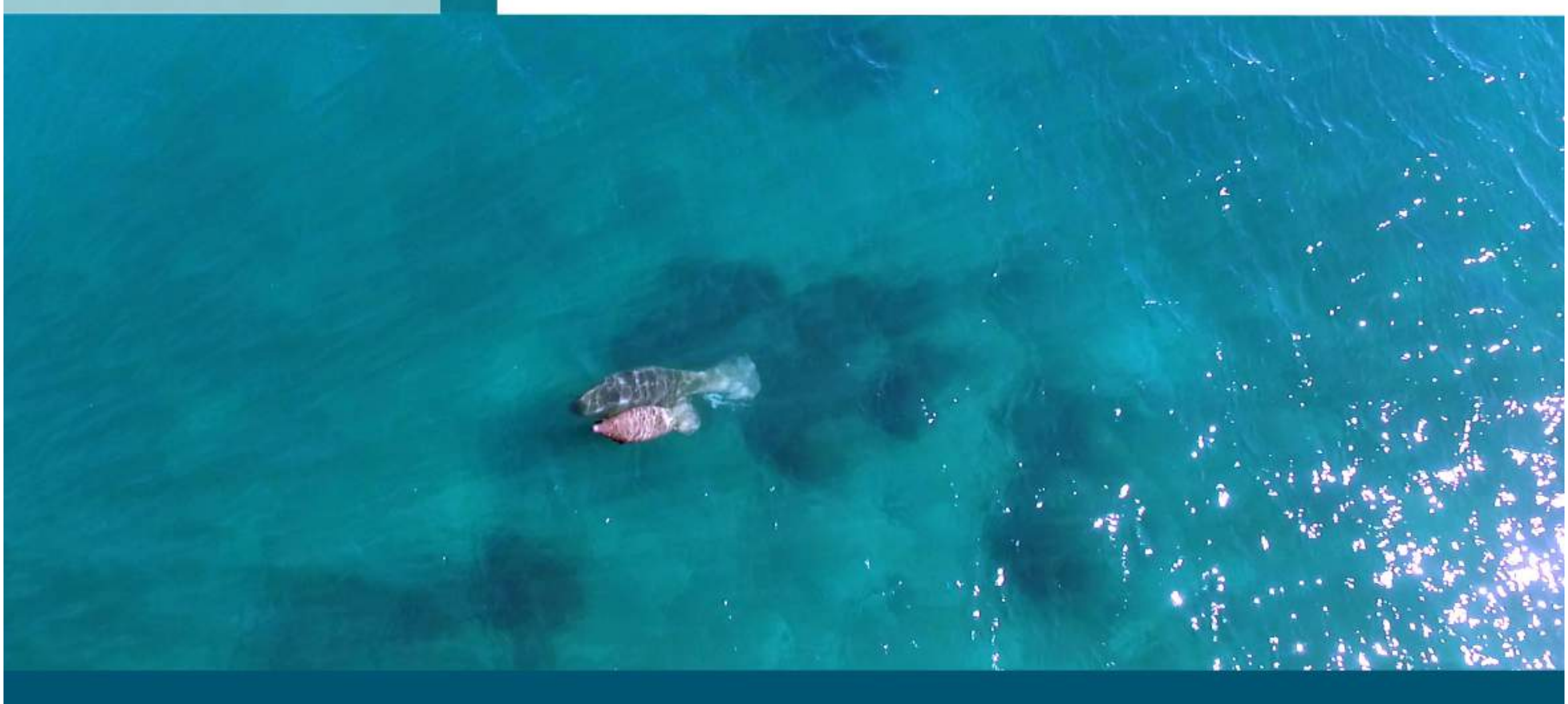
Unmanned Aircraft System (UAS) for Surveying Antillean Manatees in Puerto Rico



January 2018

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Executive Summary

1. UAS are an efficient method to quantify Antillean manatee populations in coastal areas.

2. Sixty-five total sightings of manatees were made during this study, a maximum of eleven in one day.

3. Each individual manatee can be measured to determine population structure.

4. Surveys can be programmed and re-deployed as necessary, which guarantees the same area is sampled during each replicate.

5. The UAS are portable and easy to transport, which reduces shipping costs.

6. The UAS can be assembled in a short period of time, reducing preparation and planning of missions.

7. A minimum crew of two persons is necessary to operate the UAS, training is less costly and has no risk to observers.

8. A small launch platform can be used to survey in remote areas.

9. Each survey produces a geo-referenced collection of images that can be processed, evaluated by multiple observers and provides a permanent record of that time and place.

10. This system is currently limited by environmental conditions such as wind speed, water clarity, rain, daylight, and line of sight from observer.

11. No evidence of disturbance to manatees was observed during surveys.

Introduction

Antillean manatees (*Trichechus manatus manatus*) are one of the most threatened marine mammals in the Caribbean. In order to determine their population numbers, aerial surveys have been conducted in Puerto Rico since the late 1970's. Most of these surveys have been completed with the use of small aircraft or helicopters. The most recent island-wide manatee aerial surveys in Puerto Rico were completed from airplanes between 2010 and 2014 under USFWS contract (ATKINS 2010-1014). The purpose of these surveys (ATKINS 2010-1014) was to implement a new protocol that allowed the estimation of a detection probability and thus allowing for a more reliable population estimate. Although airplane and helicopter aerial surveys are useful methods for assessing manatee population distribution and abundance, they can be logistically difficult, expensive and risky for onboard personnel (Reynolds *et al.* 2012, Hodgson *et al.* 2013).

Recent developments in unmanned aircraft systems (UAS) technology and their availability have grown significantly, leading to pursue the potential of these systems for aerial surveys to study the distribution, abundance and behavior of animals on land and in the water (Anderson and Gaston 2013, Hodgson *et al.* 2013, Christie *et al.* 2016). Recent studies of large bodied animals of marine ecosystems have revealed previously unknown behaviors and the advances in technology provide a more accurate species identification as well as potentially cheaper way to estimate true densities (Hodgson *et al.* 2016, Kiszka *et al.* 2016).

Most relevant to this study is the recent case of dugong surveys in Australia, which successfully demonstrated the potential of UAS as a tool for conducting aerial surveys (Hodgson *et al.* 2013). Hodgson *et al.* (2013) detailed a number of limitations from the traditional manned aircraft surveys that can be overcome by using UAS. Some of the benefits of using USAs include increased accuracy, human-risk free, ability to survey inaccessible areas and reduced costs. The study by Hodgson *et al.* (2013) provides a basis for conducting the proposed work to evaluate Antillean manatees in Puerto Rico. In addition, UAS can provide an unbiased estimate of manatee availability, and a critical estimate for the design of population surveys. Initiation of this pilot program will help the Department Natural and Environmental Resources of Puerto Rico (DNER) and US Fish and Wildlife Service (USFWS) maintain and improve the ability to assess, monitor and protect manatee populations with this information.

Unmanned aircraft systems are composed of individual system elements consisting of an unmanned aircraft, remote control with a control station (tablet) and any other system elements necessary to enable remote flight. The UAS coupled with cameras and sensors is able to fly autonomously by following pre-programmed paths and obtain high quality spatial data at a fraction of traditional data acquisition cost (Nex and Remondino 2014). UAS or ‘drones’ are transforming environmental management by reducing the time, skills and cost of acquiring highly accurate spatial information. On the most basic level, UAS have proven useful for the collection of near-real time, georeferenced aerial imagery for habitat, resource and wildlife mapping and monitoring distribution patterns and abundance, particularly in impenetrable and remote areas (Hodgson *et al.* 2015). Likewise advantages in aerial image processing software and associated spatial analyses are making habitat mapping a less lengthy process, helping resource managers more accurately monitor and detect changes over time (Colomina and Molina 2014).

The goal of this study is to evaluate the use of high resolution aerial imagery collected with UAS to study wild populations of Antillean manatees in Puerto Rico. In order to increase the utility of population assessments over time the objectives of this pilot study are the following:

- Assess the potential of UAS for detecting Antillean manatees in natural conditions.
- Determine the factors that are critical for the application of UAS for surveying manatee populations in Puerto Rico.
- Improve the accuracy and increase the number of aerial surveys in the study area (Guayanilla and Peñuelas).

