2019

Complex transboundary movements of marine megafauna in the Western Indian Ocean

Amanda N. Barkley

Matthew Gollock

Melita Samoilys

Fiona Llewellyn

Mahmood Shivji

See next page for additional authors

This is a pre-publication author manuscript of the final, published article.

Citation/Publisher Attribution

Barkley, A.N., Gollock, M., Samoilys, M., Llewellyn, F., Shivji, M., Wetherbee, B. and Hussey, N.E. (2019), Complex transboundary movements of marine megafauna in the Western Indian Ocean. Anim Conserv, 22: 420-431. https://doi.org/10.1111/acv.12493

Available at: https://doi.org/10.1111/acv.12493

Authors

Amanda N. Barkley, Matthew Gollock, Melita Samoilys, Fiona Llewellyn, Mahmood Shivji, Bradley M. Wetherbee, and Nigel E. Hussey

Complex transboundary movements of marine megafauna in the Western Indian Ocean

Amanda N. Barkley[1], Matthew Gollock[2], Melita Samoilys[3], Fiona Llewellyn[2], Mahmood Shivji[4], Bradley Wetherbee[4,5], Nigel E. Hussey[1*]

[1] University of Windsor, Biological Sciences, Windsor, Ontario, Canada. 401 Sunset Ave. N9B 3P4

[2] Zoological Society of London, Regent's Park, London, England

[3] Coastal Oceans Research and Development – Indian Ocean, Mombasa, Kenya

[4] Guy Harvey Research Institute and Department of Biological Sciences, Nova Southeastern University, Fort Lauderdale, Florida, USA

[5] University of Rhode Island, Biological Sciences, College of Environment and Life Sciences, Kingston, Rhode Island, USA

*Corresponding author: nehussey@uwindsor.ca

Running title: Transboundary movements in the WIO

Abstract

Transboundary marine species have an increased risk of overexploitation as management regimes and enforcement can vary among states. The complex geopolitical layout of exclusive economic zones (EEZs) in the Western Indian Ocean (WIO) introduces the potential for migratory species to cross multiple boundaries, consequently a lack of scientific data could complicate regional management. In the current study we highlight both the relative lack of spatial data available in the WIO, and the prevalence of transboundary movements in those species that have been studied. Five tiger sharks (*Galeocerdo cuvier*) were tracked with near real time positioning (SPOT) satellite tags to determine individual shark movements relative to EEZs within the WIO. Concurrently, a literature search was performed to identify all satellite telemetry studies conducted to date in the WIO for marine megafunal species, and the results compared to global satellite telemetry effort. Finally, the satellite tracks of all marine species monitored in the WIO were extracted and digitized to examine the scale of transboundary movements that occur in the region. Tiger sharks exhibited both coastal and oceanic movements, with one individual crossing a total of eight EEZs. Satellite telemetry effort in the WIO has not matched the global increase, with only 4.9% of global studies occurring in the region. Species in the WIO remained within the EEZ in which they were tagged in only three studies, while all other species demonstrated some level of transboundary movement. This study demonstrates the lack of spatial data available for informed regional management in an area where transboundary movements by marine species are highly prevalent. Without more dedicated funding and research, the rich biodiversity of the WIO is at risk of overexploitation from the diverse threats present within the various political regions.

Keywords: Western Indian Ocean, spatial management, tiger sharks, exclusive economic zones, satellite tags, telemetry, tracking, transboundary, migration

Introduction

The establishment of marine boundaries is necessary for resource allocation among states and stakeholders and are used frequently for conservation efforts (Song *et al.*, 2017). One of the most prominent examples of marine boundaries are exclusive economic zones (EEZs) in which a state is given sovereign rights for the exploitation and conservation of the natural resources contained within. However, geopolitical boundaries such as EEZs, with varying policies and governance, rarely reflect the natural boundaries of the biological resources they contain, leading to an increased risk of over-exploitation when international agreements or basic knowledge on species distributions are lacking (Folke, 2007; McWhinnie, 2009). In particular, the development of effective co-management for highly migratory fish stocks and bycatch species among states can be severely hindered by the often complex life histories of these animals that impede research, resulting in a lack of scientific data to support management (Lascelles *et al.*, 2014).

Over the past two decades, the ability to monitor and manage mobile marine species has radically improved with the advent and technological advances of telemetry (Cooke *et al*., 2004; Hussey *et al*., 2015; Hays *et al*., 2016). Specifically, satellite tracking has enabled the identification of hotspot and aggregation sites (Block *et al*., 2011), elucidated spatial and temporal limits of migration corridors (Morreale *et al*., 1996) and identified philopatric behaviour of elusive megafauna (Bonfil *et al*., 2005; Jorgensen *et al*., 2009; Werry *et al*., 2014). With recognition of inter-annual variation in environmental conditions that regulate animal movements, telemetry data are also now guiding flexible and adaptive fisheries management approaches and investigating how ongoing climate change will shape species distributions (McMahon & Hays, 2006; Maxwell *et al*., 2015; Crossin *et al*., 2017). Moreover, these satellite tracking data can be used to direct the designation and test the effectiveness of boundaries established for conservation such as marine protected areas (MPAs) as well as determine the extent of movement within transboundary fish stocks with regards to EEZs and international waters (Ballard *et al*., 2012; Howey-Jordan *et al*., 2013; White *et al*., 2017). To date, however, it would appear there is a bias in the focus of global satellite telemetry efforts towards more developed countries (Hussey *et al*., 2015), limiting their potential for management in less developed areas that urgently require monitoring of both commercially important and imperilled species.

The Western Indian Ocean (WIO), a distinct biogeographic province (Spalding *et al*., 2007; Obura, Church & Gabrié, 2012), and a significant portion of FAO area 51 (FAO, 2017), represents a region that is telemetry data poor. While there are mounting concerns over the status of WIO fisheries regarding both the sustainability of targeted fisheries as well as bycatch of large predators including elasmobranchs (Robinson & Sauer, 2013; Sumaila *et al*., 2014; Samoilys *et al*., 2017; WCS *in press*), there is a significant lack of data to delimit species distributions and core habitats to aid in the development of effective MPAs and co-management efforts among states. The importance of the WIO as a global biodiversity hotspot (Obura *et al*., 2012; Worm & Branch, 2012), combined with the complex geopolitical layout of its numerous EEZs suggests a need for increased analysis into the distribution of the diverse mobile fauna in the region.

Tiger sharks (*Galeocerdo cuvier*) are widely distributed across the tropics and display complex migratory behaviours such as partial migration whereby some individuals remain resident in coastal waters while others undertake long-distance migrations (Papastamatiou *et al*., 2013; Holmes *et al*., 2014). In the nearshore environment of Reunion Island in the WIO, acoustically-tagged tiger sharks display sex-dependent seasonal fluctuations in abundance, however the extent of their offshore movements remains unknown (Blaison *et al*., 2015). These large, apex predators likely play an important top down role in marine ecosystems (Navia, Cortés & Mejía-Falla, 2010), yet the presence of threats such as commercial shark fishing and localized shark control programs have the potential to impact tiger shark populations (Dudley & Simpfendorfer 2006; Blaison *et al.*, 2015; Samoilys *et al*., 2015), making them an ideal focal species to highlight the complexity of management in the WIO.

In the current study, we use novel tracks of tiger sharks to demonstrate issues facing the management of migratory megafauna in the WIO. The objectives of the study were to (i) summarize satellite telemetry monitoring undertaken to date in the WIO and compare to the scale of global monitoring, (ii) use satellite tracks of tiger sharks to show complex regional transboundary movements in the WIO and (iii) synthesize all satellite telemetry studies in the WIO to date, to determine if large-scale movements of megafauna commonly cross the region's numerous geopolitical boundaries. We sought to assess the relative needs and issues around managing mobile species in the WIO and highlight the requirement for investment in research for the WIO's developing countries to improve regional scale management.

Materials and Methods

Literature review

All global satellite telemetry studies undertaken up to December 2013 were accessed from Hussey *et al*. (2015) and updated for the WIO up to December 2016. In brief, telemetry studies were identified using an ISI Web of Science search with the search term 'satellite', 'PSAT' and 'SPOT' followed by each of the words, 'telemetry', 'tracking' and 'tag'. In addition, any studies cited in the identified publications, but not highlighted in the original search were included. The cumulative number of global satellite telemetry studies over time was then calculated and compared with those undertaken specifically in the WIO region. The countries of the WIO are defined as the ten member states of the Nairobi Convention (2010) and span from Somalia to South Africa on the mainland eastern African coast, and extend to the island states of Seychelles, Comoros, Madagascar, Mauritius and include the French Southern Territories.

