Abundance, spatial distribution and threats to Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) in an Important Marine Mammal Area in Tanzania

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Abstract

Abundance estimates of cetaceans in the western Indian Ocean are rare, but important, as many cetacean populations are under threat, especially those in coastal habitats. This study aimed to generate first estimates of abundance for Indo-Pacific bottlenose dolphins (*Tursiops aduncus*), assessed as Near Threatened on the IUCN Red List, in an area identified by the Marine Mammal Protected Area Task Force as an 'Important Marine Mammal Area'. Two study sites were surveyed along the east and west coastlines of the Pemba Channel, Tanzania. Between 2014 and 2016, four boat-based visual surveys conducted a total of 2467 km of survey effort sighting a total of 16 groups of *T. aduncus* in west Pemba. Abundance was estimated using mark-recapture models of photo-identified individuals as 89 individuals (CV 7.7 %, 95 % CI 76-103) in the 1084 km^2 study area. In the Tanga study area in 2016 two boat-based visual surveys covered 1254 km of effort during which 15 groups of *T. aduncus* were sighted, resulting in a photo-ID based mark-recapture abundance estimate of 177 individuals (CV 8.6 %, 95 % CI 150-210) in the 1562 km^2 study site. Group encounter rate for this species in Tanga was at least double that recorded in the Pemba study site. A total of 23 % of identified dolphins bore the scars of interactions with fishing gear.

Keywords: Indo-Pacific bottlenose dolphin, *Tursiops aduncus*, abundance, photo-identification, important marine mammal area, western Indian ocean

Introduction

A lack of information on whales and dolphins due to limited research in many developing countries frequently prevents assessment of their status, and for informed management actions to aid in their conservation (Kuit *et al.*, 2021). Cetaceans typically occur at low densities, in hard to access habitats, and because they spend much of their lives underwater are also challenging to detect, with the result that gathering baseline data requires several years of study; requiring funds and time that are often unavailable. Obtaining an abundance estimate is an essential component of a baseline survey, and this is especially important for coastal species that are under threat from anthropogenic activities in their habitat impacting both survival and health. In these situations, baseline surveys and abundance estimates are important in order to guide and monitor species protection and habitat management (Kuit *et al.*, 2021; Avila *et al.*, 2018; de Vere *et al.*, 2018).

While there have been extensive long-term studies on coastal cetaceans around Unguja Island in Tanzania (see Amir *et al.*, 2002; Berggren *et al.*, 2007; Stensland *et al.*, 2006; Stensland and Berggren, 2007; Sharpe and Berggren, 2019), prior to 2016 information on cetaceans was almost completely lacking for the rest of the 800 km long Tanzanian mainland coastline. To fill the information gap, a rapid cetacean assessment was conducted which combined visual and acoustic surveys, compilation of citizen science records and documentation of skeletal material (Braulik *et al.*, 2017).

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A total of 19 species were documented from Tanzanian waters, and a cetacean fauna dominated primarily by tropical delphinids. The most frequently encountered species were spinner dolphins (*Stenella longilostris*) and Risso's dolphins (*Grampus griseus*) which occur primarily in deep waters, followed by Indo-Pacific bottlenose (*Tursiops aduncus*) and Indian Ocean humpback dolphins (*Sousa plumbea*) both in shallow coastal waters (Amir *et al.*, 2012; Braulik *et al.*, 2017). The rapid assessment concluded that the Pemba Channel was one of the most important areas for cetaceans in Tanzanian waters as relative species diversity and relative abundance were both higher than in all other areas (Braulik *et al.*, 2017). The Greater Pemba Channel was subsequently identified as an Important Marine Mammal Area (IMMA) by the IUCN/World Commission on Protected Areas Marine Mammal Protected Areas Task Force (IUCN-MMPATF, 2019), adding to its previous identification by the Convention on Biological Diversity as an Ecologically and Biologically Significant Area (EBSA). The Pemba Channel separates Pemba Island from the Tanzania mainland and is only 56 km wide but just over 900 m deep at its deepest point (Fig. 1). The biological importance of the Pemba Channel is likely to be because of the extremely steep bathymetric slopes on either side, and the rapid northward flowing East African Coastal Current (EACC), which can reach 2.5 ms^{-1} and brings cooler water and nutrients to the surface, leading to high productivity and resilience from increasing sea surface temperatures due to climate heating (McClanahan, 2020; Barlow *et al.*, 2011).

The current study was initiated to understand more about the status of cetaceans within the Pemba Channel focussing on Indo-Pacific bottlenose dolphins (*Tursiops aduncus*), coastal dolphins which are one of the species likely to be under greatest threat as their nearshore habitat is most extensively utilised and exploited by people. *T. aduncus* is listed as Near Threatened on the IUCN Red List and generally exists in small, semi-isolated populations in coastal areas, where they are impacted by habitat degradation, and are vulnerable to bycatch in fishing gear – primarily gillnets (Braulik *et al.*, 2019). Indo-Pacific bottlenose dolphins are one of the more common cetacean species recorded in coastal parts of Tanzania and in other regions in the western Indian Ocean (Berggren and Coles, 2009; Amir *et al.*, 2012, Braulik *et al.*, 2017). Although cetaceans are protected both in mainland Tanzania under the Fisheries Regulations, 2009, and in Zanzibar under the Zanzibar Forestry Act, 1996, cetacean protection measures are not routinely enforced. Fisheries bycatch has been identified as a large threat to this species both in Tanzania (Braulik *et al.*, 2017), in Unguja Island, Zanzibar (Amir, 2010; Amir *et al.*, 2002), as well as in other areas of the region including Kenya (Pérez-Jorge, 2016), the island of Mayotte (Kiszka *et al.*, 2008), Madagascar (Razafindrakoto *et al.*, 2004), and the Algoa Bay area of South Africa (Reisinger and Karczmarski, 2010).