Methods

Study area

Guayanilla Bay is located in Peñuelas, southwest Puerto Rico (18.0065 N; 66.7678 W). In the area at least two rivers discharge into the bay, Río Loco and Rio Yauco. The submerged habitats in this area are mostly composed of seagrasses, fringing mangroves and fine sediment mud bottom. Further offshore the entrance to the bay is composed of coral reef habitats that occur in emergent areas and into the deeper canyons. This bay is a highly industrialized area where petroleum and liquid gas are offloaded at piers in harbors that supply to electrical power generating plants (Appendix 1). All the mangrove keys in the areas offshore of the bay are part of the La Parguera Insular Forest designation and the marine protected area (MPA) Guánica Forest is located further west and Punta Las Cucharas Natural Reserve is located to the east (figure 1). The management of both of these MPAs is under the jurisdiction of DNER.

According to Krachey *et al.* 2008 this area is also known as a manatee hot spot for the island. Previous aerial surveys have identified the number of manatees in Guayanilla Bay (± 12 in 2014) and habitat use patterns in this area (ATKINS 2010-1014). Therefore, this provides sufficient evidence to support this site as an area feasible for the pilot study to use another technology to detect manatees.

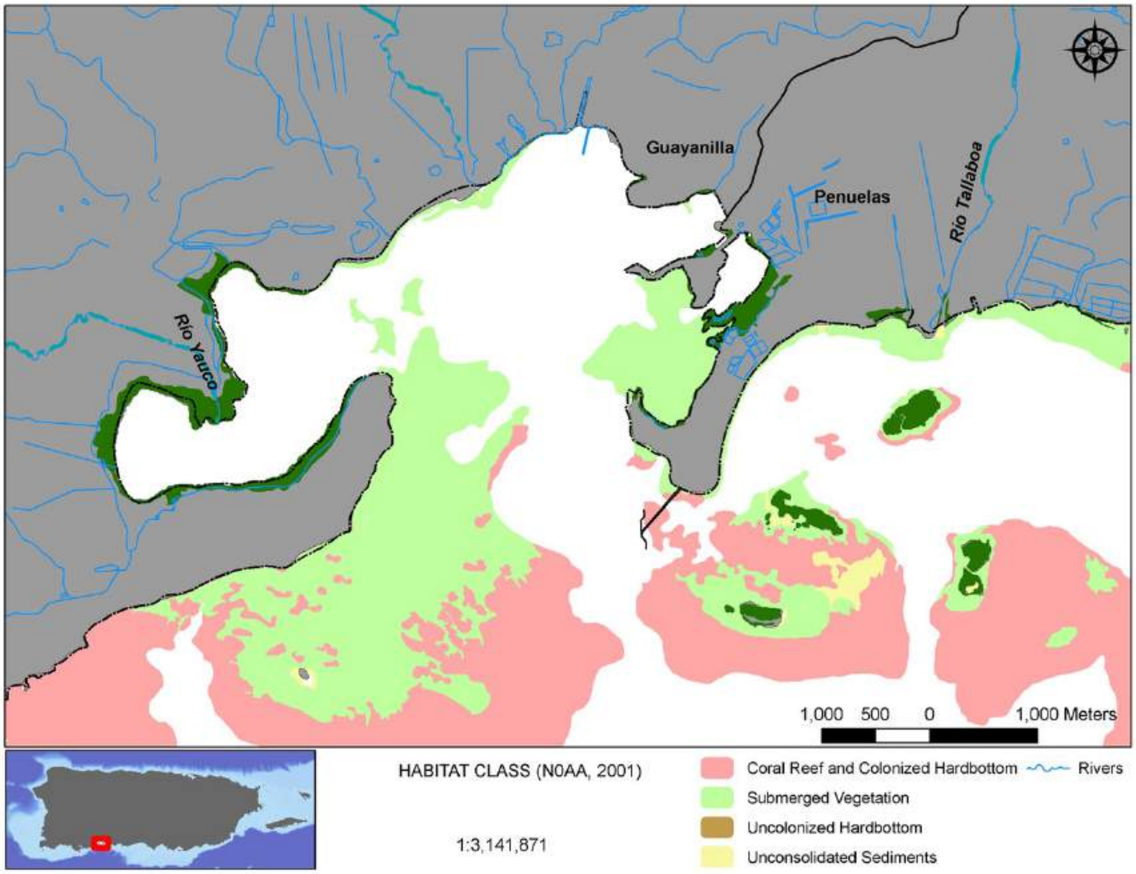

Figure 1. Benthic habitats (NOAA 2001) of the study area in Guayanilla, Puerto Rico.

Unmanned Aerial System

For this project we used the Phantom 3 Advanced (UAS) measuring 30 x 30 x 18 cm and less than 1 kg mass. This electrically powered quadcopter is made by DJI Company (figure 2). DJI is one of the largest UAS developers worldwide with 12 years of experience. Their UAS have been tested by a number of researchers investigating the use of UAS for wildlife monitoring (Ivosevic *et al.* 2015, Vas *et al.* 2015, Kiszka *et al.* 2016). The specifications of the Phantom 3 are provided in Table 1. The key capabilities of this particular UAS are the platform flexibility, stable gimbal with a rectilinear lens (lowering barrel distortion), high resolution RAW output (facilitating image analysis from hi-resolution photos), GPS module and reliability in flight.

Table 1. Specifications of the Phantom 3 Advanced UAS.

Attribute	Specification
Maximum Speed	Horizontal: 16m/s Ascent: 5m/s Descent: 3m/s
Flight Time (maximum)	23 minutes (depending on conditions)
Weight (including battery and propellers)	1280 g (2.82 pounds)
Diagonal size (including propellers)	59 cm
Camera Stabilization	3 –axis (pitch, roll, yaw)
Remote controller maximum distance	2000 m (outdoors and unobstructed)

Figure 2. DJI Phantom 3 Advanced unmanned aircraft system (UAS) quadcopter used for this study (photo credit: Jan Paul Zegarra).

The image system payload in the Phantom 3 Advanced contain a 12.4 megapixel camera with a Sony sensor ½" CMOS mounted in a 3 –axis gimbal (pitch, roll, yaw) and a FOV 94° 20 mm (35mm format equivalent) f/2.8 lens. The camera has an ISO range of 100-1600 for photos. All images were store on the camera memory card (Lexar 633x micro SD of 32GB) and downloaded post flight. Under normal operating conditions, the Phantom can fly for 18 minutes and can survey 0.25 km^2 at 2.2 cm $pixel^{-1}$ ground resolution.

The UAS was pre-programed in Map Pilot app version 2.7.2 installed in an Ipad Air 2. Each mission was planned with the help of a kml file showing the flight zones to be surveyed (figure 3). Failsafe logic within the autopilot was programmed to return the UAS to the landing zone if it experienced anomalies or exceeded a maximum flight time of 15 minutes. In an extreme emergency (were the UAS does not respond to autonomous pre-programed return commands) the UAS can be manually controlled by a push of a bottom in the radio control.

System Software

There are a number of software applications required to operate the UAS and allow the collection of data and image production for analysis. The following is a list of system software applications used to operate the DJI Phantom 3 Advanced (airframe/controller; payloads; flight planning) and create information useful for the manatee detections.

1. DJI GO App- UAS and camera control: https://www.dji.com/goapp

2. Mission planner (Desktop)- https://www.mapsmadeeasy.com/point_estimator

3. Map Pilot App- (iOS only)- planning and conducting of UAS flights (figure 4); https://www.dronesmadeeasy.com/Articles.asp?ID=254

4. UAS Flight restriction and weather Mobile Apps

   a) Wunderground (real-time weather): https://www.wunderground.com/download

   b) Windfinder (wind forecasts): https://www.windfinder.com/apps

c) Before You Fly (flight restrictions & requirements): https://www.faa.gov/uas/where_to_fly/b4ufly/

5. Post-processing, counting and measuring software (Desktop): Photoshop CS5.1

During each mission a UAS mission logbook (Appendix 2) was used to record details of each UAS mission, flight/times and the flight inspection and checklist conducted. After each flight, the observer was responsible for completing the mission data sheet as it serves as the official statement documenting each UAS mission operation and the procedures applied. The logbook checklist is a useful method to avoid UAS accidents. The UAS remote pilot certificate number used during this study was is 3960481.

