Marine Mammal Science

NOTE

Measuring Availability Bias in Florida Manatee (*Trichechus manatus latirostris*) Aerial Surveys Using Controlled Experiments and a Life-Sized Manatee Replica

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For decades, scientists have used aerial surveys over large spatial scales to count marine mammals, assess abundance and trends over time, compare population estimates between locations and years, and gauge if management objectives are being met (Eberhardt et al. 1979; Pollock et al. 2006; Edwards et al. 2007; Nichols 2014; Hammond et al. 2021). When data are collected appropriately, abundance estimates derived from aerial survey data can provide useful information about a population's status. However, estimating abundance from aerial surveys can be challenging. For example, detecting marine mammals that are present during a survey can be difficult, and even when methods are standardized such as altitude, aircraft, observer experience, minimum weather conditions, and so on, detection of animals often varies within or between surveys, making it problematic to interpret or compare results.

Detecting a free-ranging marine mammal during aerial surveys is influenced by several factors, including those that relate to the animal itself, such as the size of the animal, size of groups or aggregations of animals, how much time the species spends near the water's surface, behavior, and reproductive status (Edwards et al. 2021). Environmental conditions, such as surface water condition (sea state), water clarity/visibility, glare, and cloud cover, also influence whether a marine mammal is detected and recorded on a survey (Williams et al. 2002). The presence of white caps or waves can hinder an observer's ability to notice an animal on the surface or to see an animal that is underwater. Poor light penetration in turbid water or opaque water conditions can make animals below the water's surface difficult or impossible to see; for example, tannic or turbid waters make it hard to see even slightly below the water's surface, but animals in clear water are more easily visible. Lighting conditions, such as glare (sun glint or glitter) and cloud cover, can also prevent an animal from being seen by an observer moving rapidly above it. In addition, other considerations such as survey platform, distance from the species of interest, or even survey protocols can influence whether an animal is detected.

In aerial surveys designed to estimate a population's abundance, imperfect detection can affect survey accuracy and precision (Kellner & Swihart 2014; Hammond et al. 2021), which can lead to biased or inaccurate population size estimates because the proportion of the animals that go undetected in the survey is unknown. Nevertheless, the fraction of animals missed in a survey can be measured, and when errors are accounted for, the resulting estimates are more comparable over space and time (Williams et al. 2002; Martin et al. 2007; Kellner & Swihart 2014; Martin et al. 2015; Hammond et al. 2021). The importance of accounting for detection bias has been well described by many authors (Marsh and Sinclair 1989; Williams et al. 2002; Pollock et al. 2006; Edwards et al. 2007; Martin et al. 2007).

The probability of a marine mammal being detected during an aerial survey consists of two components: (1) availability bias: the probability of an animal being in a location or position that is observable by an aerial observer; and (2) observer or perception bias: the probability of an animal being detected or seen by an aerial observer, given that it is available to be detected (Marsh and Sinclair 1989; Pollock et al. 2006). This relationship is denoted by $P(\text{animal available}) \times P(\text{animal detected}|\text{available})$; Edwards et al. 2007). Observer or perception bias can be measured by several approaches, including using distance sampling (Anderson et al. 1983; Buckland et al. 2005; Burnham et al. 2004), mark-recapture methods with dual observer protocols, or multiple passes over the same area (Marsh and Sinclair 1989; Edwards et al. 2007; Pollock et al. 2004, 2006; Barker 2008; Sucunza et al. 2018; Collazo et al. 2019; Hammond et al. 2021). Availability bias can be measured, for example, by tracking animal behavior through telemetry or biologging studies and through direct measurements (e.g., time-depth recording to measure surfacing intervals; Laake et al. 1997; Pollock et al. 2006; Hagihara et al. 2014; Fuentes et al. 2015; Hagihara et al. 2018; Sucunza et al. 2018; Dunn et al. 2024), or through other modeling efforts (Borchers et al. 2013). Availability bias can be integrated with components of observer and perception bias (Williams et al. 2002; Pollock et al. 2006; Royle and Dorazio 2008) to help account for both environmental conditions and observer perception on survey counts. Ultimately, the most prudent means for avoiding biased estimates is to account for the components of detection within each survey.