The objective of this study was to generate a first estimate of abundance of Indo-Pacific bottlenose dolphins in coastal waters of the Pemba Channel. This three-year study is the first of its kind to be conducted for cetaceans in northern Tanzania. Baseline abundance estimates for this coastal cetacean are important for informed conservation and management planning in areas with high overlap of anthropogenic activities.

Material and methods

Study area

The Pemba Channel is located in the northern part of the coast of Tanzania in the western Indian Ocean. There were two study sites: 1) West Pemba Island, which occurs on the eastern side of the Pemba channel; and 2) Tanga coast, which occurs on the western side of the channel (Fig. 1). Both study areas included predominantly coastal waters extending to 10-15 km from shore depending on location.

Pemba Island is part of the Zanzibar archipelago, and lies about 40 km NNE of Unguja Island at approximately 4° south and 39° east. The western coast of Pemba Island has, since 2005, been designated as the Pemba Channel Conservational Area (PECCA), which is Tanzania's largest area legally set aside for marine conservation. (Fig. 1) (McLean *et al.*, 2012). The western coast of the island has a complex configuration and contains a variety of habitats; there are extensive shallows with mudflats, mangroves and sea grass beds, rich coral reefs and islets separated by deep tidal channels, as well as numerous rocky peninsulas that extend westwards (McLean *et al.*, 2012; McClanahan 2020). The study area covered was 1084 km^2 in size and encompassed all of the marine conservation area. The Tanga coast study area was located within the Tanga Coelacanth Marine Park (TACMP) located on the northern coastline of Tanga City, and covered 1562 km^2, extending from the Pangani River estuary along the coastal belt north to Kenya. These inshore waters are characterized by fringing and patch coral reefs, sea grass beds, mangrove forests, and several estuaries and bays. The marine park was established as a result of multiple records of coelacanth (*Latimeria chalumnae*) in the area, after which the park is named.

Field surveys

Between 2014 and 2016 six boat-based surveys were conducted each lasting 12-14 days. In Pemba four surveys were carried out, one each in October 2014, 2015 and 2016, and March 2016, while in Tanga two surveys were conducted, one in March and one in November 2016. These months were selected as they fall within the inter-monsoon period and are those with the lowest mean wind speeds annually (Mahongo *et al.*, 2011). A locally available wooden dhow 7 m in length, with a 40 hp outboard motor and viewing platform 2 m above the water surface, was used for the surveys.

Transects were systematically laid, running from east-west, perpendicular to the coast and depth contours, using the survey design function in the program DISTANCE (Thomas *et al.*, 2010). In the Pemba study area 38 transects, 2 km apart were laid, whereas in the Tanga study area there were 30 transects, 3km apart (Fig. 1). New transect positions were generated for each survey to avoid exact repetition.

Prior to all surveys, observers underwent a day of methods training and two days of field training. During all surveys, three trained observers scanned the ocean continuously for dolphins, each using a pair of 7x50 Fujinon marine binoculars, with internal compass. Dolphin position and survey effort were recorded via GPS using the WGS84 reference coordinate system. Survey effort was postponed when the sea state reached greater than Beaufort 4 because sighting rate declines with increasing wind speed (Nichol, 2009). When dolphin groups were sighted, survey effort stopped and the boat left the transect line and followed the group. A Canon EOS 60D camera with a 70-200 mm zoom lens was used to obtain