According to the Federal Aviation Administration (FAA) the use of UAS is restricted to the following rules:

1. No operations are allowed in restricted areas like airports, heliports, military bases, correctional facilities, power plants, critical areas, national parks and highly populated areas. Any planned flight in these restricted areas must request permission to fly and be approved by authorities in advance.

2. Daylight-only UAS operations (Official sunrise to official sunset, local times) are permitted.

3. Visual line of sight (VLOS) flight only, the unmanned aircraft must remain within VLOS of the operator.

4. Pilot in Command (PIC) must use visual observer at all times. No Person may act as an Operator or Observer for more than one UAS operation at one time.

5. Minimum weather visibility of 3 miles is required from control station

6. Maximum flight altitude of 400 feet (121 meters) above ground level (AGL).

7. PIC must yield right of way to other aircraft, manned or unmanned.

8. UAS may not operate directly over groups of people.

9. Pre-mission inspections are required: prior to leaving for the field, once on-site, and before each repetitive flight.

It is also a requirement of the FAA that all UAS airframes and operators are registered (our UAS certificate number is FA39MPNXPF). Moreover, commercial uses of UAS require a remote pilot certificate with a small UAS rating. The following fundamental requirements are recommended to obtain a commercial UAS license:

1. Be at least 16 years old
2. Be able to read, speak, write, and understand the English language
3. Be in a physical and mental condition that would not interfere with the safe operation of SUAS
4. Fulfill training and testing requirements

Mission Programming

Missions were planned prior to and only conducted under optimal weather conditions, which include no rain, low wind speed (less than 15 kts) and calm seas, which favor higher visibility. Surveys were divided in four to three areas inside each of the three flight zones. The UAS was programmed to cover an area of 0.25 km^2 per flight (due to battery limitations) over predetermined zones (figure 4). In order to cover a complete zone, three to four flights were required. Each zone (1,2,3) was sub-divided into three or four sections with dimensions of approximately 500 m x 500 m, which provided a complete coverage area of 1.0 km^2. Each survey zone consisted of 13 parallel lines of 500 meters in length. The lines were spaced with overlap to provide complete coverage of the area during the survey. This was achieved with a 50% latitudinal (frontlap) and a 50% longitudinal (sidelap) to cover the target during each flight (battery capacity). All flights were programmed for an altitude up to 90 meters, in compliance with FAA regulations. Each mission was expected to last between 12-15 minutes.

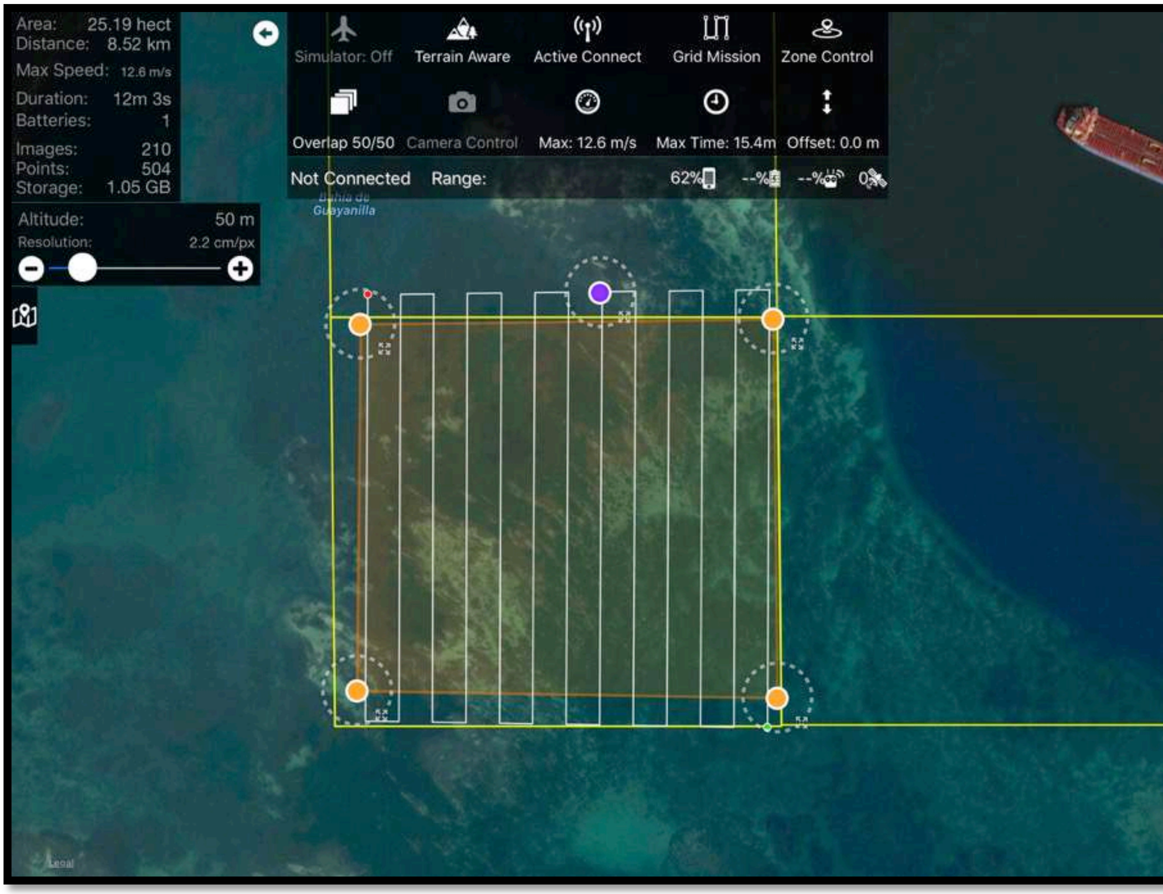

Figure 3. Plan mission using Map Pilot app.