Abundance estimates have been and continue to be an important means of informing management decisions and for evaluating the status of the Florida manatee (*Trichechus manatus latirostris*) population (Martin et al. 2015; Runge et al. 2017). Accounting for sources of error has been an important component of these surveys, and much effort has been devoted to measuring and adjusting for both observer (perception) and availability bias in Florida manatee aerial survey counts (Martin et al. 2015; Hostetler et al. 2018; Gowan et al. 2023; Gowan et al. 2026).

In this study, we focused solely on availability bias and show how to design an experiment for quantifying it in Florida manatee aerial surveys. We used a manatee replica and manatee dive behavior data from time-depth data loggers to account for availability in abundance estimation. Although this project was specific to Florida manatees, a similar experiment was conducted to estimate detection of dugongs in Australia (Pollock et al. 2006) and methods to account for availability bias have been implemented in studies of other marine mammals (Hiby 1999; Hammond et al. 2013; Sucunza et al. 2018; Hammond et al. 2021). The methodology used here can easily be adapted to measure availability bias of sirenian populations in other locations or habitats and could be adapted for other marine species studied using aerial survey methods. The intent of this note is to help researchers interested in addressing availability bias in aerial survey data devise an empirical method to measure availability for their species of interest. The details on how the probability of availability was applied in Florida manatee abundance estimation are not presented in this note but can be reviewed in Martin et al. (2015); Hostetler et al. (2018); Gowan et al. (2023); Gowan et al. (2026).

To quantify the effects of environmental conditions (covariates) on the likelihood that a manatee is detectable to an aerial observer (available to be seen), we developed an experimental approach using a manatee replica (Figure 1) placed under a range of environmental conditions. We evaluated how combinations of these conditions influenced the probability of a manatee being available to be detected when the aircraft flew at varying distances from the replica and when the replica was positioned at depths ranging from the surface to 3 m. We combined that information with estimates of how often a manatee was above a depth threshold based on its diving behavior (Martin et al. 2015) to quantify the overall probability of a manatee being available during an aerial survey. Because we were only interested in measuring the influence of environmental conditions on availability, and not observer bias, the location of the replica was known to the observers.

The life-sized replica was three-dimensional and constructed from chicken wire (poultry netting) bent over PVC piping and held together by flexible steel wire to form the shape of an average-sized adult manatee (approximately 2.7 m long; Figure 1). We covered the chicken wire with gray waterproof fabric and created small slits in the fabric to let the water freely pass through. We mounted the chicken wire body onto a PVC frame using plastic zip ties. Detachable poles were attached on one side of the frame to help raise and lower the replica (Figure 1). Styrofoam floats or inflatable lift bags were used to help keep the manatee replica level in the water and to give it positive buoyancy (Figure S1). We attached dive weights to the frame when ballast was needed to balance and help hold the manatee in place (Figure 1). In some locations, SCUBA divers controlled the depth and placement of the replica (Figure S1) using PVC pipes marked at 0.5 m-intervals to measure distance

FIGURE 1 | A replica of a Florida manatee, constructed with chicken wire (poultry netting), was used to measure the probability of detecting a manatee under different environmental conditions. Dive weights (top photo) and the yellow/red inflatable lift bags can be seen in the photos.

from the surface, and mushroom anchors were used to secure the replica at the desired depth.

We were interested in how manatee availability varied with water visibility, sea state, cloud cover, and glare. To test the influence of those conditions on availability, reconnaissance boat trips were taken to select and ground truth locations with appropriate environmental conditions for visibility (scored from 1 to 4; Table 1). Sea-state conditions were based on the scale in Table 1 (developed using the descriptions from the Beaufort Wind Scale; Owens 1982) and determined by weather conditions on the day of the experiment. Weather forecasts were monitored so that appropriate sea state conditions would likely be present at the selected locations. We attempted to survey on days and in locations such that each combination of visibility and sea state was present during at least one of the flights. In some cases, a particular combination of covariates was present at more than one site, whereas some other combinations of covariates were never available at any site during the flights (Table 2; Figure 2). Cloud cover and glare were recorded based on conditions at the time of the survey; however, these covariates thus far have not been used to calculate availability for statewide Florida manatee abundance estimation (Martin et al. 2015; Hostetler et al. 2018; Gowan et al. 2023). Cloud cover was measured as a percentage of coverage in 25% increments (0%, 25%, 50%, 75%, or 100%) and was also rated "yes" when the shadows or overcast skies produced from the clouds impacted an observer's ability to see manatees or "no" when it did not. Glare was rated as "yes" when it hindered the observer from being able to see manatees or "no" when it did not. A subjective rating of "yes" or "no" was important to record because the presence of cloud cover or glare did not always negatively impact observations. For example, in some conditions, 100% cloud cover did not obscure an observer's ability to see animals that were underwater, but shadows cast from a sky with 25% cloud cover under sunny conditions did impact the observer's ability to see animals that were underwater. The same was true for glare since it usually obscured only some, but not all, areas being observed from the aircraft.

