Cetacean rapid assessment: an approach to fill knowledge gaps and target conservation across large data deficient areas

Gill T. Braulik, Magreth Kasuga, Anja Wittich, Jeremy J. Kiszka, Jamie MacAulay, Doug Gillespie, Jonathan Gordon, Said Shaib Said, and Philip S. Hammond

Cetacean rapid assessment: an approach to fill knowledge gaps and target conservation across large data deficient areas

Journal:	*Aquatic Conservation: Marine and Freshwater Ecosystems*
Manuscript ID	AQC-17-0004.R1
Wiley - Manuscript type:	Research Article
Date Submitted by the Author:	19-Jun-2017
Complete List of Authors:	Braulik, Gill; Wildlife Conservation Society, Tanzania Program; University of St. Andrews, Scottish Oceans Institute Kasuga, Magreth; Wildlife Conservation Society, Tanzania Program Wittich, Anja; 23 Adamson Terrace Kiszka, Jeremy; Florida International University, Department of Biological Sciences Macaulay, Jamie; University of St. Andrews, Scottish Oceans Institute Gillespie, Doug; University of St. Andrews, Scottish Oceans Institute Gordon, Jonathan; University of St. Andrews, Scottish Oceans Institute Said, Said; University of Dar es Salaam, Institute for Marine Science Hammond, Philip; University of St. Andrews, Scottish Oceans Institute
Broad habitat type (mandatory) select 1-2:	ocean < Broad habitat type, coastal < Broad habitat type
General theme or application (mandatory) select 1-2:	survey < General theme or application, biodiversity < General theme or application
Broad taxonomic group or category (mandatory, if relevant to paper) select 1-2:	mammals < Broad taxonomic group or category
Impact category (mandatory, if relevant to paper) select 1-2:	fishing < Impact category, shipping < Impact category

Cetacean Rapid Assessment: an approach to fill knowledge gaps and target conservation across large data deficient areas

Gill T. Braulik[1,2], Magreth Kasuga[1], Anja Wittich[3], Jeremy J. Kiszka[4], Jamie MacCaulay[2], Doug Gillespie[2], Jonathan Gordon[2], Said Shaib Said[5], Philip S. Hammond[2]

[1] Wildlife Conservation Society Tanzania Program, Zanzibar, Tanzania

[2] Sea Mammal Research Unit, Scottish Oceans Institute, University of St Andrews, St Andrews, Fife KY16 8LB, United Kingdom

[3] 23 Adamson Terrace, Leven, Fife, United Kingdom

[4] Department of Biological Sciences, Florida International University, North Miami, USA

[5] Institute of Marine Science, University of Dar es Salaam, Tanzania

Email: gillbraulik@downstream.vg

Abstract

1. Many species and populations of marine megafauna are undergoing substantial declines, whilst many are also very poorly understood. Even basic information on species presence is unknown for tens of thousands of kilometres of coastline, particularly in the developing world, which is a major hurdle to their management and conservation.
2. Rapid ecological assessment is a valuable tool used to identify and prioritize areas for conservation, however, this approach has never been clearly applied to marine cetaceans. Here a rapid assessment protocol is outlined that will generate broad-scale, quantitative, baseline data on cetacean communities and potential threats, that can be conducted rapidly and cost-effectively across whole countries, or regions.
3. The rapid assessment was conducted in Tanzania, East Africa, and integrated collection of data on cetaceans from visual, acoustic, and interview surveys with existing information from multiple sources to provide low resolution data on cetacean community relative abundance, diversity, and threats. Four principal threats were evaluated and compared spatially using a qualitative scale: cetacean mortality in fishing gear (particularly gillnets); cetacean hunting, consumption or use by humans; shipping related collision risk and noise disturbance; and dynamite fishing.
4. A total of 91 groups of 11 species of marine mammal were detected during field surveys. Potentially the most important area for cetaceans was the Pemba Channel, a deep, high-current waterway between Pemba Island and mainland Africa, where

by far the highest relative cetacean diversity and high relative abundance were recorded, but which is also subject to threats from fishing.

5. A rapid assessment approach can be applied in data deficient areas to quickly provide information on cetaceans that can be used by governments and managers for marine spatial planning, management of developments, and to target research activities into the most important locations.

Keywords: cetaceans; distribution; environmental impact assessment; management, marine spatial planning; rapid assessment; Tanzania.

1. Introduction

Marine megafauna, such as elasmobranchs, marine mammals and sea turtles are some of the most iconic components of ocean biodiversity, yet many populations are undergoing large and unprecedented declines due to unsustainable direct exploitation or incidental mortality in fisheries (Heithaus, Frid, Wirsing, & Worm, 2008; Lewison, Crowder, Read, & Freeman, 2004). Beyond their flagship status, these species can be critical to maintain the structure and function of marine ecosystems and their loss can have large negative ecological consequences (Bowen, 1997; Ferretti, Worm, Britten, Heithaus, & Lotze, 2010). Conservation of cetaceans globally is seriously challenged because even basic information on species presence is lacking for tens of thousands of kilometres of coastline in many places, especially in the developing world (Kaschner, Quick, Jewell, Williams, & Harris, 2012). Recent modelling studies suggest that hotspots of cetacean diversity as well as many at-risk species are likely to occur in some of these data deficient areas (Davidson et al., 2011; Kaschner, Tittensor, Ready, Gerrodette, & Worm, 2011; Pompa, Ehrlich, & Ceballos, 2011).

In contrast to many other species groups, cetaceans are time consuming and expensive to survey and assess. This is because they generally occur at low densities, spend most of their time underwater, and range over wide areas far from land. Consequently, their study involves chartering expensive sea-worthy vessels or light aircraft, and surveys often need to last for many weeks or be repeated over multiple years to generate sufficient data for robust population assessments (Jewell et al., 2012). The result of a lack of basic information, combined with the perceived difficulty and expense of collecting dedicated data to fill these data gaps, mean that cetaceans are often simply omitted, or are given only cursory attention in environmental impact assessments, national marine conservation planning and coastal zone management activities, or during identification of global or regional sensitive, priority or marine protected areas. Realistically the funds and expertise are not available to enable dedicated intensive studies to estimate abundance of cetaceans across the large, unevaluated coastlines of the world. What would be invaluable is a quick and relatively cost-effective way of generating robust baseline data on cetacean communities and threats from regions and numerous countries in order to identify and prioritize species and locations where there is the greatest need for, and greatest potential benefit from, conservation action.

In other environments, this is routinely accomplished using rapid ecological assessments (Alonso, Deichmann, McKenna, Naskrecki, & Richards, 2011; Barbour, Gerritsen, Snyder, & Stribling, 1999; Fennessy, Jacobs, & Kentula, 2007; Maragos & Cook, 1995; Maragos et al., 2004). A protocol for rapid assessment of cetaceans has never been clearly described or applied, but it would be an important tool in the effort to conserve cetaceans globally. Here a framework for cetacean rapid assessment is outlined, that can be applied over a period of less than one year across large data deficient areas to provide a quantitative snapshot of cetacean species diversity, relative abundance, distribution and potential threats. The objective is to fill extensive data gaps on cetacean distribution, and for the information generated to provide basic information to government agencies for conservation planning, prioritization and management.

To demonstrate the approach, a rapid assessment was conducted focused on the entire coast of Tanzania, a little-known but potentially important area for cetaceans, with a range of habitats and threats especially relating to fishing, shipping and exploration for oil and gas. Prior to this study, 16 cetacean species had been recorded in Tanzanian waters, the majority odontocetes that are expected to be largely resident, but also humpback whales (*Megaptera novaeangliae*) which are present in Tanzanian waters only from June to November (Amir, Berggren, & Jiddawi, 2012; Berggren, 2009). Previous cetacean research has concentrated in south-western Unguja Island on resident coastal dolphins (Christiansen, Lusseau, Stensland, & Berggren, 2010; Stensland & Berggren, 2007; Temple, Tregenza, Amir, Jiddawi, & Berggren, 2016), but there is very little information available on cetaceans from the 800km long coast of the Tanzanian mainland and several other outlying islands.

2. Methods

2.1. Study Area

The Tanzanian coastline is dominated by the warm, nutrient-poor East African Coastal Current and is subject to two seasonal monsoons, the NE from December to February and the SE from June to September, these interspersed with calm, rainy periods. The study area encompassed the entire coastal waters of Tanzania (4-10^{o}S) out to approximately 50km from the mainland coast, irrespective of depth (Figure 1). It included the Rufiji delta which is one of the largest estuaries in eastern Africa, oceanic waters more than 1000 m deep in the Pemba Channel and south of Kilwa, and the islands of Pemba, Unguja, Mafia and Latham which have considerable fringing reefs and seagrass habitat (Figure 1). Due to time and logistical constraints, the east coasts of Pemba and Zanzibar were not included in the study area.

2.2. Approach

One of the biggest challenges to a rapid cetacean assessment is balancing the need to keep investment of time and resources low, with the use of robust, repeatable methods that generate sufficient data to draw meaningful conclusions. The approach, detailed in Table 1, integrates collection of data on cetaceans from visual and acoustic surveys with existing information from multiple sources to provide low resolution, broad-scale data on cetacean relative abundance and diversity. To evaluate threats, a largely qualitative assessment of potential human impact on cetaceans (not absolute risk) was adopted, based on, and adapted from, the ecological risk assessment framework described by Hobday et al. (2011), which allows for a spatial comparison and prioritization of potential threats to cetaceans, across the entire country.

To aid in spatial interpretation and comparison of the results in a way that is useful for management, the study area was split into five 'Zones', each defined as "*an area with a definable boundary within which the character of habitats, biological communities, and/or management issues have more in common with each other than they do with those in adjacent areas*" (Alliance for Zero Extinction, 2003). The zones, which align approximately with the Tanzanian coastal provinces, are from north to south: Zone 1 – Pemba Channel; Zone 2 – Zanzibar Channel; Zone 3 - Dar es Salaam; Zone 4 – Rufiji

Delta; and Zone 5 – Mtwara/Lindi (Figure 1). The entire study area was 37,100 km^2 in size, with each zone as follows: 1 - 7425 km^2; 2 - 5749 km^2; 3 - 5201 km^2; 4 - 9722 km^2; 5 - 9003 km^2.