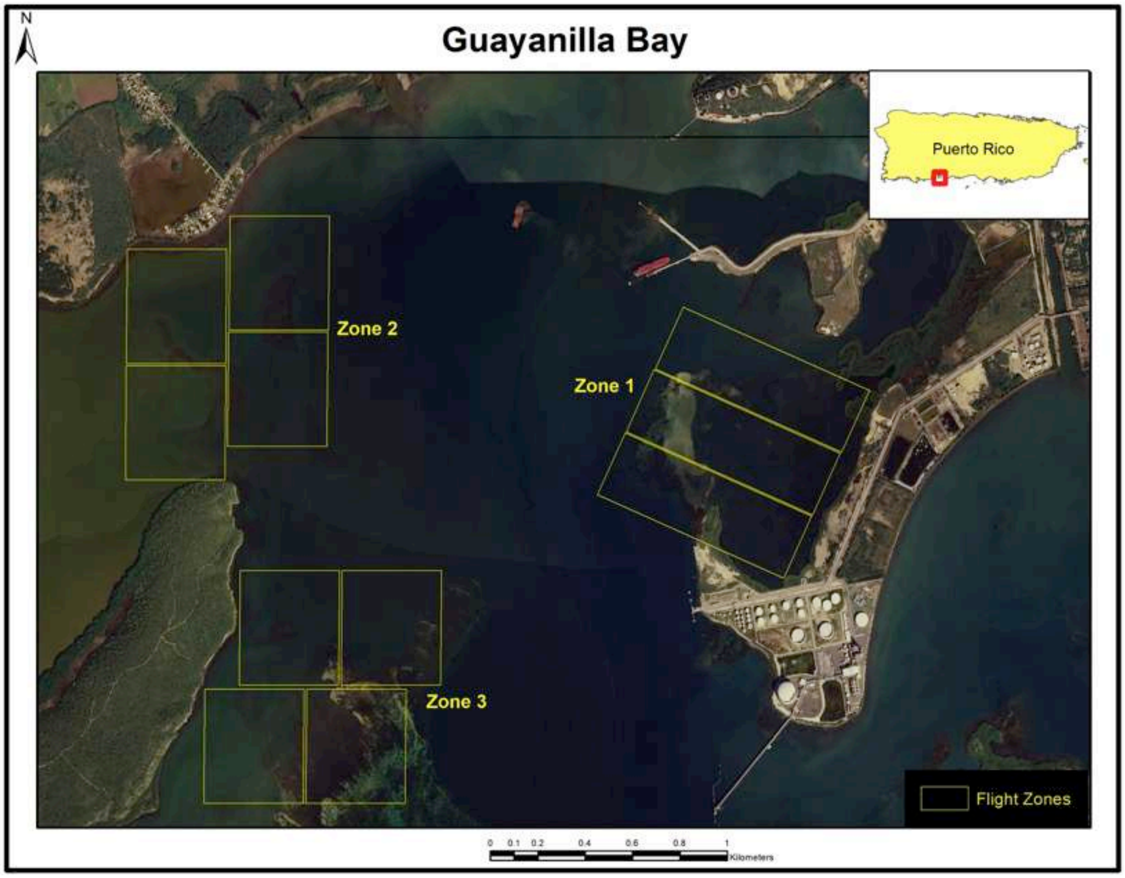

Figure 4. Flight zones delimited within the study area.

Flying missions

The vessel was anchored in the middle of each zone to be flown, which allowed executing four missions without moving. This also gave the AUS a constant return to home location in case of abort mission or emergency call back. A small buoy was attached to the end of the anchor line for a quick release in case a situation arose where the AUS required capture or getting closer. The observer in the vessel helped the pilot with AUS compass calibration and inspection prior to every mission. During missions the observer scanned the skies for other possible air traffic or objects aloft or on the water. A fully charged battery was used for each flight mission. The aircraft was launched and recovered from a research vessel by hand (figure 5).

Figure 4. UAS recovery at the boat (photo credit: Jan Paul Zegarra).

Image analysis

Post-flight, the data was extracted from the drone via micro SD of 32GB and downloaded to a 16TB My Book Duo Desktop RAID External Hard Drive for storage. Images of the AUS missions were organized in folders of dates, zones and areas. For each mission two observers manually reviewed the hi- resolution 12 megapixel images. Each manatee sighting was recorded in each image following Hodgson *et al*. (2013). Sighting data were recorded as the number of juvenile/adult Antillean manatees, the number of calves, date, time, altitude, zone, area, and activity. Individual animals re-sighted (double counted) in successive images along each transect could be identified and were subtracted from the count of individuals for that image. All images containing manatee sightings were then re-checked by the same reviewer to ensure manatee counts and associated sighting data were accurate. Manatee length was estimated to the nearest 0.1 m for each sighting using Photoshop CS5.1 after calibrating the image to centimeters based on the altitude. Each photo was zoomed to 200%

and the distance between the snout to the end of the tail was measured with the function ‘Ruler Tool’ in Analysis section of the program.

All flight logs were downloaded for quality assurance and quality control (QA/QC) and stored with each photo set. These files recorded 59 parameters (latitude, longitude, altitude, time, sats, speed, range, battery, roll, picth, yaw, images, high definition signal, remote control signal, battery temperature, ect.) during each flight in comma separated values file (CSV). All original imagery used in completing this project is available from the authors upon request and provided with this report. More information available at HJR Reefscaping webpage: Http://www.hjrreefscaping.com/web/.

Results and Discussion

Over the course of a year (November 2, 2015 to November 29, 2016) 88 missions were completed in the study area. The first missions were used to refine the parameters (altitude, speed, cover area) on the app that controls the UAS (Map Pilot) and create the best images for manatee discrimination. Different factors were observed to affect the sighting probability of Antillean manatees in Guayanilla Bay.

Altitude

The UAS were flown at an altitude of 75 meters which generates a 3.2 cm/px resolution and a reduced flight time (around 8 minutes) to cover 0.25 km^2. At this altitude (75m) manatee identification and measurement was unfeasible (figure 6). At this altitude the manatees are harder to detect in the photo and when the image is enlarged measurements of length were not possible. In order to meet project objectives, the altitude was reduced to 50 meters, which increased flight time of 13 minutes and a resolution of 2.2 cm/px. However, during field tests most flights at this altitude were aborted because battery levels were below the 30% safety recommendations suggested by the manufacturer. Finally, it was determined that 55 meters altitude was ideal for the objectives of this project (figure 7).

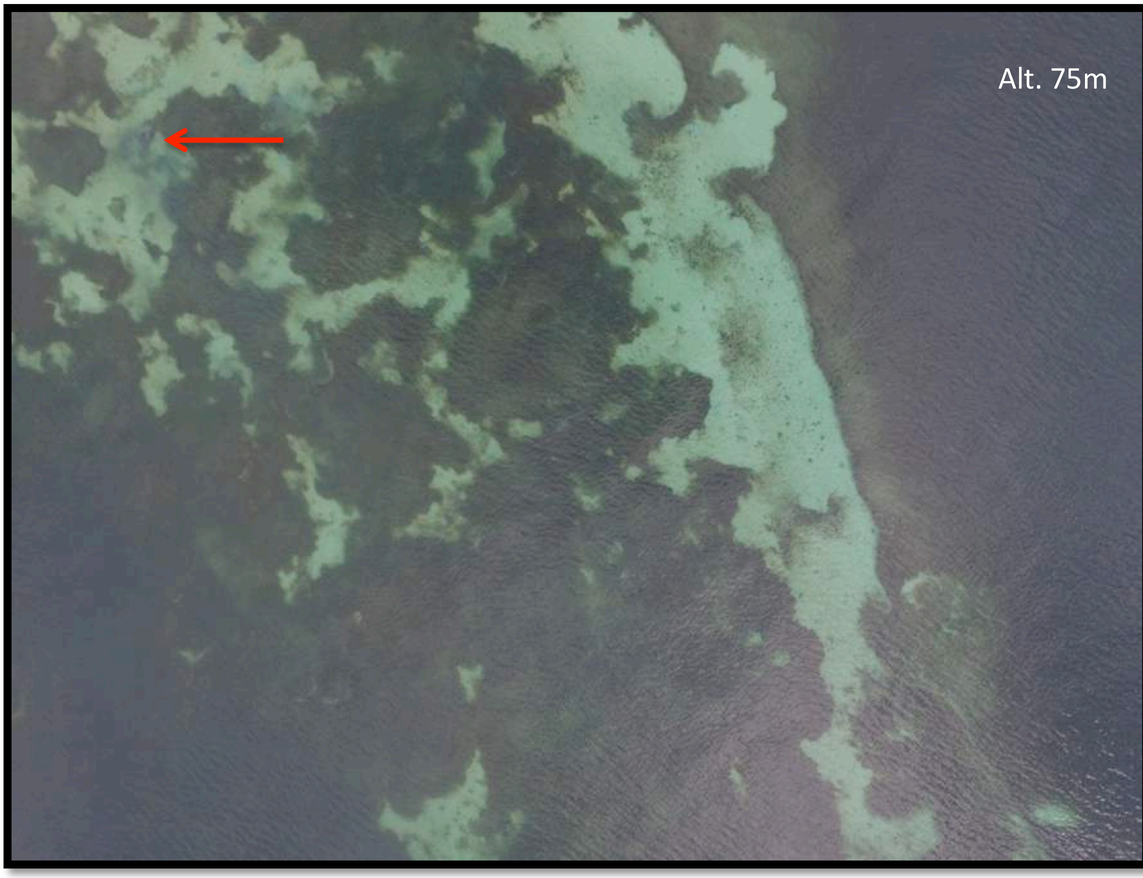

Figure 5. Photo taken with the AUS at an altitude of 75 meters, a manatee detection shown with the red arrow.

Figure 6. Photo taken with the AUS at an altitude of 55 meters, an adult manatee and a calf sighted clearly shown with the red arrow.

