Journal of Experimental Marine Biology and Ecology 450 (2014) 47–54

Contents lists available at ScienceDirect

Journal of Experimental Marine Biology and Ecology

journal homepage: www.elsevier.com/locate/jembe

Special issue: Charismatic marine mega-fauna

Employing sea-level rise scenarios to strategically select sea turtle nesting habitat important for long-term management at a temperate breeding area

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ARTICLE INFO

Available online 1 November 2013

Keywords:
Coastal squeeze
Evidence-based management
Nest site selection
Resilience
Sex ratio
Vulnerability assessment

ABSTRACT

Management strategies to protect endangered species primarily focus on safeguarding habitats currently perceived as important (due to high-density use, rarity or contribution to the biological cycle), rather than sites of future ecological importance. This discrepancy is particularly relevant for species inhabiting beaches and coastal areas that may be lost due to sea-level rise over the next 100 years through climate change. Here, we modelled four sea-level rise (SLR) scenarios (0.2, 0.6, 0.9 and 1.3 m) to determine the future vulnerability and viability of nesting habitat (six distinct nesting beaches totalling about 6 km in length) at a key loggerhead sea turtle (*Caretta caretta*) rookery (Zakynthos, Greece) in the Mediterranean. For each of the six nesting beaches, we identified (1) the area of beach currently used by turtles, (2) the area of the beach anticipated to become inundated under each SLR, (3) the area of beach anticipated to become unsuitable for nesting under each SLR, (4) the potential for habitat loss under the examined SLR, and (5) the extent to which the beaches may shift in relation to natural (i.e. cliffs) and artificial (i.e. beach front development) physical barriers. Even under the most conservative 0.2 m SLR scenario, about 38% (range: 31–48%) total nesting beach area would be lost, while an average 13% (range: 7–17%) current nesting beach area would be lost. About 4 km length of nesting habitat (representing 85% of nesting activity) would be lost under the 0.9 m scenario, because cliffs prevent landward beach migration. In comparison, while the other 2 km of beach (representing 15% nests) is also at high risk, it has the capacity for landward migration, because of an adjoining sand-dune system. Therefore, managers should strengthen actions on this latter area, as a climatically critical safeguard for future sea turtle nesting activity, in parallel to regularly assessing and revising measures on the current high-use nesting habitats of this important Mediterranean loggerhead population.

1. Introduction

Recent studies assessing climate change scenarios on various terrestrial, avian and marine species have questioned whether current biodiversity conservation strategies adequately incorporate the future habitat requirements of endangered species (Hannah, 2009; Parmesan and Yohe, 2003; Walther et al., 2002). At present, the identification and prioritisation of conservation areas are based on current conditions, ranges and environmental parameters, using quantitative or qualitative datasets (Hansen et al., 2009; Hyrenbach et al., 2000; Sutherland et al., 2004). While many models predicting future climate scenarios exist (Araujo et al., 2005; Murphy et al., 2004), they are rarely integrated into current management programmes, due to practitioners being unsure as to what actions to take, the risks of implementing strategies and questionable effectiveness of such strategies at reducing the impacts of climate change (Fuentes et al., 2012; Halpern et al., 2007; Tercek et al., 2012). This discrepancy is particularly relevant for species inhabiting coastal zones that may be lost through climate change, due to predicted global sea-level rises of 0.2 m to 0.6 m over the next 100 years, reaching a possible 1 to 2 m when considering melting ice-sheets and glaciers (IPCC, 2007; Pfeffer et al., 2008; Rahmstorf, 2010).

Sea-level rise is anticipated to cause extensive coastal flooding, the inundation of low-lying coastal areas and heightened coastal erosion (Feagin et al., 2005; IPCC, 2007; Poulter et al., 2009), threatening important economic areas for fisheries, agriculture and tourism, worldwide. Under natural conditions, beaches are predicted to be subject to increased erosion, and an upward and landward migration (Bruun, 1962); however, the extent of this movement will be inhibited by the presence of natural (i.e. cliffs) and/or artificial (i.e. beachfront

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http://dx.doi.org/10.1016/j.jembe.2013.10.017

development, groynes and jetties) barriers, which has been termed "coastal squeeze" (Feagin et al., 2005; Fish et al., 2008; Mazaris et al., 2009a). Consequently, it is difficult to foresee how beaches might change over the next 100 years, or how species dependent on these habitats, or adjacent habitats buffered by beaches (such as wetlands), might be impacted (Baker et al., 2006; Michener et al., 1997). Both tropical and temperate beaches provide essential nesting habitat for endangered sea turtles, and are constantly changing through natural processes, such as seasonal erosion and accretion as a result of intensive winter storms; hence, this group of animals has evolved in conjunction with hundreds of thousands of years of continuous habitat alteration (Fuentes et al., 2011; Kamel and Mrosovsky, 2004; Katselidis et al., 2013). However, there remains much debate as to whether sea turtles are able to adjust to the accelerated loss or major alteration of these breeding habitats through sea-level rise in the next 100 years, due to the presence of numerous additional anthropogenic stressors (Fuentes et al., 2012; Hawkes et al., 2007, 2009; Poloczanska et al., 2009; Witt et al., 2010).

