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Evidence-based marine protected area planning for a highly mobile endangered marine vertebrate

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ABSTRACT

Marine Protected Areas (MPAs) now form an important part of marine conservation and fisheries management; hence, there is broad interest in developing procedures that optimize their design. We used data collected over a 10-year period (2003–2012) from direct surveys and >100 adult male and female loggerhead sea turtles (*Caretta caretta*) tracked with devices, including GPS loggers and Fastloc GPS-Argos, to consider the optimum design for a MPA at a globally important breeding area, where there is already an existing national marine park aiming to protect the population (Zakynthos, Greece). Turtles primarily used areas very close to shore (approx. 7 km in length by 1 km in width, within the <10 m isobath) for breeding and foraging activity at different times of the year. We calculated that this small nearshore coastal zone encompassed 72% of all turtle GPS locations recorded in the MPA, and is therefore important for conservation management. We developed an index to evaluate the suitability of the existing and proposed conservation zones based on (1) home range area use by turtles in these zones versus (2) zone size, so that the benefit to turtles could be maximized while minimizing the negative impacts to other stakeholders (e.g., boat operators). With this evidence-based approach, we propose a modification to the existing MPA that might both enhance local economic tourism activities and better safeguard this key sea turtle breeding population. The approaches used here will have general application for the design of MPAs used by mobile species that can be tracked.

1. Introduction

Over the last two decades there has been a rapid increase in developing procedures for optimizing the design of Marine Protected Areas (MPAs) worldwide (McCay and Jones, 2011). In theory, MPAs should conserve marine biodiversity, maintain productivity, and contribute to economic and social welfare (Christensen et al., 1996; Pressey et al., 2007). However, it is unrealistic to assume that complete knowledge about the biodiversity, current and potential threats, or the effectiveness of management strategies may be obtained within a planning area. Hence, significant gaps often remain in the design and functioning of MPAs (Agardy et al., 2011; Botsford et al., 2003; Pullin et al. 2004; Sale et al., 2005). In general, ecosystem approaches are advocated over a single-species approach when designing and evaluating the effectiveness of MPAs (Agardy, 1994; Friedlander et al., 2007). Yet, more is often known about specific species targeted for protection than other components of the ecosystem (Hooker et al., 1999; Taylor et al., 2007; Maxwell et al., 2011). Within MPAs, the spatial placement of zones (or marine spatial planning) allows or restricts different anthropogenic activities, serving as the primary management mechanisms for protecting biodiversity and/or target species. In addition, many species of conservation concern are migratory; hence, some areas (e.g., foraging or breeding areas) may only be vulnerable at certain times of the year, requiring seasonal rather

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than year-round protection. Therefore, zones require systematic planning for optimal delineation (Fernandes et al., 2005; Leslie et al., 2003; Witt et al., 2008).

Information about the spatial and temporal movement patterns of individuals is increasingly used to identify area use by terrestrial, avian and marine animals, and therefore sites worth protecting (e.g., dolphins, Hooker et al., 1999; geese, Jensen et al., 2008; caribou, Johnson et al., 2004; turtles, Scott et al., 2012). In marine environments, trends in animal spatial distributions are often determined by both fixed features (such as topography) and variable oceanographic features (such as temperature and salinity) (Ardron et al., 2008; Hooker et al., 1999). In general, MPAs based on static (e.g., bathymetry) or persistent (e.g., tides) environmental features are easier to implement (Hooker et al., 1999; Hyrenbach et al., 2000) than transient oceanographic or environmental features (Ardron et al., 2008; Hooker et al., 2002, 2011). Furthermore, these different approaches require different levels of environmental and wildlife data input. In theory, by obtaining baseline information about the requirements of target species and associated indicators, it is possible to develop programs that reduce threats to species, while enhancing economically important anthropogenic activities. However, the updating of existing MPAs presents logistical and governance issues, particularly when delineated using precautionary rather than science-based information (Thompson et al., 2000). Hence, the population might not necessarily frequent the zones designed to protect them. To redress this discrepancy, long-term field monitoring techniques are crucial for conducting population/species level assessments (e.g., Scott et al., 2012). Such effort requires stable funding, a baseline understanding of key species, and the correct interpretation of assimilated data to objectively drive policy change (Pullin et al., 2004; Sutherland et al., 2004). Here we consider this important role of the extent of animal movements (e.g. Hays and Scott, 2013; Pala, 2013) for the optimal planning of MPAs.

