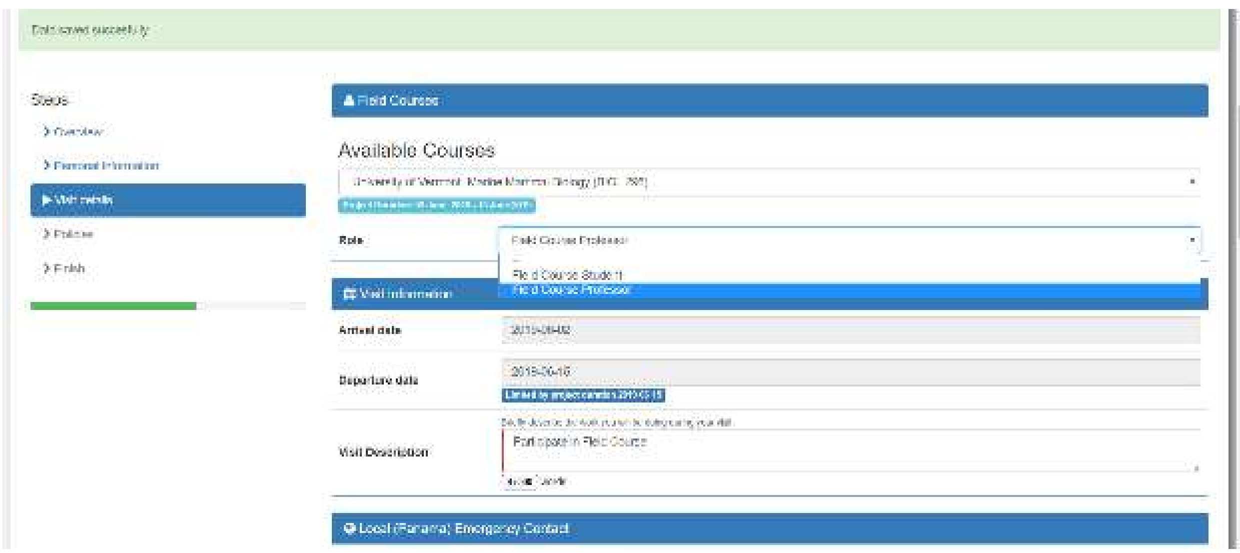


Create a new registration profile

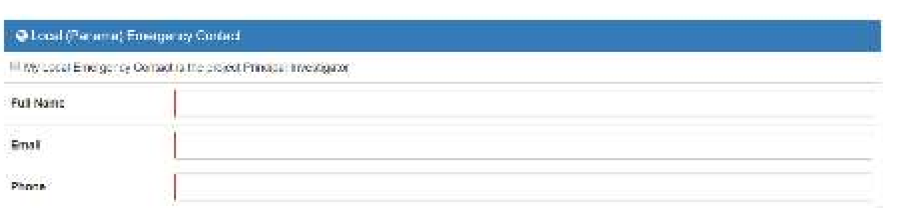
You will be prompted to fill out the Personal Information

Visit details:

Select Field Course Marine Mammal Biolog (BIOL296)

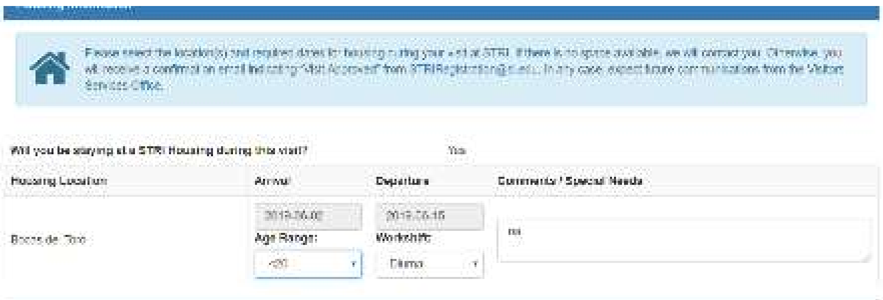


Local Emergency Contact: click “My local emergency contact is the project principal investigator”



Housing and Facilities

- Housing and Facilities Bocas del Toro
- Dates: Arrival June 2-Departure June 15.
- STRI Facilities: click Yes, same dates as above and under comments in both housing and facility typed: "arranged by Prof. May-Collado"



Policies: Click each document, read it, and then check.

Finish

2. **iAbroad: as we get closer to leave to Panama you will be prompted to complete information in the iAbroad platform. If you do not complete these forms in a timely matter, you won't be allowed to travel.**
3. **A passport that is valid for at least three months after date of entry.**
4. **Flights we will be arranged by Angie Atkinson-Accent Travel. Please add travel insurance.** I will send an email to her including you on the email to begin the booking the international flight USA-Vermont. The idea is that no matter where you start your trip, she can get students to travel together as much as possible and select flights that arrive about the same time to Panama on June 1st.

What to pack?

The most important thing is not to over pack! Try to travel light! A backpack is better than a wheel luggage. We are traveling from Panama to Bocas in a small plane so make sure you pack light.

At the Station you'll have:

- Sheets and blankets.
- Towels.
- Toilet paper.
- Internet
- Potable water
- Free laundry and drying machines at the station.
- Laundry liquid
- Safety box to put away valuables

What to bring with you from home?

- Laptop or MacBook. You won't need special adaptors for electronics (cellphones and computers). The regular wall adaptor will be fine.
- External USB drives
- Sandals or flip-flops
- One pair of shoes that stays dry in your room
- Small towel (to bring in the boat).
- Headlamp or small flash light (and batteries)
- A light sweater (it gets chilly in the labs because of the AC).
- Mosquito repellent and a mosquito net. There is not AC in the rooms so the mosquito net is key.
- Light Raincoat
- Comfy and light clothing T-shirts, a couple of long sleeve shirt, shorts, yoga pants, bathing suit, socks etc. Pants and long sleeve clothing are important at night when mosquitos are active.
- Aloe cream

- Toiletries (tooth paste, shampoo, conditioner, moisturizer, deodorant, etc.).
- Bring your prescribed medicine with you (e.g., antibiotics, allergy, malaria, etc.). We will have a basic first aid kit in each boat and there is a drugstore in town where you can find over- the-counter medications (e.g., pain killers).
- If you wear contact lenses bring an extra pair and eye drops.
- Note book and pencils

On the boat you will need:

- Small dry bag to carry your items
- Sun scream (we will be 8 hours in the boat you need good quality sun scream)
- Wet shoes or sandals
- One long sleeve shirt
- Hat or cap
- Extra shorts/yoga pants
- Raincoat
- Sunscreen
- Sunglasses
- 1 large Reusable water bottle (there is filtered water at the station)
- Snorkeling gear (nothing fancy please)

If you already have any of these items feel free to bring them too. Do not buy them if you don't have them!

- Go pro and accessories
- Canon or Nikon camera with zoom lens 70-200 mm or 70-300mm
- Binoculars

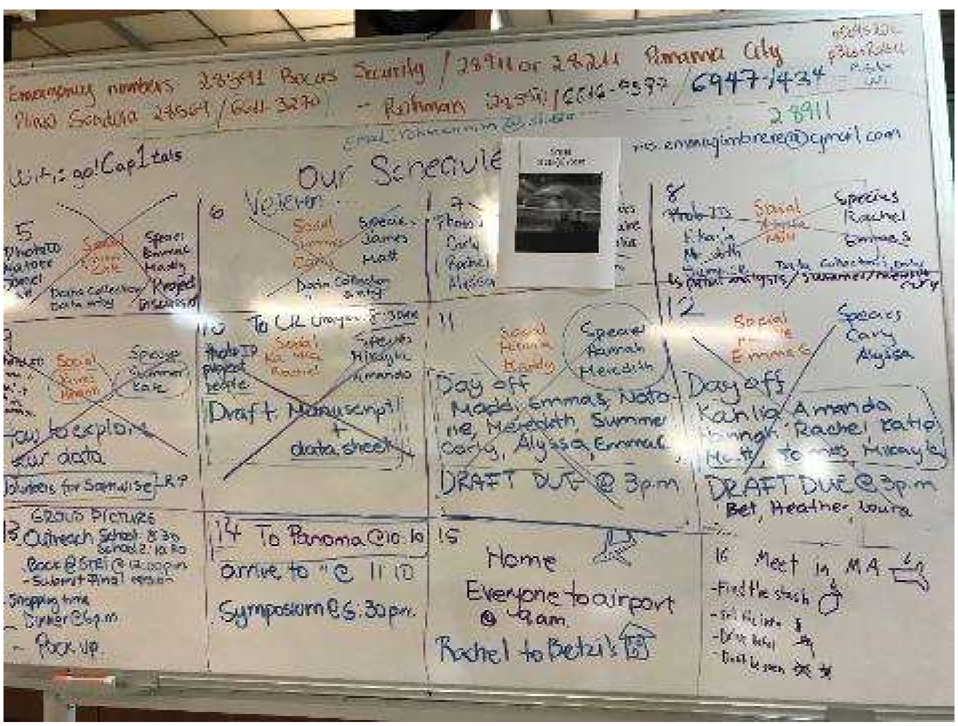
On your laptop you will need the following programs and documents:

- Audacity FREE download at sourceforge.net/projects/audacity
- Only for Windows: SOCPROG compiled 2.4 for early versions of Windows or SOCPROG complied 2.5 FREE download at: myweb.dal.ca/hwhitehe/formqq.htm
- JMP/SPSS download is free at…
- Or if you prefer R
- Your species presentation (see format in syllabus)
- Dolphin Catalogue in Black Board

The Plan

May 27 Online Lecture1: Diversity and distribution of marine mammals Lecture2: Evolution and Adaptations. Lecture3: Marine Mammal Reproduction. **BB Assignment 1**	**May 28** Online Lecture4: Behavior and Social Structure Lecture 6: Sensory Systems and Communication **BB Assignment 2**	**May 29** Online Lecture7: The Dolphins of Bocas del Toro: • PhotoID • Field Data Sheets • Map of the Area • Equipment • Boat Surveys **BB Assignment 3**	**May 30** Get ready for travel to Panama • Download requested programs and documents to your laptop • Prepare your Species assignment before going to Bocas • **Heather your TA will be available via phone to answer any question.**	**May 31** Get ready for travel to Panama • Make sure you double check the information on how to prepare for this trip. • **If you have a question, contact us over our WhatsApp Group**
June 1 Flying to Panama! Don't forget your passport! Print out your flight information for both flights Keep us inform if you have any travel delays.	**June 2** Flight to Bocas STRI Orientation Review of Dorsal Fin Catalogue, equipment, and your survey assignments	**June 3** Breakfast at 6:30 a.m. Field Work: 7:30 to 5 p.m. everyday Boat 1: Distribution/Abundace/Bathymetry/ PhotoID Boat 2: Behavior/PhotoID/Acoustics/Drone Night: discussion of independent projects Data Entry Blogging	**June 4** Breakfast at 6:30 a.m. Field Work: Boat 1: Distribution/Abundace/Bathymetry/ PhotoID Boat 2: Behavior/PhotoID/Acoustics/Drone Night: Write up 1- page proposal with presentation/discussion Data Entry Blogging	**June 5** Breakfast at 6:30 a.m. Field Work: Boat 1: Distribution/Abundace/Bathymetry/ PhotoID Boat 2: Behavior/PhotoID/Acoustics/Drone **Night: Heather's talk** Data Entry Blogging
June 6 Breakfast at 6:30 a.m. Field Work Boat 1: Distribution/Abundace/Bathymetry/ PhotoID Boat 2: Behavior/PhotoID/Acoustics/Drone **Night: Noise, Stress and Reproduction (by Betzy Perez)**	**June 7** Breakfast at 6:30 a.m. Field Work: Boat 1: Distribution/Abundace/Bathymetry/ PhotoID Boat 2: Behavior/PhotoID/Acoustics/Drone Night: Student PPT Species Presentation Data Entry	**June 8** Breakfast at 6:30 a.m. Field Work: Boat 1: Distribution/Abundace/Bathymetry/ PhotoID Boat 2: Behavior/PhotoID/Acoustics/Drone Night: Student PPT Species Presentation Data Entry	**June 9** Breakfast at 6:30 a.m. Field Work: Boat 1: Distribution/Abundace/Bathymetry/ PhotoID Boat 2: Behavior/PhotoID/Acoustics/Drone Night: Student PPT Species Presentation Data Entry	**June 10** Breakfast at 6:30 a.m. Field Work: Boat 1: Distribution/Abundace/Bathymetry/ PhotoID Boat 2: Behavior/PhotoID/Acoustics/Drone Night: Species Presentation Data Entry& Data Analysis

Reality



The awesome memes!


Please Do Not Pet the
Parasitic Puppies of
Bocas del Toro
No one can or will stop me


Dwight schnoot


STRI room #3: *exists*
Bats:
It's Free Real Estate
I HAVE HAD A VERY LONG DAY.... I AM VERY SMALL
AND I HAVE NO MONEY SO YOU CAN IMAGINE
THE KIND OF STRESS I AM UNDER


Sh(e)
b(e)li(e)v(e)d

The Projects

Dolphin Watching Compliance:

- Alyssa
- Emma S and Natalie

Dolphin Population Biology:

- Kahlia
- Amanda
- Katie
- Rachel

Dolphin Spatial patterns:

- Hannah
- James
- Matt
- Mikayla

Dolphin Acoustic Behavior

- Meredith and Summer
- Carly
- Emma G and Maddy

COMPLIANCE OF DOLPHIN-WATCHING BOATS TO CURRENT PANAMANIAN REGULATIONS IN BOCAS DEL TORO, PANAMA

ALYSSA NEUHAUS, Department of Biology, University of Vermont,

Vermont, Burlington, VT 05405, USA

ABSTRACT: In Bocas del Toro, Panama, dolphin-watching tourism has significantly impacted the resident bottlenose dolphin (*Turiops* spp.) population. According to recent studies in Bocas del Toro, boats pose a threat to cetaceans due to the noise pollution and potential of the motors to injure animals. In 2014, the Panamanian government instilled official whale-watching regulations to protect the species. However, there is no enforcement of the regulations, so it is hypothesized that the dolphin-watching boats are not complying. The results show that dolphin-watching boats were not compliant to the regulations 95% of the time. 81% of boat operators were within 100 meters of a dolphin, and 30.7% were travelling faster than permitted. A maximum of 19 boats were seen around one group of dolphins within one hour, and there was an average of six boats present simultaneously. It is suspected that boat operators are violating these regulations due to the fact that they were put into place over five years ago and there is no reinforcement in Dolphin Bay. Encouraging the community of Bocas del Toro to monitor the dolphin-watching boats more closely would benefit the health of the bottlenose dolphin population, and the sustainable practices may also attract more tourists in the future.

Key words: Tourism, whale-watching, Bottlenose Dolphin, habitat loss

The Archipelago of Bocas del Toro is home to a genetically-isolated community of bottlenose dolphins. Within this area, a cove called Dolphin Bay has the highest amount of dolphin-watching boats as the dolphins tend to spend most of their time foraging in the bay. The resident population of dolphins in the bay is less than 150 individuals, and the inner part of dolphin bay has been shown to be most frequently used by mothers and calves (May-Collado et al 2012). As a result, mothers and calves are the target of dolphin-watching boats. The presence of multiple dolphin-watching boats triggers avoidance behaviors and reduces the foraging time and social interactions. Previous studies showed that these patterns are intensified when calves are present, and the diving frequency of mother-calf pairs increased (Bas et al. 2017). The increase in noise levels caused by the dolphin-watching boats has also been shown to change the acoustic structure and emission rate of their communicative signals (May-Collado and Wartzok 2008). The dolphin-watching industry has increased rapidly since 2000, meaning that dolphins are exposed to a dangerously high number of boats each day (May-Collado and Quinones-Lebron 2014, May-Collado et al. 2017). A study in 2015 found that the behavior of dolphins was less significantly altered when vessels complied with guidelines than when they did not (Sitar et al. 2016).

Due to the negative impacts of dolphin-watching boats on the behavior of the dolphins, the Panamanian government instilled a number of regulations in 2014 in attempt to protect the Bocas dolphin population (Resolución No. DM-0530. 2017) and other cetaceans in Panama. The regulations were updated again in 2017. The regulations currently allow for only two boats to interact with dolphins at a time for a maximum of 30 minutes, followed by a 30-minute break before the next interaction. Regulations also state that boats should not get closer than 100 meters of the dolphins to view them, the engine must be idle/off, they must have a slow leaving speed, and they must travel parallel to the dolphins. If there is a mother and calf present, then the engine speed must be further reduced. The dolphin-watching boats must not interrupt foraging or socializing, and the group of dolphins must be out of the way before the boat starts moving again. Currently, there are currently no surveillance or enforcement measures in Bocas del Toro to monitor the dolphin-watching boat activity.

Since there are no enforcements in place, the proposed study will focus on the compliance of dolphin-watching boats in Dolphin Bay with the Panamanian dolphin-watching regulations. The number of compliant dolphin-watching boats is expected to be less than 50%, which is based on a previous study conducted by Sitar et al. (2015) that found that boats were compliant 45% of the time. To assess the compliance of dolphin-watching boats in Dolphin Bay, I collected data on the types of maneuvers and distances of boats in relation to the dolphins over a time span of two weeks in June 2019.

MATERIALS AND METHODS

Study Site

The Archipelago of Bocas del Toro is located on the eastern coast of Panama. Dolphin bay is located within the islands of the archipelago at approximately 9°N and 82°W. The bay is shallow and is home to many mother-calf bottlenose dolphin pairs. Tour boats typically include Dolphin Bay in their day tours around Bocas del Toro, so many dolphin-watching boats gather here.

Field Sampling

Surveys were conducted in boats between the hours of 8:00am and 4:00pm during the low-season in terms of tourism. When in Dolphin Bay, the research boat was turned off when it was closer than 100 meters to the dolphin so as to minimize our impact. Boat observations began once the first dolphin-watching boat entered into Dolphin Bay. All other types of boats (i.e. transport or personal) that were not engaging in dolphin-watching were disregarded from the study. The approaching speed, engine status (on/idle), distance from dolphins, leaving speed, and total duration in dolphin bay was recorded for every dolphin-watching boat in the bay. The speeds were categorized as either "fast" or "slow", and the distance from dolphins was categorized as either less than 100 meters or more than 100 meters. The number of dolphins and their behavior was also monitored to gauge how they respond to the boat activity. Additional notes were taken to keep track of dangerous maneuvers made by the boats, such as circling or harassing. Sightings were concluded once the last dolphin-watching boat left Dolphin Bay.

Statistical Analyses

A total of 44 boats were observed in Dolphin Bay over a time period of 4.7 hours. The data was analyzed using Excel to determine the overall proportion of compliant boats to non-compliant boats. If a boat violated at least one regulation, it was considered to be noncompliant. Each type of boat maneuver was also analyzed to determine if there were specific regulations that were violated more often than others or in combination with others.

RESULTS

Of the 44 boats that were observed over 4 days, 42 were considered to be noncompliant due to the violation of at least one regulation. 81% of the boats that were watching dolphins were closer than 100 meters (Fig. 1 & 2). The average number of boats that were present in Dolphin Bay simultaneously was 6.25 boats, and there was a maximum of 8 boats seen at one time (Fig 3). The maximum number of boats seen within one hour was 19 boats, and the minimum was 5 boats (Fig. 4). The greatest number of dolphins was seen when there were 4-5 boats present in the area (Fig. 5). 89% of the boats within 100 meters of the dolphins had a fast leaving speed, and there were more boats that had a fast leaving speed than a fast approaching speed (Fig, 6 & 7). However, 30% of the boats approached and left at a fast speed, and 35% of the boats had their engine on for the entirety of their time in Dolphin Bay. The dolphin watching boats stayed in the bay for an average of 17.37 minutes.

DISCUSSION

This study was conducted five years after the whale-watching regulations were put in place in Bocas del Toro. The results indicate that the levels of noncompliance are very high, and the two regulations that were most commonly violated were that boats must be more than 100 meters from a dolphin and that only two boats can be observing the group of dolphins at a time. At one point, a total of 19 boats were seen within one hour of being in Dolphin Bay, and there was an average of 6 boats watching a group of dolphins at once throughout the study. Boats rarely exceeded the 30-minute time limit, but this resulted in more engine noise since boats were constantly coming and leaving. Only two boats were considered to be following the regulations perfectly, while the other 42 boats were all in violation. The high number of dolphin-watching boats with a single group of dolphins makes it likely that the resident bottlenose dolphin population in Bocas del Toro is being negatively affected.

Boat operators were farther than 100 meters from the dolphins less than 19% of the time, and there was rarely a buffer of 200 meters between boats because there were often more than 2 boats present at the same time. Approximately 14% of the boats that were closer than 100 meters were also violating other regulations. Dangerous maneuvers that are performed less than 100 meters away from a group of dolphins pose a greater threat than those performed at greater distances because the dolphins are directly targeted and harassed. Two boats were recorded circling a group of dolphins, and four boats were recorded driving within or through the dolphin group.

Since the engines are on during these maneuvers, the change in speed and direction can interfere with the dolphins' communication and even impair their hearing (Richardson et al. 1995). A study by May-Collado and Wartzok (2008) found that the speed and direction in which a boat approaches can have a greater impact on the dolphins' communicative signals than the noise from multiple dolphin-watching boats. Repeated noise disturbance may also prevent dolphins from foraging and can induce a chronic stress response due to the increase in energetic costs. Since Dolphin Bay is known to have many mother-calf pairs, this level of noise disturbance may be extremely harmful to the bottlenose dolphin population (Bas et al. 2017). During the sightings in this study, the mother-calf pairs often appeared to get split up. The mother would dive in the presence of many boats, but the calf would often approach the boats and socialize, which unfortunately condones more boats to violate the regulations. More research must be done to examine this pattern, but it is apparent that the lack of compliance to the whale-watching guidelines by boat operators is likely to disturb or injure the dolphins in Dolphin Bay.

A reason for the lack in compliance could be that boat operators often compete with each other to be the closest to the dolphins to enhance their customers' experiences. However, a study in Australia found that there was no correlation between a customers' satisfaction and the proximity to a dolphin (Orams 2000). Another study in the Caribbean also found that tourists prefer to be involved with whale-watching outings that have sustainable practices (Luksenburg and Parsons 2014), so boat operators would actually benefit from abiding by the guidelines. The lack of compliance of dolphin-watching boats to the Panamanian regulations is also likely due to the fact that there is no enforcement or management in Dolphin Bay. In 2015, 45% of boats were compliant with the regulations (Sitar et al. 2015). Based on this study, it is evident that between 2015 and 2019, the compliance of boats to Panamanian regulations has not improved in Dolphin Bay.

To enforce the regulations, it is necessary to have a government presence in Bocas del Toro to monitor the activity of dolphin-watching boats. There are currently fines in place for those that violate the regulations, but without government reinforcement, they cannot be distributed. Another suggestion to increase the compliance of tour boats and reduce the impact on the dolphins is to remove Dolphin Bay from the tour route of the boats. A previous study on the perspectives of dolphin-watching found that most tourists do not visit Bocas del Toro to see dolphins (Sitar et al. 2015). Most tour trips include Dolphin Bay in their route as a default, so everyone that participates in a tour is taken to watch dolphins whether they express interest or not. If Dolphin Bay was removed from the route, the boat traffic in the area would be greatly reduced. Boats that are specifically designated for dolphin-watching would be more likely to follow the regulations as the tourists interested in seeing dolphins also likely prefer licensed, educational practices.

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I would like to thank the University of Vermont, the Smithsonian Tropical Research Institute, and the Panacetacea Research Group for organizing this trip and providing us with the accommodations and means to conduct our research. I would also like to thank Heather and Betzi for leading the group and teaching us valuable information about bottlenose dolphins and marine biology in general. In addition, I would like to thank the captains of the boats for skillfully guiding us around Bocas del Toro and helping us search for dolphins. Lastly, I would like to thank Laura May-Collado for organizing this trip, supporting our ideas, teaching us everything there is to know about bottlenose dolphins, and being a great role model. Without her, none of this would be possible.

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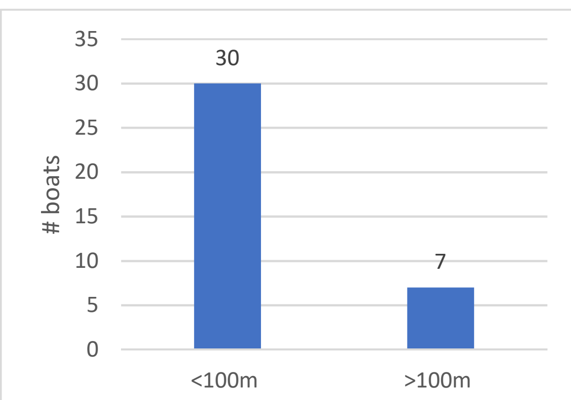

Figure 1. Bar graph showing the number of dolphin-watching boats within 100 meters of a dolphin and the number of boats farther than 100 meters from a dolphin.

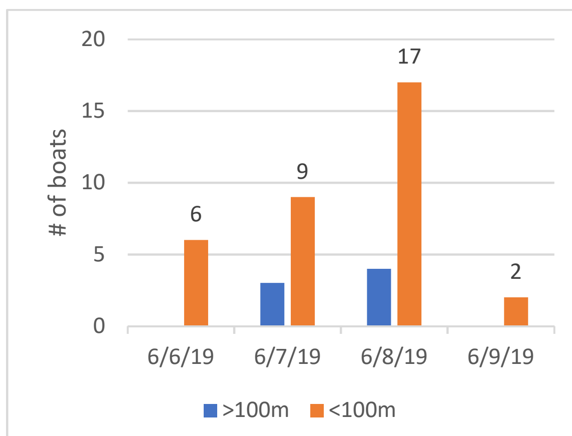

Figure 2. Bar graph showing the number of boats that were greater than (blue) and less than (orange) 100 meters from a dolphin on each day that data was collected.