The manatee replica was deployed at 19 sites (data from 13 of those sites were used in abundance analyses in Martin et al. 2015, and 15 were used in Hostetler et al. 2018 and Gowan et al. 2023; because of equipment failure and other issues, not all availability surveys using the replica were completed). The Cessna 172 aircraft flew circular passes around the model at an altitude of 230 m, a speed of 130–170 km/h and at horizontal orbit distances of 200, 300, and 400 m from the center of the model. Starting with the replica on the water's surface, it was circled twice, then lowered at 0.5-m increments, to a maximum depth of 3 m. Circling twice allowed the observer to confirm the observation. The pilot navigated (orbited) around the replica at each distance by flying a circular pattern to each of four coordinate points (at each cardinal direction N, S, E, W; Figure 3) that were entered into and tracked by the aircraft's Electronic Flight Display for each distance category. Any orbit flown off track was flown again, and data from the corrected pass were the ones recorded and used in the analyses. Both front- and back-seat observers were present in the aircraft to establish whether there were differences in availability based on the observer's location in the aircraft. Results from the front and back seats were only slightly different under some conditions in some locations, since each had a different angle of view from the aircraft (four of 256 records differed at the greatest distances and depths). However, only the front-seat observer's data were used in this study and

TABLE 1 | Covariate information collected to measure the probability of a manatee being available to be detected by an observer in an aircraft (Martin et al. 2015).

Visibility rating	Sea-state rating	Cloud cover (%)	Glare/cloud cover
1	0	0	Yes
Bottom is visible, manatees can be clearly seen	Sea surface smooth and mirror-like	0% of sky covered by clouds	Has some impact on an observer's ability to see a manatee
2	1	25	No
Bottom visible but detail is unclear	Small ripples, no foam crests	25% of sky covered by clouds	Has no impact on an observer's ability to see a manatee
3	2	50	
Water may be clear but difficult to tell because bottom not visible due to depth	Small wavelets, no breaking	50% of sky covered by clouds	
4	3	75	
Water is turbid or tannic, can see less than ~1 m in depth	Large wavelets, crests beginning to break with scattered white caps	75% of sky covered by clouds	
		100	
—	—	100% of sky covered by clouds	

TABLE 2 | Combinations of survey conditions (covariates) collected to measure the probability of a manatee being available to an observer in an aircraft (best to worst conditions).

Date	Visibility rating	Sea state	Glare	Cloud cover
2012-05-24	1	1	Yes	No
2012-06-11	1	2	Yes	No
2016-05-26	1	2	Yes	Yes
2016-05-26	1	2	Yes	Yes
2013-11-20	2	0	Yes	Yes
2012-05-24	2	1	No	No
2013-11-20	2	1	Yes	Yes
2016-03-31	2	3	Yes	No
2012-05-17	3	1	Yes	Yes
2012-05-24	3	1	Yes	No
2013-11-20	3	1	No	Yes
2016-03-31	3	1	Yes	No
2012-05-24	3	2	Yes	No
2012-06-11	3	2	Yes	No
2016-03-31	3	3	Yes	No
2013-11-20	4	0	Yes	Yes
2012-05-17	4	1	No	Yes
2012-06-11	4	1	No	No
2016-05-26	4	1	Yes	Yes

A.

B.