While sea turtles often migrate 1000s of kilometers between breeding and foraging grounds, adult males and females tend to aggregate for several months at discrete breeding areas to mate and nest (Henwood, 1987), presenting ideal sites for implementing protected area management. However, information remains limited about temporal shifts in spatial area use across this period by both sexes, with most studies focusing on inter-nesting female activity, as they are easier to detain for instrumentation when emerging on beaches to nest. Within the Mediterranean, the Greek island of Zakynthos has a well-established MPA and national park that, within its boundaries, primarily safeguards the breeding habitats of the largest population of endangered loggerhead sea turtles in the region. However, legislation for marine zoning was first implemented in 1991 with the establishment of zones A and B and completed in 1994 with the establishment of zone C (9 and 6 years before the establishment of the national park), and was based on nesting beach use by female sea turtles, rather than the actual marine habitat requirements of both sexes (for more details see Schofield et al., 2007). The marine protected area is primarily subject to two major uses (1) year-round small-scale commercial fishing (except for 1 May to 31 October in the marine protection Zone A; see Fig. 1), and (2) boat-based wildlife watching of sea turtles from May to September, while water-sports are prevalent along the island's eastern coastline.

Several tracking studies (Fossette et al., 2012; Hays et al., 2010; Schofield et al., 2007, 2009a,b, 2010a,b; Zbinden et al., 2007, 2011) have contributed preliminary insights about the marine area use, physiological requirements and environmental drivers, as well as providing tentative suggestions for protection of this population. However, the effectiveness of existing legislation at safeguarding this breeding population has not been addressed, because these studies were (1) biased towards one sex, (2) of limited duration, and (3) based on small sample sizes (<20 individuals) and small volumes of data that might not be representative at the population level (Borger et al., 2006; Lindberg and Walker, 2007; Murray, 2006; Schofield et al., 2013). For instance, our research group has previously suggested that males and females occupy similar areas during the breeding period (Schofield et al., 2010a); however, this study was limited to just May and June, with a sample size of just 13 females and seven males. Here, we used data assimilated from 109 tracked (including GPS loggers and Fastloc GPS-Argos) male and female turtles, in addition to direct in-water surveys, over a 10 year period, as a case study to determine the utility of evidence-based information to pragmatically improve existing protection measures and drive policy change. We use the data to (1) map year-round habitat use by this adult breeding population using GIS and R software, (2) evaluate the effectiveness of existing zoning with respect to temporal and spatial use by the turtles, and (3) model the effectiveness of theoretical park boundaries using kernel analyses to identify core areas used by turtles and thus the optimum zoning that maximizes protection, while minimizing space restrictions for anthropogenic use (i.e., small-scale commercial fishing and turtle-watching ecotourism activities). Based on our findings, we consider the importance of both maximizing the protection of endangered species and the logistics of practical implementation of legislation at a governmental and local level.

2. Materials and methods

2.1. Instrumentation

Between 2006 and 2012, a total of 77 loggerhead turtles ($n = 45$ males, of which six were tracked for more than one breeding season; $n = 32$ females of which one was tracked for more than one breeding season) from the Greek island of Zakynthos in the central Mediterranean basin (Fig. 1; 37°43′N, 20°52′E), were instrumented with satellite transmitters or TrackTag GPS dataloggers. During

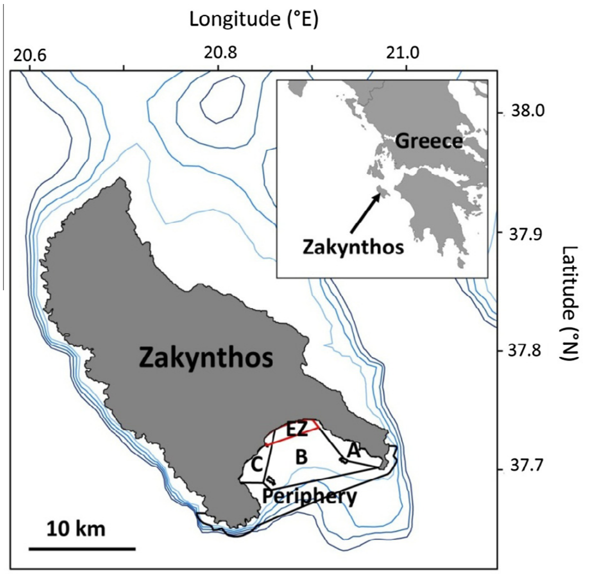

Fig. 1. Map of Zakynthos (with insert showing the location of the island in Greece). National Marine Park of Zakynthos maritime zones are shown, in addition to the previously suggested NMPZ Ecotourism zone (EZ) to improve turtle protection and the regulation of turtle watching activity. Protective legislation is in place from May to October only. Maritime Zone A = no sea vessels permitted; Maritime Zone B = sea vessels permitted at 6 km h^{-1} but no mooring; Maritime Zone C = sea vessels permitted at 6 km h^{-1} and mooring. Island bathymetry contours (i.e., 50, 100, 150, and 200 m) were extracted from the ETOPO1 1 arc-min global relief model (Amante and Eakins, 2009).