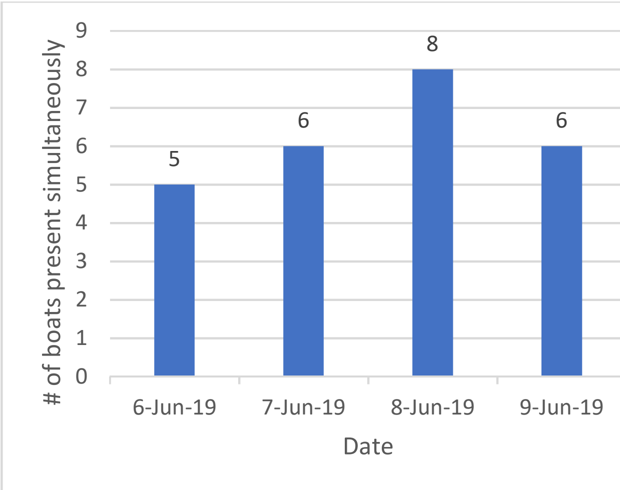

Figure 3. Bar graph showing the number of boats that were present simultaneously on each day that data was collected.

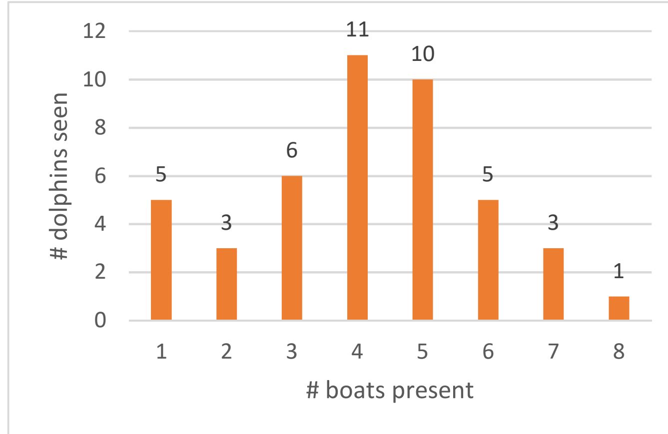

Figure 5. Bar graph showing the number of dolphins seen in Dolphin Bay as the number of boats increases.

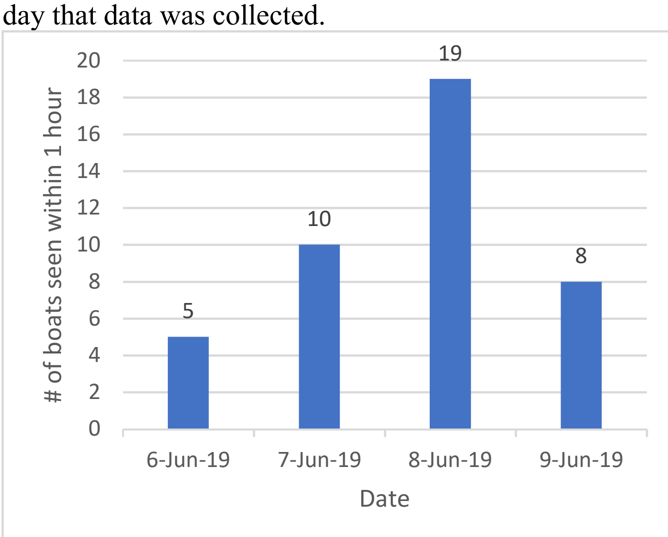

Figure 4. Bar graph showing the number of boats seen within one hour of observations on each day of data collection.

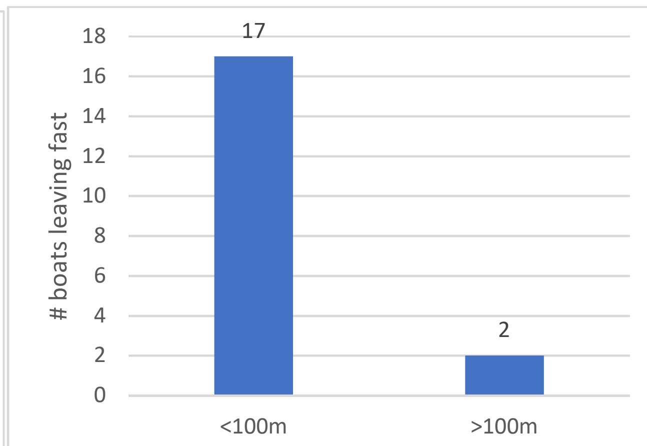

Figure 6. Bar graph showing the number of boats approaching fast that are closer than 100 meter or farther than 100 meters from a dolphin.

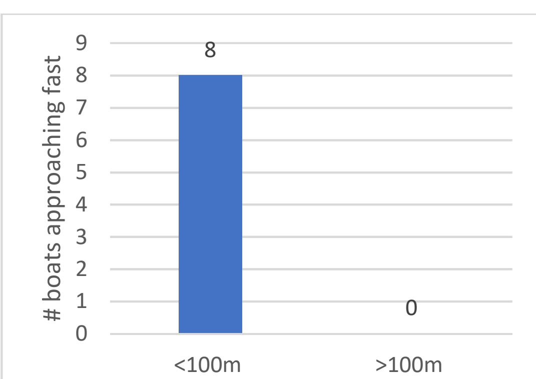

Figure 7. Bar graph showing the number of boats leaving fast that are closer than 100 meters or farther than 100 meters from a dolphin.

BOTTLENOSE DOLPHIN (*TURSIOPS TRUNCATUS*) MOTHER AND CALF BEHAVIOR IN THE PRESENCE OF BOATS- BOCAS DEL TORO, PANAMA

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ABSTRACT: Bocas del Toro, Panama, is home to a small bottlenose dolphin population (*Tursiops truncatus*). This population is unique as it is genetically isolated and does not interbreed with other dolphin populations in the Caribbean. This makes the population especially susceptible to extinction. Additionally, the Archipelago of Bocas del Toro is characterized by high boat traffic and is currently home to the largest dolphin watching industry in Panama. While tourism is beneficial to the economy and businesses of the islands, it can have devastating effects on the dolphin population that resides in the bay, specifically mother-calf pairs. Boat traffic has been shown to disrupt crucial mother-calf pair behaviors such as feeding, resting, and breathing in synchrony. Here, we study the response of mother-calf dolphin pairs to tour boats. Mother-calf interactions were surveyed in relation to tour boat compliance in terms of distance (closer than 100m and more than 100m). The Panamanian dolphin-watching regulation stipulates that no more than two boats can approach a dolphin group and should maintain a distance of 100 m. Our results indicate that when boats are closer than 100m, mother-calf pairs are separated and spend more time underwater. Our results show there is a lack of compliance in distance, which can have negative effects on mother-calf pairs, regarding loss of nursing opportunities and lower chances of calf survival. We recommend to the government of Panama to develop in situ enforcement of the regulations.

Key words: calf development, avoidance behaviors, boat compliance, dolphin watching, tourism.

The dolphin population of Dolphin Bay in Bocas del Toro, Panama, is intensely exposed to high levels of tour boat activity (Kassamali-Fox et al., 2015). In the past 15 years, the dolphin watching industry has grown rapidly (May-Collado et al., 2012). Although Panama has regulations for dolphin watching activities, there are no *in situ* enforcements. Compliance to regulations are left in the hands of the boats' captains. Under these circumstances, the activity can have harmful and cumulative effects to the local dolphin population.

Previous studies at this site show that tour boats elicit short-term changes in dolphin behavior (Kassamali-Fox et al., 2015) and acoustic structure of communicative signals (May-Collado & Wartzok, 2008). These short-term behavioral changes have long-term cumulative effects on dolphin populations. For example, causing animals to avoid preferred habitats, disruption of energy budgets, reduction of energy acquisition, and/or increase of energetic expenditure (Lusseau 2004, Williams et al. 2006, Christiansen et al. 2013, Symons et al. 2014). Typically, mother-calf pairs have very tight bonds, with calves swimming in close proximity to their mothers for approximately three months of their lives. Mother-calf pairs swim at the front of dolphin groups in what is called the "echelon position" (Noren & Edwards, 2011). Edwards (2002) found that with calves swimming above the mother, and in the front of the dolphin group, they are susceptible to boat strikes. Given the reported aggressive behavior of boat captains in Bocas, the described calf behavior can increase their chances of mortality due to boat strikes. In addition, calves sleep and are nursed during resting activities, thus interruptions by boats can significantly affect their growth and development (Lyamin et al. 2007). The high number of dolphin watching boats in Dolphin Bay, a critical habitat for mother-calf pairs, can disrupt their routines to the point to which their chances of survival is compromised (Kassamali-Fox et al., 2015).

Here, we study the impact of boat captains' compliance to Panama's regulations in relation to distance and number of boats allowed during a mother-calf pair encounter. We hypothesize that tour boat traffic will increase mothers' protective behaviors. We predict females will exhibit behavior such as tail slapping, chuffing, and putting themselves in between the boat and their calves. We also hypothesize that when boat activity is aggressive, mothers will encourage their calves to dive for longer periods of time, a form of vertical avoidance to boats.

MATERIALS AND METHODS

Study Site

We collected data around the archipelago of Bocas del Toro, Panama. This area is located at 9°N and 82°W, along the Caribbean side of Panama. The area is characterized by islands and islets of mangrove forests (May-Collado et al., 2014).

Data Collection

Observations were made from a 10 m fiber boat during four days in June 2019. Once a group of dolphins was sighted, we proceeded to collect information on mother-calf behavior and boat presence in three-minute intervals. These behaviors included: foraging, resting, social, traveling, diving, milling, and underwater. Underwater and diving behaviors were subsequently merged into a single category. In addition, the initial and final latitude and longitude of the pair was noted. Regarding boats, we collected information on the total number of boats present and their distance to the dolphins. Distance was estimated based on the Panamanian regulations, which state that tour boats must be more than 100 meters away from the mother-calf pair. The type of boat (dolphin watching, transportation, personal) and their behavior was also recorded during the sighting. For example, dolphin watching boats tend to go faster and closer to the pods than a transportation vehicle would. The speed and distance of the boats to the group can influence a dolphin's behavior and is therefore important to note.

Statistical Analyses

Data was analyzed using descriptive statistics and Chi-square test was used to determine if behaviors are independent from boat distance.

RESULTS

Our results indicate that mother-calf behavior is significantly different in the presence of boats regarding their distance. We found that mothers and calves spend more time underwater (vertical avoidance) when the number of boats is high (x^2=25, df=5, p=0.0001, Fig.1). When accounting for boat distances mother-calf pairs spend significantly more time under water when the boats were less than 100 m than when they were more than 100 m (x^2=25.5, df=5, p=0.0001, Fig.2).

Behavior in the absence of boats:

We found that a mother bottlenose dolphin showed relaxed behavior when boats (besides our research vessel) were not present, by allowing calves to play or stray from their side. Calves were often seen jumping, flipping, or socializing. When boats were not present, mother and calf pairs were more likely to have synchronized diving and breathing and be in the echelon position.

Behavior when boats are present:

If a mother-calf pair's initial behavior was foraging, at the arrival of boats they would change their behavior to diving, staying underwater for longer periods of time than when boats were not present. They would only resurface for short periods of time for air, going back underwater until the boats left. When there were many boats present, the calf would occasionally approach the boat to try and play in its wake; however, the mother would be seen either very far from the calf, or not at all. When boats came very close to the mother-calf pair, the mother showed aggression by chuffing, and then dove with her calf to leave the area.

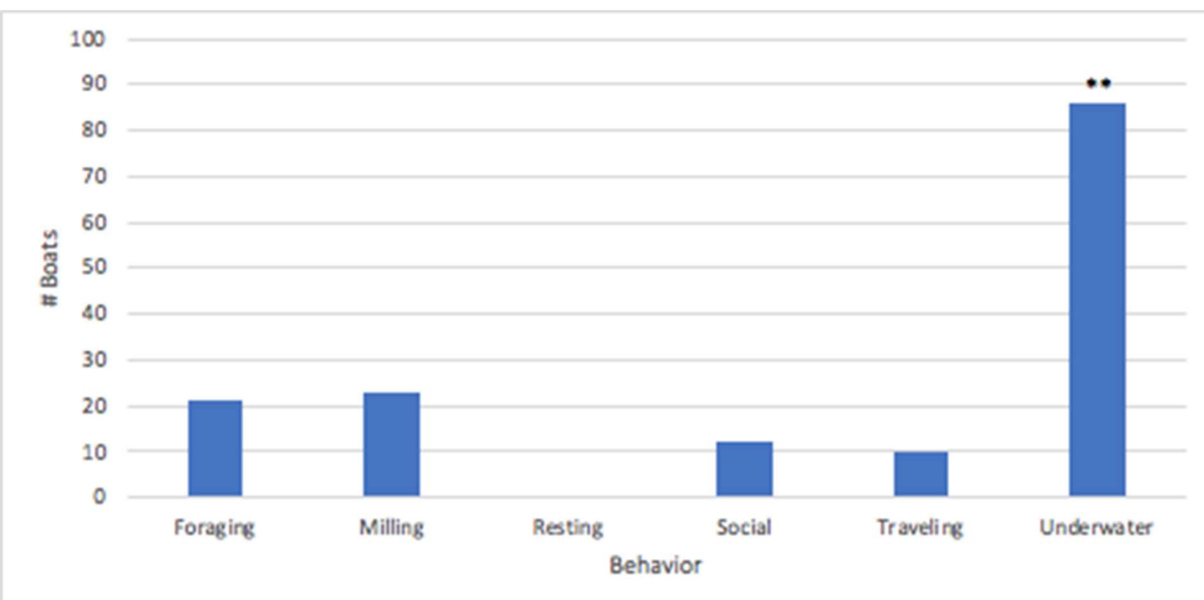

Figure 1. Number of tour boats present during different behavioral activities of mother and calves.

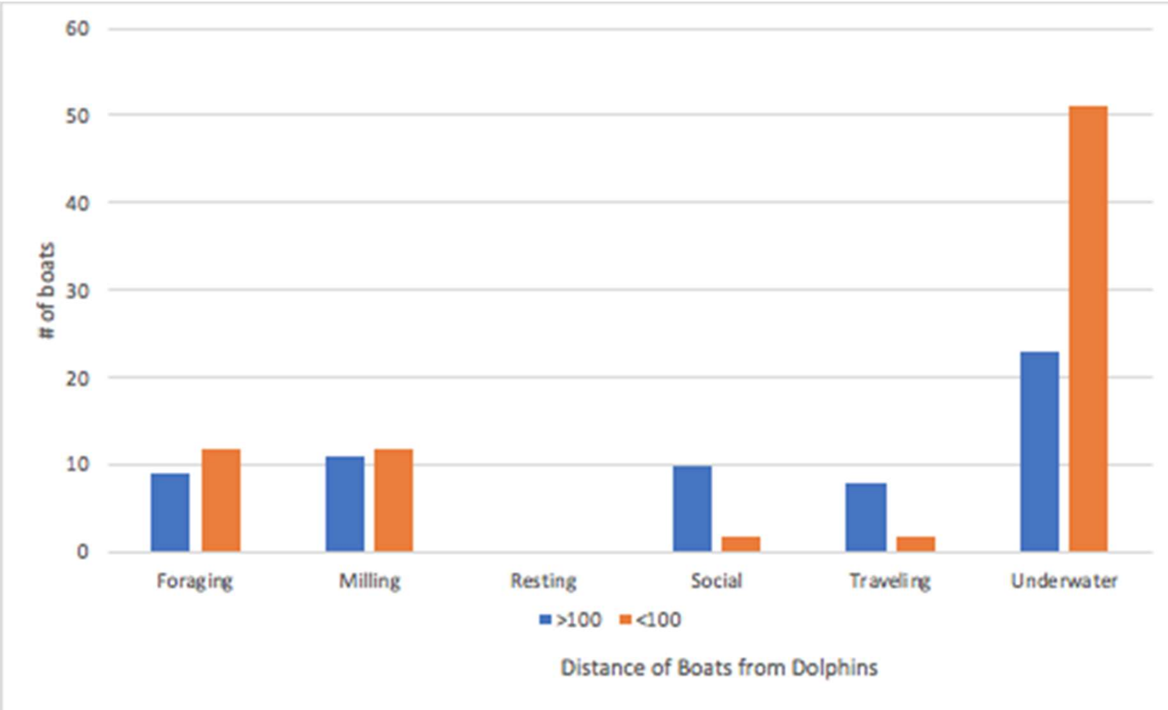

Figure 2. Number of boats according to distance from mother and calf, and their behavior.

DISCUSSION

Our results indicate that lack of compliance to observation distance can negatively impact mother-calf pairs behavior. Boats interrupted dolphins' natural activity, often causing mother-calf pairs to separate. For example, if a pair was foraging when a boat arrived, they would often switch to diving. Even after the boat had left, they would oftentimes not return to feeding. In addition, it was found that mother-calf pairs never rested- a crucial part of a calf's development. Interrupting these activities could have serious implications on a dolphin's health. When vessels approached, mothers with calves were statistically more likely to take longer dives to avoid boats. Consequently, greater time was required at the surface to recover in addition to increasing their energetic demand (Nowacek et al., 2001). If the dolphins do not return to feeding, they will not get enough nutrients, consequently causing them to lose body mass and endurance. This interruption may also be stressful enough that it could deter the mother-calf pair from returning to their initial behavior, as shown by a previous study (Kassamali-Fox et al., 2015). This is especially detrimental if the calf is in its first few days of life. Gonzales et al. (2019) found that the Dolphin Bay bottlenose dolphin calves have a mortality rate of approximately 42%. Calves feed from their mothers every few hours when they are first born; if a newborn calf is interrupted while feeding this can have high costs in terms of growth and development (Lyamin et al., 2007). A mother's presence is vital in her calf's first few years of life, and even after. Our data showed that boat traffic separated the pairs. As calves are naive and have not yet learned the dangers of being close to boats, they are inclined to jump in the wakes or interact with the vessel. Mothers, however, stay underwater and separate from their calf to avoid being hit. This creates a negative feedback loop; jumping is categorized as a positive behavior, encouraging dolphin watching vessels to continue to get as close as they can to the animals. This keeps the pair separated and poses a danger to the calf. Even "positive interactions" could have long-term effects on populations by detracting from foraging, resting, or socializing (Tseng, et al., 2011).

During this study we noticed that Dolphin Bay resident dolphins appear to be relocating to areas away from the Bay. For example, we observed two of the oldest females, Bity and Supermessy in areas farther away from the bay, where they have not been observed before. Past studies have deemed Dolphin Bay as a critical habitat for mothers and their calves. The present levels of tour boat traffic may be altering this habitat to the point at which dolphins do not have other alternatives but to leave. We strongly recommend to the government of Panama to develop *in situ* enforcement of the regulations. Our study also shows the impact of off-season tourism, indicating that the effects could be even more detrimental during peak tourist season.

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FEMALE PRODUCTIVITY AND CALF SURVIVORSHIP OF BOTTLENOSE DOLPHINS (*TURSIOPS TRUNCATUS*) IN BOCAS DEL TORO, PANAMA

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Abstract

The resident bottlenose dolphins of the Archipelago of Bocas del Toro are regularly exposed to intense interactions with dolphin-watching boats. Previous research has shown that Bocas dolphin foraging behavior is disrupted throughout the day by tour boats. This has created concerns about the health of the population, particularly lactating mothers and the potential effects on calf survival. In this study we used mark-recapture data from 2004 to 2014 to infer dolphin female reproductivity and calf mortality rates. A total of 35 females were identified from 140 dolphins in the current catalogue. 23 have Dolphin Bay as a key part of their home range where they regularly interact with dolphin watching boats. Each female in this population had between one and three calves during the study period, with an average calving cycle of 62 months (SD: 21.91 months**,**Range: 24-97 months), longer than many known populations. Furthermore, calf mortality was estimated to be 0.46 which is higher than other populations at risk. The survival rate for this population was 0.54. Understanding female reproductive success in this local population of dolphins may provide a quantifiable measure of health and individual fitness, which are essential to protect this population.

Keywords: Boat Compliance; Bottlenose Dolphin; Calf Mortality; Dolphin watching; Photo Identification; Reproductive Rate.

Female bottlenose dolphins only calve once every two years (Mead, 2018), and like most long-lived mammals, they can only produce one calf at a time, with a calving interval of 3.8 years (Robinson et al. 2017). Calves continue to grow until 5 to 10 years of age. Sexual maturity of cetaceans occurs between 6 to 10 years of age and, for females, is defined by the start of ovulation and the ability to become pregnant. Females can continue to ovulate and produce young until death (Mead, 2018).

Time at birth, predator presence/absence, pollution, disturbance, and resource availability are among the many factors that influence both calf survivorship and reproductive success. In some populations, females tend to give birth seasonally during the spring and fall (Mann et al. 2000). During these times, the waters are warmer which is thermally efficient for both calves and mothers (Mann et al. 2000). Food and resource availability also fluctuate to favor seasonal births. This allows females to maximize nutritional intake both throughout their gestation period and once their calf is born. (Oftedal, 1997). Birth season and mortality data suggests that females resume reproduction rapidly if the timing of calf loss allows them to give birth within season the following year (Mann et al. 2000). Calf survivorship and female reproductive success are among parameters used to estimate the overall health of a population. Calf survivorship fluctuates among different populations based upon the specific conditions of their respective habitats. For example, a population off the coastline of the outer Moray Firth, in northeast Scotland, was found to have an inter-birth interval of 3.72 years, and a calf mortality rate of 0.1037 (Sim, 2014). Similarly, in the Bay of Islands, New Zealand, a different population of bottlenose dolphins had an estimated calving interval of 4.3 years, and a calf mortality rate that ranged from 0.34 to 0.52 (Tezano-Pinto et al. 2015).

In our population, habitat disturbances are the key factor that determines calf survivorship and female reproductive success. The resident bottlenose dolphins of the Archipelago of Bocas del Toro are regularly exposed to intense interactions with dolphin-watching boats (May-Collado et al. 2012, 2015). Despite the intense interactions the dolphins remain in the area for two reasons: the bay's safety from predators and abundance in food resources. However, ongoing studies indicate that while their preferred food source, sardines, is abundant, they provide low caloric gain. Sardines' lack of nutrition forces the dolphins to constantly eat (Barragan-Barrera et al. 2019). Previous research has shown that Bocas dolphin foraging behavior is disrupted throughout the day by tour boats. This has raised concerns about the health of the population, particularly lactating mothers and the potential effects of the tour boats on calf survival (Kassamali-Fox et al. 2015).

Over the course of ten years, 2004-2014, catalogued mothers and their calves have been tracked by photo-identification in Bocas del Toro, Panama. Through this, the mother and calf sightings in each year, day, time, and location can be recorded; from there the female productivity rates and calf mortality rates can be calculated. Calf mortality can be estimated by recording the initial sighting of the individual mother and her calf. If the mother is sighted without the calf for two consecutive years, when the calf is less than 24 months old, than the calf is presumed dead (Wells and Scott 1990, Mann et al. 2000).

The goal of this study is to study female reproductive success by estimating the female calving interval and calf survivorship. Given the intensity of the tour industry around these animals, we hypothesize that populations under such stress, such as the Bocas dolphin females, will have a longer calving cycle and a higher calf mortality.

Methods

The Archipelago of Bocas del Toro is located in the Caribbean coast of Panama and covers and are of about 79.2 km^2 within the inner part of the Archipelago. The region is characterized by shallow and clear waters and bottom substrates consisting of seagrass, coral, and sand (May-Collado et al. 2015). This study focuses on data collected in Dolphin Bay, which is a major part of the local dolphin's home range, considered an important nursery ground, and is the area with the greatest interactions with boats (Fig.1; Fig. 3).

Photo-identification data——which are photographs of unique natural marks caused by contact with propellers, fishing nets, or other dolphins, on the dorsal fins——and sighting data──group size, location, behavior, presence/absence of other boats, and mother-calf associations──were obtained from May-Collado et al. 2015. The current dorsal fin catalogue for this dolphin population consists of roughly 140 dolphins. A small number of females are confirmed with genetic and hormone information. The rest of the females were identified based on the repeated association with calves and juveniles. Calves were classified into age classes based upon their size. Neonates (0─3 months old) were identified as those that were less than half the size of an adult and had paler coloration (Mann and Smuts 1998), calves (3 months─3 years old) measured roughly half the size of an adult, and juveniles (3─9 years old) measured 2/3 the size of an adult (Kasuya et al. 1997; Tezano-Pinto et al 2015).

If a calf was spotted with its mother for two consecutive years after its' year of birth, then it was considered to have survived. Calves born between 2012 and 2014, and 2019 were marked as "unknown" because there is insufficient data to assess their survival. Dolphins typically stay with their mothers for 3-6 years (Wells 2000), therefore, if the first sighting of a mother was with a juvenile, the juvenile was presumed alive because it's common for them to separate from their mothers at that age. A subset of these data from 2004-2014 consisting only of calves with known fates were used to estimate calving intervals.

The calving interval was estimated by calculating the difference in months between the first sighting of a mother-calf pair and the first time the same mother was seen with a different calf. This number was rounded to the nearest quarter-months, and the standard deviation was found. Reproductive success and calf mortality were determined by the number of calves that survived/died, respectively, divided by the total number of calves produced in the overall population.

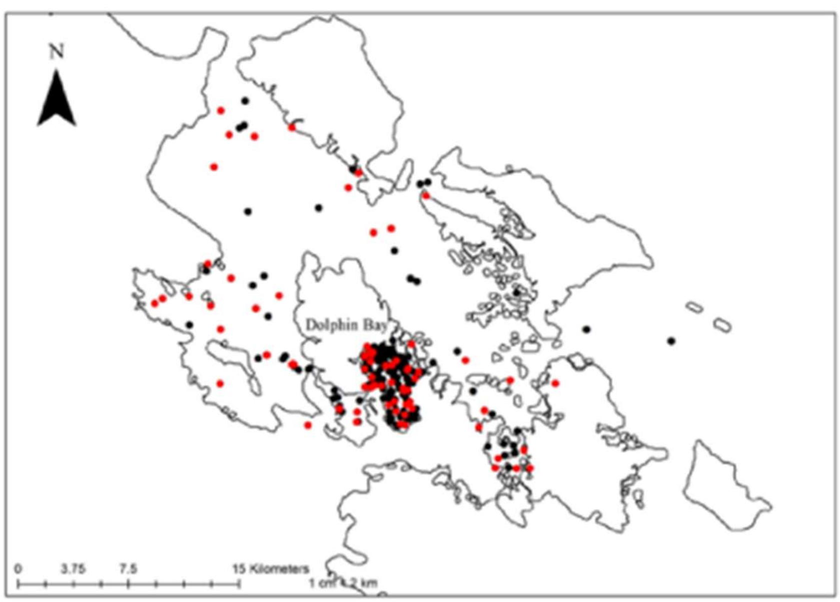

Figure 1: This figure is a map of mother-calf pair sightings in Bocas del Toro, Panama from 2004-2014. The red dots represent mother and calf pairs when there are no boats present. The black dots represent mother-calf pairs when boats were present.

