NELSON MANDELA UNIVERSITY

Zoning the Southwestern Indian Ocean to mitigate impacts from ocean-based hydrocarbon exploration and production on sea turtles

By

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Submitted in fulfilment of the requirements for the degree of Master of Science at the Department of Zoology at the Nelson Mandela University

December 2018

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DECLARATION:

In accordance with Rule G5.6.3, I hereby declare that the above-mentioned treatise/ dissertation/ thesis is my own work and that it has not previously been submitted for assessment to another University or for another qualification.

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DATE: 17 December 2018

Acknowledgements

I would like to thank my supervisors, Ronel and Linda. Your guidance, advice and willingness to assist me on this journey has been invaluable. I have gained much respect for your wealth of knowledge on the natural environment and ability to think critically about topics at hand. Thank you for transferring some of that wealth to me. Undertaking this study has changed my perspective and approach to the world we live in, and have engrained a new approach to the natural sciences in me, that I know will be instrumental to my life going forward.

To my fiancé, your support on all fronts area greatly appreciated, and without it, I would not have been able to complete this study.

To my farther, thank you for installing a great love and appreciation of the natural environment in me. One of my earliest memories as a little child was undertaking to help your write-up your master's thesis, when I realised that the stacks of hard copy books and printouts became too high. Only now I comprehend what an effort that must have been, respect.

Lastly, to the various scientist that have contributed to the invaluable information used in this study, I thank you. Often through the writing-up this study and reading through papers, I wondered how it would be to meet some of these truly amazing people, that have devoted their lives to understanding the sciences.

Nothing in life is to be feared, it is only to be understood.
Now is the time to understand more, so that we may fear less.
- Maria Skłodowska-Curie

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Abstract

The conflict between sea turtles and the numerous socio-economic developments in the Southwestern Indian Ocean (SWIO) are set to intensify as countries are looking to develop their ocean-based economies. The Hydrocarbon Exploration and Production (HEP) industry is of particular importance, since many of the SWIO governments view it as catalyst for development. This has raised concerns about potentially significant environmental impacts from the HEP industry, to sea turtles and their habitats, based on international examples where sea turtles have been severely negatively impacted upon, like the Deepwater Horizon spill in the Gulf of Mexico. Given that the four sea turtles species in the SWIO are listed on the IUCN Red List of threatened species, the aim of this study was to derive priority areas for sea turtles in the face of HEP, that could be used in an ocean zoning strategy for sustainable economic development of HEP in the SWIO region. To achieve this, the study spatially represented the main life-history stages of sea turtles, i.e. the breeding, migrating and foraging areas of *Caretta caretta* (loggerhead turtles), *Dermochelys coriacea* (leatherback turtles), *Chelonia mydas* (green turtles) and *Eretmochelys imbricata* (hawksbill turtles), within a telemetry derived distribution for each species. This spatial representation was used to quantify the extent of Marine Protected Areas (MPAs) conserving sea turtles in the SWIO, which revealed that sea turtle breeding areas were well represented in MPAs, including *C. caretta* (~40 %), *C. mydas* (~53 %), *E. imbricata* (~59 %) and *D. coriacea* (~22 %), the latter being least protected by MPAs during breeding, possibly due to a far greater extent of their internesting areas than the other three species. MPA coverage of breeding areas could be positively correlated to the increasing population trends of *C. caretta* and *C. mydas* in the SWIO, and therefore the assumption was made that increasing population trends of sea turtles are in part related to MPA protection of their breeding areas. In addition, the potential impacts on sea turtles from existing and proposed HEP developments were assessed and mapped by using a novel, species-specific rating index. The results revealed the extensive nature of potential water pollution impacts on sea turtles, constituting 16 of the top 28 most significant impacts from HEP on sea turtles. Other significant impacts on sea turtles associated with the HEP industry, included habitat destruction, light pollution and noise pollution. Importantly, this study found that ~70 % of all potential HEP impacts (irrespective of significance) on adult nesting sea turtles could be avoided if seasonal sea turtle movement during critical life stages are included as species-specific HEP mitigation measures. The data and maps on the main life-history stages of sea turtles, and the potential cumulative impacts from the HEP industry, were used in a Systematic Conservation Planning process, to derive a concept ocean zoning. As final outcome of this study, the concept ocean zoning highlighted areas where increased protection to sea turtles, and management of the conflict between sea turtles and the HEP industry, will be required if the HEP industry is to develop in a sustainable manner in the SWIO.

Chapter 1 : **Introduction**

Environmental impacts related to hydrocarbon resource exploitation are well documented in developed countries (Patin & LeProvost, 2001), providing an appropriate prequel of the impacts that can be expected in the Southwestern Indian Ocean (SWIO) region, due to the recent discovery of energy resources. In the late 1970s, the Gulf of Mexico experienced an increase in hydrocarbon exploration in marine coastal areas for both oil and gas from conventional and unconventional resources (Austin, et al., 2008). Simultaneously, concern was raised over declining populations of sea turtles in the Gulf, and more information was needed to identify potential effects of the hydrocarbon-based industry on the environment and particularly sea turtles (Fritts & McGehee, 1982; Hall, et al., 1983). Most of the marine species threatened by Hydrocarbon Exploration and Production (HEP), are listed on the IUCN Red List of threatened species (Bailie, et al., 2004). Three decades after the energy "boom" in the Atlantic, the SWIO is experiencing a similar increase in hydrocarbon exploration (ADB and AU, 2009; PWC, 2013), also with sea turtle populations here under severe pressure (Bourjea, et al., 2008).

Each phase in the hydrocarbon resource industry has a suite of potential negative environmental impacts (Patin & LeProvost, 2001). These impacts, also called stressors, include: (i) pollution; (ii) habitat destruction and alteration; (iii) disturbance; and (iv) physical impact from vessels (Borthwick, et al., 1997; Iversen & Stokke, 2009; BPC, 2012). In the worst cases, several of these stressors might manifest in a single disaster. In April 2010, the explosion at the Deepwater Horizon drilling rig in the Gulf of Mexico began one such disaster (National Commission, 2011). Six months after the initial explosion and ensuing spill, wildlife responders had collected 8,183 birds, 1,144 sea turtles, and 109 marine mammals affected by the spill (National Commission, 2011). The cumulative environmental impact of the disaster remains unquantified, subsequent to the fact that hydrocarbons formed surface slicks that oiled more than a 1,000 km of coast in the Gulf of Mexico (Aeppli, et al., 2012). It is, however, not only the major catastrophes that have negative effects on the environment cumulative effects of lesser magnitude spills from hydrocarbon extraction in the marine environment can also have significant impacts on the environment (Fraser, et al., 2008). Consequently, the cumulative threat to marine species warrants distinct attention given the magnitude and significance of the potential impacts from the hydrocarbon industry.

One group of animals that have been identified as warranting distinct attention given their suite of unique characteristics (Luschi, et al., 2006; Bourjea, et al., 2008; Wallace, et al., 2010; Hamann, et al., 2013) is sea turtles. This research focuses on ocean zoning as mechanism to reduce threats to sea turtles in a specific geographic area, located in the SWIO, from the growing hydrocarbon industry. The study area comprises the Exclusive Economic Zones (EEZs) and coastal zones of the African mainland countries in the SWIO, i.e. Kenya, Tanzania, Mozambique, and South Africa (excluding the Prince Edward Islands). The island nations included are Madagascar, Mauritius, Seychelles, Comoros, and France with Réunion and the Scattered Islands - Europa, Juan de Nova, Bassas da India, Tromelin, Mayotte, and Glorioso. These zones fall within the Agulhas and Somali Current Large Marine Ecosystems (ASCLME/SWIOFP, 2012) and thus form an ecologically coherent study area.

The geographical area was confined to the EEZs of these countries because of the particularly significant offshore hydrocarbon finds over the past decade within this area (ADB and AU, 2009; Deloitte, 2014). The EEZs also present a defined geographical area governed by country-specific legislation and policy where implementation of management and mitigation measures is more likely than on the high seas (Guerreiro, et al., 2011).

1.1 Background information

1.1.1 Sea turtles

Of the seven species of sea turtles found globally, five have been documented in the study area (Mortimer, 2002; Bourjea, et al., 2008). All five species have a circumglobal distribution but with distinct populations tied to their natal rookeries. They are highly migratory and undertake complex movements and migrations through contrasting habitats (Seminoff, 2004; Mortimer & Donnelly, 2008; Wallace & Tiwari, 2013). In the SWIO the most widely distributed and most abundant are green turtles (*Chelonia mydas*) and hawksbills (*Eretmochelys imbricata*) (Bourjea, et al., 2008), which occur globally throughout all tropical and subtropical ocean waters (Seminoff, 2004; Mortimer & Donnelly, 2008). The SWIO also harbours loggerheads (*Caretta caretta*), which occur throughout all tropical and temperate oceans (Dodd, 1988; Hamann, et al., 2013) and pelagic, deep-diving leatherbacks (*Dermochelys coriacea*) that have a range extending from tropical nesting beaches and foraging grounds to temperate and even sub-polar seas (Wallace, et al., 2013). The olive ridley (*Lepidochelys olivacea*) appears to be a vagrant in the study area with no known rookeries (Bourjea, et al., 2008), and is therefore not included in this study.

The global IUCN Red Listing of the four sea turtle species found in the SWIO vary between Vulnerable (VU) for *C. caretta* (Casale & Tucker, 2017) and *D. coriacea* (Wallace, et al., 2013), Endangered (EN) for *C. mydas* (Seminoff, 2004) and Critically Endangered (CR) for *E. imbricata* (Mortimer & Donnelly, 2008). Frameworks like IUCN Red Listing, which assess the global risk of extinction, did not consider the conservation status of spatially and biologically distinct sea turtle Regional Management Units (RMUs), up until the last decade (Wallace, et al., 2011; Figure 1 1). Currently, two sea turtle species have IUCN extinction risk ratings based on their RMU distribution in the SWIO, namely: *D. coriacea*, listed as Critically Endangered (Wallace, et al., 2013); and *C. caretta*, listed as Near Threatened (NT) (Nel & Casale, 2015), there are no official IUCN assessments of *E. imbricata* and *C. mydas* RMUs available for the SWIO.

The categorised RMU ratings provide us with a perspective of the symptoms of endangerment of specific sea turtles subpopulations, i.e. in terms of population reduction (decline in the number of mature individuals), the SWIO subpopulation of *C. caretta* is rated as Least Concern, yet the global population is rated as being Vulnerable, furthermore the SWIO subpopulation is rated Near Threatened in terms of geographic range, yet the global population is rated as being least concern (Nel & Casale, 2015). Similarly, the SWIO subpopulation of *D. coriacea* is rated as Critically Endangered in terms of their small population size (less than 250 mature individuals) even though the subpopulation has an overall stable to slightly decreasing trend (Nel, et al., 2013), and Endangered in term of the very small and restricted population (occupancy=1,500 km2 at a single location), whereas the global population is rated as Least Concern under the same criteria (Wallace, et al., 2013). Global and RMU population trends are particularly important indicators of sea turtle conservation priorities (Wallace, et al., 2011), and on a global scale all four sea turtles pertinent to this study have decreasing population trends (IUCN, 2018). However, to undertake robust risk assessment for sea turtles it's pivotal that changes in population trends, impacts of threats, and the need for conservation actions be assessed at RMU level (Wallace, et al., 2011), and hence the further focus on these four sea turtles at RMU level.

The information on *C. caretta* in the SWIO is largely derived from long-term research in South Africa, which was initiated in 1965 and has been ongoing for the past 53 years (Nel et al., 2013). Nevertheless, *C. caretta* in the SWIO RMU nests across South Africa, Mozambique and Madagascar, yet there is no indication of substantial current nesting in the Madagascar (Nel & Casale, 2015). The majority (95 %) internesting habitat for the species is conserved in the iSimangaliso Wetland Park, South Africa and Ponta do Ouro Partial Marine Reserve, Mozambique (Harris, et al., 2015; Figure 1-1a). According to the latest IUCN assessments *C. caretta* is the only species in the study area showing an increasing population trend (Nel & Casale, 2015). Markedly, the *C. caretta* population has been growing exponentially over the last decade, with a total of ~1300 nesting females per annum (Nel et al., 2013).

The small (less than 100 nesting females per annum) population of *D. coriacea* has been relatively stable over the past four decades (Nel, 2010; Nel, 2012; Nel, et al., 2013; Figure 1-1b). *D. coriacea* nesting occurs along the north coast of South African to the south coast of Mozambique, most of the nesting occurs within the iSimangaliso Wetland Park, South Africa and Ponta do Ouro Partial Marine Reserve, Mozambique (Nel, et al., 2013). Although only 25 % of *D. coriacea* sea use during internesting is conserved within the aforementioned mentioned MPAs (Harris, et al., 2015), most of the rookery is well-protected from threats such as fisheries (Bourjea et al., 2008). In contrast, the vast post-nesting distribution of *D. coriacea* (Hughes, et al., 1998) makes them particularly vulnerable to threats like high-seas fisheries (Fiedler, et al., 2012; Harris et al., 2018).

Indications are that *C. mydas* in the SWIO has recovered from its discernible population decline over the last three generations (Seminoff, 2004) to show increasing populations numbers (Bourjea, et al., 2007). *C. mydas* nesting takes place along the east African mainland coast from northern Mozambique to Kenya, as well as many of the SWIO islands, including Europa, Glorioso, Tromelin, Mayotte, Seychelles and Madagascar (Lauret-Stepler, et al., 2007). Collectively this RMU population is rated to be large, i.e. ~10000 nesting females per annum (Lauret-Stepler, et al., 2007; Wallace, et al., 2010; Figure 1-1c). The latest genetic information indicates that the SWIO RMU consists of at least three stocks in the south, central and northern Mozambique Channel (Bourjea, et al., 2007).

E. imbricata populations in the SWIO are increasing in locations like the Seychelles, and others where the species has been protected for some time, yet sites where protection has been negligible or poaching continuing, population declines continue (Mortimer & Donnelly, 2008). Population trends for most rookeries are described as either unknown, depleted, or declining (Mortimer & Donnelly, 2008). *E. imbricata* nesting occurs along the east African mainland coast from central Mozambique to Kenya, with the largest stocks hosted by the islands of

Madagascar (~1000 nesting females per annum), Seychelles (~625 nesting females per annum on inner islands and ~800 nesting females per annum on outer islands) and the British Indian Ocean Territories (~300-700 nesting females per annum). Collectively this RMU population is rated to be large, i.e. more than ~2000 nesting females per annum. However, this is but a fraction of the population from a century ago, prior to the major exploitation of the species (Mortimer & Donnelly, 2008; Figure 1-1d).

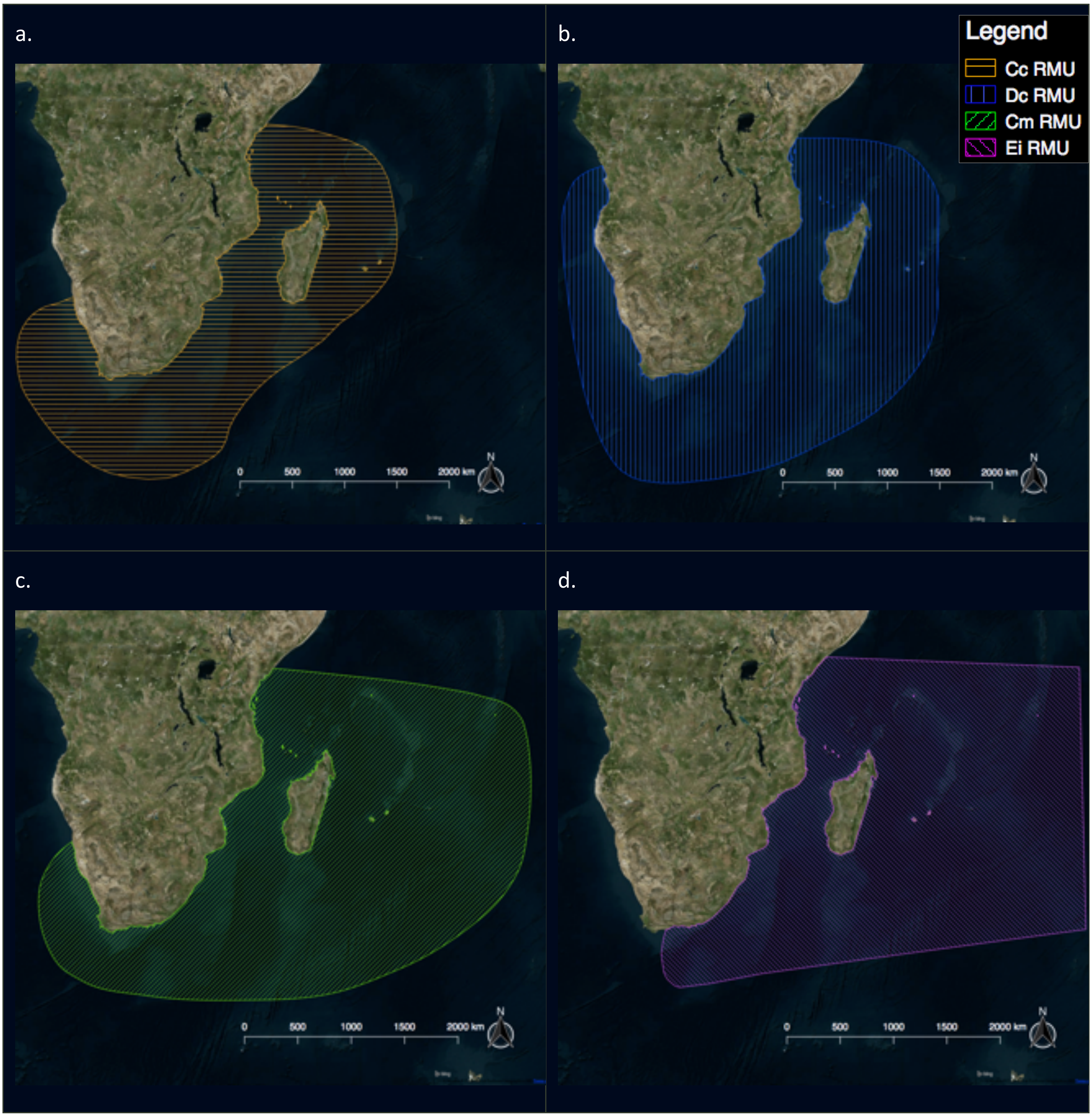

Figure 1-1 | The SWIO RMUs for: a. *C. caretta* (Cc), b. *D. coriacea* (Dc), c. *C. mydas* (Cm) and d. *E. imbricata* (Ei) (Wallace, et al., 2010). **(Imagery used in terms of Microsoft® BingTM Maps Platform)**

Some sea turtles populations have declined dramatically over the last century due to suites of threats like direct exploitation, incidental mortality, and habitat loss and degradation (Seminoff, 2004; Bolten, et al., 2010; Wallace, et al., 2013). This has resulted in a lack of knowledge or a reliable baseline (prior to the last century's over exploitation) for comparison against their current state, which means that we cannot fully comprehend what ecological roles (relating to their influence on the structure and function of communities) (Sheppard, 1995; Lutz & Musick, 1997) they might have played during periods of greater abundance. An example of the importance of these species include the die-off of seagrass in Florida Bay and the Gulf of Mexico during the 1980s directly linked to the ecological extirpation of *C. mydas* (Jackson, et al., 2001). Further, where sea turtle populations are severely depleted, there is the possibility of total ecosystem collapse on which people's livelihoods depend (McClenachan, et al., 2006).

Sea turtles are marine focal species (Frazier, 2005) with several characteristics mandating, but also complicating, deliberate inclusion in Marine Spatial Planning (MSP) processes, i.e. they are long-lived migratory species with broad distributions across multiple countries, and life histories that sees them inhabit both the neritic and oceanic environment (Luschi, et al., 2006; Bourjea, et al., 2008; Wallace, et al., 2010; Hamann, et al., 2013). The value of sea turtles is not limited to their representative role as focal species, but they also perform critical ecological functions in ocean ecosystems by maintaining healthy seagrass beds (Duarte, 2002) and coral reefs (Bellwood, et al., 2006), assisting to balance marine food webs (McClenachan, et al., 2006) and facilitating nutrient cycling from sea to land (Lutz & Musick, 1997; Wilson, et al., 2010; Shigenaka, et al., 2010). Their roles within ecosystems differ depending on the species and relative population size, yet even diminished populations play an important role in ocean ecosystems (Wilson, et al., 2010). Thus, given their overall importance and threatened status in the SWIO (IUCN, 2018), these species warrant further study.