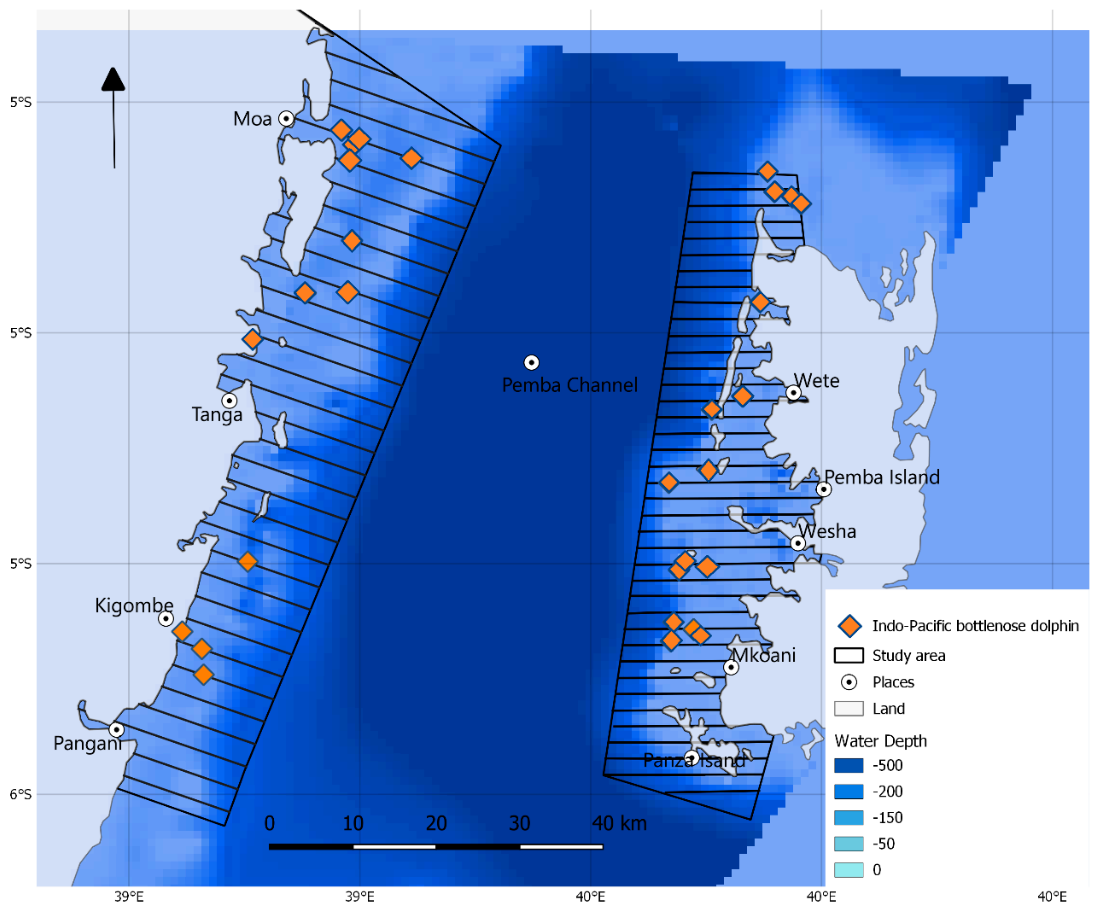

Figure 1. Location of the two study areas; Tanga in the west, and Pemba Island in the east, and Indo-Pacific bottlenose dolphin (*Tursiops aduncus*) sightings, transect lines and towns from the surveys conducted between 2014 and 2016.

high quality images of both sides of all animals in each group. Once all animals were photographed, or if the group was lost, the boat returned to the transect line and surveying efforts resumed. The following information was recorded during each sighting: species, best estimate of group size, high and low estimates of group size, number of calves, geographic location, sea state (wind), and whether photos were taken. Calves were defined as animals half the size of the mother or smaller, and groups were defined as animals sighted within 200 m of one another that appeared to be engaged in similar activities and moving in a similar direction. Although slightly counter-intuitive, as with most cetacean studies, the term 'group' is used to refer to all cetacean detections including those composed of only 1 or 2 animals, e.g. a group of one. Sightings recorded when transiting between transects or when following another dolphin group were recorded as 'off effort'. Photographs obtained from off-effort groups were used in analysis but not in calculations of encounter rate. After each day of field work all effort and sighting data were entered into Excel spreadsheets, and the GPS positions, survey track and photos were downloaded to a computer and stored in folders labelled by date.

Photo-processing

A separate photo-ID catalogue was created for each study area. Individual dolphins were identified on the basis of permanent marks and distinctive features on the dorsal fin and tail peduncle, including distinct fin shapes, notches, scars and cuts. Other secondary features such as colour pigmentation and tooth rakes were not used for identification, but only as supporting evidence, as these features are often not permanent. Images with no dolphins, or where the dorsal fin was not discernible, were discarded and those where dolphin fins were clearly visible were renamed, digitally enhanced and cropped, and given temporary identification numbers. Image quality was assessed and provided with codes based on four aspects: 1) focus, 2) angle of subject, 3) size of fin in the image, and 4) proportion of the entire fin visible in the photograph. Each of these were coded from 0 (very poor) to 3 (excellent). For each photograph, the four codes were summed to give a single quality (Q) score, with the maximum possible for the best images being 12. The quality rankings were made independently by two recorders (MK and GB), results were compared, and where there was a discrepancy a final revised quality code given. Photographs were sorted into three subfolders based on quality: Q0-8, Q9 and Q10-12. Only images of the highest quality Q10-12 were entered into the catalogue and used for photo-ID analyses. Dorsal fin distinctiveness was rated as highly distinct where fins were deformed or had major nicks or injuries; medium distinctiveness was assigned to fins with two or more small to medium sized nicks; and low distinctiveness were fins with one small nick or a unique fin shape. Photographs of left (LDFs) and right (RDFs) dorsal fins were treated as two separate datasets when creating the catalogues and during analysis. This was due to the inability in most cases, to definitively link the LDFs and RDFs of individual dolphins; this approach is commonly used in the studies of cetaceans (Minton *et al.*, 2013, Kuit *et al.*, 2021).

Matching was done by comparing each new fin image with all other existing fins in a catalogue; any individual that did not match was given a new identification number, entered into the catalogue as a new individual and was subsequently verified by an independent observer (GB). As is the case for most photo-identification studies, calves were excluded from the mark-recapture analysis as their probability of capture is not independent from that of their mothers; in addition, all calves were unmarked and could not be identified.

Abundance estimation

Capture–recapture models were applied in the program MARK (version 9, 2019) (Cooch and White, 2010) to the Indo-Pacific bottlenose dolphin catalogues giving separate abundance estimates for each study site. Closed models were selected as the species showed a good degree of residency to the areas (as shown by multiple recaptures), and due to the relatively short study period substantial demographic changes due to deaths, births or emigration were unlikely. Closed models have been used to estimate abundance of a number of other coastal dolphin populations that occur in similar habitat (Minton *et al.*, 2013; Stensland *et al.*, 2006; Sharpe and Berggren, 2019). Population closure was tested using the program Close Test to see if the assumption of closure was violated, and it was not for either study site (Stanley and Burnham, 1999). Sampling occasions corresponded to each 14-16 day survey; there were four sampling occasions in Pemba and two in Tanga. A capture history for each unique individual in each catalogue was created where 1 means that a dolphin was sighted on that sampling occasion, and 0 means that it was not seen. Individuals sighted multiple times in a survey were counted only once.

Five models were run (Mo, $M_{b,}$ $M_{t,}$ M_{tb} and the Pledger mixture model), as follows:

- The basic model, where capture and recapture probabilities were assumed to be the same and constant over time (model M_o) in program MARK
- Model capture and recapture probabilities assumed to be different, but not changing over time - equivalent to M_b
- Capture probabilities change over time - the model is equivalent to M_t in program MARK
- Models that assume change in capture probability over time and different recapture probability (M_{tb})
- Models that assume different capture probabilities for different classes of animals, referred to as heterogeneity in CAPTURE probabilities, formulated as a Pledger mixture model in program MARK.

