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Defining hotspots for toothed cetaceans involved in pelagic longline fishery depredation in the western Indian Ocean: a preliminary approach

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Abstract

False killer whale (*Pseudorca crassidens*), short-finned pilot whale (*Globicephala macrorhynchus*) and Risso's dolphin (*Grampus griseus*) are the known cetacean species involved in pelagic longline depredation in the tropical and subtropical waters of the western Indian Ocean. In order to better understand interactions between these cetaceans and fisheries, it is crucial to investigate the spatial distribution, density and habitat preferences of these species. A review of the literature (published from 1973 to 2011) noted 500 presence sightings (*P.crassidens* 219, *Globicephala macrorhynchus* 108, *Grampus griseus* 173), resulting from ~1,991,112 kilometres of survey effort. Data were compiled for the western Indian Ocean region (IUCN region 12) using two approaches, those being the presence-only IUCN recommended α-hull and widely used density kernel. The study observed that although both methods utilised fundamentally different approaches there was observed a significant correlation between increasing mean regional density and the increasing mean-ranked occurrence of species presence within the region. The main hotspots for the three species investigated were located around the Seychelles. For false killer whales, highest densities were identified throughout the Mozambique Channel and off NE Madagascar. Risso's dolphin highest densities were identified off the Seychelles, in the central and southern Mozambique Channel.

Introduction

Depredation is a common term for removal or damage of the catch (or bait) from fishing gear or cultured animals in stocking facilities due to interaction with predators, mainly marine mammals and sharks (Nishida 2007). Depredation by predators on pelagic and bottom longlining is a global issue that can have negative impacts both for the species and the fishing industry (Rosa and Secchi 2007). False killer (*Pseudorca crassidens*) and short-finned pilot whales (*Globicephala macrorhynchus*) are the known cetacean species involved in depredation in the tropical waters of the SWIO, while the killer whale (*Orcinus orca*) is involved in depredation events off South Africa (Petersen and Williams 2007). In addition, longline fishermen frequently report Risso's dolphin (*Grampus griseus*) as responsible of bait depredation, particularly in the Mozambique Channel (Kiszka 2012). Previous observations on depredation related this phenomenon with the specific features of bottom topography such as seamounts, shoals and semi-closed sea areas. Although cetacean depredation is sporadic, its impact is high in the catch of the fishing industry. The magnitude of the depredation is poorly understood; furthermore available data is lacking to determine whether there are population level effects from injury and mortality induced by incidental entanglement (Rosa and Secchi 2007). In the western Indian Ocean, toothed cetacean depredation is particularly high for the swordfish fishery off the Seychelles (Rabearisoa *et al.* 2007). To date, no long-term solution has been found to reduce depredation between toothed cetaceans and longline fisheries, including the use of acoustic deterrent devices. Recently, depredation mitigation devices have been designed and experimentally tested off the Seychelles (Rabearisoa *et al.* 2012), but their efficiency seems to be limited.

In order to better understand depredation, it is critical to collect information on the ecology of species involved, particularly on their spatial and temporal distribution, habitat preferences and population density. Indeed, managing depredation may be improved, at least partially, in avoiding areas and habitats where the involved cetacean species involved mostly occur. In the western Indian Ocean, very limited information exists on the distribution, abundance and habitat characteristics of cetaceans. This region contains a globally important diversity of cetaceans with up to 33 species recorded including 16 delphinids (Kiszka *et al.* 2009). However, despite this diversity, the presence of important populations of cetaceans (such as critically endangered blue whales *Balaenoptera musculus*) and high levels of interactions between cetaceans and fisheries (both oceanic and artisanal; Kiszka *et al.* 2008), little is known regarding the ecology, spatial distribution, stock identity and abundance of cetaceans, with very few extensive region-wide survey campaigns conducted (Elwen *et al.* 2011). The majority of those studies conducted have focused on continental coastal waters as well as the islands within the eastern reaches of the SWIO, such as off La Réunion (Dulau-Drouot *et al.* 2008), Zanzibar (e.g. Stensland *et al.* 2006) and Mayotte (e.g. Kiszka *et al.* 2011).
In the frame of a recent project aiming to identify major cetacean habitats and densities in the Southern Hemisphere (conducted by the Whale and Dolphin Conservation Society, UK), we analysed the spatial distribution of toothed cetaceans involved in pelagic longline depredation in the western Indian Ocean (IUCN- World Commission on Protected Areas (WCPA) Marine Region 12), especially *Pseudorca crassidens*, *Globicephala macrorhynchus* and *Grampus griseus*. Two approaches using available sighting data (published or grey) were used, including the use of species presence occurrence (α-hulls) and effort-adjusted relative abundance (kernel densities).