In order to understand the nature and impact of threats on sea turtles, it's important to grasp the basic ecology of the species. Bolten et al. (2010) grouped sea turtle life-history in to eight stages namely: egg; hatchling terrestrial; hatchling swim frenzy and transitional; juvenile oceanic; juvenile neritic; adult oceanic; adult neritic and nesting female. The life-history of the four sea turtle species share numerous similarities (Lutz & Musick, 1997), although these widespread marine species often exhibit inter-population variation in life-history traits and population dynamics (Wallace, et al., 2010). Sea turtles are almost entirely marine living, with mature females returning to beaches primarily to nest (Shigenaka, et al., 2010). The pelagic hatchlings of most sea turtles live for several years in the open ocean where they shelter in so called weedlines (Sargassum or epipelagic debris) associated with convergence zones and open ocean gyres, returning as juveniles to nearshore habitats (Eckert & Abreu Grobois, 2001; Shigenaka, et al., 2010). The early life-history stages of all sea turtle species are earmarked by high mortality rates (Abreu-Grobois & Plotkin, 2008), yet they are a long-lived species that may grow in excess of 50 years old (Avens & Snover, 2013). Sea turtles of the families Cheloniidae and Dermochelyidae migrate hundreds of kilometres between feeding habitats and nesting colonies (Musick, 2002; Al-Mohanna & George, 2010). The importance of the above-mentioned similarities, and numerous others, lies in the fact that threats that affect sea turtles are often specific to particular life stages and not so much to the species per se.

1.1.2 Sea turtles and MPAs

Marine Protected Areas (MPAs) are a valuable conservation tool that greatly support protection of the marine environment from anthropogenic threats, and over the last decade there has been a substantial global expansion of MPAs in order to strengthen conservation efforts (Juffe-Bignoli, et al., 2014; UNEP-WCMC and IUCN, 2016). Globally, great strides have been made towards spatial conservation targets with the percentage of MPAs within national jurisdiction (opposed to the high seas) increasing from just more than 1 % in 1990 to 10.2 % in 2016 (UNEP-WCMC and IUCN, 2016). The SWIO boasts several expansive MPAs, e.g. the French Marine Nature Parks of Glorioso and Mayotte, which along with numerous other MPAs, protect sea turtles during certain life stages, e.g. iSimangaliso Wetland Park and Ponta do Ouro Partial Marine Reserve, which protect nesting beaches of both *C. caretta* and *D. coriacea* (Nel, et al., 2013). To this end, it has been advocated that if sea turtle populations are to avoid extinction, countries will have to support international agreements and programmes that provide coordinated protection of the species, and conservation of their habitat by means of MPAs (Mortimer, 2000).

In its simplest form, an MPA has two main functions it must fulfil: 1. It should sample or represent the biodiversity of each geographically distinct area; and 2. it should protect this biodiversity from activities that may threaten its persistence (Margules & Pressey, 2000). For MPAs to offer functional protection to exploited species they must protect a significant percentage of the specific population for an unlimited period of time (Acosta, 2002). However, since MPAs are spatially delineated, the accumulation and equilibrium population sizes of mobile species, such as sea turtles, will be subject to the size and boundary conditions of these sanctuaries (Acosta, 2002). Considering that sea turtles migrate for thousands of kilometres during their complex migratory lifecycle (Luschi, et al., 2006), in most cases sea turtles will move out of MPAs for extended periods. Consequently, for MPAs to meaningfully conserve sea turtles they must conserve them during certain critical periods. Part of this study will aim to determine what coverage by MPAs sea turtles need to be afforded during their main life history stages in order to successfully conserve the species.

1.1.3 **The hydrocarbon industry**

The hydrocarbon industry has changed the world immeasurably. Economies are built on it, politics are shaped by it, and the environment is transformed by it (Basedau, 2005). Although renewable energies are an emerging industry in the region's energy sources (Bugaje, 2004; Deichmann, et al., 2010), hydrocarbons i.e. non-renewables are still the main driver behind economic growth, which is seen as catalyst for changing the patterns of unemployment, poverty and equity that many African countries face (Ackah & Kizys, 2015). Economic growth enhances the standard of living and levels of development, and energy is a key a determinant of economic growth (Stern and Cleveland, 2004). The hydrocarbon industry has, however, been coined a "resource curse" in many sub-Saharan African countries (Basedau, 2005). Nigeria, Angola and Guinee are prime examples of countries where the exploitation of oil and gas has not delivered on the prospects envisaged with the initial greenfield discoveries, and has rather seen the demise of the social and biophysical environment (Frankel, 2010).

The hydrocarbon industry is a global industry traversing every continent on earth. The global community is intrinsically reliant on the hydrocarbon industry and will continue to be for the foreseeable future (WEF, 2016). The industry focuses on three types of products, namely: crude oil; natural gas; and condensates. It comprises three main parts, namely: the "upstream" sector, which focusses on exploration and production; the "midstream" sector which focus on storage and transportation; and the "downstream" sector, which includes refining and producing products from the hydrocarbons as well as distributing and marketing these products, (Figure 1 2) (Borthwick, et al., 1997). The focus in this study is the marine component of the upstream sector as it influences the sea turtle's persistence in the study area. This upstream sector is subdivided into two key phases: exploration and production. Exploration comprises three key stages: surveying, drilling and appraisal. If the appraisal of the resource is found to be favourable, then the production phase is initiated, which consists of development, production and decommissioning. Transport was included in this study where it related directly with exploration or production, i.e. transport of crude products from drilling by pipeline to terminals. These fundamental components of the upstream sector are pivotal to be able to distinguish the time and scale of potential impacts on sea turtles and their habitats.

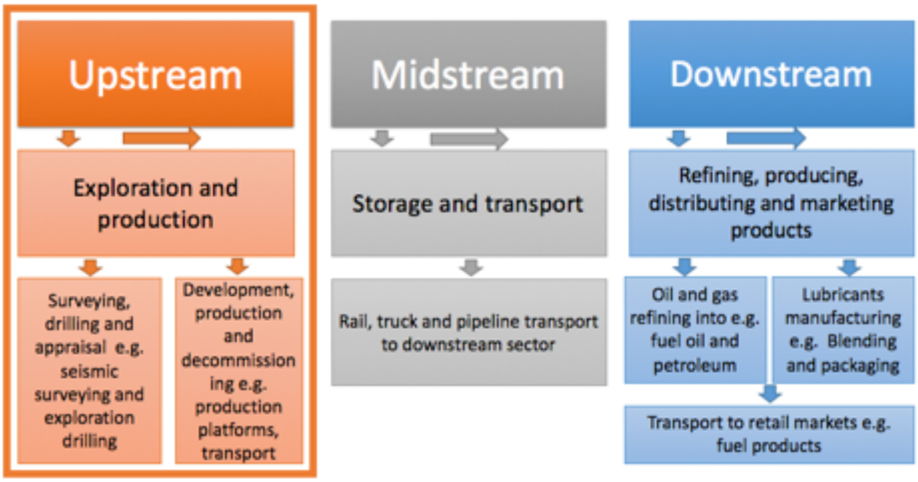

Figure 1-2 | The fundamental components of the upstream (orange), midstream (grey) and downstream (blue) hydrocarbon sectors, adopted from Borthwick et al (1997). The focus of this Dissertation is on the marine component of the upstream sector as it influences the sea turtle's persistence in the study area.

The very first step in the upstream sector is to find the resources. This is done by exploration surveying, a process that has essentially not changed since first initiated by geologists in the USA in 1912 (Borthwick, et al., 1997). Seismic surveys are the most common method of identifying potential source rock in the offshore environment. Seismic surveys are conducted by survey vessels from which an acoustic pulse is emitted (commonly through an seismic airgun). These results are then analysed to identify potential source rock. Once promising source rock has been identified, the only way to further to confirm the viability and existence of hydrocarbons is through exploration drilling. The appraisal process of a successful exploration well includes drilling more "appraisal wells" to establish the size and nature of the hydrocarbon deposit. Once the size and nature of the hydrocarbon deposit has been established, "production wells" are drilled. Several production wells may be drilled from a single production pad and each of the wells may contain several tubing strings, which produce oil or gas from different layers of source rock (Borthwick, et al., 1997). Production platforms are constructed because typical exploration drilling rigs aren't designed for full-scale operation. Production platforms can be made from steel or concrete and on large fields may be supported by several satellite platforms linked by subsea pipelines to the main production pad (Figure 1 3). Once the resource is successfully obtained it needs to get to the market in a usable form. Oil and gas can either be shipped or piped to the mainland from the production rig. Throughout all the exploration and production stages, there is significant vessel traffic to undertake seismic surveys as well as to transport infrastructure components, workers, waste and products between the mainland and offshore locations. By default, these vessels are reliant on access to ports and harbours within reasonable distance from the resource fields to support and supply the ongoing activities. Once the resource has been utilized to its full capacity and the wells reach the end of their commercial life, they are decommissioned. Decommissioning entails dismantling all associated infrastructure, rehabilitating and restoring the site, and capping the wells with a cement plug.

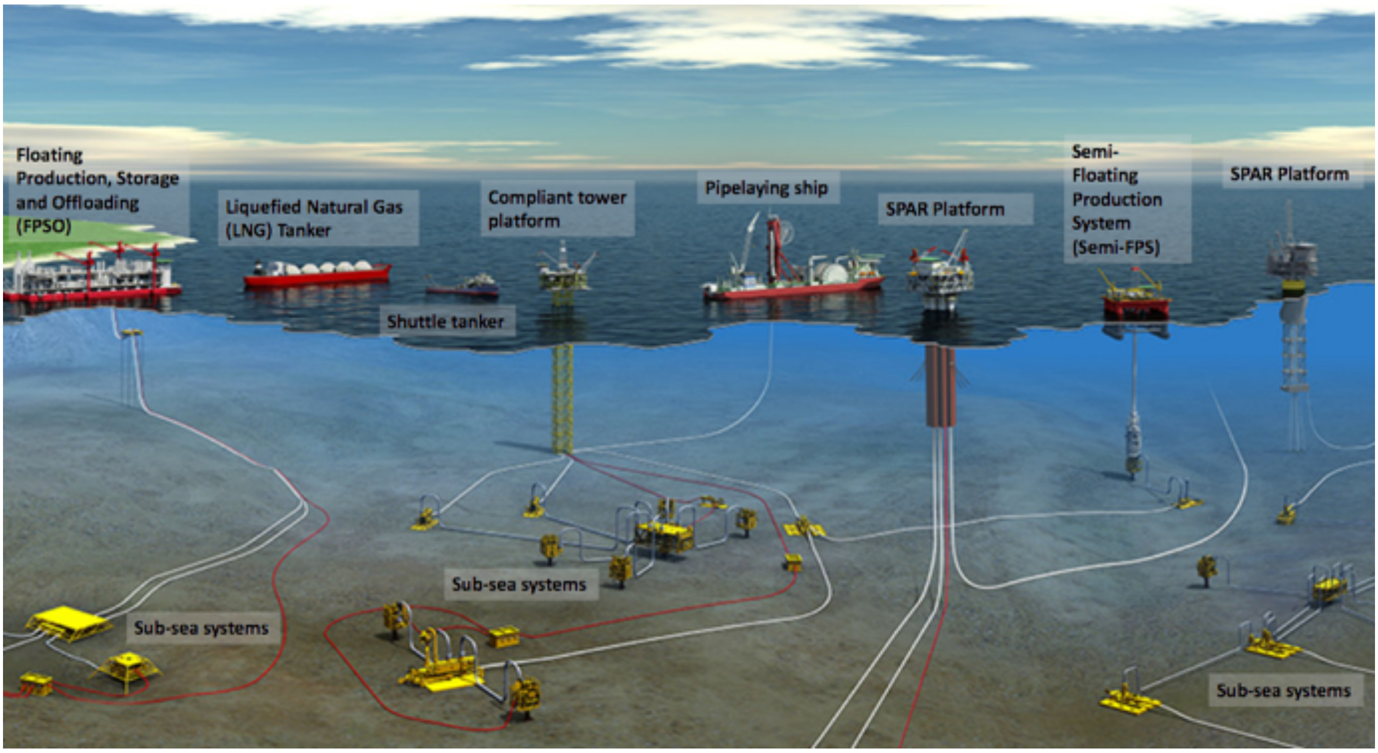

Figure 1-3 | Several different types of HEP vessels and infrastructure including production platforms supported by sub-sea systems, including satellite platforms, which are linked by pipelines to the main production platforms. (adapted from: http://www.genesisoilandgas.com, accessed 2018-10-04)

The SWIO's proven hydrocarbon reserves have increased significantly in the last few decades (ADB and AU, 2009). This includes significant finds of commercially viable gas in the offshore regions of Tanzania and Mozambique (African-Energy, 2015), and also lesser finds in South Africa and Kenya (Deloitte, 2014). Consequently, the governments of SWIO countries are keen to develop an attractive investment climate to accelerate economic growth and social development, exemplified by Operation Phakisa in South Africa designed to fast track the implementation of solutions on critical development issues, which includes offshore oil and gas (Spamer, 2015). The oil and gas industry has a long history in SWIO, with prospecting records dating back to the 1940s in Mozambique and 1950s in Kenya (Deloitte, 2014). However, the scale of the recent finds and speed at which the exploration and production are driven are unprecedented in the region. Further, simply the prospect of finding additional significant gas and commercially viable oil reserves will lead to even greater prospecting efforts in the rest of the region. The race to develop the hydrocarbon reserves is not only driven by the countries in which the discoveries have been made, but also first-world countries such as the United States of America and the People's Republic of China, who are actively competing for access to the SWIO's resources to stabilise their own dependencies (Frynas & Paulo, 2006). The economic pressure to rapidly develop a viable hydrocarbon export industry in SWIO is met with several significant challenges, including potential environmental impacts underpinned by a lack of environmental policies (Ledesma, 2013). Predictions that SWIO could become the world's third-largest exporter of natural gas over the long-term have been supported by a number of recent gas strikes on the region's seaboard (KPMG, 2013).

1.1.4 **Hydrocarbons and sea turtles**

A major potential anthropogenic stressor for sea turtles around the world is the hydrocarbon industry (Gitschlag & Barcak, 1997; Shigenaka, et al., 2010). The complex nature of the various sea turtle life-history stages along with multiple habitats utilised, expansive geographic ranges and subpopulation variability (Abreu-Grobois & Plotkin, 2008; Seminoff, 2004; Wallace, et al., 2013), makes it likely that any new hydrocarbon development could have some associated environmental perturbation on these species. The inherent variation in natural environments, the variable temporal and spatial scales of studies, and unpredictability of industry accidents has contributed to the difficulty to predict the potential long-term environmental impacts of offshore hydrocarbon industry (Holdway, 2002). However, the effects from offshore hydrocarbon industry related to offshore platforms, undersea pipelines, shipping channels, port terminals and other ancillary activities on sea turtles can be reduced with research-guided planning and operational changes through active management, e.g. monitoring of sea turtle occurrence, and adaptive management, e.g. making robust decisions on monitoring outcomes to affect positive change and improve management (Kamrowski, et al., 2012; Chevron Australia, 2014; Sinclair Knight Merz, 2014). Considering the depleted nature of most sea turtle stocks and evident current-day population declines, a holistic conservation approach that addresses threats at all sea turtle life-history stages is required (Dutton & Squires, 2011).

Environmental impacts related to hydrocarbon resource exploitation are well documented in countries like Australia (Melville, et al., 2009; Whittock, 2017), USA (Campagna, et al., 2011), and throughout Europe (Patin & LeProvost, 2001), which provides an appropriate prediction of what can be expected in the SWIO. Each phase of the hydrocarbon industry has its own suite of potential impacts. Of key importance is that exploration and production can exert multiple stressors on sea turtles, including inter alia: (i) pollution; (ii) habitat destruction and alteration; (iii) water sedimentation;(iv) disturbance; and (v) physical impact from vessels (Borthwick, et al., 1997; Iversen & Stokke, 2009; BPC, 2012). Importantly, none of these stressors are unique to the hydrocarbon industry (albeit they manifest in different ways); other sectors, i.e. fisheries and tourism, also contribute to these stressors and therefore no mitigation measure can inherently be viewed or implemented in isolation. For effective conservation strategies, it is therefore crucial that the relationships among the areas used by each population are identified to determine anthropogenic impacts at the population level (Wallace, et al., 2013). What is more, is that the stressors don't work in isolation and are often exacerbated by phenomena like sea-level rise which, e.g. cause shoreline erosion (Fuentes, et al., 2010), and in turn requires remediation action, which may further impact the natural environment due to habitat alteration (Ko & Day, 2004).

Sea turtles can be influenced by major catastrophic events such as oil and gas spills (National Commission, 2011), but often the cumulative effect of smaller chronic events is equally important, such as those from accidental spills from oil and gas extraction in the marine environment (Fraser, et al., 2008). However, information on how stressors associated with hydrocarbon activities explicitly interact with sea turtles, and to what extent this interaction negatively affects sea turtles has mostly been documented circumstantially. Exemplifying the anecdotal nature of this conflict is the remedial response to the 2010 Deepwater Horizon spill and the response of sea turtles to these actions. Remedial actions were taken as mitigation to the spill, which included the relocation of sea turtle nests in order to transport eggs away from beaches at risk of oiling (Peterson, et al., 2012). This action carried a huge risk of reducing Gulf populations by imprinting of surviving female sea turtles to return to nest on a different coast through a phenomenon known as natal homing (Peterson, et al., 2012). Furthermore, sand berms excavated to protect high value shoreline habitats from the oil slick preceding the spill created unstable and eroding areas where sea turtles previously nested (Peterson, et al., 2012), which would negatively influence sea turtle nesting success rate (Rumbold, et al., 2001). In précis, we know that there are multiple stressors from the hydrocarbon industry that might impact on sea turtles in different ways depending on the nature of the stressor and the response of the species to it, the prevailing environmental conditions and potential cumulative effect of other stressors. Exploring the impending conflict of sea turtles with major stressors to understand how they can be spatially represented is essential to this study.

1.1.5 **Assessing HEP impacts at a regional scale**

Comprehensive documentation of environmental impacts facilitates us in understanding what aspects underpin the significance of adverse impacts and the environment's ability to resist or recover from these impacts (Glasson, et al., 1994). This understanding enables us to predict potential impacts resulting from further exploitation of the natural resources and provides us with an opportunity to make decisions on impact acceptability, often guided by environmental law (Weiss, 2011). However, evidence of interactions of hydrocarbon activities with sea turtles are scarce, often documented circumstantially and the extent of these interaction often remain ill defined. This complicates remedial actions, e.g. the use of oil dispersants to break down crude oil spills (Barron, 2012), and the assessment of potential impacts relating to hydrocarbon activities, e.g. noise impact on sea turtles (McCauley, et al., 2000), since the science to back-up decisions is often weak. Therefore, to make decisions on where hydrocarbon developments can take place, and what activities and impacts might be permissible in certain areas, or at certain times, a standardise method that enables the assessor to make repeatable and defendable deductions on the potential impact and the acceptability thereof is needed (Morgan, 2002). This is especially important since decisions on proposed HEP developments are made based on potential future impacts in an environment (relating to both HEP and sea turtles) typically subjected to multiple variables, e.g. location of HEP infrastructure (Iyer & Grossmann, 1998), or dispersal of hatchling sea turtles (Scott, et al., 2014) and complexities, e.g. synergistic effects of environmental impacts (Cordes, et al., 2016).

There is often a substantial gap between research and implementation of management and conservation recommendations on environmental issues (Toomey, et al., 2016). This "research-implementation" gap also exists in global sea turtle conservation programs (Hamann, et al., 2010; Velez-Zuazo, et al., 2017); the SWIO, faced with potential large-scale developments such as HEP, is no exception. Each country in the SWIO has sea turtle monitoring and conservation programs but the challenge is on the known HEP impacts on turtles, to enable predictions on future impacts. Typically, before a decision is made to undertake a large-scale development associated with HEP, an Environmental Assessment (EA) would be undertaken to assist decision makers to consider the merits of the specific development, before granting an authorisation, or not. Although EA methodology has been widely utilised in many countries to inform Environmental Impact Assessments (EIAs) or Environmental Impact Statements (EIS), these studies are often site-specific or, in the case of Strategic Environmental Assessments (SEAs), are high-level consideration of policies, plans or programmes. These assessment methods are found to be inappropriate for predicating impacts on specific species, like sea turtles, across large spatial scales, and seldom consider multiple proposed HEP developments. Moreover, the limited inclusion of EIAs on wide-ranging inter-nesting movement patterns of sea turtles have been highlight as a flaw in ensuring adequate protection to inter-nesting sea turtles (Whittock, et al., 2014).

Classic EA methods take multiple variables of a specific scenario (e.g. project, plan, policy) into consideration, all of which are rated on a scale from low to high, and then combined to provide an end rating, whether it be positive, negative or neither (Morris & Therivel, 2001). It starts with a "process of identifying, predicting, evaluating and mitigating the biophysical, social, and other relevant effects of development…" (IAIA, 1999) prior to decision making. This study is an expert analysis, that will apply the first steps of the EA procedure to assess the impacts of HEP on sea turtles at an industry level across the EEZs of all countries in the study area. Although HEP is undertaken in a country-specific context, the extent of impacts, such as pollution, are likely to traverse country borders (Fraser, et al., 2008), either directly or indirectly. Comparably, sea turtles' nest and forage in specific countries, but their migratory life cycle may invariably see them migrate to waters of other countries. Hence, an objective and repeatable method that can evaluate impacts of HEP on species and their habitats, across a broad region, would be beneficial. Such an assessment can be applied with an area-based approach such as MSP to plan across different scenarios (Greiber & Knodel, 2007), and ultimately balance multiple use objectives through ocean zoning to reduce conflict between sea turtles and the HEP industry.

