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Estimating Florida manatee (*Trichechus manatus latirostris*) abundance using passive acoustic methods

Athena M. Rycyk,[1,a)] Cora Berchem,[2] and Tiago A. Marques[3,b)]

[1]*Division of Natural Sciences, New College of Florida, Sarasota, Florida 34243, USA*
[2]*Save the Manatee Club, Maitland Florida 32751, USA*
[3]*Centre for Research into Ecological and Environmental Modelling, University of St Andrews, St Andrews, KY16 9LZ, Scotland*

arycyk@ncf.edu; *cberchem@savethemanatee.org*; *tiago.marques@st-andrews.ac.uk*

Abstract: Manatees are difficult to detect, particularly cryptic populations that inhabit areas with limited water clarity. The effectiveness of using vocal detections to estimate manatee abundance was evaluated in a clear water spring where manatees congregate seasonally. Vocalizations were extracted by a detection classifier that clustered sounds with similar spectral properties. Vocalization counts from recordings in Blue Spring, FL, USA were strong predictors of manatee abundance. The link between independent visual counts and abundance estimates from passive acoustic monitoring was used to provide an estimate of 1.059 (95% confidence interval 0.963–1.127) vocalizations/manatee/5-min, which might be used elsewhere for cue counting of manatees. © 2022 Author(s). All article content, except where otherwise noted, is licensed under a Creative Commons Attribution (CC BY) license (*http://creativecommons.org/licenses/by/4.0/*).

1. Introduction

All species of manatees are known to produce vocalizations that offer opportunities for ecological surveys through passive acoustic monitoring (PAM) (Evans and Herald, 1970; Rycyk *et al.*, 2021; Schevill and Watkins, 1965; Sonoda and Takemura, 1973). Of particular importance is the ability to translate acoustic detections into distribution, abundance, and density information. Such methods of using PAM to estimate population information have been demonstrated in many other marine species including numerous species of cetaceans and pinnipeds (Baumgartner *et al.*, 2019; Kiehbadroudinezhad *et al.*, 2021; MacIntyre *et al.*, 2013; Marques *et al.*, 2011; Marques *et al.*, 2013; Mellinger *et al.*, 2007). Widespread application of PAM methods for manatee species would be particularly beneficial for data deficient species like the African (*Trichechus senegalensis*) and Amazonian (*Trichechus inunguis*) manatees, for which there are large geographic areas with little to no information available (Keith Diagne, 2015; Marmontel *et al.*, 2016). These species are also difficult to visually detect in some regions due to limited water clarity and cryptic behavior. Such visual limitations make acoustic surveys promising but ground-truthing acoustic detections difficult. Additionally, extracting manatee vocalizations from a large dataset can be a barrier to using passive acoustic methods. Automating vocalization extraction is particularly difficult because manatee vocalization structure lies along a continuum between simple tonal calls and calls with numerous nonlinear features including deterministic chaos, biphonation, frequency jumps, and subharmonics (Brady *et al.*, 2020; Mann *et al.*, 2006).

Florida manatees (*Trichechus manatus latirostris*) are the easiest to monitor of the manatee species, particularly in winter when they congregate at warm-water refugia. This permitted us to ground truth passive acoustic methods with complementary visual information. Here, we investigate the ability to acoustically monitor Florida manatee use of a warm water refugia, Blue Spring, FL, USA, where the clear spring water facilitates visual counts of the manatees in the spring run.

Our objectives were to (1) test a method of extracting manatee vocalizations from a large dataset based on spectral properties, (2) determine if vocalization detections predict the number of manatees using a resource (warm-water refugia), (3) compare predictive strength of vocal counts over varying time windows, and (4) provide an estimate for individual vocalization rate to facilitate other efforts for predicting manatee abundance acoustically *via* cue counting.

[a)]Author to whom correspondence should be addressed.
[b)]Also at: Centro de Estatística e Aplicações, Departamento de Biologia Animal, Faculdade de Ciências da Universidade de Lisboa, Lisboa, Portugal.