Materials and Methods

To address the need for determining suitable analytical approaches available for assessing cetaceans involved in depredation, a region wide meta-analysis of published presence sightings and spatially explicit density estimates was conducted for cetaceans surveyed within the IUCN-WCPA East African Marine Region, hence forth referred to as 'Marine Region 12'. After a-review of the literature a total of 37 publications (published between 1960 and 2011) were available for meta-analysis, with noted 500 presence sightings (*P.crassidens* 219, *Globicephala macrorhynchus* 108, *Grampus griseus* 173), presence sightings, resulting from ~1,991,112 kilometres of survey search effort.
The next two approaches, those being the presence-only IUCN recommended a-hull (for the assessment of species range, occurrence and occupancy conservation criteria), and the widely used kernel density (for estimation distribution and spatial abundance) were chosen for comparison because of their relatively simple, yet statistically robust, nature concerning differing data sources and the fundamental difference in their design (non-effort versus effort-corrected). Each of these approaches are summarised below.

a-hull

For many species and regions of the world the only data available for large-scale assessment are species presence records, resulting from opportunistic records, sightings surveys and museum collections. The previous method standard, 'convex hulls', have been replaced with the more robust 'α-hulls', due to the reduction in bias from spatial and sampling errors (e.g. evenness of sampling effort, sample sizes) (Okabe *et al.* 2000). Additionally the advantages of α-hulls are their ability to provide a more detailed description of the species habitat shape, breaking the hull into many discreet hulls when it spans potentially uninhabitable regions (Burgman and Fox 2003). Steps required when constructing an α-hull around a given species presence (Burgman and Fox 2003) is to make a Delauney triangulation of the points (sightings) in a sample (using ArcGIS Release 10, Environmental Systems Research Institute ESRI). The triangulation is created by drawing lines joining the points, constrained so that no lines intersect between points (O'Rourke 1998). All lines measured that are longer than a multiple (α) of the average line length were deleted. The value of α can be chosen with a required level of resolution in mind. The smaller the value of α, the finer the resolution of the hull is. The IUCN guidelines (2009) recommend an α of 2 times the average line length. This process results in the deletion of lines joining points that are relatively distant, the space between which is unlikely to represent good habitat, the outer surface of this new shape being the complete α-hull. Optionally the varying the value of α between zero (finest level of resolution, i.e. a set of discrete points in space) and infinity (coarsest level of resolution, i.e. a convex hull) generates different configurations of the hull, and perhaps provides a more reliable estimate of habitat extent when the shape of the range is irregular (Burgman and Fox 2003).

To represent these varying degrees of cetacean distribution in the study presented, the now completed α-hull polygons, constructed from the triangulation of each sighting, were next divided into four relative levels of regional occurrence. These included a zero occupancy level (area of no regional occurrence), calculated at the recommended threshold of double the mean triangulated perimeter length and the maximum perimeter calculated for the completed α-hull, removing those sections of the α-hull populated by potential outliers and sightings records in unsuitable habitat, and thereby not representative of the species regional distribution (Burgman and Fox 2003). The remaining sections of the α-hull were divided into three ranks of relative occurrence using a Natural Jenks classification (in ArcMap 10) of the mesh's perimeter values ranging between the recommended threshold (after IUCN 2009) and the minimum triangulated perimeter length. Therefore the now observed three ranks of occurrence were assigned relative classifications of *Low*, *Medium* and *High*, describing the normal distribution of the species presence records observed within the estimated species range.

Kernel Density

As a species' occupancy varies over a given geographical range, the characterisation and quantification of spatial abundance can provide critical insight into the habitat use and population structure of that species (Fortin *et al.* 2005). In particular kernel density estimators (KDEs) have become increasingly popular for the spatial analysis of species home ranges, distribution and abundance (Freiberg 2007). Reasons for this widespread use across a range of studies include ease of use and attractive statistical properties (e.g. true mathematical probability density functions), ensuring results are more than heuristic graphical representations, making them competitive against other spatial interpolation procedures such as kriging (Fortin *et al.* 2005). For adequate application to the spatially analysis of cetaceans two primary considerations should be taken into account which include sampling rates, duration and optimal smoothing parameters used (Freiberg 2007). Firstly it is considered that studies of longest duration are more preferable over temporally-fixed survey campaigns, to characterise long-term space use when location data are highly auto-correlated (high sampling rate over limited areas of survey). Secondly though smoothing of population density may serve to increase precision this can often be at the expense of increased bias if the problems of spatially auto-correlated data cannot be overcome or accounted for. However, despite these considerations KDEs with typical methods of smoothing parameters are likely to provide competitive distribution and population density estimates for species (Fortin *et al.* 2005, Freiberg 2007).