1.1.6 **Ocean zoning to reduce spatial conflicts between sea turtles and HEP**

MSP is a "*public process of analysing and allocating the spatial and temporal distribution of human activities in marine areas to achieve ecological, economic, and social objectives that are usually specified through a political process*" (Ehler & Douvere, 2009). Therefore, the MSP process can take the requirements of the marine ecosystem into account to protect areas essential to ecosystem processes, productivity, and function (Craig & Hughes, 2014). This is critically important since the foremost threat to marine ecosystem resilience is a loss of the ecosystem functions that marine biodiversity provides, leading to adverse regime-shifts. Thus, from a resilience perspective, the sum of species is less important than the functions that they perform (Craig & Hughes, 2014). MSP is usually implemented through ocean zoning, a tool which seeks to reduce conflict across seascapes, among different users, with multiple use objectives. However, ocean zoning may not apply across entire regions, i.e. areas not zoned can still be managed by other measures such as permitting. There are several benefits to ocean zoning, e.g. mitigating the negative effects of energy developments on numerous stakeholders by identifying specific energy-development zones (White, et al., 2012), and establishing spatial trade-offs between industries and other stakeholders (Yates, et al., 2015).

The challenge faced by ocean zoning is that when it's applied on a regional scale, e.g. in the SWIO region, the objectives which are typically specified through a political process (Ehler & Douvere, 2009) may become appreciably more complex. Implementing ocean zoning as part of MSP is not a new concept to the SWIO with the introduction of the Integrated Coastal Zone Management (ICZM) plans to the SWIO in the 1980s, and in 1993 the Arusha Resolution on ICZM was signed in response to the United Nations (UN) Rio Conference in 1992 (Linden & Lundin, 1996). These ICZM plans essentially divided the coastal areas into different use zones for different stakeholders that often had conflicting interest in uses (Linden & Lundin, 1996). These conflicting uses are still evident today with increased pressure from different stakeholders, e.g. infrastructure development, ocean-dependent communities and conservation entities (Obura, 2017). Today, countries like Seychelles are placing a strong emphasis on using MSP to create ocean zones to manage their Exclusive Economic Zone (EEZ) sustainably (SMSP, 2018). Subsequently, it's advocated that the implementation of regional-scale ocean zoning with the focus on sea turtles and the HEP industry, be dealt with in terms of an appropriate regional framework such as the Memorandum of Understanding on the Conservation and Management of Marine Turtles and their Habitats of the Indian Ocean and South-East Asia (IOSEA) (IOSEA, 2001). The objective of the IOSEA MoU is to "protect, conserve, replenish and recover marine turtles and their habitats, based on the best scientific evidence, taking into account the environmental, socio-economic and cultural characteristics of the signatory States" (IOSEA, 2001), and since all the countries in the SWIO are signatories to the IOSEA MoU, it is a suitable platform to oversee engagement between countries on the management of potential conflict between sea turtles and the HEP industry.

Central to undertaking ocean zoning, is a cumulative impact assessment that aims to identify areas of potential significant impact, e.g. from the HEP industry, and seeks to mitigate some of these impacts on, e.g. sea turtles, by excluding certain activities which might impact negatively on these species (Halpern, et al., 2008a). Given the potentially lucrative activities that the HEP industry would have to forego if in conflict with high importance sea turtle areas, a robust and defendable approach to prioritise sea turtle conservation areas will be required. Systematic Conservation Planning (SCP) is a tool that can be used to identify sites of high importance to sea turtles and prioritise for conservation areas through a process that is underpinned by the principles of representation, complementarity and irreplaceability (Margules & Pressey, 2000). Since part of the objective of SCP is to identify a conservation network, which contains a sufficiently representative collection of biodiversity features (Margules & Pressey, 2000), it would require comprehensive spatial information on areas important to sea turtles. Furthermore, the conservation areas selected based on importance to sea turtles must promote long-term persistence (Margules & Pressey, 2000), by maintaining their populations, and excluding potential impacts from HEP.

This study will use, Marxan decision-support software to run an automated selection of sites as part of the SCP process. The Marxan optimisation algorithm (Ball, et al., 2009) aims to select the fewest sites within a specific study area to comprise a conservation network. The algorithm is set to meet user-specified conservation targets for each feature, at the least cost (the cost is depended on the specific objective), e.g., 50 % of all coral reefs within a study site must be conserved in a reserve network at the least cost (high productivity fishing grounds) to the local fishing industry. Accordingly, the Marxan algorithm will preferentially select sites which will make up the 50 % coral reef target and avoid the areas that are of high cost (value) to the fishing industry. The Marxan algorithm attempts to find suitable network of sites through simulated annealing, an iterative optimisation process, which runs (repeats) a user-defined number of times and ultimately produces an optimal solution (and alternatives) given the input parameters. It also provides information on the number of times a specific site was selected to be part of the conservation network across all of the runs, which is indicative of the site's irreplaceability. It's the site irreplaceability (how useful a planning unit is for creating an efficient reserve system, based on selection frequency) that will be used to inform which areas are of conservation priority and should be included as part of zoning.

The SWIO is a prominent marine biodiversity hotspot, with a high degree of species endemism (Roberts, et al., 2002; Bellard, et al., 2013; Postaire, et al., 2014). Consequently, the region is of high conservation value, yet the marine biodiversity of the SWIO is one of the least known globally, with major gaps in many species' distribution records (Wafar, et al., 2011; Richmond, 2002). These gaps present several challenges to SCP, which can be overcome by using surrogates, including focal species, to help define effects of habitat modification, gaps in protected-area networks, conservation goals, monitoring and management responses (King & Beazly, 2005). Marine focal species are valuable for understanding, managing and conserving natural environments as well as informing the selection of protected areas (Zacharias & Roff, 2001; King & Beazly, 2005). Therefore, the application of sea turtles as focal species approach to support space-habitat perspectives (e.g. the Large Marine Ecosystem concept), may lead to more efficient planning of management zones, including MPAs (Campagna, et al., 2008). Due to the variable nature of ocean ecosystems, one species alone cannot make up for the paucity of data and limited methodological tools that underpin the concept of integrated ecosystem conservation as a framework to achieve sustainable management of biodiversity. It can, however, contribute to the integration of scientific knowledge, enhance international cooperation, and promote a rationale that most stakeholders can comprehend (Campagna, et al., 2008).

A big question for the SWIO is to what extent the previously demonstrated negative impacts from HEP on sea turtles (Shigenaka, et al., 2010; Hueter & Tyminski, 2012) will occur in the SWIO. Assuming that there will be a spatiotemporal overlap between areas important to sea turtles and HEP, it is imperative to quantify the extent of overlap to know where potential impacts might occurs. This will allow appropriate mitigation measures to implemented in order to resolve the space-use conflict. Sale et al. (2014) proposed the expanded use of MSP as a framework for more effective and practical management based on ocean zones to accommodate conflicting uses. Ocean Zoning as a planning mechanism can be used to manage both conflicts and compatibilities in ocean use and thus mitigate potential threats from HEP on marine focal species (Ehler & Douvere, 2009). Moreover, comprehensive Ocean Zoning is one management tool that can explicitly deal with the reality of the cumulative and interactive effects of multiple stressors (Halpern, et al., 2008a). Managing the ocean spatially makes intuitive sense because all activities and their associated consequences (threats or benefits) are essentially spatially explicit (Halpern, et al., 2008a). The goal is to direct and focus the planning of future hydrocarbon development in the SWIO in a way that minimizes its impact on sea turtles. This will likely transform how countries manage marine resources and will require major changes in policy and politics, implemented with sufficient flexibility to accommodate societal variations, e.g. different laws, rates of urbanisation and economic change (Sale, et al., 2014). Furthermore, it will require a willingness to relinquish exhausting the last portions of natural ecosystems for short-term economic gain, because once they are gone, it will be very difficult and expensive to bring them back, if they can be brought back at all (Sanderson, et al., 2002). Thus, the aim of this study is to is to derive priority areas for sea turtles in the face of HEP, that could be used in an ocean zoning strategy for sustainable economic development of HEP in the SWIO region.

1.2 Dissertation structure

This introduction (Chapter 1) covers the background to sea turtles and the hydrocarbon industry in the SWIO, as well as key concepts that are addressed throughout this Dissertation. This introduction is followed by three content chapters (Figure 1 4). Chapter 2, identifies high-use areas of sea turtles in the SWIO and quantifies the role of MPAs in sea turtle conservation based on the inclusion of these areas into MPAs. In Chapter 3, a method is developed to assess impacts from existing and proposed HEP developments specifically on sea turtles. Chapter 4 is a Discussion Chapter where the spatial products from Chapter 2, i.e., a map of the high use areas of sea turtle in the SWIO, and Chapter 3, i.e. a cumulative HEP impact map for the SWIO, is used in a MSP process, and SCP as tool with the use of Marxan software to derive a concept zoning of the SWIO. In conclusion, this concept zoning will propose to inform future decision-making pertaining sea turtle conservation and HEP development in the SWIO.

Note: All content chapters are written as stand-alone chapters to assist with the successive publication and therefore repetition may be evident from one chapter to the next, although an attempt was made to minimise repetition.

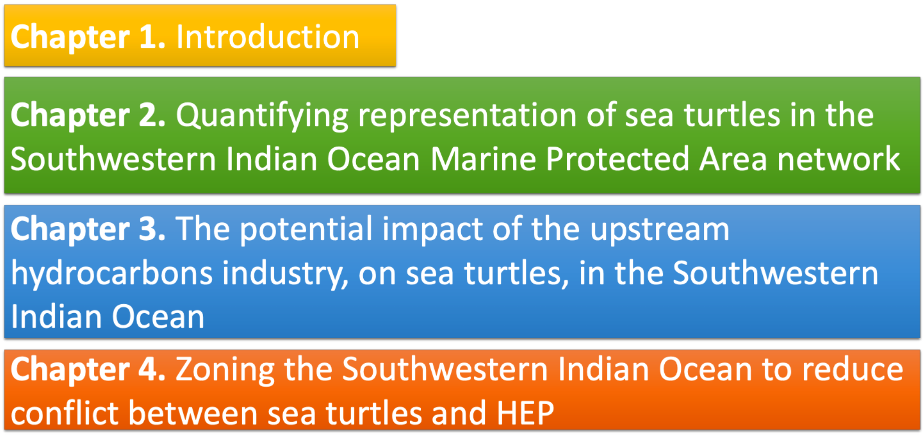

Figure 1-4 | The structure of this Dissertation, comprising an introduction and three content chapters of which Chapter 3 is also the Discussion Chapter.

1.2.1 **Chapter 2**

The **aim** of this study is to map three areas central to sea turtle life-history stages, i.e. breeding areas, foraging areas and migration areas, of four sea turtle species, to quantify the spatial extent of MPAs conserving sea turtles in the SWIO region. The **objective** is to determine the overlap between turtle distributions during main life-history stages and MPAs, in order to deduce whether these protected areas contribute to these species' current population trends. It's **hypothesised** that positive sea turtle population trends can directly be related to MPA coverage at regional scale of known areas critical for sea turtles. In order to quantify and compare areas of population increase for *C. caretta* and *C. mydas* in the SWIO, in-context of MPA coverage, this study will consider high-use sea turtle areas such as nesting beaches, internesting areas, foraging areas and migratory routes, at a regional scale in-context of telemetry-based distribution and relate MPA representation of these high-use areas to population trends. It's **predicted** that the key to understanding why populations of *C. caretta* are increasing exponentially, *C. mydas* are increasing, *D. coriacea* are stable and *E. imbricata* decreasing in the SWIO Regional Management Units (RMUs), lies in the fact that some or all of these high-use areas are sufficiently represented within MPAs under current conditions. The main **product** of this Chapter will be a map of foraging areas, breeding areas and migration areas for sea turtles in the SWIO, which will be used in Chapter 4 as a biodiversity priority features map.

1.2.2 **Chapter 3**

Given the potential impact of HEP on sea turtles in the SWIO, the **aim** of this chapter is to identify areas of HEP development that may significantly impact on sea turtles. The specific **objectives** are 1) to identify the HEP-related infrastructure and activities, and their location in the SWIO, and 2) to establish the type and extent of impacts (spatially), where they could impact on sea turtles and their habitats across different life-history stages; and 3) to derive a standardised, globally usable method to deal with the uncertainty of existing and future spatial conflict between HEP, and sea turtles including their habitat, in a comparable manner. It is **hypothesized** that HEP infrastructure and activities will be focussed on nearshore areas, with an offshore extent to the 1000 m isobath (with the exception of shipping lanes). It's **predicted** that if the focus of HEP infrastructure and activities are greatest in nearshore areas, up to the 1000 m isobath, then these areas will be most heavily spatially occupied by HEP infrastructure and will thus also have the greatest potential impact on sea turtles. The main **product** of this Chapter will be a cumulative impact map of the existing and proposed HEP industry in the SWIO, which will be used in Chapter 4 as a cost layer proxy for the HEP industry.

1.2.3 **Chapter 4**

The **aim** of this study is to derive priority areas for sea turtles in the face of HEP that could be used in an ocean zoning strategy for sustainable economic development of HEP in the SWIO region. The specific **objectives** are 1) to test increasing spatial biodiversity targets of sea turtle breeding, foraging and migratory areas in relation to lost opportunity cost to the HEP industry. It's **hypothesized** (1) that coastal areas will have the highest priority when biodiversity targets are low, because of fixed sites such as breeding areas of relatively limited extent, with migration and offshore areas to have the lowest priority, because they are large areas supporting sea turtles for only part of the time, and that migration and offshore areas will increase in priority as targets are increased. It's **predicted** (1) that there will be a high selection frequency of coastal sites and lower selection frequency for offshore sites, and for areas to increase as targets increase. As final outcome this study will attempt to provide a preliminary ocean zoning to highlight areas where increased protection to sea turtles and management of the conflict between sea turtles and the HEP industry will be required.

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Chapter 2 : Quantifying representation of sea turtles in the Southwestern Indian Ocean Marine Protected Area network

2.1 Abstract

Marine Protected Areas (MPAs) are a valuable conservation tool that greatly support protection of the marine environment from anthropogenic threats. However, due to the spatial limitations of these designated areas, their value to migratory species such as sea turtles is potentially limited, unless they are part of an extensive network of MPAs. This study aims to quantify the spatial extent of MPAs conserving sea turtles in the Southwestern Indian Ocean (SWIO) region. The objective is to determine the spatial overlap between the distribution of four species of turtles during three main life-history stages (breeding, migrating, foraging) and MPAs. It's is hypothesised that positive sea turtle population trends can be directly related to MPA coverage at regional scale of known areas critical to the life-history stages of sea turtles. To test the hypothesis, the breeding, migrating and foraging areas of *Caretta caretta* (loggerhead turtles), *Dermochelys coriacea* (leatherback turtles), *Chelonia mydas* (green turtles) and *Eretmochelys imbricata* (hawksbill turtles) were spatially represented within a distribution derived from telemetry data for each species. The spatial representation of the main life-history stages was then overlaid by existing MPAs in the study area. The results indicated that sea turtle breeding area inside MPAs included: *C. caretta* (~40 %), *D. coriacea* (~22 %), *C. mydas* (~53 %) and *E. imbricata* (~59 %), with *D. coriacea* being least protected during breeding. Sensitive habitats such as corals, seagrass and mangroves in coastal areas were substantively included in MPAs, ranging ~15% - 50 %, which meant that foraging areas for, *C. mydas* and *E. imbricata* were well represented in MPAs. Species specific foraging areas for *D. coriacea* and *C. caretta* were poorly represented in MPAs at ~3 % and ~8 %, respectively. The overall coverage by MPAs of sea turtle migratory routes were low at i.e. *C. caretta* (~4 %), *D. coriacea* (~2 %), *C. mydas* (~8 %) and *E. imbricata* (~9 %), however the intensity of use by *C. mydas* of MPAs were high at ~45 % of the highest intensity category based on telemetry data. The study found that MPA coverage of breeding areas, could be positively correlated to the increasing population trends of *C. caretta* and *C. mydas* in the SWIO, and therefore the conclusion was made that they are related.

2.2 **Introduction**

In most of the world's oceans, sea turtles have been reduced to remnants of past populations (Bjorndal & Jackson, 2003) and face multiple contemporary threats, such a plastic pollution and accidental capture by pelagic longline fisheries (Scott, et al., 2017). The persistence of sea turtle populations today is disadvantaged by historical population imbalances and lowered carrying capacities of ecosystems (Hamann, et al., 2010; Levy, et al., 2015) as well as being underpinned by future uncertainties e.g. climate change (Butt, et al., 2016). The global IUCN Red Listing of the four sea turtle species found in the SWIO range between Vulnerable (VU) for *Dermochelys coriacea*: leatherback turtles (Wallace, et al., 2013) and *Caretta caretta*: loggerhead turtles (Casale & Tucker, 2017), Endangered (EN) for *Chelonia mydas*: green turtles (Seminoff, 2004) and Critically Endangered (CR) for *Eretmochelys imbricata*: hawksbill turtles (Mortimer & Donnelly, 2008). However, at regional scale, *D. coriacea* is listed as Critically Endangered (Wallace, et al., 2013) and *C. caretta* as Near Threatened (NT) (Nel & Casale, 2015). *Lepidochelys olivacea*: olive ridley turtles (VU) (Abreu-Grobois & Plotkin, 2008) is a vagrant to the study area (Van der Elst, et al., 2015) with no substantial rookeries and with little regional information available on the species; it is therefore ignored for the rest of this study. According to the latest IUCN assessments *C. caretta* is the only species in the study area showing an increasing population trend (Nel, et al., 2013a; Nel & Casale, 2015), with indications that *C. mydas* has also recovered from negative population growth (Seminoff, 2004) to show increasing numbers at some rookeries (Bourjea, et al., 2007). However, the precarious position of D. coriacea, due to small population size (Nel, et al., 2013a) warrants protection measures that focus on the population protection and E. imbricata, due to declining numbers (Mortimer & Donnelly, 2008) warrants protection measures that focus on the population recovery, with due appreciation of how biology and management is poised within the parameters of the biophysical and social environment that underpin modern day conservation (Hamann, et al., 2010).

There are many current-day conservation measures that aid sea turtle populations (Campbell, 2007) both directly e.g. species-specific harvest regulations (Richardson, et al., 2006) and recovery or management plans (Roberts & Hamann, 2016), or indirectly e.g. habitat protection (Hamann, et al., 2010). Treaties and agreements such as the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) and the Convention on Migratory Species (CMS), help conserve sea turtles and their habitats through international cooperation. Furthermore, sea turtles, like many other migratory species (e.g., cetaceans and sharks), have been shown to benefit from overarching protection tools such as MPAs (Hyrenbach, et al., 2000), which may offer protection in, and of high-use habitats from direct and indirect threats. However, due to their migratory lifecycles, these species invariably move out of spatially designated protected areas where they become vulnerable to threats such as longline fisheries (Lewison, et al., 2004) or illegal, unreported and unregulated (IUU) fishing (Riskas et al., 2018). Considering conservation measures followed in the SWIO over the last few decades, the continuing decline of *E. imbricata* populations (Mortimer & Donnelly, 2008) means that these measures have been unable to turn around the fate of the species, yet certain measures have seen

D. coriacea relatively stable for the last three decades (Nel, et al., 2013a), whilst species such as *C. mydas* have shown increasing population trends (Bourjea, et al., 2007; Lauret-Stepler, et al., 2007), and *C. caretta* have shown exponential increase over the last decade (Nel & Casale, 2015). This is in due recognition that the short-term and long-term population trends in sea turtles are greatly influenced by the level of impact that came before the current day conservation measures were implemented (Mortimer, 2000) and current levels of enforcement.

The gaps in existing marine conservation tools (Murawski, 2007; Agardy, et al., 2011) and increased anthropogenic pressures on the marine environment (Stelzenmüller, et al., 2010) has seen a substantial global expansion of MPAs over the last decade in order to bolster conservation efforts (Juffe-Bignoli, et al., 2014; UNEP-WCMC and IUCN, 2016). Globally, great strides have been made towards spatial conservation targets with the percentage of MPAs within national jurisdiction (as opposed to the high seas), increasing from just more than 1 % in 1990 to 10.2 % in 2016 (UNEP-WCMC and IUCN, 2016). However, targets measuring the number and size of MPAs often provide a unidimensional display of political commitment to biodiversity conservation (Chape, et al., 2005). Moreover, sea turtle presence-only within an MPA, does not guarantee the persistence of a species with demanding habitat and area requirements (Rodrigues, et al., 2004). However, the limitations of MPAs in conserving migratory species, such as sea turtles, can be overcome through tools like large-scale marine spatial planning (MSP) (Agardy, et al., 2011). Global examples have shown where substantial portions of sea turtle foraging habitat, e.g. seagrass beds, are conserved in MPAs it protects the aggregations of sea turtles that feed on it (Scott, et al., 2012). Thus, the value of MPAs to sea turtles in the SWIO is potentially of great importance, yet to date the role of MPAs in protecting sea turtles at a regional scale remains poorly quantified.