Satellite telemetry tracking of tiger sharks

Study location, capture and tag attachment

Tiger sharks were caught on the Watamu Bank (3°24.00'S, 40°08.00'E), northern Kenya. The bank is approximately 1.6 km long with depths between 50 and 100 m that drop off into deeper surrounding waters. Sharks were caught using standard recreational fishing gear (rod and reel) with yellowfin tuna as bait. Once hooked, sharks were guided in next to the boat and a wire strap passed over the head and body to secure the caudal fin. A lifting strap was placed around the mid-section, posterior to the pectoral fins and anterior to the dorsal fin to secure the mid-section of the animal. The rear platform of the boat was partially submerged allowing irrigation of the gills with seawater as the boat drifted. Length measurements, fork and total length (FL and TL; cm) were recorded as the distance from the tip of the snout to the centre of the caudal keel and as a direct line to the top of the caudal fin, respectively. Sex was recorded based on the presence (male) or absence (female) of claspers.

To track the horizontal movements of tiger sharks, SPOT5 tags (models 257A and 258A with battery life of 980 and 220 days, respectively; Wildlife computers Ltd, Redmond, Seattle) were attached to the dorsal fin. To attach the tags, a template was held against the fin and four holes drilled using a hand held electric drill. The SPOT5 tag was then attached by inserting a rod through the fin and securing the tag with washers to the rods by inserting two screws into either end. Once the tag was secured, the straps were removed, the shark held by the caudal fin, and released once strokes were powerful enough to propel the animal forward. Its post release behaviour was then monitored from the surface and with a GoPro camera held underwater by the side of the boat. All animal handling was approved under the animal care protocol for the Zoological Society of London.

Data processing and analyses

For all SPOT tag data, ARGOS location estimates were first screened to remove invalid positions (primarily location class Z or 0). The geolocations were then filtered using a Bayesian state-space model through the package '*bsam*' in R (R core team 2018) and interpolated into regular time intervals of 24 hours. The 24h position estimates were plotted for each individual shark using GIS software (ArcGIS 10.2.2, esri 2014) and overlaid on regional exclusive economic zones (EEZs) to determine the relative number of days spent within each EEZ and international waters. EEZ boundaries were sourced from the Flanders Marine Institute (2016), cognisant that some of these are disputed (Okonkwo, 2017). The relative number of days each shark spent in different EEZs was calculated as the number of daily positions located within each EEZ divided by the total number of tracking days for that individual. The total distance travelled by each shark was also calculated in ArcGIS as the cumulative distance between each daily position.

Synthesis of satellite telemetry studies in the WIO

To examine spatial movement patterns of all marine species equipped with satellite tags in the WIO relative to geopolitical regions and associated EEZs, animal tracks from published papers were digitized in ArcGIS. Map images extracted from published papers were georeferenced by matching coastlines within the image to a shapefile with known geographic coordinates. Animal tracks were then traced with points or lines where appropriate. Digitization resulted in a certain level of distortion of the track data; however, tracks were accurate enough for the broad-scale analysis of presence within an EEZ. In many cases, separating the tracks of individual animals of the same species per publication was not possible; therefore, data were combined at the species level. Studies that re-used telemetry data, or which contained both novel and shared data were combined into one reference track, while studies examining multiple species were separated by species. Finally, studies that manipulated the movements of animals (for example, through translocation to a different area prior to release) as well as reviews were omitted from the analysis.

Results

Literature review

Of the total 597 global satellite telemetry studies (Hussey *et al*., 2015), only 28 (4.7%) occurred in the WIO (Fig. 1), with the majority of these (17; 60.7% of WIO total) undertaken off South Africa (a list of data sources can be found in Appendix 1). When considering species tagged, 15 (53.6%) monitored the movements of turtles (green [*Chelonia mydas*], leatherback [*Dermochelys coriacea*] and loggerhead [*Caretta caretta*]), however these studies often re-used the same telemetry data for different applications, while others focused on turtle behaviour following displacement (Table 1). Additional species where multiple studies were conducted included whale sharks (*Rhincodon typus*: 4; 14.3%) tagged off Seychelles, Mozambique and South Africa as well as southern right whales (*Eubalaena australis*: 2; 7.1%; Fig. 2) tagged at three independent sites off South Africa. Also of note, sample sizes within papers were typically low, with 13 instances where five or less animals of the same species were tagged (Table 1). Lastly, the study by Roquet *et al.,* (2014) used satellite-tracked elephant seals (*Mirounga leonine*) to obtain hydrographic profiles off the coast of South Africa but was not included in the following analysis as movement data could not be extracted.

Tiger shark satellite telemetry

Five tiger sharks ranging in total length from 280-380 cm TL were equipped with SPOT5 satellite tags off northern Kenya. Of the five sharks, four successfully transmitted geolocation data to ARGOS. The average time between transmissions was 0.42 ± 1.4 days, suggesting that daily positions from the SSM were appropriate (Block *et al*., 2011). There was only one instance where the time between transmissions was >20 days (near the end of TS04's transmissions), however given that the locations before and after this time gap were both within the Tanzania EEZ, it was not split. Track periods for three tiger sharks were less than three months while one individual was monitored for five months.

Sharks TS01 and TS02 spent their entire track time (44 and 35 days respectively) within the Kenyan EEZ (Figs. 3 & 4), while TS04 moved along the coast transiting back and forth between Kenya (number of days [% of total track days]: 41 [17%]) and Tanzania (194 [83%], Figs. 3 & 4). Shark TS03 moved offshore, spending time in seven different EEZs: Kenya (1 [2%]; where the shark was tagged), Comoros (12 [18%]), Seychelles (5 [8%]), Iles Eparses (14 [21%]) and Mayotte (10 [15%]; both French southern territories), Mozambique (3 [5%]) and Madagascar (17 [26%]), as well as international water (4 [6%], Figs. 3 & 4).

Satellite telemetry for the Western Indian Ocean

Synthesized satellite telemetry studies for the WIO resulted in data from 20 references (defined as single tracks; see methods) for 10 species (Figs. 2 & 5). Of these 20 tracks, there were only three instances (15%) where the animals stayed within the EEZ where they were tagged and released, two of which were turtles (green and loggerhead; Fig. 5) and the third the sand tiger shark (*Carcharias taurus*; Fig. 5). All other species tracks showed movements away from their tagging EEZ into those of neighbouring countries or international waters (Figs. 2 & 5). The number of transboundary movements was highest for marine mammals (number of EEZs ± SD; 6 ± 2) and similar for elasmobranchs and reptiles (4 ± 3 and 3 ± 4, respectively).

Discussion

The WIO is characterized by a complex geopolitical layout of states with multiple marine boundaries that intersect an ocean rich in species biodiversity. This complexity presents a challenge for management, as political boundaries do not reflect the distributions of highly mobile marine species. Given the limited number of studies undertaken to date, satellite telemetry effort in the WIO does not reflect the scientific knowledge required on species movements, highlighting an urgent call for invested effort in this data-poor region. Synthesized tracking data as well as novel satellite tracks of tiger sharks off Kenya, highlight how megafauna in the WIO cross multiple EEZs, making conservation efforts difficult in the face of varying management and enforcement regimes.

Since the advent of satellite telemetry, there has been an exponential increase in its application to understand aquatic species globally (Hussey *et al*., 2015). Studies occur across diverse water bodies, including remote regions such as the poles (Dalla Rosa *et al*., 2008; Fisk, Lydersen & Kovacs, 2012) and the deep sea (Peklova *et al*., 2012), but areas of the developing world are lacking. Considering only 2% of global telemetry studies have occurred in the WIO, with its rich species diversity and endemism (Allen, 2008; Wafar *et al*., 2011; Obura *et al*., 2012), the need for more dedicated research and funding is apparent. Marine biodiversity estimates in the southern WIO are some of the highest globally (Tittensor *et al.*, 2010), where 161 of these species have been identified as threatened (defined as species that are critically endangered, endangered or vulnerable on the IUCN red list; Richmond, 2015). Of particular note, the WIO is a global hotspot for oceanic taxa (Tittensor *et al*., 2010), highlighting the urgent need for regional information on species' spatial ecology. Increasingly, studies focused on animal movements to determine stock distribution have led to changes in management and improved conservation regimes (Kaunda-Arara & Rose, 2004; Espinoza *et al*., 2015; Hussey *et al*., 2017; *reviewed in* Crossin *et al*., 2017). This demonstrates the benefit of investing in telemetry to improve our ability to develop meaningful, practical and beneficial legislation.