2. Methods

2.1 Acoustic recordings and vocalization extraction

An underwater acoustic recording device (SNAP, Loggerhead Instruments, Inc., Sarasota, FL) was deployed near the mouth of the Blue Spring run in Volusia County, FL (Fig. 1). A HTI-96-min hydrophone was used with a sensitivity of -170.3 dB re 1 V/μPa, frequency response of 2 Hz to 30 kHz, and sampling rate of 44.1 kHz. Hydrophone signals were digitized with 16-bit resolution and gain was set to 2 dB. Recording was continuous from February 16, 2021, to April 7, 2021, with data stored in 5-min .wav files on microSD cards exchanged approximately every week. The length of the Blue Spring run is approximately 650 m with the recorder deployed approximately 100 m inside the entrance. The recorder was secured to a pole at a depth of approximately 1.5 m in water that was 2.2 m deep. The spring run is approximately 35 m wide at this location and the recorder was approximately 4 m from the southeast bank.

An advanced manatee vocalization detection classifier was built using Kaleidoscope Pro (Wildlife Acoustics, Inc., Maynard, MA) to identify manatee vocalizations regardless of structure (e.g., tonal and chaotic vocalizations). In the first stage, sounds were located in the acoustic recordings based on user-selected frequency and timing parameters (frequency range of 4–10.5 kHz, duration range of 0.1–1 s, and maximum inter-syllable gap of 0.1 s) resulting in 428 262 sounds that met these parameters. In the second stage, the advanced classifier feature in Kaleidoscope Pro was used to train the software to identify which of those sounds were manatee vocalizations. A subset of detected sounds ($n = 36\,456$) was manually classified as either a manatee vocalization ($n = 17\,945$) or noise ($n = 18\,511$). These manually classified sounds were used to train the advanced classifier (settings used are in the supplementary material[1]). The advanced classifier was applied to the full dataset and classified 235 641 sounds as manatee vocalizations. In the third stage, classifications were verified in a randomly selected set of 96 5-min sound clips that contained a total of 3194 manatee vocalizations. The classifier correctly captured 81% of the manatee vocalizations with 7% of detections being false.

2.2 Estimating acoustic detection range

The manatee vocalization detection range (R_M) was estimated using Eq. (1), an adaptation of an expression from Phillips *et al.* (2006),
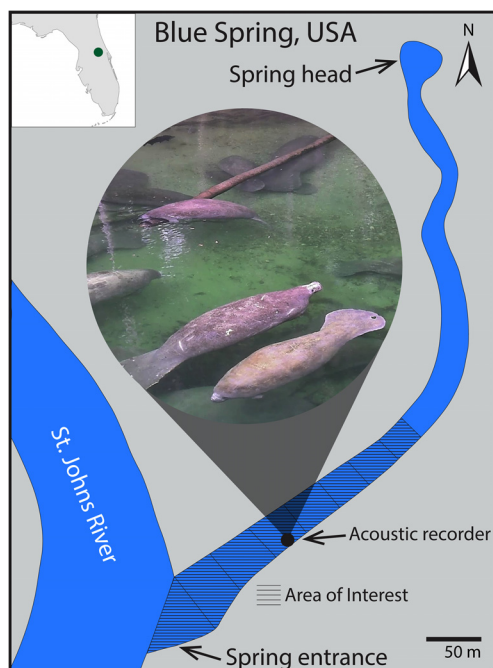

Fig. 1. A diagram of the study area. The acoustic recorder (black circle; 28.9438°N, −81.3405°W) was deployed in the Blue Spring run in Florida, USA (inset in the top left corner shows Florida, USA, with a green circle indicating the location of Blue Spring). The narrow run leads to a natural warm-water spring at the North end. The clear water (inset picture) allows for visual counts of the manatees using the spring run. The hatched area represents the combined zones (zones are demarcated by black lines) from which visual manatee counts were grouped to estimate the number of manatees within acoustic range of the recorder (Area of Interest). The area of interest is 286 m in length. The contours of the spring run and St. Johns River were traced from Google earth imagery (Google Earth, 2021).