Conservation strategies involving MPAs, which typically have fixed spatial boundaries, may be considered ineffective for managing sea turtles whose ranges are extensive and inherently dynamic (Bull, et al., 2013). Even in the case where MPAs do cover a sufficient spatial extent to theoretically conserve these species the regulations and enforcement of these areas play a pivotal role in their success. Considering this it's pivotal to note that whilst global population trends for *C. caretta* are still decreasing (Casale & Tucker, 2017), the increasing population trend of *C. caretta* in the SWIO regional management unit (Nel & Casale, 2015) implies that certain conservation measures (although not necessarily only MPAs) of this discrete population are successful. Studies in the SWIO on *C. caretta* have shown that coastal MPAs can attribute to the recovery of sea turtle populations (Nel, et al., 2013a). Comparable studies on *C. mydas* populations in Europa, Tromelin, Glorioso (Lauret-Stepler, et al., 2007) and Mayotte Island, prior to its designation as MPA (Bourjea, et al., 2007), have also shown positive population growth. Therefore, understanding the success in *C. caretta* and *C. mydas* protection in these locations may shed light on why protection tools such as MPAs succeed or fail sea turtles in the SWIO.

The aim of this study is to map three areas central to sea turtle life-history stages, i.e. foraging areas, breeding areas and migration areas, of the four sea turtle species, in order to quantify the spatial extent of MPAs conserving sea turtles in the SWIO region. The objective is to determine the overlap between turtle distributions during main life-history stages and MPAs, in order to deduce whether these protected areas contribute to the species current population trend. It's hypothesised that positive sea turtle population trends can directly be related to MPA coverage at regional scale of known areas critical for sea turtles. In order to quantify and compare areas of population increase for *C. caretta* and *C. mydas* in the SWIO, in context of MPA coverage, this study will consider high-use sea turtle areas such as nesting beaches, internesting areas, foraging areas and migratory routes, at a regional scale in context of telemetry-based distribution and relate MPA representation of these high-use areas to population trends. It's predicted that the key to understanding why populations of *C. caretta* are increasing exponentially, *C. mydas* are increasing, *D. coriacea* are stable and *E. imbricata* decreasing in the SWIO Regional Management Units (RMUs), lies in the fact that some or all of these high-use habitats are sufficiently represented within MPAs under current conditions. It's accepted that MPAs are not a fail-safe conservation measure for all sea turtle species as pressures change over time (Nel, et al., 2013a), yet the potential for MPAs to contribute towards positive population growth warrants a closer look at the factors that underpin the contribution to conservation success of these geographically defined areas.

2.3 **Methods**

2.3.1 **Study area**

The study area comprises the EEZs (Flanders Marine Institute, 2018) and coastal zones of the African mainland countries in the SWIO, i.e. Kenya, Tanzania, Mozambique, and South Africa (excluding the Prince Edward Islands). The island nations included are Madagascar, Mauritius, Seychelles, Comoros, and France with Réunion and the Scattered Islands - Europa, Juan de Nova, Bassas da India, Tromelin, Mayotte, and Glorioso (Figure 2 1). These EEZs fall within the Agulhas and Somali Current Large Marine Ecosystems (ASCLME/SWIOFP, 2012) and thus form an ecologically coherent study area. In total, the EEZs amount to 8 317 103 km2 (Flanders Marine Institute, 2018) of which 240 762 km2 (~3 %) is mapped as MPAs (Figure 2 1) within the EEZs (UNEP-WCMC and IUCN, 2018). Where conservation areas overlapped, they were dissolved into single geographic units because no distinction was made on the level of protection among MPAs. (Note that these analyses were undertaken prior to the announcement of 20 new MPAs for South Africa on 25 October 2018 that takes marine protection of mainland South Africa from 0.4 % to 5 %. The new boundaries were unavailable in time for inclusion in this study).

All data were mapped in the Geographical Information System (GIS) software, QGIS version 2.18.15 "Las Palmas" with GRASS 7.4.0. All data were projected into the European Petroleum Survey Group (EPSG) 54032, World Azimuthal Equidistant Coordinate Reference System (CRS) and converted to 10 km × 10 km grid comprising 83 491 grid squares. A grid square was classified as being inclusive of a feature if it intersected, contained, overlapped or touched the specific data layer. The planning unit resolution was chosen as a compromise between the coarse- and fine-resolution input datasets, and is consistent with European Union guidelines (Directive 2007/2/EC) and other large-scale regional planning studies (Kark, et al., 2009; Mazor, et al., 2014) used in the absence of specific African Union guidelines (AUC, 2012). The 10 km × 10 km resolution is deemed to provide a valuable baseline in sufficient detail to apprise the conservation value of MPAs, whilst it can easily be adjusted as more detailed or more accurate species data become available. Processing and analysis of summary statistics of the spatial data were undertaken in Microsoft Excel 2016.

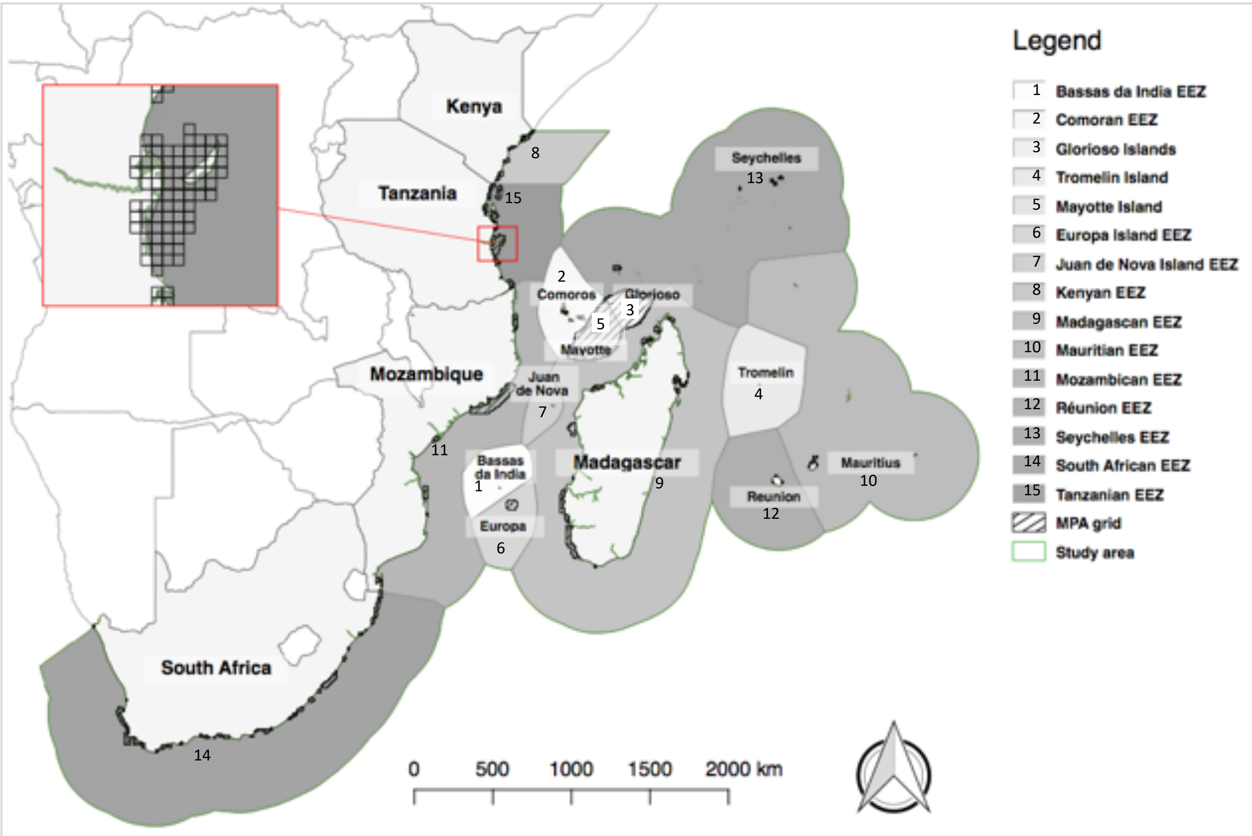


Figure 2-1 | EEZs and coastal zones of the respective countries and islands within the SWIO study area. MPAs are outlined in black with the entire study area in grey. An example of the 10 km x 10 km grid squares is provided in the insert.

2.3.2 Sea turtle information

All four sea turtle species have an approximated distribution that covers all of the study area (SWOT, 2018). However, the IOTC telemetry data (Nel, et al., 2013b) used to verify species distributions indicated that on a species-specific basis, the sea turtles' distribution was limited to ~31 % to ~58 % of the study area. In order to refine the result in this study for sea turtle in the Regional Management Units (RMUs), the IOTC telemetry data were used as proxy for sea turtle distribution. Although the telemetry-based distribution (hereon referred to as distribution) is biased towards adult turtles, mostly post nesting females (juvenile tracks were added where available, but they are underrepresented given lack of data, Appendix A), the focus on adults is justified because their relative reproductive value is much higher than that of juveniles (Wallace, et al., 2008), and because tracking data on the other size and age classes are largely lacking in the SWIO. Telemetry datasets for each sea turtle species were categorised in terms of the percentage of total tracks that intersected each grid square within the study area and graduated (arrange in a series based on intensity of use) into one of five classes (i. 0 %, ii. 1 – 25 %, iii. 26 - 50 %, iv. 51 - 75 % and v. 76 - 100 %), of which this first class (0 %) are units inside the study area, yet outside the distribution. The data were graduated in order to differentiate between species-specific low-use areas to high-use areas. The number of tags accounted for in the IOTC data included *D. coriacea* (30), *C. caretta* (20), *C. mydas* (35) and *E. imbricata* (8). Also, the 2.5° X 2.5° grid across the IOTC was transformed to a 10 km x 10km grid, thus the results are susceptible to influences in terms of effort and scale. Available data from published and unpublished sources (Appendix A) were assembled to create maps of sea turtle-use areas for three life-history stages: breeding, foraging and migration areas. Currently there is no single repository for sea turtle data and data sets differ substantially in scale and methodology used to collect the data. Also, some datasets, like sea turtle nesting sites, include location-based information on species that are sensitive to poaching (Bourjea et al., 2008) and illegal wildlife trade (Senko et al., 2011). Therefore, consideration must be given when disseminating the data and results without compromising these populations. Consequently, not all data sources are made available from open sources and not all data can be shared which does limit large scale projects dependant on multiple data sources.

2.3.3 **Mapping breeding areas**

Nesting sites were obtained from the SWOT database (SWOT, 2018). Sites where populations were unquantified, or had only anecdotal accounts of incidental nesting, were excluded from analysis. An internesting data layer was created using a 5 km buffer from nesting sites for *C. caretta*, *C. mydas* and E. imbricata. The 5 km buffer is based on a relative mean of findings from a number of studies that looked at the distances travelled by female turtles during internesting periods (Hart, et al., 2010; Waayers, et al., 2011; Walcott, et al., 2012; Walcott & Horrocks, 2014; Harris, et al., 2015). It must be noted that this is a generalisation of internesting habitat use which differ among species and rookeries. A separate analysis was undertaken for *D. coriacea* because the internesting distribution mean distance of ~60 km from the shore (Harris, et al., 2015). The nesting and internesting layers were consolidated into a breeding area layer, since the spatial differentiation between these two layers at a 10 km × 10 km spatial resolution would be mostly inconsequential and since nesting and internesting presents one key life phase i.e. internesting does not occur in isolation of nesting. No quantitative distinction was made based on the size of the rookeries, i.e. they were equally weighted.

2.3.4 **Mapping foraging areas**

Foraging areas were mapped on basis of species-specific dietary requirements. Data from various international sources were collated for coral reefs (UNEP-WCMC, 2010), seagrass (UNEP-WCMC, 2016), seamounts (Yesson, et al., 2011) and mangroves (Giri, et al., 2011). All appropriate foraging habitats were clipped to the distribution of the specific turtle species. No specific juvenile foraging areas were included because juvenile foraging grounds are not mapped for the SWIO. However, some studies suggested that the foraging grounds of juveniles of certain sea turtle species becomes their foraging grounds as adults (Hays, et al., 2010; Scott, et al., 2014). Hence, the foraging areas included for adult females is assumed to provide a reasonable surrogate for the majority of juveniles, even if they are from other rookeries or RMUs.

Foraging areas for *C. mydas* consisted of seagrass meadows within the species distribution, which along with marine algae (there is currently no geospatial information available for marine algae in the study area), form the basis of the species' diet (Bjorndal, 1997; Arthur, et al., 2008). *C. caretta* feed on a variable diet of crustaceans, salps, fish and numerous other benthic and pelagic organisms (Bjorndal, 1997; Thomas, et al., 2001), therefore seagrass meadows and coral reefs (Williams et al., 2017) within the species distribution were mapped as their foraging areas. *C. caretta* are also known to feed in deeper, soft bottomed habitats found on seamounts (Morato, et al., 2008) and therefore these areas within the species distribution were included as foraging areas. Several of *C. caretta* foraging habitat types do not have robustly mapped habitat proxies i.e. soft bottom sediments (on the continental shelf not associated with seamounts) (Plotkin, et al., 1993) and pelagic grounds where they feed on fish (Thomas, et al., 2001). Therefore, a supplementary layer was created based on known *C. caretta* foraging area (Harris, et al., 2018) and a buffer of 30 km around coral reefs within the *C. caretta* distribution as proxy for soft bottom sediments based on findings from Harris et al., (2018) on the species movements during foraging.

E. imbricata feed primarily on sponges and anthozoans (León & Bjorndal, 2002) and therefore coral reefs were mapped as foraging areas. Although *E. imbricata* ingest seaweeds and seagrass, it's believed that this occurs incidentally because they tend to grow in close proximity of certain demosponges (Von Brandis, et al., 2014) and hence seagrass meadows were not included as a proxy for their foraging areas. Mangroves are important developmental and foraging grounds for juvenile sea turtles (and in some cases adults) of the *E. imbricata* (Gaos, et al., 2012), *C. caretta* (Foley, et al., 2000) and *C. mydas* (Limpus & Limpus, 2000) were included under these species foraging area (Robinson, et al., 2017).*D. coriacea* have highly-specialized dietary requirements, which consist of gelatinous zooplankton (Wallace, et al., 2015) e.g. jellyfishes, siphonophores and salps (Henschke, et al., 2016), which means their prey can theoretically be found anywhere in their distribution. This study used only seamounts as a foraging area proxy for *D. coriacea* since these features are associated with increased productivity (Santos, et al., 2007; Morato, et al., 2008; Fossette, et al., 2010). Records of *D. coriacea* diving depth go as deep as ~1300 m (Doyle, et al., 2007), yet seamounts with greater summit depths still see increased prey productivity in the water columns above due to localised upwelling (Pitcher, et al., 2007; Probert, et al., 2007). Therefore, all seamounts rising more than 1000 m from the seafloor were treated as being of equal importance. Although other means of establishing key foraging areas have been suggested as proxy for *D. coriacea* e.g. oceanic frontal systems where prey productivity is high (ALTRT, 2006), these areas and their relationship with *D. coriacea* are poorly defined for the region and thus not used in this study as foraging area proxy. However, a supplementary layer was created based on known *D. coriacea* foraging areas (Luschi, et al., 2006; Lambardi, et al., 2008; Robinson, et al., 2016; Harris, et al., 2018).

2.3.5 **Mapping migratory areas**

Sea turtle migratory areas within the study area were derived from telemetry data on *C. caretta*, *D. coriacea*, *C. mydas* and *E. imbricata* obtained from an Ecological Risk Assessment and Productivity - Susceptibility Analysis of sea turtles overlapping with fisheries in the Indian Ocean Tuna Commission (IOTC) region Nel et al., (2013b) and supplemented by State of the World's Sea Turtles (SWOT) telemetry data (Appendix A). The IOTC data did not included the west coast of South Africa and therefore telemetry tracks from SWOT were used to supplement this region for *C. caretta* and *D. coriacea*. The data from Nel et al., (2013b) as supplemented by the SWOT data, were converted from original 2.5^{o} grid squares to smaller 10 km × 10 km grid squares (hence the square appearance of telemetry data). Finer scale data and individual tracks could not be shown due to data protection considerations of the primary data holders. To distinguish between migratory areas and other high-use areas, i.e. foraging areas and breeding areas, the latter were clipped from the telemetry data which provided a layer showing only the migratory routes.

2.3.6 Data analysis

The data were analysed based on the number of grid squares (spatial extent) of breeding areas, foraging areas and migratory areas inside and outside MPAs, within the distribution of each species. This output was displayed in terms of percentage area inside and outside MPAs, across the main life-history stages and compared in terms of the relative percentages. In order to break down the MPAs coverage of distribution, the intensity of use based on telemetry data was categorised into five classes and the percentages of each class compared in terms of intensity to distinguish the area usage of the species within its specific distribution. The results on the analysis of the life-history stages, in terms of MPA coverage, were compared to the current population trends of the specific-species in the study area. A list of all data sources are provided in Annexure A of this Dissertation.

2.4 Results

2.4.1 Breeding area analysis

The breeding areas *C. caretta* were confined to the north coast of South Africa and the adjoining south coast of Mozambique, with one small breeding site situated of the south coast of Madagascar near Fort-Dauphin and Manantenina (Haman et al., 2013). The breeding area of *D. coriacea* was limited to only one continuous site on the north coast of South Africa and the adjoining south coast of Mozambique. The breeding areas of *C. mydas*, included several sites on the SWIO islands of Seychelles, Mayotte, Glorioso, Europa and Madagascar as well as site on the East African cost in Mozambique, the coastal islands near Tanzania and northern Kenya. Breeding areas for *E. imbricata* includes the islands of Seychelles, Comoros, Mayotte, Juan de Nova and Madagascar with one site in northern Kenya. The percentage of sea turtle breeding area inside MPAs, included: *C. caretta* (~40 %), *C. mydas* (~53 %), *D. coriacea* (~22 %), and *E. imbricata* (~59 %), (Figure 2-2). The markedly lower percentage of *D. coriacea* (~22 %) breeding areas inside MPAs is likely a function of the significantly greater internesting area, 60 km radius from the shore, allocated to *D. coriacea* compared to 5 km radius for the other species.

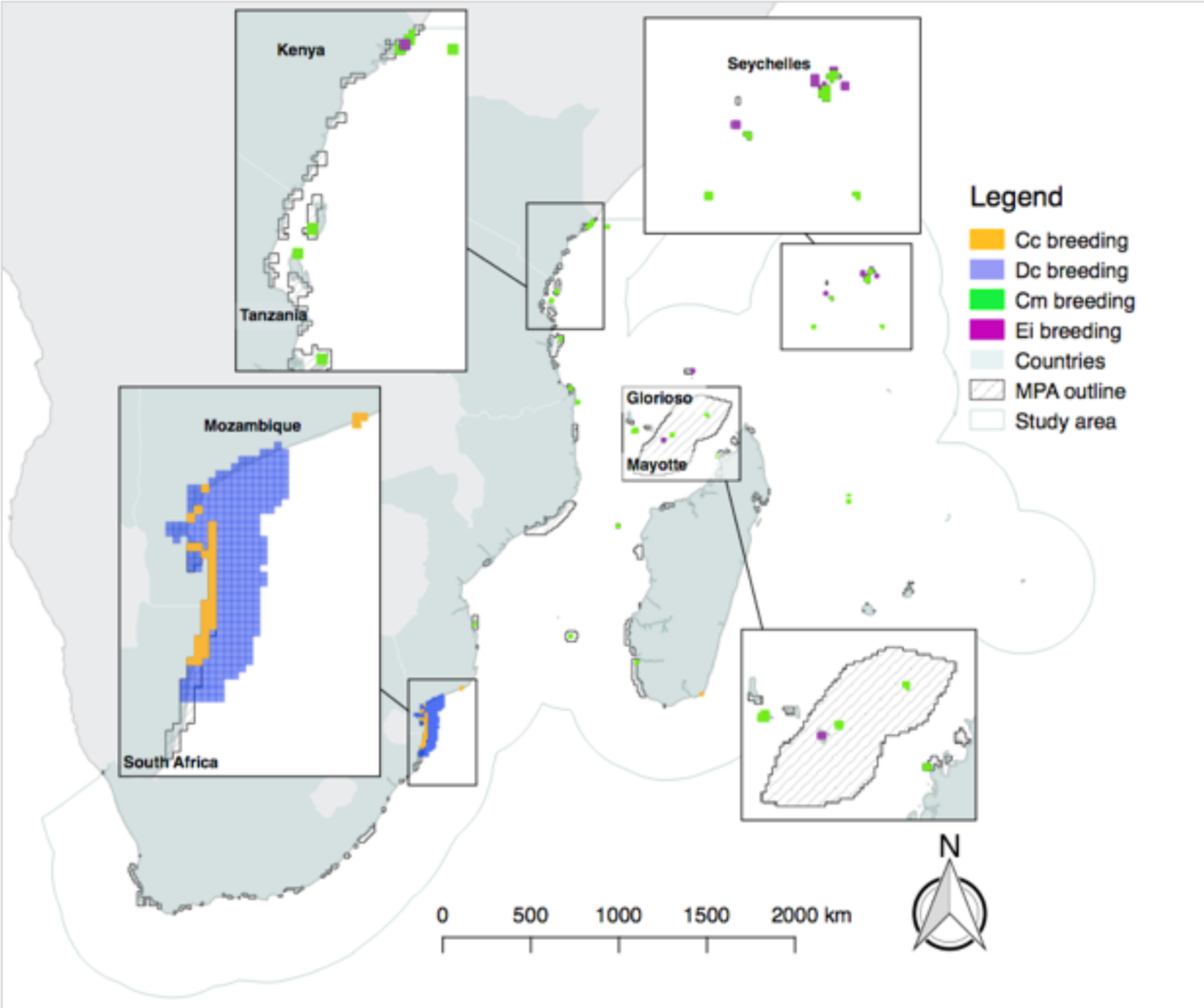


Figure 2-2 | Sea turtle breeding areas for *E. imbricata,* Ei (purple), *D. coriacea,* Dc (blue), *C. mydas,* Cm (green) and *C. caretta,* Cc (orange). Also included is the MPA grid outline (black) for the study area. The top left-hand corner illustrates the 10 km × 10 km grid used to map breeding areas, in this case on the border of Mozambique and South Africa.