Due to the small sample size AICc (Burnham and Anderson, 2003) was used to select the most appropriate model with the smallest number of parameters, according to the following guidelines: (1) differences of less than two in AICc values were taken to indicate that the models have approximately the same weight; (2) the differences of more than two but less than seven in AICc values indicate there is significant support for a real difference between the models; and (3) differences of more than seven between AICc values indicate that there is strong evidence of a difference between the two models (Burnham and Anderson, 2003). To account for uncertainty in model selection, if the best fitting models were separated by less than two AICc units, they were averaged based on their normalised AICc weights. Unlike other mark-recapture models, there is no good way to test goodness of fit for closed capture models, nevertheless, model averaged estimates of abundance, weighted according to AICc, are more robust than single model estimates. If this method is used, the necessity for testing goodness of fit is not maintained (Stanley and Burnham,1998).

The confidence intervals were constructed following Williams *et al.* (2002) by assuming that N is log-normally distributed according to the following: the lower and upper 95 % confidence limits were (N/c and N x c) where:

$$c=e^{1.96}\sqrt{\ln(1+CV^2N)}$$

The proportion of distinctly marked individuals in the population was calculated by examining all photographs of good quality (Q10-12) of all individuals in each sampling occasion and recording the number of marked and unmarked individuals in each photo. The proportion of marked animals in the population was calculated from the total number of individuals photographed divided by total number of photographed animals that were marked. The final abundance estimate was generated by correcting the estimated abundance of marked individuals generated by MARK.

The following assumptions associated with this mark-recapture model were adopted:

- The population probability of first capture is the same as recapture
- Unmarked animals have the same probability of being recaptured as marked
- Marks are not lost or missed
- Every marked animal has the same probability of survival

These assumptions are discussed below.

If dolphins changed their behaviour after being initially 'captured' photographically, they might then be less likely to be recaptured. For this study, the dolphins did not bow ride, or appear to actively move toward or away from the vessel. Given this behaviour, the probability of animals, whether marked or unmarked, being photographed on the first and subsequent occasions is likely to be the same and not to have changed over time. Behavioural bias affecting capture was included in the designed models (Mb). In dolphin photo-identification studies, the recapture probabilities are usually the same as capture probabilities (p=c), and capture probabilities are more likely to vary by sampling occasion (M_t) (Hammond, 2010).

A standard assumption of mark-recapture models is that there is equal capture probability for all individuals in all circumstances. It is possible that single animals are more likely to be missed than animals in larger more visible groups, leading to frequently sociable individuals being over-represented in the data. To account for this capture heterogeneity, the Pledger mixture model, which accounts for several groups of animals with different capture probabilities, was applied (Pledger, 2000). The assumption that marks are not missed or lost was addressed by using only high-quality photographs, thereby ensuring the maximum likelihood of not missing captures, and using only significant long-lasting marks on the dorsal fin, thereby reducing the likelihood of losing identifying features and missing recaptures.

Distribution and habitat use

Survey data was plotted in QGIS to illustrate the spatial distribution of sightings. The General Bathymetric Chart of the Oceans (GEBCO) 2014 Grid data at 30 arc-second intervals (equivalent in Tanzania to approximately 920 m square pixels) was used for bathymetry, however the resolution was too poor to accurately extract the depth at group locations. In the absence of any other form of suitably detailed digital depth data, images of digital Navionics navigation charts (webapp.navionics.com) were geo-rectified, which are the most accurate source of data available. Depth and distance to shore were then calculated for each sighting.

Assessment of dolphin-fishery interactions

An analysis was conducted to evaluate the impact of fisheries interactions on this population by determining the number of fishery-related scars present on individuals. For all individuals in the catalogue, injuries, wounds, lacerations and scars on the body or dorsal fin that may have been caused by fishing were identified following the detailed guide in Barco and Touhey (2006). Animals were classified as showing signs of fishing interactions if they had one of the following two injuries: 1) Linear marks - Linear cut, impression, scar or abrasion that was deep or shallow on the leading or trailing edge of the dorsal fin, or a series of parallel lines which is likely to be caused by fishing gear (lines/nets); and 2) Deformed or damaged fin - A partially or completely missing part of the fin likely to be caused by cutting from either fishing lines or nets. Based on the above evidence, fins were classified as having no evidence of fishing interactions, clear evidence of fishery interactions, and where there was some uncertainty, possible evidence of fishery interactions (Barco and Touhey, 2006; Kiszka *et al.*, 2008). Evaluation of the level of injuries to dorsal fins was evaluated following Kiszka *et al.* (2008), to determine a 'fishing gear exposure risk (R_i)' according to the following formulae:

$$R_i = (N^{dis} / \Sigma^{id}) \ \%^{id}$$

Where N^{dis} is the number of individuals having clear evidence of fishery interaction, Σ^{id} is the total number of identified individuals, and $\%^{id}$ is the proportion of identified individuals. Possible values of R_i range from a minimum of 0 %, where no animals have marks consistent with injuries sustained from interactions with fishing gear, to a maximum of 100 %, where all animals have fishing gear related injuries.

Results

Pemba: A total of 50 days of surveying was conducted in the Pemba study area, including 2467 km on effort searching and the detection of a total of 16 groups of *T. aduncus* at an encounter rate of 0.65 groups/ 100 km of survey effort, or 1 group per 154 km of survey. Group sizes ranging from 1 to 20 individuals (mean group size 17.65; SD=12.41). This species was the third most frequently encountered in the study area, after the spinner dolphin (*Stenella longirostris*; encounter rate of 2.03 groups/ 100 km), and Indian Ocean humpback dolphin (*Sousa plumbea*; encounter rate of 0.97 groups/ 100 km). Sightings occurred in water that was between 1 m and 46 m deep, with both the mean and median depth at sightings 15 m.