$$R_M = 10 \wedge \left(\frac{SL_M - BL - DT}{10} \right), \tag{1}$$

where SL_M is source level of manatee vocalizations (118 dB from Phillips *et al.*, 2006), BL is background noise level (93.3 dB re 1 μPa), and DT is the detection threshold (3 dB). Transmission loss due to spreading was approximated by a cylindrical spreading model because the spring run is shallow and narrow. The resulting R_M was 147.9 m.

2.3 Manatee counts

During the same period that acoustic data were collected the number of manatees in the spring run was counted on most days (37 of 51 days). The spring run was divided into 21 zones that started at the spring entrance and ended at the spring head. The number of manatees were counted in each zone and the counts in the eight zones within the acoustic range of the recorder were combined to estimate the number of manatees within the acoustic range of the recorder (area of interest in Fig. 1). Counts were conducted by human observers in a canoe between the hours of 8:00 and 10:00. During the morning hours, manatees were mostly resting or slowly milling. Individuals were recognized by distinctive scar patterns on their backs and tails to avoid counting individuals more than once. Observers surveyed each zone by slowly paddling around the manatees while recording individuals in a notebook. Once observers were certain to have counted all manatees in each zone, they moved on to the next. Due to the clarity of the spring water, visual detection of manatees was excellent in most zones (e.g., Fig. 1). Water clarity closer to the St. Johns River was sometimes less clear due to stirred up sediment or dark water intrusion from the river, but manatees were still clearly visible to the observers.

2.4 Analysis

The mean and standard deviation of detected vocalizations per 5-min (vocs/5-min) period was calculated across the 51-d sampling period. Manatee vocalization rates can vary (see Sec. 4) therefore vocalization counts should be either averaged or pooled over a suitably long period before estimating manatee abundance. To relate the daily visual manatee counts from the area of interest to the vocalization detections, we smoothed the number of detected vocalizations per 5-min interval using a moving average with a sliding window of the same temporal resolution as the visual counts, 24 h (MATLAB, Mathworks Inc, 2021). Each daily visual manatee count for the area of interest was paired with the 5-min smoothed detected vocalization count (averaged over 24 h) for the same time as the visual count. The predictive strength of detected vocalizations (unsmoothed) to explain the observed manatee count was tested for a 2-, 6-, 12-, and 18-h window. Detected vocalizations for a 2-, 6-, 12-, and 18-h window before each visual manatee count of the area of interest were calculated. Linear models without an intercept (which is biologically sensible and consistent with the data) were fitted to (1) measure predictive power of the detected vocalization counts for the number of manatees and (2) evaluate which time window best predicts the number of manatees present in the area of interest.

We estimated the individual vocalization rate (cue rate) that best predicted manatee abundance from vocalization counts as follows. An adaptation of the expression from Marques *et al.* (2009) can be used to estimate manatee abundance in the area of interest as

$$\widehat{N}_M = \frac{n_c(1 - \widehat{c})}{\widehat{P} T \widehat{r}}, \tag{2}$$

where $\widehat{N}_M$ is the estimated number of manatees, n_c is the number of detected vocalizations within a 24-h time period (T) centered around the start time of the visual count, $\hat{c}$ is the false detection rate (0.07 based on the verified vocalization detections described in 2.1), $\widehat{r}$ is the vocalization rate, and $\widehat{P}$ is the probability of detecting a vocalization. For $\widehat{P}$, we used 0.81 based on the verified vocalization detections described in 2.1. This expression provides a convenient way to estimate the vocalization rate. Since the visual counts provide an independent estimate of abundance for the area of interest ($\widehat{N_M^V}$), we can substitute $\widehat{N}_M$ by $\widehat{N_M^V}$ and rearrange the equation above to obtain the expression of a linear model without an intercept, where the slope is the cue rate we want to estimate, and for which an estimator is readily available by regression,

$$\widehat{N_M^V} \widehat{r} = \frac{n_c(1 - \widehat{c})}{\widehat{P} T}. \tag{3}$$