Results

Of the total 140 dolphins in the catalogue, 35 were identified as females, of which 11 produced more than one calf between 2004 and 2014 (Table 1). The females Bity, Almostclean and Supermessy had the shortest calving intervals of 24.25, 38, and 39 months apart, respectively. Middlenotchy and Plinia had the longest calving intervals of 97 months and 84 months, respectively. Five females have intermediate calving cycles ranging between 70 and 76.25 months. The average calving interval is 62.08 (SD= ±21.91) months. During the study period, a total of three females produced three calves, eight females produced two calves, and 24 females produced one calf. Almostclean, Notchy3, and Tipless were the most reproductive females they each gave birth to three calves over a 10-year period. Supermessy and Bendy are the most reproductively successful females they each produced two calves respectively both of which survived. Of the total 49 calves identified 41% of them survived the first year (n=20), while 34% died (n=17), and for 25% (n=12) the fate was unknown (Table 1). Calf mortality was estimated to be 0.46 and calf survival rate was 0.54.

Table 1: This table shows the number of calves produced by each reproductive female, the calf's birth year, and the number of years the calf survived. If a calf survived to two years of age, then it was marked as alive and is counted as a successful reproduction for the mother. The number next to the Adult ID, the mother's identification, represents which calf, in order of chronological birth, is being studied, Ex: Supermessy (1). S represents survived, U represents unknown, D represents dead, U/S represents fate unknown but likely survived, U/D represents fate unknown but likely dead. (**) shows that it is unknown how many calves the mother has had due to deficient data.

Adult Id	Year of Calf Birth	Survived 1+ Year	Survived 2+ Years	Lived Past 2 Years
NOTCHY2	2004	S	S	YES
NOTCHY3 (1)	2004	S	S	YES
NOTCHY3 (2)	2004	U	D	NO
ALMOSTCLEAN (1)	2004	U	D	NO
NOTASMESSY	2004	U	D	NO
BUMPY	2004	S	S	YES
MIDDLENOTCHY (1)	2004	S	S	YES
SUPERMESSY (1)	2004	S	S	YES
AGUILA	2006	U	U/S	YES
AMELIE	2006	S	S	YES
CERRITO	2006	U	U/S	YES
HOLY	2006	U	D	NO

LUNA	2006	S	U/S	YES
MESSY	2006	S	S	YES
PLINIO (1)	2006	U	D	NO
SCRATCHY	2006	U	D	NO
SCAR2	2006	U	D	NO
URANIA	2006	S	S	YES
ALMOSTCLEAN (2)	2007	S	S	YES
BENDY (1)	2007	S	S	YES
TIPLESS (1)	2007	S	S	YES
TIPLESS (2)	2007	U	D	NO
CHIRIQUI (1)	2007	S	S	YES
CRISTAL (1)	2007	S	S	YES
NOTCHY2	2007	U	D	NO
SUPERMESSY (2)	2007	S	S	YES
DISELVIA	2007	U	D	NO
VALDEZ	2007	U	D	NO
NOTCHY3 (3)	2008	U	D	NO
GARAY	2008	U	D	NO
TIPLESS4	2009	U	D	NO
RACHEL (1)	2010	S	S	YES
BENDY (2)	2010	S	D	NO
BITY (1)	2012	S	U	UNKNOWN
DAISY	2012	U	U	UNKNOWN
MIDDLENOTCHY (2)	2012	U	U	UNKNOWN
ALMOSTCLEAN (3)	2013	U	NO DATA	UNKNOWN
CRISTAL (2)	2013	S	NO DATA	UNKNOWN
TIPLESS (3)	2013	U	NO DATA	UNKNOWN
CHIRIQUI (2)	2013	S	NO DATA	UNKNOWN
MO	2013	S	S	YES

PLINIO (2)	2013	U	U	UNKNOWN
TOPW	2013	U	NO DATA	UNKNOWN
BITY (2)	2014	NO DATA	NO DATA	UNKNOWN
GIGI	2014	NO DATA	NO DATA	UNKNOWN
MUFFIN	2014	NO DATA	NO DATA	UNKNOWN
CRISTAL (2)	2014	NO DATA	NO DATA	UNKNOWN
LUNITA2	2014	NO DATA	NO DATA	UNKNOWN
MURRAY	2014	NO DATA	NO DATA	UNKNOWN
RACHEL (2)	2014	NO DATA	NO DATA	UNKNOWN
TOPNOTCHY (**)	2019	NO DATA	NO DATA	UNKNOWN
CRISTAL (**)	2019	NO DATA	NO DATA	UNKNOWN
ALMOSTCLEAN (**)	2019	NO DATA	NO DATA	UNKNOWN
RACHEL (**)	2019	NO DATA	NO DATA	UNKNOWN
MO (**)	2019	NO DATA	NO DATA	UNKNOWN
SUPERMESSY (**)	2019	NO DATA	NO DATA	UNKNOWN
TRESLUNAS (**)	2019	NO DATA	NO DATA	UNKNOWN
BITY (**)	2019	NO DATA	NO DATA	UNKNOWN

Table 2: This table shows the amount of time that passed in between births for each dolphin that produced >1 calf. The number next to the Adult ID represents which calf, in order of chronological birth, is being studied. The dates represent the first, and last time each mother-calf/juvenile pair was seen. The resting period is the difference, in months, between the sighting of the mother and her first calf and the sighting of the same mother with a subsequent calf. This value was rounded to the nearest ¼ month. A resting period was marked with "N/A" if the first calf sighting was a juvenile.

Adult ID	Date first seen with offspring	Date last seen with offspring	Resting Period (Months)
ALMOSTCLEAN (1)	6/20/2004	6/23/2004	
ALMOSTCLEAN (2)	9/26/2007	7/25/2014	38
ALMOSTCLEAN (3)	7/23/2013	9/25/2013	70
BENDY (1)	6/7/2007	2/20/2010	

BENDY (2)	7/24/2012	7/25/2012	72.5
BITY (1)	7/7/2012	7/7/2012	
BITY (2)	7/13/2014	7/26/2014	24.25
CHIRIQUI (1)	3/4/2007	2/17/2009	
CHIRIQUI (2)	7/11/2013	7/24/2014	76.25
CRISTAL (1)	9/26/2007	7/13/2012	
CRISTAL (2)	9/28/2013	7/21/2014	72
MIDDLENOTCHY (1)	6/22/2004	10/20/2006	
MIDDLENOTCHY (2)	7/22/2012	7/22/2012	97
NOTCHY3 (1)	6/20/2004	6/20/2004	
NOTCHY3 (2)	6/20/2004	6/22/2004	N/A
NOTCHY3 (3)	3/30/2008	3/30/2008	45.5
PLINIO (1)	7/22/2006	7/23/2013	
PLINIO (2)	7/23/2013	7/23/2013	84
RACHEL (1)	4/17/2010	9/27/2013	
RACHEL (2)	7/26/2014	7/26/2014	51.25
SUPERMESSY (1)	6/23/2004	3/31/2008	
SUPERMESSY (2)	9/26/2007	9/28/2013	39
TIPLESS (1)	10/18/2006	6/11/2007	
TIPLESS (2)	6/11/2007	6/11/2007	N/A
TIPLESS (3)	9/27/2013	9/27/2013	75.25

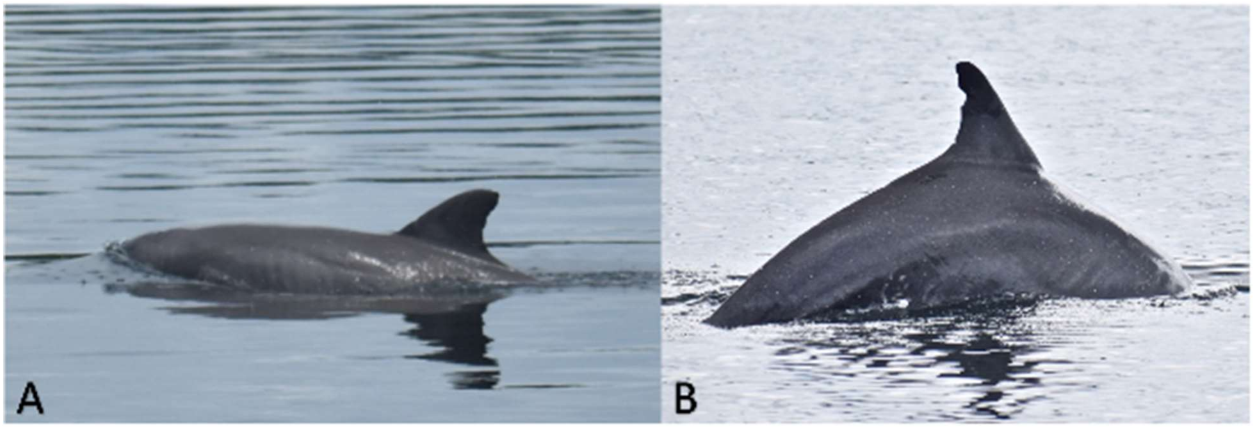

Figure 3: Images of emaciated bottlenose dolphin mothers. Ribs can be seen in the photos, and the concavity behind the blowhole shows a depleted blubber storage. Topnotchy, the mother in photo A, had a calf at the time the photo was taken. The mother in photo B, Rachel, had both a juvenile and a calf at the time the photo was taken.

Discussion

The dolphin population of Dolphin Bay is estimated to be between 40-45 dolphins (Jones Unpublished). We found that at least 50% of these dolphins are reproductive females that produce >1 calf every 5.17 years. These values are greater than those estimated for other populations; for example, 3.8 years for North Sea dolphin populations (Robinson et al. 2017). Mothers will give birth to their next calf if her previous calf didn't survive, or if her previous calf became a juvenile and separated from her (Robinson et al. 2017). Therefore, it is possible that the calves in the Bocas del Toro population are simply staying with their mothers for slightly longer periods of time, causing an increased calving interval. However, we did find variation in these females calving cycles with some producing calves more frequently than others, suggesting a combination of differences in reproductive age and that some females may be losing their babies in the first year.

Several factors may favor longer maternal care before separation including life history, habitat, provisioning, and group size (Mann et al. 2000). Calves stay with their mothers because their mothers teach them valuable skills such as how to breathe, hunt, and avoid predators (Bardroff, 2014). Boats are extremely prominent in Dolphin Bay, creating continuous habitat disturbances. Although boats aren't what typically come to mind when thinking of the term "predator," they can have very similar effects: death. This means that mothers have to teach their calves how to properly avoid the boats. Therefore, it is possible that the combination of these factors combined with the teachings of boat-avoidance might explain why longer maternal care is favored in this population.

In Bocas, female reproductive calving cycles may be influenced by intense dolphin-watching activities which occur within the core part of their home range (May-Collado et al. 2012, Kassamali-Fox et al. 2015). Dolphin interactions with boats often result on increasing avoidance behaviors and mother-calf separation (Kassamali-Fox et al. 2015). In a personal communication with Ph.D. student Betzi Perez, we were provided with information about how these dolphins show increased stress-related hormone levels during a high tourism season. In our study, 23 out of the 35 reproductive females were found in Dolphin Bay. This means that these individuals are not only constantly exposed to the potential danger of permanent mother-calf separation, but are showcasing increased stress levels. Therefore, it is probable that stress due to boat activity is one of the reasons for the slight increase in resting period between calf births. However, the current sample size is small, causing our data to be limited. It is possible that more time and data collection will help make these trends evident.

Furthermore, there are other scenarios in which mother-calf separation can occur while the mother is pregnant, soon after the birth of the mother's next calf, or years before the next birth. There are also cases in which the calf stays with its mother after her next calf was born (Wells et al. 1987; Wells 1991; Mann and Smuts 1999; Connor et al. 2000; Mann et al. 2000).. This specific behavior is evident in 3 of the 11 most reproductive dolphins

The calf mortality rate of Bocas del Toro, Panama is extremely high with a 46% death rate. The survival and mortality rate are roughly at a 1:1 ratio. The survival rate, 54%, is significantly low when compared to other studies. In Sarasota Bay, the calf survivorship rate is 81% and in Doubtful Sound, New Zealand there is a calf survivorship rate of 86% (Robinson et al. 2017; Wells et al. 1990; Currey et al. 2008). Although we had a small sample size, the Bocas population was roughly the same of other populations, such as Sarasota Bay or Doubtful Sound, which raises great concern for the animals of Bocas del Toro.

There are many factors which may contribute to this high calf mortality rate. One main factor is the increased boat activity in Bocas due to tourism. Direct impacts to calf, and adult, mortality include strikes by propeller, asphyxiation in fishing nets, and competition between boats to get closer to the dolphins (Trejos Lasso et al. 2015). The greater vulnerability of calves is another factor which can lead to a higher mortality (Fruet et al. 2010). We believe that the increased presence of boats is responsible for the higher rate of calf mortality, which may be due to boat strikes, increased stress, and mother-calf separations.

In Bocas del Toro, from 2012-2014, at least 10 dolphins died due to boat collisions with created serious wounds (Sitar et al. 2016). This is a large proportion of the population, which creates concern for the health and size of the population. There is great concern for potential boat collisions with calves, due to their curious nature. Shallow waters are used to shelter, rear, and feed calves (Sitar et al. 2016). Mothers and calves move slow, and mothers will remain close to their calf. With these vulnerable animals and the increased risk of collision is a concern which has been a reality in Bocas del Toro (Sitar et al. 2016). The close proximity of the boats to the dolphins can disrupt the dolphin's behavior, such as foraging, and can cause an increase of energetic cost and stress, which is detrimental to the population. The official Panamanian whale watching guidelines (Resolution DN-0530, 2017) state that boats must remain 100 m from the dolphins; speed restriction to 7 kmph; a maximum observation time of 30 minutes; a minimum separation of 30 minutes between observation events and encounters; the maximum number of boats in attendance to these events should be only two, and two boats must be 200 m apart from each other; restrictions on feeding the dolphins and making loud noises; and prohibiting the pursuit of these animals. For groups with calves, special considerations state that boats must remain 250 m away and to decrease the observation time to 15 minutes. Even with these laws in place many boats break them and continually harass the dolphins, especially mother-calf pairs. In Sitar et al. 2016, they observed that 71% of the time boats were closer than 100 m to the dolphins, and boat engines were switched off or idled 31% of the time when 50 m or closer. Only 55% of all dolphin-watching activity followed the guidelines of 1-2 boats watching a group, and 45% of the time there were 3-

15 boats following a group. There is clearly a high level of noncompliance with the whale watching guidelines, since there is no law enforcement.

There needs to be stricter enforcement of the whale watching guidelines in Dolphin Bay. May-Collado et al. 2014, 2015 suggests that action must be taken to preserve this population and prevent further harm to them. Figure 3 shows two emaciated mothers, one of which (in 2019) has a juvenile and a calf, and the other has a calf. Both mother have ribs showing, and depleted blubber storages, which can be seen as a concavity behind their blowhole (DuBrul, unpublished). These mothers are using significant metabolic energy to keep their calves healthy, but they are depleted of their own nutrients due to increased stress from the intense dolphin watching boats which stops their foraging behavior and created an avoidance behavior. During bottlenose dolphins' long lactation period, mothers endure the metabolic costs of their calf for prolonged periods of time, which results in a lower efficiency of offspring production, meaning they cannot have another calf in this period, and there is a higher nutritional cost to the mother. Essentially, the extensive learning during the prolonged lactation is accomplished through higher nutritional and energetic costs to the mother (West et al. 2007). In captivity, bottlenose dolphins have an 18-month lactation period, but wild bottlenose dolphins reportedly have a lactation period twice that duration (Mann et al. 2000). The most demanding part of lactation is mid-lactation; captive female *Tursiops truncatus* can increase food intake by 50%-200% during this period, suggesting that there is a significant nursing cost (Mann et al. 2000; Reddy et al. 1991). In Reddy et al. 1991, the nursing mother which exhibited the lowest increase in food intake had the highest activity level and was in good physical condition. In contrast, the mother with the highest increase in food consumption during lactation had the lowest activity level. This suggests that the energy demands of lactation can be offset by an animal's good physical condition (Reddy et al. 1991). The long duration of lactation in bottlenose dolphins is due to the calves difficulty of learning to forage for themselves, as they must be able to do so successfully before weaning.

The high calf mortality rate is of great concern for the Bocas population, which poses the need for increased monitoring of Dolphin Bay of Bocas del Toro, Panama. Increased boat activity, especially tourism, has created detrimental effects to mother-calf pairs. Increased stress caused by net entanglement, avoidance of areas, and increased injury have all been seen since the boat-activity has increased in Bocas (Sitar et al. 2016). We propose that Dolphin Bay of Bocas del Toro should have Governmental enforcement of the whale watching guidelines from 8-5 every day in Dolphin Bay to ensure the health of mothers and their calves. Since 23 mothers and their calves reside in Dolphin Bay, continuous law enforcement of the guidelines is necessary to protect the livelihood of these animals. Given the high calf mortality rate and studies showing impact on bottlenose dolphin reproductive success, management should reduce the sources of anthropogenic impact in Dolphin Bay.

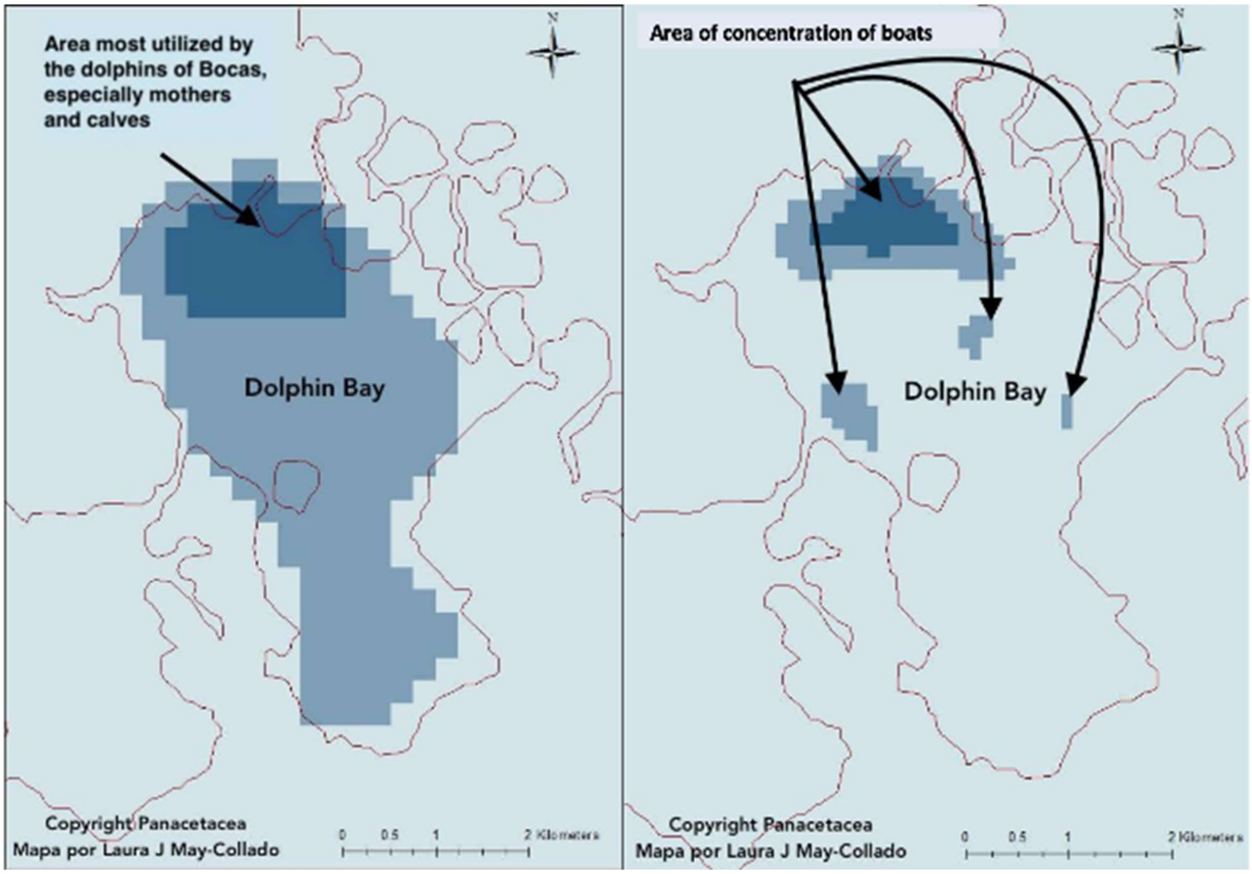

Figure 3: The map on the left shows the distribution of mothers and calves in Dolphin Bay, Bocas del Toro, Panama. The mothers and calves utilize most of the bay, but there is a highly concentrated area when they spend most of their time. The map on the right shows the concentration of dolphin watching boats in the same bay. These boats continually harass the mother-calf pairs, which can cause mothers to stop foraging to escape from the boats, leaving many mothers emaciated.

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ANALYSIS OF THE POPULATION SIZE OF BOTTLENOSE DOLPHINS (*TURSIOPS TRUNCATUS)* IN BOCAS DEL TORO, PANAMA

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ABSTRACT

Human activities can pose a threat to coastal bottlenose dolphin populations, due to habitat overlap. In the Archipelago of Bocas del Toro, Panama, a genetically isolated population of dolphins are regularly under pressure from intense interactions with dolphin-watching boats. Because human activities can influence population dynamics, it is important to estimate population size to establish conservation strategies and species status. In this study, photo identification data and five capture-recapture models are used to estimate the population size of dolphins in the archipelago of Bocas del Toro, Panama. The mortality+trend model, which best fits the data, indicates that the population in Bocas del Toro is between 60-90 dolphins. There is evidence for fluctuations in population size over the years. These differences are likely due to variation in sampling efforts. Future survey efforts need to be made to maintain similar efforts between years. However, it is confirmed that the population is small and possibly at risk due to activities that directly target them, such as dolphin watching. Future research will address differences in survey efforts and increase sample size.

Keywords: capture-recapture, photo identification, conservation, ecology

INTRODUCTION

Coastal bottlenose dolphins (*Tursiops truncatus)* live in isolated populations in close proximity to human activities, often making them a focal point of tourism (Nowacek, et al. 2001, Constantine, et al. 2004). Boat-based dolphin watching is characterized by following dolphins on a regular basis, which can lead to behavioral changes such as a decrease in resting behavior and an increase in milling behavior (Constantine, et al. 2004). In bottlenose dolphins off the coast of Italy, during interaction with recreational boats, dolphins surfaced more often and did not partake in activities such as feeding or socializing as frequently (Pennino, et al. 2016). In addition, a high amount of boat activity poses an increased risk of injury to the animals (Wells & Scott 1997, Trejos and May-Collado 2015).

In the Archipelago of Bocas del Toro, Panama, a resident population of bottlenose dolphins has been under increased stress due to a high number of dolphin-watching boats in the area (May-Collado, et al. 2015). Since this population already has low genetic diversity (Barragán-Barrera, et al. 2017), the added pressures that boats put on this population put it further at risk. Boat collisions killed 10 dolphins over just a three-year span, which cannot be afforded by this small, isolated population (Trejos & May-Collado 2015). Many boats also fail to follow the whale-watching regulations, frequently get too close to the dolphins, and do not switch off their engines within the proper distance of the animals (Sitar, et al. 2016).

In order to understand the impact of these activities at the population level, photo-identification data from 2004 to 2014 will be analyzed using capture-recapture models. A previous study using photo-ID data from 2004-2012 estimated the overall population of the Archipelago to be between 70-90 dolphins (May-Collado, et al. 2015). In this study, capture-recapture data from 2013, 2014, and 2019 is added, along with additional mortality information. Given the state of the population and the pressure from dolphin-watching activities, it is predicted that the population is declining.

MATERIALS AND METHODS

Study Area and Fieldwork

The Archipelago of Bocas del Toro is located in the Caribbean coast of Panama. Survey efforts covered approximately 79.2 km^2 within the inner part of the Archipelago, which is characterized by shallow and clear waters and bottom substrates consisting of sea grass, coral, and sand (May-Collado et al. 2015). The main mode of transportation between the islands and mainland is through powered boats with 50 and 150 hp engines and canoes. This study focuses on the entire archipelago, with emphasis on Bocas Torito Bay, also known as Dolphin Bay. This closed bay is an important nursery ground. The area was surveyed using a 10 m fiberglass boat with two engines (150 hp/4-stroke) from 7 a.m. to 6 p.m., following predetermined routes. Survey effort varied from 7 days to 4 weeks a year, depending on funding support. Once a group of dolphins was encountered, the boat approached slowly and in a parallel position to avoid dolphin disturbance (Würsig and Jefferson 1990, Resolution ADM/ARAP NO. 01, 2007). A distance of 30-50m from the group was maintained before turning the engine off to initiate data collecting and photoID. This type of approach is standard in cetacean studies because it minimizes behavioral impact on the group (e.g., Würsig and Jefferson 1990). A group was defined as "a collection of conspecifics in a limited area, often engaged in similar activities and moving in the same general direction, maintained by social factors as a unit" (Wells et al.1999). The following information was collected: group size (minimum, maximum, and best estimation), photo-ID data, geographical position using a GARMIN GPS, predominant behavioral state at the moment of the encounter and during acoustical recording sessions, presence/absence of boats other than the research boat, and acoustic recordings.

Photo Identification Processing

Photo identification (photoID) is a form of capture-recapture data collection that does not involve physical tagging of animals. Capture-recapture data assumes that the population is steady, the tags (in this case, photographs) are correctly recorded, and that animals act independently (Amstrup et al. 2010). PhotoID was used to identify individual dolphins based on high-quality photographs of their dorsal fins. New photos of dorsal fins were compared to an existing catalogue of dorsal fin photos of known dolphins in the population. All parties had to agree upon the identity of each dolphin before it was recorded as being "present" during a certain sighting. Once a dolphin had its identity verified, a photo of its fin was saved and recorded as present in a presence/absence matrix. If a dolphin was seen multiple times during the same sighting, its presence was only marked once in the matrix. In some of the photos, the dolphin was unable to be identified either because of the quality of the photo or the angle of the animal such that its identity could not be confirmed. Those photos were marked as “unknown” and were not included in this study.