Very little is currently known about the movements of tiger sharks in the WIO and population indices are contrasting, with one study off South Africa suggesting numbers may be increasing (Dudley & Simpfendorfer 2006), while a failure to record tiger sharks on coral atolls off East Africa was attributed to fishing and bycatch (Clarke, Lea & Ormond, 2012). Without even a basic understanding of tiger shark spatial ecology in the WIO, localized population estimates may be ineffective in describing accurate population trends as they may target animals of only a certain life stage, or they may be targeting mixed populations whereby one is healthy while the other is experiencing potentially harmful declines that are masked in the survey (Cooke *et al.*, 2016). In the present study, the two sharks that were tracked for >60 days exhibited a divide in spatial use, with one remaining along the coast and continental shelf, while the second moved into the open ocean, similar to movements described in both Australia and the Hawaiian Islands (Papastamatiou *et al*., 2013; Holmes *et al*., 2014). Tiger sharks recently tracked off South Africa also demonstrated a mix of coastal and oceanic movements, however coastal movements were most prominent with relatively restricted spatial use (Daly *et al*., 2018). The presence of tiger sharks in extremely shallow waters along the coast of Kenya as well as over the deep waters of the high seas highlights their vulnerability to multiple fishing operations. Typically, small-scale fisheries operate close to shore while larger, industrial vessels of predominantly foreign fleets exploit the offshore (Branch *et al*., 2002; Mora *et al*., 2009). The occurrence of tiger sharks in both regions suggests they are likely targets of intense artisanal fisheries as well as both the target and bycatch of commercial fleets. Although illegal fishing in the WIO may be declining (Agnew *et al*., 2009), overall fishing effort is increasing with concerns over under-reported catches (FAO, 2016) where large elasmobranchs such as the tiger shark may be targeted for the fin trade.

The loss of two satellite tags (TS 01 and TS 02) in the present study well before the expected life-span of the instruments could be a result of multiple factors. The tag model of these two differed from the others (257A vs. 258A), with a smaller housing and shorter battery life that may be more prone to device failure. Indeed, other studies have reported SPOT satellite tag failures on tiger sharks around or before 30 days (Heithaus *et al*., 2007; Meyer, Papastamatiou & Holland, 2010; reasons for failure reviewed in Hays *et al*., 2007). However, the area around Lamu, north of Watamu where the current study took place, was historically a shark fishing region (Marshall, 1998) and traditional practices have continued to this day, although catch rates have been in decline (Samoilys *et al*., 2015). The presence of sharks in these shallow, coastal waters prior to tag failure may suggest that the tag stopped transmitting as a result of fisheries capture. Artisanal fisheries target nearly all catchable species and monitoring of elasmobranch catch is limited or near non-existent so the true catch of these taxa in the region remain relatively unknown (Smale, 2008; Pauly, 2015; Robinson & Sauer, 2013; Samoilys *et al*., 2017).

The movements of tiger sharks in the present study highlights a common trend among telemetered species in the WIO: far-ranging species often cross multiple political boundaries. For example, one of the tagged tiger sharks travelled 4779 km and crossed into eight EEZs. Transboundary and highly migratory fish are at a greater risk of being overharvested because the status of shared stocks is difficult to determine (Bjørndal *et al*., 2000; McWhinnie, 2009; White & Costello, 2014), and spatial conservation efforts (such as MPAs) are often less effective than for sedentary species, especially with limited spatial data (West *et al*., 2009; Lascelles *et al*., 2014). Given policies for transboundary fish are required to be far-ranging, they inevitably impact a large and diverse group of stakeholders that might be less inclined to agree with, and adapt to, changes in management (Song *et al*., 2017). Even in instances where states are motivated to implement co-management regimes, variability in stability, prosperity, and institutional capacity can affect enforcement, ultimately resulting in a regional disparity in levels of protection. In the WIO there exists abundant legislation and policies for the protection of marine and coastal environments that scale from the local and/or state level, to regional and global inter-governmental institutions. One of the most prominent regional governmental partnerships is the Nairobi Convention, signed in 1985 which has been instrumental in laying the framework for the development of institutions, policies and legislation to protect the marine environment. However, the existence of these institutions does not immediately translate to environmental protection, as multiple transboundary issues have been identified, but have yet to be resolved due to the complex nature of addressing their root causes (UNEP/Nairobi Convention Secretariat and WIOMSA, 2009; Momanyi, 2015; Okonkwo, 2017). For example, social issues such as poverty and limited capacity to administer compliance activities contribute to habitat destruction, pollution, and unregulated fishing which in turn impact commercial and non-commercial marine species abundance (UNEP/Nairobi Convention Secretariat and WIOMSA, 2009; Samoilys *et al*., 2015). The plethora of governmental institutions can also negatively impact meaningful change when mandates are overlapping, contradictory, inconsistent, and/or poorly enforced (Momanyi, 2015). There are also EEZ boundary disagreements between neighbouring states, which have a direct impact on the marine environment (Okonkwo, 2017). Finally, a consistent and reoccurring theme in addressing transboundary resources in the WIO is the lack of scientific data to support and inform management, as regional institutions cannot implement effective governance without sound evidence to direct decision-making (UNEP/Nairobi Convention Secretariat and WIOMSA, 2009; Momanyi, 2015; Samoilys *et al*., 2015).

Although the number of studies investigating marine megafaunal movements in the WIO are limited, synthesized results demonstrate that significant regional cooperation will be needed to manage wide ranging species, while also highlighting cases where local MPAs may also be effective for species protection. For example, when considering localized management, inter-nesting loggerhead turtles remained close to shore, not only within the EEZ in which they were tagged, but also inside coastal reserves and MPAs (Harris *et al.*, 2015). However, juvenile loggerhead turtles tagged off Reunion Island crossed 13 EEZs demonstrating this species may be much more vulnerable in its early years (Dalleau *et al.*, 2014). Similarly, post-nesting green turtles tagged off St. Joseph Island in the Seychelles demonstrated relatively restricted foraging migrations, with genetic evidence suggesting a discreet population that would require local conservation efforts (Bourjea *et al.*, 2015). In contrast, green turtles tagged in Vamizi migrated through five EEZs to reach foraging grounds (Garnier *et al.*, 2012) highlighting intra species variation in behaviour of the same life stage. The final animal that showed residency within a single EEZ, the sand tiger shark, is considered a coastal shark that does not typically move offshore although it may range far distances along the coast (Dicken *et al.*, 2007, Smale *et al.*, 2012, Bansemer & Bennett 2011). For all the species in the present study that displayed some level of transboundary movements (>2 EEZs), 78% are considered threatened (as defined above). Although it is reasonable to assume that these studies were undertaken given concern for the conservation status of the study species, it is possible that many are threatened in part because of their long-distance and transboundary movements that expose individuals to multiple fishing operations and inconsistent management of critical habitats. While it is important to note that these studies are not standardized with respect to tag type and attachment method, age, sex or statistical techniques to process movement data, and that most studies have low sample sizes and a restricted number of tracking days, these synthesized data still highlight the scale of transboundary movements in the WIO.

Other biodiversity hotspots with high concentrations of regional boundaries, such as the central Indo-Pacific and Caribbean Sea, likely reflect similar trends as observed here in the WIO (see Harrison *et al*., 2018 for the Pacific Ocean). Telemetry data voids are often the result of limited funding available for marine conservation work in conjunction with limited capacity that hinders both scientific research and enforcement. However, new research in the WIO continues to become available (for example: Rohner *et al.*, 2018 and Daly *et al.*, 2018, published after the current meta-analysis cut-off date), suggesting that effort is being made to increase scientific knowledge in the region. Such studies are especially pertinent for the WIO to inform management as fisheries exploitation in both coastal and offshore waters are estimated to be approaching maximum harvest potential (FAO, 2016); an issue that is likely exacerbated by underreporting of artisanal catches (Jacquet *et al*., 2010). Moving forward, data voids on species distributions in developing regions of the world need to be addressed, with greater access to funding to promote development, self-management and appropriate species conservation strategies.

Acknowledgments

We are extremely grateful to Peter Darnborough and the fishing crew of the Alleycat for assistance with catching and tagging tiger sharks. We also wish to thank all the fishing operators in Watamu for their support of this tagging program and Roy Beale for support in the field. This paper is a contribution of ideasOTN, a synthesis committee from the Ocean Tracking Network (OTN). Research in Kenya was covered under Research Permit No. NACOSTI/P/18/08032/21763 to CORDIO East Africa, from the National Commission for Science, Technology and Innovation. Fieldwork was funded through Selfridges Project Ocean. NEH was funded by NSERC Discovery funds.

Appendices & Supplementary Material

Appendix 1: Data sources for satellite tracked animals in the Western Indian Ocean.

References

Agnew, D. J., Pearce, J., Pramod, G., Peatman, T., Watson, R., Beddington, J. R., & Pitcher, T. J. (2009). Estimating the worldwide extent of illegal fishing. *PloS one* 4, e4570.

Allen, G. R. (2008). Conservation hotspots of biodiversity and endemism for Indo-Pacific coral reef fishes. *Aquat. Conserv. Mar. Freshwater Ecosyst* 18(5), 541-56.

Ballard, G., Jongsomjit, D., Veloz, S. D., & Ainley, D. G. (2012). Coexistence of mesopredatores in an intact polar ocean ecosystem: the basis for defining a Ross Sea marine protected area. *Biol. Conserv.* 152, 72-82.

Bansemer, C. S., & Bennett, M. B. (2011). Sex-and maturity-based differences in movement and migration patterns of grey nurse shark, *Carcharias taurus*, along the eastern coast of Australia. *Mar. Freshwater Res.* 62(6), 596-606.