2.4.2 **Foraging area analysis**

The foraging areas for *C. caretta* and *D. coriacea* included vast offshore areas in the ocean south of South Africa and then coastal areas in Mozambique, on the Sofala bank and several sites in the Mozambique channel (Figure 2-3 and Figure 2-5a and b). Areas around the islands of Reunion and Mauritius were also identified. The foraging areas for *D. coriacea* extended towards the west coast of South Africa as well as a greater extent offshore from the Sofala bank in Mozambique. The foraging areas for *C. mydas* were all coast associated spanning the east coast of Madagascar and the East African coast from southern Mozambique to northern Kenya (Figure 2-3 and Figure 2-5c). The foraging areas for *E. imbricata* included northern and eastern Madagascar, the islands of Mayotte, Glorioso, Juan de Nova, Comoros, Seychelles, Mauritius, Reunion and the coastal areas of Tanzania and Kenya (Figure 2-3 and Figure 2-5d).

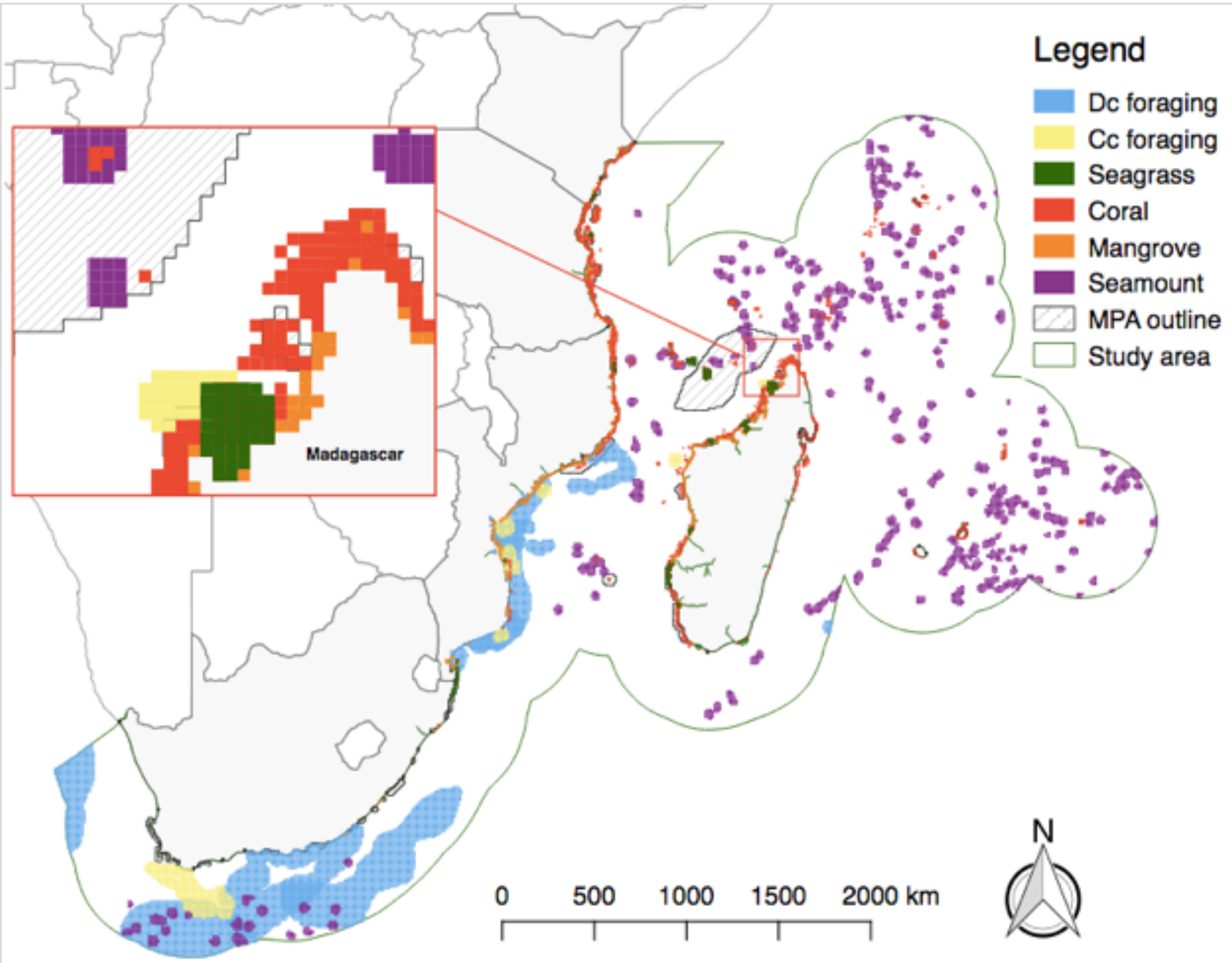


Figure 2-3 | Spatial representation of sea turtle foraging areas specifically for *D. coriacea* (blue) and *C. caretta* (yellow) as well as habitat types, including: seagrass (green), seamounts (purple), coral (red) and mangroves (orange) respectively. Also included are the MPA grid outlines (black) for the study area. The top left-hand corner illustrates the 10 km × 10 km grid used to map each of the foraging area, in this case around northern Madagascar.

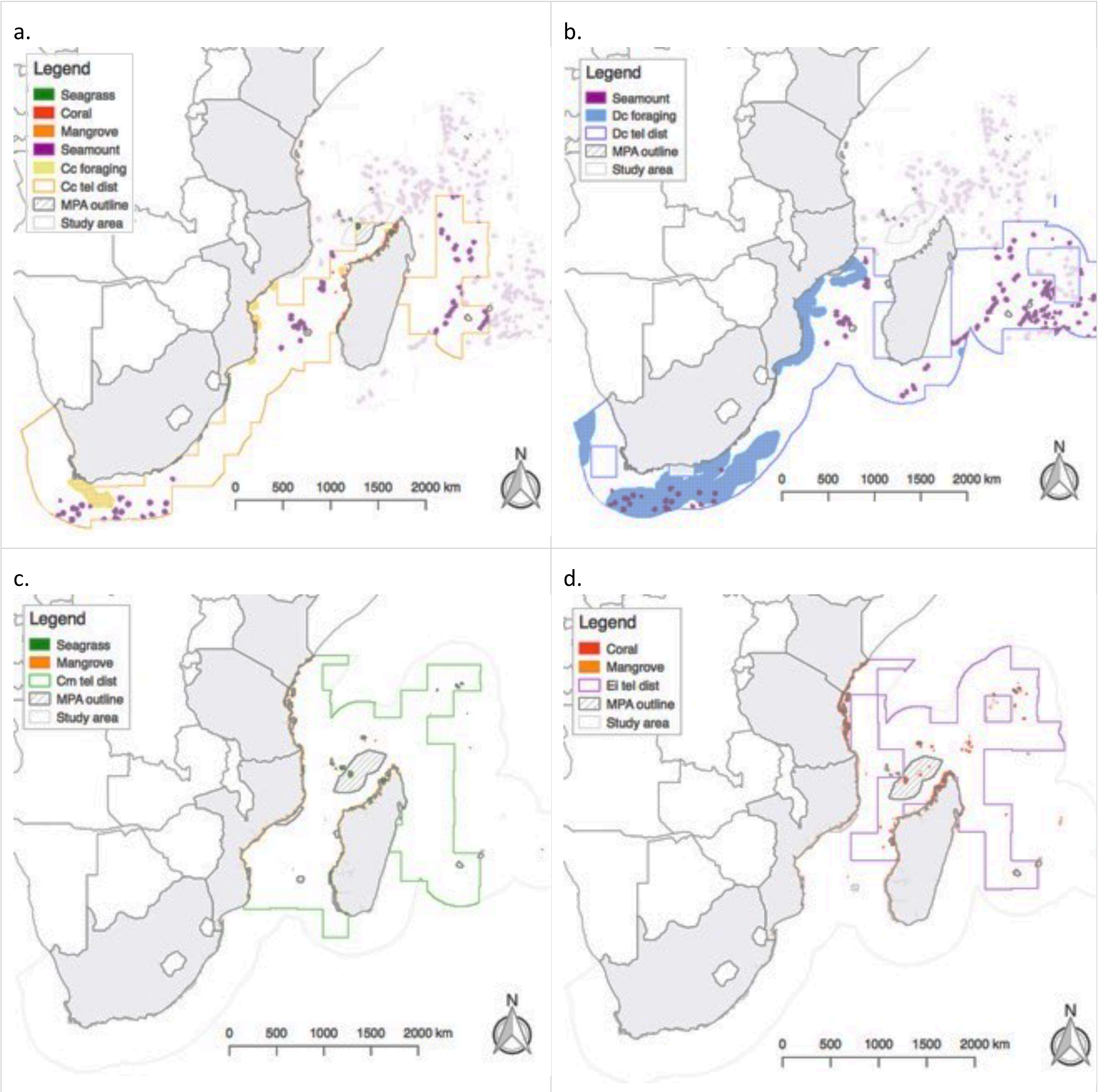
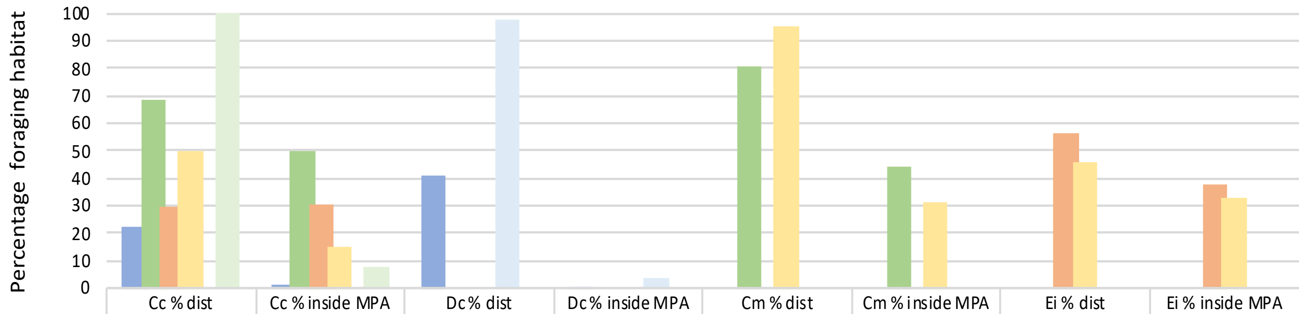


Figure 2-4 | Seamount, seagrass, coral, and mangrove foraging areas, as well as specific foraging areas for *C. caretta* and *D. coriacea*, as function of the distribution (outline) of *C. caretta,* CC (a. orange outline), *D. coriacea,* DC (b. blue outline), *C. mydas,* CM (c. green outline) and *E. imbricata,* EI (d. purple outline).

D. coriacea foraging areas i.e. seamounts are markedly under-protected by MPAs (less than ~1 %), compared to the other foraging areas (Figure 2-5). Seamount inclusion for *C. caretta* is similarly low at ~2 %, yet the importance of most seamounts included in the analysis to *C. caretta* is likely low based on the species maximum diving depth and hence ability to access food associated with these seamounts (Morato, et al., 2008). The inclusion of specific foraging layers for *D. coriacea* (~3 %) and *C. caretta* (~8 %) is markedly low (Figure 2-5), possibly due to the vast extent and pelagic nature of these areas. Coral, seagrass and mangrove inclusion into MPAs for all species are substantive, likely due to these habitats being of high conservation value (Unsworth, et al., 2008; Almany, et al., 2009) and because they are situated in coastal areas (Agardy, et al., 2011). The mangrove inclusion for *C. caretta* within its distribution is low at ~15 %, possibly explained by the species' temperate and subtropical distribution (Casale & Tucker, 2017), whilst mangroves are generally confined to tropical and subtropical regions (Giri, et al., 2011).



	Cc % dist	Cc % inside MPA	Dc % dist	Dc % inside MPA	Cm % dist	Cm % inside MPA	Ei % dist	Ei % inside MPA
Seamount	22	2	41	0				
Seagrass	69	50			80	44		
Coral	29	31					56	38
Mangroves	50	15			95	31	46	33
Dc foraging			97	3				
Cc foraging	100	8						

Sea turtle species

Figure 2-5 | The MPA coverage of foraging areas for *C. caretta* (Cc), *D. coriacea* (Dc), *C. mydas* (Cm) and *E. imbricata* (Ei) based on the percentage inclusion within their distribution. % Dist = Percentage of habitat type in study area within distribution; % inside MPA = Percentage of habitat coverage inside MPAs within telemetry-based distribution. Habitat type represented include seamounts, seagrass, corals and mangroves as well as specific foraging layers for *C. caretta* (Cc foraging) and *D. coriacea* (Dc foraging).

2.4.3 Distribution and migration area analysis

The distribution areas for *C. caretta and D. coriacea* included the waters of South Africa and Mozambique and the islands of Madagascar Europa, Juan de Nova, Bassas da India, Tromelin, Mayotte, Glorioso Mauritius. The distribution areas for *C. mydas*, included the water of Mozambique, Tanzania and Kenya as well as the island of Madagascar, Mauritius, Seychelles, Comoros, Réunion, Europa, Juan de Nova, Bassas da India, Tromelin, Mayotte, and Glorioso. The distribution areas for *E. imbricata,* included the coastal water of Tanzania and Kenya as well as island of Madagascar, Mauritius, Seychelles, Comoros, Réunion, Juan de Nova, Bassas da India, Tromelin, Mayotte, and Glorioso. The distribution of the species in the study area (Figure 2-7) represent only a portion of the study area, i.e. *C. caretta* (~37 % of the study area), *D. coriacea* (~58 %), *C. mydas* (~49 %) and *E. imbricata* (~31 %), (Figure 2-6). Consequently, the percentage MPA coverage within the distribution differs for each species differs from the total study MPA coverage of ~3 %, i.e. *C. caretta* (~4 %), *D. coriacea* (~2 %), *C. mydas* (~8 %) and *E. imbricata* (~9 %). As expected, based on the species vast migratory extent these percentages are low.

The vast expanse of the Mayotte and Glorioso Marine Nature Park, which is fully included in *C. mydas* and *E. imbricata* distribution and partially in *C. caretta* distribution, represents ~54 % of the MPAs in the study area (Figure 2-2). The Mayotte and Glorioso MPAs alone account for around ~5 % of *C. mydas* and ~3 % *E. imbricata* coverage of MPAs. In order to break down the MPAs coverage of distribution, the intensity of use provide insight to sea turtle use areas within MPAs (Figure 2-6). These results indicate that *C. mydas* has a comparatively large percentage of grid squares (~45 %) in the highest use intensity category (76 - 100 %) within MPAs, which is indicative of the inclusion of high-use areas for *C. mydas* into MPAs. In the same use intensity category *C. caretta* (~4 %), *D. coriacea* (~6 %) and *E. imbricata* (~6 %), have fairly low inclusion into MPAs, which is the same for the other use intensity categories.

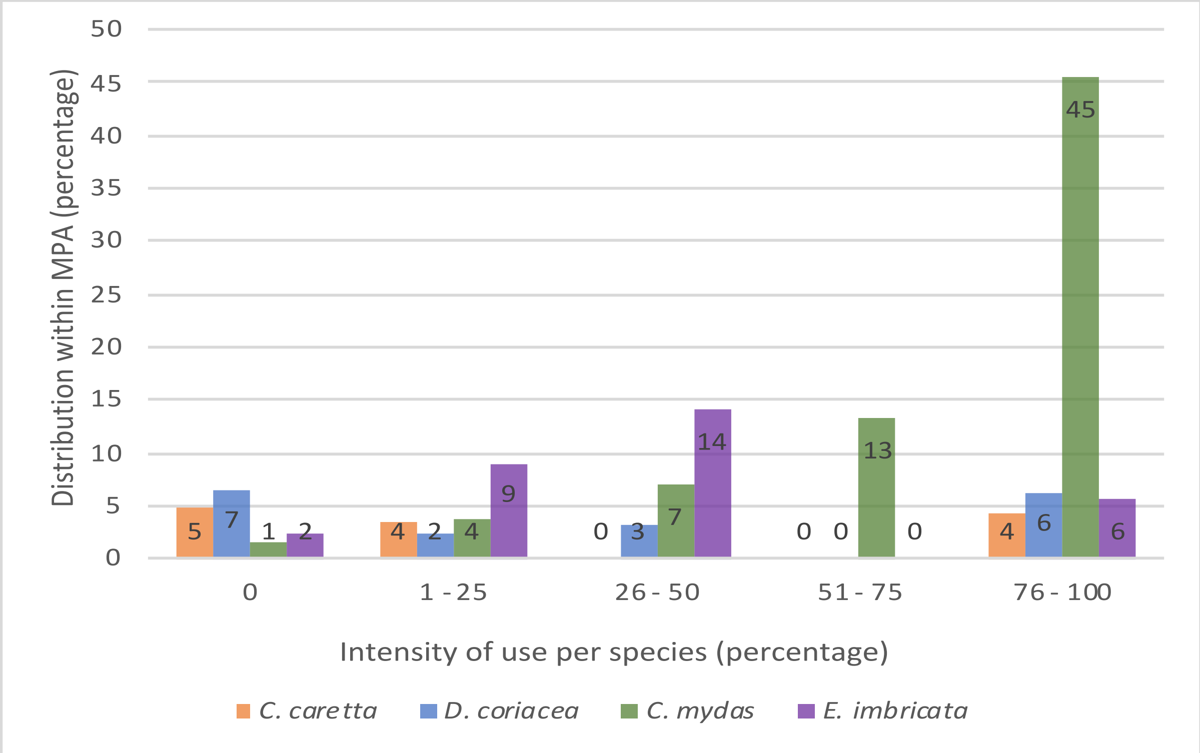


Figure 2-6 | Percentage of each of the five use intensity categories (i. 0 %; ii. 1 - 25 %; iii. 26 - 50 %; iv. 51 - 75 %; and v. 76 - 100 %) inside MPAs containing sea turtle telemetry tracks, per species. Percentages are based on the intensity of sea turtle use, as function of the percentage telemetry tracks within each grid square.

Only a fraction of the migration routes of each species are included in MPAs; for *C. caretta* (~3 %), *D. coriacea* (~2 %), *C. mydas* (~7 %) and *E. imbricata* (~7 %), which is expected given the vast extent of the species migratory range Figure 2-7. When the extent of distribution and migratory areas are compared, the difference in extent exemplifies the small portion of breeding and foraging covered by MPAs, i.e. *C. caretta* (~0.6 %), *D. coriacea* (~0.1 %), *C. mydas* (~1.2 %) and *E. imbricata* (~1.7 %).