Population Analyses

Population analyses were performed using the software SOCPROG, which utilizes several population models. The following models were included in the analysis: Closed Petersen, Closed Schnabel, Jolly-Seber, Mortality, and Mortality+Trend. The Closed Petersen model assumes a closed population between each pair of consecutive sampling intervals. The Closed Schnabel also assumes a closed population, whose size is estimated by maximum likelihood. The Jolly-Seber model accounts for variation in mortality/emigration rates and birth/immigration rates. The Mortality model assumes a population of constant size, where mortality and emigration are balanced by birth and immigration. The Mortality+Trend model assumes that the population changes at a constant rate. Both mortality and population size are estimated using maximum likelihood (Whitehead 2017). The matrix used for the estimations consisted of 97 individuals. While many other dolphins were identified during the photoID process, they were unable to be included in this study.

RESULTS

All population models indicate the population size of bottlenose dolphins in Bocas del Toro is small, ranging from 54-100.5 animals (Table 1). The highlighted Mortality+Trend model best fits the data, as it has the lowest AIC. The population trend over time is unclear, as the Closed Petersen, Jolly-Seber, and Mortality+Trend models all show different patterns (Fig. 1).

Table 1: Population estimates for the bottlenose dolphin population of Bocas del Toro

Model	Population Size	Bootstrap 95% c.i.	Mortality Rate	AIC
Closed (Petersen)	54	40-68	---	---
Closed (Schnabel)	95.6329	82.4-113.1	---	358.5726
Jolly-Seber	100.5	---	---	---
Mortality	67.0199	57.2-81.9	0.063805	342.453
Mortality+Trend	71.8201	60-90.4	0.051874	**342.0804**

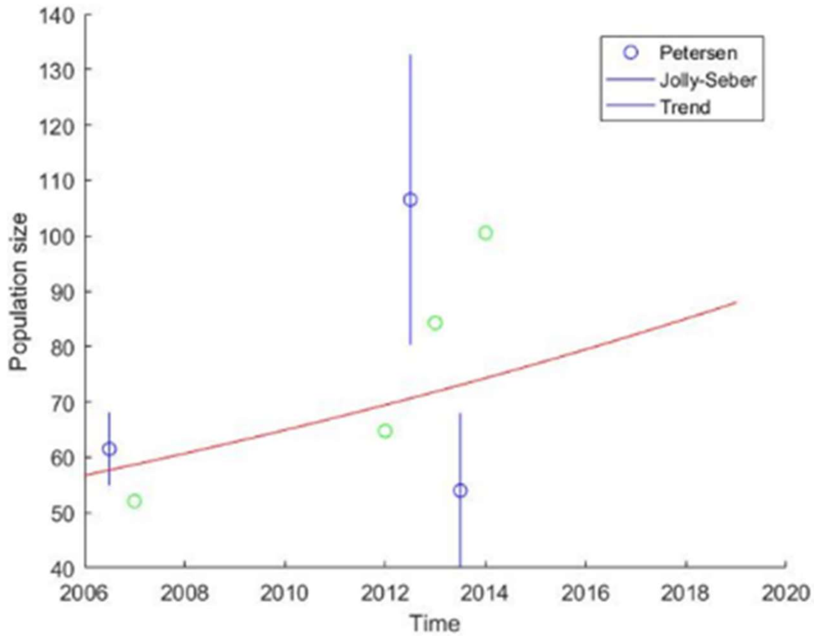

Figure 1: Closed Petersen, Jolly-Seber (open) and Mortality+Trend population estimates over time of the population of bottlenose dolphins in Bocas del Toro

DISCUSSION

All models suggest that the population of Bocas del Toro is small, with the maximum estimation just over 100 animals. The mortality+trend model best fits the data, indicating that mortality is a driving factor for this population. While the estimated mortality rate of 0.052 is low, it is likely misleading. According to previous research regarding the health of this population, there were 15 dolphins killed due to boats and fishing nets from 2009-2014 (Trejos & May-Collado 2015). If the population is about 100 animals, that would be a 15% mortality rate over those five years, which is much higher than the estimated rate according to this analysis. The mortality rate would be even higher if the population size were as small as is suggested by some of these models.

Each model shows a different trend, making it difficult to determine the actual growth rate of this population over time. The mortality+trend model shows a steady increase in the population, while the Jolly-Seber model shows exponential growth and the Closed Petersen model shows a decline. These drastically different patterns are due to a small sample size and uneven sampling across years. Only 97 individuals were included in this analysis over 6 sampling periods. There are many more animals in the population than were able to be included in this analysis. More data was included for later years, which explains why the models show increase. The analyses are biased due to uneven samples across periods. The lack of individuals included for earlier years led to an underestimation in population size for that time period.

Many of the individuals included in this analysis reside in Dolphin Bay, which is a tourism hotspot. May-Collado et al. (2012) found that a group of dolphins could interact with up to 40 boats in one hour during the low tourism season, and up to 100 boats per hour at peak tourist times.

This high boat traffic in the bay has severely impacted the resident dolphins' behavior and habitat use (May-Collado, et al. 2015), but particularly of the females, which are the main contributors to population growth (Kassamali-Fox et al. 2015). In an ongoing study by graduate student Betzi Perez, she finds that there is evidence of increasing stress hormones in these dolphins during times of high boat activity, which increases concerns of the impact of these hormones on immune system function and reproductive success (e.g. female calving cycles, calf survivorship).

Previous research has found that reducing the impact of boats to only two dolphin-watching boats at a time should be allowed to interact with a group of dolphins, with a 30-minute resting period between interactions (May-Collado, et al. 2014). The government of Panama does have regulations in place for dolphin-watching boats to ensure safety of the dolphins (Sitar et al. 2016). However, there is no one to enforce these rules on site. Future management strategies to protect this dolphin population should include a monitoring system of boat-dolphin interactions and control the number of boats that are in the bay at one time. Minimizing the number of boats will result in fewer interruptions during key biological behaviors such as foraging and reproduction (Kassamali-Fox, et al. 2015), and reduce the potential negative impacts of a stressed population.

In order to get a more clear idea of the size of the entire population, missing data must be filled in. There is a gap of missing data between 2014-2019, as well as data from earlier years that was unable to be included in this analysis. A more in-depth analysis including the sex of dolphins, reproductive status, and mortality will also be included in order to gain a better representation of the population trends.

In conclusion, more data must be included in order to determine the population size and trends for the bottlenose dolphins in Bocas del Toro.

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IS THERE CONNECTIVITY BETWEEN THE COASTAL AND OCEANIC BOTTLENOSE DOLPHINS IN BOCAS DEL TORO, PANAMA?

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ABSTRACT: To understand how genetics are passed from one population to another, I investigated a newly discovered population of Oceanic Bottlenose Dolphins in Chiriquí Lagoon, Bocas del Toro using photo-identification data from April 11, 2019 to May 24, 2019. A fin catalogue was created with all the individuals identified by left and right dorsal fin and was compared to the Coastal Bottlenose dolphin catalogue which the data was collected from 2004 through 2014. A dorsal fin match between the catalogues would determine possible genetic flow, indicating an individual from the Oceanic dolphin travels to the coastal waters for reproduction purposes. Data from different sightings in Chiriquí Lagoon show that traveling is the most common behavior seen in the population. Based off the photo-identification data, results indicate that genetic flow is not present between the Coastal and Oceanic Bottlenose dolphin population. However, data collection for the Oceanic Bottlenose Dolphin population in Chiriquí Lagoon is in its beginning stages of research and data collection. Oceanic dolphins are part of fission-fusion societies so identifying every individual in large groups can take time and new individuals are frequently discovered. Although attempts to take biopsies on the oceanic dolphins have been unsuccessful, future attempts will be needed to get an understanding the populations DNA and if there are similarities with the coastal dolphin population.

Key words: Gene flow, Bottlenose Dolphin, Photo-identification, Chiriquí Lagoon, Fission-Fusion societies

Genetic flow and diversity are important pieces to a species survival. In order for gene flow to be effective, the species has to disperse and migrate to pass on their DNA. Without gene flow, issues include low fitness, birth-defects, reproduction problems, and vulnerability to diseases and extinction (Ellstrand 2014). The Bottlenose Dolphins of Bocas del Toro, Panama are of great importance for conservation research on the species and the socio-economic ties to the region, where tourism is highly prominent. Although the species is not listed under the IUCN as vulnerable or endangered, the species population in the Bocas del Toro could be facing extinction.
The dolphins in Bocas are genetically unique due to the population being isolated from the others in the region (Barragan-Barrera *et al*., 2019). Having a small and secluded population could be a danger to the health of future dolphins in the area. The factors that may lead to extinction is the small population size, high site fidelity, genetic isolation, and range overlap with human activities. (Barragan-Barrera, et al) High boat activity has had a dangerous effect on the coastal dolphin's population. Speeding boats has caused an increase in mortality rates of the Bottlenose dolphins in the region and boat noise has disturbed communication between family members, making it easier for young calves to be separated from their mothers (Barragán-Barrera *et al*. 2018).

The Bottlenose dolphins in the archipelago of Bocas del Toro are separated into two groups: the coastal population and the oceanic population. Both populations are part of fission-fusion societies. The coastal group consists of 100 to 150 individuals, small in size, have wide and short dorsal fins, and located in the coastal waters of Bocas del Toro. The oceanic group have a small population compared to the coastal population. Individuals located in Chiriquí Bay, are larger in size and have thin and tall dorsal fins. Since these individuals of the coastal region are in close proximity with each other, it is important to know who the population is interbreeding with, to determine if there is genetic flow. When a small group of a species breed with each other, there is a lack of genetic diversity. By observing the behaviors and retrieving data on the oceanic dolphins of Chiriquí Lagoon, research may provide a better understanding on how genes pass on to isolated populations.

MATERIAL AND METHODS

Bocas del Toro, Panama is located on the northern Caribbean coast, ranging from cloud forest mountains to tropical island chains. The archipelago contains 9 main islands, 52 cays and over 1,000 islets. Bocas is home to two groups of bottlenose dolphins. One population is located on the coast and the other is located in the ocean. In this study, oceanic dolphin individuals of Chiriquí Lagoon were recorded on data sheets by a Panacetecea researcher, Betzi Perez between April 11 of 2019 to May 24 of 2019. Data sheets recorded location, GPS coordinates, time, behavior and the number of dolphins in the sighting. By using photo identification, each individual was identified by observing the physical characteristics of the dorsal fin and body. Characteristics included scars, scrapes, punctures or missing parts of the fin. A catalogue was then created with all the Chiriquí Lagoon dolphins. The oceanic dolphin catalogue was then compared to the coastal dolphin catalogue to observe similarities and differences and to indicate if any of the dolphins on the catalogue are identical. Matches would indicate that the oceanic dolphins move to coastal waters determining gene flow.

RESULTS

The results indicate that there was an increase in the number of individuals identified for the first time from April 11 of 2019 to June 4 of 2019 (Fig. 1). 53 individuals were identified using photo-identification. 5 dolphins were seen more than once in Chiriquí Lagoon. 14 individuals were found in the first day of sighting in Chiriquí Lagoon. According to Figure 2, the most common behaviors are traveling (48%), diving and foraging at (18%). When individuals from the oceanic population of Bottlenose Dolphin was compared to the individuals in the coastal population, matches between dorsal fins were not present.

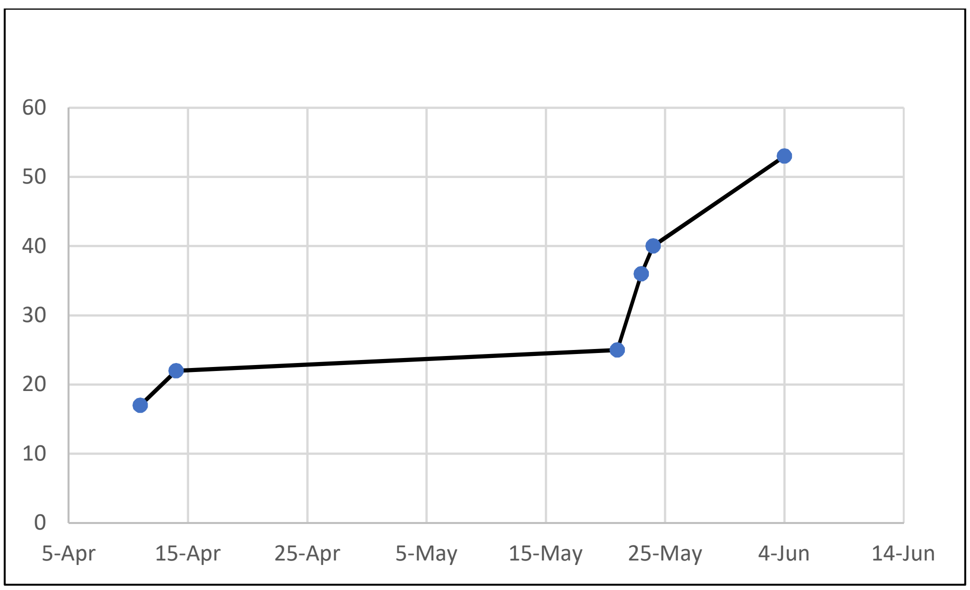

Figure 1. Cumulative curve of dolphins found in the Chiriquí Lagoon from April to June 2019

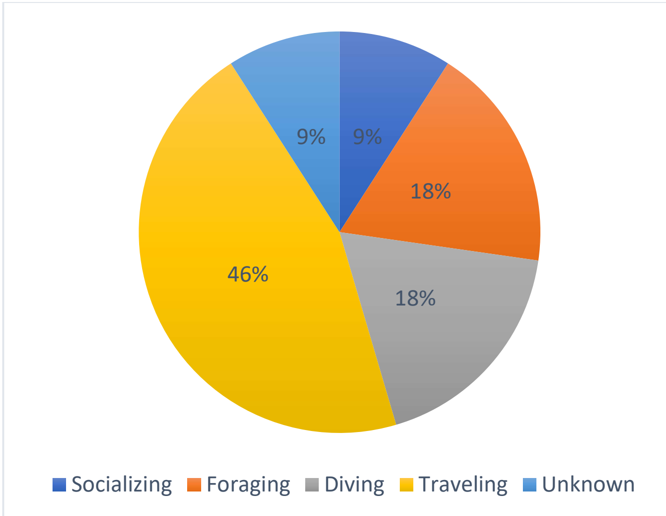

Figure 2: Percentage of predominant behaviors of oceanic dolphins at the Chiriquí Lagoon

DISCUSSION

I did not find evidence of connectivity between the oceanic bottlenose dolphins of Chiriquí Lagoon and the coastal dolphins of Bocas del Toro. This could mean that there is no gene flow between areas, and that these areas are inhabited by independent dolphin populations.

A large majority of the identified oceanic dolphins had scars and punctures on their dorsal fins and back which suggests entanglement in fishing nets could be an issue. In addition, large shipping boats travel in and out of the Chiriquí Lagoon, which may indicate that the dolphins are also exposed to boats, which may result in boat collisions. Some of the scars could indicate aggressive behavior between the dolphins, possibly associated with reproduction and its affiliative behavior. A recent study from Shark Bay, Australia found that during breeding seasons, adult males are far more aggressive with each other than the females. The behaviors were measured by tooth rake marks in the dorsal fins, with 87% of the females receiving aggression from the juvenile males and the mature males during breeding season (Connor *et al.,* 2005).

Based on photo identification, we estimate that the population is likely about 53 dolphins. However, for every new sighting there has been new dolphin individuals found in the area, which means that more new dolphins will be discovered as we increase survey efforts. Even if more individuals are identified, the population is likely to be small as is typical of dolphins that inhabit the coastal areas (Barragan-Barrera *et al.,* 2017).

The oceanic dolphins' predominant behavior was traveling. This may indicate that dolphins travel far to breed with the other population. Also, the data indicates that the oceanic dolphins thrive in an open population which will be more genetically diverse. A study in Marlborough Sounds, New Zealand found that the Bottlenose dolphins that were included in an open population were seen to have long-term site fidelity and tend to distribute all around the sound. The population of bottlenose dolphins observed in the Marlborough Sounds were found to be semi- individuals utilizing the Sounds year-round while other individuals were found to migrate in and out of the area on an annual basis (Merriman 2007).

In conclusion, our results indicate that there are dolphins that occupy Chiriquí Lagoon, but we cannot determine their degree of residency. Future studies should increase survey efforts to collect more data to test the theory. Since there is little data on the oceanic dolphin population, it was difficult to compare the data to a similar research paper. More information including DNA results from biopsies of the coastal and oceanic dolphin and data on the populations behaviors are necessary for future studies.

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THE EFFECTS OF LOCALITY ON BOTTLENOSE DOLPHIN, *TURSIOPS TRUNCATUS,* BODY CONDITION IN BOCAS DEL TORO, PANAMA

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ABSTRACT

The Bottlenose dolphin, *Tursiops truncatus*, is an apex predator in many coastal and marine environments. Due to their long life span and high trophic level, they often accumulate biotoxins and therefore can be used as a sentinel species to estimate the health of an ecosystem. Much can be learned about the health of an individual dolphin through observations of its physical appearance. To better understand how locality of a dolphin could impact its body condition, I studied the distribution and physical conditions of a Bottlenose dolphin population in Bocas del Toro, Panama. I compared these observations to those made in an oceanic population in the nearby Laguna Chiriqui. By using photo-identification data, individual dolphins can be tracked and observations regarding skin conditions, wounds, and an estimation of weight can be recorded. The results indicate that there are noticeable similarities in the body condition of those that reside only in the archipelago and those that frequent the Laguna. The archipelago population has higher incidences of minor injuries like scratches and lesions, while the oceanic ecotype is more prone to emaciation and large wounds. The poor body conditions of the archipelago dolphins is most likely the result of human activities and boat traffic, while the laguna dolphins are faced with coastal threats as well as commercial fishing nets and lines in the open ocean.

Key words: Bottlenose dolphin, Body condition, Bocas del Toro, Photo-Identification, *Tursiops truncatus*

Tursiops truncatus, more commonly known as the bottlenose dolphin, is a species of marine mammal that is found in tropical and temperate waters around the world. Their intelligence and social behavior promote individuality among these animals, and each population can be quite unique. One such population resides in the archipelago of Bocas del Toro, Panama. This population can often be found throughout the archipelago, however it is relatively small and isolated, which could raise concerns of decreased genetic variation and the possibility of inbreeding (Barragán-Barrera, et al, 2017). Furthermore, one specific location, Dolphin Bay, is the largest site of dolphin watching in Panama, so the dolphins here have an added stress of boat noise, net entanglements, and boat collisions (May-Collado, et al, 2015). These stressors negatively affect a dolphin's health, and interactions with boats can cause serious harm.

In order to predict overall dolphin body condition in a noninvasive manner, photo identification can be employed (Hart, et al, 2010). This entails taking pictures of each individual's dorsal fin, and compiling the pictures into a catalog. Animals can be named, identified, and tracked over time to see changes in health, which has been occuring in Bocas del Toro for over a decade. By using photo ID to check each animal for lesions, scratches, tumors, discolorations, or wounds, the health of the dolphin population can be estimated (Karczmarski & Cockcroft, 1998). A measure of the dolphin's body condition in regards to weight can also be estimated using photographs. A deep concavity posterior to the blowhole or ribs showing indicates emaciation of the individual. A mild concavity indicates thinness, and convexity of the area indicates an overweight dolphin (Joblon, et al, 2014).

Due to their isolation and high levels of boat traffic, the dolphins that have a home range inside the Bocas del Toro archipelago most likely have lower levels of overall health. Abundant dolphin watching boats flood the area with noise pollution, and the boats themselves cause wounds and separate mothers from their calves. The photos of dolphins taken within the archipelago will show higher incidences of skin lesions and wounds, indicating poorer body condition than those of the dolphins that frequent Laguna Chiquiri. This oceanic population has a much larger home range and less human interactions, so they will have more favorable body conditions. By studying the body conditions of the archipelago dolphins and comparing them to the oceanic ecotype, information about the health of the Bocas dolphins as well as the overall ecosystem can be discovered.

MATERIALS AND METHODS

The dolphin population of Bocas del Toro, Panama has been researched since 2004. Over that time, an extensive catalog of photo identification data has been compiled. This entails using unique dorsal fin markings and scars to identify each individual dolphin. In this study, multiple sites throughout the Bocas del Toro archipelago, including Dolphin Bay, Bocas del Drago, Punta Caracol and Almirante were sampled. These locations are fairly small, isolated, and have frequent interactions with dolphin watching boats, personal vessels, and other watercrafts. Boats are particularly prevalent in Dolphin Bay, which is also the most common dolphin sighting location. Small water channels between the mangrove forests connect areas like Punta Caracol and Almirante, while Bocas del Drago is more exposed. In order to compare to an open oceanic site, the dolphins present in the nearby Laguna Chiriqui were also photographed and used for the study. The Laguna is adjacent to the Bocas archipelago but directly open to the ocean. It is also subject to human activities, as it is often traversed by large shipping vessels or fishing boats. Furthermore, it is slightly more polluted than the archipelago, as plastic water bottles and other trash can be seen floating on the surface.

Using photo ID, dolphins that frequent each location were identified using the Panacetacea research database, and then notes on their overall observable body condition were recorded. Categories to assess condition include the presence or absence of lesions, fungus, tumors, scratches, wounds and finally emaciation of the animal. Using these observations, the body condition of individual dolphins that have a home range within each area can be measured and compared between the two sites.

RESULTS

Due to the low number of sightings of the oceanic dolphins in Laguna Chiriqui, there is insufficient data to perform a statistical analysis. However, there are patterns in the observations that can be examined. For example, *Figure 1* shows that the most prominent body condition between both locations is healthy, however fungus, emaciation, and scratches are common ailments shared between the sites. Lesions, tumors, and wounds were the least common body conditions when looking at both populations. *Figure 2* shows that both locations have incidences of emaciation, fungi, tumors, wounds, and some healthy individuals. Individuals afflicted with lesions or scratches were only seen in the Bocas archipelago.

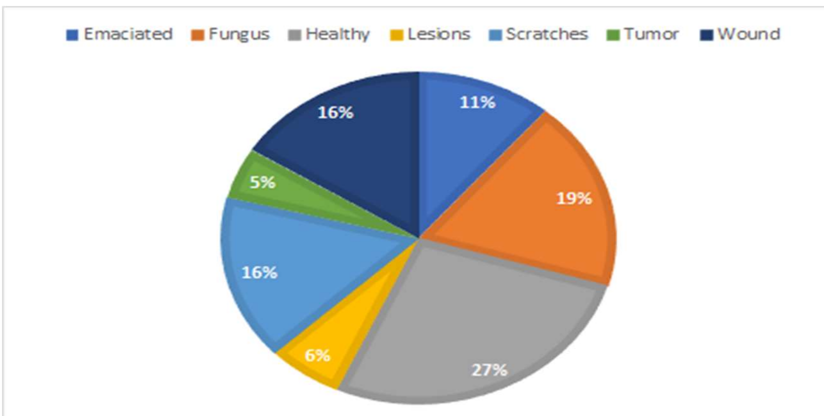

Figure 1 is a pie chart displaying the combined percentages of individuals that have various body conditions in both the Bocas archipelago and Laguna Chiriqui.

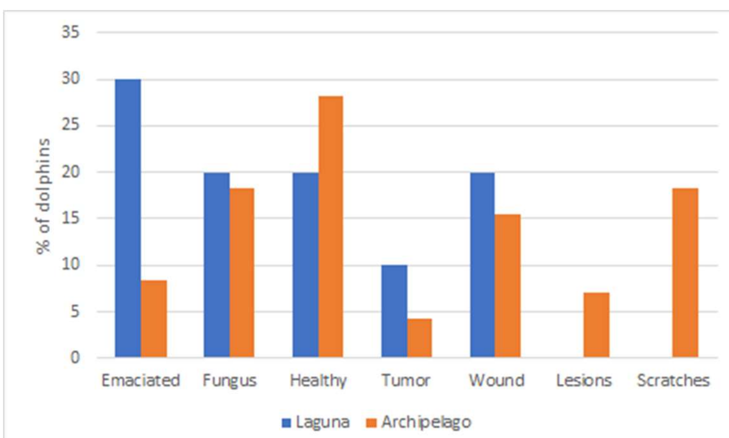

Figure 2 is a graph directly comparing the body conditions of those dolphins in the Bocas archipelago and those in the Laguna Chiriqui.

DISCUSSION

The detectible patterns in this study indicate that there are no significant differences in the body conditions of those dolphins that only reside in the Bocas archipelago and the oceanic dolphins in Laguna Chiriqui. Both locations show considerable instances of emaciation, wounds, and fungus. Only the archipelago dolphins were observed to have scratches or lesions, however they also have more healthy dolphins. The high proportion of archipelago dolphins with scratches could be explained by the large amount of overlap between the dolphins' home ranges. (Kass, 2019)[1]. Since the location is rather enclosed, more social interactions and competition for resources between dolphins leads to more injuries like tooth rakes and scrapes (Lee, et al, 2019).

This result is somewhat surprising, since the archipelago dolphins show a lower frequency of significant wounds from boat propellers than expected based on the high amount of boat traffic in Bocas. Conversely, entanglement in fishing lines and more harsh open ocean conditions could explain the higher levels of wounds and emaciation that were observed in the Laguna population, rather than intraspecies or boat interactions. However, it is also important to consider the sample sizes for the two areas, which were 71 and 10 dolphins for the archipelago and Laguna, respectively. Differences in sample size could skew the results, so more testing should be done in the future to achieve better results (Hau & Marsh, 2004).

In conclusion, while there is no significant difference in the distribution of dolphins with various body conditions between the two locations, many individuals still show signs of poor body condition. Underlying factors that negatively affect the dolphins could be whale watching boats, particularly those that do not follow compliance regulations, excess engine noise, pollution, and fishing net entanglements. Future studies should focus on obtaining more data regarding the oceanic dolphins, and the impacts of human activity on dolphin health.