Bjørndal, T., Kaitala, V., Lindroos, M., & Munro, G. R. (2000). The management of high seas fisheries. *Ann. Oper. Res.* 94(1), 183-196.

Blaison, A., Jaquemet, S., Guyomard, D., Vangrevelynghe, G., Gazzo, T., Cliff, G., … & Soria, M. (2015) Seasonal variability of bull and tiger shark presence on the west coast of Reunion Island, western Indian Ocean. *Afr. J. Mar. Sci.* 37(2), 199-208.

Block, B. A., Jonsen, I. D., Jorgensen, S. J., Winship, A. J., Shaffer, S. A., Bograd, S. J., ... & Ganong, J. E. (2011). Tracking apex marine predator movements in a dynamic ocean. *Nature* 475(7354), 86-90.

Bonfil, R., Meÿer, M., Scholl, M.C., Johnson, R., O'Brien, S., Oosthuizen, H., … & Paterson, M. (2005). Transoceanic migration, spatial dynamics, and population linkages of white sharks. *Science* 310, 100-103.

Bourjea, J., Mortimer, J. A., Garnier, J., Okemwa, G., Godley, B. J., Hughes, G., ... & Muths, D. (2015). Population structure enhances perspectives on regional management of the western Indian Ocean green turtle. *Conserv. Genet.* 16(5), 1069-1083.

Branch, G. M., Hauck, M., Siqwana-Ndulo, N., & Dye, A. H. (2002). Defining fishers in the South African context: subsistence, artisanal and small-scale commercial sectors. *S. Afr. J. Mar. Sci.* 24(1), 475-487.

Clark, C., Lea, J., & Ormond, R. (2012). Comparative abundance of reef sharks in the Western Indian Ocean. *Proceedings of the 12th international coral reef symposium,* Cairns, Australia.

Cooke, S. J., Martins, E. G., Struthers, D. P., Gutowsky, L. F., Power, M., Doka, S. E., ... & Krueger, C. C. (2016). A moving target—incorporating knowledge of the spatial ecology of fish into the assessment and management of freshwater fish populations. *Environ Monit Assess*, 188(4), 239.

Cooke, S. J., Hinch, S. G., Wikelski, M., Andrews, R. D., Kuchel, L. J., Wolcott, T. G., & Butler, P. J. (2004). Biotelemetry: a mechanistic approach to ecology. *Trends Ecol. Evol.* 19(6), 334-343.

Crossin, G. T., Heupel, M. R., Holbrook, C. M., Hussey, N. E., Lowerre-Barbieri, S. K., Nguyen, V. M., ... & Cooke, S. J. (2017). Acoustic telemetry and fisheries management. *Ecol. Appl.* 27(4), 1031-1049.

Dalla Rosa, L., Secchi, E. R., Maia, Y. G., Zerbini, A. N., & Heide-Jørgensen, M. P. (2008). Movements of satellite-monitored humpback whales on their feeding ground along the Antarctic Peninsula. *Polar Biol.* 31(7), 771-81.

Dalleau, M., Benhamou, S., Sudre, J., Ciccione, S., & Bourjea, J. (2014). The spatial ecology of juvenile loggerhead turtles (*Caretta caretta*) in the Indian Ocean sheds light on the “lost years” mystery. *Mar. Biol.* 161(8), 1835-1849.

Daly, R., Smale, M. J., Singh, S., Anders, D., Shivji, M., K. Daly, C. A., ... & Clarke, C. R. (2018). Refuges and risks: Evaluating the benefits of an expanded MPA network for mobile apex predators. *Divers. Distributions*. doi: doi.org/10.1111/ddi.12758

Dicken, M. L., Booth, A. J., Smale, M. J., & Cliff, G. (2007). Spatial and seasonal distribution patterns of juvenile and adult raggedtooth sharks (*Carcharias taurus*) tagged off the east coast of South Africa. *Mar. Freshwater Res.* 58(1), 127-134.

Dudley, S. F., & Simpfendorfer, C. A. (2006). Population status of 14 shark species caught in the protective gillnets off KwaZulu–Natal beaches, South Africa, 1978–2003. *Mar. Freshwater Res.* 57(2), 225-40.

Espinoza, M., Lédée, E. J., Simpfendorfer, C. A., Tobin, A. J., & Heupel, M. R. (2015). Contrasting movements and connectivity of reef-associated sharks using acoustic telemetry: implications for management. *Ecol. Appl.* 25(8), 2101-2118.

FAO (2016). The State of World Fisheries and Aquaculture 2016. Contributing to food security and nutrition for all. Rome, 42-44pp.

FAO (2017). Major Fishing Areas; Indian Ocean, Western (Major Fishing Area 51). CWP Data Collection. In: FAO Fisheries and Aquaculture Department, Rome. Accessed: 13 November 2017.

Fisk, A. T., Lydersen, C., & Kovacs, K. M. (2012). Archival pop-off tag tracking of Greenland sharks *Somniosus microcephalus* in the High Arctic waters of Svalbard, Norway. *Mar. Ecol. Prog. Ser.* 468, 255-265.

Flanders Marine Institute (2016). Maritime Boundaries Geodatabase, version 1. Available online at http://www.marineregions.org/. Consulted on 2017-11-09.

Folke, C. (2007). Social–ecological systems and adaptive governance of the commons. *Ecol. Res.* 22(1), 14-15.

Garnier, J., Hill, N., Guissamulo, A., Silva, I., Witt, M., & Godley, B. (2012). Status and community-based conservation of marine turtles in the northern Querimbas Islands (Mozambique). *Oryx*, 46(3), 359-367.

Harris, L. R., Nel, R., Oosthuizen, H., Meÿer, M., Kotze, D., Anders, D., ... & Bachoo, S. (2015). efficient multi-species conservation and management are not always field-effective: The status and future of Western Indian Ocean leatherbacks. *Biol. Conserv.* 191, 383-390.

Harrison, A. L., Costa, D. P., Winship, A. J., Benson, S. R., Bograd, S. J., Antolos, M., ... & Kohin, S. (2018). The political biogeography of migratory marine predators. *Nat. Ecol. Evol*. doi: 10.1038/s41559-018-0646-8

Hays, G. C., Bradshaw, C. J. A., James, M. C., Lovell, P., & Sims, D. W. (2007). Why do Argos satellite tags deployed on marine animals stop transmitting? *J. Exp. Mar. Biol. Ecol.* 349(1), 52-60.

Hays, G. C., Ferreira, L. C., Sequeira, A. M., Meekan, M. G., Duarte, C. M., Bailey, H., ... & Eguíluz, V. M. (2016). Key questions in marine megafauna movement ecology. *Trends Ecol. Evol.* 31(6), 463-475.

Heithaus, M. R., Wirsing, A. J., Dill, L. M., & Heithaus, L. I. (2007). Long-term movements of tiger sharks satellite-tagged in Shark Bay, Western Australia. *Mar. Biol.* 151, 1455-1461.

Holmes, B. J., Pepperell, J. G., Griffiths, S. P., Jaine, F. R., Tibbetts, I. R., & Bennett, M. B. (2014). Tiger shark (*Galeocerdo cuvier*) movement patterns and habitat use determined by satellite tagging in eastern Australian waters. *Mar. Biol.* 161(11), 2645-2658.

Howey-Jordan, L. A., Brooks, E. J., Abercrombie, D. L., Jordan, L. K., Brooks, A., Williams, S., … & Chapman, D. D. (2013). Complex movements, philopatry and expanded depth range of a severely threatened pelagic shark, the oceanic whitetip (*Carcharhinus longimanus*) in the western North Atlantic. *PloS one* 8(2), e56588.

Hussey, N. E., Hedges, K. J., Barkley, A. N., Treble, M. A., Peklova, I., Webber, D. M., ... & Fisk, A. T. (2017). Movements of a deep-water fish: establishing marine fisheries management boundaries in coastal Arctic waters. *Ecol. Appl.* 27(3), 687-704.

Hussey, N. E., Kessel, S. T., Aarestrup, K., Cooke, S. J., Cowley, P. D., Fisk, A. T., ... & Flemming, J. E. M. (2015). Aquatic animal telemetry: a panoramic window into the underwater world. *Science* 348(6240), 1255642.

Jacquet, J., Fox, H., Motta, H., Ngusaru, A., & Zeller, D. (2010). Few data but many fish: Marine small-scale fisheries catches for Mozambique and Tanzania. *Afr. J. Mar. Sci.* 32(2), 197-206.

Jorgensen, S. J., Reeb, C. A., Chapple, T. K., Anderson, S., Perle, C., Van Sommeran, S. R., ... & Block, B. A. (2009). Philopatry and migration of Pacific white sharks. *Proc. R. Soc. London, Ser. B* rspb20091155.

Kaunda-Arara, B., & Rose, G.A. (2004). Out-migration of tagged fish from marine reef national parks to fisheries in coastal Kenya. *Environ. Biol. Fishes* 70(4), 363-372.