2.3. Description of Cetacean habitat

The distribution of cetaceans over large-scales is influenced by environmental characteristics driving the distribution of their prey: primarily depth, and also slope of the sea bed, sea surface temperature, and chlorophyll-a concentration, although many other factors might also influence fine scale distribution (Cañadas, Sagarminaga, & García-Tiscar, 2002; Mannocci et al., 2014; Redfern et al., 2006). Chlorophyll-a and sea surface temperature (SST) can be highly variable in space and time, whilst depth and slope are fixed habitat characteristics that do not change from one survey to another. We describe the available habitat along the coast of Tanzania in terms of depth and slope. Using General Bathymetric Chart of the Oceans (GEBCO) 2014 Grid data at 30 arc-second intervals (equivalent in Tanzania to approximately 920m square pixels) and software QGIS (QGIS Development Team, 2016), the amount (m^2) and proportion of habitat was quantified, and presented in the following four depth classes: Very shallow: 0-20; Shallow:21-100m; Moderate: 101-800m; and Deep: 801m+, and three slope classes: Flat: 0-2%; Gentle Slope: 2.1-4%; Steep: 4.1-7% which correspond broadly to habitat preferences of cetaceans known to occur in Tanzania.

2.4. Rapid Assessment of Cetacean Communities

2.4.1. Vessel-Based Cetacean Survey

A 50-foot catamaran was used as the survey platform. Although aerial surveys quickly cover large areas they may have a higher species misidentification rate than boat surveys; in Tanzania vessels are more easily available, are cheaper and safer to operate, allow for collection of more types of data (e.g. photos, biopsies, behaviour, acoustics, etc.) and also provide more opportunities for training. The survey was designed to maximize cetacean detections, by 1) surveying in the calmest month of the year, 2) observing from a high viewing platform so that the field of view was large, 3) combining a visual survey with a concurrent acoustic survey, and 4) including experienced observers in the team, as well as inexperienced researchers undergoing training.

The visual survey was conducted using standard line transect survey methods in closing mode enabling the data to be used for abundance estimation in the future if additional data become available (Buckland et al., 2001). Line transects that ran perpendicular to the depth contours were laid out using the programme DISTANCE (Thomas et al., 2010) resulting in 36 transect lines, spaced 21 km apart, and a combined total of 2500 km of on effort survey track (Figure 1). Three observers scanned continuously for cetaceans from a platform 4m above the sea surface, using 7 x 50 Fujinon marine binoculars with an internal compass. A central observer scanned 45 degrees either side of the trackline, and two observers scanned from the beam to the track. Observers took 1 hour of rest for every 1.5 hrs of observations to maintain concentration. Survey effort and sea conditions measured by the Beaufort scale were logged at 30 minute intervals throughout the day, and when conditions changed. Surveying was suspended when sea conditions rose above Beaufort 4. The vessel waited at port for conditions to improve and attempted to cover every transect in good weather conditions. When cetaceans were first sighted, the vessel's location was recorded using a GPS, the distance to the group was determined by measuring the angle subtended between the sighting and the horizon using the binocular's reticules, and the angle to the group determined using the internal binocular compass. Cetaceans were approached and photographed, the species identified, and group size recorded with a best, high and low estimate of numbers.

Coincident to the visual survey, during daylight hours, passive acoustic monitoring (PAM) using a towed hydrophone array was conducted to detect the echolocation clicks, whistles, and other vocalizations of cetaceans. This was especially useful to detect elusive species such as beaked whales (Ziphiidae) and other odontocetes that dive to great depths and have a very short surface interval meaning they were likely to be missed by the visual survey. A Vanishing Point (http://vpmarine.co.uk/) stereo towed hydrophone array was deployed on 100 m of Kevlar strengthened cable. This had a towing depth of 5-10 m depending on vessel speed which varied from 10-12 km/hr. The array included a high frequency hydrophone pair that consisted of two Magrec HPO3 hydrophone elements spaced 0.3 m apart, each comprising a spherical hydrophone ceramic element coupled with a Magrec HP02 preamplifier with 28 dB of gain and with a low-cut filter set to provide -3 dB at 2 kHz. The streamer section contained a pressure sensor to provide information on tow depth and was filled with inert oil (Isopar M). A TASCAM DR680 recorder was used to make continuous 2 channel, 192kHz, 24 bit recordings. A custom SoundTrap 202 High

Frequency self-contained archival acoustic recorder with low flow noise housing (http://www.oceaninstruments.co.nz/) was towed simultaneously from the end of the array. The device had a frequency range of 20Hz to 238kHz and sampled at 576 kHz so that the data could be used to detect the high frequency clicks produced by *Kogia* spp. which would be missed by the lower sample rate on the array. PAMGuard was the software used to analyse the PAM data (Gillespie et al., 2008).

A multi-stage process was used to detect the echolocation clicks of sperm whales (*Physeter macrocephalus*), beaked whales, and *Kogia* spp. The PAMGuard click detector was used to extract all transient sounds within frequency bands matching the typical frequency range for each species' echolocation clicks. Sperm whale clicks are broad band in nature, with most energy concentrated between 2 and 22 kHz (Mellinger, Thode, & Martinez, 2002), beaked whales have species-specific frequency modulated (FM) upswept echolocation clicks with a peak frequency of between 16-70 kHz (Baumann-Pickering et al., 2013; Johnson, Madsen, Zimmer, Aguilar de Soto, & Tyack, 2004) and *Kogia* spp. produce high frequency narrow band clicks at frequencies between 100 and 150kHz (Madsen, Carder, Bedholm, & Ridgway, 2005). Detected transients in each frequency band were then classified as likely belonging to the target species using a combination of automated algorithms and manual inspection, based primarily on click length, frequency modulation, frequency range, and (where possible) directionality of a detected click train. Multiple consistent transient sounds from a similar direction are more likely to be biological in origin than random noise and this provides useful additional information during the classification process. Computer machine learning algorithms are being developed to automatically identify and classify cetacean whistles to species (Gillespie, Caillat, Gordon, & White, 2013; Roch et al., 2011). Development of classification algorithms using the whistles of delphinids from the western Indian Ocean is still in its infancy (Erbs, Elwen, & Gridley, 2017; Gruden et al., 2016), therefore the process of developing a new classifier was initiated. Whistles were detected using the PAMGuard Whistle and Moan detector (Gillespie, et. al, 2013). Acoustic whistle detections that coincided with a visual sighting with a positive species identification were then used to train the PAMGuard whistle classifier so that it could be subsequently applied to acoustic detections that were not accompanied by a visual sighting. Six species were included in the classifier: short-finned pilot whale (*Globicephala macrorhynchus*), Fraser's dolphin (*Lagenodelphis hosei*), false killer whale (*Pseudorca crassidens*), pantropical spotted dolphin (*Stenella attenuata*), spinner dolphin (*Stenella longirostris*) and common bottlenose dolphin (*Tursiops truncatus*). Indo-pacific bottlenose dolphin (*Tursiops aduncus*), Risso's dolphin (*Grampus griseus*) and Indian Ocean humpback dolphin (*Sousa plumbea*) could not be included, even though they were encountered many times, because they had low whistle rates in recordings and there were insufficient data to train the classifier.

Cetacean encounter rate (cetacean group detections / 100 km of survey effort in sea conditions of Beaufort 4 or less, termed 'good' conditions), individual encounter rate (cetacean individuals detected/ 100km of good survey effort), and relative species richness (cetacean species / 100 km of survey effort in good survey conditions) were determined for the entire study area and for each zone using all on-effort visual and acoustic detections divided by the total amount of good survey effort. All acoustic detections were included in the calculation of group encounter rate, but as only acoustically detected beaked whales were identified to species with confidence only these were included in the calculation of relative species diversity. Encounter rate variance and coefficient of variation (CV) was determined as described by Buckland et al. (2001).

2.4.2. Existing information and opportunistic data on cetaceans

Existing information on cetaceans was collated by: examining museum collections; identifying cetacean skeletal remains displayed in hotels, scuba-diving centres, and in coastal communities; searching libraries for published and unpublished information; gathering cetacean sighting reports from dive centres, sport fishers, tourists, sailors, etc.; collating sightings from Marine Mammal Observers (MMOs) on seismic survey vessels and from unpublished coastal dolphin surveys. Records were entered in a database provided there were good quality supporting photographs to allow verification of the species. Bottlenose dolphin sightings that could not be identified to species were retained as *Tursiops* spp. All other records for which the species could not be identified, that did not have a location of origin or that were outside the study area were excluded. The number of species present, and the number of records of each species were determined for each zone.

2.5. Rapid Assessment of Threats to Cetaceans

The assessment evaluated the threats to cetaceans that are most ubiquitous; temporary or localized threats (e.g. dolphin tourism, seismic surveys, point sources of pollution) were not considered. Four primary threats were the focus of the evaluation: 1. cetacean mortality in fishing gear, which comprised two factors: the bycatch rate and the size of the fleet; 2.

cetacean hunting, consumption or use by humans; 3. shipping related collision risk and noise disturbance; and 4. dynamite fishing. Data on each potential threat were either generated for this study (bycatch, dynamite fishing, consumption, hunting) or were compiled using existing information that could act as a proxy (shipping and size of fishing fleet) (Table 1). Each threat was evaluated as described in the sections below.

Each of the threats was normalized on a scale of 0-100 based on rates (e.g., boats per km) with the zone with the highest rate set to 100 and other zones scaled accordingly. An overall potential threat score for each zone was the sum of these values with higher scores representing a greater potential for human impact on cetaceans and a lower score indicating lower threat levels. The objective was to assess relative potential risk to cetaceans in relation to two metrics: relative cetacean abundance and relative species richness (number of species recorded) for each zone sampled. Although the evaluated threats are unlikely to have equal potential impact and some are likely to interact, in the absence of any information on which to base a weighted or cumulative impact score, we consider them to be of equal potential impact, while acknowledging that this is simplified and may omit differences in the severity of threats.

2.5.1. Cetacean bycatch, hunting and consumption

Fisher interviews were conducted to collect information on marine mammal bycatch, hunting, consumption and use. The rapid bycatch assessment questionnaire developed by Moore et al. (2010) was used, and interviews were conducted in Swahili, one-on-one with fishermen at fish landing sites. Gillnet fishers were the primary target of the interviews because this gear type has by far the highest bycatch rates for marine megafauna globally and in the Western Indian Ocean (Kiszka et al., 2009). However long-line, purse-seine and hook and line fisheries also kill cetaceans and as a secondary priority smaller numbers of fishers that used these gears were also interviewed. Time and budget allowed for approximately 5% of the mainland fishing fleet to be interviewed (Ministry of Livestock Development and Fisheries, 2010). The target was to collect 15 interviews from each village and two villages in each district. It was not possible to select villages randomly because in many there were no gillnetters. As recommended by Moore et al. (2010) the most experienced fishermen and captains were targeted as they were likely to have most knowledge. Only one fisher per vessel was interviewed, and it was assumed that this provided an estimate of per-boat catch. Illustration cards were shown to help fishers identify species. Marine mammals are legally protected in Tanzania so interviewees were assured anonymity, and questions regarding hunting, catch, use, consumption and sale included questions about how others in near-by communities use marine mammals to increase the chances of receiving reliable responses.