ACKNOWLEDGEMENTS

I would like to extend my deepest appreciation to Dr. Laura May-Collado for firstly sparking my interest in marine sciences, and also giving me this opportunity to explore dolphin research firsthand. I would also like to thank Betzi Perez and Heather Daszkiewicz for teaching me research methods and supporting me through the process of data collection. I also recognize the Smithsonian Tropical Research Institute faculty and staff for providing housing and meals during my stay here, as well as equipment needed for research. Finally, thank you to boat drivers Demetrio, Eric, Arcadio, and Sebastian, and as well as chef Gustavo and everyone else who made my experience here the very best.

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SPATIAL ANALYSIS OF HOME RANGES OF MOTHER-CALF PAIRS OF BOTTLENOSE DOLPHIN (*TURSIOPS TRUNCATUS*) IN BOCAS DEL TORO

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ABSTRACT

This study presents 10 years of inclusive data collected on bottlenose dolphins (*Tursiops Truncatus)* in Bocas del Toro, Panama to find home ranges of individual mothers. The study tracked geographic locations of 11 females; 6 were known to be reproductively successful, and 5 whose calves did not survive to maturity. Photo identification was used to catalogue and track individuals. A spatial analysis was created using Arc GIS 10.6.1 with a kernel density analysis to find the critical areas for these individuals. A critical area is defined by a contour of 95% of sightings within the map. Home ranges were defined by 25% contours. The results showed that critical areas for all individuals in both groups was in Dolphin Bay, although there is a high presence of boat disturbance due to the dolphin watching industry there. Although critical areas were about the same size and location across the two groups ($6.2km^2$ for living and $6.5km^2$ for unknown fate), the total ranges were 197% larger for the living calf group ($85.7km^2$ and $43.5km^2$, respectively). The correlation between habitat size and female reproductive success has not yet been studied in *T. truncatus*.

Key words: *delphinidae*, cetacean critical area, distribution, ecology, habitat use, home range, spatial analysis

Bottlenose dolphins (*Tursiops truncates)* are one of the most widely studied marine mammal species. They are a good indicator of the health of the ecosystems in which they reside, making them evermore qualified for study subjects (Reynolds et al. 2000). Bottlenose dolphins live in fission-fusion societies with dynamic social groups, communication patterns, and spatial compositions (Jenkins, 2009). One important relationship is between mother and calf. Studies on mother-calf relations have shown that mother dolphins raise their calves for approximately three years, sometimes more, until the calves are self-dependent. Female calves tend to stay longer with their mother, and sometimes reconnect with the mother after gaining independence. Males tend to leave to establish social bonds with other males (Shane et al. 1986). In bottlenose dolphins the caretaking period is critical for the calf to learn important behaviors like surfacing for air and foraging/diving techniques (Shane et al. 1986).

Dolphin critical areas supply reliable food sources and protection from predators (Samuel, et al. 1985). The dolphins of Bocas del Toro forage on low trophic level and low-calorie prey (Barragán-Barrera, et al. 2019), suggesting that these dolphins likely must spend more time foraging during the day to gain enough energy. This is particularly important for lactating mothers (Kassamali-Fox, et al. 2015). In Bocas del Toro, females typically reproduce every 62.08 (SD= ±21.91) months (Gonzales, et al. 2018). The population of bottlenose dolphins in Dolphin Bay consists of approximately 48 core individuals (Jones 2018). Calf survival rate is extremely important for the persistence of generations because bottlenose dolphins have a long period of parental care. A study done from 2004 to 2014 found that there has been a 54% survival rate of calves in the Bocas population (Gonzales, et al. 2018). This shows that the population may be vulnerable to human activities due to small population size and high degree of genetic isolation. Here I study the spatial distribution of females to determine their home range and critical areas. I also consider female reproductive success to determine if success is dependent on specific distribution patterns.

METHODS

The Study Site

The Archipelago of Bocas del Toro is in the Caribbean coast of Panama. The survey effort covered approximately 79.2 km2 within the inner part of the Archipelago, characterized by shallow and clear waters and bottom substrates consisting of sea grass, coral, and sand. The main mode of transportation between the islands and mainland is through powered boats with 50 and 150 hp engines and canoes.

Data Collection

The study site was surveyed using a 10 m fiberglass boat with two engines (150 hp/4-stroke) from 7 a.m. to 4 p.m. following predetermined routes. Survey effort varied between 1-20 weeks a year depending on funding support. The data recorded for this analysis began in 2004 and ended in 2014. Photos for identification were collected during each sighting, in addition to information on latitude and longitude, the size of the groups, calf presence, and boat presence. Group size was estimated by consensus of observers.

Analysis

Photo identification was used to catalogue individual dolphins based on the shape, and unique notches found on dorsal fins. This study included 11 reproductively active females in the population. The females chosen for the study were photo identified at minimum 15 times throughout the study period. Maps A-F included 6 individuals that were confirmed to have been successful in raising offspring to maturity. These included named Supermessy, Messy, Luna, Almostclean, Mo, and Chiriqui. Five individuals shown in maps G-K (Figure 2) had calves that were not seen for two consecutive years after a sighting, so they were pronounced dead. Their names are Plinio, Tipless, Valdez, Scratchy, and Bity. The spatial analysis using Garmin GPS data from group sightings between 2004 and 2014. Kernel density maps were generated using ArcGIS 10.6.1 to identify core areas for individuals included in the study. All points that had a geographical location on land were considered error and, removed from the data.

RESULTS

The results indicate that the 11 females included in this study overlap in their critical area in the northeast portion of Dolphin Bay (kernel density 95%). Other area used (kernel density 25%) are more variable among females. The average home range size for mothers with living calves was 85.7km^2, while for mothers with deceased calves was 43.5 km^2. The total home range area of the successful mothers was 197% larger than the unsuccessful mothers. The average size of critical area in mothers with living calves and deceased calves was 6.2km^2, and 6.5km^2 respectively. the critical area for the successful mothers was 5% smaller than the unsuccessful mothers.

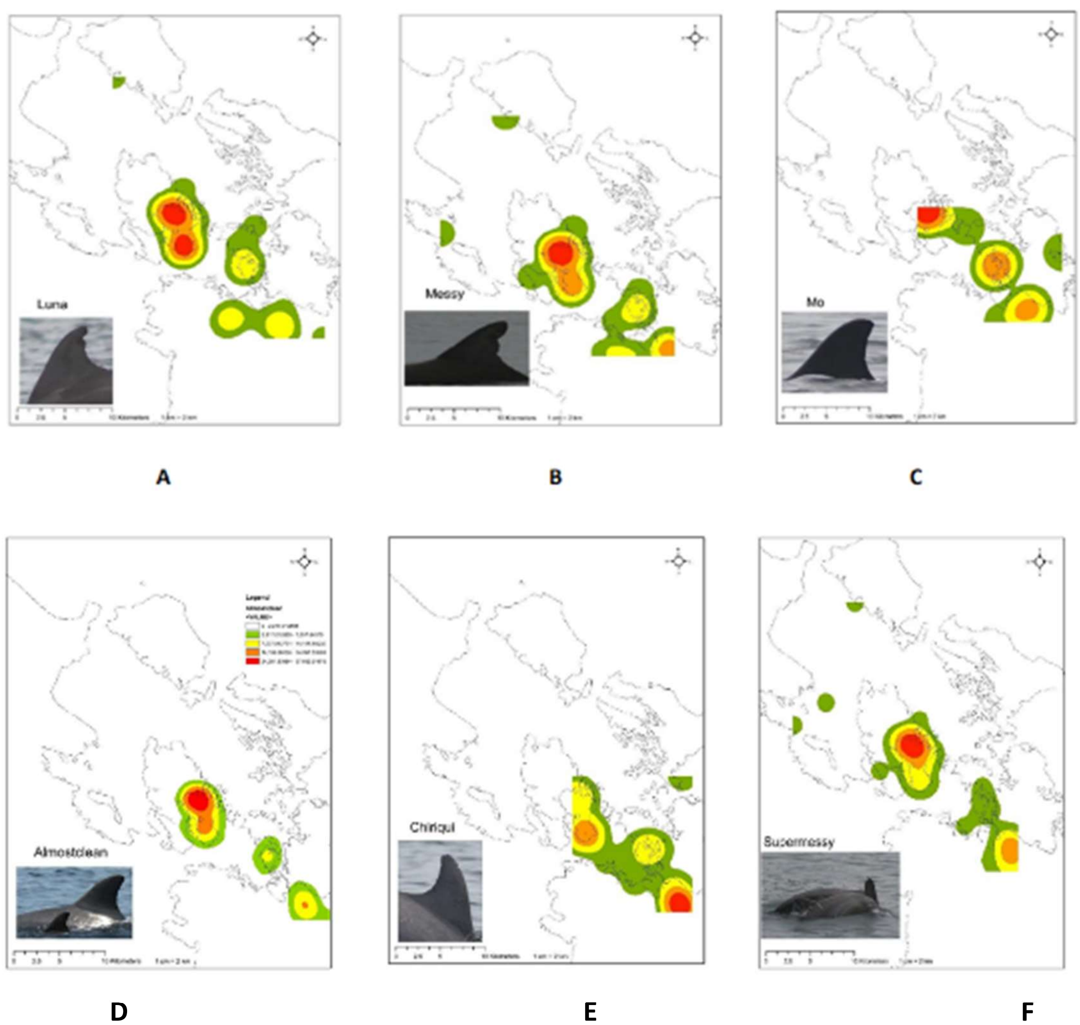
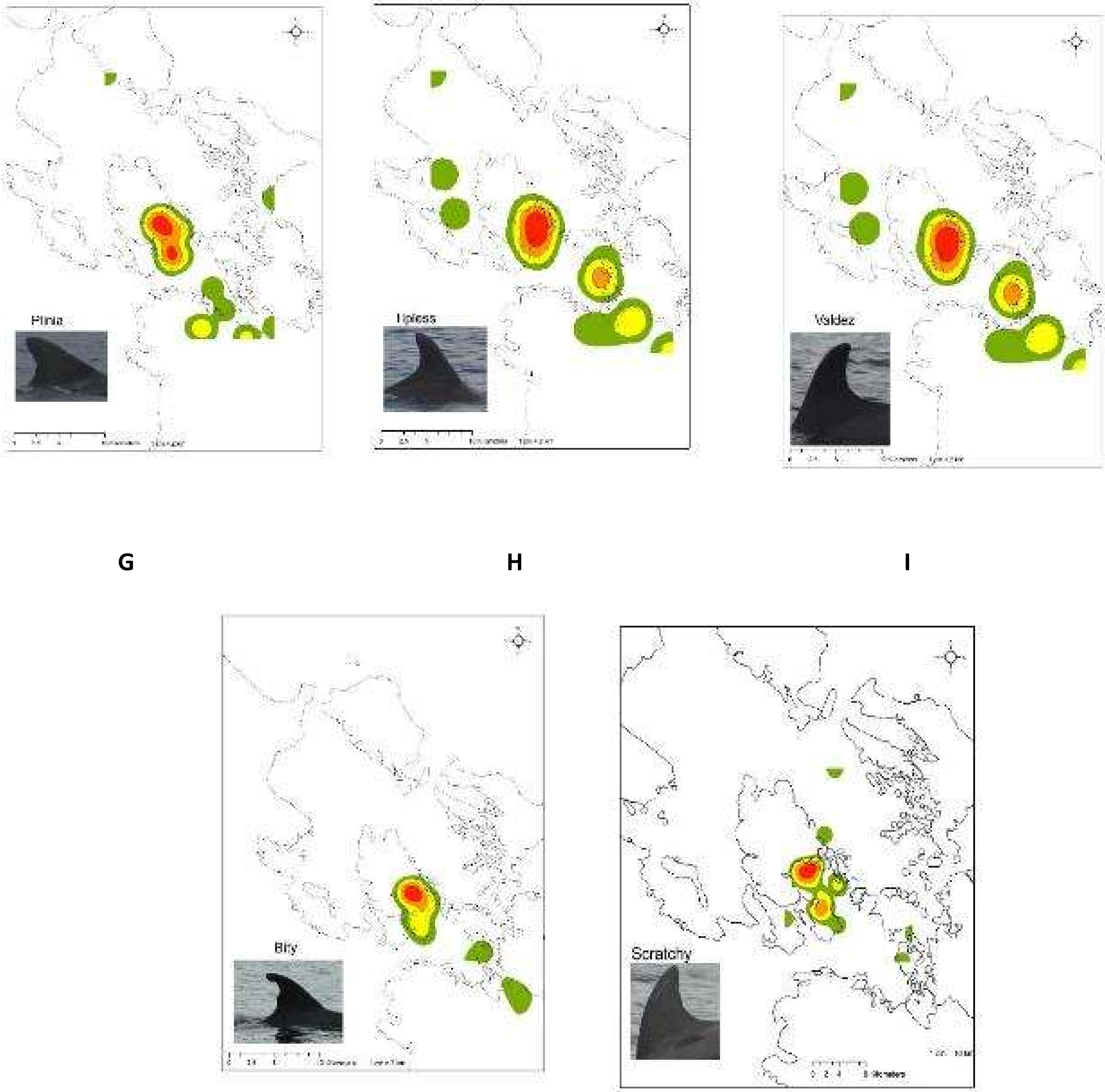


Figure 1. Home ranges for mothers who have raised calves to maturity.



G H I

J K

Figure 2. Home ranges for mothers who have not raised calves successfully to maturity.

DISCUSSION

This study finds that all females have overlapping critical areas in Dolphin Bay. However, they vary in home range size at kernel density 25%. Females with surviving calves have larger home ranges than those without surviving calves. The reason why some females have not been successful, even when using the same critical area, remains unclear. Females likely come to this area because there is food in supply (Barragán-Barrera, et al. 2015). Malnourishment is a threat to this population considering a previous study indicated that 16% of individuals in this population are emaciated (Dubrul 2019).

The Bocas population is constantly disturbed by a high presence of boat traffic due to the dolphin watching industry. One group of dolphins can interact with 39 boats in one hour with no time to rest (May-Collado, et al. n.d.). Many of these interactions occur in Dolphin Bay (May-Collado, et al. 2015). One study on this population showed that between the years of 2012 and 2014, at least 10 dolphins passed away from boat watching activities (Sitar, et al. 2016). Acoustic behavior is also impacted by the presence of boats in this population, making it harder for the animals to communicate with one another (May-Collado, et al. 2015). This may explain the high mortality rate of calves in the population (Gonzalez et al. 2018). Even with such high levels of anthropogenic disturbance in Dolphin Bay, a study on behavior in the presence of boats in Bocas dolphins found that the cost of leaving is greater than staying, even when boat traffic continues to grow (Barragán-Barrera, et al. 2017).

Interestingly, the home range size at 25% density is highly variable between the two groups, with the successful mothers using an area 197% larger the unsuccessful mothers. A study in Sarasota Bay, FL on mother-calf pairs found that their home ranges varied from 20-230km^2 (McHugh 2011). The home ranges for this population fall within that range. The study in Sarasota Bay found that there was natal philopatry in the species (McHugh 2011). However, it did not specify how home range size of mothers' effects calf survivorship. There has been little previous investigation on the relationship found in this study. Future studies may be done to provide supplemental evidence to this conclusion.

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THE EFFECT OF BOTTLENOSE DOLPHIN (*TURSIOPS TRUNCATUS*) CALVES ON GROUP DISTRIBUTION AND BEHAVIOR IN BOCAS DEL TORO, PANAMA

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Abstract

Bottlenose Dolphins, or *Tursiops truncates,* are widely distributed across the world, living in both ocean and coastal habitats. One of these coastal habitats is the Archipelago of Bocas del Toro, Panama. Bottlenose dolphins travel in social groups with other individuals, and calves are often present among the groups. The distribution of bottlenose dolphins is affected by factors such as food availability and the presence of mates. However, it is not known if the presence of the calves has an effect on the group's distribution and behavior. In this study I examine how groups with calves differ from groups without calves, comparing the groups locations and behaviors. The data was collected over a period of fifteen years in the Archipelago of Bocas del Toro, where the coordinates and behavior of dolphin groups was recorded. A spatial kernel analysis was used to map the distribution of the two groups: those with calves and those without. The spatial kernel analysis showed that groups with calves and groups with adults occupy the same core area: in the Northeast section of Dolphin Bay. However, adult groups seem to occupy areas farther away from Dolphin Bay, and more so than groups with calves. A correspondence analysis shows that group composition is influenced by behavior. Groups with calves are more likely to engage in social behavior while adult groups are more likely to engage in milling or foraging behavior. The study showed that group composition did not significantly effect distribution, but the group composition did have a significant effect on the groups behavior. Future studies could be done using photo ID and ArcGIS to analyze the effect of calves on the home range of individual dolphins.

Key words: Marine mammals, cetaceans, habitat, foraging, social behavior

The Archipelago of Bocas del Toro, Panama, is home to a population of bottlenose dolphins, which are one of the most common species of dolphin in the world. The area consists of protected bays, islands and deep waters with an abundance of prey for the dolphins. Bottlenose Dolphins are social animals, and are known to have fission-fusion social groups, which means that they form groups where individuals enter and leave the group over time (Shane et all 1986). The groups remain together for long periods of time and can be seen foraging and traveling together. The area that a group occupies in order to do so is referred to as their home range (Gubbins 2002). In these groups there are often calves and/or juveniles, which remain with their mothers for the first part of their life (Robinson et all 2017). Bottlenose dolphins do not stay in one place; they move in order to forage for food and to find mates as well for other reasons. Their movement and distribution is affected by factors such as food availability and safety (Gubbins 2002).

Distribution of marine mammals can be determined using data form surveys. In these surveys, dolphins are sighted and data such as GPS coordinates, current behavior, and group composition is recorded. Data on the number of calves present and the number of individuals present can be compared with the location to view the distribution of dolphins based on their group composition. Once this data is obtained, it can be viewed on a map using the geographic information system ArcGIS for further analysis.

In this study I will examine the influence that bottlenose dolphin calves have on group distribution and behavior. To do so, I compile data from a database containing information on the dolphin population of Bocas del Toro. Specifically, I compile the coordinates and behaviors of groups with calves and of groups with only adults. I then compare the distribution and behavior of these two types of groups using the geographic information system ArcGIS. I also use a correspondence analysis to examine the relationship between group composition and behavior.

Materials and Methods

Study site

Located in northern Panama, the archipelago of Bocas del Toro is on the Atlantic coast and consists of many small islands. It is located at approximately 9ºN and 82ºW. The area is primarily mangroves and seagrass with coral reefs throughout. The archipelago contains calm and protected areas that serve as habitat for the bottlenose dolphin population. Among these areas is Dolphin Bay, which is located on the West side of the Archipelago and is where many dolphins are sighted. The bay contains plentiful food and shelter for the dolphins to mate and socialize.

Data collection

To obtain the data needed, I assisted in the collection of distribution data and also compiled previously collected data. The Panacetacea research team has been collecting data on the distribution and behavior of bottlenose dolphins in the area of Bocas del Toro for fifteen years. I divided the data into two categories: sightings with calves present and sightings with only adults. I used data from 2004 up until June of 2019. I also included the number of individuals and the behavior at the time of the sighting. 458 sightings in which calves were present and 565 sightings with only adults were used.

Analysis

In order to see the distribution of groups with calves compared to the distribution of groups with only adults, the coordinates for each type were plotted on a map of Bocas del Toro using ArcGIS, which is a geographic information system. ArcGIS is able to use a kernel analysis on the map of coordinate points, which shows the density of the two groups in the archipelago. A correspondence analysis was used to determine if the group composition is related to the behavior of the group.

Results

A total of 458 recorded sightings of groups with calves from 2004 to 2019 were mapped in this study. The kernel density analysis shows groups with calves occupy a core area in Dolphin Bay, with the highest density being in the upper Northeast section (Figure 1). 565 sightings of adult groups were mapped as well. The adult groups have the same core area as the groups with calves, but seem to explore other parts of the archipelago, such as Almirante Bay, Tierra Oscura, Pastores, and Cerro Brujo (Figure 1). The correspondence analysis shows that behavior is influenced by group composition ($X^2=13.94, p=0.0083$). Groups with calves present were associated with social behavior, while adult groups were associated with milling (resting at the surface) and foraging behavior (Figure 2).

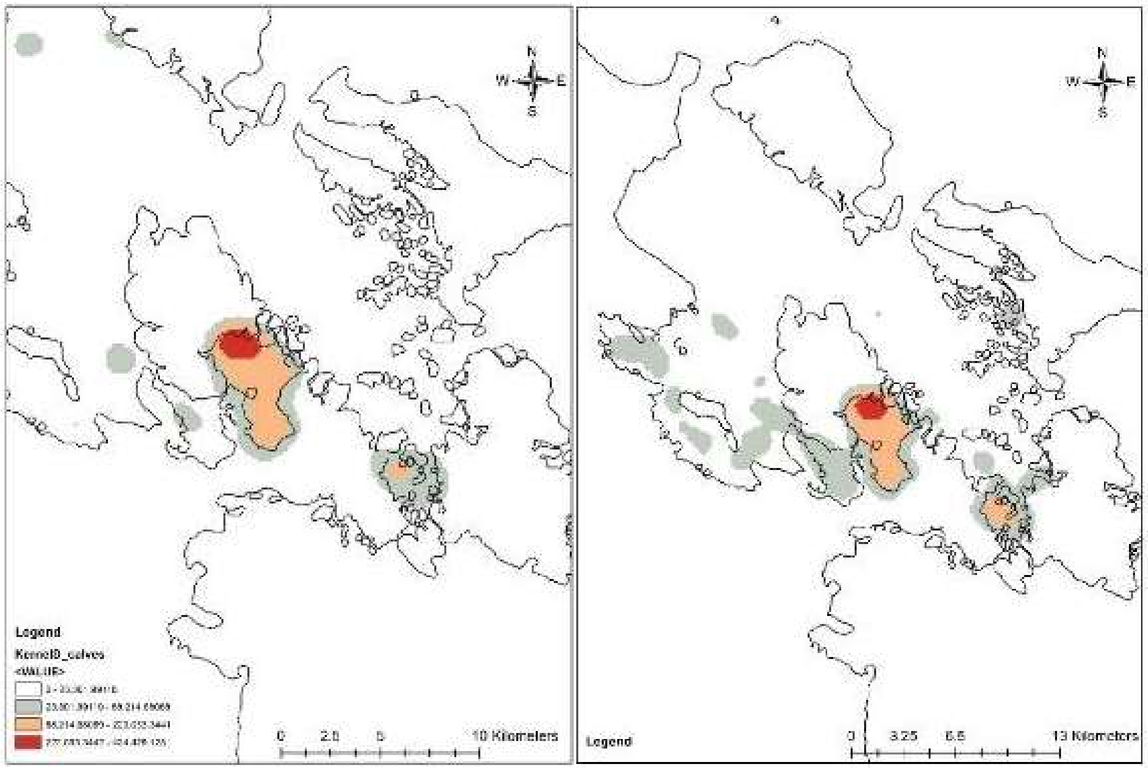

Figure 1. Kernel density analysis of groups with calves present and of groups with only adults. The core area is the same for both groups but groups with only adults have a higher presence outside the core area.

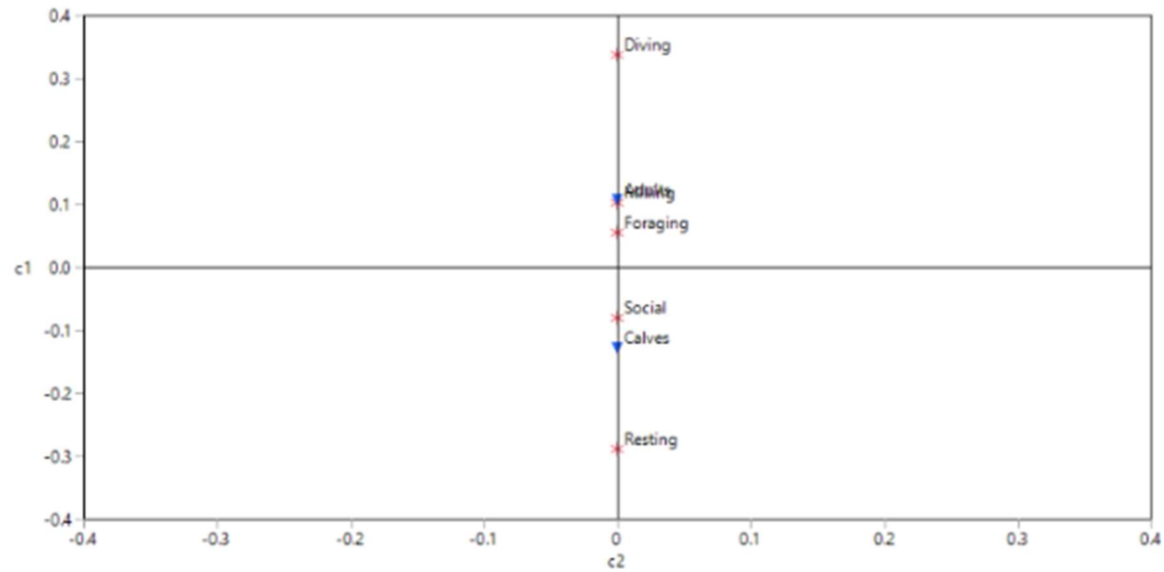

Figure 2. Correspondence analysis comparing group composition with behavior (X^2=13.94, p=0.0083). Groups with calves are more likely to be engaging in social behavior, while adults are associated with milling and foraging.

Discussion

This study does not support the hypothesis that groups with calves will occupy smaller areas than adult groups, as both groups occupied similar core areas. However, adult groups seem to explore areas outside the core habitat. This overlap between calf and adult groups is most likely due to it being a space that provides food and resources for the dolphins. Also, the home ranges of mammals increase with body mass because smaller animals cannot travel as far or as quickly (Swihart et al 1988). This is a possible explanation for the adult group occupying areas outside of the core area. Calves are smaller than the adults in their groups, so a calf present would mean that the group is not able to travel as far as a group with only adults. Food availability and habitat type can also affect the distribution of bottlenose dolphins (Cobarrubia-Russo et al 2019), which is most likely the reason we find the highest number of dolphins in Dolphin Bay, regardless of calf presence.