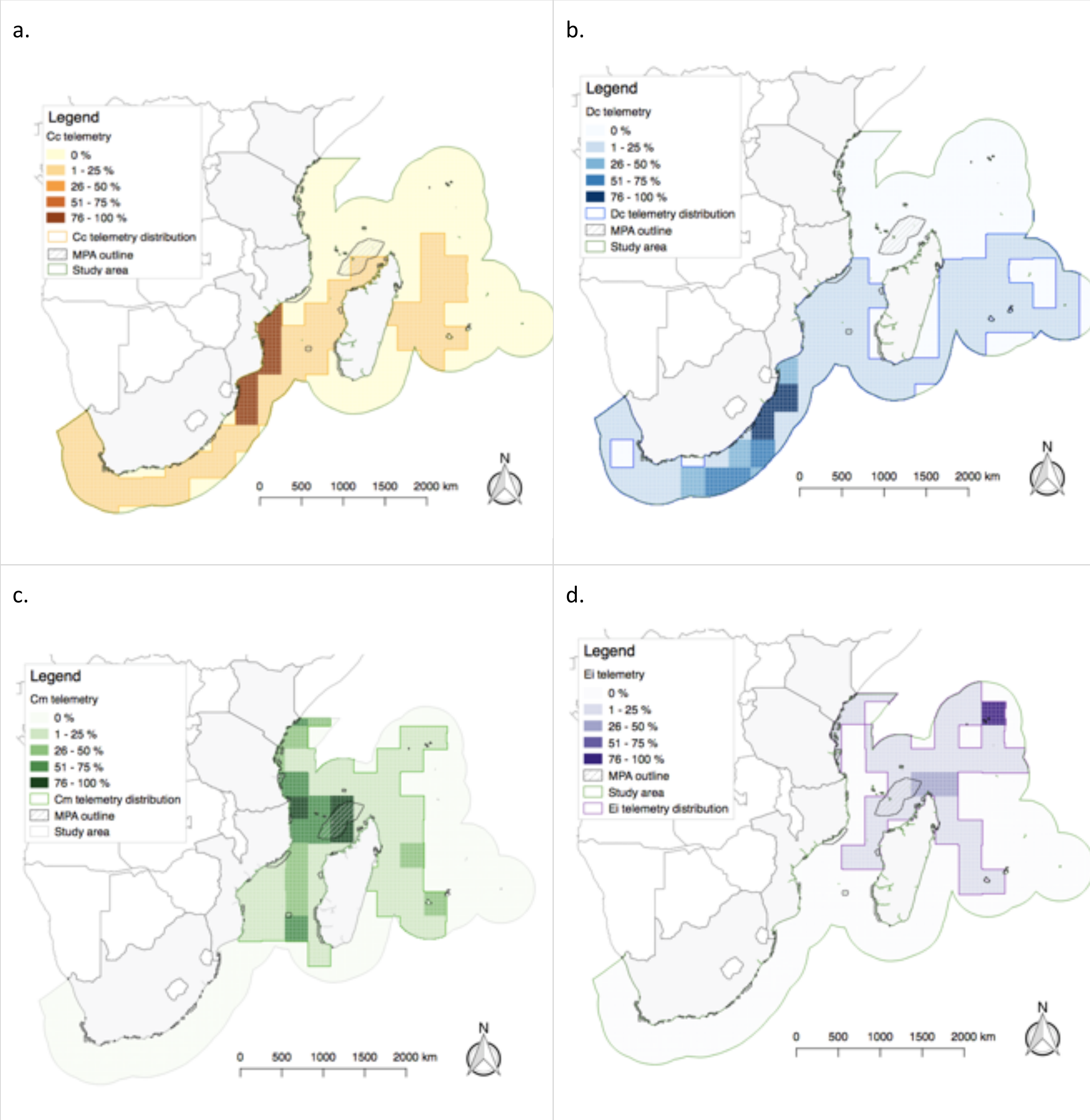


Figure 2-7 | Distribution of *C. caretta*, Cc (b. orange); *D. coriacea*, Dc (a. blue); *C. mydas*, Cm (c. green); and *E. imbricata*, Ei (d. purple), as per telemetry data (Appendix A). MPAs are outlined in black. Grid squares are 10 km × 10 km (derived from 2.5o grid squares). Each grid square within the study area was graduated into one of five groups based on the percentage of total telemetry tracks intersected by each square: i. 0 %; ii. 1 - 25 %; iii. 26 - 50 %; iv. 51 - 75 %; and v. 76 - 100 %.

2.5 Discussion

The aim of this study was to map three life-history stages, i.e. foraging areas, breeding areas and migration areas, of the four sea turtle species, to quantify the spatial extent of MPAs conserving sea turtles and their habitat in the SWIO region. The objective was to determine the overlap between turtle distributions during three main life-history stages and MPAs, in order to deduce whether these protected areas contribute to the species current population trend. It was hypothesised that positive sea turtle population abundance trends can directly be related to MPA coverage at regional scale of known areas critical for sea turtle. This study found that *C. caretta* and *C. mydas* have substantive MPA protection for breeding areas, which was correlated to high usage of the largest breeding sites in terms of females nesting (Bourjea, et al., 2007; Nel & Casale, 2015). Since both *C. caretta* (Nel & Casale, 2015) and *C. mydas* (Bourjea, et al., 2007) are showing positive population trends the assumption was made that they are related and hence, MPAs are contributing to the positive population trend. Conversely, *D. coriacea* has a low MPA coverage of breeding areas, where the species move out of the MPAs during internesting periods even though the actual nesting sites are within MPAs (Harris, et al., 2015). Since the species might be more vulnerable to anthropogenic threats such as longline fisheries (Lewison, et al., 2004; Nel, et al., 2013a) when moving out of the MPAs, it was assumed that this could impede on the species ability to reproduce effectively and thus influence population trend, which has been stable for the last 30 years (Nel, et al., 2013a). Thus, the MPAs could better protect *D. coriacea* during breeding if it included a greater extent of the species-internesting range, of which the mean distance from shore was ~60 km and the main MPA conserving the species, i.e. iSimangaliso Wetland Park and Ponta do Ouro Partial Marine Reserve only covered an extent of ~5.5 km from shore. Although an increase in conservation extent would not guarantee a population increase (since we don't know if the population was ever any greater in number) it would aid in reducing threats to the existing population during internesting.

The study's findings on MPA coverage of the main life-history stages for *E. imbricata* in comparison to the other three species indicated that *E. imbricata* had the highest percentage of breeding area and migratory area covered by MPAs and that foraging areas for the species were well represented in MPAs. Following the logic used to infer why *C. caretta* and *C. mydas* populations were increasing based on MPAs coverage of the main life-history stages, it would seem that *E. imbricata* population should collectively be increasing, but they are not (Mortimer & Donnelly, 2008). This finding exemplifies the complexity associated with correlating species population trend with MPA overlap and prompted the study to do a pair-wise comparison of the results in order to elucidate the factors which underpin the populations increase, stability and decrease, based on MPA coverage and its influence on population trends. Therefore, the results of this study are further discussed in context of *D. coriacea* and *C. caretta* as well as *C. mydas* and E. imbricata. These groupings were chosen based on an overlap in distribution and certain key habitats, like nesting beaches and foraging areas, which are best placed to highlight potential disparities in MPA coverage, which could influence population trends.

2.5.1 Why *D. coriacea* numbers are stable, whilst *C. caretta* are increasing

There are several apparent findings on MPA coverage that could contribute to the success or failure of conservation strategies. These include the lack of *D. coriacea* breeding areas inside MPAs (~22 %) compared to the other species, *C. caretta* (~40 %), *C. mydas* (~53 %), and *E. imbricata* (~59 %). The low protection levels of *D. coriacea* foraging areas in MPAs (seamounts at less than ~1 % and known foraging areas ~3 %), compared to the other sea turtle species, which ranged between ~2 % and ~50 %. As well as the low percentage of *D. coriacea* migratory areas included in MPAs, the lowest coverage of the four species at ~2 %. Even though there is an overall low inclusion of key life stages of *D. coriacea* into MPAs, and the fact that their population has been stable for the last 35 years, means that MPAs could be contributing to the successful conservation of the species (Nel, et al., 2013a). Thus, there is an evident gap in the conservation of *D. coriacea* based on MPA coverage, but it has not led to a decline in population over the past 35 years. Consideration also needs to be given to the purpose of conservation areas, i.e. are seamounts and *D. coriacea* currently threatened by activities that can be overcome by including these areas in to MPAs, or are the pressures exerted on the species from another origin. To better understand the conservation requirements of *D. coriacea* we consider the aspects that has contributed to the increasing regional population trend of *C. caretta* (Nel & Casale, 2015), a species that shares habitat features such as nesting beaches with *D. coriacea* in the SWIO (Nel, et al., 2013a).

C. caretta are showing an exponential increasing regional population trend (Nel & Casale, 2015) even though their distribution area covered by MPAs is low at ~4 %. However, the percentage of breeding areas inside MPAs were ~40 %, nearly half of all breeding areas in the study area. Although the percentage of breeding areas inside MPAs might seem substantive, studies on *C. caretta* populations in the region indicate that the protection level is even higher than necessarily portrayed through spatial representation of their breeding areas (Harris, et al., 2015). In the study area, the total length of known *C. caretta* nesting beaches is estimated to consist of one continuous strip of coast, 300 km in linear extent, which extends from South Africa to Mozambique (Nel & Casale, 2015). The majority (~75 %) of the nesting of *C. caretta* takes place in South Africa (Nel, 2010) of which the entire section falls within iSimangaliso Wetland Park (UNEP-WCMC, 1999). Therefore, the ~40 % of breeding areas in the study area, which are within these MPAs, represent at least 75 % of the nesting taking place. The adjoining Ponta do Ouro Partial Marine Reserve (Mozambique) further contributes to *C. caretta* breeding areas (Nel & Casale, 2015; SWOT, 2018). Considering that the *C. caretta* population in the study area has shown an overall increase over the last five decades (Nel & Casale, 2015), it would be reasonable to infer that existing conservation efforts are adequate to sustain current populations of *C. caretta* under prevailing conditions.

The success cannot only be attributed to the ~40 % breeding areas inside MPAs, but also the ~75 % of actual nesting activity that is taking place within the iSimangaliso Wetland Park. Moreover, Harris, et al., (2015) found that the joined marine reserves of iSimangaliso Wetland Park and Ponta do Ouro Partial Marine Reserve offers 95 % protection of *C. caretta* sea-use area during internesting. Thus, *C. caretta* is receiving substantial protection because of MPAs in a high-use area during a critical stage of its life, which has seen its population exponentially increase over the last decade (Nel & Casale, 2015). Importantly, a marked difference in the percentage of areas (~40 % breeding, ~75 % nesting and 95 % internesting) inside MPAs can be noted here. This difference is attributed to the scale of studies undertaken. In the case of *C. caretta* finer scale studies by Harris, et al., (2015) and Nel (2010) indicated greater protection levels than the findings in this study. The potential difference in outcomes of studies at different scales should therefore also be noted for *D. coriacea, C. mydas,* and *E. imbricata.* This emphasises the importance of undertaking fine scale studies, to verify findings at the appropriate scale for decision making.

C. caretta and *D. coriacea* are both prevalent in iSimangaliso Wetland Park, where they nest annually, yet the positive population growth of *C. caretta* is not shared by *D. coriacea* (Nel, et al., 2013a). The reason why *D.*

coriacea population failed to expand after its initial abundance increase have been attributed to factors from both inside and outside the MPA and highlights the need for species-specific measures to be incorporated into reserve design and monitoring (Nel, et al., 2013a). This is of particular importance since the small SWIO population of *D. coriacea* predominantly (more than 90 %), nests along the South Africa coast (within iSimangaliso Wetland Park) with the remainder of nesting in Mozambique (Wallace, et al., 2013). Results from this study highlighted that ~22 % of *D. coriacea* breeding areas in the study area are inside MPAs, which is comparable to findings by Harris et al., (2015) that ~25 % of *D. coriacea* internesting areas (of females nesting in these MPAs) are within iSimangaliso Wetland Park and Ponta do Ouro Partial Marine Reserve (the only *D. coriacea* rookery in the region). This emphasises the lack of protection of *D. coriacea* internesting areas as one of the MPAs shortcomings towards conservation of the species. Internesting areas are important for female sea turtles between laying clutches (Schofield, et al., 2007) and not coincidently also important to juvenile turtles making their way to the ocean post-hatching (Bolten, 2003).

Considering that *C. caretta* internesting areas were buffered at 5 km and *D. coriacea* at 60 km (prior to being converted into grid squares), based on extent of species area-use during internesting periods (Eckert, 2006; Harris, et al., 2015), it's conceivable that the conservation of *D. coriacea* could be jeopardised by nesting females moving out of MPAs during internesting periods, where they are more vulnerable to anthropogenic threats e.g. longline fisheries (Lewison, et al., 2004; Nel, et al., 2013a). However, it was found this *D. coriacea* breeding area is relatively well-protected with threats from fisheries fairly low (Bourjea et al., 2008). This comparison between the relative conservation success of *C. caretta* and *D. coriacea* in the same MPA clearly illustrates the difficulty in allocating spatial targets to conservation tools like MPAs for specific species, without understanding species specific spatial requirements. Since five decades of *D. coriacea* nesting beach inclusion in a protected area has not seen any long-term population increase for this Critically Endangered subpopulation (Wallace, et al., 2013), and if we concede that the species was once more abundant in this region as speculated by Hughes (1974), it's clear that these MPAs are currently inadequate as a solitary conservation measure for D. coriacea. However, the reason for the lack of *D. coriacea* population increasing could be attributed to something as simple as the monitoring program not capturing the increasing trend, e.g. more wide spread nesting exhibited due to range expansion or sex biased incubation affecting the population dynamics (Nel, et al., 2013a; Harris, et al., 2015). Considering the large area that will have to be covered by MPAs in order to sufficiently protect *D. coriacea* internesting habitat, it may be questioned if MPAs are the most effective tool to protect these areas. The specific area in question was declared an MPA on 24 October 2018, effectively an expansion of the existing iSimangaliso Wetland Park (GCIS, 2018). Nevertheless, this further motivates why focus will have to be shifted towards understanding what limitations are being placed on population growth at all life-history stages (Mortimer, 2000; Dutton, et al., 2005) and specifically outside these protected areas where significant data gaps exist (Wallace, et al., 2013).

It's not only the large internesting areas of *D. coriacea* that create spatial challenges for inclusion into MPAs, but also the species' vast foraging areas. MPAs covered less than 1 % of seamounts, which were used as foraging area proxy for D. coriacea, within the species distribution. The feeding habitat layer created for *D.*

coriacea based on known feeding areas were also sparsely included into MPAs, at ~3 %. It is evident that these features are under protected when considering the extent of their spatial inclusion into MPAs in the study area, as is the case globally (Probert, et al., 2007). Seamounts represent areas of increased localised productivity where the gelatinous organism on which *D. coriacea* prey aggregate (Witt, et al., 2007a). Spatially representing foraging areas for *D. coriacea* by using primary productivity of gelatinous organisms (Witt, et al., 2007a) through other means e.g. oceanic frontal systems where prey productivity is high (ALTRT, 2006) presents an ever-shifting target as sea-surface temperature and chlorophyll concentrations fluctuate (Witt, et al., 2007a). Therefore, even if ocean-basin-scale maps of gelatinous organism distributions can be used to spatial associate satellite-tracked D. coriacea, conserving such vast varying areas by means of conventional MPAs may be considered unviable. Moreover, it's not only *D. coriacea* that aggregate in these areas of higher productivity, but also many of the fish species targeted by pelagic longline fisheries, an industry seen as a key threat to the region's *D. coriacea* population (Bourjea, et al., 2008; Harris, et al., 2018). This inherent space-use conflict makes a case for spatial protection measures with flexible boundaries (Hoffmann & Ruzafa, 2008), especially since some of the main drivers behind primary productivity i.e. sea surface temperature (ALTRT, 2006) may be influenced by global climate change and associated ocean warming (Lutjeharms, et al., 2001). Therefore, alternative measures can include spatio-temporal conservation management (Makino, et al., 2014) of these areas based on e.g. sea-surface temperature and chlorophyll concentrations, which would negate possible impacts on sea turtles or at least provide a case for more stringent mitigation measures during times when these indicators reach a specified threshold. The interpretation of sea turtle foraging behaviour using remote-sensed patterns of primary productivity in the SWIO would however require robust knowledge of food-web spatial-dynamics (Grémillet, et al., 2008).

2.5.2 Why *C. mydas* numbers are increasing, whilst *E. imbricata* are declining

C. mydas is showing positive regional population growth (Bourjea, et al., 2007), with recent studies based on global analysis of satellite telemetry data indicating that aggregated populations of adult *C. mydas* (~34 %) are conserved in Indian Ocean basin MPAs (Scott, et al., 2012). Therefore, the limited MPA coverage of *C. mydas* distribution at ~8 % does hold conservation value, because this MPA coverage of distribution includes ~53 % of *C. mydas* breeding areas where the species are known to aggregate in MPAs (Scott, et al., 2012). The apparent anomaly of limited inclusion of *C. mydas* distribution in formally protected areas, met by positive population growth, notions to the point that even though MPAs cover only a small portion of the species distribution, they might well provide considerable protection due to coverage of high-use areas. This is supported by findings in this study that *C. mydas* has a comparatively (to other sea turtle species in the study area) large percentage (~45 %) in the highest use intensity category (76 - 100 %) within MPAs, which is indicative of the inclusion of high-use areas for *C. mydas* into MPAs. In contrast to the Endangered and global decreasing population of *C. mydas* (Seminoff, 2004), the SWIO populations range between stable and significantly increasing, and is deemed not to be Endangered (Bourjea, et al., 2007). One such example is the Aldabra Atoll (Seychelles), which was proclaimed as nature reserve in 1968, and where there was a 500 %–800 % increase in nesting sea turtles during 40 years of complete protection (Mortimer, et al., 2011).

Therefore, the stability and increases of these populations are contributed to long-term conservation measures, specifically ones aimed at protecting rookeries (but not necessarily formally proclaimed MPAs) (Bourjea, et al., 2007), i.e. high-use habitat pivotal to the species population increase.

E. imbricata population has declined to a mere remnant due to more than a century of overharvesting in areas such as northern Madagascar, which formerly hosted one of the world's greatest densities of *E. imbricata* (Mortimer & Donnelly, 2008). Other geographies within the study area including Kenya, Tanzania, Mozambique, Mayotte and Mauritius still had relatively abundant populations until the 1970s, when drastic declines occurred and today, nesting is rare in these countries (Mortimer & Donnelly, 2008). At the time of writing, the only increasing nesting populations of *E. imbricata* are found in the Seychelles, where in 1994, the government enacted legislation to protect all species of sea turtles (Mortimer & Donnelly, 2008). Even in this stronghold for the species, legislation to allow *E. imbricata* to be effectively protected and propagate have been found lacking (Burt, et al., 2015) as well as the impact of illegal, unreported and unregulated (IUU) fishing (Wood, 2004; Riskas et al., 2018). Thus, the high percentage of MPA coverage based on breeding, foraging and distribution areas is still not sufficient, and it's estimated that inclusion targets for breeding areas should be greatly increased, given that it is only a fraction of what is left that is currently protected. Furthermore, the nesting sites of the Madagascan population (~1000 females.y-1) is still under pressure from anthropogenic threats (Mortimer & Donnelly, 2008; Humber, et al., 2016), consequently this former stronghold has little chance of recovery under the *status quo* protection. The noteworthy difference between increasing populations of *C. mydas*, and declining *E. imbricata* is that the two main nesting populations of *E. imbricata* in Madagascar and Seychelles (Mortimer & Donnelly, 2008) are either poorly protected based on MPA coverage or lacking robust legislation and enforcement thereof (Burt, et al., 2015). Thus, where *C. caretta* and *C. mydas* overcame population declines through the conservation effort at a few large nesting populations, *E. imbricata* populations are still underpinned by a lack of large conserved nesting populations that could stabilise population numbers.

2.5.3 Where sea turtles can benefit from MPAs

The positive conservation outcomes from a few large nesting populations should not overshadow the importance of smaller rookeries, since focussing on a small number of large populations is a risk-prone strategy (McClenachan, et al., 2006). Thus, even though the regional *C. caretta* and *C. mydas* populations have shown positive population growth at a few large nesting sites, which invariably have turned these species' nett regional population growth positive, it does not mean that these conservation strategies will by default ensure long-term resilience of the species. Sea turtles face multiple current day threats e.g. climate change (Patel, et al., 2016) and oil spills (Putman, et al., 2015) that could see entire nesting populations at risk. Consequently, Bourjea et al. (2007) put emphasis on the importance of monitoring smaller nesting sites in the region because of the vital role these rookeries play in the genetic diversity of *C. mydas*. Equally, smaller and depleted rookeries for *E. imbricata* have been highlighted as being of the utmost importance in recovery strategies for the species (Ratsimbazafy, 2004; Humber, et al., 2015). The latest insights into natal homing plasticity of

C. caretta (Carreras, et al., 2018) may see smaller rookeries be of particular worth in the context of adaptation and resilience of the species to stressors such as global climate change (Hamann, et al., 2010).

Breeding areas, i.e. nesting beaches and internesting areas, have been earmarked as being as the most critical for conservation of sea turtles (Hart, et al., 2010; Katselidis, et al., 2014), since these species are particularly vulnerable during reproduction (Mortimer, 2000). This is supported by findings of Nel, et al (2013a) which indicate that *C. caretta* have the potential to effectively increase in abundance over a relative short time (~10 years) under adequate protection, as proven in South Africa, where increases of ~250 to more than 1700 nests per annum were documented. Although current protection of core *C. caretta* nesting sites are deemed adequate, since it protects such a large percentage of current nesting sites (~75 %) (Nel, 2010), the nesting sites outside MPAs are also of considerable potential value, especially for a species whose subpopulation is classified as Near Threatened in the study area (Nel & Casale, 2015). In contrast, due to diminished population size of *E. imbricata*, this inclusion will have to be proportionately greater, based on the number of nesting females and internesting habitat than that of *C. caretta* and *C. mydas*, if it is to be successful. Similarly, *D. coriacea* may benefit from greater inclusion of nesting sites into MPAs, yet the complexity lies with the species movement and therefore protection mechanisms and tools at a minimum will need to include internesting areas. Although internesting areas for *D. coriacea* are large, these areas in the SWIO are limited by the current small population size and therefore it's motivated that these areas be included into MPAs. Thus, all nesting beaches and internesting areas in the study area are of potential value to recovering sea turtle populations, which emphasises the need to conserve and monitor these areas in order to promote recovery (Velez-Zuazo, et al., 2017).