Note that this is just $y = \widehat{N_M^V} \widehat{r}$, where we note that y, the expression on the right-hand side of Eq. (3), is an acoustically estimated abundance except for the estimated cue rate. We estimated $\widehat{r}$ from the regression of y as a function of the visual counts. A naive estimate of the precision of the cue rate *via* the slope of the above regression model will underestimate the true variability in the cue rate estimate because all the random components in Eq. (2) would be treated as known constants. To propagate the variability from the random components forward to the cue rate precision estimate, we implemented a non-parametric bootstrap, considering 999 resamples. At each bootstrap resample we sampled all random components and then re-estimated the slope: to get $\hat{c}$ and $\widehat{P}$, we resampled the 96 5-min sound clips used to verify vocalization classifications (described in Sec. 2.1), and a visual count and the corresponding value of n_c were sampled

randomly from the days with visual counts. We report the percentage coefficient of variation (CV) and a bootstrap 95% confidence interval based on the percentile method (Rousselet *et al.*, 2021) for the estimated cue rate. All statistical analyses and figures were implemented in R (R Core Team, 2021) and the corresponding code and data can be found in the supplemental materials[1].

3. Results

The detected vocalization rate across the whole 51-d continuous recording period is 16.5 ± 33.5 (mean $\pm$ standard deviation, SD) vocs/5-min. There is a very strong positive correlation between the number of manatees using the area of interest and the smoothed number of detected vocalizations [$r(36) = 0.99$, $p < 10^{-4}$] (Fig. 2; see the supplemental materials[1]). The number of vocalizations detected in 2 [$R^2 = 0.93$, $F(36) = 502$, $p < 10^{-15}$], 6 [$R^2 = 0.95$, $F(36) = 679.2$, $p < 10^{-15}$], 12 [$R^2 = 0.96$, $F(36) = 944.9$, $p < 10^{-15}$], or 18 [$R^2 = 0.96$, $F(36) = 936.4$, $p < 10^{-15}$] hours before each manatee count are very strong predictors of the number of manatees in the area of interest (Fig. 3). Longer time windows (12 and 18 h) are slightly stronger predictors.

The estimated $\hat{r}$ (individual vocalization rate) was 1.059 (95% CI [0.963, 1.127]; CV = 3.94%) voc/manatee/5-min (Fig. 4).

4. Discussion

The number of detected manatee vocalizations recorded was a strong predictor of the number of manatees using the area. Raw vocalization counts from the preceding 2-, 6-, 12-, and 18- hours and smoothed vocalization counts over a centered 24-h window were all strong predictors of the number of manatees visually verified. Individual manatee vocalization rates can vary with time of day, activity, age, group size and composition, and environmental noise (reviewed in the supplementary material[1]) (Bengston and Fitzgerald, 1985; Miksis-Olds and Tyack, 2009; O'Shea and Poché, 2006; Rivera Chavarria *et al.*, 2015; Rycyk *et al.*, 2021; Sousa-Lima *et al.*, 2002; Umeed *et al.*, 2018; Williams, 2005). Despite these variations in individual manatee vocalization rates, we showed that the number of detected vocalizations can still serve as a valuable measure of manatee abundance. A key aspect is that one surveys over a sufficiently long time so that short term changes in vocal rates average out; our results suggest for manatees at our site that a few hours might be enough but care should be taken when considering other sites or times.

PAM has many advantages including sampling around the clock, long term deployments, not depending on water clarity, and minimal time investment relative to labor-intensive methods like visual surveys. One challenge of using PAM is extracting vocalizations from large datasets, a common hurdle across species. For manatees, there is an additional hurdle because of the high variance in manatee vocalization structure which complicates developing extraction algorithms. Here, we found that an extraction method based on clustering of similar spectral properties can successfully identify manatee vocalizations regardless of structure. However, a high level of manual labeling of detections was required to successfully detect vocalizations. Manually labeling detections, while time consuming, is also an important step for utilizing many of the rapidly developing deep learning methods of vocalization detection (Stowell, 2021).

