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Effects of nature-based tourism and environmental drivers on the demography of a small dolphin population

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ABSTRACT

Many marine top predators are experiencing significant declines due to anthropogenic impacts, and therefore reliable monitoring is essential to understand their population dynamics. We used Pollock's robust design capture–recapture modelling to assess the influence of oceanographic variables, artisanal fisheries and human disturbance on several demographic parameters (abundance, temporary emigration and survival) of the Indo-Pacific bottlenose dolphin (*Tursiops aduncus*), using long-term data on marked individuals from East Africa. Photo-identification data was collected over 551 boat-based surveys between 2006 and 2009, with 137 individuals identified. Our best fitting model indicated that exposure to tourism (represented by the number of tourist boats) increased the probability of dolphins seasonally emigrating from the study area. The return rate of temporary emigrants was negatively linked to the seasonal sea surface temperature, probably associated with food availability. That model supported the existence of heterogeneity in annual local survival estimates, with transient dolphins showing a lower value than resident individuals (0.78 and 0.98, respectively). Furthermore, abundance estimates showed a small population size ranging from 19 individuals (95% CI: 11–33) to a maximum of 104 dolphins (95% CI: 78–139). This small population, together with their high site fidelity and coastal distribution, might be particularly vulnerable to human disturbances. This study highlights the influence of environmental and anthropogenic factors on dolphin demography and population dynamics and the need to integrate these drivers to provide robust evidences for conservation stakeholders in an adaptive management framework.

1. Introduction

As populations of marine top predators decline worldwide (Pauly et al., 1998), there is an urgent need to estimate robust demographic parameters to accurately inform and assess management decisions. Assessing population dynamics for long-lived and highly migratory marine species is complex but an essential component for managing populations. Marine top predators play a major role on the structure and functioning of marine ecosystems, and are dependent upon a broad range of trophic links within the marine food web (Heithaus et al., 2008). As a result, these species are vulnerable to anthropogenic pressures, climate variability and subsequent habitat alterations (Barbraud and Weimerskirch, 2001), fisheries interactions (Lewison et al., 2004), and overfishing among others. Thus, understanding the effects of biotic and abiotic factors on demographic parameters can provide valuable information to evaluate changes in these populations (Weimerskirch et al., 2003).

Mark-recapture modelling techniques have been widely used to estimate population dynamics and demographic parameters (Oro et al., 2004). These methods have traditionally been developed from either closed population models, where no population losses (through emigration or death) occur along the sampling period, or open, which rely on the assumption that all emigration is permanent. Consequently, animal population studies can introduce bias into demographic parameters if temporary emigration is not correctly accounted for (Fujiwara and Caswell, 2002). Pollock's robust design, which combines close and open population models under a nested sampling framework, brings a more biologically realistic approach into the analysis by allowing animals to temporarily emigrate and return to the study area (Kendall et al., 1997; Pollock et al., 1990). The significance of estimating the probability of temporary emigration has been proved in multiple taxa: amphibians (Muths et al., 2006), bats (Frick et al., 2010), voles (Kendall et al., 1997), and marine top predators (Kendall and Bjorkland, 2001), including marine mammals (Smith et al., 2013). In fact, many studies have recognized that temporary emigration fluctuates due to temporal

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components that may reveal changes on environmental conditions or seasonal behavioural patterns (Dwyer et al., 2014; Smith et al., 2013). This temporal variation has also been reported in capture probability (Silva et al., 2009), which has been suggested to be partially linked to temporary emigration (Muths et al., 2006). However, to our knowledge, temporary emigration parameters modelled as a function of candidate biotic or abiotic covariates has received little quantitative attention in cetacean demographic studies.

Investigating how environmental variations shape the dynamics of animal populations is of paramount importance in an increasingly changing world (Barbraud and Weimerskirch, 2001). Recent studies have evidenced the effect of climate change and anthropogenic activities on local fish stocks, and how changes in prey availability can impact on marine top predator populations (Ford et al., 2010). In the case of cetaceans, exposure to human disturbance, through dolphin-watching, can caused short term changes on individuals activity such as: breathing rates (Janik and Thompson, 1996); diving times (Ng and Leung, 2003); swimming directions (Lemon et al., 2006) or specific behavioural states (Christiansen et al., 2010). In addition, it can cause long-term effects on cetacean vital rates, such as a decrease in female reproductive success (Lusseau et al., 2006) or a decline in relative abundance (Bejder et al., 2006). At the population level, consequences depend upon the proportion of the population exposed to different levels of human interactions. Moreover, repeated human disturbance is significantly more important if it occurs within the core habitat of the species, or is concentrated during critical periods, which can affect the viability of the population (Bejder et al., 2006; Williams et al., 2006). As a result, the estimation of demographic parameters is considered a crucial step for identifying negative impacts on animal populations (Gormley et al., 2012).