Tanga: A total of 26 days of surveying was conducted in the Tanga study area, including 1254 km of effort during which 15 groups of *T. aduncus* were sighted at

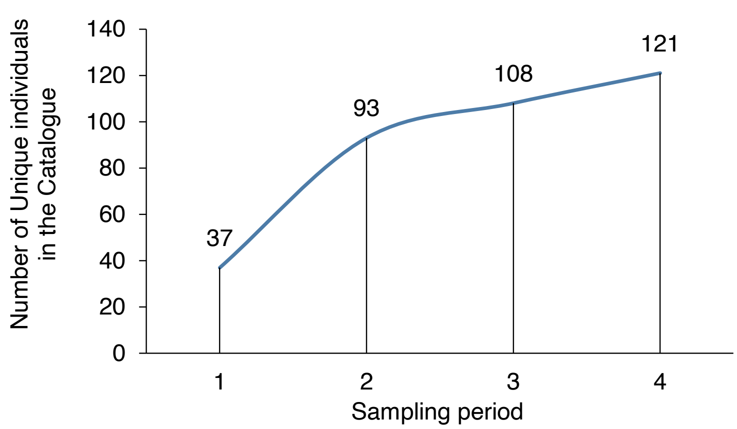

Figure 2. Discovery curve of new photo-identified Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) individuals in the study site, west of Pemba Island, Tanzania.

an encounter rate of 1.20 groups/ 100 km of survey effort, or 1 group every 84 km. Only a single group was encountered during the November 2016 survey, while 14 groups were sighted in the March 2016 survey to give an encounter rate of 1.96 groups/ 100km of survey effort for that survey. Group sizes ranged from 1 to 37, with mean group size 11.75 (SD=9.58). *T. aduncus* was the most frequently encountered species along the Tanga coast, followed by spinner dolphins (1.12 / 100 km) and then Indian Ocean humpback dolphins (0.24 / 100 km). Sightings occurred in water that was between 10 m and 46 m deep, with the median depth 28 m and the mean 30 m. Indian Ocean humpback dolphins were in mixed species aggregations with Indo-Pacific bottlenose dolphins on two occasions. A Pearsons correlation of depth against group size for all bottlenose dolphin sightings data pooled gave a correlation coefficient of -0.22, which indicates no significant relationship.

Photo-ID based abundance estimates

Pemba: A total of 1631 photographs of Indo-Pacific bottlenose dolphin dorsal fins from Pemba (of which 303 were of quality 8 or less, 599 were of Q9, and 729 were of quality score 10-12) were examined for entry into the catalogue. The final catalogue contained 65 left dorsal fins (LDFs) and 56 right dorsal fins (RDFs). The rate of discovery of new individuals is shown in Figure 2 and was higher within the first two sampling occasions and started to decline in the subsequent two surveys. Although discovery of new individuals in the 2016 sampling periods slowed, it had not yet plateaued. A closure test was performed on both the LDF and RDF data separately, and no significant results were returned indicating that there was no evidence of significant losses or gains to the population between sampling intervals and the population could be considered to be closed for the purposes of analysis (Stanley and Burnham, 1999).

The abundance estimates derived from mark-recapture analysis were LDFs 76 (CV 2.3 %, 95 % CI 64-89) and RDFs 67 (CV 2.4%, 95 % CI 55-99). The best fitting model in both cases was one where the capture probability varied by time, with no heterogeneity in capture probabilities. The larger of the two estimates (LDF), which is based on the larger photo-ID catalogue is considered the best estimate of abundance for the study site. Determination of mark rate showed that 1246 dorsal fins were identified as marked and 199 as unmarked, giving a mark rate of 0.8623. The LDF final abundance estimate corrected for unmarked individuals was 89 individuals (CV 7.7 %, 95 % CI 76-103).

Repeated sightings of the same individuals across the four-year study, including 6 dorsal fins (5 % of all fins in the catalogue) that were seen in every survey, and 20 dorsal fins (16.5 % of all fins in the catalogue) that were seen in three or four surveys, suggest that a proportion of the animals are resident in the area over

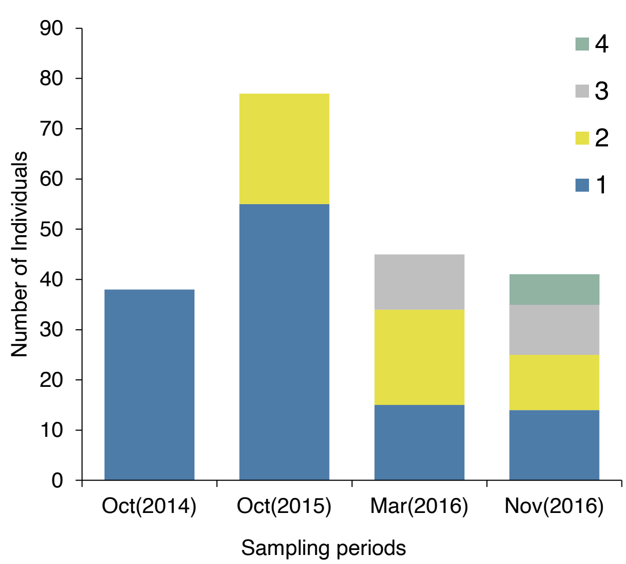

Figure 3. Number of sampling periods (equivalent to surveys) in which a photo-identified Indo-Pacific bottlenose dolphin (*Tursiops aduncus*) was sighted in the study area west of Pemba Island, Tanzania.

multiple years. However, 50 % of the dorsal fins in the catalogue were only encountered once (Fig. 3). Calves were sighted in all surveys.

Tanga: In Tanga a total of 1339 photographs were taken, of which 243 were of quality 8 or less, 471 were of quality 9 and 625 were of good or excellent quality (scored 10-12), and were examined for entry into the catalogue. The final catalogue of photos contained 57 unique LDF and 53 unique RDFs. Only one group was sighted during the second survey / sampling period, and there were very few (n=17, 15 % of dorsal fins) resights. The abundance estimate below is therefore fairly imprecise and should be considered preliminary pending more information. LDFs of 144 individuals (CV 6.0 %, 95 % CI 76-459) and RDFs 173.5 (CV 7.0 %, 95 % CI 72-821) were estimated. The best fitting models for both left and right fins was one where capture probabilities varied by time, with no individual heterogeneity and no difference in behaviour. The larger catalogue, and most precise abundance estimate was that of the LDFs and this was used for the final abundance estimate. The proportion of marked individuals in this population was 0.810, giving a total corrected abundance estimate of LDFs of 177 individuals (CV 8.6 %, 95 % CI 150-210) individuals.