2.5.2. Dynamite fishing

The cetacean acoustic survey described above also recorded 318 blast fishing explosions during a total of 231 hours of recording along the entire Tanzanian coast (see Braulik, Wittich, et al., 2015 for details of analysis). The blast data were analysed to calculate the number of blasts per hour in each zone.

2.5.3. Shipping related threats

As a broad-scale approximation of the potential for shipping related threats to impact cetaceans, the total amount of goods brought by ship into ports located within each zone was used as a proxy (Tanzania Ports Authority, 2015).

3. **Results**

3.1. *Cetacean Habitat*

The southern portion of the Tanzanian coastline (Zone 5) between Kilwa and Mtwara has a very narrow continental shelf, the depth drops off quickly down to more than 2000m less than 30km from the coast. This zone has the deepest depths and the largest amount of slope habitat; approximately 60% of the area is greater than 800m deep and has a sloping seabed of more than 5^{o} (Figure 1 & 2). Similarly, Zone 3 around Dar es Salaam has a narrow continental shelf, but the majority of the habitat includes intermediate depth primarily ranging from 100-800m. In contrast, the Zanzibar channel (Zone 2) is almost exclusively shallow water, with 94% of the habitat less than 100m deep with a relatively flat bottom. In the Rufiji Delta and Mafia (Zone 4) approximately 70% of the habitat is less than 100m deep, but there are also some deeper zones east and south of Mafia Island. Finally, the Pemba Channel (Zone 1) is intermediate in terms of depth and slope habitat; approximately 30% of the area is less than 100m deep and the remaining 70% is between 100-800m. Thirty percent of this zone including slopes $>5^{o}$. A notable feature of the Pemba Channel is that it has a rapid consistent northward flowing current and is shaped like a trough, somewhat similar to a submarine canyon with steep drop offs from 50-700m on either side separated by approximately 40km (Figure 1 & 2).

3.2. *Rapid Assessment of Cetacean Communities*

3.2.1. Vessel-based cetacean survey

Over 34 days in March and April 2015, 2616 km of visual boat-based survey effort was conducted. Weather was acceptable for the majority of the survey; 90.5% (2368 km) was in sea conditions of Beaufort 4 or less, and 75.5% (1974km) in Beaufort 3 or less. Sighting rates in Beaufort 4 (1.5 groups/ 100km) were less than half those in Beaufort 1 (3.7 groups/ 100km). The towed acoustic array was deployed during 32 survey days collecting 216h of recordings, and the SoundTrap data totalled 237h of recordings.

In total, 75 marine mammal groups of 11 species were sighted (Table 2). Most acoustic detections coincided with visual encounters. However, 11 groups of delphinids and five groups of ziphiids identified in the acoustic data had no associated visual sighting. This takes the total combined number of cetacean groups detected during the survey using both visual and acoustic methods to 91 (Table 2). The cetacean community was mostly composed of delphinids, but also included several large odontocetes, including beaked whales (Ziphiidae) and the short-finned pilot whale (*Globicephala macrorhynchus*). The most frequently encountered species was the spinner dolphin, followed by Risso's dolphin, Indo-Pacific bottlenose and common bottlenose dolphins. Indian Ocean humpback dolphins were sighted in shallow near-shore waters less than 30m deep close to Kilwa and along the mainland coast of the Zanzibar Channel. One mixed species group of short-finned pilot whales with Fraser's dolphins (*Lagenodelphis hosei*), and several of Indo-Pacific bottlenose dolphins with Indian Ocean humpback dolphins were observed (Table 2). A single sighting of two dugongs (*Dugong dugon*) was made north of Mafia Island.

Of the 75 visually detected groups, 12 were made when the acoustic array was not deployed. Of the remaining 63 sightings, all but four groups were also detected acoustically. A total of 19 groups consisting primarily of Risso's dolphins, Indian Ocean bottlenose dolphins, and unidentified species, were detected acoustically based only on clicks, with no whistles recorded. There were five acoustic detections of beaked whales which did not have an associated visual sighting. The peak click frequency for each was between 31 and 35 kHz which is consistent with identification as Blainville's beaked whale (Johnson, Madsen, Zimmer, de Soto, & Tyack, 2006). One detection had a secondary peak at 40kHz, therefore this was identified as a probable Blainville's beaked whale but it is possible it was a Cuvier's beaked whale (*Ziphius cavirostris*) (Baumann-Pickering et al., 2013), or another species whose vocalizations have yet to be characterized (Table 2).

Restricting data to sea conditions of Beaufort 4 or less resulted in 2368 km of effort and the inclusion of 77 sightings (63 visual, and 14 acoustic). The proportion of survey effort conducted in different sea conditions was similar in all zones, but weather was slightly better than average in Zones 2 and 3, and slightly poorer in Zone 5 (Figure 2). By far the highest number of species (nine), and relative species diversity were recorded in Zone 1 – the Pemba Channel, and this area also had high group encounter rate and the highest individual encounter rate (Table 3; Figure 3). Low species encounter rates, number of species and relative abundance were recorded in Zone 2, the Zanzibar Channel, where only small groups of Indo-Pacific bottlenose and Indian Ocean humpback dolphins were recorded. Very few cetaceans were encountered in Zone 4 – Mafia / Rufiji. Zone 5 – Mtwara/Lindi had the highest group encounter rate of any zone, but relatively low diversity indices with sightings dominated by spinner and Risso's dolphins. Differences between zones are accentuated when individual encounter rates are compared, because the two zones with the highest group encounter rates (1 & 5) also had large numbers of spinner dolphins that occur in large groups (Table 3). The two most commonly encountered cetacean species were different in every zone (Table 3). To investigate whether changing our definition of good survey conditions would have changed these results, we examined encounter rates by zone over a range of sea states (Figure 4). Irrespective of sea conditions, the same two zone (1 and 5) had the highest encounter rates, and the same two zones (3 and 4) had comparatively lower encounter rates.

The mean classification rate of the whistle classifier was 60%. This is lower than some other comparable studies e.g. (Erbs et al., 2017), likely driven by the low sample sizes in the training datasets. However, for initial assessment purposes it was acceptable. Classification accuracy was highest for false killer whales (87.5%) and spinner dolphins (69.2%). It performed poorly for pilot whales (38.0%) and pantropical spotted dolphins (36.8%) and intermediate for the remaining two species. Insufficient whistles were recorded from any of the unidentified visual sightings to enable their input into the whistle classifier. There were 11 acoustic detections that had no accompanying visual sighting; of these, eight were classified as spinner dolphins, and the remaining three were classified as two species or as one of the species for which the classifier performed poorly. Because of the low certainty of the resulting species classifications, all acoustic only delphinid whistle detections were included in analysis as unidentified species.

3.2.2. Existing information and opportunistic data on cetaceans

In total, 406 records of marine mammal sightings, strandings, and skeletal material were compiled, comprising 20 stranded animals, 43 skeletal remains and 339 live sightings. Fourteen species were represented in the data, but 80% of the records were of five species:

- Spinner dolphin (n=126; 31% of all records)
- Humpback whale (n=61; 15%)
- Indo-Pacific bottlenose dolphin (n=56; 14%)
- Indian Ocean humpback dolphin (n=41; 10%);
- Risso's dolphin (n=35; 9%).

Three species in the qualitative data had not been seen during the vessel-based survey. These were common dolphin (*Delphinus delphis*) and dwarf sperm whale (*Kogia sima*) both recorded in the Pemba Channel. Humpback whales were absent from Tanzania at the time of the boat survey but were documented from every zone in the qualitative data. This takes the total number of documented species in the entire assessment to twelve. Once humpback whales are removed from the data, the species with the largest number of qualitative records in each zone, is the same as the species most frequently encountered during the boat-based survey (Table 3).

3.3. *Rapid assessment of threats to cetaceans*

3.3.1. Cetacean bycatch

In total, 573 interviews were conducted, comprising 296 interviews from 31 villages in all four regions of the Tanzanian mainland coast and 277 interviews from 12 villages in Pemba and Unguja (Figure 1). By zone the number of interviews were as follows: 1 - 270; 2 - 147;

3 - 22; 4 - 78; 5 - 56. The average age of respondents was 43 years (SD=13), and was similar (ranging between 37 and 45 years) in all regions. A total of 71% (n=407) of interviews were with fishermen who used gillnets as their primary gear type and another 10% used gillnets as their secondary gear type. Remaining interviews were with hook and line (11%, n=66), purse-seine (8%, n=47), longline (5%, n=27), trap (4%, n=21) and octopus spear fishers (1%, n=5). Of those interviewed, 95% were full-time fishers, and just over half also had another source of income with agriculture the most common (37%). Boat captains constituted 63% of respondents, while the remaining 37% were crew. Outboard motors were present on 29% of the boats used by interviewees, and the remaining 71% were oar or sail powered.

Close to two-thirds of fishers (59%) believed that there was only one type of dolphin in Tanzania. Due to uncertainty in species identification by fishermen an overall cetacean bycatch rate is provided rather than species specific rates.

A total of 17.4% of gillnetters reported that they had caught dolphins in the last calendar year. Based on this an estimated national bycatch rate of 0.17 dolphins / gillnet boat / year was calculated. The zone with the highest reported bycatch rate was Zone 1 - Pemba Channel, with 0.24 dolphins / gillnet boat / year, almost five times higher than the lowest reported rates in Zones 3 and 4, Dar es Salaam and Mafia/Rufiji, which were 0.05 and 0.04 dolphins / boat / year, respectively. In general, the bycatch rate on the islands of Pemba and Unguja, collectively 0.24 dolphins / gillnet boat / year, was two and half times greater than from the mainland Tanzania coast (0.10 dolphins / gillnet boat / year). Because few interviews were conducted with fishers that use gear other than gillnets we note only that these limited data suggest that cetacean bycatch rates in purse-seines, longlines and with hook and line were much lower than gillnets.

3.3.2. Cetacean hunting, consumption and use

Fishers were asked during interviews the fate of dolphins that were caught in a fishing net. Perhaps reflecting reluctance at admitting knowledge about an illegal activity, 50% of respondents did not answer the question. Of the remainder who did answer, 43% said the animals were either released alive or discarded dead, 37% said that dolphins were eaten, 14% that they were used as bait for sharks in the longline fishery, and 4% that the flesh was rotted and the oil then used as a wood preservative for boats. The proportion of fishers that reported eating dolphins was highest on Pemba (46%) and in Zone 4 Mafia/Rufiji (50%). Of a total of 55 fish vendors interviewed, only one, who was from Ziwani on Pemba, asserted that he had sold dolphin meat in the market recently. The meat was only rarely available and was sold for the comparatively small sum of $7.5-$10 / whole dolphin. No definitive evidence that dolphins were directly hunted was obtained.