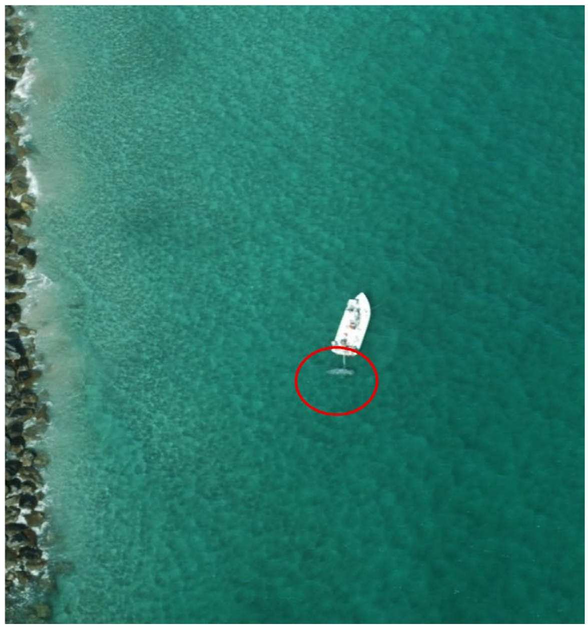

FIGURE 2 | (A) Manatee replica deployment in visibility category 3 (bottom not visible, clarity hard to tell) and sea state 1 (B) visibility category 1 (bottom is visible, manatees can be clearly seen) and sea state 1. Red circles indicate the position of the manatee replica.

used to calculate availability in the Florida manatee statewide abundance analyses because that person was the more experienced observer and, in this study, they had a better angle of view of the replica (Martin et al. 2015). Observers recorded the covariates for visibility, sea state, glare, cloud cover, and other ancillary data at each site (Figure S2). On each pass, at each distance and depth, observers assessed if the replica could be seen at or between each of the cardinal directions along the circular path and recorded whether they could see the replica using a “1” to indicate “yes” or a “0” to indicate “no.” When the observers completed two passes at a certain distance they radioed the boat and the manatee would be lowered by 0.5 m, and the process would start again. This pattern continued until all distance categories for a site were flown twice or until the replica could no longer be seen by the observers at a particular distance (up to a maximum of 400 m) and depth from any direction after two passes (Martin et al. 2015). If the replica was seen from any of the four directions, circling would continue.

Knowing how a manatee's behavior might influence its availability to an observer is also an important aspect of quantifying detection. Therefore, the next component of our study was to estimate the probability of a manatee being above a depth threshold that allowed it to be available for an observer to detect it. Dive data collected during a previous study (Deutsch et al. 2009; Rycyk et al. 2018) in which digital acoustic recording tags (DTAGs) were attached to 18 free-ranging manatees were used to estimate if a manatee was likely to be near enough to the surface of the water to be visible to an observer in an aircraft. We calculated the ratio of the number of depth records above 0.5 m increment thresholds to the total number of depth records from each of the DTAGs. We used depth thresholds in 0.5 m increments up to 3.0 m (0.5, 1.0, 1.5, 2.0, 2.5, and 3.0 m), representing the maximum depths at which manatees could be observed during our flights. For each threshold category, we computed the mean ratio and variance across all animals and derived beta distributions (Martin et al. 2015). In each of the abundance estimates presented in Martin et al. (2015), Hostetler et al. (2018), and Gowan et al. (2023), availability of manatees was calculated as the average availability across distance categories (200, 300, 400 m) for each combination of sea state and visibility (derived