Environmental conditions

Environmental conditions affected image quality in different manners, which alters the detection probability of manatees. Factors such as water clarity, wind speed and solar reflection (sun glint) must be considered during flight programming. Of these factors, water clarity is the one less likely to be anticipated or effectively mitigated. When the water is clear the manatee sightings are highly successful (figure 8). Water in the study area is affected by many factors such as sediment from land and rivers, resuspension of marine sediments during wave action, phytoplankton blooms, algae blooms and vessel transit to the harbor. When water quality is poor, manatees can be sighted only when they are near the surface (figure 9). To mitigate these factors flight scheduling should be avoided on windy days, and water quality monitoring *in-situ* is necessary.

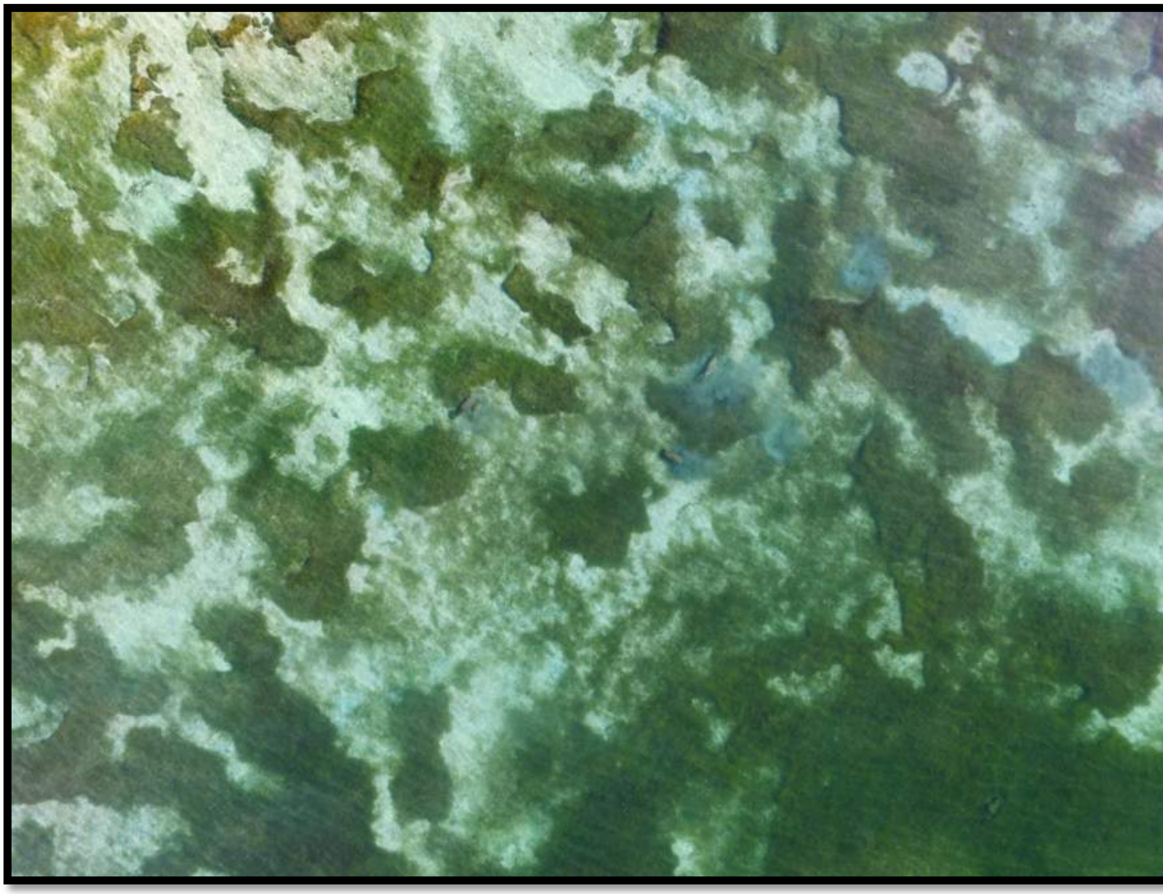

Figure 7. Photo of clear waters with 4 manatees sighted.

Figure 8. Photo of manatee on the surface in poor water quality conditions.

Water clarity is affected by wind speed and as the wind increases the water surface becomes uneven or rippled and thus decreases light penetration beyond the surface. Detection of manatees located near the seafloor in deeper areas is significantly reduced especially if combined with deteriorated water clarity. In order to avoid these water quality and visibility problems we concluded that the best time to plan for the flights was early morning. On average winds tend to be calmer during early morning and increase in the after noon. The resulting working time window was usually less than three hours long. In this time frame eight 0.25 km^2 (1 km^2) flights or approximately 12-15 minutes long were completed. Flights occurred between 8:00 and 11:00 h, and only when visibility conditions were optimal.

Sun glint is another factor that needs to be considered when planning flights. Sun glint is an optical phenomenon that occurs when sunlight reflects off the surface of water at the same angle of the camera lens or sensor. The result is a mirror-like specular reflection of sunlight off the water and back at the lens that results in a shiny gleam (figure 10). This gleam of overexposed area in the photo usually starts at the edge of the picture during the morning and subsequently moves to the center of the picture at mid-day. Images with a high percent of sun glint hinder the detection of any organisms in that photo thus reducing or avoiding its effects is extremely important. In UAS surveys conducted during this project it appeared that overlap between successive images (along the transect line) and timing the flights during early morning were sufficient to mitigate the sun glint problems. During early morning the percent of the image affected by sun glint did not exceed 40% and its effects were counteracted by planning flights with end lap (overlap of subsequent pictures along the transect) settings of 50%.

Figure 9. Photo taken in the study area with a high percent of sun glint.

Planning specifics

Planning flights with parameters of 50% of overlap in both dimensions (side lap and end lap) also helped maximize battery efficiency to safely complete the target area of 0.25 Km^2. Although the factory specifications of the quadcopter state the battery can last for 23 minutes this time span was significantly reduced in the field due to windy conditions. The effective battery duration for an average wind condition in Guayanilla Bay (10 kts) was 16 minutes. The software used for planning and autonomously executing the missions was primarily designed for photo mosaicking thus its default parameters were set to a vey high overlap (70%). Since creating mosaics over water is not feasible (with current software available), we adjusted the overlap parameters to 50%. This amount of overlap combined with a set altitude of 55 m allowed us to complete the target area with one battery during normal wind conditions. These settings also counteracted detections missed due to sun glint, and identifying animals initially captured at awkward body angles. An average of 1.5 hours is needed to survey a 1.0 Km^2 area.

Manatee observations

The images taken during surveys covered a combine study area of 20.25 km^2. A total of 16,471 images were analyzed for manatee detections. Of all images capture along predefined flight paths, across all surveys, a total of 40 images contained positive sightings of manatees. The total count, after eliminating double sightings from overlapping images along the flight line, is of 65 manatee sightings, including 8 calves. When standardized to area, this provided an average density of 3.2 ± 1.2 individuals per Km^2. A maximum of eleven manatees were sighted in one day (two zones covered).

Of all these sightings manatees were feeding in 48%, swimming in 40% and resting in 12% of the instances. Feeding or foraging behavior can easily be distinguished from swimming in the photos by the presence of a sediment plume as manatees pull the seagrass from the seafloor. Swimming was determined by sightings in consecutive images where the distance travelled could be detected or if near the seafloor a wake was produced in the seafloor sediments (figure 11).

Manatees were determined to be resting if there was no movement between successive photos and no wake in the sediment or surface layers was evident. Calves were distinguished in these surveys as manatees that were relatively smaller in total size, usually in close proximity to an adult manatee, presumably the mother (figure 12).