Spatial distribution of sightings

Pemba: The distribution of Indo-Pacific bottlenose dolphin sightings was clumped geographically in the centre of the west coast of Pemba Island waters, adjacent to the towns of Mkoani and Wesha, and close to the islands of Misali, Uvinje and Njao, whereas, by contrast, few sightings occurred in the north of the study area, and none were seen in the southern part of the study area near Panza Island (Fig. 1). The location of the six photo-identified dolphins that were sighted on all four surveys are shown in Figure 4. The distance between the sighting locations of these six individuals ranged from a maximum of 59 km to a minimum of 21 km; four individuals were recorded in locations just over 50 km apart, while two were recorded on four occasions only 20 km apart.

Tanga: Indo-Pacific bottlenose dolphins occurred throughout the Tanga study area from north to south, but did not occur seaward of the fringing barrier islands and reefs that occur along the Tanga coast. One photo-identified individual was recorded just south of the village of Moa close to the Kenya border in April 2016, and was resighted 71 km south, near the Pangani river mouth in November 2016.

Photo-ID catalogues from the two study sites were compared and no matches were found.

Fisheries interactions

Many identified individuals in both study areas had marks that were likely to be injuries sustained from fishing gear. Among the 121 dorsal fins in the LDF and RDF catalogues for the Pemba study area, 28 (23.1 %) had marks clearly associated with fishery interactions (Fig. 5), 58 (47.9 %) had marks possibly associated with human interaction and 35 (28.9 %) individuals had no marks attributed to fishing gear. The calculated fishing gear exposure risk ratio, R_i: was 20.0 % of individuals that have definite marks, and 61.3 % of individuals if marks that are both definite and possibly caused by fishing gear are included. By comparison, in the Tanga study area, from a total of 117 unique individuals (left and right dorsal fins combined), 27 (23.1 %) had marks and injuries clearly associated with fishing gear interactions, 34 (29.1 %) had marks possibly associated with human interactions and 56 animals (47.9 %) had no marks from fishing interactions. The fishing gear exposure risk ratio was 18.7 % for animals with marks definitely related to fishing, and 42.2 % of animals if both definite and possible marks were included.

Discussion

Abundance

The findings of this study show that the population of Indo-Pacific bottlenose dolphins in the west Pemba study site is very small, numbering just under 100 individuals (89 individuals (CV 7.7 %, 95 % CI 76-103). The discovery curve of new individuals into the photo-ID catalogue was still slowly increasing at the end of the study (see Fig. 3) at a rate of approximately 10-15 individuals per 12-day survey suggesting that there are a number of dolphins that use the area that have not yet been identified. Based on the shape of the discovery curve it is likely that 20 to 30 animals would be added in subsequent surveys. The abundance estimates were similar to studies from nearby areas. For example, off the south coast of Unguja Island (Zanzibar) a small population of Indo-Pacific bottlenose dolphins was estimated to comprise 136 individuals (log-normal 95 % CI 124-172) from surveys conducted in 1999 and 2002 (Berggren *et al.*, 2007, Stensland *et al.*, 2006). In southern Kenya, a small population of this species was estimated as ranging from 19 individuals (95 % CI: 11–33) to a maximum of 104 dolphins (95 % CI: 78–139) (Pérez-Jorge *et al.*, 2016). For discrete, small populations, of slow to reproduce and long-lived species such as cetaceans, even low levels of anthropogenic mortality may be sufficient to extirpate them in a relatively short period of time (Thompson *et al.*, 2000). Species such as Indo-Pacific bottlenose dolphins in Pemba that show high site fidelity and coastal distribution are likely to be exposed to high levels of human disturbances and are the most likely to suffer declines (Pusineri *et al.*, 2014; Smith, 2012).

The abundance estimate from Tanga should be considered a preliminary estimate because there was only a single group encountered during the second survey, and a small number of recaptures which resulted in an imprecise abundance estimate. In addition, survey effort was lower in the Tanga study area than the Pemba study area because of funding constraints, so the abundance estimate is based on less data. However, the provisional estimate is larger (approximately double) the estimate for Pemba and indicative of a larger dolphin population. Similarly, the overall group encounter rate for Tanga (1.20 groups/ 100 km of survey effort) was approximately double the group encounter rate in Pemba (0.65 groups/ 100 km of survey effort), and the encounter rate for the March 2016 survey in Tanga (1.96 groups/ 100 km of survey effort) three times higher than the average for Pemba, again suggesting that many more animals use the Tanga