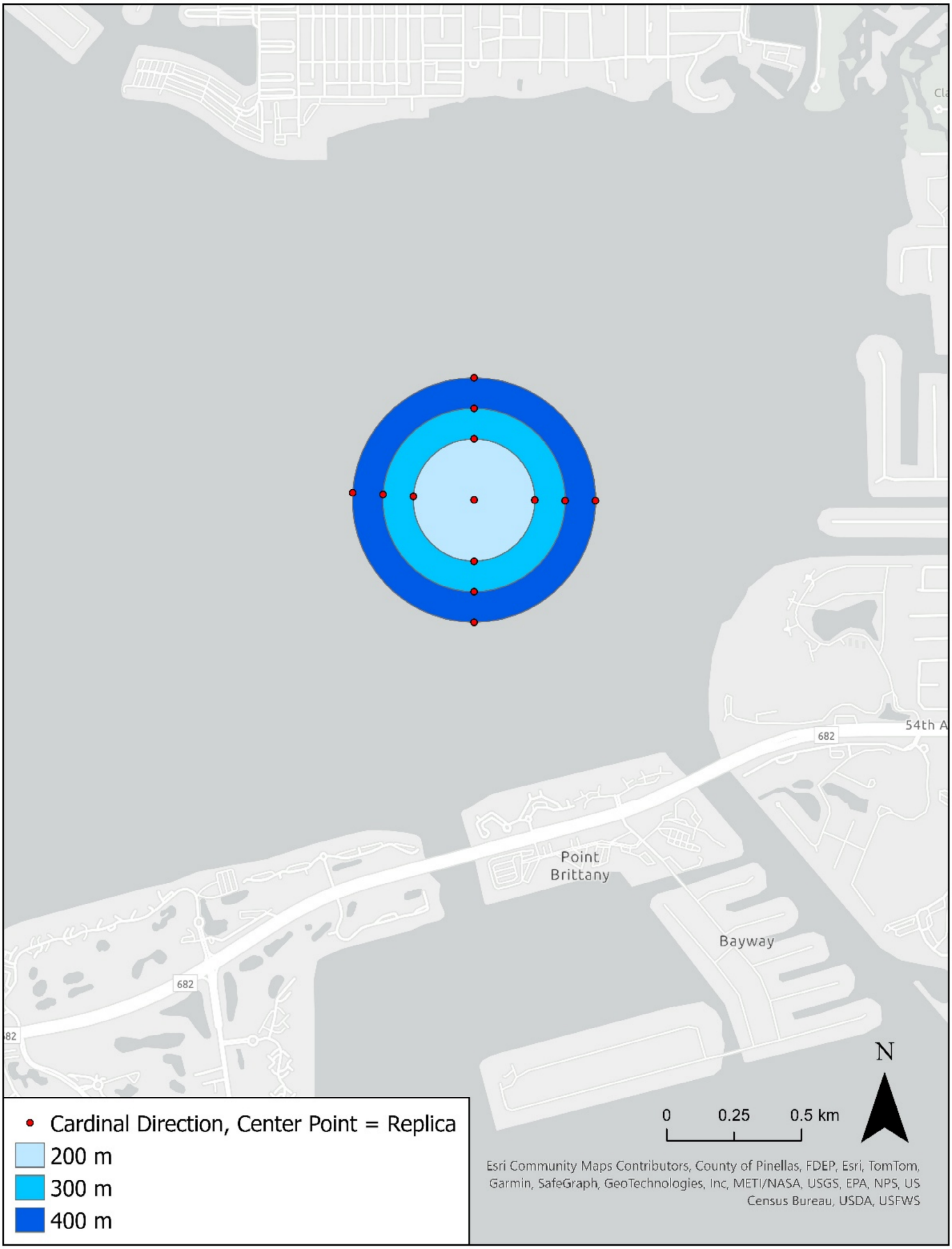

FIGURE 3 | Survey aircraft orbited the manatee replica (center point) at 200 m (inner ring), 300 m (middle ring), and 400 m (outer ring). Observers recorded the distance and depth at which the replica could be seen at or between each of the four cardinal directions (red points).

TABLE 3 | The maximum depth at each distance, for each combination of covariates sampled (some were measured in more than one location and averaged), at which the manatee replica was seen by the observers and the probability (*p*) of a manatee being above that maximum depth threshold calculated from dive data from a DTAG. These values were used to calculate the probability of availability in Martin et al. (2015), Hostetler et al. (2018), and Gowan et al. (2023). NA indicates that a measurement was not available for that category.