Lascelles, B., Notarbartolo Di Sciara, G., Agardy, T., Cuttelod, A., Eckert, S., Glowka, L., ... & Tetley, M. J. (2014). Migratory marine species: their status, threats and conservation management needs. *Aquat. Conserv. Mar. Freshwater Ecosyst.* 24(S2), 111-127.

Marshall, N. (1998). The Kenyan shark fishery: a resource worth managing. *Kenya Past and Present* 30(1), 18-24.

Maxwell, S. M., Hazen, E. L., Lewison, R. L., Dunn, D. C., Bailey, H., Bograd, S. J., ... & Benson, S. (2015). Dynamic ocean management: Defining and conceptualizing real-time management of the ocean. *Mar. Policy* 58, 42-50.

McMahon, C. R., & Hays, G. C. (2006). Thermal niche, large-scale movements and implications of climate change for a critically endangered marine vertebrate. *Global Change Biol.* 12, 1330-1338.

McWhinnie, S. F. (2009). The tragedy of the commons in international fisheries: An empirical examination. *J. Environ. Econ. Manag.* 57(3), 321-333.

Meyer, C. G., Papastamatiou, Y. P., & Holland, K. N. (2010). A multiple instrument approach to quantifying the movement patterns and habitat use of tiger (*Galeocerdo cuvier*) and Galapagos sharks (*Carcharhinus galapagensis*) at French Frigate Shoals, Hawaii. *Mar. Biol.* 157(8), 1857-1868.

Momanyi, A. (2015). Governance: Legal and Institutional Frameworks. In J. Paula (Eds.) *Regional State of the Coast Report Western Indian Ocean* (pp. 445-457). Nairobi, Kenya: UNEP-Nairobi Convention and WIOMSA.

Mora, C., Myers, R. A., Coll, M., Libralato, S., Pitcher, T. J., Sumaila, R. U., ... & Worm, B. (2009). Management effectiveness of the world's marine fisheries. *PLoS Biol.* 7(6), e1000131.

Morreale, S. J., Standora, E. A., Spotila, J.R., & Paladino, F. V. (1996). Migration corridor for sea turtles. *Nature* 384(6607), 319-320.

Navia, A. F., Cortés, E., & Mejía-Falla, P. A. (2010). Topological analysis of the ecological importance of elasmobranch fishes: A food web study on the Gulf of Tortugas, Colombia. *Ecol. Modell.* 221(24), 2918-2926.

Nairobi Convention (2010). Final text of the Amended Nairobi convention for the protection, management and development of the marine and coastal environment of the Western Indian Ocean. Nairobi, Kenya 31 March 2010.

Obura, D. O., Church, J. E., & Gabrié, C. (2012). Assessing marine heritage from an ecosystem perspective: the western Indian Ocean. Paris, France: World Heritage Centre, United Nations Education, Science and Cultural Organization (UNESCO).

Okonkwo, T. (2017). Maritime boundaries delimitation and dispute resolution in Africa. *Beijing Law Rev.* 8, 55-78.

Papastamatiou, Y. P., Meyer, C. G., Carvalho, F., Dale, J. J., Hutchinson, M. R., & Holland, K. N. (2013). Telemetry and random-walk models reveal complex patterns of partial migration in a large marine predator. *Ecology* 94(11), 2595-606.

Pauly, D. (2015). The fisheries in the South-Western Indian Ocean, with emphasis on reconstructed catches. Universidad de Alicante. Instituto Interdisciplinar para el Estudio del Medio. doi: 10.14198/MDTRRA2015.ESP.02

Peklova, I., Hussey, N. E., Hedges, K. J., Treble, M. A., & Fisk, A. T. (2012). Depth and temperature preferences of the deepwater flatfish Greenland halibut *Reinhardtius hippoglossoides* in an Arctic marine ecosystem. *Mar. Ecol. Prog. Ser.* 467, 193-205.

R Core Team (2017). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Richmond, M. D. (2015). Threatened marine species. In J. Paula (Eds.) *Regional State of the Coast Report Western Indian Ocean* (pp. 129-153). Nairobi, Kenya: UNEP-Nairobi Convention and WIOMSA.

Robinson, L., & Sauer, W. H. H. (2013). A first description of the artisanal shark fishery in northern Madagascar: implications for management. *Afr. J. Mar. Sci.* 35(1), 9-15.

Rohner, C. A., Richardson, A. J., Jaine, F. R., Bennett, M. B., Weeks, S. J., Cliff, G., ... & Pierce, S. J. (2018). Satellite tagging highlights the importance of productive Mozambican coastal waters to the ecology and conservation of whale sharks. *PeerJ*. 6, e4161.

Roquet, F., Williams, G., Hindell, M. A., Harcourt, R., McMahon, C., Guinet, C., ... & Fedak, M. (2014). A Southern Indian Ocean database of hydrographic profiles obtained with instrumented elephant seals. *Sci. Data* 1.

Samoilys, M. A., Osuka, K., Maina, G. W., & Obura, D. O. (2017). Artisanal fisheries on Kenya's coral reefs: Decadal trends reveal management needs. *Fish. Res.* 186, 177-91.

Samoilys, M. A., Pabari, M., Andrew, T., Maina, G.W., Church, J., Momanyi, A., … & Mutta, D. (2015). Resilience of Coastal Systems and their human partners; Ecological and social profile of coastal systems in Kenya, Mozambique and Tanzania. M. A. Fitzgerald (Eds). Nairobi, Kenya: IUCN ESARO, WIOMSA, CORDIO and UNEP Nairobi Convention.

Smale, M. J. (2008). Pelagic shark fisheries in the Indian Ocean. In M. D. Camhi, E. K. Pikitch, & E. A. Babcock (Eds.), *Sharks of the Open Ocean: Biology, Fisheries and Conservation* (pp. 247-259). Oxford, UK: Blackwell Publishing Ltd.

Smale, M. J., Booth, A. J., Farquhar, M. R., Meÿer, M. R., & Rochat, L. (2012). Migration and habitat use of formerly captive and wild raggedtooth sharks (*Carcharias taurus*) on the southeast coast of South Africa. *Mar. Biol. Res.* 8(2), 115-128.

Song, A.M., Scholtens, J., Stephen, J., Bavinck, M., & Chuenpagdee, R. (2017). Transboundary research in fisheries. *Mar. Policy* 76, 8-18.

Spalding, M. D., Fox, H. E., Allen, G. R., Davidson, N., Ferdaña, Z. A., Finlayson, M. A. X., ... & Martin, K. D. (2007). Marine ecoregions of the world: a bioregionalization of coastal and shelf areas. *BioScience* 57(7), 573-583.

Sumaila, U.R., Samoilys, M., Allison, E., Cinner, J., DeYoung, C. & Kavanagh, C. (2014). Economic Impacts of Ocean Acidification on Fisheries and Aquaculture in the Western Indian Ocean: Current Knowledge and Recommendations. *Indian Ocean and Red Sea (FAO 51, 57),* IAEA Report.

Tittensor, D. P., Mora, C., Jetz, W., Lotze, H. K., Ricard, D., Berghe, E. V., & Worm, B. (2010). Global patterns and predictors of marine biodiversity across taxa. *Nature*, 466(7310), 1098.

UNEP/Nairobi Convention Secretariat and WIOMSA (2009). Transboundary diagnostic analysis of land-based sources and activities affecting the Western Indian Ocean coastal and marine environment. UNEP. Nairobi, Kenya

Wafar, M., Venkataraman, K., Ingole, B., Khan, S. A., & LokaBharathi, P. (2011). State of knowledge of coastal and marine biodiversity of Indian Ocean countries. *PLoS One* 6(1), e14613.

Wildlife Conservation Society (WCS) *in press*. Sharks and rays of the western Indian Ocean – Biodiversity, fisheries and trade, management, and conservation. Report for the Nairobi Convention.

Werry, J. M., Planes, S., Berumen, M. L., Lee, K. A., Braun, C. D., & Clua, E. (2014). Reef-fidelity and migration of tiger sharks, *Galeocerdo cuvier*, across the Coral Sea. *PLoS One* 9(1), e83249.

West, C. D., Dytham, C., Righton, D., & Pitchford, J. W. (2009). Preventing overexploitation of migratory fish stocks: the efficacy of marine protected areas in a stochastic environment. *ICES J. Mar. Sci.* 66(9), 1919-1930.

White, T. D., Carlisle, A. B., Kroodsma, D. A., Block, B. A., Casagrandi, R., De Leo, G. A., ... & McCauley, D. J. (2017). Assessing the effectiveness of a large marine protected area for reef shark conservation. *Biol. Conserv.* 207, 64-71.

White, C., & Costello, C. (2014). Close the high seas to fishing? *PLoS Biol* 12(3), e1001826.

Worm, B., & Branch, T. A. (2012). The future of fish. *Trends Ecol. Evol.* 27(11), 594-599.