The overall high mean detected vocalization count (16.5 ± 33.5 mean $\pm$ SD, vocs/5-min) across the entire 51 days suggests many manatees were acoustically detected given the relatively low vocalization rate of individual manatees (reviewed in the supplementary material[1]). The detected vocalization counts also have high variance, potentially reflecting
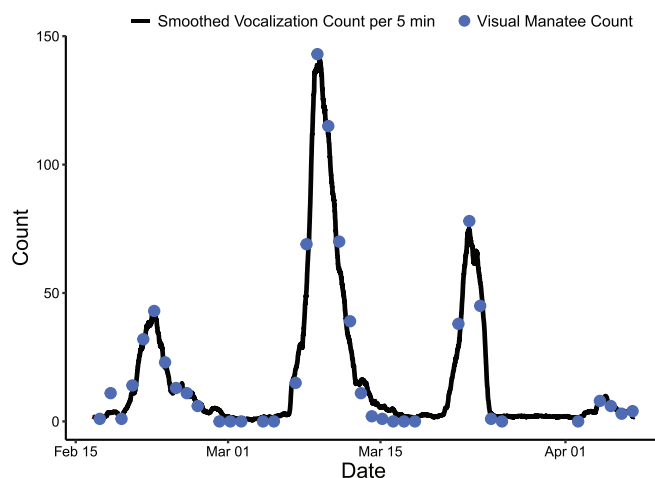

Fig. 2. The number of detected vocalizations per 5-min interval smoothed by a 24-h moving window (black line) compared to the number of manatees visually counted in the area of interest (blue circles). A plot of the raw vocalization counts can be found in the supplemental materials (Ref. 1).
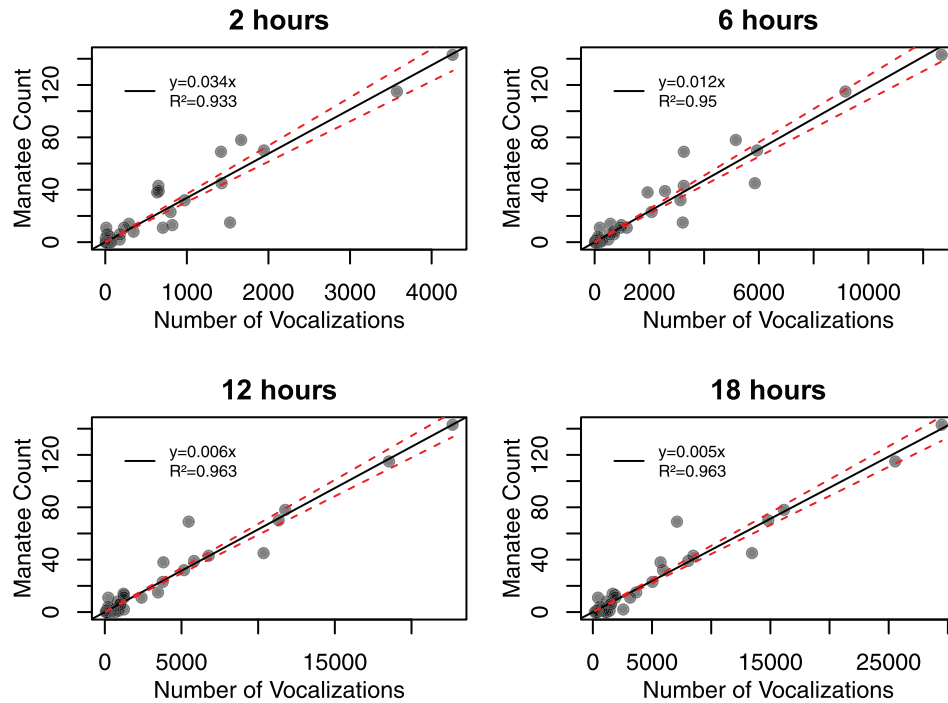
Fig. 3. Number of detected vocalizations within 2(A), 6(B), 12(C), and 18(D) hours before each visual manatee count in the area of interest are represented by circles. The solid lines represent fitted linear models with the dashed lines representing the 95% confidence intervals.