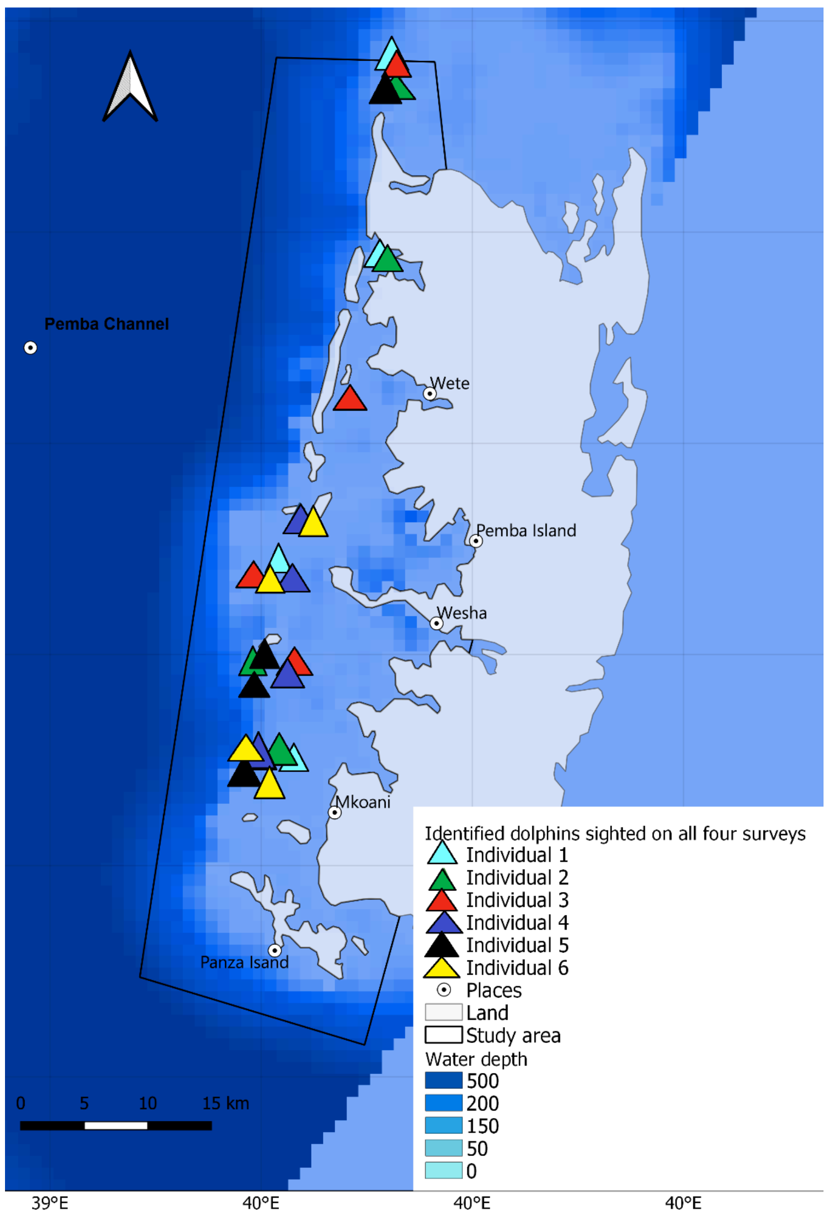

Figure 4. Sighting locations of the six most frequently sighted Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) encountered during four surveys conducted between 2014 and 2016 in the west Pemba study area.

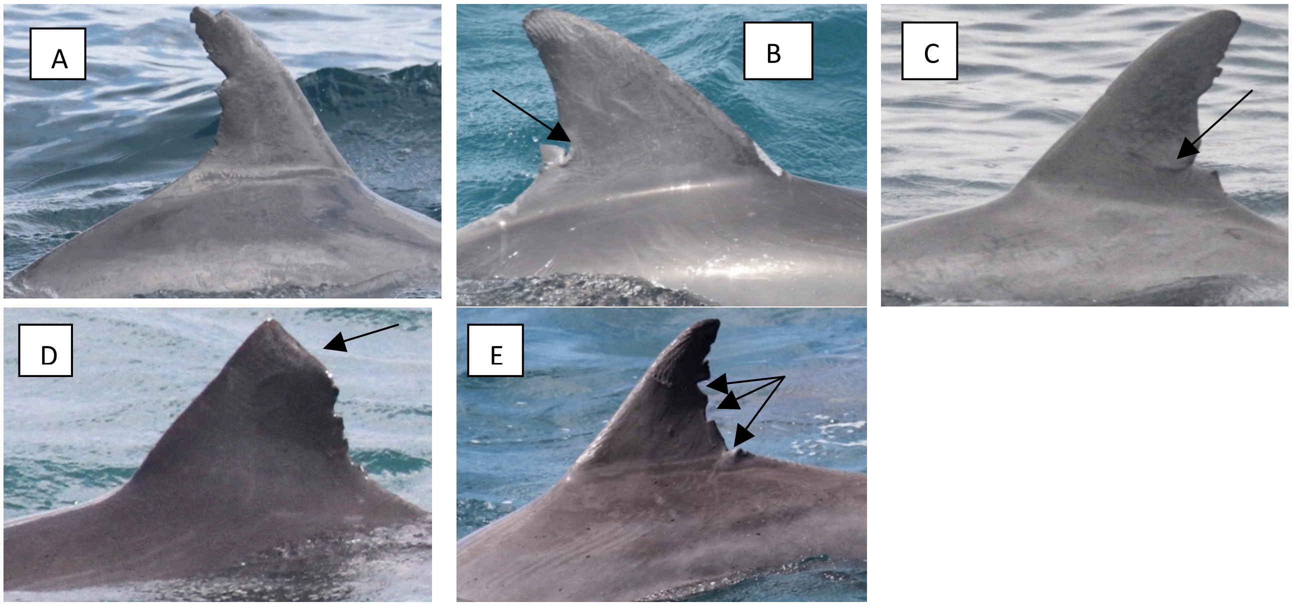

Figure 5. Examples of individual Indo-pacific bottlenose dolphin dorsal fin showing distinctive natural markings and deformed fins. A) shows dorsal fin mutilations likely caused by human impacts of unknown further classification; B) shows signs of major injuries (arrow) probably caused by net or unknown impact; C) has a clean-cut pointed notch and associating scar (arrow), which was possibly caused by fishing gear; D) has a linear section (arrow) probably due to fishing line interactions; and E) shows examples of major nicks (arrows) that can be easily recognized. (Photo credit: Magreth Kasuga and Gill Braulik).

coast than Pemba Island.

