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A novel approach to estimate the distribution, density and at-sea risks of a centrally-placed mobile marine vertebrate

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ABSTRACT

Formulating management strategies for mobile marine species is challenging, as knowledge is required of distribution, density, and overlap with putative threats. As a step towards assimilating knowledge, ecological niche models may identify likely suitable habitats for species, but lack the ability to enumerate species densities. Traditionally, this has been catered for by sightings-based distance sampling methods that may have practical and logistical limitations. Here we describe a novel method to estimate at-sea distribution and densities of a marine vertebrate, using historic aerial surveys of Gabonese leatherback turtle (*Dermochelys coriacea*) nesting beaches and satellite telemetry data of females at sea. We contextualise modelled patterns of distribution with putative threat layers of boat traffic, including fishing vessels and large ship movements, using Vessel Monitoring System (VMS) and Automatic Identification System (AIS) data. We identify key at-sea areas in which protection for inter-nesting leatherback turtles could be considered within the coastal zone of Gabonese Exclusive Economic Zone (EEZ). Our approach offers a holistic technique that merges multiple datasets and methodologies to build a deeper and insightful knowledge base with which to manage known activities at sea. As such, the methodologies presented in this study could be applied to other species of sea turtles for cumulative assessments; and with adaptation, may have utility in defining critical habitats for other central-place foragers such as pinnipeds, or sea bird species. Although our analysis focuses on a single species, we suggest that putative threats identified within this study (fisheries, seismic activity, general shipping) likely apply to other mobile marine vertebrates of conservation concern within Gabonese and central African coastal waters, such as olive ridley sea turtles (*Lepidochelys olivacea*), humpback dolphins (*Sousa teuszii*) and humpback whales (*Megaptera novaeangliae*).

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1. Introduction

Multiple modelling techniques exist to build an understanding of habitat niches for species in the marine environment (Aarts et al. 2008; Edrén et al. 2010; Forney et al. 2015; Matthiopoulos et al. 2004; Pikesley et al. 2014; Wedding et al. 2016). These methods are challenged by the issue of enumerating species densities, which has traditionally relied upon sightings-based distance sampling (Buckland et al. 2001), with data being collected primarily by way of boat or aerial surveys (Aerts et al. 2013; Becker et al. 2014; Hammond et al. 2002). Typically, distance sampling relies on three key assumptions being met (Thomas et al. 2010); species are detected with certainty, species do not move, distance measurements are exact (Thomas et al. 2010). As such, application of distance sampling methodologies to aerial based surveys have helped reveal density patterns across a broad spectrum of marine species "at sea" (Lauriano et al. 2011; Scheidat et al. 2012; Seminoff et al. 2014) and have also proved their efficacy in enumerating densities of marine species whilst on land (Stapleton et al. 2016).

However, many marine species are challenging to observe at sea because of their cryptic nature, spending limited time at the sea surface, or due to restrictions imposed by environmental conditions (weather and sea state) (Evans and Hammond 2004). To provide for an alternative complementary process to estimate at-sea distributions and relative densities, we formulated a method that was independent of the need to visually sight species at sea, that instead utilised existing available data: aerial surveys of leatherback turtle nest counts and satellite tracking data.

Increased understanding of spatial and temporal habitat use, together with associated densities, may facilitate successful management strategies. However, design, implementation and regulation of protection for mobile marine species is challenging; particularly for far ranging, pelagic and migratory species (Briscoe et al. 2016; Hyrenbach et al. 2000). Defining appropriate spatial and temporal bounds to managed areas is more tractable when animals seasonally aggregate (Maxwell et al. 2014; Whittock et al. 2014; Witt et al. 2008). In 2002, the central African country of Gabon created a system of coastal and terrestrial National Parks with the aim of protecting key areas of biodiversity-rich habitats. Thirteen National Parks were designated, including a single marine park to the south of the country at Mayumba (Fig. 1). Gabon's beaches support important nesting sites for sea turtles, including globally important breeding aggregations for the leatherback turtle (*Dermochelys coriacea*); the Southeast Atlantic Ocean subpopulation is currently listed as IUCN Red List Data Deficient (Tiwari et al. 2013). The northern and southern extremes of the Gabon coast (Pongara and Mayumba National Park) receive the highest densities of nesting activity (Witt et al. 2009). Additionally, the olive ridley (*Lepidochelys olivacea*), green (*Chelonia mydas*) and hawksbill sea turtles (*Eretmochelys imbricata*) also nest (Casale et al. 2017; Maxwell et al. 2011; Metcalfe et al. 2015).