the impact of distance of detection, as manatees move into and out of acoustic range of the hydrophone. The high detected vocalization counts further support visual evidence that manatees commonly frequent this area in winter and that the area serves as a good location to sample and monitor long term trends. Unlike open-water cetacean species, manatees live in spatially complex environments that include narrow passageways that serve to concentrate manatees as they pass through. Narrow passageways coupled with location-based resources that manatees rely on, like warm-water refugia, fresh-water, and food (Deutsch *et al.*, 2003; Edwards *et al.*, 2021; Gannon *et al.*, 2007; Haase *et al.*, 2020; Laist and Reynolds, 2005), provide great opportunities to maximize the probability of acoustically detecting manatees and sample a larger portion of the population (Fig. 1). While other manatee species do not rely on warm-water refugia they can also have preferred habitats and travel corridors. For example, African manatees have been acoustically sampled at the narrow entrance to a preferred habitat (Lake Ossa, Cameroon) that served as a bottleneck to maximize detections (Rycyk *et al.*, 2021). A key consideration is what portion of the population uses the sampling area.
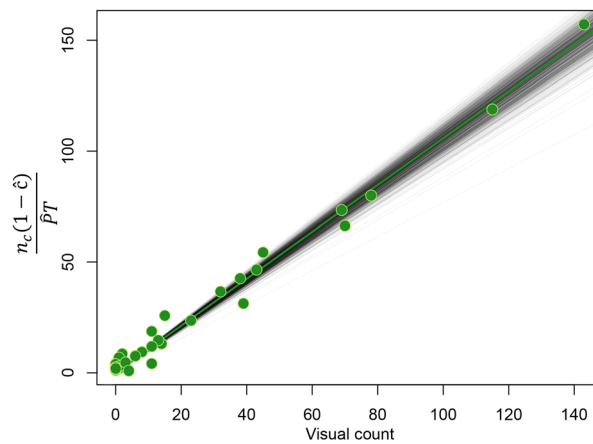

Fig. 4. The number of manatees in the area of interest determined by visual counts compared to $n_c(1 - \widehat{c})/\widehat{P}T$ from Eq. (3). The green circles use $\hat{c} = 0.07$ and $\widehat{P} = 0.81$ (from the verified vocalization detection set described in 2.1) and the green line is the no-intercept regression of those values (slope = 1.059). The gray lines serve as a measure of precision in which each gray line represents one of the resampled sets from the bootstrap analysis that varied $\widehat{P}$ and $\hat{c}$.