3.3.3. Dynamite Fishing

Zone 3 – Dar es Salaam had an average blast fishing rate of 5.3 explosions / hour, which is approximately seven times higher than anywhere else along the Tanzanian coast. With an average of 1.4 blasts / hour, Zone 2 – Zanzibar Channel was the second most greatly impacted zone, and all other areas blast rate was relatively low (Braulik, Wittich, et al., 2015).

3.3.4. Shipping

Dar es Salaam is by far the biggest port in Tanzania; in 2014, it was visited by just over 1000 ships, and handled 93% of the country's ocean cargo traffic: approximately 14.3 million tons (Tanzania Ports Authority, 2015). Ships typically approach from the wider Indian Ocean and do not travel extensively along the Tanzanian coast, therefore Zone 3 - Dar es Salaam is likely to be most extensively affected by shipping related noise and disturbance. Much smaller ports in Tanga and Mtwara each handle about 0.36 Million tons per year (~2.4% each of the national total) and Zanzibar 0.15 Million tons per year (Zanzibar Ports Corporation). One of the busiest high-speed ferry routes in East Africa runs between Zanzibar and Dar es Salaam, therefore disturbance, underwater noise and the potential for marine mammal - ship strikes is moderate in Zone 2.

3.3.5. Overall threat evaluation

Information on dolphin hunting and consumption was equivocal and so this potential threat was not included in the overall score. The zone with the highest overall potential threats to cetaceans was assessed to be Zone 3 – Dar es Salaam which is influenced by the major port as well by the very high prevalence of blast fishing (Table 4; Figure 5). By contrast cetaceans in Zone 1, the Pemba Channel are also evaluated as being under higher potential threat than other areas, but here they are subject to fisheries related impacts with higher estimated dolphin bycatch rates and total number of gillnets.

4. **Discussion**

4.1. Conservation Priorities for Cetaceans in Tanzania

This assessment demonstrated considerable cetacean diversity in Tanzania as well as substantial variation in cetacean relative abundance and diversity along the coast. Three new mammal records; Blainville's beaked whale, dwarf sperm whale and common dolphin (seen in the wild by GTB & MK and verified with good quality photographs) were documented taking the total number of cetaceans confirmed in Tanzania from 16 (Amir et al., 2012) to 19. Cetacean abundance indices were highest in the two deepest parts of the coast (Zone 1 - Pemba Channel and Zone 5 - Mtwara), almost double those of the shallower areas (Zone 2 and 4). Higher diversity and abundance of cetaceans in areas with a greater variety of depth and slope habitat is typical and is related to increased mixing of nutrient rich waters which increases productivity and prey availability (Cañadas et al., 2002; Hooker, Whitehead, & Gowans, 1999).

Based on this study, with high relative cetacean abundance and diversity, we consider the Pemba Channel (Zone 1) in the north of Tanzania to be the most important area for cetaceans nationally. A total of 16 of the 19 cetacean species known to occur in Tanzania have been documented from this location, including the endangered Indian Ocean humpback dolphin. The channel between the Tanzanian mainland and Pemba island is only 50km wide but it is 1000m deep, and has bathymetric features similar to submarine canyons which are well known as important areas for cetaceans (Moors-Murphy, 2014). There is a fast (0.5-3m/s) north-flowing current, and the turbulence and vertical mixing that occurs along the margins of the channel create nutrient-rich conditions (Barlow et al., 2011; Mahongo & Shaghude, 2014). This type of mixing, which is common adjacent to tropical islands, can provide oases of biodiversity in otherwise nutrient-poor tropical oceans (Kiszka, Ersts, & Ridoux, 2010). The Pemba Channel was recently identified as an Ecologically and Biologically Significant Area (EBSA) by the Convention on Biological

Diversity (2013) and it is renowned for catches of large pelagic fish (Hemphill, 1995). Even though there are marine protected areas (MPAs) along the Tanga and Pemba coastlines, our assessment suggests that the Pemba Channel is also subject to relatively high levels of potential threat, from bycatch in fishing gear and dynamite fishing. Therefore, from the perspective of cetaceans we conclude that this location is the priority for future research and conservation (Figure 5).

The Rufiji delta (Zone 4) is one of the largest estuaries and mangrove stands on the east coast of Africa, and harbours the only remaining population of dugong in Tanzania (Muir, Sallema, Abdallah, De Luca, & Davenport, 2003), whale sharks (*Rhincodon typus*) (Cagua et al., 2015) and large numbers of nesting sea turtles (Bourjea, Nel, Jiddawi, Koonjul, & Bianchi, 2008). The same issues, principally fisheries bycatch, threaten all these endangered species and conservation actions on behalf of one are likely to benefit all.

Mtwara/Lindi (Zone 5) in southern Tanzania is the least developed part of the country's coastline. It was evaluated as the area with the lowest relative potential threat to cetaceans, and the area of highest cetacean relative abundance. Cetacean communities recorded were dominated by spinner and Risso's dolphins, both species that preferentially occur on the margins of the continental shelf (Jefferson et al., 2014; Perrin, 2009). This area is a focus of exploration and extraction of oil and gas and, given the high relative abundance of cetaceans and the presence of species that are known to be sensitive to anthropogenic sound, such as beaked whales and also humpback whales, it is important that potential impacts of these activities be carefully evaluated and mitigated (Cerchio, Strindberg, Collins, Bennett, & Rosenbaum, 2014; Southall et al., 2009).

It is important to note that the east coast of Pemba and Zanzibar, and offshore waters beyond 50km from the mainland coast, were not included in the study area and it is probable that additional areas within Tanzanian waters that were not surveyed may be important for marine mammals. Two areas that are high priority to investigate because of potential small-scale upwelling are the east coast of Pemba and the sea mount located due east of Pemba in 2000m of water (Mahongo & Shaghude, 2014).

Indian Ocean humpback and Indo-pacific bottlenose dolphins occur predominantly in shallow coastal areas. This near-shore distribution places them in the marine waters most heavily utilized by humans (Keith, Atkins, Johnson, & Karczmarski, 2013; Stensland, Carlen, Sarnblad, Bignert, & Berggren, 2006). Throughout their range, both species are threatened by bycatch in fishing gear, coastal development and pollution, and in Tanzania they are also exposed to the noise and physical threat of dynamite fishing. The Indian Ocean humpback dolphin which has the most near-shore distribution of the two, is thought to be the most threatened cetacean in the region (Braulik, Findlay, Cerchio, & Baldwin, 2015). Indian Ocean humpback dolphins appear to have a discontinuous distribution along the Tanzanian coast with concentrations in large shallow areas, including on both sides of the Zanzibar and Pemba channels (Zone 1 and 2), and in the Rufiji Delta (Zone 4). Although they may occur along the 200km stretch of coast between Kilwa and Mtwara, no evidence of their presence was found during surveys and the available shallow habitat along that exposed coastline is extremely limited. As one of the most threatened marine megafauna species regionally, conservation of Indian Ocean humpback dolphins should be a national priority. Humpback whales are present in Tanzania in considerable numbers from June to November, but they are also regularly entangled in drift gillnets (Amir et al., 2012). All three of these cetacean species are potentially under pressure from fisheries bycatch and habitat degradation, and it is important to generate information on areas of concentration, residency, movement and connectivity, as well as abundance, in order that key areas may be identified and protected. It is important to note that there can be considerable population structure within cetaceans, and potentially other more pelagic species in Tanzania may well also be under threat. For example, in Hawaii, which is not dissimilar tropical habitat to Tanzania, long-term research showed that there were small, demographically isolated, island associated populations of false killer whales that were declining rapidly due to bycatch in the longline fishery (Reeves, Leatherwood, & Baird, 2009).

Fishing is the single largest threat to cetaceans worldwide with around 300,000 estimated cetacean mortalities per year in fishing nets (Read, 2008). Fisheries interactions are also likely to be the largest threat to cetaceans in Tanzania, with negative impacts arising from direct entanglement, hooking on longlines, as well as potential disturbance and injury from fishing with explosives (Kiszka et al., 2009). Marine fisheries operating in the study area in Tanzania are artisanal and near-shore. They use a variety of gears to target multiple species and the distinction between target and bycatch species is vague, especially as captured dolphins can be utilized in many ways including as food, bait and oil. Cetaceans are legally protected in Tanzania although this is rarely enforced and fines seldom imposed. Some fishers did appear to express reluctance in discussing use of cetaceans, which may mean that our calculated bycatch level has been underestimated. However, if biases are uniform across the country, the comparative levels of bycatch threat by zone should still be valid. The interview-based bycatch rates reported here were similar to those reported from Zanzibar in 1999 (0.46 dolphins/boat/year) (Amir, Berggren, & Jiddawi, 2002). The dolphin capture rates per boat are not high, however, there are estimated to be over 16,000 fishing vessels in the country and gillnets constitute about 35% of documented fishing gear (Ministry of Livestock Development and Fisheries, 2010; Zanzibar Ministry of Livestock and Fisheries, 2010), so the total number of dolphins captured in Tanzania is likely to be considerable each year. As would be expected there is a loose correlation between the recorded cetacean relative abundance in each zone and bycatch rate, with higher bycatch rates recorded in areas with higher cetacean relative abundance. To know if these rates are causing cetacean population declines it is necessary to understand the size of populations; this information is currently lacking from most places in east Africa. However because dolphins reproduce slowly, populations generally cannot sustain mortality rates greater than a few percent of population size, and especially for small, coastal cetacean populations in heavily fished areas mortality rates are frequently unsustainable (Read, 2008). This was demonstrated during on-board observer programmes in Zanzibar, which estimated that 9.6% of the estimated population of Indo-Pacific bottlenose dolphins and 6.3% of Indian Ocean humpback dolphins were taken as bycatch annually, rates which were unsustainable based on abundance estimates for both species (Amir, 2010). Further investigation of bycatch is a priority, focusing on understanding the effects of gear type and habitat on capture levels, placing bycatch rates in context by estimating abundance of the most frequently caught cetacean species and ultimately developing, implementing and monitoring mitigation strategies.