The leatherback turtle is highly migratory with expansive post-nesting dispersal patterns (Fossette et al. 2014; Roe et al. 2014), but will seasonally aggregate off Gabon's nesting beaches. Protection of large scale aggregations likely represents a significant management target within coastal waters (Hitipeuw et al. 2007; Nel et al. 2013; Roe et al. 2014; Witt et al. 2008). However, for protection to be effective, density and distributions of turtles need to be ascertained and relevant threats identified, and if possible quantified, preferably in space and time. In the marine environment, sea turtles may negatively interact with a broad suite of vessel activity. These interactions can lead to bycatch from coastal (Alfaro-Shigueto et al. 2007; Lum 2006; Witt et al. 2011) and oceanic (Huang 2015; Lewison et al. 2004) fisheries, boat strike (Denkinger et al. 2013; Nabavi et al. 2012), crude oil contamination (Follett et al. 2014), or possible displacement from critical habitats or auditory damage from seismic surveying (Nelms et al. 2016). Within Gabon's territorial waters bycatch from fisheries (Casale et al. 2017) and/or boat strike (Billes et al. 2003) may negatively impact leatherback turtles. There is also extensive offshore petrochemical extraction primarily located to the south of Port Gentil (http://www.seaturtle.org/mtrg/projects/gabon/MarineAtlas.pdf).

At-sea vessel activity may be gathered by both Vessel Monitoring System (VMS) and Automatic Identification System (AIS) data. The use of VMS, primarily as a tool for providing at-sea densities of fisheries (Hintzen et al. 2012; Vermard et al. 2010; Witt and Godley 2007) has revolutionised the process of mapping, analyzing and interpreting fisheries activity patterns. The advent of AIS may prove to provide additional capabilities due to time resolution of data (Natale et al. 2015) and inclusion of multiple vessel types (Metcalfe et al. 2018; Shelmerdine 2015). The installation and operation of VMS is discretional among maritime nations; the requirement to fit AIS systems is, however, mandatory aboard vessels making international voyages with gross tonnage ≥300 t, cargo vessels ≥500 t and all passenger ships regardless of size (Shelmerdine 2015).

In this study, we combine aerial survey nest count data for leatherback turtles together with satellite telemetry data from nesting females and contextualise these with VMS and AIS data. Our aims were to (i) model leatherback turtle distribution and relative density at sea using a method that was independent of the need to sight species at sea, (ii) investigate areas of spatial overlap between leatherback turtles and putative threats from vessels associated with multiple industry categories, and (iii) identify key areas for inter-nesting leatherbacks within the Gabonese Exclusive Economic Zone (EEZ) that may benefit from application of Marine Protected Areas (MPAs).

2. Methods

2.1. Aerial survey data

Aerial surveys were flown along the Gabonese coast using a variety of high-wing light aircraft (Supplementary material, Table A.1) as described in (Pikesley et al. 2013). Surveys were organised to coincide with the main period of leatherback turtle nesting activity (December–February; (Witt et al. 2009)). Multiple surveys were conducted in 2002/2003 (n = 2), 2005/2006 (n = 3) and 2006/2007 (n = 3), with no surveys in 2003/2004 and 2004/2005. Each survey represented a 600 km flight path (approximate straight-line distance). Flights commenced at dawn. Surveys were timed to coincide with periods when the maximum width of the nesting beach was unaffected by tide during early morning daylight hours, hence ensuring the greatest number of nesting activities could be recorded after sunrise and before the next high tide removed traces of activity. Surveys were typically split over two days to take advantage of morning low sun angle, which aids detection of marine turtle nesting tracks during video analysis.

Survey aircraft were flown at a groundspeed of 180 to 190 km h^{-1} at an altitude of 50 to 60 m, with the aircraft positioned 100 to 200 m offshore. Surveys were flown in a southeast direction from north to south, parallel to the coastline. The survey start location was northern most limit of Pongara National Park (Fig. 1). The survey end location was the southern limit of Mayumba National Park's border with the Republic of Congo. A 50 km section of coast to the north and east of Port Gentil was excluded from all surveys as this area consisted of mangroves and mudflats, which are unlikely to support leatherback turtle nesting activity.

A video camera was used to record footage of the nesting beach during each aerial survey. Leatherback turtle nesting activities were then counted from this video data in accordance with the methodology

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