Connectivity and isolation

Indo-Pacific bottlenose dolphins are known to prefer predominantly coastal habitat (Braulik *et al.*, 2019) and throughout this study were found only in water less than 50 m deep. In Tanga one dolphin was recorded at locations 71 km apart, in the north and far south of the study area. Dolphins occurring within the Tanga study area are likely to be able to move along the coast, including into waters to the north in Kenya, and further south towards Bagamoyo, and are likely to form part of a connected coastal super-population on the coast of eastern Africa. By contrast Pemba is an island surrounded by water close to 1000 m deep on all sides, and it therefore seems plausible that the presence of deep-water habitat limits the regular movement of this coastal species from Pemba to the mainland (and vice versa). In addition, the marine habitat west of Pemba is quite different to the mainland coast, with less continental runoff, less exposure to onshore winds, and also small-scale upwelling leading to lower sea surface temperatures and localised high productivity, all of which might make Pemba more suitable for a resident population than the mainland environment (Kizenga *et al.*, 2021; Sekadende *et al.*, 2021). Further surveys in other seasons, studies of genetics, and comparison of photo-identification catalogues with other regions will provide a deeper understanding of the degree of isolation of this population.

Group size

Group size is highly variable in Indo-Pacific bottlenose dolphins, partly due to their fission-fusion society, and is thought to be related to activity, availability of food resources, predators and time of day (Shane *et al.*, 1986). Smaller groups are generally correlated with feeding and foraging and larger groups with socializing (Fury, 2009; Fury and Harrison, 2008). Mean group size in Tanga (11.75 individuals / group) was slightly smaller than in Pemba (17.65 individuals per group), however the difference was not statistically significant ($p=0.1712$, $t=1.4057$, $df=27$) and the range in group sizes was similar. Group sizes of this species in Menai Bay in southern Unguja had a median size of between 8 and 21 (Stensland and Berggren, 2007) and in Mayotte there was a mean of 6.5 animals per group (range 1-15) (Kiszka *et al.*, 2010). The highest mean group size reported for this species in the western Indian Ocean was in southern Kenya where 62 individuals/group (range 20-102) were reported (Pérez-Jorge *et al.*, 2016). The larger group size seen in southern Kenya may reflect differences in habitat and prey.

Fisheries interactions

Fishing gear entanglement and subsequent mortality is the largest threat to cetaceans worldwide and 75 % of odontocetes species are known to be at high risk from bycatch in gillnets (Reeves *et al.*, 2013). Because of its coastal distribution, *T. aduncus* is vulnerable to threats from anthropogenic activities throughout its range, including entanglement in fishing nets (Amir, 2010; Braulik *et al.*, 2019). Although both the Pemba and Tanga study sites are protected areas, fishing is permitted, and they are, in fact, some of the most intensively fished parts of the Tanzanian coastline (MLDF, 2010; ZMLF, 2010). In Tanzania bycaught animals are subsequently either discarded, eaten, the meat used as shark bait on longlines, or the meat is allowed to rot and the oil used as water proofing on boats (Amir, 2010; Braulik *et al.*, 2017; Robards and Reeves, 2011). Evidence of scars from injuries that are possibly linked to fishery interactions were observed on close to three-quarters of all identified dorsal fins in this study, and marks that were clearly due to fisheries were found on close to a quarter of all individuals, which means that both populations are clearly affected by fishery interactions. This mark rate is similar to other studies, such as in Bangladesh, where 28 % of identified individuals exhibited injuries related to entanglements with fishing gear (Smith *et al.*, 2015), and the island of Mayotte in the Mozambique channel where 19 % of the identified individuals showed significant marks and injuries that could be related to fishery interactions (Kiszka *et al.*, 2008). More than 30 % of Indo-Pacific humpback dolphins photo-identified off Taiwan, an intensely developed area, had scars or injuries most likely caused by interactions with fisheries (Dungan *et al.*, 2011; Reeves *et al.*, 2013). Investigation of fisheries bycatch conducted between 2003 and 2006 around Unguja Island showed that 48 % of all documented fishery-related dolphin mortalities were Indo-Pacific bottlenose dolphins (Amir, 2010). This large proportion is likely linked to their nearshore distribution and moderate local abundance of this species, and the overlap of core habitat with fishing effort (Amir, 2010). It is probable, similar to Unguja, that Indo-Pacific bottlenose dolphins are one of the most frequently captured cetacean species in the Pemba and Tanga areas, because of the overlap between their preferred habitat and intensive coastal fisheries. The mortality of only four individuals per year from a population of 100, or 7 from a population of 200 would result in a 50 % population decline over three generations (Moore, 2015). The existence of non-lethal injuries on many identified individuals (Dungan *et al.*, 2011; Kiszka *et al.*, 2008), combined with the small size of the population and the low reproductive rate of the species mean that the population of Indo-Pacific bottlenose dolphins west of Pemba may well be under threat and declining due to fishery interactions.

The issue of cetacean bycatch could be evaluated through fisheries observers or monitoring of fish landing sites, and a conservation strategy developed in conjunction with fishing communities and local governments. An approach such as that used by Verutes *et al.* (2020) which maps data on dolphin distribution and on fishing effort gained through community participation to identify high risk bycatch zones has potential to identify targeted areas where fishing effort may be restricted for maximum benefit to dolphin populations. The fisheries sector in Tanzania and Zanzibar is growing, and especially in Tanga and Pemba both of which are rural, fishing plays a key role in household food security, providing income and employment opportunities to communities where there are few other economic activities available. The enforcement capability of the government is weak and therefore communities need to be directly involved in management and conservation activities otherwise ecosystems are likely to continue to be overexploited (Jansen *et al.*, 2000).

Future studies

For conservation and management purposes these estimates are important and form a first baseline from which monitoring can be conducted. Future work may replicate these boat-based surveys to allow trends in abundance over time to be determined, as well as to provide more information on residency, movements and home range. The study areas were already quite large compared to other similar studies, many of which have study areas <500 km^2, however, especially in Pemba it would be useful to extend the current study site to include the remainder of the shallow water habitat to the northeast of the island, so that all probable habitat areas are included. To provide information that is helpful for managers, understanding the environmental drivers of distribution as well as identifying distribution hotspots is an important first step to prioritising locations that may be considered as areas for the removal of gillnet fishing, to reduce the risk of bycatch, which is likely to be the biggest threat to these coastal dolphin populations.

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