In our study, published cetacean spatial abundance within Marine Region 12 were collated within a meta-data table of effort coverage (distance surveyed or area of effort extent in kilometres) and population density (relative population size or animals per distance effort in kilometres) were described from the original figures presented within the published peer-reviewed literature. This collated meta-data was then spatially displayed within a set of geo-rectified shape files managed within a GIS (ArcMap 10) and spatially joined to the presence sightings of those cetacean species (mean sightings rate) requiring KDE. The kernel density for each of the species sightings points, now containing the relevant mean population statistic, was calculated and an optimal output grid cell extent of 50km^2 preferred, though a variable grid extent was selected which would select the most optimal cell size (ranging from 25-100km^2) based on the number of presence samples and adjoining spatial coverage, in order to increase precision yet maintaining potential bias at a minimum (Freiberg 2007). Therefore the maximum search distance for the calculation of Kernels between related points, at a minimum of three times the grid cell extent, also varied ranging from 75-300km (Euclidean distance).

Results

Kernel density and occurrence estimates

Findings of the study indicated that though both methods utilised fundamentally different statistical approaches and data types, there was observed a sufficient similarity in the increasing ratio of the calculated distribution and areas of highest ranked occurrence or density observed those cetaceans investigated. These patterns were further investigated using a Pearson's correlation coefficient (using R code after Borghers and Wessa 2012) to determine the presence of a significant positive correlation between increasing mean estimated kernel density and ranked occurrence within Marine Region 12 ($C=0.64$ $df=13$ $p=0.005$). This correlation could also be observed in the spatially mapped regional density and occurrence measures estimated. Though certain differences in overall range and aggregation extent could be observed, overlapping hotspots in occurrence and density were easily discernible (Figures 1 to 3). In particular noted areas of persistent overlap included extensive areas south of Madagascar and the Seychelles and Mascarene Islands.

Therefore it was considered that even though the effort-adjusted kernel density estimate did provide the most valuable resolution of spatially detailed distribution information, the presence only ɑ-hulls provided statically correlated, and therefore sufficiently similar, outputs for initial mapping of hotspot areas, of likely high density, for application to region-wide assessments and strategic management planning. Furthermore, in certain cases the ɑ-hulls were able, due to a lack of constraint to survey effort, to identify hotspots in occurrence from presence sightings which were missed by the kernel density estimation. However, caution must be considered in any interpretation of potential correlated density information from the non-effort corrected ɑ-hulls, due to the observed tendency of this approach to potentially over estimate the spatial extent of underlying detectable species density.

Area of Occupancy (AOO) and Extent of Occurrence (EOO)
As recommended by the IUCN guidelines and criteria (2001), the AOO and EOO of cetacean species within Marine Region 12 were calculated using the completed α-hulls as used in the above comparison. These were done to help provide further region-wide information for the additional conservation assessment of these species but also to further compare and relate the properties of AOO and EOO to the potentially positive correlations between density and species ranked occurrence. Results of the AOO and EOO measures calculated per species were observed to correlate at a region-wide scale, with estimated EOO increasing with recorded increased AOO. These patterns were further investigated using a Pearson's correlation coefficient (using R code after Borghers and Wessa 2012) to determine the presence of a significant positive correlation between increasing AOO and EOO within Marine Region 12 (C=0.53 df=15 p=0.014).

Discussion

Methodological considerations
Two important findings regarding spatial methodologies were found from the meta-analysis conducted. Firstly that though the effort-adjusted kernel density estimates did provide spatial information regarding distribution and abundance of a greater resolution, the presence-only α-hulls provided statically correlated, and therefore sufficiently similar, outputs for initial mapping of hotspot areas, of likely high density. Secondly that the AOO and EOO measures, as recommended by the IUCN, for species were observed to correlate at a region-wide scale, with estimated EOO increasing with recorded increased AOO. These findings are considered important and highly relevant in the light of increasing concern regarding cetacean conservation assessments mandates on monitoring and regional marine spatial management (Hooker and Gerber 2004, Fortin *et al.* 2005, Hoyt 2012). However, a number of important considerations should be taken into account before further application of the study findings or on further direction in methodological development.