Many uses of accidentally captured dolphins in Tanzania were identified, including consumption, but little commercial sale of the meat. Cetacean consumption is increasing worldwide, and can quickly shift from occasional consumption of accidentally entangled animals to intentional targeting and hunting (Cosentino & Fisher, 2016). Pemba is the main location where dolphins are known to be sold and regularly consumed and monitoring of fish markets may reveal that consumption and sale is more common than suggested by our interviews.

Tanzania is the only country in the Western Indian Ocean where fishing with explosives has been widely practised for more than 50 years (Wells, 2009). The sound from a single blast can travel up to 50km from the source. With more than 70 blasts/day in some areas, this represents considerable additional noise in the ocean (Braulik, Wittich, et al., 2015). The majority of blast fishing occurs in coastal waters in the habitat of Indian Ocean humpback and Indo-Pacific bottlenose dolphins and these species will be impacted to the greatest extent, with effects ranging from abandoning heavily dynamited habitats, lost feeding, socializing or resting opportunities, as well as the potential for physical injury (including impaired hearing) and death at short range (McGregor, Horn, Leonard, & Thomsen, 2013). Blast fishing negatively impacts many aspects of the marine environment; it is complex to combat, but a high priority to prevent.

4.2. Advantages and Disadvantages of Cetacean Rapid Assessment

Marine mammals are much less well understood than their terrestrial mammal counter-parts, whilst the level of threat they face is believed to be just as high (Schipper et al., 2008). The number of species threatened with extinction far outstrips available conservation resources, which places a premium on prioritization and the importance of identifying and protecting `biodiversity hotspots' (Myers, Mittermeier, Mittermeier, da Fonseca, & Kent, 2000). This rapid assessment is a useful and flexible approach to quickly evaluate large areas of coastline and draw general conclusions about cetacean communities, habitat and threats. This type of broad-scale, level-one rapid investigation which generates community rather than species-specific information is appropriate because, from a management perspective, while there are nuances in species-specific vulnerability, essentially the same threats (e.g. fishing, underwater noise, habitat degradation, etc.) impact all cetaceans to some degree, and therefore effective mitigation actions are likely to be very similar for all species. In addition, using cetacean community encounter rates is a quantitative metric that requires a much lower input of survey effort than generation of species specific abundance estimates.

Using simple cetacean community encounter rates without accounting for variation in detection probabilities among species in different surveying conditions, even when poor weather is excluded, could introduce bias. Generally speaking, such encounter rates will be dominated by species that are more visible, occur in larger groups and spend longer at the surface. In addition, the impact on detection probability of the combined effects of wind and swell are more apparent further from shore and in deep water. Thus, surveys in zones with different habitats may be affected differentially by variable survey conditions.

However, our results were consistent regardless of sea conditions (Figure 4). The combination of a visual survey with an acoustic survey likely contributed to this consistency, and it is important that future rapid assessments consider using acoustic technology as well as visual surveys to minimise the impact of variable sea conditions on cetacean community encounter rates, as well as comprehensively exploring the impact of survey conditions on the conclusions.

In this survey, we were fortunate that cetacean encounter rates were relatively high generating sufficient data to draw broad conclusions. The ratio of distance surveyed in good conditions to area was between 0.06-0.07 in every zone. This level of effort relative to area worked well in the current assessment and could be used as a starting point when planning future rapid assessments. However, in areas with lower encounter rates, or consistently poor weather, a rapid assessment of cetaceans would be more challenging and may not generate enough information to draw any meaningful conclusions without expending considerably more survey effort.

A rapid assessment, as with almost all surveys, can confirm species presence, but it cannot confirm species absence. A single survey will not capture temporal shifts in species distribution and migratory species not present would also not be detected (e.g. in this instance humpback whales but also possibly other seasonal species). Some rare and uncommon species, arguably amongst the most important from a conservation perspective, will also not have been documented. For example, humpback dolphins were not seen in Zone 1 – Pemba, during this rapid assessment but were frequently observed during more intensive coastal surveys along both the Tanga and Pemba coasts. The use of a large seaworthy catamaran enabled the survey to safely navigate offshore waters which was important, but because of its draft we were restricted for safety reasons in our ability to survey shallow areas <20m deep which is where the majority of humpback dolphins are found (Braulik, Findlay, et al., 2015). In areas with extensive shallows future rapid assessments could deploy two different survey platforms, a larger seaworthy vessel for offshore areas and a smaller shallower draft vessel for near-shore areas.

Care must be taken in the designation of zones for presenting the data. In this instance, it worked well to split the study area into five zones based on depth, which also coincidentally broadly matched the provincial boundaries, providing a biological and a political rationale for presenting the information. In other applications, it will be equally important to select zones based on habitat because this will influence the cetacean community that is present.

The evaluation of threats in a rapid assessment is necessarily relatively superficial but to evaluate threats comprehensively is complex. For example, Crain, Kroeker, & Halpern (2008) found that of the cumulative effects of multiple stressors in the marine environment, 26% were additive, 36% synergistic, and 38% antagonistic. The evaluation of potential threats conducted here using coarse scale qualitative data provided a general indication of the important issues, and their relative intensity. To develop effective mitigation of threats, which can be complex and interacting, will require more in-depth studies.

Whether completing a cetacean rapid assessment in one year is sufficiently quick for it to be accurately termed 'rapid' depends upon your perspective. In comparison to some of the targeted terrestrial or coral reef rapid assessments that may be completed in a matter of months, this is slow, but given the large geographic scope and compared to the majority of other marine mammal studies it can be considered rapid.

A strength of this approach is that it can be adapted to the local situation, particularly regarding the use of different types of opportunistic data. In this assessment, very little historical information was found in the literature, but a large quantity of data were compiled from the dive and sport fishing operators. In other countries, the most useful sources of historical or opportunistic data will vary, but it is important that all possible avenues are explored. A rapid assessment is an initial investigation and it is important that it is not seen as the end point or its results over interpreted. It is hoped that initial studies such as these will act as a catalyst for more intensive targeted work that generates more detailed species-specific information to capture temporal changes in distribution and estimate abundance.

Despite the many caveats noted above, there is a place for rapid assessment of cetaceans as a tool to provide important initial information about the marine environment and the threats to species. This is a useful approach to quickly provide broad-scale information on relative occurrence of common cetacean species across large data deficient areas that can be used to target research needs and guide the development of management priorities.

Generating robust baseline data on marine mammal communities and threats at a wide spatial scale is a critical first step to identifying and prioritizing species and locations that require urgent conservation action. This kind of information is vital to enable cetaceans to be included in global and regional initiatives to identify important biodiversity areas, such as EBSAs, Important Marine Mammal Areas (IMMAs), Key Biodiversity Areas (KBAs) and MPAs and, similarly, to feed into the environmental impact assessment (EIA) process. It can also be a useful first activity for researchers entering a new, unknown area, to identify where to focus future intensive research. The baseline marine ecological information generated is increasingly required by governments as they seek to meet the target to protect 10% of their waters by 2020, and to manage and reduce the impact of burgeoning development, disturbance and use of the oceans.

5. Acknowledgements

We thank Kate Grellier, Albert Reichert, Randy Reeves, Simon Northridge, and Tim Davenport for their help in getting this project off the ground. The crew of the yacht Walkabout, Gerry Hallam and Sabina Montserrat, Laura Morse, Haji Mohammad Haji were instrumental in the project success. We thank Matt Richmond, Mohammad Sharif, Omar Amir, Hosea Mbilinyi, Lindsey West and Mwanaidi Mlolwa for their assistance and guidance. Community interviews were conducted by Gumbo Majubwa and Nassoor Akida Ally, and GIS analysis by Yussuf Said Yussuf and Yves Barthelemy. Helpful reviews of the report were provided by Tim Davenport, Howard Rosenbaum, Gianna Minton, Nell Hamilton and Robin Baird. The work was funded by the Pew Marine Fellows Program and WCS.

6. References

Alliance for Zero Extinction. (2003). *Criteria for the Definition of Conservation Areas*. Alliance for Zero Extinction. http://www.zeroextinction.org/criteria.html.

Alonso, L. E., Deichmann, J. L., McKenna, S. A., Naskrecki, P., & Richards, S. J. (Eds.). (2011). *Still Counting...: Biodiversity Exploration for Conservation – The First 20 Years of the Rapid Assessment Program.* Arlington, VA, USA: Conservation International.

Amir, O. A. (2010). *Biology, ecology and anthropogenic threats of Indo-Pacific bottlenose dolphins in east Africa. PhD Thesis.* (PhD Thesis), Stockholm University, Sweden.

Amir, O. A., Berggren, P., & Jiddawi, N. S. (2002). The incidental catch of dolphins in gillnet fisheries in Zanzibar, Tanzania. *Western Indian Ocean Journal of Marine Science, 1*(2), 155-162.

Amir, O. A., Berggren, P., & Jiddawi, N. S. (2012). Recent records of marine mammals in Tanzanian waters. *Journal of Cetacean Research and Management, 12*(2), 249-253.

Barbour, M. T., Gerritsen, J., Snyder, B. D., & Stribling, J. B. (1999). *Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish, Second Edition.* EPA 841-B-99-002. U.S. Environmental Protection Agency; Office of Water; Washington, D.C.

Barlow, R., Lamont, T., Kyewalyanga, M., Sessions, H., van den Berg, M., & Duncan, F. (2011). Phytoplankton production and adaptation in the vicinity of Pemba and Zanzibar islands, Tanzania. *African Journal of Marine Science, 33*(2), 283-295. doi:10.2989/1814232X.2011.600430

Baumann-Pickering, S., McDonald, M. A., Simonis, A. E., Solsona Berga, A., Merkens, K. P. B., Oleson, E. M., . . . Hildebrand, J. A. (2013). Species-specific beaked whale echolocation signals. *The Journal of the Acoustical Society of America, 134*(3), 2293-2301. doi:doi:http://dx.doi.org/10.1121/1.4817832

Berggren, P. (2009). *Whales and dolphins: A field guide to marine mammals of East Africa.* . Norwich, UK: East Publishing Limited.

Bourjea, J., Nel, R., Jiddawi, N. S., Koonjul, M. S., & Bianchi, G. (2008). Sea turtle bycatch in the West Indian Ocean: review, recommendations and research priorities. *Western Indian Ocean Journal of Marine Science, 7*(2), 137-150.

Bowen, W. D. (1997). Role of marine mammals in aquatic ecosystems. *Marine Ecology Progress Series, 158*, 267-274.

Braulik, G. T., Findlay, K., Cerchio, S., & Baldwin, R. (2015). Chapter Five - Assessment of the Conservation Status of the Indian Ocean Humpback Dolphin (*Sousa plumbea*) Using the IUCN Red List Criteria. In T. A. Jefferson & B. E. Curry (Eds.), *Advances in Marine Biology* (Vol. 72, pp. 119-141): Academic Press.