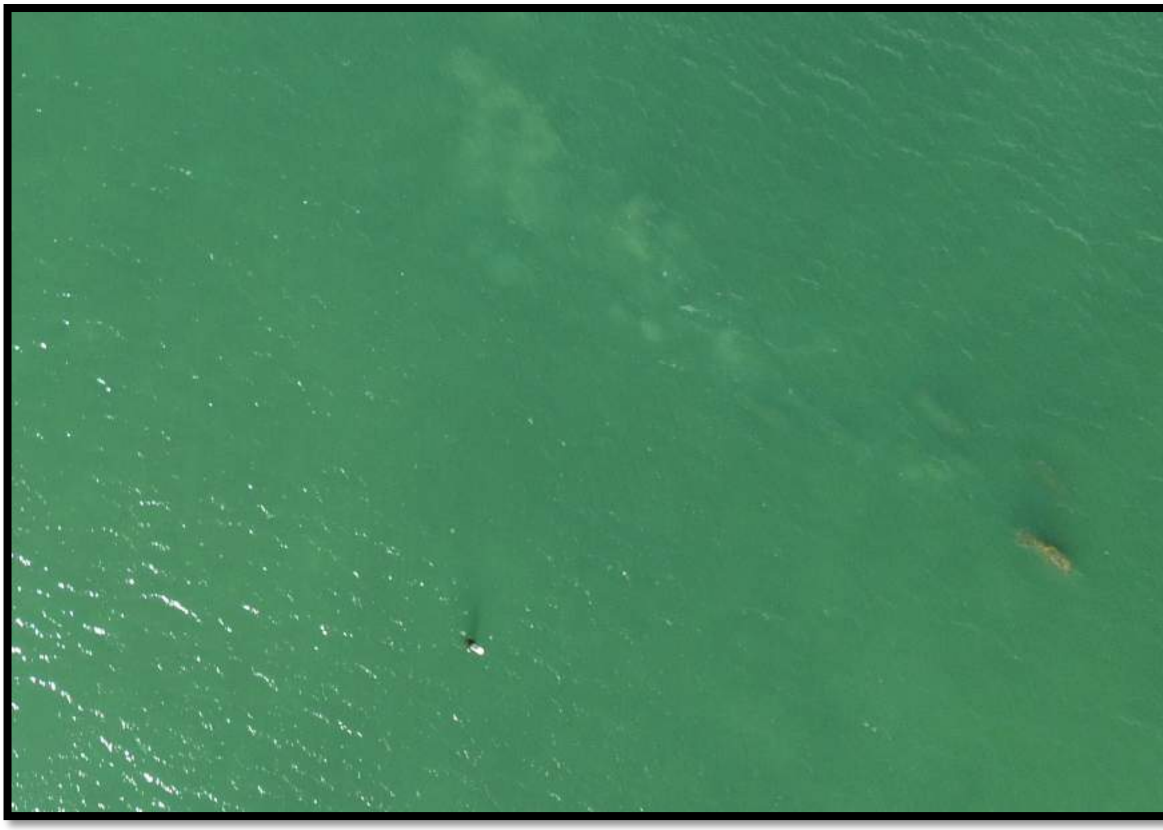

Figure 10. Photo of manatees swimming near a buoy with evidence of sediment plumes left by tail movement behind them.

Figure 11. Manatee calf and adult.

Size structure

Only manatees that were completely visible from head to tail were measured. Photos with the presence of the research vessel were used to corroborate measurements after calibration at different altitudes. Manatee lengths of 65 animals were calculated in two separate groups, calves and non-calves, which could be juveniles or adults. Non-calves had an average of 2.28 m ± 0.32 SD ranging from 1.8 to 3.0 m. Manatee calf mean size was 1.47 m ± 0.25 ranging from 1.0 to 1.7 m. A size frequency distribution evidences that most of the manatees sighted were in the 2.0 - 2.5 m size category (figure 13).

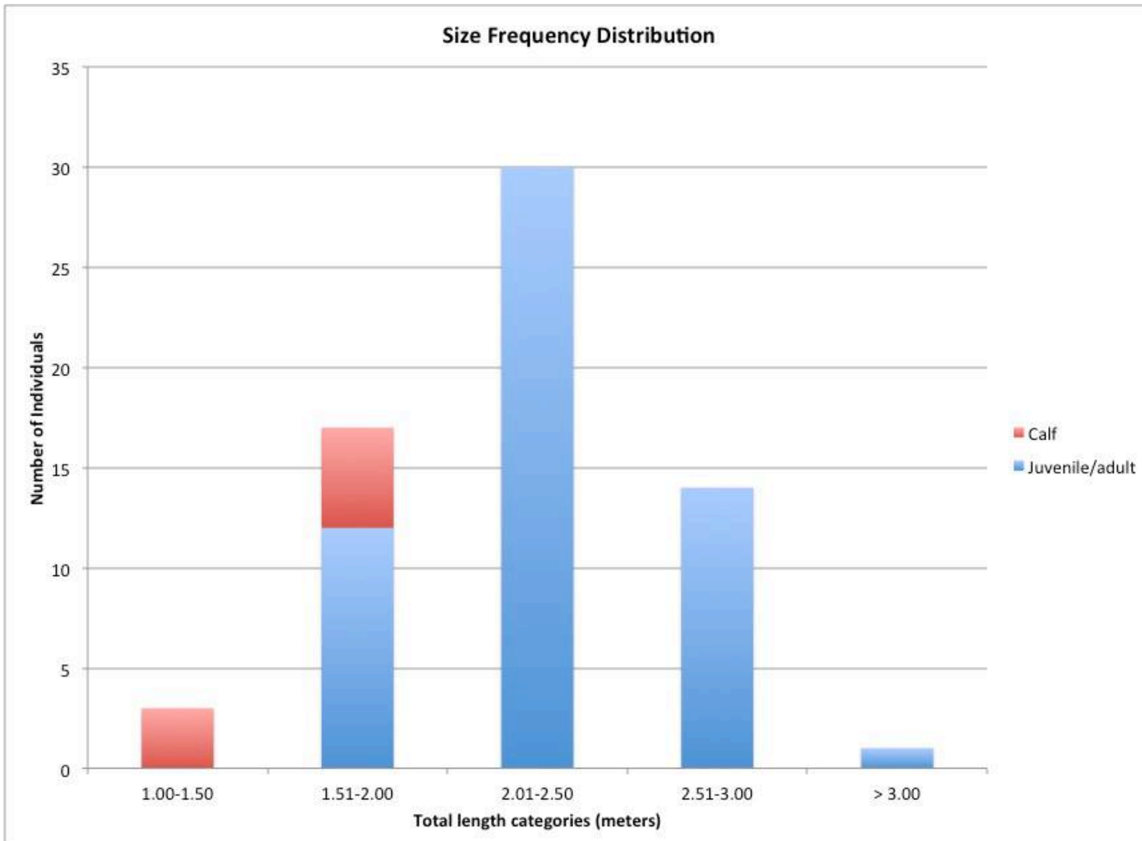

Figure 12. Size frequency distribution of manatees measured (N=65).

According to Odell 2009 manatees in Florida of this range of sizes are mostly in the age class > 1 and < 2 years. However, a manatee mortality study conducted in Puerto Rico categorized manatees into three age classes: calves (<1.75 m total length, <2years old); Sub adults (1.76 m total length, 3-7 years old); and adults (>2.25m total length, >7 years old). This was determined using histological analysis of tympanic bullae or in case of adulthood and sexual maturity, by examining the carcasses for pregnancy, lactation, or histological analysis of gonads (Mignucci *et al.* 2000). Therefore, the sub-population sighted in Guayanilla are of lengths corresponding to sub-adults and young adults.

Spatial patterns

Of all the manatee sightings recorded 57.5% were in Zone 3 and of these 35% were in the lower southeast quadrant of that zone (figure 14). Zone 2 was the next highest area of sightings with 25% with most associated to the shallow < 2 m depth areas of seagrass habitat within this zone. Finally Zone 1 had 17.5% of the sightings located in the north eastern section. Most of the detections were within the 2 m depth contour in the survey zones.

Depth was the most critical factor that influenced the detectability of manatees, because they spend much of the early part of the day feeding in shallow seagrass habitats. Habitat areas less than 1 m depth were not accessed by these manatees, although food is available. Water quality is another factor that may decrease detectability unless manatees surface to breathe or are swimming close to the surface. A potential solution to determine if the manatees are present or not would be simultaneous observers to quantify manatee activity in areas of low water quality. This availability bias could be used to model the detectability of manatees in areas of less than suitable water quality.