The data collected also provides information on how group composition is related to the behavior of the group. The correspondence analysis comparing group composition with behavior showed that groups with calves have been sighted engaging in social behavior more than groups with adults only. One study found that the social network of a bottlenose dolphin calf is related to the overall fitness of the calf (Stanton and Mann 2012), which supports the claim that groups with calves are more likely to be engaging in social behaviors than groups without calves.

Future studies can study the distribution of certain individuals with calves. Photo identification could be used to identify the individuals within groups that have calves present, and their distribution could be mapped using a geographic information system, similar to this study.

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DOES SOCIAL GROUPS ACTIVITY OF BOTTLENOSE DOLPHIN (*TURSIOPS TRUNCATUS)* IN BOCAS DEL TORO VARIES WITH TIME OF DAY AND SPACE?

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ABSTRACT

Group living provides many advances to animals, reduces the risk or predation and increases opportunities for finding food and social skills. In Bocas del Toro, bottlenose dolphins live in a space free of natural predators. Here I study the potential effect of time of day and space in social group formation using a database from 2004 to 2019. The results indicate social group size does not change with time of the day alone (afternoon=6.41±3.5; morning= 7.7±5.4), but that time and location are important determinants of social group activities. I found that social groups are concentrated in the Northeastern part of Dolphin Bay and tend to be less active during morning hours while in the afternoon they are spread throughout the bay and are more active. This diffusion of concentration explains why the group sizes during the afternoon are slightly smaller. The increase and spread of social activity during the afternoon show that most of the dolphins in the bay are concentrated in one area during the morning but are less active. As morning turns to afternoon, they then begin to spread out and become more active. Knowing this pattern helps us predict where the dolphins will be based on time of day and gives us a better understanding of the behavior of these threatened species.

Key words: behavior, toothed whales, group formation, group size variation

Many species of mammals live in groups that vary in size throughout time and space. Such variations can play an important role in when and where mammals socialize (Markham et al. 2015). Bottlenose dolphins live in fusion-fission societies, with group composition and size changing at various temporal scales (Connor et al. 2000). Gregory and Rowden (2001) indicate that bottlenose dolphin' habitat use can be driven by many factors including environmental (e.g., Wilson et al. 1997) and biological factors such as prey availability and predation risk (e.g., Heithaus and Dill 2006).

Here I study the effect of time of day and space in social group formation. I hypothesize that social group size will vary between morning and afternoon hours as well as with location. I predict that group size will increase in the afternoon (Bräger S. 1993) and that most of the social activity will occur with larger groups (Irvine et al. 1981). Learning when and where coastal bottlenose dolphins socialize helps to provide a better understanding of the habitat use and daily behavior of the species which is critical for protecting the vulnerable populations.

MATERIALS AND METHODS

Study site

All of the dolphin sightings were recorded from the Bocas del Toro archipelago. Bocas del Toro is an archipelago on in Northern Panama that faces the Carribean Sea to the East. The area is home to an isolated population of bottlenose dolphins that is thought to be made up of two communities of dolphins.

Data collection

I extracted social dolphin group size and GPS location from the Dolphin Project long-term data based (2004-2019). Time of day was categorized into morning and afternoon hours. This data was then exported to ArcGIS 10.6.1 to be analyzed using the Kernel density spatial tools using natural breaks for three categories: 95%, 50%, and 25% habitat use. The Kernel analysis calculates a magnitude-per-unit are from points features using a kernel function to fit a smooth surface for each point.

RESULTS

The results indicate that mean group size does not significantly change with time of the day ($p>0.05$, Fig. 1). However, social group size seem to be slightly greater in morning hours. Although group size did not varied with time, I found that the space in which dolphins socialize does vary with time of the day. Figure 2 shows the distribution of social groups with time of day. In the morning social groups are using primarily the northeast part of Dolphin Bay, this could explain the slightly larger group sizes during morning hours. In the afternoon, groups are dispersed throughout the bay which seems to correspond to the slightly smaller groups at this time.

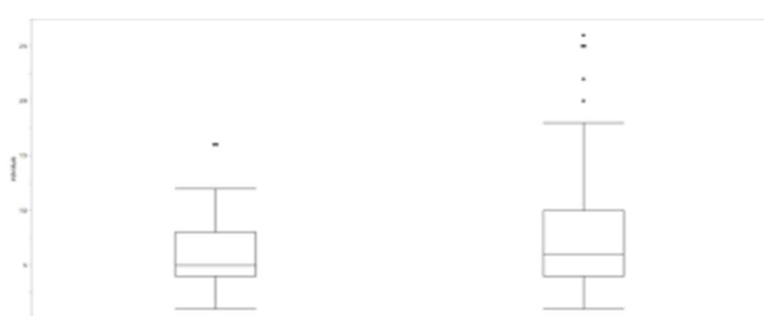

Figure 1. Social group size of bottlenose dolphin sightings in Bocas Del Toro between 2004-2019.

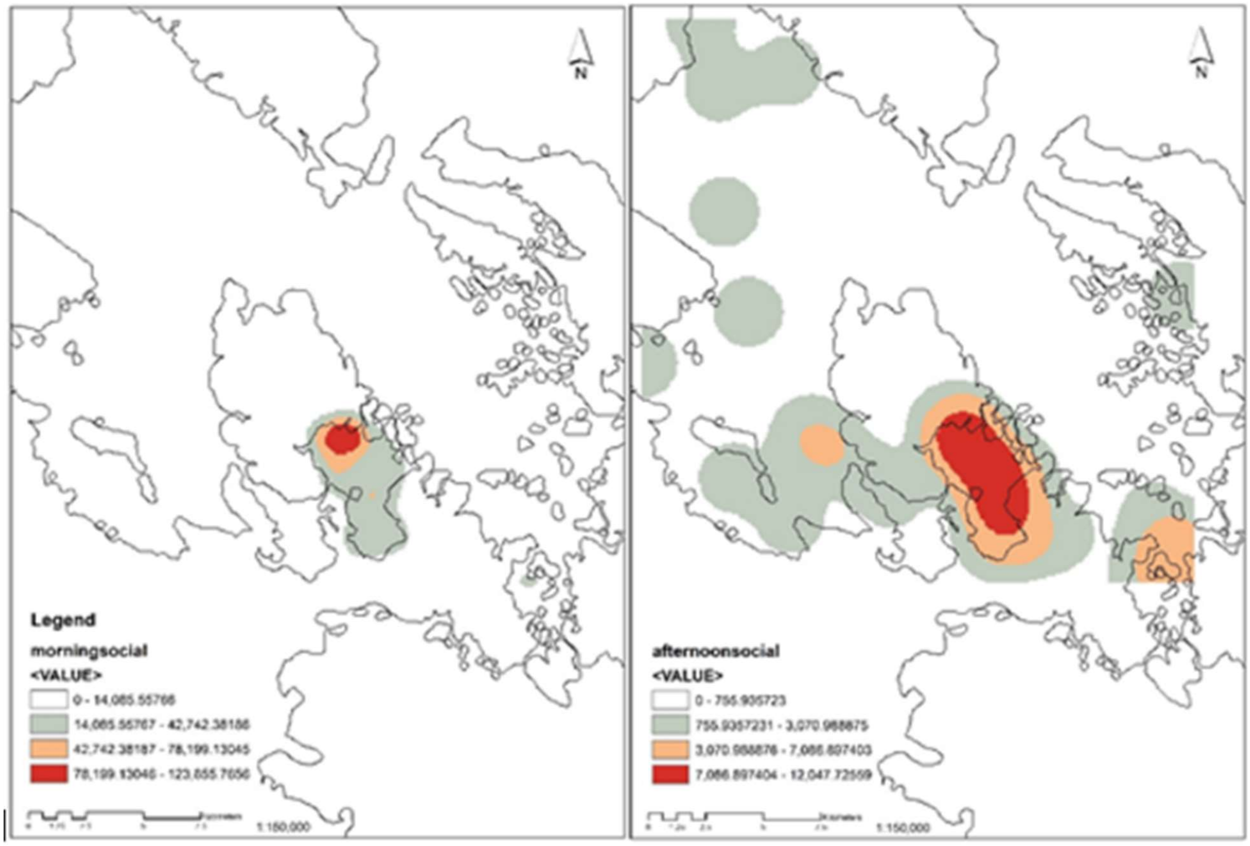

Figure 2. Habitat use of social groups during morning hours (8am-12pm) and afternoon (12-4p.m.) in the Archipelago of Bocas del Toro, Panama between 2004 and 2019.

Although there are not differences in social group size in the morning and afternoon there are differences spatially with social groups concentrated on the NE part of Dolphin Bay while in the afternoon groups are distributed throughout the bay.

DISCUSSION

This study finds that mean group size varies spatially with time of day. While group size differences are small between morning and afternoon hours, these differences may represent differences in dolphin activity. In other bottlenose dolphin populations like in Galveston, Texas dolphin socialization and travelling occurring primarily in the afternoon and foraging happening in the morning (Bräger 1993). In contrast to this study the spatial distribution of the social dolphin groups in Bocas suggest that they congregate in the northeast part of the bay, where they form slightly larger groups, and in the afternoon these social groups are more dispersed, likely moving in smaller groups.

In conclusion, while I cannot directly test the hypothesis that group size varies with time of the day, I do find evidence that the Bocas dolphins social group size varies in time but in association with space. Learning more about the social behavior of dolphins in terms of time and space is useful as it provides information that can help us understand the species at local and global scales. Under the strain of climate change, pollution, and overfishing, learning about how animals use their space is key in establishing conservation strategies. For example, the most immediate threat to the Bocas dolphins is boat traffic, with critical social areas overlapping with high tour boat activity (May-Collado et al. 2012). Knowing when and where these animals socialized is important for their survival. Therefore, future conservation efforts should focus in establishing *in situ* enforcement of dolphin-watching regulations.

For future studies, I would be interested in learning more about how other behaviors such as foraging, milling, etc. vary with time of day and space. Combining the knowledge of all of the behaviors would help give a better picture of where the dolphins are likely to be performing specific behaviors based on the time of day.

ACKNOWLEDGEMENTS

I would like to express my deep gratitude and respect for professor Dr. May-Collado for giving me the opportunity to take such an amazing course and generously donating her time to help not only mine, but all of my classmates understanding. I would also like to thank Betzi Perez, and Heather Daszkiewicz for leading the dolphin sightings, being willing to help, and resourceful in knowledge. I have a great respect for all of their dedication and passion for their studies. Additionally, I would like to thank the Smithsonian Research Institute as well as all staff involved in any aspect on campus.

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HOME RANGE OF BOTTLENOSE DOLPHINS (*TURSIOPS TRUNCATUS*) IN BOCAS DEL TORO, PANAMÁ

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ABSTRACT

Mammal home range is dependent on several factors ranging from body size to reproductive opportunities to food source. Marine mammals tend to have larger home range size than their terrestrial counterparts and may travel long distances to obtain necessary resources. Bottlenose dolphins (*Tursiops truncatus*) live in fission-fusion societies, a social structure in which social associations are fluid. A population resident to Bocas del Toro, Panamá is isolated from other populations and occupies a specific, restricted area. This study investigates the relationship between individual home range overlap and social associations using photo-identification, GPS data and Kernel analysis for 7 males and 3 females from the population. The results reveal that all ten individuals frequently inhabit the same three core areas: Shark Hole, Laguna de Chiriqui and Dolphin Bay. Despite significant home range overlap, not all individuals belong to the same social unit. This finding is consistent with the findings of current literature. These critical areas are also busy with anthropogenic activity and may have critical implications on this population's home range, social structure, and therefore survival.

Key words: bottlenose dolphins, habitat use, critical habitats, photo-identification, association index

The home range of animals largely depends on the abundance, type, and level of quality of resources such as food, water, living space. Other factors influencing the size and location of an individual's home range includes body size, sex, age, reproductive status, landscape fragmentation, trophic level and intra- and inter-specific competition, predation risk and anthropogenic activity (Nekolny, 2017; van Beest, 2011). The selection of one's home range is affected by a mixture of intrinsic and extrinsic factors. As seen in moose (*Alces alces* L.), for example, the most important factors in determining the boundaries of one's home and range are calf presence, food availability and quality, and hours of daylight (van Beest, 2011).

Compared to terrestrial mammals, aquatic organisms can have a much larger home range. Bottlenose dolphins are extremely capable swimmers and can travel long distances to find necessary resources. Male bottlenose dolphins often have larger home ranges compared to females because they also need access to reproductively available females. Adult females on the other hand may be more concerned with predation and ensuring a safe environment for her calf (Nekolny, 2017). Bottlenose dolphins are known to live in fission-fusion societies, a social structure in which associations and relationships between individuals are fluid (Genoves, 2018). Long term relationships are not typically formed in this type of society, but when resources and therefore home ranges are restricted, a stable fission-fusion social structure with strong bonds between individuals can form (Louis *et al.*, 2017).

A population of bottlenose dolphins (*Tursiops truncatus*) resident to Bocas del Toro, Panamá have been the subject of ongoing research since 2004. The population is thought to be isolated from other populations, putting them at higher risk of extinction. Similar to that of Louis *et al.* (2017), this population's resources are concentrated in certain areas, site fidelity is increased and home range is restricted. Using this population, I investigate the relationship between home range overlap and association between individuals. Among other resource requirements, could the distribution of others in the population affect an individual's decision in choosing home range?

METHODS

Data collection was conducted in the inner parts of the Bocas del Toro archipelago, located on the Caribbean coast of Panamá, to track dolphins in the population and survey efforts covered approximately 79.2 km^2. The area's marine environment consists of shallow, clear waters with sand, sea grass and corals. Powered boats were used for transportation and to approach individuals during sightings (May-Collado *et al.*, 2012).

Ten individuals of the Bocas del Toro population, consisting of seven males and three females, with more than fifteen documented sightings since 2004 were selected for this study. Male individuals include Dolpho3, Piquito, Halfin, Panama, Curvy, Littlesawy, and Sawy; females include Scratchy, Topnotchy, and Middlenotchy. Photo-identification, a method of distinguishing individuals based on unique marks, scars and notches of the dorsal fin, was used to recognize individuals in each sighting. Photo-identification and sighting location data from 2004-2014 was extracted from our master database and organized into a matrix containing longitude-latitude coordinates for each individual. GPS locations were used in a Kernel spatial analysis to identify home range and critical areas for the Bocas dolphins.

RESULTS

The ten selected individuals appear to frequently occupy three core areas or hotspots, shown in red, around the archipelago: Shark Hole, the opening to Laguna de Chiriqui, and most notably, Dolphin Bay. Areas highlighted in red represent where individuals spend 95% of their time, orange represents 50%, and gray 25%. Shark Hole, the Laguna and Dolphin Bay are where the sightings are most dense and the distribution range of all the individuals overlap (Fig. 1). Dolpho3, deceased in 2016, and Piquito were reportedly always sighted together and their home ranges appear to be nearly identical. All other males of their social network also have a similar distribution (Fig. 2). All females appear to have similar home ranges (Fig. 3). All seven males appear to have similar home ranges and, with the exception of Sawy, belong to the same social network. Within that social network, however, certain individuals have a higher index of association than others. Dolpho3, Piquito, Halfin, and Littlesawy have a high association index and Panama and Curvy also have a high association index that is farther from the former group. Topnotchy and Middlenotchy belong to the same social unit but Scratchy is a member of a different unit (Figure 4).

DISCUSSION

The results suggest that although individuals' home ranges may overlap and they heavily use a shared space, reliance on the area itself does not necessarily determine social associations. Individuals can use the same space and not be sighted together, as is the case with Scratchy who shares a similar home range with Topnotchy and Middlenotchy but is not part of their social group. Dolphin Bay appears to be a critical area for all ten dolphins and within this shared space the individuals are separated into distinct social units. These findings are consistent with other studies, such as one conducted in the north Adriatic Sea, Croatia which also determined from home range overlap that the dolphin population was made of two social units and shared ranging patterns (Rako-Gospić, 2017). Another study on a population in Southern Brazil also found that despite significant home range overlap between individuals, separate social units were established. The authors reported that social and spatiotemporal patterns were the driving factors behind this phenomenon (Genoves, 2018). Researchers investigated foraging behavior in the presence of fishermen found that dolphins associate with other individuals that act in a similar manner and not for the purpose of performing the foraging strategy (Machado *et al.*, 2019), suggesting association between individuals is not purely based on resource location.

In agreement with previous studies that have shown that Dolphin Bay is a critical area, especially for mother-calf pairs, this study also find that Dolphin Bay is important to this population. Dolphin Bay provides a safe, predator-free habitat that also has an abundance of food, making it an ideal area to raise a calf and thus an important part of any dolphin's home range in Bocas. This area is also dominated with boat activity, specifically ecotourism boats which often harass the dolphins. Studies have shown that these boats negatively affect the dolphins, including collisions that result in injury and death and noise that disrupts echolocation (Sitar *et al.* 2014; Sitar *et al.* 2015). Boat presence has also been shown to interrupt and change behavior (May-Collado *et al.*, 2012; Sitar *et al.* 2014; Sitar *et al.* 2015). Despite the harmful effects of these boats, the population persistently uses Dolphin Bay because the resources it provides may be too critical for them to give up.

Investigation of dolphin home range and social associations has important implications for future conservation of this population. Further understanding of the importance of Dolphin Bay and other core areas and the social interactions occurring in these locations will guide future recommendations to protect this dolphin population's critical habitats.

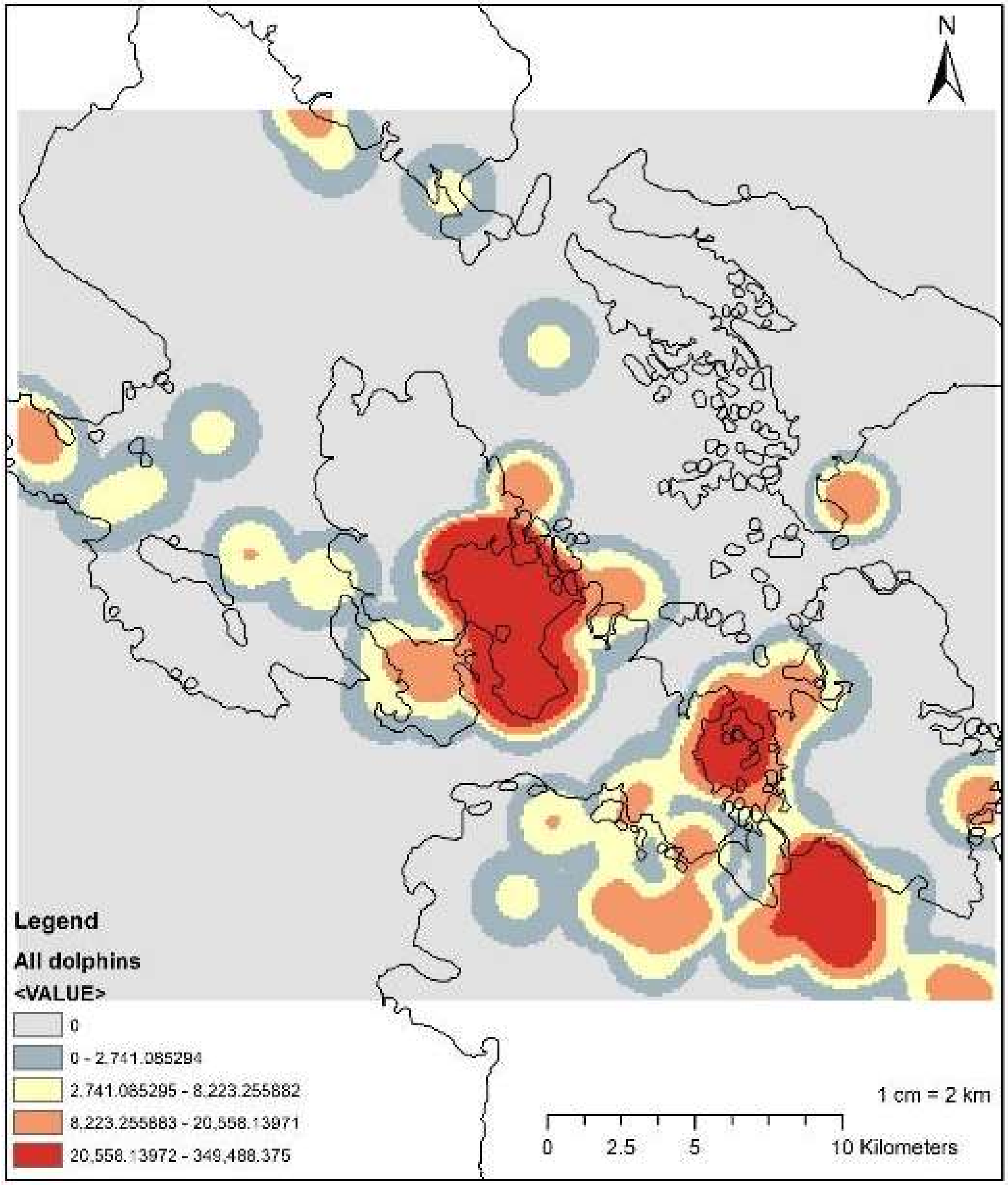

Figure 1. Home ranges for all ten individuals in Bocas del Toro compiled from 2004-2014 sighting data. Red represents core areas.

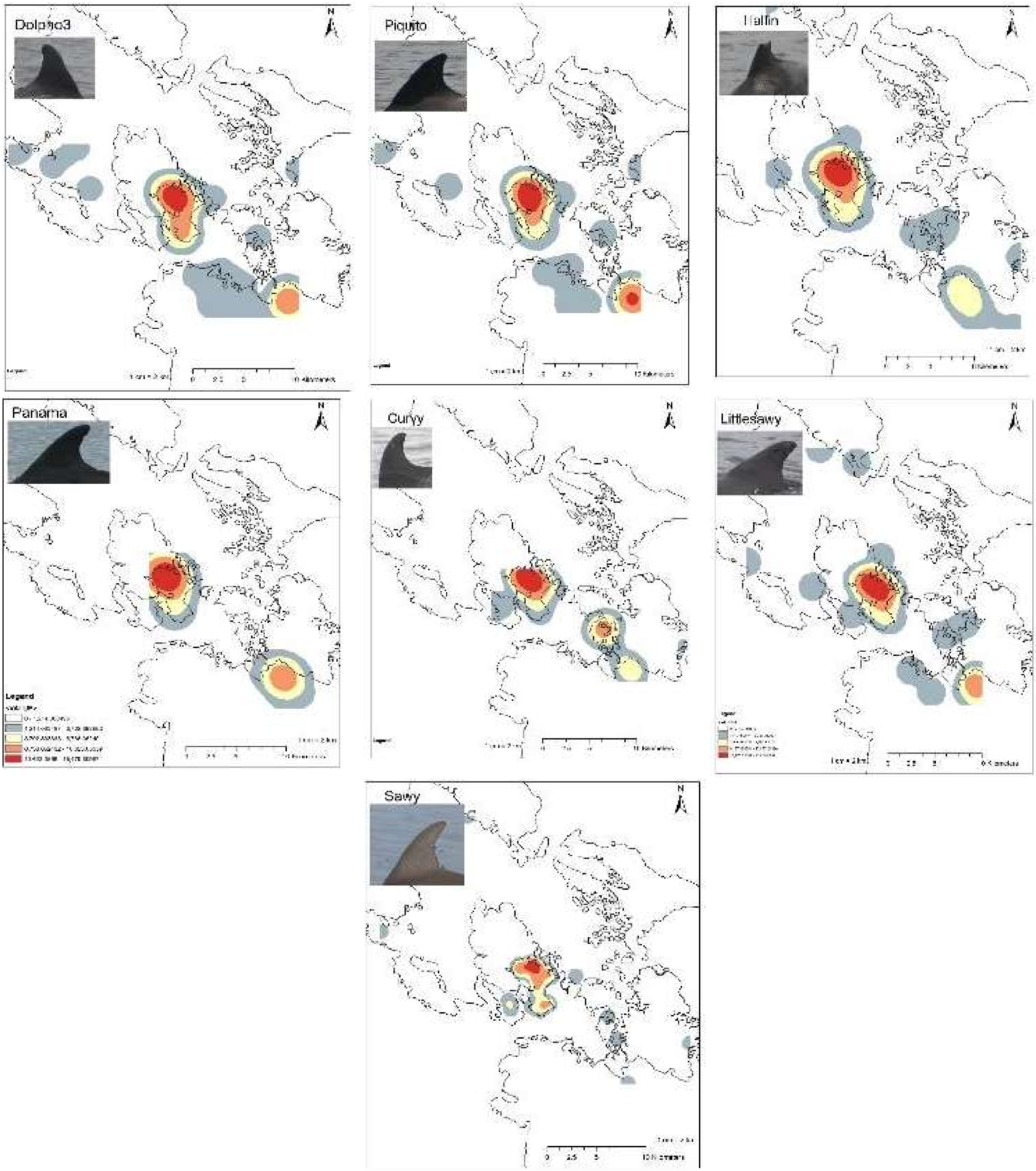

Figure 2. Home ranges for males Dolpho3, Piquito, Halfin, Panama, Curvy, Littlesawy and Sawy in Bocas del Toro compiled from 2004-2014 sighting data. Red represents core areas.