Particularly, demographic studies on cetacean populations are urgently needed in the Western Indian Ocean (WIO) due to the increase of potential anthropogenic threats in the area (e.g., overfishing, dolphin-watching, seismic exploration)(Kenya Wildlife Service, 2011). Based on demographic modelling, we studied the population dynamics of the IUCN data deficient Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) in southern Kenya at the Kisite-Mpunguti Marine Protected Area (KMMPA). Specifically, we assessed four years of mark-recapture data to fit multiple competing models to investigate a set of hypothesis about dolphin population parameters within the Information Theoretic Approach. We considered the effect of natural factors (oceanographic conditions and prey availability) and human disturbance. Regarding the latter, artisanal fishing and tourism are the main economic activities for local communities, and dolphins are considered flagship species and the main attraction for the 60,000 yearly park visitors (Emerton and Tessema, 2001). We estimate seasonal temporary emigration movements influenced by environmental, human disturbance or fisheries covariates. Finally, we estimated seasonal population abundances across the study period. This study overcomes the challenge of integrating multiple data sources to study the effect of natural and human-related pressures on the population dynamics of a highly mobile predator.

2. Material and methods

2.1. Study area

Kisite-Mpunguti Marine Protected Area (KMMPA, 04°04′S–39°02′E), located on the southern coast of Kenya, lies south of Wasini Island and incorporates the Kisite Marine Park, the largest no-take area in Kenya (28 km^2), and the adjacent Mpunguti Marine Reserve, Kenya's smallest reserve, where traditional fishing is allowed (11 km^2) (Fig. 1). This MPA was established in 1978 and it has been under the administration of the Kenya Wildlife Service (KWS) since 1988. KMMPA covers shallow waters (<20 m depth) and supports a high marine biodiversity from corals to marine mammals and sea turtles.

2.2. Sampling methods

Boat-based surveys were conducted on a monthly basis all year around between January 2006 and December 2009 off the south coast of Kenya (with the exception of the period comprised between January and June 2008 due to national political instability). Searching effort was carried out with Beaufort sea states ≤3, low swells and good visibility (≥1 km), reducing the probability of missing dolphins. When a group was sighted, we recorded on location and time of the sighting, group size and group composition. A group was defined as the total number of individuals encountered, moving in the same direction or engaged in the same activity, within 100 m of each other (Wells et al., 1987).

2.3. Data analysis

2.3.1. Photo-identification process

Photo-identification was performed following standard cetacean protocols (Würsig and Jefferson, 1990). Dolphins within photographic range were photographed irrespective of their level of marking in order to have an unbiased estimation of the number of animals with marks in each mark class (Wilson et al., 1999). Because several pictures contain more than one individual, the term "fin image" was used to refer to a single dorsal fin in a picture (Verborgh et al., 2009). Each fin image was given information on sighting number, frame number, date, flank, angle (every 30° starting from 0° when the dolphin was facing the camera), individual fin image quality "Q" and code of the individual in the photo-identification catalogue. The quality rating (Q) was assigned on a scale of 0 to 2 (poor to excellent) considering four characteristics: exposure, focus, size and orientation. Every individual dorsal fin image was compared to a photo-identification catalogue, which included left and right dorsal fins from previously identified animals. This process was verified by two independent researchers to minimize misidentifications. Nicks and marks on the leading and trailing edges of the dorsal fin were used to identify individual Indo-Pacific bottlenose dolphins (Wilson et al., 1999). A quality marking level (M) was given to each animal in the catalogue ranging from 1 (few nicks/marks) to 3 (highly marked). Individuals showing light marks were assigned to M_1 were lightly marked and those with conspicuous marks to levels M_2 and M_3 (Verborgh et al., 2009). To minimize heterogeneity resulting from mark distinctiveness, only dorsal fin images with Q1 and Q2 and well-marked individuals were used on the analysis. Our analysis did not include calves, as they were not enough marked for identification and recapture. For more details see 'Robust design assumptions' section in Supporting material.

2.3.2. Covariates description

Covariates were selected based on their potential influence on dolphin demography: anthropogenic factors such as tourist boats and swimmers numbers, oceanographic variables or prey availability (Table A1). Previous studies have shown that tourist boats can have negative impacts on dolphin populations, especially when dolphin-watching activities are not monitored or sustainably managed (Christiansen et al., 2010). Impacts may be long-term and life-threatening; both at the individual and population level (Bejder et al., 2006). We predicted that the number of tourist boats operating around the MPA could influence the presence of dolphins in the area. Specifically, we hypothesised that spring months (April–June) would have the largest number of dolphins, as this is the season with the lowest number of tourist boats. We also predicted that a higher number of swimmers would negatively affect the probability of dolphin encounters, as tourists snorkel during their trips around Kisite Island, which is the core habitat for the Indo-Pacific bottlenose dolphin (Pérez-Jorge et al., 2015). We obtained 4 variables to assess the possible impact of the dolphin-watching tourism: number of tourist boats (BOATS) and swimmers (SWIMMERS) having access to the MPA on a given month. We also considered both covariates of the previous month (BOATS_1 and