Braulik, G. T., Wittich, A., Macaulay, J., Kasuga, M., Gordon, J., Gillespie, D., & Davenport, T. R. B. (2015). *Fishing with explosives in Tanzania: spatial distribution and hotspots* 19pp. Wildlife Conservation Society Tanzania Program. Zanzibar, Tanzania.

Buckland, S. T., Anderson, D. R., Burnham, K. P., Laake, J. L., Borchers, D. L., & Thomas, L. (2001). *Introduction to distance sampling: estimating abundance of biological populations*. Oxford: Oxford University Press.

Cagua, E. F., Cochran, J. E., Rohner, C. A., Prebble, C. E., Sinclair-Taylor, T. H., Pierce, S. J., & Berumen, M. L. (2015). Acoustic telemetry reveals cryptic residency of whale sharks. *Biology letters, 11*(4), 20150092.

Cañadas, A., Sagarminaga, R., & García-Tiscar, S. (2002). Cetacean distribution related with depth and slope in the Mediterranean waters off southern Spain. *Deep-Sea Research Part 1, 49*, 2053-2073.

Cerchio, S., Strindberg, S., Collins, T., Bennett, C., & Rosenbaum, H. (2014). Seismic surveys negatively affect humpback whale singing activity off northern Angola. *PLoS ONE, 9*(3), e86464. doi:10.1371/journal.pone.0086464

Christiansen, F., Lusseau, D., Stensland, E., & Berggren, P. (2010). Effects of tourist boats on the behaviour of Indo-Pacific bottlenose dolphins off the south coast of Zanzibar. *Endangered Species Research, 11*, 91-99.

Convention on Biological Diversity. (2013). *Southern Indian Ocean regional workshop to facilitate the description of Ecologically or Biologically Significant Marine Areas*, Mauritius.

Cosentino, A. M., & Fisher, S. (2016). The utilization of aquatic bushmeat from small cetaceans and manatees in South America and West Africa. *Frontiers in Marine Science, 3*, 163.

Crain, C. M., Kroeker, K., & Halpern, B. S. (2008). Interactive and cumulative effects of multiple human stressors in marine systems. *Ecology Letters, 11*(12), 1304-1315.

Davidson, A. D., Boyer, A. G., Kim, H., Pompa-Mansilla, S., Hamilton, M. J., Costa, D. P., . . . Brown, J. H. (2011). Drivers and hotspots of extinction risk in marine mammals. *PNAS*, www.pnas.org/cgi/doi/10.1073/pnas.1121469109.

Erbs, F., Elwen, S. H., & Gridley, T. (2017). Automatic classification of whistles from coastal dolphins of the southern African subregion. *The Journal of the Acoustical Society of America, 141*(4), 2489-2500.

Fennessy, M. S., Jacobs, A. D., & Kentula, M. E. (2007). An evaluation of rapid methods for assessing the ecological condition of wetlands. *Wetlands, 3*, 543-560.

Ferretti, F., Worm, B., Britten, G. L., Heithaus, M. R., & Lotze, H. K. (2010). Patterns and ecosystem consequences of shark declines in the ocean. *Ecology Letters, 13*(8), 1055-1071.

Gillespie, D., Caillat, M., Gordon, J., & White, P. (2013). Automatic detection and classification of odontocete whistles. *The Journal of the Acoustical Society of America, 134*(3), 2427-2437. doi:doi:http://dx.doi.org/10.1121/1.4816555

Gillespie, D., Gordon, J., Mchugh, R., McLaren, D., Mellinger, D. K., Redmond, P., . . . Deng, X. Y. (2008). Pamguard: semiautomated, open source software for real-time acoustic detection and localisation of cetaceans. *Proceedings of the Institute of Acoustics, 30*(5), 9pp.

Gruden, P., White, P. R., Oswald, J. N., Barkley, Y., Cerchio, S., Lammers, M., & Baumann-Pickering, S. (2016). Differences in oscillatory whistles produced by spinner (*Stenella longirostris*) and pantropical spotted (*Stenella attenuata*) dolphins. *Marine Mammal Science, 32*(2), 520-534. doi:10.1111/mms.12280

Heithaus, M. R., Frid, A., Wirsing, A. J., & Worm, B. (2008). Predicting ecological consequences of marine top predator declines. *Trends in Ecology & Evolution, 23*(4), 202-210. doi:http://dx.doi.org/10.1016/j.tree.2008.01.003

Hemphill, S. (1995). *The ecology and exploitation of yellowfin tuna, Thunnus albacares (Bonnaterre 1788) in the Pemba Channel, Kenya. PhD Thesis.* (PhD), University of Wales, Bangor.

Hobday, A., Smith, A., Stobutzki, I., Bulman, C., Daley, R., Dambacher, J., . . . Furlani, D. (2011). Ecological risk assessment for the effects of fishing. *Fisheries Research, 108*(2), 372-384.

Hooker, S. K., Whitehead, H., & Gowans, S. (1999). Marine Protected Area Design and the Spatial and Temporal distribution of cetaceans in a submarine canyon. *Conservation Biology, 13*(3).

IUCN. (2015). *IUCN Red List of Threatened Species. version 2015.4*: <http://www.iucnredlist.org> Downloaded on 26 January 2016.

Jefferson, T. A., Weir, C. R., Anderson, R. C., Ballance, L. T., Kenney, R. D., & Kiszka, J. J. (2014). Global distribution of Risso's dolphin *Grampus griseus*: a review and critical evaluation. *Mammal Review, 44*(1), 56-68. doi:10.1111/mam.12008

Jewell, R., Thomas, L., Harris, C., Kaschner, K., Wiff, R., Hammond, P. S., & Quick, N. J. (2012). Global analysis of cetacean line-transect surveys: detecting trends in cetacean density. *Marine Ecology Progress Series, 453*, 227-240. doi:10.3354/meps09636

Johnson, M., Madsen, P. T., Zimmer, W. M. X., Aguilar de Soto, N., & Tyack, P. L. (2004). Beaked whales echolocate on prey. *Proceedings of the Royal Society of London B: Biological Sciences, 271*(Suppl 6), S383-S386. doi:10.1098/rsbl.2004.0208

Johnson, M., Madsen, P. T., Zimmer, W. M. X., de Soto, N. A., & Tyack, P. L. (2006). Foraging Blainville's beaked whales (*Mesoplodon densirostris*) produce distinct click types matched to different phases of echolocation. *Journal of Experimental Biology, 209*(24), 5038-5050. doi:10.1242/jeb.02596

Kaschner, K., Quick, N., Jewell, R., Williams, R., & Harris, C. M. (2012). Global coverage of cetacean line-transect surveys: status quo, gaps and future challenges. *PLoS ONE, 7(9): e44075. doi:10.1371/journal.pone.0044075*.

Kaschner, K., Tittensor, D. P., Ready, J., Gerrodette, T., & Worm, B. (2011). Current and future patterns of global marine mammal biodiversity. *PLoS ONE, 6*(5), e19653.

Keith, M., Atkins, S., Johnson, A. E., & Karczmarski, L. (2013). Area utilization patterns of humpback dolphins (*Sousa plumbea*) in Richards Bay, KwaZulu-Natal, South Africa. *Journal of Ethology, 31*(3), 261-274. doi:10.1007/s10164-013-0375-z

Kiszka, J., Ersts, P., & Ridoux, V. (2010). Structure of a toothed cetacean community around a tropical island (Mayotte). *African Journal of Marine Science, 32*(3), 543-551.

Kiszka, J., Muir, C., Poonian, C., Cox, T. M., Amir, O. A., Bourjea, J., . . . Bristol, N. (2009). Marine mammal bycatch in the southwest Indian Ocean: Review and need for a comprehensive status assessment. *Western Indian Ocean Journal of Marine Science, 7*(2), 119-136.

Lewison, R. L., Crowder, L. B., Read, A. J., & Freeman, S. A. (2004). Understanding the impact of fisheries bycatch on marine megafauna. *Trends in Ecology and Evolution, 19*(11), 598-604.

Madsen, P. T., Carder, D., Bedholm, K., & Ridgway, S. (2005). Porpoise clicks from a sperm whale nose—Convergent evolution of 130 kHz pulses in toothed whale sonars? *Bioacoustics, 15*(2), 195-206.

Mahongo, S. B., & Shaghude, Y. W. (2014). Modelling the dynamics of the Tanzanian coastal waters. *Journal of Oceanography and Marine Science, 5*(1), 1-7.

Mannocci, L., Catalogna, M., Dorémus, G., Laran, S., Lehodey, P., Massart, W., . . . Ridoux, V. (2014). Predicting cetacean and seabird habitats across a productivity gradient in the South Pacific gyre. *Progress in Oceanography, 120*(0), 383-398. doi:http://dx.doi.org/10.1016/j.pocean.2013.11.005

Maragos, J. E., & Cook, C. W. (1995). The 1991–1992 rapid ecological assessment of Palau’s coral reefs. *Coral Reefs, 14*(4), 237-252. doi:10.1007/BF00334348

Maragos, J. E., Potts, D. C., Aeby, G. S., Gulko, D., Kenyon, J., Siciliano, D., & VanRavenswaay, D. (2004). 2000-2002 Rapid Ecological Assessment of Corals (Anthozoa) on Shallow Reefs of the Northwestern Hawaiian Islands. Part 1: Species and Distribution. *Pacific Science, 58*(2), 211-230.

McGregor, P., Horn, A., Leonard, M., & Thomsen, F. (2013). Anthropogenic Noise and Conservation. In H. Brumm (Ed.), *Animal Communication and Noise* (Vol. 2, pp. 409-444): Springer Berlin Heidelberg.

Mellinger, D. K., Thode, A. M., & Martinez, A. (2002). Passive acoustic monitoring of sperm whales in the Gulf of Mexico, with a model of acoustic detection distance. *Proceedings of the Twenty-first annual Gulf of Mexico information transfer meeting*, 493-501.

Ministry of Livestock Development and Fisheries. (2010). *Marine Fisheries Frame Survey Results 2009*. Government of the United Republic of Tanzania.

Moore, J. E., Cox, T. M., Lewison, R. L., Read, A. J., Bjorkland, R., McDonald, S. L., . . . Kiszka, J. (2010). An interview-based approach to assess marine mammal and sea turtle captures in artisanal fisheries. *Biological Conservation, 143*, 795-805.