Table 1- Satellite telemetry studies undertaken within the western Indian Ocean. Full references can be found in Appendix 1. The first column includes the species common name with the scientific name in brackets and the IUCN red list status in bold below. EEZ # stands for the number of exclusive economic zones crossed by the study species, where studies that were not applicable for this analysis are indicated by ‘n/a’ or further justification is given. Sample size is the number of animals equipped with satellite tags, with the minimum and maximum range of days tracked for those animals in brackets. When the day range was not available, the average number of days ± standard deviation is reported.

Species & IUCN red list status	**Authors**	**Year**	**Country**	**Capture/release location**	**EEZ #**	**Sample size (day range or average)**
Loggerhead turtle (*Caretta caretta*) **Vulnerable**	Papi *et al*.	1997	South Africa	Maputaland Marine Reserve	2	4 (15-46)
	Hays *et al.*	2003	n/a	Indian Ocean	n/a	
	Luschi *et al.* (a)	2003	South Africa	Maputaland Marine Reserve	*omitted	
	Luschi *et al.*	2006	South Africa	Maputaland Marine Reserve	review	
	Mencacci *et al.*	2010	South Africa	Maputaland Marine Reserve	*omitted	
	Dalleau *et al.*	2014	France	Reunion Island	13	18 (20-401)
	Harris *et al.*	2015	South Africa	Bhanga Nek and Manzengwenya	1	18 (14-55[†])
Leatherback turtle (*Dermochelys coriacea*) **Vulnerable**	Hughes *et al.*	1998	South Africa	Maputaland Marine Reserve	4[a]	1 (114)[a]
	Hays *et al.*	2003	n/a	Indian Ocean	n/a	
	Luschi *et al.* (b)	2003	South Africa	Maputaland Marine Reserve	4[a]	3 (124-223)[a]
	Sale *et al.*	2006	South Africa	Maputaland Marine Reserve	4[a]	4 (16-168)[a]
	Luschi *et al.*	2006	South Africa	Maputaland Marine Reserve	review	
	Lambardi *et al.*	2008	South Africa	Maputaland Marine Reserve	4[a]	9 (17-242)[a]
	Hays *et al.*	2009	South Africa	Maputaland Marine Reserve	4[a]	2 (168-223)[a]
	Harris *et al.*	2015	South Africa	Adlams Reef to Black Rock	2	16 (8-80[†])
	Robinson *et al.*	2016	South Africa	iSimangaliso Wetland Park	6	16 (111.5±41.3)

Green turtle (*Chelonia mydas*) **Endangered**	Garnier *et al.*	2012	Mozambique	Vamizi	5	4 (127-231)
	Bourjea *et al.*	2015	Seychelles	Amirantes	1	4 (39-175[†])
White shark (*Carcharodon carcharias*) **Vulnerable**	Bonfil *et al.*	2005	South Africa	Gansbaai	4	24 (31-371)
Whale shark (*Rhincodon typus*) **Endangered**	Gifford *et al.*	2007	South Africa	Cape Vidal	2	5 (2-132)
	Rowat & Gore	2007	Seychelles	Mahe	3	9 (7-123)
	Brunnschweiler *et al.*	2009	Mozambique	Tofo	2[b]	1 (87)[b]
	Brunnschweiler *et al.*	2011	Mozambique	Tofo	2[b]	1 (87)[b]
Bull shark (*Carcharhinus leucas*) **Near threatened**	Lea *et al.*	2015	Seychelles	Amirantes	4	1 (151)
Sand tiger shark (*Carcharias taurus*) **Vulnerable**	Smale *et al.*	2012	South Africa	Struis Bay	1	5 (43-126)
Ocean sunfish (*Mola mola*) **Vulnerable**	Hays *et al.*	2009	South Africa	near Cape Bay	2	4 (64-208)
Elephant seal (*Mirounga leonina*) **Least Concern**	Roquet *et al.*	2014	South Africa	Kerguelen Isl., Davis Station, Casey Station	n/a	207 (n/a)
Southern right whale (*Eubalaena australis*) **Least Concern**	Mate & Best	2008	South Africa	Saldanha Bay and St. Sebastien Bay	4[c]	21 (1-161)[c]
	Mate *et al.*	2011	South Africa	St. Helena Bay	4[c]	21 (1-161)[c]
Humpback whale (*Megaptera novaeangliae*) **Least Concern**	Fossette *et al.*	2014	Comoros	Moheli Island and Mayotte Island	6	11 (8-49)
	Cerchio *et al.*	2016	Madagascar	Ile Saite Marie and Anakao	7[d]	23 (2-58)[d]
	Trudelle *et al.*	2016	Madagascar	Ile Saite Marie and Anakao	7[d]	25 (2-58)[d]

[a,b,c,d] Tracks that have been combined as the data is reused in multiple studies, sample sizes and day ranges reflect combinations of animals that were tracked in multiple studies and novel ones.

*Omitted as these turtles were relocated and released in a novel location

[†] Day ranges that were not explicitly reported, but calculated from available data.

Table 2- Information on tiger sharks equipped with satellite tags off the coast of Kenya. TL = total length, F = female, M = male. Number of geolocations is the total number of locations provided by the satellite tags (location quality 1-3, A and B).

Shark number	**Size (TL)**	**Sex**	**Tag model**	**Date tagged**	**Number of geolocations**	**Days tracked**	**Distance travelled**
TS01	330	F	257A	21-11-2014	45	44	272 km
TS02	380	F	257A	03-12-2014	96	35	536 km
TS03	280	F	258A	02-12-2014	162	66	2926 km
TS04	280	F	258A	02-12-2014	556	235	4779 km
TS05	324	F	258A	04-12-2014	0	0	n/a

Figure 1- Cumulative number of studies on satellite tracked marine animals over time, separated by the global total encompassing all world oceans (Hussey *et al.*, 2015), and those which only took place within the Western Indian Ocean.

Figure 2- Satellite tracks of all animals studied up to December 2016 within the Western Indian Ocean, extracted from published papers (see Table 1 for references). Coloured areas mark unique country exclusive economic zones. Tracks are colour coded based on taxon. In the case of pop-up archival satellite telemetry studies where only the tagging and pop-up location of the tag are provided, locations were marked by a star.

Figure 3- Satellite tracks of individual tiger sharks (*Galeocerdo cuvier*) tagged off the coast of Kenya in the Western Indian Ocean. Exclusive economic zone boundaries are marked with black lines; FSL stands for French Southern Lands.

Figure 4- Occurrence of tiger sharks (*Galeocerdo cuvier*) in the exclusive economic zones (EEZ) of countries within the Western Indian Ocean, presented as a percentage of the number of days spent in each EEZ out of the total number of days that animal was tracked (total days indicated by ‘n’ above each bar). Note: FSL stands for French Southern Lands.

Figure 5- Number of EEZs crossed by all species tracked with satellite tags in the Western Indian Ocean up until December 2016. Each colour refers to a unique reference track for that species, which may encompass one or more references depending on if the track is unique to a study or used in multiple studies.