Translating vocalization detections into an abundance or density estimate is challenging. For some species, the ability to localize vocalizing individuals using multiple hydrophones can refine the estimated number of individuals if sounds are produced from different locations and therefore produced by different individuals (Barkley et al., 2021; Spiesberger et al., 2021). Multiple hydrophones also increase precision of an abundance estimate (reviewed in Marques et al., 2013). Manatees in large groups, like those found at warm-water refugia, are difficult to acoustically separate into distinct locations because of the high density of animals. However, we found that even without the ability to localize sound-producing individuals, detected vocalization counts are strong predictors of abundance. Therefore, even without the ability to localize vocalizing manatees, a calibration approach is possible (Fig. 3; e.g., Oppel et al., 2014). Cue counting, another method of estimating abundance, requires a cue rate, the average number of cues produced per unit time per individual. There have been numerous studies that report individual vocalization rates for manatee species (see supplementary material[1]) and most of these were under circumstances that may affect individual vocalization rates, such as captivity, isolation, or being followed. Here, we found, under natural conditions, that a vocalization rate of 1.059 voc/manatee/5-min rate optimally predicted manatee abundance using Eq. (2). This individual vocalization rate fits within the range of reported individual vocalization rates for Florida manatees (supplementary material[1]) and can serve as a guide for future manatee abundance estimates using passive acoustics, keeping in mind individual vocalization rates may differ between populations, locations, and context (Bengston and Fitzgerald, 1985; Miksis-Olds and Tyack, 2009; Nowacek et al., 2003; Phillips et al., 2004; Sousa-Lima et al., 2002; Sousa-Lima et al., 2008; Williams, 2005). Another possible method of acoustically estimating manatee abundance is using individually-distinct features of manatee vocalizations to count individuals (O'Shea and Poché, 2006; Sousa-Lima et al., 2002, 2008; Williams, 2005). Even without previous recordings of wild individuals, this may be feasible by clustering vocalizations based on similarity to estimate the number of individuals (Castro et al., 2015; Merchan et al., 2019).

Our estimate of $\widehat{P}$ was based on the probability of automatically extracting vocalizations captured in the acoustic recordings. In other words, we implicitly assume that all vocalizations produced within the acoustic detection area are captured in the acoustic recordings, and none beyond that area is. This remains an untested assumption; however, during our sampling period, most manatees were in the area of interest rather than other areas of the springs run (for the 37 days visual counts were conducted, 803 manatees were counted in the area of interest, and only 64 in other areas of the spring run). This means if the actual acoustic detection area is different than our estimated acoustic detection area our results would vary little. Future work could estimate the probability of vocalization detection by conducting in situ experiments to estimate the probability of vocalization detection based on distance from the hydrophone. However, properly applying a probability of vocalization detection based on distance assumes either an even distribution of manatees or the ability to weight probability of detection based on an assumed known distribution of distances, and this assumption might be difficult to meet, especially with a single hydrophone.

We demonstrate that PAM can be highly successful for Florida manatees. These methods are also useful for other manatee species particularly the vulnerable and data deficient African and Amazonian manatees (Keith Diagne, 2015; Marmontel et al., 2016). These species are difficult to visually detect and deploying acoustic recorders can greatly expand our understanding of species distribution, identify important habitats, and monitor relative abundance. Indeed, ongoing research in Cameroon has found that African manatees are several times more likely to be detected using passive acoustics than by visual surveys (Factheu et al., 2022). Beyond long term deployments of stationary acoustic recorders at strategic locations, acoustic surveys could easily expand geographic coverage. Moving acoustic surveys, even those that incorporate stops along the path, would have a low probability of reliably detecting manatees because of their low individual vocalization rates. However, coupling acoustic surveys with manatee vocalization playbacks could overcome this hurdle. Playback experiments of manatee vocalizations elicit an increase in vocalization rate (approximately 2–5 times higher) in Antillean and Florida manatees (Phillips et al., 2004; Umeed et al., 2018). Therefore, incorporating playbacks of manatee vocalizations into acoustic surveys (stationary or moving) to elicit a vocal response could sharply increase the probability of acoustically detecting a manatee's presence. Using data from playbacks to estimate abundance can be challenging, but there are methods available to do so, opening the door to another effective way of surveying manatees (Buckland et al., 2006; Summers and Buckland, 2011).

In conclusion, detection of manatee vocalizations can be used to estimate manatee abundance. Adopting PAM methods can greatly enhance our understanding of manatee distribution, monitor trends in relative abundance, and identify critical habitats that should be protected.

Acknowledgments

References and links

[1]See supplementary material at https://www.scitation.org/doi/suppl/10.1121/10.0010495 for the general method and settings used to create an advanced classifier in Kaleidoscope Pro, R code and data used in analysis, a plot of the raw vocalization counts over time, and a collection of vocalization rates for individual manatees reported in the literature.

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