Hotspots for toothed cetaceans involved in depredation
For the first time, this preliminary study highlights the probable existence of density hotspots for false killer whales, short-finned pilot whales and Risso's dolphins in the western Indian Ocean. For all species, it appears that the Seychelles, the Mozambique Channel and, at a lesser extent, the Mascarene Islands constitute major areas for these species. These areas also constitute major pelagic longline fishing areas in the western Indian Ocean. Therefore, our study clearly underlines the probably high level of spatial interactions between these cetacean species and pelagic longline fisheries. In order to better understand factors driving toothed cetacean density in those areas, it is now needed to link physiographical and oceanographic features with toothed cetacean density. Linking pelagic longline fishing effort and toothed cetacean habitat would be also important to better understand interactions between those fisheries and toothed cetaceans.

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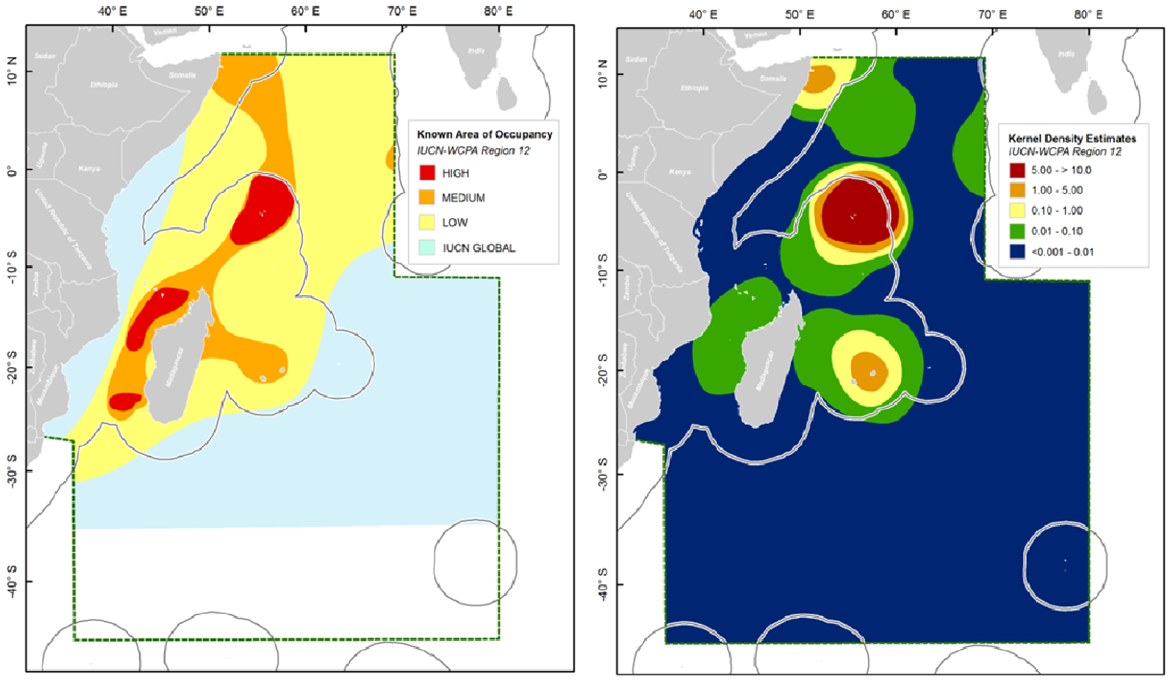

Figure 1: Rank occurrence and Kernel density (sightings/1000km) of short-finned pilot whales (*Globicephala macrorhynchus*) in the western Indian Ocean