Figure 1

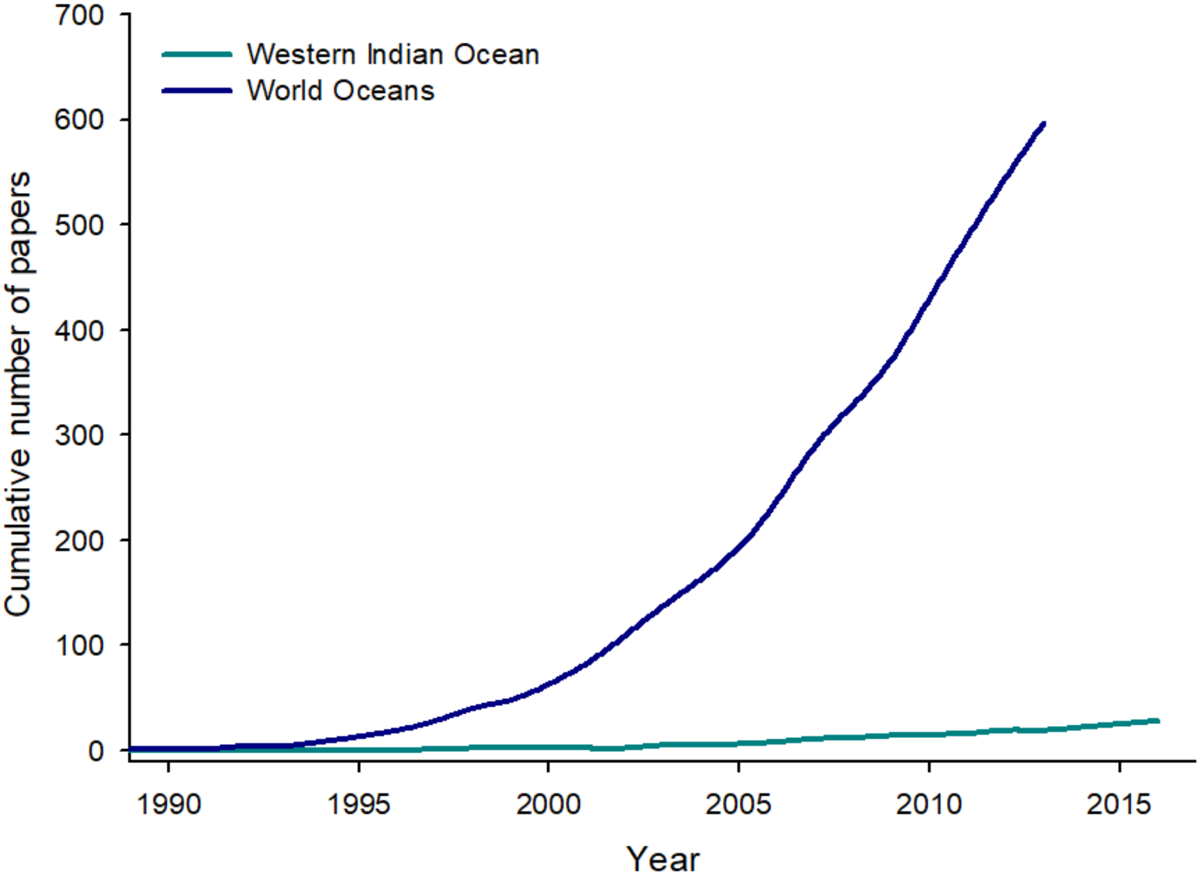

Western Indian Ocean
World Oceans
Cumulative number of papers
700
600
500
400
300
200
100
0
1990
1995
2000
2005
2010
2015
Year

Figure 2

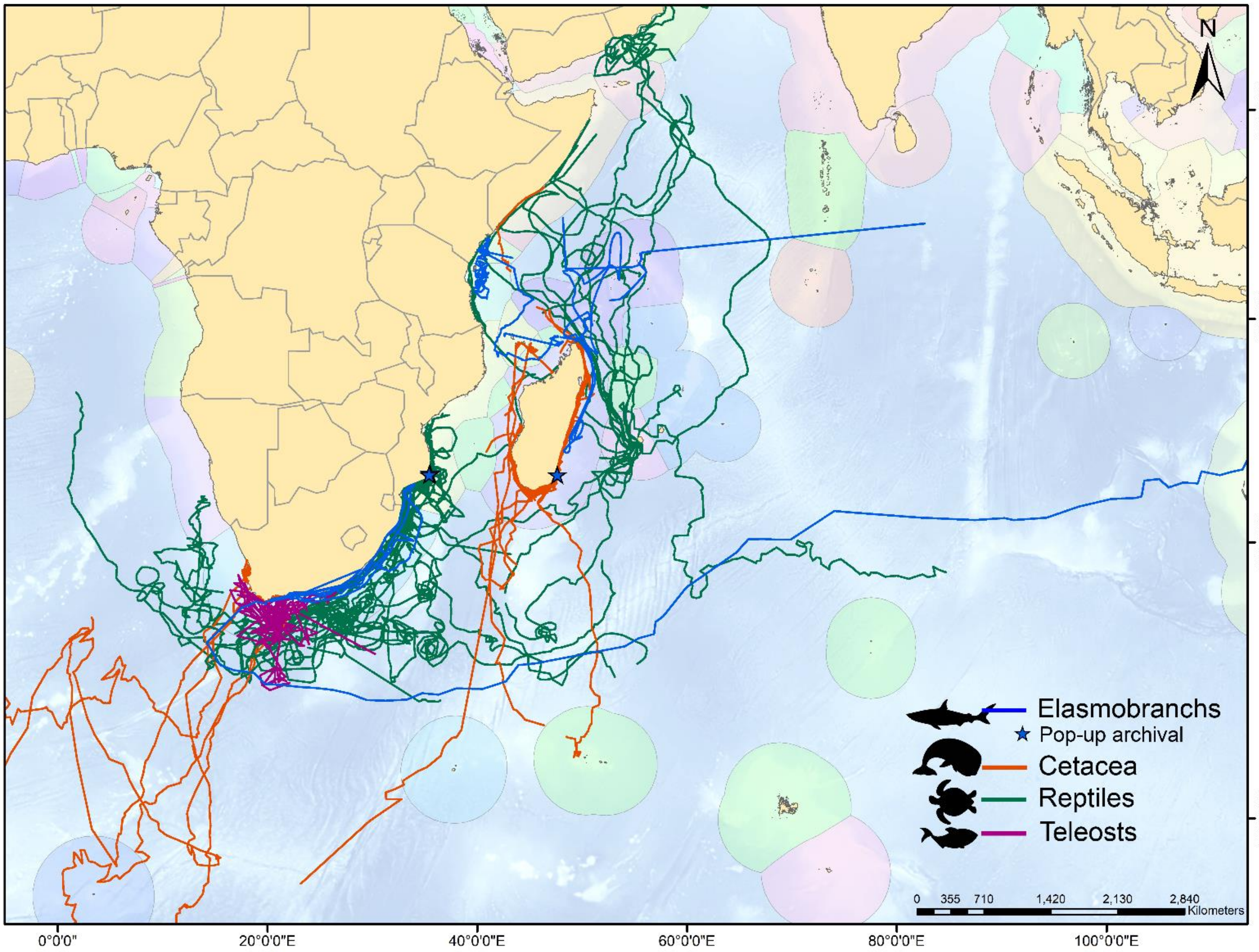

N
10°0'0"N
10°0'0"S
30°0'0"S
50°0'0"S
0°0'0"
20°0'0"E
40°0'0"E
60°0'0"E
80°0'0"E
100°0'0"E
Elasmobranchs
★ Pop-up archival
Cetacea
Reptiles
Teleosts
0
355
710
1,420
2,130
2,840
Kilometers

Figure 3

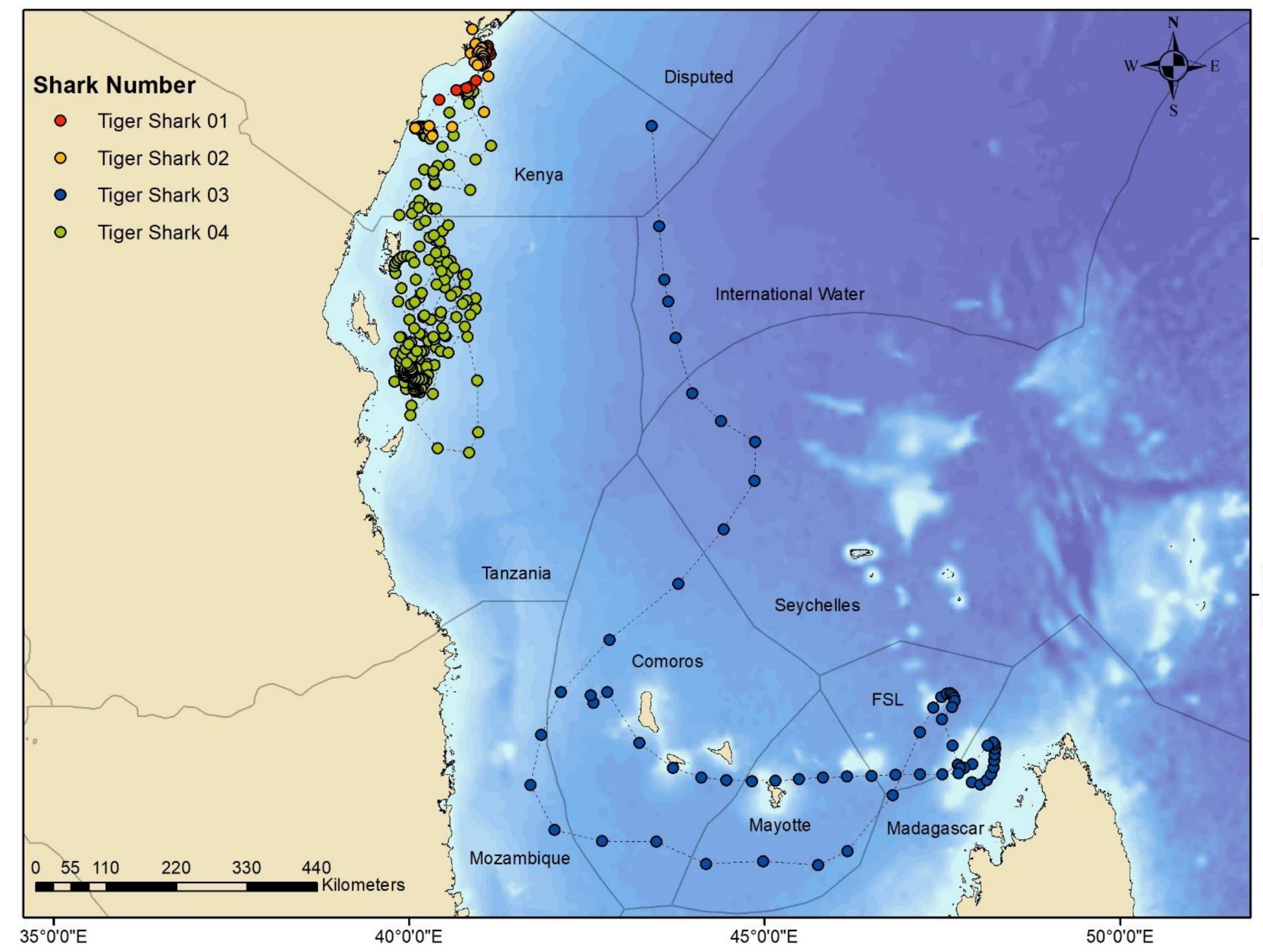

Shark Number
● Tiger Shark 01
● Tiger Shark 02
● Tiger Shark 03
● Tiger Shark 04
Disputed
Kenya
International Water
Tanzania
Seychelles
Comoros
FSL
Mayotte
Madagascar
Mozambique
0 55 110 220 330 440
Kilometers
N
W
E
S
5°0'0"S
10°0'0"S
35°0'0"E
40°0'0"E
45°0'0"E
50°0'0"E