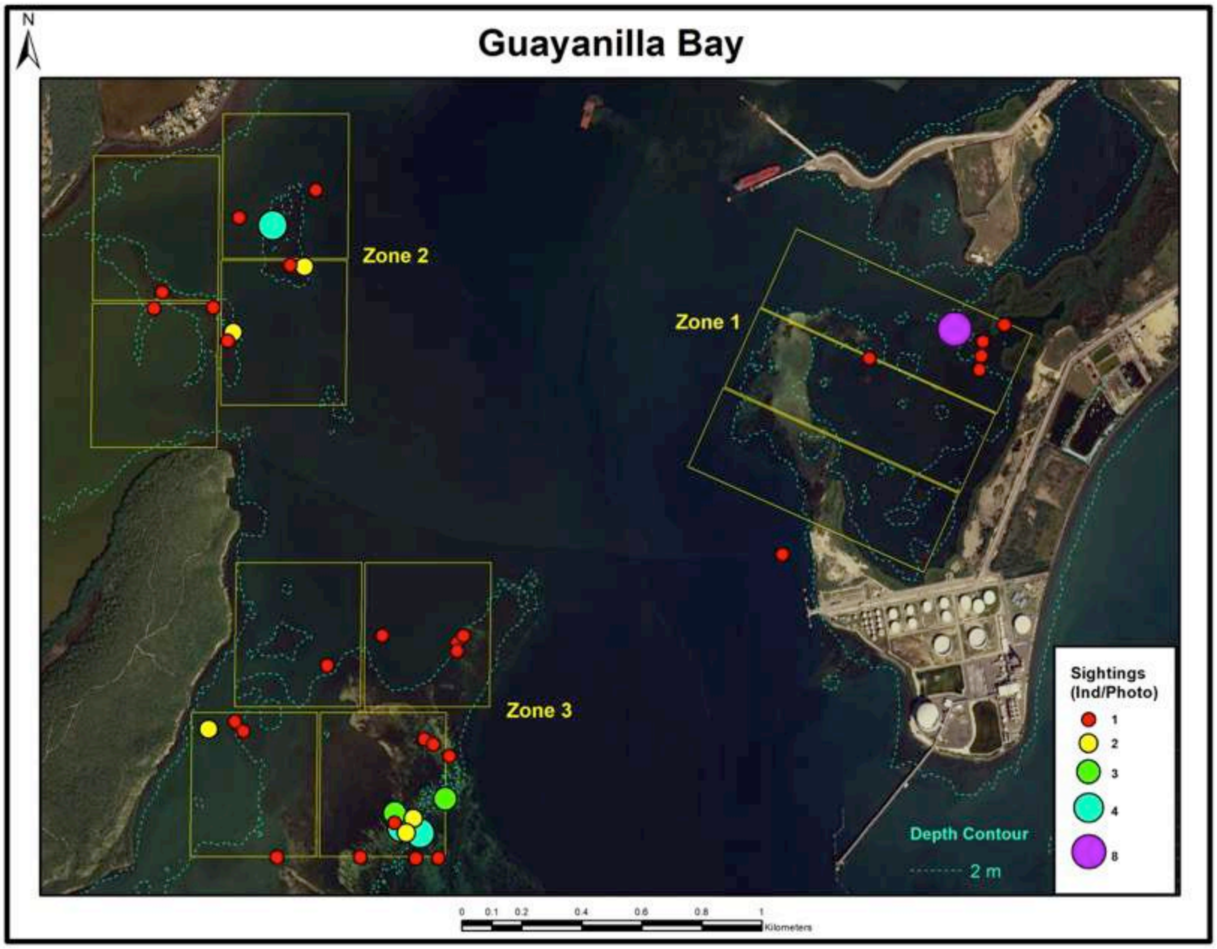

Figure 13. Map with the abundance of manatee sightings for all the flights combined.

Additional sightings

This is the first effort to determine the capabilities of UAS for tropical marine fauna in the Caribbean. Although the focus for this trial was on manatees, we also noted a range of other species in images captured. It was possible to identify turtles (n=5), sharks (n=23), rays (n=144), fish schools, tarpon (n=13), jellyfish and birds on the water surface. We noted that sharks and rays could be identified to species level in many cases (figure 15). The distribution of other animal sightings was determined to be similar to that of the manatees, suggesting that the habitat is an important area for the ecosystem as a whole (figure 16).

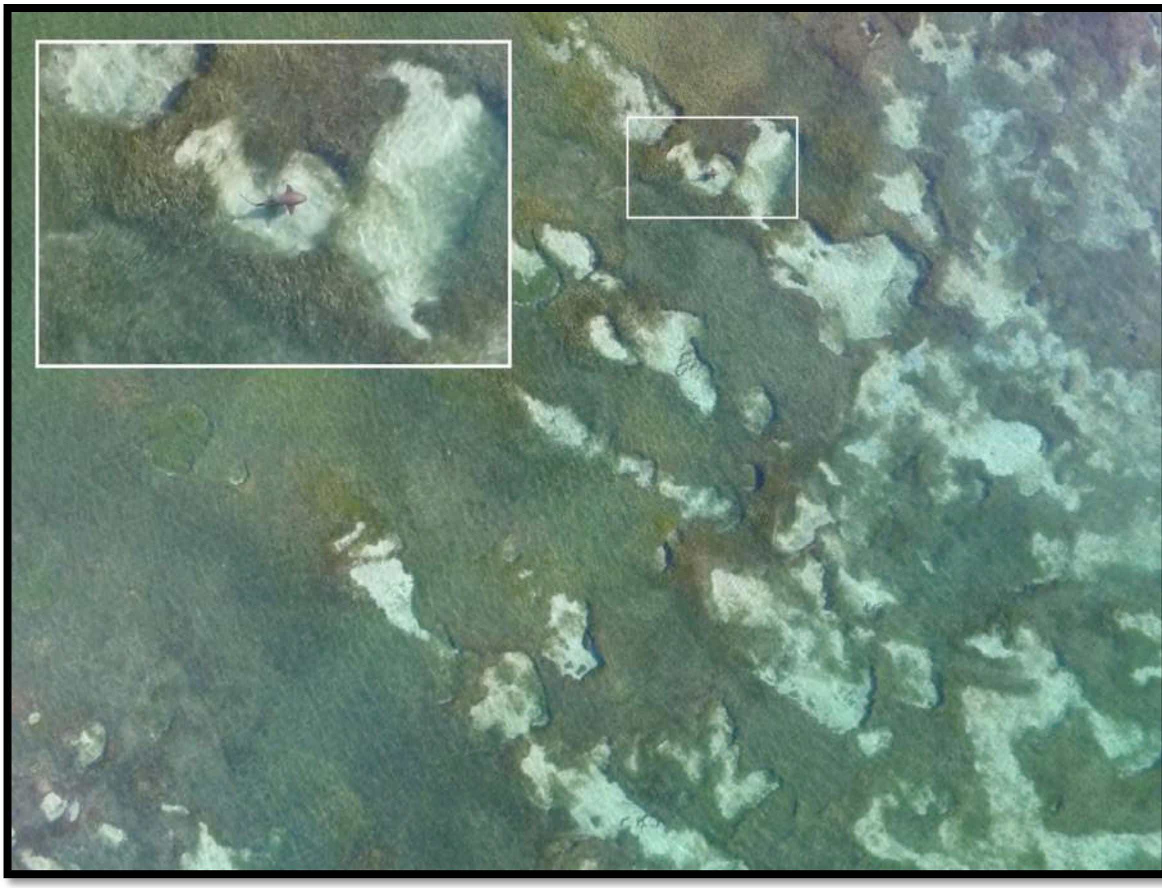

Figure 14. Photo of shark that can be identified as a nurse shark in the close up (*Ginglymostoma cirratum*).