Moors-Murphy, H. B. (2014). Submarine canyons as important habitat for cetaceans, with special reference to the Gully: A review. *Deep Sea Research Part II: Topical Studies in Oceanography, 104*(0), 6-19. doi:http://dx.doi.org/10.1016/j.dsr2.2013.12.016

Muir, C. E., Sallema, A., Abdallah, O., De Luca, D., & Davenport, T. R. B. (2003). *The dugong (Dugong dugon) in Tanzania: A national assessment of status, distribution and threat*. 31pp. Wildlife Conservation Society.

Myers, N., Mittermeier, R. A., Mittermeier, C. G., da Fonseca, G. A. B., & Kent, J. (2000). Biodiversity hotspots for conservation priorities. *Nature, 403*(6772), 853-858. doi:http://www.nature.com/nature/journal/v403/n6772/suppinfo/403853a0_S1.html

Perrin, W. F. (2009). Spinner dolphin *Stenella longirostris*. In W. F. Perrin, B. Würsig, & J. G. M. Thewissen (Eds.), *Encyclopedia of Marine Mammals. Second Edition* (pp. 1100-1103): Academic Press.

Pompa, S., Ehrlich, P. R., & Ceballos, G. (2011). Global distribution and conservation of marine mammals. *PNAS, 108*(33), 13600-13605.

QGIS Development Team. (2016). *QGIS Geographic Information System*. Open Source Geospatial Foundation Project. http://qgis.osgeo.org.

Read, A. J. (2008). The looming crisis: interactions between marine mammals and fisheries. *Journal of Mammalogy, 89*(3), 541-548.

Redfern, J. V., Ferguson, M. C., Becker, E. A., Hyrenbach, K. D., Good, C., Barlow, J., . . . Werner, F. (2006). Techniques for cetacean-habitat modelling. *Marine Ecology Progress Series, 310*, 271-295.

Reeves, R. R., Leatherwood, S., & Baird, R. W. (2009). Evidence of a possible decline since 1989 in false killer whales *(Pseudorca crassidens*) around the main Hawaiian Islands. *Pacific Science, 63*, 253-261.

Roch, M. A., Scott Brandes, T., Patel, B., Barkley, Y., Baumann-Pickering, S., & Soldevilla, M. S. (2011). Automated extraction of odontocete whistle contours. *The Journal of the Acoustical Society of America, 130*(4), 2212-2223. doi:doi:http://dx.doi.org/10.1121/1.3624821

Schipper, J., Chanson, J. S., Chiozza, F., Cox, N. A., Hoffman, M., Katariya, V., . . . Young, B. E. (2008). The status of the world's land and marine mammals: diversity, threat, and knowledge. *Science, 322*, 225-230.

Southall, B., Berkson, J., Bowen, D., Brake, R., Eckman, J., Field, J., . . . Winokur, R. (2009). *Addressing the effects of human-generated sound on marine life: an integrated research plan for U.S. federal agencies*. 72pp. Interagency task force on anthropogenic sound and the marine environment of the joint subcommittee on ocean science and technology. Washington DC.

Stensland, E., & Berggren, P. (2007). Behavioural changes in female Indo-Pacific bottlenose dolphins in response to boat-based tourism. *Marine Ecology Progress Series, 332*, 225-234.

Stensland, E., Carlen, I., Sarnblad, A., Bignert, A., & Berggren, P. (2006). Population size, distribution, and behavior of Indo-pacific Bottlenose (*Tursiops aduncus*) and humpback (*Sousa chinensis*) dolphins off the South Coast of Zanzibar. *Marine Mammal Science, 22*(3), 667-682.

Tanzania Ports Authority. (2015). *Tanzania Ports Authority annual report and accounts for the year ended 30th June 2014*. 58pp. Ministry of Transport. Dar es Salaam.

Temple, A. J., Tregenza, N., Amir, O. A., Jiddawi, N., & Berggren, P. (2016). Spatial and temporal variations in the occurrence and foraging activity of coastal dolphins in Menai Bay, Zanzibar, Tanzania. *PLoS ONE, 11*(3), e0148995. doi:10.1371/journal.pone.0148995

Thomas, L., Buckland, S. T., Rexstad, E. A., Laake, J. L., Strindberg, S., Hedley, S. L., . . . Burnham, K. P. (2010). Distance software: design and analysis of distance sampling surveys for estimating population size. *Journal of Applied Ecology, 47*, 5-14. DOI: 10.1111/j.1365-2664.2009.01737.x.

Wells, S. (2009). Dynamite fishing in northern Tanzania – pervasive, problematic and yet preventable. *Marine Pollution Bulletin, 58*(1), 20-23. doi:10.1016/j.marpolbul.2008.09.019

Zanzibar Ministry of Livestock and Fisheries. (2010). *Marine Fisheries Frame Survey for Zanzibar 2010*.

Zanzibar Ports Corporation. http://www.zpc.go.tz/index.php/ports/port-of-malindi.

Table 1 - Summary of methods used to generate information on cetacean community structure and threats in Tanzania

<table>
<tr><td>Objective</td><td>Methods or Approach</td><td>Metric</td></tr>
<tr><td>Describe Cetacean Communities</td><td>1. <u>Cetacean Survey</u> – a single boat-based visual and acoustic cetacean survey conducted during optimum weather window using line transect methods.
2. <u>Collation of existing/historical information</u> – from fishers, experts, published and unpublished information, museum records, citizen science etc.</td><td>Species presence

Index of relative abundance

Index of diversity

Presence of threatened species</td></tr>
<tr><td rowspan="2">Evaluate potential threats</td><td colspan="2"><u>General Approach</u>
1. Identify potential threats based on existing knowledge
2. Gather semi-quantitative information to illustrate potential for key threats to impact cetaceans throughout the study area (for specific details, see below)
3. Evaluate each risk spatially, rank and assign a score between 0 and 100 according to relative risk (see Table 4).
4. Assess the spatial overlap between cetaceans and potential threats to identify priority areas for conservation (see Figure 5).</td></tr>
<tr><td><u>Evaluation of potential threats by zone</u></td><td></td></tr>
</table>

	1. Determine cetacean bycatch rates using fisher questionnaire surveys	Number of dolphins killed / year / per gillnet boat
	2. Document total number of gillnetters recorded in national fisheries surveys	Total number of gillnets
	3. Evaluate relative levels of port and ship related noise, disturbance, pollution, and potential for ship strikes from port authority records	Number of tons of goods brought to each port by ship / year
	4. Investigate presence of dolphin hunting, consumption and use of cetaceans through fisher interviews	Proportion of fishers interviewed that claim that dolphins are hunted, eaten or sold in the market.
	5. Analyse acoustic survey to quantify incidence of blast fishing	Mean number of blasts / hr

934

935

Table 2 - Species and number of groups of marine mammals detected visually and acoustically during a March-April 2015 survey of the Tanzania coast

Rank	Species	No. of Groups detected (Visual + only Acoustic)	Red List Status (IUCN, 2015)	Mean Depth m (min-max)
1	Spinner dolphin (*Stenella longirostris*)	17	DD	457 (71-1100)
2	Risso's dolphin (*Grampus griseus*)	14	LC	955 (370-2600)
3	Indo-Pacific bottlenose dolphin (*Tursiops aduncus*)	14	DD	37 (10-73)
4	Blainville's beaked whale (*Mesoplodon densirostris*)	1+5[a]	DD	597 (400-1050)
5	Common bottlenose dolphin (*Tursiops truncatus*)	5	LC	464 (318-439)
6	Pantropical spotted dolphin (*Stenella attenuata*)	4	LC	1650 (700-2600)
7	Indian Ocean humpback dolphin (*Sousa	4	EN	18

	plumbea)			(5-40)
8	Short-finned pilot whale (*Globicephala macrorhynchus*)	2	DD	700
9	Fraser's dolphin (*Lagenodelphis hosei*)	1	LC	700
10	False killer whale (*Pseudorca crassidens*)	1	DD	400
11	Dugong (*Dugong dugon*)	1	VU	4
	Unidentified	11+11[b]		-
	Total	**91**		

[a] One acoustic beaked whale detection included here may have been Blainville's or Cuvier's beaked whale

[b] Eight of the acoustic detections included here as unidentified were assigned to spinner dolphins by the whistle classifier which has a ~70% likelihood of being the correct identification.

943 Table 3 - Summary of marine mammals recorded during visual and acoustic survey of the coast of Tanzania

Zone	Survey effort in good[a] survey conditions (km)	Number of marine mammal species recorded	Marine Mammal Relative Diversity (no. of species / 100km of good[a] survey conditions)	Marine Mammal Group Visual and Acoustic Encounter Rate (groups / 100km of good[a] survey conditions)	Marine Mammal Individual Encounter Rate (individuals / 100km of good[a] survey conditions)	Two most frequently sighted species	Species Visual Encounter Rate (groups / 100km)
1. Greater Pemba Channel	449	9	1.78	4.01 (CV=24.6%)	573 (CV=44.0%)	1.Spinner dolphin (*Stenella longirostris*)	1.11
						2.Common bottlenose dolphin (*Tursiops truncatus*)	0.67
2. Zanzibar Channel	376	2	0.53	2.92 (CV=49.5%)	31 (CV=95.0%)	1.Indo-Pacific bottlenose dolphin (*Tursiops aduncus*)	2.13
						2.Indian Ocean humpback dolphin	0.53