Figure 4

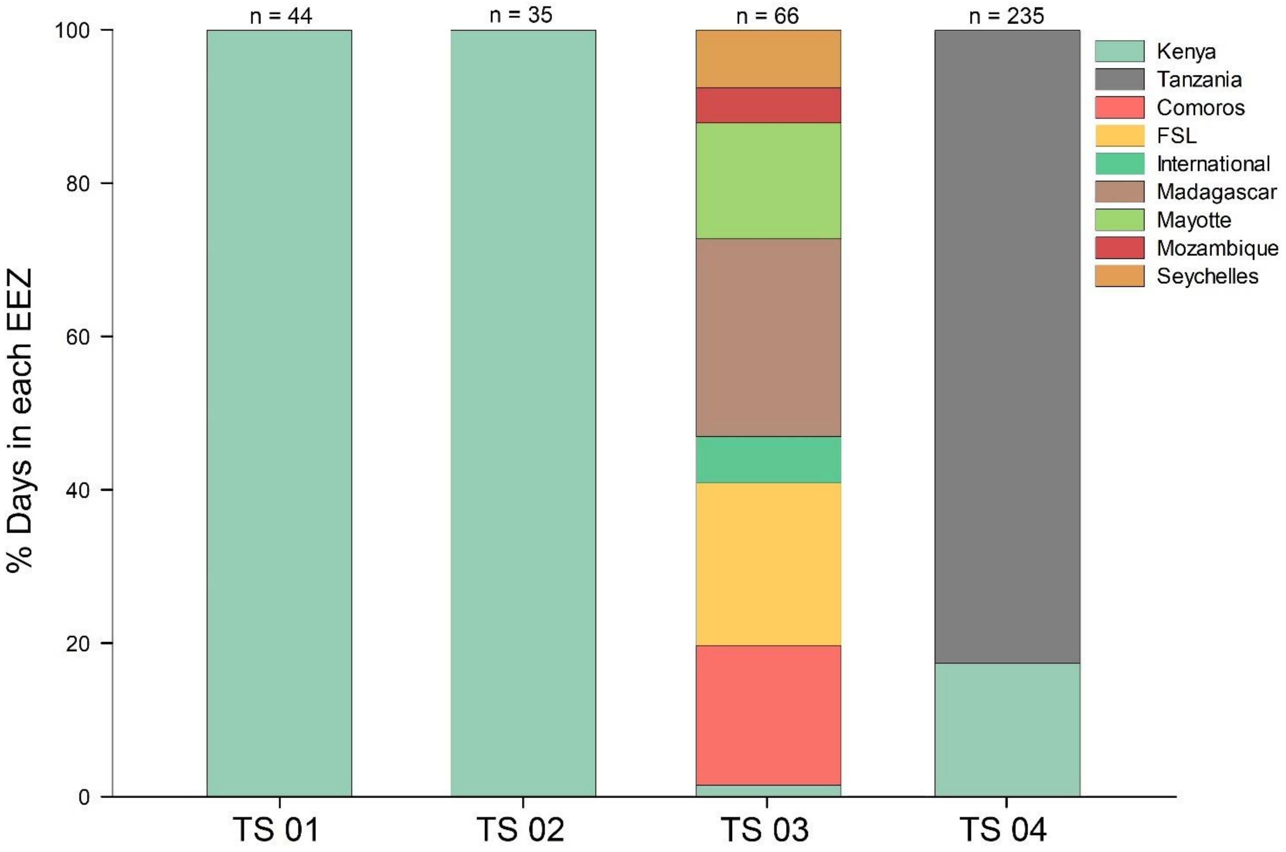
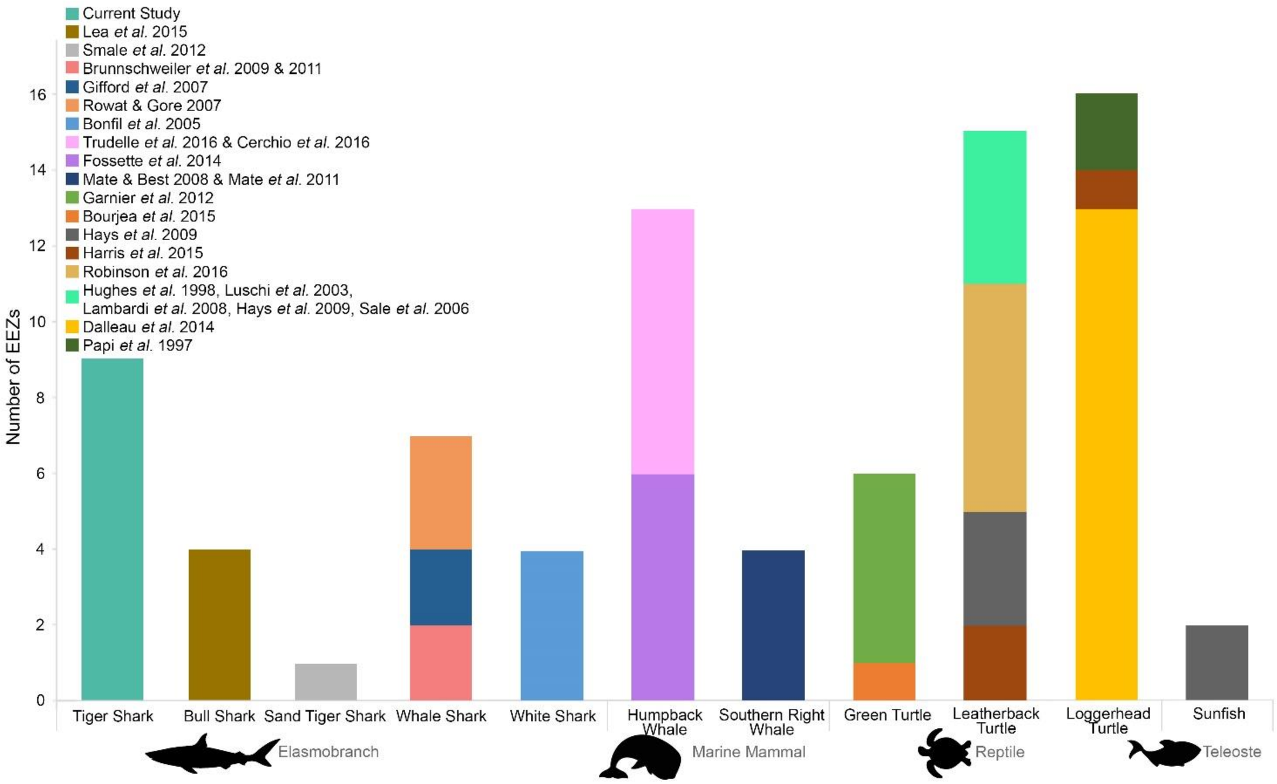

n = 44
n = 35
n = 66
n = 235
100
80
60
40
20
0
% Days in each EEZ
TS 01
TS 02
TS 03
TS 04
Kenya
Tanzania
Comoros
FSL
International
Madagascar
Mayotte
Mozambique
Seychelles

Figure 5


Current Study
Lea et al. 2015
Smale et al. 2012
Brunnschweiler et al. 2009 & 2011
Gifford et al. 2007
Rowat & Gore 2007
Bonfil et al. 2005
Trudelle et al. 2016 & Cerchio et al. 2016
Fossette et al. 2014
Mate & Best 2008 & Mate et al. 2011
Garnier et al. 2012
Bourjea et al. 2015
Hays et al. 2009
Harris et al. 2015
Robinson et al. 2016
Hughes et al. 1998, Luschi et al. 2003, Lambardi et al. 2008, Hays et al. 2009, Sale et al. 2006
Dalleau et al. 2014
Papi et al. 1997
Number of EEZs
0
2
4
6
8
10
12
14
16
Tiger Shark
Bull Shark
Sand Tiger Shark
Whale Shark
White Shark
Humpback Whale
Southern Right Whale
Green Turtle
Leatherback Turtle
Loggerhead Turtle
Sunfish
Elasmobranch
Marine Mammal
Reptile
Teleoste