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Combining information for monitoring at large spatial scales: First statewide abundance estimate of the Florida manatee

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A B S T R A C T

Monitoring abundance and distribution of organisms over large landscapes can be difficult. Because of challenges associated with logistics and data analyses uncorrected counts are often used as a proxy for abundance. We present the first statewide estimate of abundance for Florida manatees (*Trichechus manatus latirostris*) using an innovative approach that combines multiple sources of information. We used a combination of a double-observer protocol, repeated passes, and collection of detailed diving behavior data to account for imperfect detection of animals. Our estimate of manatee abundance was 6350 (95%CI: 5310–7390). Specifically, we estimated 2790 (95%CI: 2160–3540) manatees on the west coast (2011), and 3560 (95%CI: 2850–4410) on the east coast (2012). Unlike uncorrected counts conducted since 1991, our estimation method considered two major sources of error: spatial variation in distribution and imperfect detection. The Florida manatee is listed as endangered, but its status is currently under review; the present study may become important for the review process. Interestingly, we estimated that 70% (95%CI: 60–80%) of manatees on the east coast of Florida were aggregated in one county during our survey. Our study illustrates the value of combining information from multiple sources to monitor abundance at large scales. Integration of information can reduce cost, facilitate the use of data obtained from new technologies to increase accuracy, and contribute to encouraging coordination among survey teams from different organizations nationally or internationally. Finally, we discuss the applicability of our work to other conservation applications (e.g., risk assessment) and to other systems.

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1. Introduction

1.1. Monitoring abundance for conservation

Monitoring animal abundance and distribution is often needed to determine the status of a species and to inform management decisions concerning species conservation (Nichols, 2014). Estimating abundance is challenging, especially for species that occupy large areas and are difficult to see. Many management agencies have relied on uncorrected counts to infer population size (Martin et al., 2007). Such counts seldom account for two important sources of error: (1) spatial variation, which results from the inability to comprehensively survey the entire area potentially occupied by the species; and (2) imperfect detection, which results from animals being missed in areas that were surveyed (i.e., the probability of detecting an animal is less than one; Yoccoz et al., 2001; Williams et al., 2002). Thus, many managers now view uncorrected counts as the minimum number of animals known to be alive during a survey. In reality, however, such data are often of limited value for management, and management agencies seek more reliable estimates of abundance. Reliable estimates can be used to track how populations change over time or, as a key parameter in population projection models, to assess threats. In the context of decision making abundance is often treated as a state variable and can be used to explore how populations respond to management actions (e.g., Williams et al., 2002; Nichols, 2014).

1.2. Large-scale monitoring and integration of information

The logistics of surveying large landscapes can be difficult from the data analysis, financial, and safety perspectives, yet large-scale

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monitoring is often necessary because many species occupy large areas (Jones, 2011). Therefore, when selecting methods for large-scale monitoring it is important to consider tradeoffs between precision, bias, and cost/logistics (Williams et al., 2002). Common methods include counts, distance sampling and capture-mark-recaptures techniques. For example, several aerial surveys of cetaceans have used distance sampling to estimate population density (Barlow, 2006; Hammond et al., 2013). Some of the early applications of distance sampling did not account for the probability of availability, which may lead to an underestimation of population density or abundance (Diefenbach et al., 2007; Hammond et al., 2013). Indeed, the probability of detecting an animal can be viewed as the product of two probabilities: (1) the probability that an animal is available for detection by an observer (probability of availability; e.g., a marine mammal is not available for detection if it is swimming so deep that it cannot be seen by an observer in an airplane); and (2) the probability of detecting an animal given that it is available for detection (probability of detection; this probability is associated with the perception process, which often differs among observers, and reflects the ability of an observer to detect animals). More recent studies have modified estimators based on distance sampling to account for the probability of availability (Diefenbach et al., 2007; Hammond et al., 2013). Unfortunately, distance sampling and capture-mark-recapture methods are not always applicable, and creative alternatives have to be considered.

A new trend in statistical modeling is the integration of multiple sources of information (e.g., Kéry and Schaub, 2012; Gopalaswamy et al., 2012). A benefit of this approach is that it can improve the precision of an estimator by borrowing information from multiple data sources (Gopalaswamy et al., 2012). This is especially useful when some of the data are already available or can be collected opportunistically because they provide additional "free" (or "cheap") information. The growing availability of software to implement Bayesian approaches has made it easier to integrate information (Kéry and Schaub, 2012). Another benefit of integration of information is that it lends itself to incorporating information from new technologies while still using existing monitoring data. Geo-referenced images obtained from unmanned aerial systems or satellite, data loggers deployed on wildlife are just some examples of sources of information that can be integrated (Fretwell et al., 2014; Martin et al., 2012; Pollock et al., 2006). Integrated modeling to monitor wildlife at large spatial scales is still fairly new and underutilized.