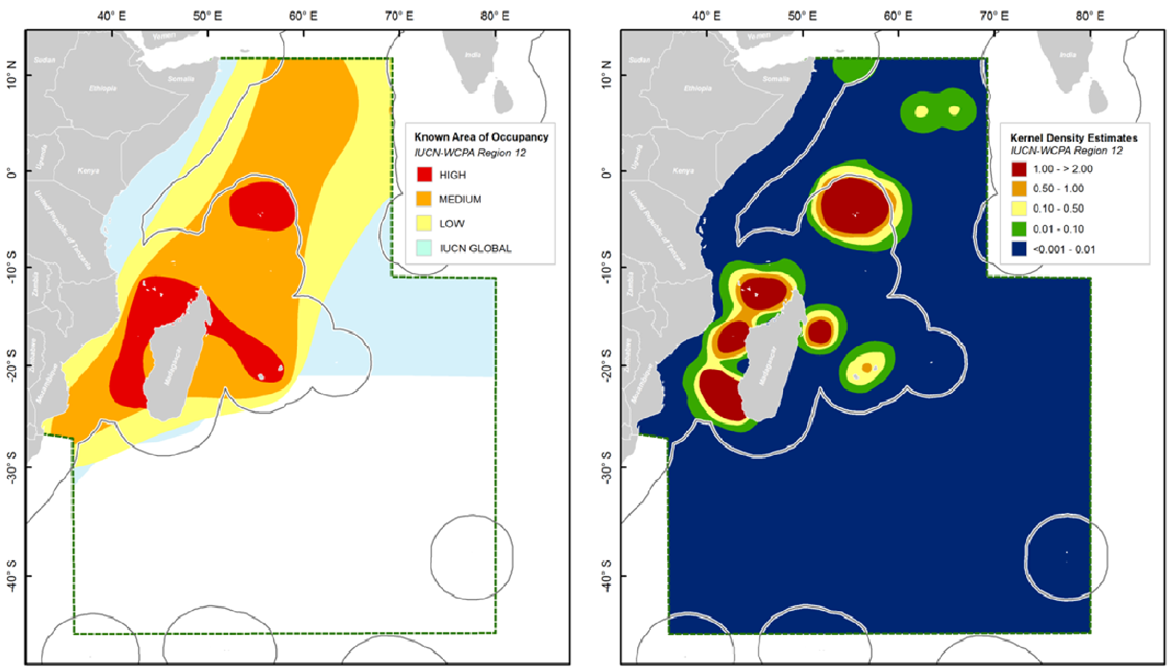

Figure 2: Rank occurrence and Kernel density (sightings/1000km) of false killer whales (*Pseudorca crassidens*) in the western Indian Ocean

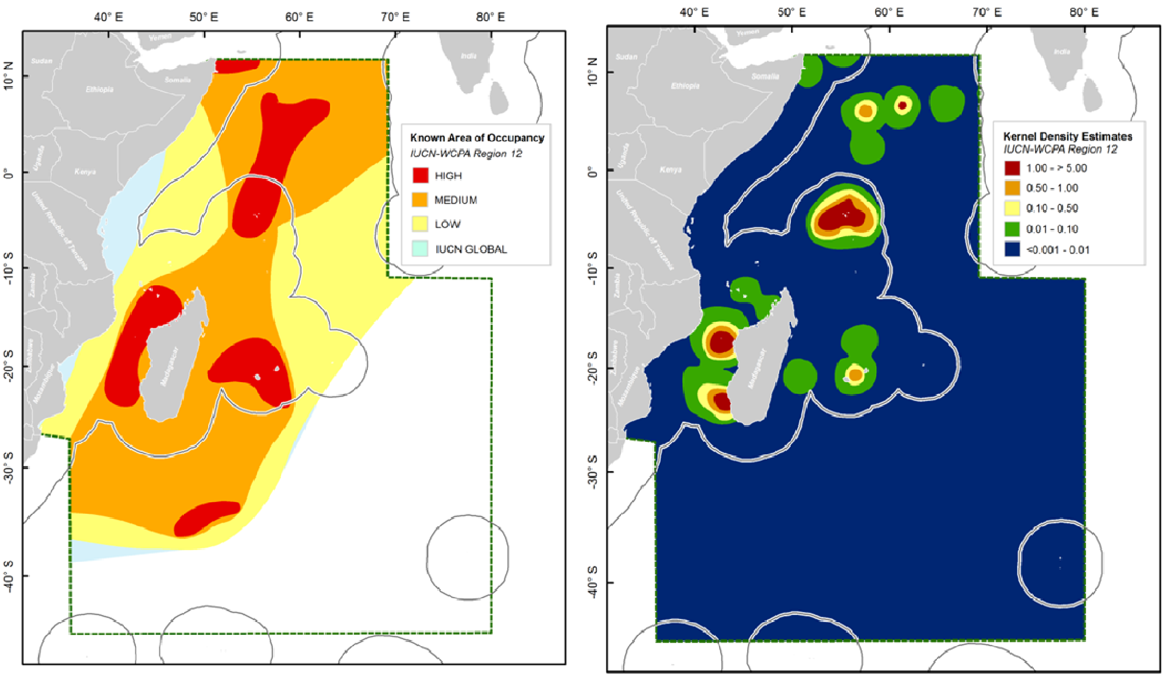

Figure 3: Rank occurrence and Kernel density (sightings/1000km) of Risso's dolphins (*Grampus griseus*) in the western Indian Ocean