MPAs encompass ~3 % of the study area, well below international standards where 10.2 % of coastal and marine areas under national jurisdiction (excluding high seas) fall within in MPAs (UNEP-WCMC and IUCN, 2018) or international targets for conservation whether it be Aichi Target 11 (2006) of 10 % or the IUCN World Parks Congress (2014) target of 30 %. Nevertheless, this low percentage of MPA coverage seems to adequately protect *C. caretta* and *C. mydas*. However, "what is adequate" is subject to multiple variables including population viability, ecological processes and the interaction between species and ecosystems, which are affected by the size and spatial arrangement of the MPA networks (Ardron, et al., 2010). Moreover, protection is only needed where there is a threat and threats outside protected areas might overshadow even the most rigorous conservation efforts inside MPAs. In consideration of the positive population growth of *C. caretta* and *C. mydas* as well as the evident relationship between population growth and MPA coverage, it is undeniable that MPAs have contributed meaningfully to the increase of these species in the study area since they reduced the most imminent threat to the species in the specific area, i.e. harvesting of eggs (Mortimer et al., 2011). Therefore, under current conditions, MPAs and the other measures used to conserve *C. caretta* and *C. mydas* in the SWIO is reasoned to be adequate. Importantly, the current success in protection of breeding areas for *C. caretta* and *C. mydas* must be contextualised in terms of the anthropogenic threats faced by the species, and the level of protection provide in MPAs. If the pressure on sea turtles outside MPAs increase to such an extent that breeding populations inside MPAs cannot replenish the stocks anymore, or the MPA allows activities which still impact on sea turtle's reproductive success, then the functioning of the MPA would ultimately be rendered inadequate. This highlights the importance of identifying the scenarios and threats that currently, and in future, might jeopardise the success of sea turtle conservation efforts i.e. having only a few successful populations inherently means that the species are vulnerable to impact from events which MPAs cannot avoid, i.e. major pollution events (Agardy, et al., 2011). Hence the need for the region, to document potential areas of conflict a priori and track environmental changes related to potential sources of impact, e.g. hydrocarbon resource exploitation including impacts on sea turtles.

E. imbricata is struggling to recover from decades of population decimation (Mortimer & Donnelly, 2008) even though MPA coverage of the species distribution and breeding areas are similar to that of *C. caretta* and *C. mydas*. Hence, what is adequate for *C. caretta* and *C. mydas* in terms of MPA coverage is not necessarily adequate for *E. imbricata*. It's advocated that the functioning of the MPAs, which currently host the greatest breeding populations of *E. imbricata*, i.e. those in Seychelles (Burt, et al., 2015), should be studied to identify opportunities to increase the population strength at these key sites. In future it will be prudent to expand on the successes realised by existing MPAs in the study area, specifically in relation to achieving a turnaround in population growth rates for *E. imbricata* through protection of key breeding areas. Conservation efforts will have to focus on currently unprotected nesting beaches (Ratsimbazafy, 2004; Humber, et al., 2015), if long-term resilience of all sea turtle species throughout the SWIO is to be realised. However, there are currently substantial data gaps on sea turtle breeding at smaller sites (Bourjea et al., 2007), which will need to be addressed, if future MPA coverage of these site are to be successfully motivated.

In recognition of the vital role that MPAs play the Government of South Africa approved 20 new MPAs for South Africa on 25 October 2018 that takes marine protection of mainland South Africa from 0.4 % to 5 % (the new boundaries were unavailable in time for inclusion in this study). Notably, the new Agulhas Front MPA will increase protection of important feeding grounds for *D. coriacea* (DEA, 2018) and the offshore extension of iSimangaliso MPA will ensure increased protection for *D. coriacea* and *C. caretta* during internesting periods (Harris, et al., 2015). These are meaningfully positive steps to conserve sea turtles by using MPAs. Notably one of the key elements in the new MPA network (the 20 new MPAs and existing MPAs) was ensuring that ocean protection and the ocean economy aligned. Similarly, the Government of Seychelles has announced two new proposed MPAs covering 16 % of its EEZ under the Seychelles Marine Spatial Plan Initiative (SMSP, 2018). Phase one of this MPA initiative will include the Aldabra group (Seychelles, 2017), the second largest *C. mydas* rookery in the Western Indian Ocean (Mortimer, 2012) and an important foraging ground for *E. imbricata* (Von Brandis, et al., 2014).

2.6 **Conclusions**

The global drive to increase MPAs, underpinned by spatial targets, has steered the research question of this Chapter to quantify the spatial extent of MPAs conserving sea turtles in the SWIO region. The results showed that the extent only of the protected area is by no means indicative of the level of protection afforded to sea turtles. However, increased protection of key areas such as breeding areas definitely contribute meaningfully to conservation of the species. MPAs do play a pivotal role in conserving some sea turtles, and it is believed that these successes can be extrapolated to other species and geographies. Importantly, all assessments have been undertaken under current conditions, yet indications are that major shifts in climate (Obura, 2005) and sea level (Weiqing, et al., 2010) anthropogenic stressor dynamics (ADB and AU, 2009) are expected for the study area. Therefore, it's proposed that to protect sea turtles throughout their distribution, and especially outside MPAs, an approach be undertaken where the main threats to the species are identified and mitigated. In the case of sea turtles this would require investigation into the actual and perceived threats from specific stressors, quantifying their potential impact on the species, assessing the risk and vulnerability of key sea-turtle-use areas to these threats, and addressing the threats in a risk averse manner. This will enable further MSP to focus on gaps in the protection of the species, whether it be an increase in MPAs, other area-based conservation measures (e.g., activity zoning (Kirkman, et al., 2019)), or an approach that protects the species without necessarily being spatially dependent (e.g., fishery equipment restrictions to reduce sea turtle bycatch (Lewison, et al., 2004)).

2.7 **References**

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Chapter 3 : **The potential impact of the upstream hydrocarbons industry, on sea turtles, in the Southwestern Indian Ocean**

3.1 **Abstract**

Recent validation of extensive recoverable gas reserves off Mozambique and Tanzania in the Southwestern Indian Ocean (SWIO) has mobilised governments to develop their blue economies through a hydrocarbon-based industry with a concomitant infrastructure investment. However, this has raised concerns about potentially significant environmental impacts from a hydrocarbon-based industry, to sea turtles and their habitats based on international examples like the Deepwater Horizon spill in the Gulf of Mexico. Given that the five sea turtles species in the SWIO are listed on the IUCN Red List of threatened species, this study aimed to identify areas of ocean-based Hydrocarbon (oil and gas) Exploration and Production (HEP), that may significantly impact on sea turtles. It was hypothesized that HEP infrastructure and activities would be focussed on nearshore areas, with an offshore extent to the 1000 m isobath (with the exception of shipping lanes). To test this hypothesis, the existing and proposed HEP industry in the SWIO was mapped and used as part of a novel impact rating index, which was used to describe five potential impacts from the hydrocarbon industry on sea turtles and their habitat. The results revealed the extensive nature of potential impacts on sea turtles between the shore and 1000 m isobath, of which the entire area may be impacted upon by the hydrocarbon industry. Impacts from existing infrastructure associated with HEP, such as ports, and activities, such as shipping, covered nearly all of the study area. In addition, the significance of potential water pollution as major contributor to impacts on sea turtles within the region was reaffirmed constituting 16 of the top 28 most significant impacts from HEP on sea turtles in the SWIO. Several other less prominent impacts associated with HEP, such as light and noise pollution, were also highlighted as being of potential threat to sea turtles, but current scientific knowledge on these stressors remain limited. Importantly, this study found that ~70 % of all potential HEP impacts on adult nesting sea turtles could be avoided if seasonality of sea turtle movement during critical life stages, i.e. breeding, are included as species-specific HEP mitigation. These findings emphasise the importance of addressing specific threats to sea turtles in the SWIO from existing infrastructure such as ports and activities such as shipping, as well as the potential impacts from an expanding hydrocarbon industry on migratory species such as sea turtles, in particular where these developments cluster.

3.2 Introduction

The economic value of oceans is globally gaining importance (Ehlers, 2016) and therefore countries are looking at diversifying their ocean-based economies as well as intensifying existing activities to increase productivity (Alshubiri, 2018; Selgrath, et al., 2018). For developed countries this might mean securing new resources where others have been depleted (Swartz, et al., 2010), or accessing alternative markets to enhance their own economies (Brown, 2013). In developing countries, the aim would be to promote inclusive and sustainable economic growth economic growth to reduce issues such as poverty and hunger (Spalding, 2016). One of the key industries that countries are particularly looking to is non-renewable energy, i.e. extraction of hydrocarbon products, because it is highly lucrative and supports numerous other downstream activities, e.g. textile, metallurgic and electrical industries (ADB and AU, 2009). It's thus understandable that most countries in the SWIO region are developing and expanding their ocean-based or "blue" economies (Obura, 2017a).

The gross marine product in the SWIO is largely from fishing, marine tourism and coastal tourism, with the rest of the sectors being underdeveloped and viewed as emerging (Obura, 2017a). These emerging sectors include offshore hydrocarbon mining, renewable energy, seabed mining, aquaculture, and transport (CSIR, et al., 2017), with these emerging markets all being energy dependent. Although renewable energies in Africa are gradually growing in importance (Bugaje, 2004; Deichmann, et al., 2010), it is hydrocarbons, i.e. non-renewables, that are prospectively viewed as the main driver behind economic growth (Donwa, et al., 2015), which in turn is seen as a catalyst for reducing unemployment, poverty and equity issues in many countries (Bo, 2003).

The development of blue economies in the SWIO based on non-renewable hydrocarbon industries does come with uncertainty. The main concern is about sustainability of these development plans particularly if they are based on an industry with a global reputation of severe negative environmental impacts (UNEP IE, 1997; Jernelov, 2010). Many other developed countries have long been dependent on their ocean waters to sustain their economies (MTIF and MPE, 2017), but even these are not without negative impacts (Halpern, et al., 2008). For example cod fisheries collapsed in Atlantic Canada (Myers, et al., 1997) and the herring fisheries collapsed in northeast Atlantic Norway (Hamilton, et al., 2006). Due to the dependence on marine resources, countries search for, or exploit substitute resources outside their jurisdictional waters or through unconventional means (Perry, et al., 2010), i.e., four of the world's major seafood markets, China (Mallory, 2013), Europe, Japan and the USA have a high level of dependence on foreign resources because their local fisheries resources are severely depleted (Swartz, et al., 2010). The question is thus whether the developing world like the SWIO, can grow a sustainable hydrocarbon industry, or whether is just facade for ocean overexploitation or "blue grabbing" (Silver, et al., 2015) of limited resources.

The hydrocarbon industry has a long history in the SWIO with prospecting records dating back to the 1940s in Mozambique and 1950s in Kenya (Deloitte, 2014). Even before then, in the 1930's, large scale transport of oil via tankers, took place around the southern tip of Africa and through the Mozambique channel (García-Borboroglu, et al., 2008). Over the last few decades large hydrocarbon reserves have been confirmed for the region (AfDB and AU, 2009; PWC, 2013; KPMG, 2013; Deloitte, 2014) with major finds of commercially viable gas offshore off Tanzania and Mozambique (African-Energy, 2015). Lesser finds have been discovered in the EEZs of South Africa, Kenya (KPMG, 2013; Deloitte, 2014), Madagascar (IRESA, 2012; Nobert, 2016), Seychelles (Brownfield & Schenk, 2016), Comoros (Ango, 2013) and potentially Mauritius (Jackson, 2011). Consequently, SWIO governments are keen to develop energy resources and attract investment, to accelerate economic growth and social development in the region. The scale of the recent finds and the unprecedented rate of exploration and production in the region (ADB and AU, 2009) is driving further prospecting for commercially viable oil and gas reserves.

The environmental community is however cautious about these economic developments (Obura, 2017a; Obura, et al., 2017b; Chevallier, 2017) largely due to historic impacts accrued from major oil pollution incidents, some rated as the biggest man-made disasters in human history, like the Ixtoc I oil spill (Jernelov, 2010). However, the industry has recognised these risks and so changed some practices, which lead to a decline in oil spills from large tankers (greater than 7 tonnes) in the last five decades, despite the doubling of total oil and gas production (ITOPF, 2017). Even the SWIO has not escaped impacts that relate to the industry, specifically oil spills. Examples include the 1983 MT Castillo de Bellver oil spill in South Africa (Saldanha) (Wardley-Smith, 1983), 1992 Katina-P oil spill in Mozambique (Maputo) (Hook, 1997), 2005 MT Ratna Shalini laden oil spill in Kenya (Mombasa) (Mwangura, 2005), the 2009 MV Gulser Ana fuel spill off Madagascar (Faux Cap) (Laruelle, 2012) and 2016 MV Benita oil spill off Mauritius (IMO, 2016). This suggests that the extent of hydrocarbon impacts, even in a poorly developed market, are both widespread and significant. Not only transport of oil, but also fixed infrastructure poses a risk; the Niger Delta oil fields being a prime example of where old, ill-maintained or damaged pipelines cause spills with increased frequency (Jernelov, 2010). The environmental community's caution about HEP developments are thus warranted due to the potential impacts which may occur during the entire HEP lifecycle.

Natural gas avoided some of the negative publicity because it is viewed as less detrimental to the environment than coal or oil (PWC, 2013). However, natural gas is not as "green" as it is perceived especially if the impacts throughout the lifecycle, e.g. acute and chronic effects of wastes associated with offshore gas production on marine ecological processes, are considered (Holdway, 2002). Contextualisation of the potential impacts from an expanding HEP industry in the study area is thus necessary, especially in the context of the current state of the environment and the increased pressure on marine species, like sea turtles and their habitats (Chevallier, 2017; Obura, et al., 2017b).

Much can be learned from the Gulf of Mexico, which experienced a remarkable increase in hydrocarbon exploration in the early 1980's. Concerns were raised only after sea turtles populations declined (Fritts & McGehee, 1982), which meant that monitoring started only after the industry was developed (Fritts & McGehee, 1982). Three decades later, East Africa faces the same development dilemma (AfDB and AU, 2009; PWC, 2013; KPMG, 2013; Deloitte, 2014), also with sea turtle populations under severe pressure (Bourjea, et al., 2008). It could be an opportunity for the region, to document potential areas of conflict a priori and track environmental changes related to hydrocarbon resource exploitation including impacts on sea turtles.

Each phase of the hydrocarbon industry i.e. upstream, midstream and downstream, has its own suite of potential impacts that should be assessed. This study will focus on the upstream (exploration and production) component with the inclusion of transportation. Exploration and production have multiple stressors on sea turtles including (i) pollution, (ii) habitat destruction and alteration, (iii) sediment resuspension and turbidity, (iv) disturbance and (v) ships strikes (Borthwick, et al., 1997; Iversen & Stokke, 2009; BPC, 2012). None of these stressors are unique to the hydrocarbon industry although they manifest in different ways in other sectors like fisheries or tourism (Bourjea, et al., 2008). Some of these stressors will also be exacerbated by the effects of climate change and sea-level rise (Fuentes, et al., 2010).

The offshore hydrocarbon industry is colloquially referred to as "the oil and gas industry" because these deposits are found in similar geological formations (Schröder, 2014), and exploitation have similar industry life cycles. The difference between oil and gas from an environmental impact perspective is the propensity of oil to cause significantly greater pollution due its chemical composition (complex mixture of more than 200 different organic compounds) than more volatile natural gas (mostly methane) that disperses more quickly (Devold, 2013). The impacts common to both oil and gas industries are: habitat destruction and alteration, e.g. construction of pipelines to offshore drilling rigs; noise and light pollution, e.g. noise from seismic blasts and light from drilling platforms; disturbance and physical impact, e.g. vessel traffic from ports to platforms. However, these are also distinguishable on a project-specific basis since it depends on variables such as scale of the operation or the habitat it is in. Therefore, when mapping the spatial impact of the industries, the greatest potential difference is the extent of pollution. This has major significance for the SWIO, since the majority of the deposits are natural gas. Very little commercially-viable offshore oil deposits have been discovered to date, but the possibility exists that it might change as exploration continues (Nairobi Convention Secretariat, 2012).

Marine impacts are not limited to marine exploration/exploitation because land-based hydrocarbons transported via tankers or pipelines, to and from coastal destinations, may also impact on the marine environment. Madagascar will use ships to transport bituminous (tar) sand from Bemolanga, and heavy oil from Tsimiroro (Nairobi Convention Secretariat, 2012) to international markets. This raises the issue of a comparatively large potential threat, with possible catastrophic pollution from land-based activities due to marine transport of hydrocarbons. However, ports provide a stationary point of potential impacts that are easy to delineate. Major shipping routes, including those in the SWIO, are well documented (World Bank IEG, 2015), but the variability of shipping traffic and extent of potential impacts, in particular of pollution events, makes spatial delineation contentious. Given the scale and extent of the developing industry (Lanfear & Amstutz, 1983; Price, et al., 2003), the whole SWIO could be vulnerable to catastrophic pollution events.

A big question for East African governments is whether the demonstrated negative impacts from HEP, including impacts on migratory species such as whales and dolphins, sharks and sea turtles, will occur in the SWIO because of spatial and temporal overlap (Shigenaka, et al., 2010; Hueter & Tyminski, 2012; Marsh, et al., 2003; Obura, et al., 2012). Sale et al. (2014) proposed Marine Spatial Planning (MSP) with zones as a framework for effective, and practical ocean management to reduce user and environmental conflicts. Comprehensive ocean zoning is also a management tool that can explicitly deal with cumulative and interactive effects of multiple stressors (Halpern, et al., 2008), which is one of the major factors environmental decision-making processes fail to include (Grech, et al., 2015). Managing the ocean spatially, makes intuitive sense because all activities and their associated consequences (threats or benefits) are essentially spatially explicit (Halpern, et al., 2008). In order for ocean zoning to be undertaken it is pivotal that the spatial extent of potential impacts, in this case from HEP, are spatially quantified at the appropriate scale.

One of the major difficulties with HEP is quantifying the spatial extent of environmental impacts associated with the industry (OSPAR, 2016), given the lack of knowledge and understanding of specific impacts on individual organisms or the cumulative effect in the environment (Mosbech, 2002; Lee, et al., 2015). The complex nature of sea turtle life-history, using multiple habitats over large spatial scales (Miller et al, 2018), population variability in abundance and environmental preferences (Abreu-Grobois & Plotkin, 2008; Seminoff, 2004; Wallace, et al., 2013a) makes impacts from hydrocarbon development likely but also difficult to quantify (Sheppard, 1995; Lutz & Musick, 1997; Sheppard, 1995; Holdway, 2002). Nevertheless, quantifying and mapping the potential impacts from offshore platforms, undersea pipelines, shipping routes, port terminals and other ancillary activities, that overlap with high-use areas of different sea turtle life-history stages (Dutton & Squires, 2011) and habitats, can assist with guided planning and proactive mitigation of impacts (Grech & Marsh, 2008; Kamrowski, et al., 2012; Chevron Australia, 2014; Sinclair Knight Merz, 2014).

There are some commonalities between sea turtles and the HEP industry that might see space-use conflict be exacerbated, i.e. the propensity for sea turtles (Sale, et al., 2006) and HEP (Zulqarnain & Fike, 2017) to be more prevalent in relative shallow-water (less than a 1000 m deep) environment. Shallow-water being a relative measurement, is defined here based on the limits of sea turtle (Dermochelys coriacea) diving depth (Sale, et al., 2006) and current day HEP drilling depth (Kaiser, 2009), which in ultra-deep locations are currently operating in water in excess of 2900 m deep (Kark, et al., 2015). Also, both sea turtles and HEP developments tend to form specific high-use zones, i.e. sea turtles have specific nesting and feeding areas where they congregate (Lutz & Musick, 1997), and HEP developments will cluster where there are viable oil and gas fields (Ledesma, 2013). Thus, where the high-use zones of sea turtles overlap with HEP clusters, conflict in sea use will be greatest.