1.3. Case in point of the endangered Florida manatee

Since 1991 the Florida Fish and Wildlife Conservation Commission (FWC) has used uncorrected aerial survey counts (synoptic surveys) to monitor the Florida manatee (*Trichechus manatus latirostris*) listed as endangered by the U.S. Fish and Wildlife Service (USFWS) and IUCN (Deutsch et al., 2008; Edwards et al., 2007). These counts are conducted in winter as required by the Florida State statute and cover the primary wintering habitats of manatees in Florida. Counts from synoptic surveys can vary substantially due to weather-related shifts in manatee distribution and differences in observers' ability to detect manatees (Packard et al., 1985, 1986; Craig and Reynolds, 2004; Edwards et al., 2007). The magnitude of such error is unmeasured, and its influence on counts is unknown. For example, counts increased from 3802 in 2009 to 5077 in 2010; it is likely that part of the variation between counts could be explained by weather-related changes in distribution of manatees or by changes in the level of detection (Edwards et al., 2007). Because of these confounding factors, FWC has discouraged the use of these counts for inferring annual changes in population size. Although several scientists have worked to improve modeling techniques for analyzing synoptic count data of manatees at winter aggregation sites for instance using Bayesian methods (Craig and Reynolds, 2004; Fonnesbeck et al., 2009), estimating abundance at aggregation sites remain a challenge (e.g., difficulties for observers to keep track of hundreds of aggregated manatees); and no good alternative for estimating manatees statewide has been used.

Agencies charged with protecting manatees have long been interested in obtaining accurate estimates of statewide abundance, considered an important quantity for informing management decisions and for evaluating the manatee's conservation status. Currently, resource managers use projection models to assess potential threats and the long-term viability of the manatee population (Runge et al., 2007). These models have relied primarily on synoptic survey counts for initial values of abundance (Runge et al., 2007; Laist et al., 2013). To better address the needs of management agencies, we developed a novel approach for modeling abundance and distribution of Florida manatees. Our approach integrates information from a stratified random sampling design, double-observer protocol, repeated passes, and manatee dive data to account for imperfect detection of animals during the surveys. We modeled detection and availability separately (e.g., Pollock et al., 2006), and we explain how decomposing detection into these two components can improve the reliability and cost-effectiveness of estimating abundance. Our approach can be applied to other species and systems and provides useful insights for the design and data analysis in other studies that also focus on modeling abundance and distribution over large landscapes.

2. Materials and methods

2.1. Study area and sampling method

We conducted aerial surveys from fixed-wing aircraft from February 28 to March 22, 2011, along the west coast of Florida and from March 5 to 13, 2012, along the east coast (Fig. S1, Fig. 1). The two coasts were surveyed in different years for logistical reasons. Resighting information from individually marked animals and genetic studies suggest that there is little movement between the two coasts (Tucker et al., 2012; K. Rood, personal communication). Estuaries, rivers, creeks, and coastlines from all or part of 26 counties on the west coast and 21 counties on the east coast were surveyed. The surveys were conducted over several days because of logistics. To minimize the risk of counting the same manatee more than once, we tried to minimize the time between surveys in adjacent areas where manatee movement was considered likely to occur (see Fig. S1 for details about the timing of the surveys for each area). Natural breaks in known manatee distribution (based on expert opinion) were used to determine the stopping points for the survey each day (Fig. S1). Escambia to Gulf, an area expected to have few manatees (Martin et al., 2014) was surveyed later due to weather. This explains the long duration of the surveys on the west coast (Fig. S1).

We timed the surveys to avoid large aggregations of manatees (e.g., >50 manatees grouped together at power plants), which can be hard to count. We used a stratified random sampling protocol in which all potential manatee habitat was included in the sampling frame and was allocated into three survey strata (determined a priori; stratum 1: warm-water aggregation habitats; stratum 2: areas deemed likely manatee habitats (e.g., based on a bathymetry <3.7 m or with seagrass); stratum 3: habitats less likely to be occupied by manatees (e.g., deeper-water areas with no seagrass) (Dorazio et al., 2013; Martin et al., 2011), see Fig. S2). Seagrass data was based on a FWC-compiled dataset (for more details see http://atoll.floridamarine.org/Data/Metadata/SDE_Current/seagrass_fl_poly.htm).