						(*Sousa plumbea*)	
3. Dar es Salaam	322	4	1.24	3.11 (CV=23.3%)	169 (CV=48.4%)	No species most frequent	-
4.Mafia, Kilwa Rufiji	660	6	0.91	2.12 (CV=43.6%)	148 (CV=57.4%)	1.Indo-pacific bottlenose dolphin (*Tursiops aduncus*)	0.76
						2.Spinner dolphin (*Stenella longirostris*)	0.30
5. Mtwara & Lindi	560	4	0.71	4.28 (CV=36.5%)	340 (CV=41.2%)	1.Risso's dolphin (*Grampus griseus*)	1.61
						2.Spinner dolphin (*Stenella longirostris*)	1.07

a – Good conditions defined as Beaufort 4 or less

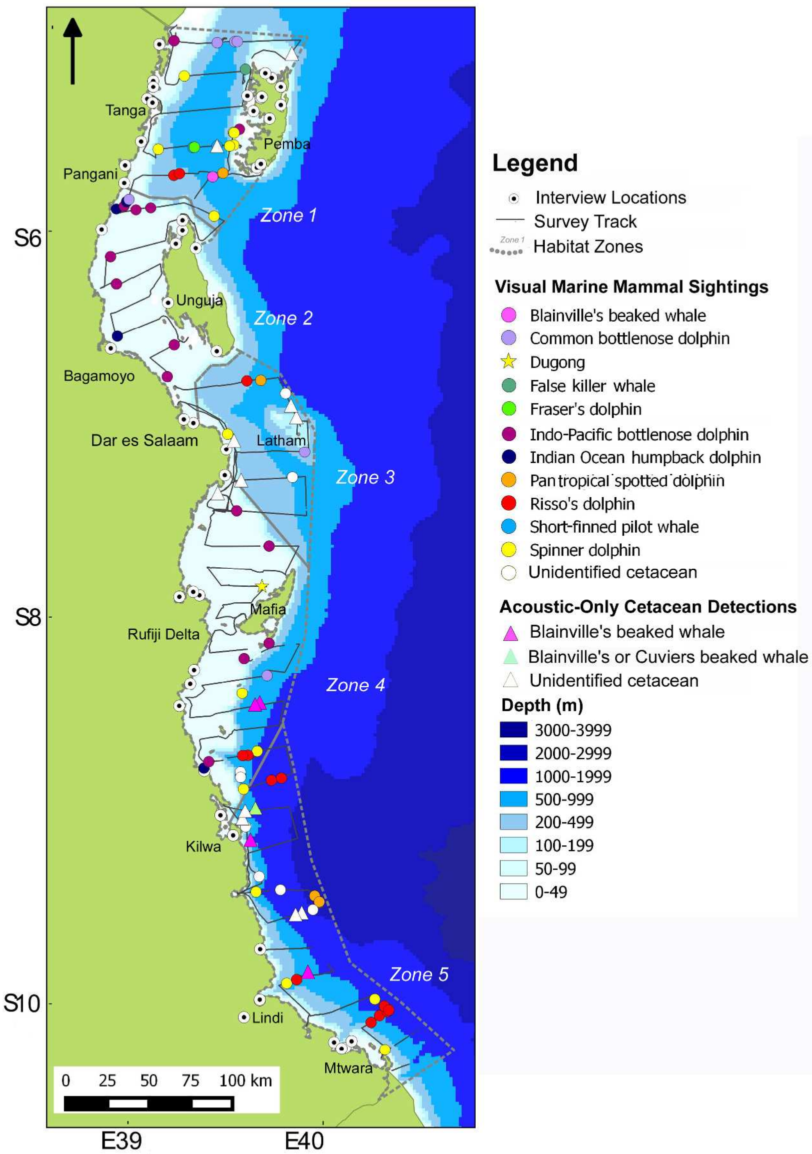
946 Table 4 – Hierarchical scores and value of rapidly assessed potential threats to cetaceans in
947 Tanzania

Potential Threat	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
Bycatch Score (dolphins/boat/year)	100 (0.24)	83 (0.20)	21 (0.05)	17 (0.04)	42 (0.10)
Gillnet Fishing Fleet Score (Gillnets/km of coast) (Total gillnets)[a]	57 (40.3) (4029)	28 (19.4) (3022)	7 (4.9) (315)	100 (70.4) (15903)	11 (7.8) (1529)
Shipping Score (M Tons of goods / year)	3 (0.37)	1 (0.15)	100 (14.3)	0 (0.05)	2 (0.35)
Dynamite Fishing Score (blasts/hr)	14 (0.76)	27 (1.41)	100 (5.31)	11 (0.59)	13 (0.68)
Total	174	138	228	128	68

948 a – numbers derived from the most recent Tanzanian mainland (Ministry of Livestock Development
949 and Fisheries, 2010) and Zanzibar (Zanzibar Ministry of Livestock and Fisheries, 2010), frame
950 surveys.

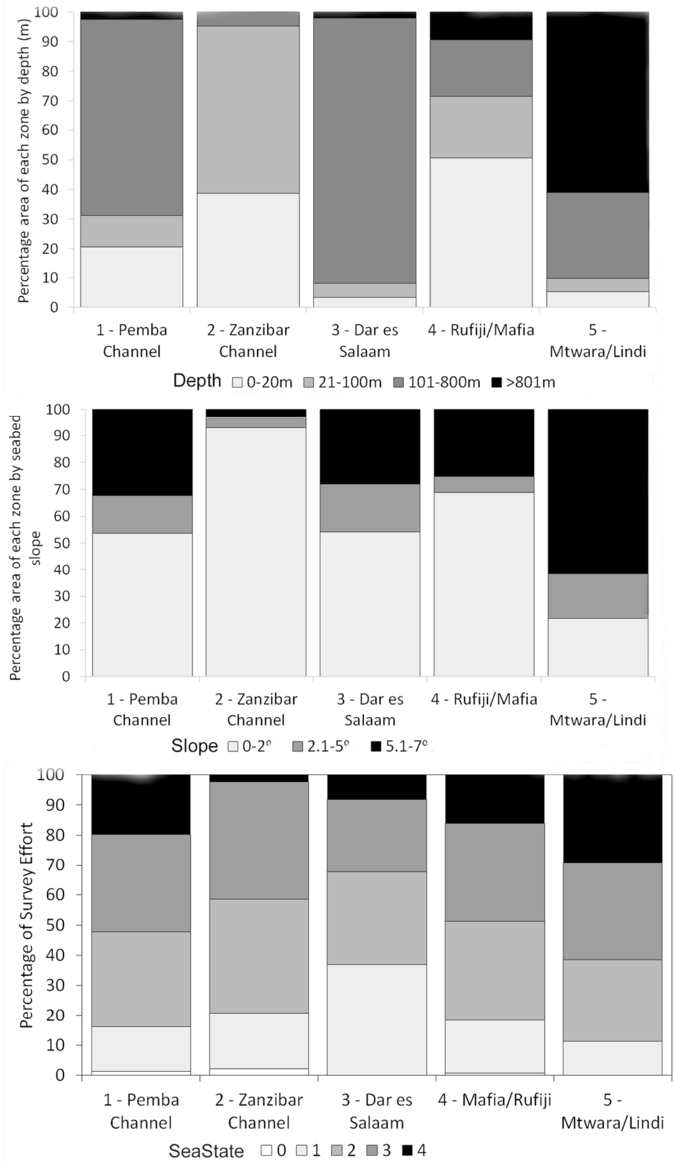
951

952



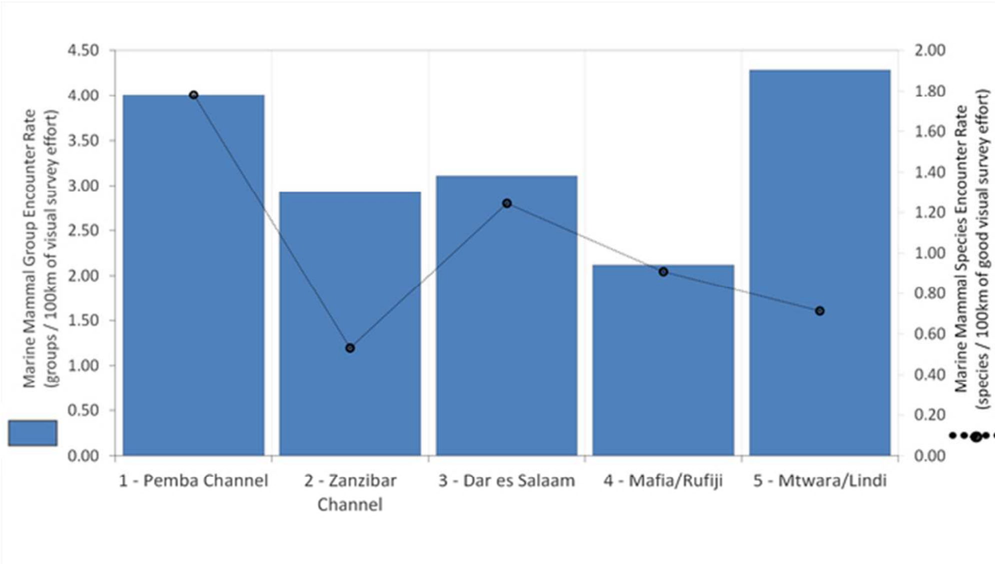
Boat survey track and the location of visual and acoustic marine mammal group detections made during the vessel-based cetacean survey of the entire coast of Tanzania conducted between March 4th and April 6th 2015.

210x311mm (300 x 300 DPI)



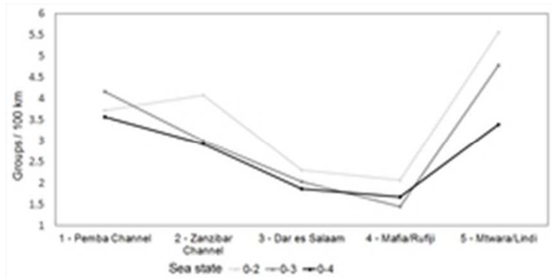
Summary of depth and slope habitat, and survey effort by sea state in each zone

115x205mm (300 x 300 DPI)



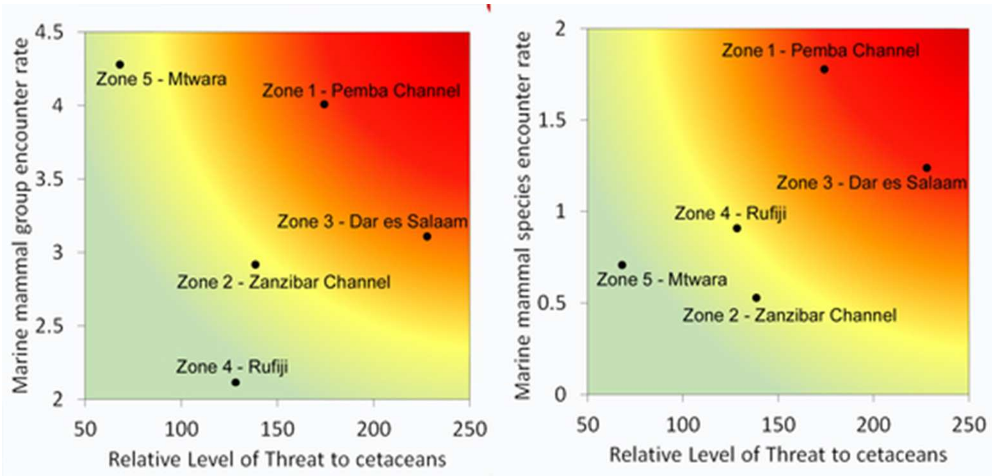
Marine mammal group and species encounter rates along the coast of Tanzania

58x33mm (300 x 300 DPI)



Comparison of cetacean encounter rate in each zone by sea state

23x11mm (300 x 300 DPI)



Relative cetacean encounter rate and relative cetacean diversity plotted against relative level of threat to cetaceans due to human activities in different zones in Tanzania.

46x22mm (300 x 300 DPI)