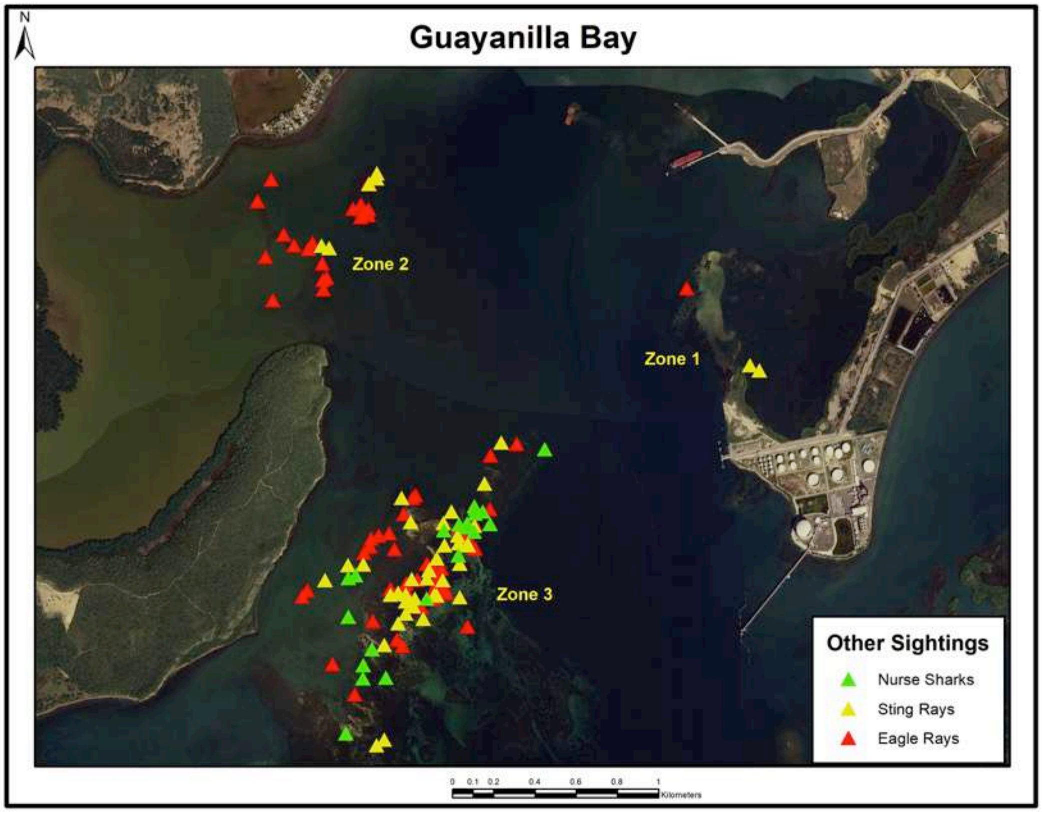

Figure 15. Map showing the distribution of sightings of other taxa (sharks, sting rays and eagle ray).

Conclusion

This work provides evidence of the feasibility and applicability of UAS to facilitate surveys for marine animals in tropical ecosystems. Small UAS also provide detail information on the habitats where they are found. This data is crucial for managing manatee's interaction with human use patterns at these locations. Locations like Zone 3, which is highly used by manatees (critical habitat), do not have any buoys for boat speed regulations. Enforcing reduced speed zones in areas with high manatee concentrations (e.g. Zone 3) have shown to reduce manatee mortality in Florida (Laist and Shaw 2006).

The advantage of having a permanent record of each sighting is that images can be re-checked to ensure sighting data are accurate, and strict criteria can be applied for eliminating uncertainties. Reviewing images in consultation with other experts can also increase the accuracy of species identification. Acquiring the GPS location of every image provides greater accuracy in location data than for manned surveys where observer are calling sightings. Our database also revealed the potential of UAS photos and data to assess the distribution of smaller taxa (sharks, rays, echinoderms) that could be couple with other *in situ* measurements and counts (figure 16).

This initial trial of a basic UAS has successfully demonstrated to be a great tool for manatee aerial surveys. The UAS demonstrated to be a safe and cost-effective platform for collecting photogrammetry images adding key scientific data about manatee's populations in specific areas. The equipment is affordable, portable, easy to use and provides high-resolution imagery that is good as, if not better than, that provided by more expensive cameras flown at higher altitudes and at greater air speeds. Also, our experience and others' (Durban *et al.* 2015, Smith *et al.*) indicate that impacts from UAS are minimal in comparison to those caused by other data collection methods (e.g., manned aircraft, boat-based surveys, net captures). At no point during our field work did we observe any indication of behavioral disturbances of manatees from exposure to the UAS.

As UAS technology keep evolving (better cameras, quieter propellers, efficient batteries, new sensors, higher resolution images and water resistance bodies) and getting more affordable, other important information can be obtain and new methods could be designed in order to get a better population estimate of manatee populations in other areas around Puerto Rico.

Information generated by this technology (more robust and accurate data sets) can quickly be available to resource managers when making decisions related to this endangered species management (like speed regulation buoy locations). This methodology needs to be replicated in other manatee hotspot to determine if it can be apply to monitor population trends. This is essential to manage manatee population in the Caribbean.

Acknowledgements

We acknowledge the hard work of the observers (Jose Vargas, Luis Rodriguez and Liajay Rivera) who have assisted in the field surveys and logbook data entry. Dra. Michelle Scharer helped with the editing of the report. EcoElectrica L.P provided additional funding to complete this work.

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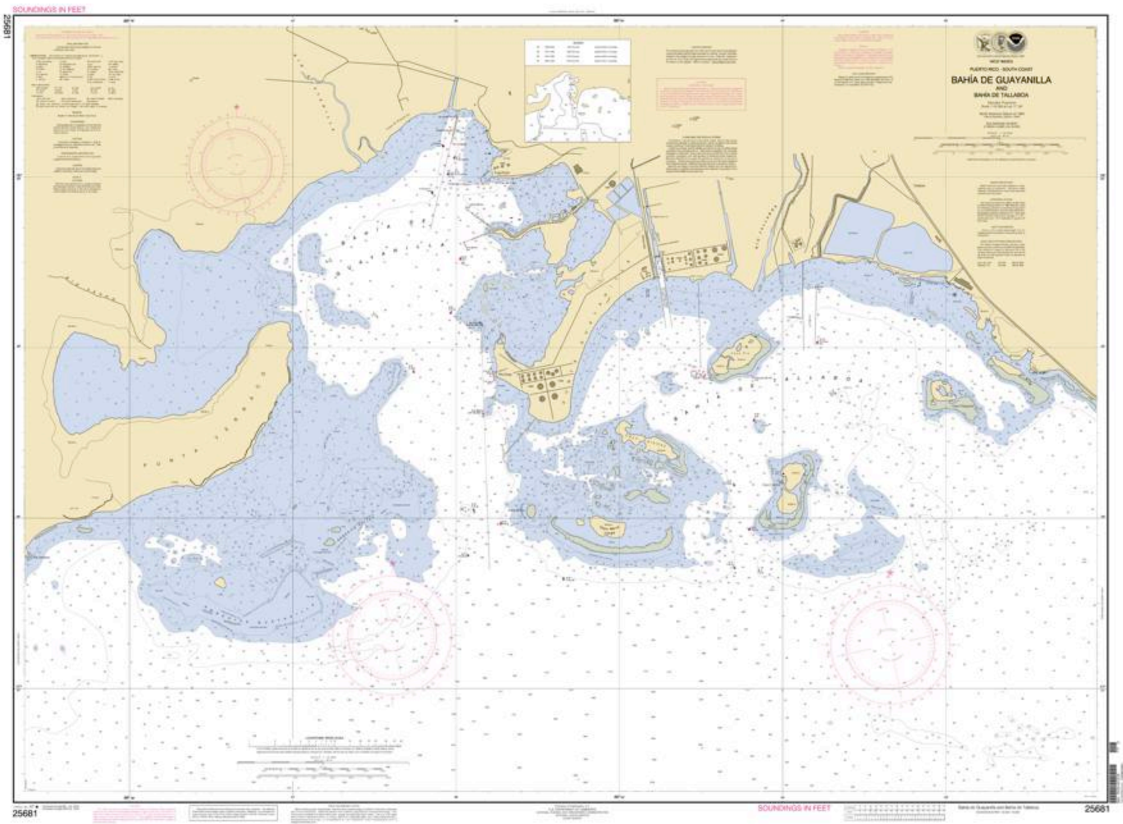
Appendices

Appendix 1. Copy of NOAA Nautical Chart of Guayanilla Bay, Puerto Rico.



Appendix 2. Flight log book