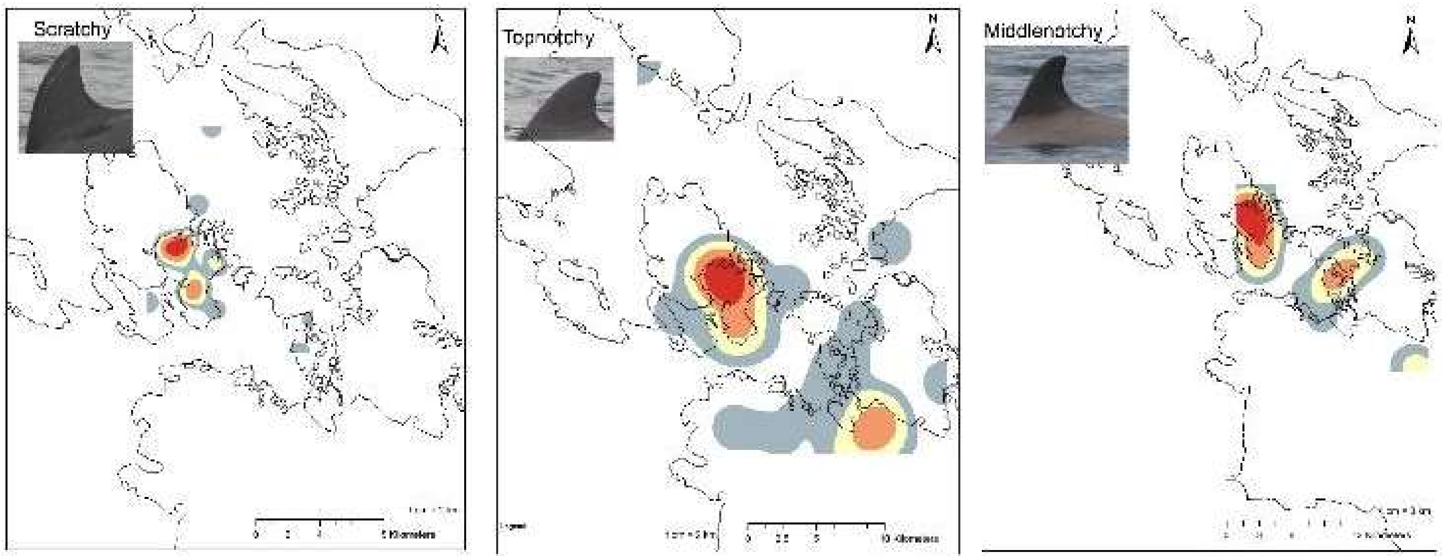

Figure 3. Home ranges for females Scratchy, Topnotchy and Middlenotchy in Bocas del Toro compiled from 2004-2014 sighting data. Red represents core areas.

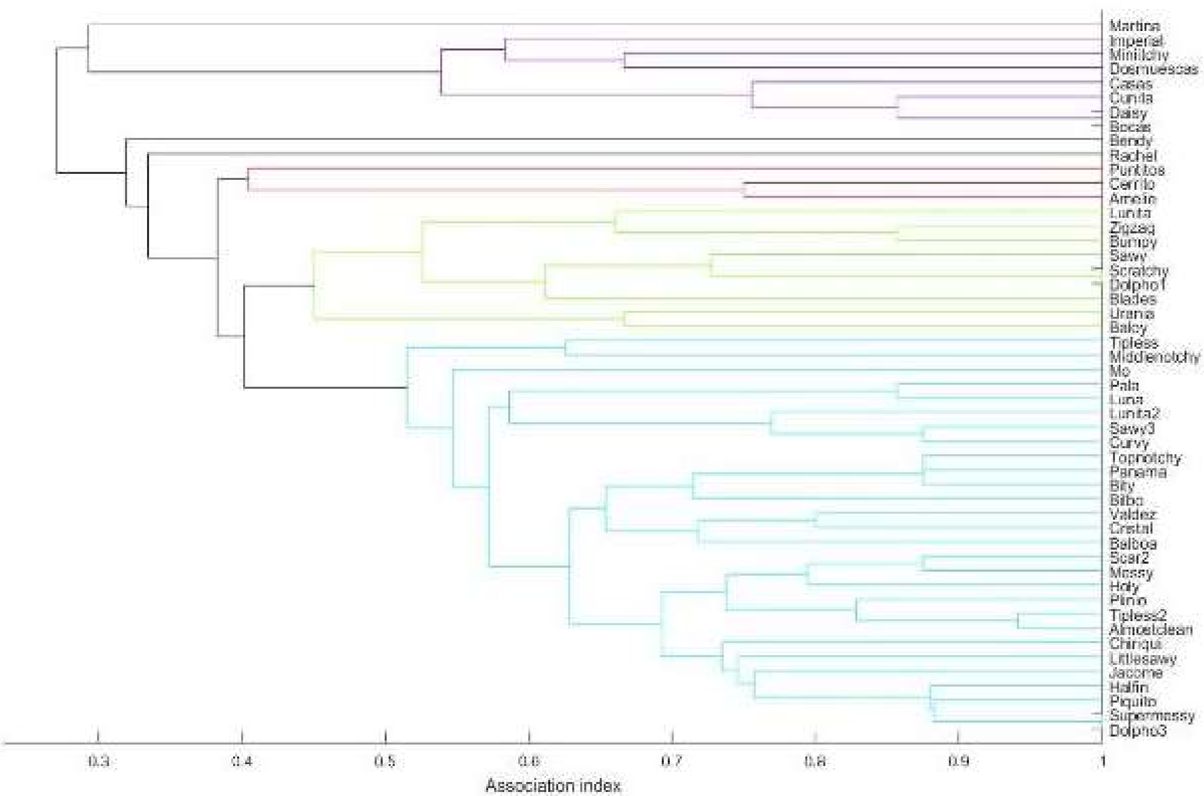

Figure 4. Association index tree containing 50 individuals of the Bocas del Toro bottlenose dolphin (*Tursiops truncatus*) population. Social units are distinguished by color.

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BEHAVIOR AND WHISTLE EMISSION FREQUENCY OF THE BOTTLENOSE DOLPHIN POPULATION OF BOCAS DEL TORO

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ABSTRACT: Bottlenose dolphins, or Tursiops truncatus, communicate using a series of clicks, barks, and whistles. Their whistles have been studied, and it has been determined that every dolphin communicates its identity using a whistle unique to itself, called signature whistles. Though, little research has been conducted to determine whether non-signature whistles vary in frequency, duration, and contour depending on the behavior type exhibited. This study examines the vocal behavior of dolphins in relation to surface behavior. This study was conducted in the Bocas del Toro Archipelago in Panama, using a resident population of bottlenose dolphins. A soundtrap and a CRT recording system were used to record acoustic data of these dolphins, which was compared to observed behavioral data of each group. The results indicate that there are significant differences among whistle frequency, contour, and duration when dolphins were engaging in different behaviors, particularly when foraging, socializing, and during fission events. Dolphins partaking in foraging behavior were found to emit low frequency whistles, while dolphins travelling were found to emit slightly higher frequency whistles, which is used as a way to compensate for distance between dolphins in communication. With the increase in boat traffic, the soundscape of this resident dolphin population has been altered over time. Therefore, the study of behavior and communication can allow for a more developed understanding of how boat traffic affects these animals and to what degree, which can be used to educate the public. This will help lead to the protection of their soundscape.

Key Words: Cetaceans, Dolphins, Communication, Tursiops Truncatus, Surface Behavior, Conservation

Communication is an essential aspect of any species, social or otherwise. It allows an individuals' needs and wants to be expressed. Marine mammals utilize a variety of methods for communication (NRC, 2003) and the Bottlenose dolphin of Bocas del Toro, Panama is no exception. They are noted to use clicks, whistles, barks, and buzzes to communicate (Tyack and Clark, 2000). These animals are reliant on acoustic communication for socialization, bonding, and transferring information (Herzing, 1996). Because water is the communication medium for all marine mammals, they use a specific form of clicks and whistles in order to find their food, socialize with other members of the population, positively or negatively, and form lasting social bonds that are essential for many of these species (Tyack, 2008).

In terms of Bottlenose dolphins, an area of specific focus in recent research is whistles, specifically the differences in whistle structure and how they may correlate to behavior. Whistles are specifically valuable, and are utilized for a variety of purposes, such as identifying oneself, communicating location, and more (Janik and Slater, 1998).However, little research has been done on the specific relationship between whistles and behavior, and how the whistle may change depending on the common behavior exhibited in the group at that time. One study conducted on Spotted dolphins, a similar species to the T. truncates, revealed that whistles are contextual, and certain acoustic parameters of the whistles when measured are reflective or related to a certain behavior (Lammers, 2006). Few studies have been carried out to this extent with the Bottlenose dolphin. Despite this, during a study looking at changes in frequency range due to behavior and boat presence was conducted in coastal Costa Rican waters on the bottlenose dolphin, which revealed that there was a distinct difference in frequency (May-Collado & Quiñones-Lebrón, 2014). Generally, lower frequencies and extended frequencies were produced with dolphin-watching boat presence. In addition, these characteristics were seen during foraging behavior, when dolphins are attempting to obtain food (May-Collado & Quiñones-Lebrón, 2014). These findings create a need for more research on the contextual nature of Bottlenose dolphins whistle structure, frequency and duration.

Recent studies have found that increasing boat presence has impacted the frequency range of all marine mammals, as the sound produced by the boats falls in the frequency range used by many, including the Bottlenose dolphin (Tyack, 2008). With increasing encroachment by boat traffic, there becomes a deeper need for the protection of the marine soundscape (May-Collado & Wartzok). The goal of this study is to determine the relationship between whistle acoustic structure and surface behavior. We predict that the contextual relationship exists, because it's a necessary component of communication and social organization

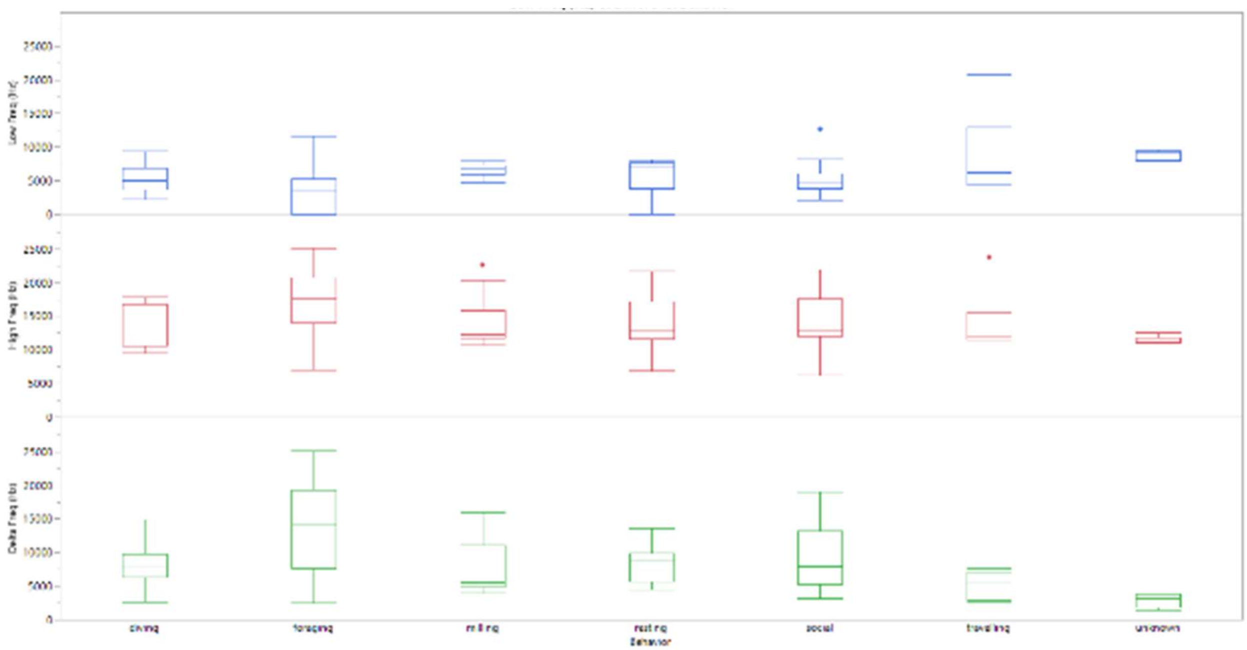
MATERIALS AND METHODS

Study Site
This study was conducted in the Bocas del Toro Archipelago, which separates the Almirante Bay and Chiriquí Lagoon from the open Caribbean Sea. The Archipelago's calm and warm waters have allowed the region to become home to a resident population of bottlenose dolphins, estimated to include 100-150 individuals. These dolphins, many of whom have been studied for over a decade, were the study subjects of this paper.

Data Collection Methods
Over the course of two weeks in early June, our research boat left the Smithsonian Tropical Research Institute at 8:00am and returned mid to late afternoon. Throughout the day, a series of measurements were taken using varying instruments, including a GPS tracking device, and two acoustic monitoring systems; a Soundtrap and Hydrophone. We used a Soundtrap 300STD (20Hz-60Hz ± 3dB, 34dB re 1µPa) and a C57 Hydrophone connected to a Spectraplus sound card (200kHz ± 3dB/-12dB). Each acoustic system allowed for the recording of clicks and whistles to later be analyzed for differences in frequency and emission type. During each sighting, GPS coordinates, time of day, number of seen individuals, observed behavior, and boat quantity/activity was recorded. Visual observations of behavior were observed and noted every three minutes or less, which when used in tandem with soundtrap and hydrophone data allowed for a comparison to be drawn between behavior and vocalization behavior.
The data collected using the Soundtrap and the C57 Hydrophone were analyzed with Raven software, using a Hano window and a 2048FFT and overlap of 50%, with the following whistle acoustic variables: low, high, and delta frequency, and duration. Tables with the following parameters were used to test for significance, and results were drawn using a nonparametric test and a Kruskal-Wallis test. These statistics were used to determine the high frequency, low frequency, and delta frequencies of whistles emitted during foraging, diving, milling, socializing, travelling, resting, and fission behaviors and the significance of the differences between behaviors was determined.

RESULTS

Our results indicate that the frequency range of Bocas Bottlenose dolphins is between 1 and 15 kHz. The measured whistle variables varied with behavior. However, when analyzed, the acoustic structure of their whistles are seen to vary significantly with behavior (Fig.1a-b). The dolphins sampled emit whistles with significantly different lower frequency during different behaviors ($x2=31.14$, $df=6$, $p<0.0001$). These differences appear to be due to dolphins emitting lower frequency whistles during foraging activities and higher lower frequency whistles during fusion-fission events, shown as unknown in referenced figures. In terms of the higher frequency range of the Bottlenose dolphins whistle, there is significant variation with behavior ($x2=20.2$, $df=6$, $p=0.0025$). These differences are shown to change as dolphins emitting whistles with lower high frequency whistles during foraging, socializing, and fission events. In addition, there was variation in whistle modulation, measured as delta frequency between behaviors (x2=35.8, df=6, p<0.0001). Again, alterations are a result of the individuals exhibiting foraging, socializing and fission events. In terms of whistle duration, differences with behavior were seen (x2=31.8, df=6, p<0.000). Whistles emitted during foraging events were significantly longer than in other observed behaviors.



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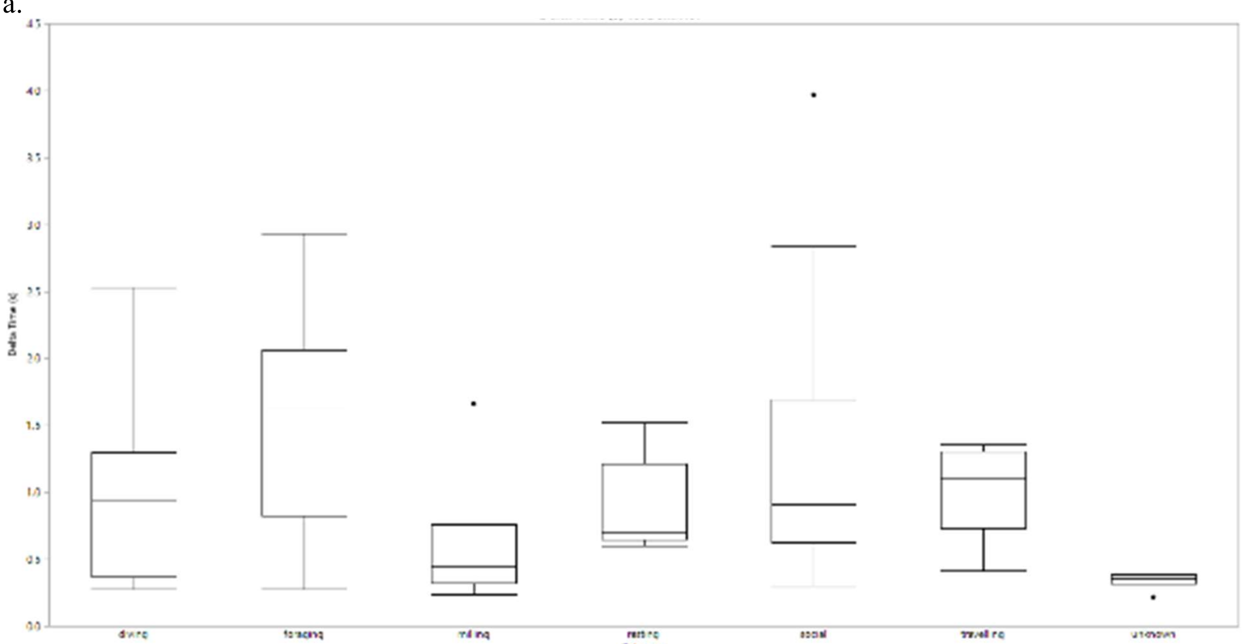

b.

Figure 1. Whistle acoustic variation in the Bottlenose dolphin population of Bocas del Toro, Panama, looking at frequency (low, high, delta) in Hertz and duration (delta) in seconds, in accordance with behavioral activity at time of the recording.

Contour of whistles were also statistically evaluated. Significant differences in the variety of whistles emitted between behaviors were found ($x2=74.4$, $df=30$, $p<0.0001$). In general, we saw that during foraging and social activities dolphins tended to emit more down sweep whistles. In contrast, whilst engaging in fission events, more sine whistle contours were produced (Fig.2)

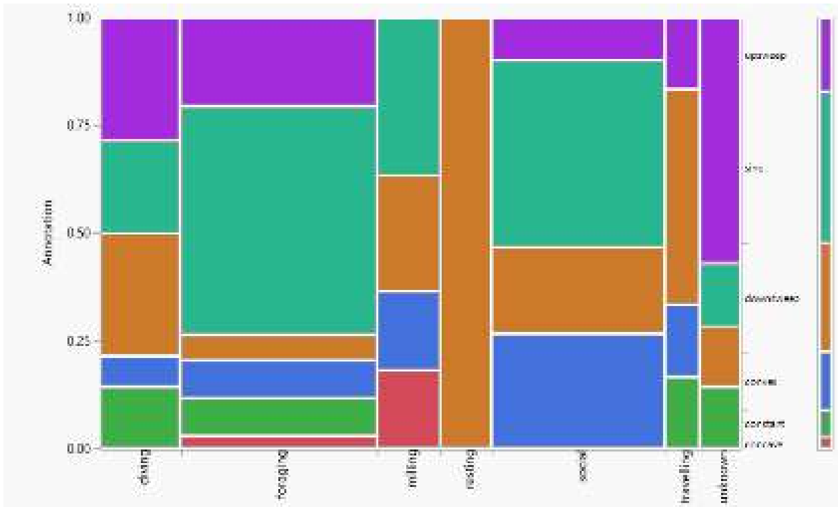

Figure 2. Whistle contour diversity of the Bottlenose dolphin population of Bocas del Toro, Panama, measured as different behaviors were observed.

DISCUSSION

Our results indicate that Bocas dolphins change their whistle structure with behavior. A previous study found that the Bottlenose dolphins of Bocas del Toro Panama have been significantly impacted by encroachment of boat traffic on their marine soundscape (May-Collado & Wartzack). Consequently, behavior and communication can give us insight as to how they navigate the ocean around them, in response to stimulation and boat traffic. In this study, the link between behavior and patterns of communication was drawn, to better understand the nature of Bottlenose dolphins in their changing environment. Whistles are a major form of the conversation strategy of these mammals. Therefore, whistle frequencies, duration, and contour were a valuable indicator of the relationship that exists between behavior and communication. These are the typical parameters used when examining bioacoustic data, as Bottlenose dolphin whistles are easily distinguishable and variable by frequency, duration, and shape (Bazúa-Durán and Au, 2004). In this study, the prominent differences were seen in foraging, social, and fission events. As expected, whistle variation existed in the frequency range of 1 to 15 kHz (Morisaka et al., 2005), however, despite the general range, key differences were noted.

The noted lower frequency range seen during foraging events is likely due to the fact that lower frequency whistles travel farther than higher frequency whistles, allowing for the dolphins to maintain communication while far apart (May-Collado & Quiñones-Lebrón, 2014). In contrast, during fission events, low whistle frequency was on the higher end of the low frequency range. We found that as dolphins come together, as is typical of species following fission-fusion population dynamics, they emitted whistles of higher low frequencies, because they were spatially arranged in close proximity (May-Collado & Quiñones-Lebrón, 2014). Similar trends were displayed when analyzing the high frequency end of whistle structure. Foraging, socializing, and fission events had lower high frequencies than behaviors such as resting, milling, or traveling. This is as expected, due to the distance changes between individuals during these different behaviors. In terms of Bottlenose dolphins, resting, milling, and traveling behaviors occur when they are in close proximity, thus higher high frequency whistles may be used. There were no significant difference in whistle structures between the behaviors of milling, travelling, and resting. In addition, overall range of frequency was greatest in foraging activities. These characteristics fit because of the complex nature of the behavior, as foraging dolphins drift apart and return together throughout this behavior type (May-Collado & Quiñones-Lebrón, 2014).

Again, foraging had a significant difference in whistle duration, as compared to other observed behaviors. This fits with previously stated expectations because of the complexity of the foraging behavior. The final parameter examined is whistle contour, which can be utilized as an identifier of signature whistles, which are unique to individuals (Janik & Slater, 1998). In the analysis of contour for the recorded whistles, we found significant differences among behaviors. Foraging, socializing, and fission events each had strongly correlated contour characteristics. Fission events were often correlated with sine whistles, which are commonly identified as signature whistles. Fission behavior is how the group composition changes. Therefore, they can be useful as unique individual identifiers. However, foraging and social events were found to be mostly aligned with down-sweep whistles. These assumptions are made based on the limited availability of research on Bottlenose dolphin whistle contour, as it is related to behavior, at this time (López, 2011). These findings are supportive of the initial assumption that whistles can be contextualized and matched with a predominant behavior being performed by the group at the time. The whistle structure and characteristics are heavily influenced by spatial arrangement and individual needs at the time of emission.

Animal communication is a vital part of the community structure and function. As environments are becoming more impacted by human presence, there is a greater need to find data to further validate their protection (Tyack 2008). Our findings reveal that behavior and communication are ultimately linked. Thus, if communication is heavily impacted by human behavior, then the behavior of the individual and group could be changed as well. In the future, further research needs to be conducted on the relationship between whistle contour and general group action, and why the trends we saw exist. In addition, how these communication and behavior patterns change, as boats continue to disrupt Bottlenose dolphin communities. This information could help strengthen the need for protection of the marine soundscape of the vulnerable Bottlenose Dolphin population of Bocas del Toro, Panama.

ACKNOWLEDGEMENTS

A special thanks to our professors and mentors, Laura May-Collado, Betzi Perez, and Heather Daszkiewicz, for their guidance and insight throughout this study. Additionally, we would like to thank the Smithsonian Tropical Research Institute of Bocas del Toro for their facilities and hospitality, and our boat captains for their expert dolphin-spotting eyes and expertise. Finally, we would like to thank our fellow classmates for their help with data collection, and their support throughout our research.

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GROUP SIZE, COMPOSITION, AND BEHAVIORAL STATE AS FACTORS AFFECTING EMISSION RATE OF SIGNATURE AND VARIANT WHISTLES IN ATLANTIC BOTTLENOSE DOLPHINS (*TURSIOPS TRUNCATUS)*

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ABSTRACT

Whistles – frequency modulated tonal sounds – have important social functions in the flexible fission-fusion societies of the Atlantic bottlenose dolphin (*Tursiops truncatus).* They can be defined into two categories: signature and variant. Both types assist group cohesion, but signature whistles are uniquely stereotypic and covey an individual's identity through its frequency modulations. While the social functions of these whistle types have been demonstrated, the factors affecting whistle emission in wild dolphins is widely unknown. Group size, group composition, behavior, and boat presence have all been investigated as factors promoting emission rate of whistles. To evaluate whether whistle emission rates or the presence of unique signature whistles can be used as a means to estimate group size, behavioral studies of bottlenose dolphins were conducted from June 3rd-10th in Bocas del Toro, Panama. Analysis of acoustic recordings demonstrated that total unique signatures were associated with group size, but signature and total emission rate were not. Greater emission rates were found in foraging, milling, and traveling behaviors but had great variability. No patterns between whistle emission and calf presence (group composition) were found. These results suggest signature whistle identification could be used as a proxy for group size when other factors are considered.

KEY WORDS: acoustic communication, acoustic behavior, contact calls, emission rate, dolphins, group size

Atlantic bottlenose dolphins (*Tursiops truncatus*) live in fission-fusion societies in which group size and composition fluctuate over time (May-Collado & Wartzok, 2008). In such a society, acoustic communication becomes an important tool to navigate an often rapidly changing social landscape. Like other delphinids, bottlenose dolphins produce whistles, a type of tonal sound that is narrow banded with frequency modulations. Whistles can be more narrowly classified into two categories: variant whistles and signature whistles (Janik et al., 2006). Variant whistles change over time and social context, while signature whistles are individual specific and maintained throughout a dolphin's life (Janik & Slater, 1998). Both variant and signature whistles function in maintaining group cohesion, while the latter specifically functions in contact calls to communicate individual identity and location. Information about the individual's identity is conveyed in the contour (frequency modulations) of the whistle, making it possible to identify a dolphin's acoustic fingerprint (Janik & King, 2013).

In the past, acoustic data has been used to track and manage a variety of marine vertebrate populations, but most existing literature on this topic focuses on acoustic telemetry. This technique uses acoustic transmitters attached to individual animals to track their movement patterns (Zeh et al., 2015). Passive acoustic monitoring, on the other hand, uses underwater microphones deployed either by a research vessel or remotely. It has been used to determine the effects of anthropogenic noise among other conservational concerns, and has great potential as a cost effective and less invasive monitoring tool (Marques et al., 2013). Nevertheless, the question still remains of what acoustic metrics can be used to estimate population size for what species. In Bocas del Toro, Panama, where this study takes place, the acoustic communication of the resident population of bottlenose dolphins has been well-studied. Boat presence has been observed to affect behavioral state as well as the vocal parameters and emission rate of both signature and variant whistles in this population (May-Collado & Warzok, 2008; May-Collado et al., 2012). Other studies on *Tursiops spp.* have demonstrated differences in emission rate based on behavior and group composition, but not group size (Santos et al.'s 2005; Hawkins and Gartside, 2010).