Visibility	Sea state	Distance	Max depth	*p* (above max depth)
1	0	200	NA	NA
1	0	300	NA	NA
1	0	400	NA	NA
2	0	200	2.0	0.92
2	0	300	1.5	0.82
2	0	400	1.5	0.82
3	0	200	NA	NA
3	0	300	NA	NA
3	0	400	NA	NA
4	0	200	1.0	0.62
4	0	300	1.0	0.62
4	0	400	1.0	0.62
1	1	200	NA	NA
1	1	300	NA	NA
1	1	400	NA	NA
2	1	200	2.0/1.5/1.0	0.79
2	1	300	1.5/0.5/1.5	0.64
2	1	400	1.5/0.5/1.0	0.57
3	1	200	1.5/1.0/2.0	0.79
3	1	300	NA/1.0/2.0	0.77
3	1	400	0.5/1.0/1.5	0.57
4	1	200	1.0/0.5/2.0	0.60
4	1	300	NA/0.5/1.5	0.54
4	1	400	1.0/0.5/1.5	0.57
1	2	200	2.0/2.5	0.93
1	2	300	2.0/2.5	0.93
1	2	400	2.0/2.5	0.93
2	2	200	NA	NA
2	2	300	NA	NA
2	2	400	NA	NA
3	2	200	1.0/1.5	0.72
3	2	300	1.5/1.5	0.82
3	2	400	1.0/1.5	0.72
4	2	200	NA	NA
4	2	300	NA	NA
4	2	400	NA	NA
1	3	200	NA	NA
1	3	300	NA	NA
1	3	400	NA	NA
2	3	200	2.0	0.92
2	3	300	2.0	0.92
2	3	400	1.5	0.82
3	3	200	1.5	0.82
3	3	300	1.0	0.62
3	3	400	1.0	0.62
4	3	200	NA	NA
4	3	300	NA	NA
4	3	400	NA	NA

from this study) weighted by the proportion of the survey area within each of those distance categories that was flown during the survey. Table 3 lists the maximum depth at which the manatee replica was seen by the observers during this study for each combination of distance and covariates sampled and the probability (*p*) of a manatee being above that depth threshold calculated from dive data (from the DTAG recordings).

The importance of accounting for availability cannot be overstated given that the results of this experiment showed that when visibility and sea state were accounted for, availability of a manatee to an observer ranged from > 90% under low sea states and good visibility to < 60% in high or low sea states and poor visibility (Martin et al. 2015; Hostetler et al. 2018). When combined with observer detection, which ranged from 67% to 76% in Florida manatee abundance surveys (Gowan et al. 2023), this bias can have a profound effect on abundance estimates (Martin et al. 2015; Hostetler et al. 2018; Gowan et al. 2023).

Aerial surveys are an important conservation tool provided that the surveys are implemented with well-defined goals using appropriate methods to achieve those goals (Nichols 2014). Accounting for availability is part of creating well-designed methods, and using a replica of the species of interest to help measure availability directly is a unique approach for helping meet those objectives. According to Pollock et al. (2006), the use of physical models to determine the probability of an animal being available can have wide applications. We have shown that creativity and a few power tools can be used to develop an effective experimental method to measure a manatee's availability to an observer under specific environmental conditions.

The covariates used in our study may not be appropriate in all situations, habitats, or for all platforms or species. While survey methods, such as drone surveys or image/video-based surveys, which are both increasingly being used for wildlife surveys, may require different methods altogether, methods like those presented here could be used to help gauge availability. Additional or modified data collection efforts or covariates may be needed in some cases, but the experiment itself can be applied in other circumstances and in other locations. As noted by Hostetler et al. (2018), estimates of Florida manatee availability could be improved by incorporating covariates such as glare and cloud cover, which were not included in previous abundance estimates; by collecting additional measurements across all sea-state and visibility categories; and by obtaining more diving data for manatees in areas with variable water depths. In addition, species-specific differences (e.g., behavior, morphology, and physiology) can be incorporated into availability models. Furthermore, the approach used here can be adapted for other sirenian species and potentially for other marine animals, such as dolphins or sea turtles, to improve the accuracy and precision of abundance estimates for those species.

Author Contributions

Holly H. Edwards: conceptualization; implementation of experiment as an observer; construction of the manatee replica; data management and curation; drafting original manuscript and final editing. **Stacie M. Koslovsky:** GIS, data management; implementation of experiment as an observer; writing – review and editing. **Thomas R. Reinert:** implementation of experiment as field staff or diver, assistance with replica construction and repair; writing – review and editing.

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The authors have nothing to report.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Data S1:** mms70141-sup-0001-supinfo.docx.