The selection of beaches and nesting sites by sea turtles has been subject to extensive investigation, with studies showing that several species nest at a mean elevation of 1 m above sea level, regardless of beach type and/or location (i.e. temperate versus tropical) (Horrocks and Scott, 1991; Johannes and Rimmer, 1984; Weishampel et al., 2004; Wood and Bjorndal, 2000). We supported this phenomenon in a recent study at the temperate loggerhead breeding area of Zakynthos, Greece, and also showed that turtles preferentially emerge and nest on beaches with steeper slopes (Katselidis et al., 2013). This observation led us to suggest that management strategies at this site should focus on protecting steeper sections of beaches; however, as 50% of the nesting area is backed by cliffs and the other 50% by a sand dune system, appropriate long-term management strategies of this habitat may ultimately conflict with proposed immediate actions when taking sea-level rise scenarios and the potential for beach migration into consideration.

Here, we evaluate the impact of four sea-level rise scenarios (0.2, 0.6, 0.9 and 1.3 m) on the vulnerability and viability of nesting habitat (six separate nesting beaches totalling about 6 km) at the key Mediterranean sea turtle rookery of Zakynthos in Greece (Margaritoulis, 2005). In addition, we assessed the extent to which beaches may shift in relation to natural (i.e. cliffs) and artificial (i.e. beach front development) physical barriers. Based on the results, we identified which nesting habitat is most likely to persist in the event of sea-level rise. Finally, we integrated our findings to the management and conservation of this site, and suggest corresponding management actions to safeguard the future of this important loggerhead nesting population in the Mediterranean region.

2. Material and methods

2.1. Study site and nesting population

The Greek island of Zakynthos (37°43′N, 20°52′E; Fig. 1) hosts the largest known breeding population of loggerhead sea turtles in the Mediterranean (Margaritoulis, 2005). Sea turtles nest from late May to early August (sometimes continuing into early September) (Katselidis et al., 2012, 2013; Schofield et al., 2013a, 2013b). On average, 1200 clutches are laid annually on six discrete nesting beaches (Gerakas, Daphni, Sekania, Crystal, Kalamaki and Marathonisi), totalling about 6 km in length. These beaches are situated within the protected area of the National Marine Park of Zakynthos (Katselidis et al., 2012; Margaritoulis, 2005). The total coastline of the protected area covers about 27.4 km, of which 7.9 km has been urbanised for tourism, while the remaining 19.5 km is undeveloped, including almost all protected nesting beaches (just 904 m of nesting beach is directly backed by development). Various buffer zones exist within the NMPZ, with development being prohibited for a minimum to 150 m behind all nesting beaches (Supplementary Fig. 1).

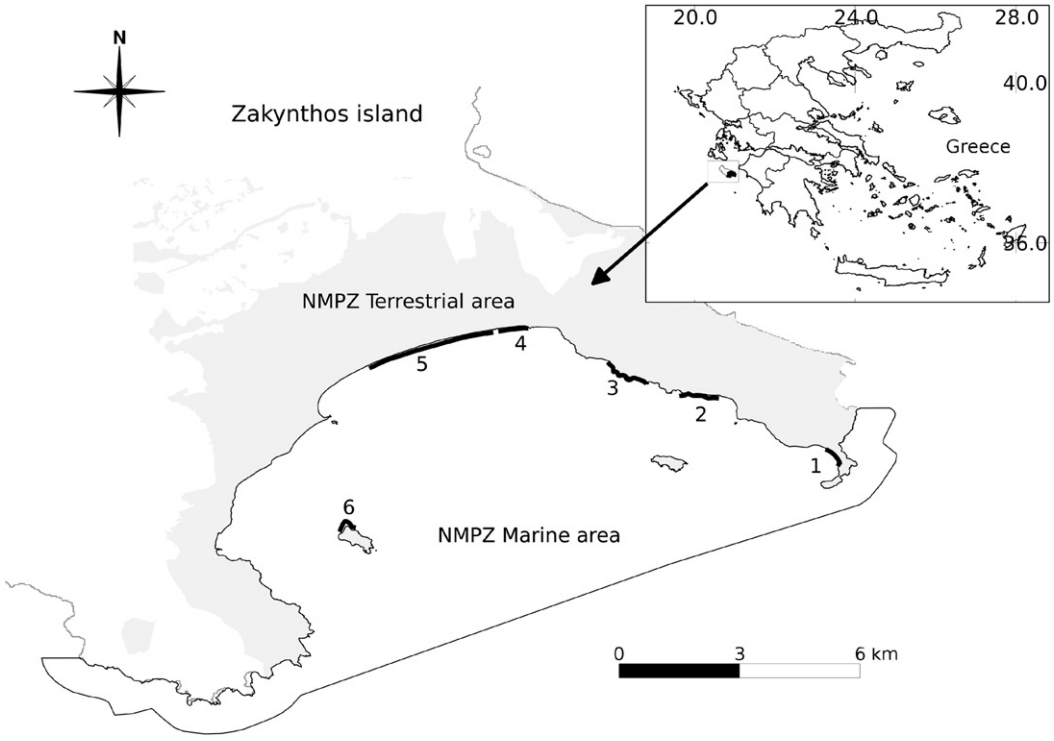

Fig. 1. Map of the breeding area of Laganas Bay in the National Marine Park of Zakynthos (NMPZ) at the southern part of Zakynthos Island, Greece, showing the six nesting beaches (1. Gerakas, 2. Daphni, 3. Sekania, 4. Crystal, 5. Kalamaki and 6. Marathonisi, with a thick black line indicating the length of each beach). For a more detailed map of the nesting beaches, see Supplementary Fig. 1.