This study aims to fill the gap in knowledge of the potential interplay between group size and composition on whistle emission by studying both signature and variant whistles in an isolated population for the purpose of evaluating signature or total whistle emission rate as an estimator of group size. Due to the social importance of whistles in bottlenose dolphin societies, detection of whistles, it was hypothesized that group size would be positively correlated with whistle emission rate, with group composition and behavioral state as moderating variables. Lastly, it was hypothesized that identification of unique signature whistles would be correlated to group size, and an effective proxy for group size due to the stereotypy of the signals.

MATERIALS AND METHODS

Study Site and Data Collection

The archipelago of Bocas del Toro, Panama is home to a population of coastal ecotype bottlenose dolphins that have been well-studied since 2004. Behavioral surveys of this comparatively small, isolated population were conducted from June 3rd through June 10th. For each sighting of dolphins during these surveys, group size was estimated based on the minimum to maximum range of individuals observed. Presence of calves (defined as dolphins under one year of age) was also recorded. The dominant behavior across individuals for a given sighting was categorized into one of the following types: resting, milling, travelling, diving, foraging, and social. Audio recordings were taken from the research vessel. A total of three acoustic devices were used throughout the experiment: a Tascam, a SoundTrap, and a Cetacean Research Technology (CRT) hydrophone.

Data Analysis and Statistics

Sound files were analyzed manually in RAVEN Lite using a Hann window with a sampling rate of 2048. Every clear whistle was counted towards the total number of whistles emitted. A clear whistle was defined as one with clear beginning and end frequencies. Whistles were considered separate vocalizations if there was an inter-whistle gap of more than 200 ms. Signature whistles were identified using the methodology defined by Janick et al. (2003); signature whistles are whistles of the same contour type that occurred within 1-10 seconds of the other. The total number of minutes recorded across one sighting was used for in calculations of emission rate. Data was graphed and analyzed for statistical significance using Excel and JMP.

RESULTS

Neither emission rate of signature whistles was associated with group size ($R^2 = 0.032$, $p>0.05$), nor the total whistle emission rate ($R^2 = 0.044$, $p>0.05$). The number of unique signature whistles observed was positively associated with group size ($R^2 = 0.457$, $p = 0.0225$, Figure 1). The number of identified unique signature whistles never exceeded the total number of individuals, but in many recordings, no signature whistles were found. Emission rate of signature whistles or total whistles was not found to be correlated with the number of calves present in a group (Figure 2). Emission rate of both signature whistles and total whistles were found to be higher when the predominant behavior was foraging, milling, or travelling, but there were not significant differences between those three behaviors (Figure 3).

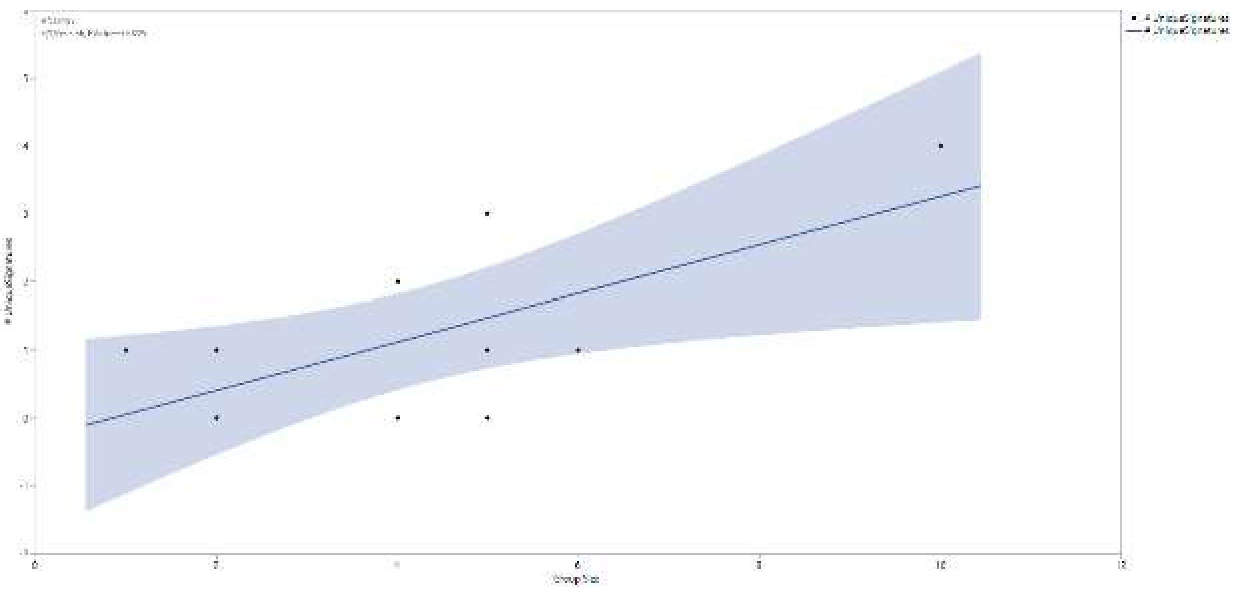

Figure 1. Scatterplot with linear regression line comparing group size (number of individuals) to the observed number of unique signature whistles

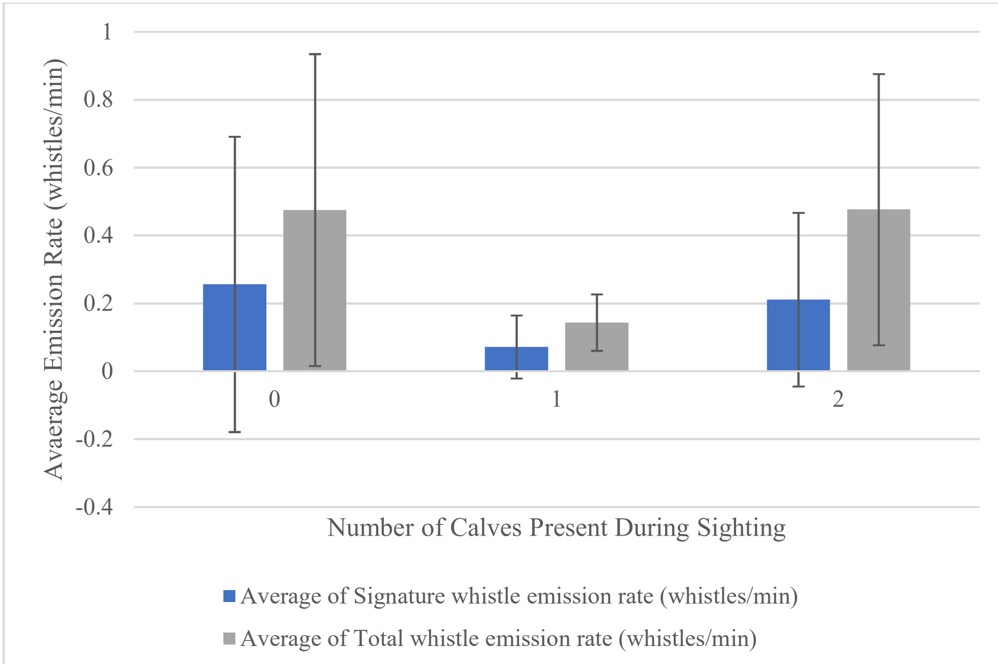

Figure 2. Signature whistle emission rate (signature whistles/min) and average total whistle emission rate (whistles/min) by the presence of calves during a sighting (from 0-2 calves).

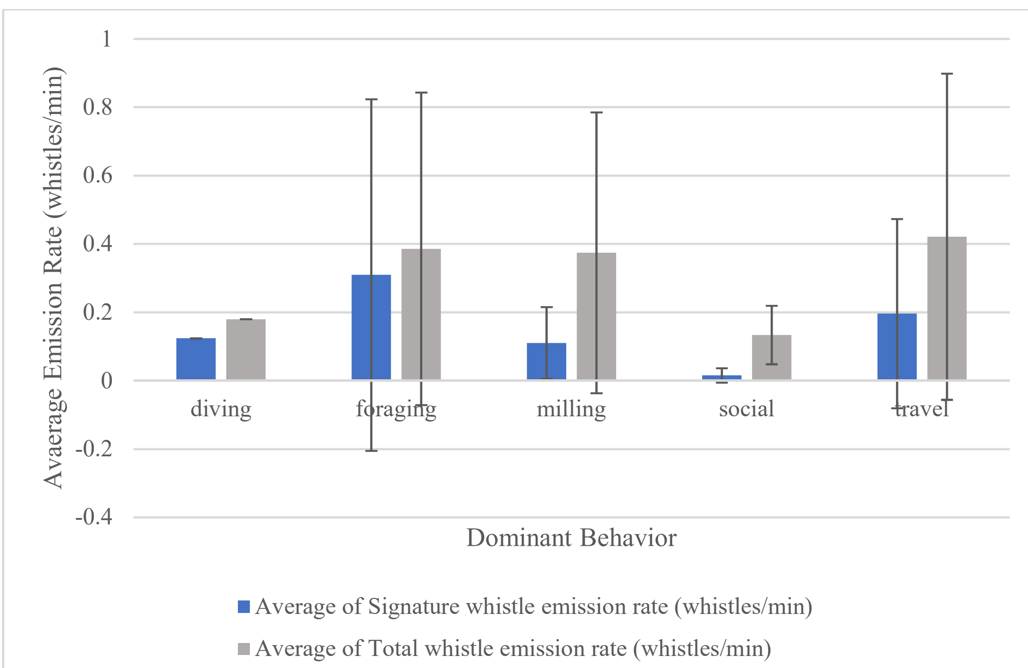

Figure 3. Signature whistle emission rate (signature whistles/min) and average total whistle emission rate (whistles/min) across five different dominant behavioral states.

DISCUSSION

There is not significant evidence to suggest that either signature whistle emission rate or total emission rate were positively correlated with group size. For this reason, I failed to reject the null hypothesis for these parameters. This lack of significance could be the result of several methodological factors. First, the overall sample size was very small. Across 58 sightings, only 12 had detectable whistles (Unpublished Data). Of those that had whistles, the emission rate was very low, with an average emission of 0.16 signature whistles/minute and 0.35 total whistles/minute. In many cases, dolphin presence was detected via clicks and buzzing, but no whistles were recorded. Additionally, average group size was 4.5 individuals, with bias towards smaller groups. The lack of variation in group size may contribute to the lack of observable patterns in group size and whistle emission rates.

Detection of unique signature whistles, however, was positively correlated with group size. While less than half of the variation in the presence of unique signature whistles can be attributed to group size, the trend I observed is still statistically significant, indicating that group size may influence signature whistle emission in combination with other currently unknown factors. Signature whistles are thought to function as contact calls, which would be especially important in mother-calf pairs, but I did not find a consistent pattern between the presence of calves and the emission rate of signature whistles and total whistles. Luis et al.'s 2015 study on bottlenose dolphins found similar results; calf presence or group behavior also did not account for all variation in emission rates. In contrast, Hawkins and Gartside found that group composition significantly affected whistle emission rate and diversity, as well as distinct whistle types associated with behavioral states (2010). Emission rates of signature and total whistles were both higher across foraging, travelling, and milling behaviors, possibly due to a greater need for group cohesion and coordination during these behaviors. The standard deviation for these rates was very high, however, so more data is needed in order to determine the significance of these trends.

Due to the lack of significant correlations between emission rate and group size, this analysis fails to demonstrate that these acoustic metrics could be effective predictors of group size. The significance of the relationship between unique signature whistles and group size is nevertheless promising. Due to the stereotypy of these whistles, signature whistles could even be used to determine identity of individuals when other methods like photo identification are not available. Some research has studied the impact of boat presence and whistle emission rate, but more research is needed to investigate potential relationships between boat presence and other variables like group size, composition, and behavior on signature whistle emission specifically (Daw & May-Collado, 2019). In order to achieve the goal of effectively modelling group size from acoustic data, more research is needed to elucidate the interplay of these variables on acoustic structure and behavior.

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THE RELATIONSHIP OF BOAT TRAFFIC AND WHISTLE EMISSIONS IN DOLPHIN WATCHING AND TRANSPORTATION SITUATIONS IN BOCAS DEL TORO, PANAMA

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ABSTRACT

Bottlenose dolphins, *Tursiops truncatus*, rely on sound that help them to communicate, forage, and navigate. These dolphins emit searching clicks, buzzing, whistles, and calls. In Bocas del Toro, the local bottlenose population is exposed to a high amount of motor boat traffic for both ecotourism and transportation. Increase of boat emissions causes physical and behavioural changes, however little is known about the impact on dolphin whistle emissions. In this study, we examine how the acoustic behavior of dolphins in two areas that vary in their type of boat traffic. To do this, we placed underwater recorders in two locations in the Archipelago of Bocas del Toro. One collected data in Almirante, an area dominated by transport boat activity, while another collected data in Dolphin Bay, an area highly trafficked by dolphin watching boats. The data suggests that there is no statistically significant correlation between boat emissions in whistle emissions in both testing sites. However, we did find significant differences in boat activity in both areas, with Almirante having the highest boat rate. We also found the highest number of whistles in Almirante. Searching clicks and echolocation clicks were also slightly higher in Almirante. Collecting data on the effect of boat traffic on dolphin communication is important in order to conserve and protect this species in an increasingly noise polluted environment.

Key words: *Bioacoustics, Tursiops truncatus, boat emissions, whistle emissions, Bocas Del Toro, boat traffic*

In recent years, cetaceans have been targeted by coastal ecotourism companies. *Tursiops truncatus* has fallen victim to this growing source of tourism. Areas within the archipelago of Bcoas del Toro are facing a rapid and disorganized establishment of dolphin watching tourism. Dolphin Bay sustains the largest dolphin watching industry in Panama (May-Collado *et al.*, 2014). Bottlenose dolphins have evolved intricate auditory production systems that allow them to use sound to communicate, forage, navigate, and detect predation (Au 1993). Because they are highly sensitive to vibrations in the water, they are susceptible to man made noise pollution. Exposures to man made noise causes physical and behavioural changes as well as making processes of conveying and acquiring information acoustically very difficult (Richardson et al. 1995). The most widespread source of anthropogenic noise pollution is from the engines of motor boats. Most medium to high frequencies created from a vessel’s engine is dues to cavitation, which is a phenomenon when air bubbles form and burst on the propeller blades. The faster the propellers move, the louder the cavitation noise is (Ross 1976). Cavitation noise is very broadband, which is problematic because it overlaps the frequency bands of dolphin noise. Since the vessel's engine masks communicational acoustics, failure to receive these signals is detrimental to the overall health of a wild bottlenose population (Gelfand 2004).

Previous studies have shown that whistle emission rate increase with the presence of boats (Scarpaci et al. 2000, Buckstaff 2004). Here we study the acoustic repertoire and emission of bottlenose dolphins in relation to boat activity. We examined dolphin watching boats, which is a threatening situation since the dolphins are specifically targeted, as well as transportation boats, which is less threatening since the dolphins encounter them in passing. From this we will be able to see that relationship between whistles and boat emissions for transport boats versus dolphin watching boats, and in which location boats have more of an effect on whistle emissions. We hypothesis that whistle emissions will increase as boat emissions increase, and that boat emissions from dolphin watching boats will cause higher whistle emissions in Dolphin Bay.

MATERIALS AND METHODS

Study Site:

The study was conducted in the Archipelago of Bocas del Toro located on the Carribean coast of Panama. The archipelago, located at 9°N and 82°W, consists of eight large islands and many small mangrove islands scattered within. The shallow clear water bay contains coral reefs, seagrass, and sand as its substrate (May-Collado *et al.*, 2014).

Recordings and Acoustic Analysis:

Sound files were collected from a locally threatened wild population of bottlenose dolphins (Barragán-Barrera *et al.*, 2017) . Two RUDAR m-K2's (96 KHZ - 169 dB re: IV/uPa) from Cetacean Research Technology were placed within the Archipelago and collected data from January, March, and April of 2018. One RUDAR was placed in Dolphin Bay, which is an area with high dolphin watching traffic, and the second in Almirante, an area with regularly scheduled transport boats passing through. These recorders were placed by the Panacetacea research team using a concrete base attached to the sea floor. Acoustic analysis was performed on Audacity 2.1.0 using spectrogram with 4096 FFT., Hann window, at 48000 sampling rate.

RESULTS

Our results indicate that both boat detection and emission rate are higher in Almirante There is a significant difference in boat noise presence rate between Almirante and Dolphin Bay (Figure 1, x^2=4.22, df=1, p=0.039). However boat emissions between each site have no statistical difference (Figure 2, p=0.134370801). Both whistle number and emission rate were higher in Almirante (Figure 2, 3). The study found that there is no statistical correlation between boat and whistle emission in both sites (Almirante p=0.09104, Dolphin Bay p=0.40022, Figure 2). The study shows that whistle emission rate is higher in Almirante than in Dolphin Bay. While whistle emissions are not statistically significant (p>0.05), there is a trend in slightly higher mean number of whistles in Almirante (figure 3). The majority of dolphin sounds emitted in both Almirante and Dolphin Bay were searching clicks and buzzing (Figure 4).

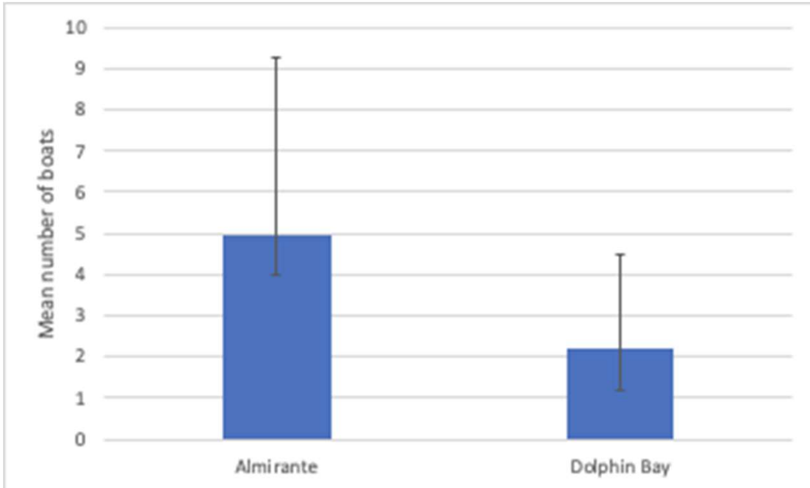

Figure 1. Mean number of boats in Almirante and Dolphin Bay of Bocas del Toro, Panama. There are significant differences in boat noise presence rate between Almirante and Dolphin Bay (x^2=4.22, df=1, p=0.039).

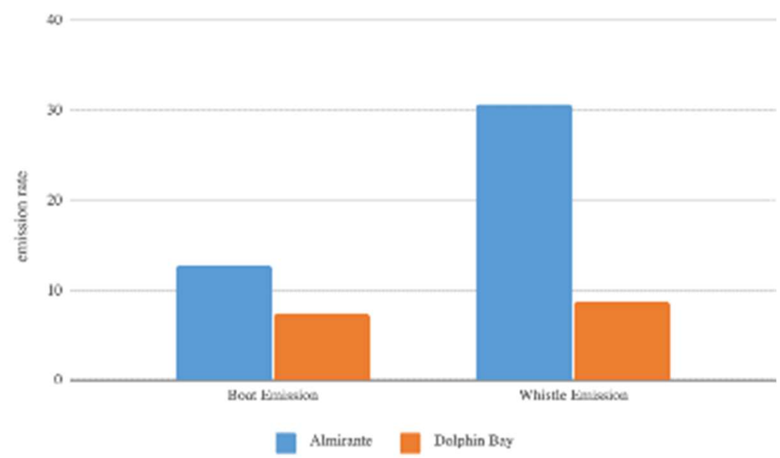

Figure 2. Average number of whistle emissions and boat emissions in Almirante and Dolphin Bay of Bocas del Toro, Panama. P-Value for boat emissions and whistle emissions in Almirante: 0.09104. P-Value for boat emissions and whistle emissions in Dolphin Bay: 0.40022. Boat emissions from Almirante compared to Dolphin Bay had a p-value of 0.1343708011. Whistle emissions comparison concluded that the p-value was 0.3124323477.

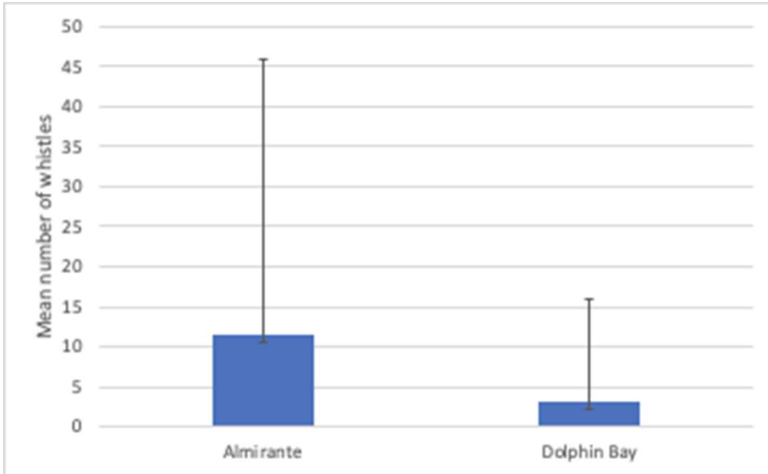

Figure 3. Mean number of whistles in Almirante and Dolphin Bay of Bocas del Toro, Panama. Variation of emission rate can be seen in the above graph. (p>0.05).

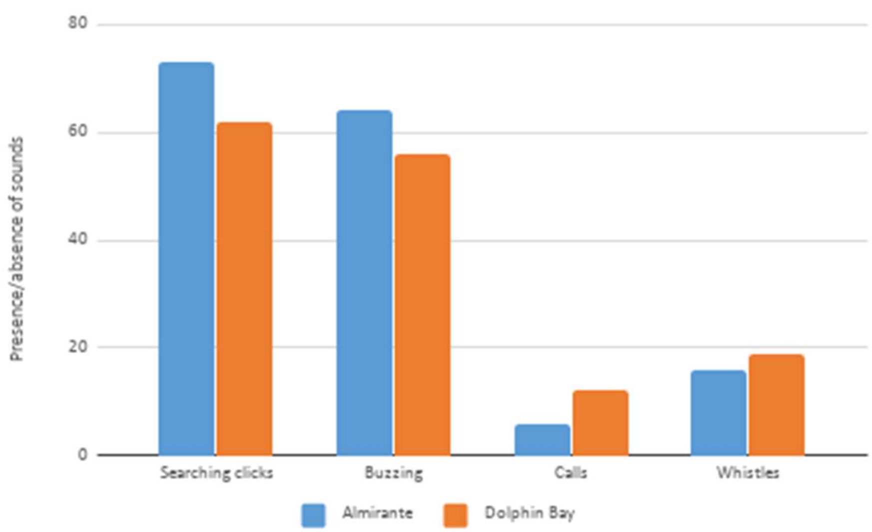

Figure 4. Dolphin sounds produced in Almirante and Dolphin Bay of Bocas del Toro, Panama.

DISCUSSION

We found that whistle emission rate is not associated with boat emission rate. However, there was a pattern of high whistle abundance in Almirante, the site with higher transport boat activity. We expected that whistle production rate in Dolphin Bay would be greater since the dolphins are specifically targeted by dolphin watching boats. In order for tourists to view the dolphins, the boats are constantly increasing and decreasing in speed to keep up with dolphins. We predicted that this sudden change will prompt dolphins to whistle more because they are trying to reunite with each other as they are often separated by the boats. However, our study finds that boat emissions for each site are nearly identical while whistle emission rates differ. This results agree with previous studies that show whistle emissions are not statistically correlated to boat emissions (Buckstaff 2006). However, this does not mean that the presence of boats do noy have an effect on the whistle emission. In our findings, we discovered that whistle emission extremely vary in Almirante and not so much in Dolphin Bay. This tells us that there could be multiple factors contributing to variation like the amount of animals present in the space and the reflection of specific behavior in that environment.

One explanation for the increase in whistles in Almirante could be due to the fact that dolphins are not being directly targeted by boats in that area, so therefore emit more whistles. The slight lower emission in Dolphin Bay may be caused by the fast acceleration and direct targeting of boats. This infers that whistling is a more social behavior or a feeding behavior that they cannot practice as much in Dolphin Bay than they can in Almirante. However, in other locations, previous studies have been conducted to observe the behavior and acoustic shifts when being approached by whistles. One study found that the impact of approaching vessels do not affect acoustic behavior, mainly changes in surface behavior occurred (Lemon et. al, 2006). Still, the specificity of the environment can have a direct effect on whistle emissions.

It is also possible that since boat noise mask the whistles, we are unable to see the whistles. Small boats emit noise at frequencies ranging from 1- 40 kHz (Albuquerque et. al, 2015), which are similar frequencies to that of dolphins. In addition, Almirante is a larger area than Dolphin Bay and may provide more resources. This could explain the slightly higher diversity of sounds, including clicks, buzzing, calls, and whistles

This study should be continued further by looking at the type of whistle rather than amount of whistle. Certain whistles are used for group cohesion. So in an area like Dolphin Bay, there might be more signature whistles emitted. The whistles emitted in Almirante could be more social or used for feeding tactics. It is necessary to note that the soundtraps are in stationary places, so the recordings may not be picking up all the sounds being emitted in that area. What sounds the RUDAR picked up on is merely by chance. In the future it is crucial that more RUDAR's are deployed in order to get many of the recordings had faint whistles, clicks, buzzes, and calls. What or what-not the soundtrap is picking up is merely due to the proximity of the dolphins to the soundtrap. Data could be fluctuated because of the few recordings with an abundance of whistles. For example, one recording from Almirante dated April 1st contains 145 whistles while other recordings usually never exceed over 70.

In conclusion, it was found that boat emission and whistle emissions do not vary depending on location, but the whistle emissions variety is different for each location. From this it is clear to say that boat emissions do not have a direct correlation with an increase or decrease of whistle emissions. However, time of day seems to have an affect on whistle emissions with more whistle emissions being produced in dark hours rather than light when boats are present. This leads us to conclude that boats have an impact on whistle variety and presence.

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Memories


Spring
Formal

Best Photo by James Grant.