The conflict between sea turtles and HEP is well recognised in areas where both are prevalent, e.g. the Gulf of Mexico, which has led to the National Oceanic and Atmospheric Administration (NOAA) of the United States Department of Commerce to focus on understanding and managing this potential issue (Shigenaka, et al., 2010). Additionally, areas such as Florida where there is significant risk of HEP impacts, specifically oil spills, have mapped sensitive sea turtle areas for oil spill response and natural resource management purposes (Zengel, et al., 1998). This is however symptomatic of the general issue facing sea turtle protection in areas where HEP has been established, since much effort goes into focussing on remedial issue, e.g. oil spill response, whereas ideally these events must be prevented from occurring in the first place. In the Adriatic Sea there has been specific focus on mapping sea turtle risk around maritime traffic routes, oil activities and sea ports, in an effort to promote better decision making on issues pertaining protection of the marine environment (Lazaj & Chariton, 2015; Štrbenac, 2015). It's initiatives like these that ultimately culminate into regional scale strategic conservation programmes that aim to protect the species throughout their regional management units (RMUs), from multiple impacts (Štrbenac, 2015). Since all of the SWIO countries have signed international agreements to protect sea turtles, i.e. the Memorandum of Understanding on the Conservation and Management of Marine Turtles and their Habitats of the Indian Ocean and South-East Asia (IOSEA, 2001), it would require stakeholders such as the HEP industry to take note in terms of their obligations to conserve the species.

Given the potential impact of HEP on sea turtles in the SWIO, the aim of this study is to identify areas of HEP development that may significantly impact on sea turtles. The specific objectives are 1) to identify the HEP-related infrastructure and activities, and their location in the SWIO; 2) to establish the type and extent of impacts (spatially), where they could impact on sea turtles and their habitats across different life-history stages; 3) to derive and apply a standardised, globally usable method to deal with the uncertainty of existing and future spatial conflict between HEP and sea turtles, including their habitat, in a comparable manner. It is hypothesized that HEP infrastructure and activities will be focussed on nearshore areas, with an offshore extent to the 1000 m isobath (with the exception of shipping lanes). It's predicted that if the focus of HEP infrastructure and activities are greatest in nearshore areas, up to the 1000 m isobath, then these areas will be most heavily spatially occupied by HEP infrastructure and will thus also have the greatest potential impact on sea turtles.

3.3 Methods

3.3.1 Study area

The study area comprises the EEZs (Flanders Marine Institute, 2018) and coastal zones of the African mainland countries in the SWIO, i.e. Kenya, Tanzania, Mozambique, and South Africa (excluding the Prince Edward Islands). The island nations included are Madagascar, Mauritius, Seychelles, Comoros, and France with Réunion and The Scattered Islands - Europa, Juan de Nova, Bassas da India, Tromelin, Mayotte, and Glorioso (Figure 2 1). These EEZs fall within the Agulhas and Somali Current Large Marine Ecosystems (ASCLME/SWIOFP, 2012) and thus form an ecologically coherent study area. Key coastal HEP infrastructure is frequently situated above the mean low water mark, which overlaps with sea turtle nesting habitat. The coastal boundary was thus mapped with a 1 km landward extent from the mean low water mark (where the EEZ ends). In addition to the EEZ, a 1000 m isobath (GEBCO, 2014) was used to differentiate between the shallow-water and deep-water environment, an important economic factor for HEP (Zulqarnain & Fike, 2017) and ecological factor for sea turtles (Sale, et al., 2006).

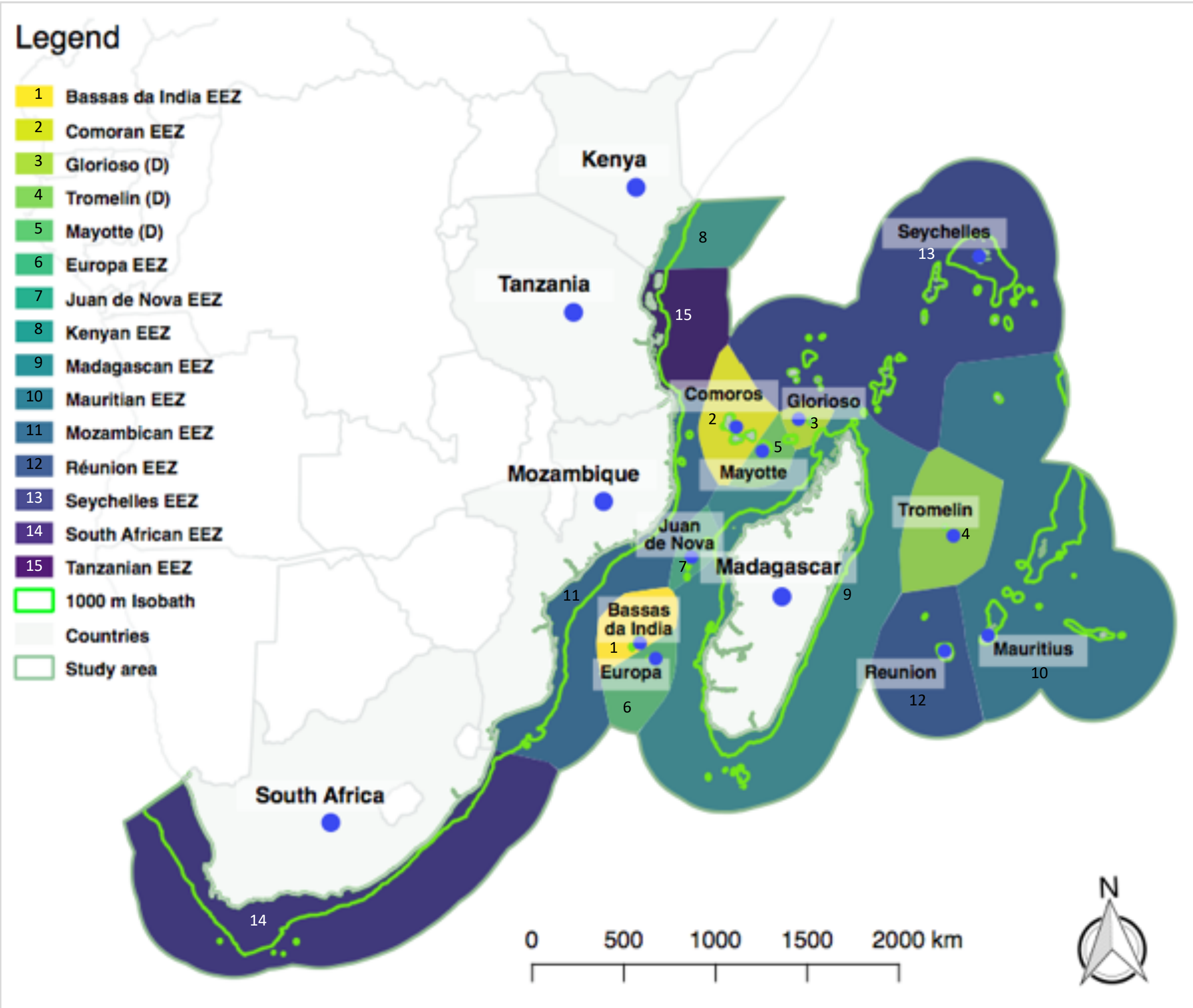

Figure 3-1 | The EEZ and territories (a "D" after the name indicates that the territory is under dispute and thus not exclusive to the island) of countries and islands in the SWIO that comprise the study area. A 1000 m isobath (bright green) was included as distinction shallow-water and deep-water environment.

3.3.2 Mapping HEP in the SWIO

Most of the data used for the assessments were obtained from Infield Systems Ltd (2018). All mapping was done in European Petroleum Survey Group (EPSG) 54032, World Azimuthal Equidistant Coordinate Reference System (CRS) using Quantum Geographical Information Systems (QGIS) version 2.18.15 "Las Palmas" with GRASS 7.4.0. Azimuthal Equidistant CRS was chosen over WGS84 to undertake more accurate analysis of geometric distances and areas, equidistant projections are typically used for the HEP industry when undertaking seismic mapping (QGIS, 2016).

To map areas of identified or highly likely HEP, the main components associated with the upstream (exploration and production) industry were categorised, including: i) fields; ii) licence areas; iii) wells; iv) platforms; v) pipelines; vi) ports; vii) terminals and viii) shipping lanes. The main impacts associated with HEP were organised into five impact categories; these categories are: a) water pollution; b) light pollution; c) disturbance (including noise pollution); d) physical impact (to turtles); and e) habitat destruction. Each of the HEP components were buffered by a specific distance (Table 3-1) representing the most plausible extent for each impact category i.e. near-, mid- and far-field zone, thereby accounting for a decline in impact with increasing distance from the source, where applicable. In this way, 40 possible impacts (8 HEP components with 5 impacts) of three intensities (based on proximity to source) from HEP activities were spatially delineated across the study area. Where impact buffer areas in the same category and from the same source overlapped, the boundaries were dissolved to indicate a consolidated impact area. Cumulative impacts from the same impact category were not assessed.

Table 3-1 | Spatial extent assigned to the five main HEP impacts, and a rationale for the near-, mid- and far-field distances of each impact, adapted from Harris, et al. (2018).

Impact category	Extent (km)			Rationale
	Near-field	Mid-field	Far-field	
Water pollution	0-20	20-100	100-200	The extent of water pollution is based on known emitters associated with HEP (Yang & Khan, 2012). Pollution sources range from relative benign pollution, which disperses without negative environmental impacts, to persistent chronic pollution and catastrophic events. Global hydrocarbon pollution events (worst case scenario events) over the last century (ITOPF, 2017; BOEM, 2016) and capability of emergency responses to effectively control spills (Peterson, et al., 2012; Chang, et al., 2014), were considered to derive a far-field extent of up to 200 km from the impact zone. Spills don't spread evenly, and slicks are often long streaks as they disperse through currents and wind, stopping only where they meet land or other barriers. Spatially, a circle of impact with a 200-km radius around the point source equates to a 125 663.71 km2 area, but the spill may affect only a portion of this area. Conversely, stochastic pollution events might extend beyond the 200 km range and major spills e.g. from shipping vessels can happen anywhere in the study area. Near-field pollution typically include impacts from drilling muds, produce water and process water. These impacts typically dilute within a few hundred meters to few kilometres from source (UNEP IE, 1997), although this is dependent on the oceanic conditions. In alignment with studies on polycyclic aromatic hydrocarbons, the components of water pollutants of most concern and known to effect sea turtles (Ylitalo, et al., 2017; Cocci, et al., 2018), the near-field distance was set at 20 km (Ekins, et al., 2005). Mid-field pollution impacts are more typically associated with well blowouts and chronic pollution from poorly capped abandoned wells. The extent of these mid-field pollution impacts may range from ~22 km (Cordes, et al., 2016) to ~100 km (Boehm & Fiest, 1982) and hence the range was set between 20 to 100 km.
Light pollution	0-15	15-25	25-35	Several sources of light pollution are associated with HEP, including safety lights, warning lights (Longcore & Rich, 2004) and light emanating from gas flaring (Hölker, et al., 2010). Although several studies have focussed on sea turtles and light pollution there is a marked variability in their findings, which is understandable considering the number of variables that dictate the manifestation of light pollution impacts. Verutes et al. (2014) derived a 32 km maximum threshold of exterior light source to nesting beaches from development, with consideration of factors such as source, location and height which affects light's ability to reach sea turtle nesting beaches. Similarly, Kamrowski, et al., (2012) derived a 25 km buffer for light sources from emitters of significant sky glow, and Pandav & Kumar (2014) estimated that the majority of disorientation of hatchlings occurred within 10 km of the light source. Finally, anecdotal examples of light generated by an aluminium refinery in Australia have shown to disrupt marine turtle orientation 18 km away (Hodge, et al., 2007). Given these thresholds a near-field range of 0 to 15 km, mid-field range of 15 to 25 km and far-field range of 25 to 35 km was set.
Noise pollution	0-1	1-2	3-4	Noise impacts are seen as a potentially substantial disturbance factor to sea turtles, especially as it relates to seismic activities associated with HEP (Nelms, et al., 2016), propeller noise from vessels and blasting (Viada, et al., 2008). However, the understanding of how different noise types impact on sea turtles are understudied with little empirical evidence suggesting specific spatial extent of impacts. Studies on *Caretta caretta* and *Chelonia mydas* indicated that the sea turtles displayed behavioural response at ~2 km from operating seismic vessels and avoidance behaviour at ~1 km (McCauley, et al., 2000). Furthermore, in the 1980s generic safety ranges for blasting was set at 915 m to prevent

Impact category	Extent (km)			Rationale
	Near-field	Mid-field	Far-field	
				most sea turtle deaths, yet the empirical and theoretical basis for this specific distance was considered weak (Viada, et al., 2008). This prompted safety zones to be revised based on standardised sound level metrics and detonation characteristics, and thus current day influence zones for noise that may cause death or injury are assigned based on the merits of the specific scenario (Popper, et al., 2014). Best practice dictates that a scale is used to define in relative terms as near, intermediate, and far with logic dictating that the nearer the sea turtle is to the source the higher the likelihood of high energy and a resultant adverse effect on individuals in said proximity (Hawkins, et al., 2014). Based on the above parameters the near-field extent was set at 0 to 1 km, mid-field 1 to 2 km and far-field 3 to 4 km.
Vessel strikes	0-10	10-20	20-30	Vessels could cause physical injury to sea turtles (Hazel, et al., 2007) anywhere in the study area, although areas with higher vessel traffic will be more dangerous (because of higher likelihood of impact) to sea turtles (Thums et al., 2018). Therefore, high-use areas such as shipping routes are considered a relevant inclusion to quantify potential HEP impacts. The near-field extent is based on the Western Indian Ocean Marine Highway Development and Coastal and Marine Contamination Prevention Project (WIOMHD), which proposed a minimum provision of a 5.56 km (3nmi) wide two directional traffic lane and 3.70 km (2 nmi) separation zone (Neil, 2007; World Bank IEG, 2015), which equates to 9.26 km wide potential impact zone, rounded here to 10 km. To consider variability of ship movement and densities, the far-field ship-lane extent was set at 30 km, with the 10 to 20 km extent assigned to the mid-field range.
Habitat destruction	0-3	3-6	6-9	The footprint of activities is viewed as the minimum spatial extent to which habitat is destroyed or altered, yet various case studies reveal the extent of damage is often not only a function of the size of the activity, but also depends on the proximity to sensitive areas, type of the substrate, the way equipment is used, mitigation methods used, and so forth (Erftemeijer & Robin Lewis, 2006; Pioch, et al., 2011). Impacted areas and ecological functioning might recover over time, yet the success of recovery is subject to numerous variables (Erftemeijer & Robin Lewis, 2006). Areas outside the immediate footprint may be influenced by factors such as sedimentation, water discolouration (Rogers, 1990; Filho, et al., 2004; Hitchcock & Bell, 2004) or fragmentation (Caley, et al., 2001). Factors such as dredge and dredge spoil can cause major habitat destruction (van't Hof, T., 1983; Fabricius & Wolanski, 2000). Considering the numerous variables, the extent of impacts was rationalised and consolidated from several studies (Dickson & Rees, 1998; Hitchcock & Bell, 2004; Fisher, et al., 2015; Jones, et al., 2016; Stark, et al., 2017; Strydom, et al., 2017). This equated to near-field impacts up to 3 km of the impact location, mid-field impacts between 3 to 6 km and far-field impacts 6 to 9 km.

3.3.3 Hydrocarbon Exploration and Production Impact Rating Index (HEPIRI)

The HEPIRI was developed based on environmental impact assessment methodology (Morris & Therivel, 2001), with two very distinct adaptations that has allowed it to be used in this study. The first change is that the spatial extent is not taken into consideration when determining the significance of an impact. The extent is a function of mapping i.e., how far an impact might spread from the source (*sensu* Table 3-1 above). This has allowed potential areas of impact to be mapped prior to assessment of impacts based on the type of activity, and allows the group or persons undertaking the assessment to better quantify the factors which determining the significance of an impact, i.e. they know the exact extent/location of the impacts that they are assessing. Secondly, the HEPIRI was derived to be sea turtle specific, i.e. in developing the intensity and duration parameters cognisance was taken of how sea turtles as a group of species might be influenced. For example, a semi-permanent duration is 16-50 years, which considers the average age to maturity for sea turtles (Seminoff, 2004; Mortimer & Donnelly, 2008; Nel & Casale, 2015). Although it has been setup to be species specific the HEPIRI can easily be amended to include other species that might be impacted by the HEP industry such as cetaceans.

The significance of an impact is calculated by first determining the magnitude of the impact, and second, the likelihood of occurrence (Figure 3-2). Impact **magnitude** is defined as the potential severity of the impact, which depends on the impact intensity and duration (Figure 3-2C). Impact **intensity** is defined as the degree of damage caused by an impact (Figure 3-2A), and **duration** as the temporal scale over which this impact is exerted on the environment (Figure 3-2B). For each predicted impact per HEP feature, intensity and duration are scored out of seven (negligible to extremely high or permanent) based on existing studies and expert judgement, with the values summed to give impact magnitude. Impact **likelihood** is defined as the likelihood that a well-defined outcome will occur in the future. The **likelihood** of an impact occurring (Figure 3-2D) is then ranked in a similar way (as intensity and duration) from exceptionally unlikely to definite. Finally, the product of the magnitude and likelihood scores gives the significance rating (Figure 3-2E).

Each predicted impact from the HEP industry (water pollution, light pollution, noise pollution, vessel strikes and habitat destruction) is evaluated per HEP feature (e.g., well points) to determine the likely impact **significance**. Here, significance is defined as the predisposition of an impact to affect sea turtles negatively, with the premise that the best-case scenario is a neutral significance, i.e. no positive impacts to sea turtles will come from any HEP developments. The significance ratings accept that industry standard mitigation will be undertaken (but not sea turtle specific) and therefore no additional ratings are provided for pre- and post-mitigation, i.e. the scoring is done on perceived residual risk (the risk after reasonable management is in place).

Magnitude — A + B = C

Significance — C X D = E

A — Intensity + **B — Duration** = **C — Magnitude** X **D — Likelihood** = **E — Significance**

A — Intensity

7 - Extremely high: Irreparable damage to habitat and/or irreplaceable loss of population (local extinction).

6 - Very high: Irreparable damage to habitat and/or exceptional loss of population (remnant population left).

5 - High: Irreparable damage to components of habitat and loss and/or displacement of population.

4 - Moderate: On-going damage to habitat and/or persistent loss / displacement of population.

3 - Low: Damage to components of habitat and/or loss / displacement of individuals.

2 - Very Low: Minor damage to habitat and/or displacement of individuals.

1 - Negligible: Negligible damage to habitat and/or displacement of individuals.

B — Duration

7 - Permanent: The impact will remain long after the life of the project

6 - Semi-permanent: 16-50 years

5 - Long term: 6-15 years

4 - Medium term: 2-5 years

3 - Short term: 7 months to 1 year

2 - Seasonal: Less than 2-6 months

1 - Negligible: 0 – 1 month

C — Magnitude

	Range
7 - Extremely high	13 - 14
6 - Very high	11 - 12
5 - High	9 - 10
4 - Moderate	7 - 8
3 - Low	5 - 6
2 - Very low	3 - 4
1 - Neutral	1 - 2

D — Likelihood

7 - Definite: There are sound scientific reasons that the impact will occur.

6 - Virtually certain: There are sound reasons that the impact will occur.

5 - Very likely: The impact may occur, but not necessarily proof that it will.

4 - Likely: The impact has occurred before and could occur in the lifetime of the project.

3 - Unlikely: The impacts occurrence is rare but has happened before.

2 - Very unlikely: There are scientific reasons that make the impact conceivable, yet improbable.

1 - Exceptionally unlikely: There are sound scientific reasons to expect that the impact will not occur.

E — Significance

	Range
5 - Severe	80 - 98
4 - Major	60 - 79
3 - Moderate	40 - 59
2 - Minor	20 - 39
1 - Minimal	1 - 19

Figure 3-2 | Calculation of impact magnitude (sum of impact intensity and duration) and significance (product of impact magnitude and likelihood), and the rankings assigned to each element

3.3.4 HEP impact assessment

A map of all impacts to sea turtles from the HEP industry was generated assigning the impact risk significance scores (following Figure 3-2) to each zone around the HEP components (from Table 1) for the five impact categories: a) water pollution; b) light pollution; c) noise pollution; d) physical impact; and e) habitat destruction. The output of the HEP impact assessment was collectively analysed based on each impact rating category, i.e. intensity, duration, magnitude and significance to identify areas of HEP development that may significantly impact on sea turtles and the factors that underpin these significance ratings. It was recognised that only part of the impacts assessed will be of significance that warrant further analysis, thus impacts rated as being of minimal and minor significance were excluded from further analysis. The impacts rated as being of severe, major and moderate significance were then analysed in terms of the five impact categories to establish where HEP will have the most significant impact on sea turtles across different life-history stages or habitats used.

3.4 Results

3.4.1 Distribution of HEP infrastructure and activities in the SWIO

The identified exploration phase components associated with HEP include: i) fields; ii) licence areas; and iii) wells (exploration wells), whilst the production phase components of HEP include: iii) wells (production wells); iv) platforms; v) pipelines; vi) ports; vii) terminals and viii) shipping lanes (Figure 3-3). Licence areas are the most expansive of the exploration components within the study area, with countries such as South Africa and Kenya having allocated licence blocks to most of their EEZ (Figure 3-3). The results of the HEP component mapping also indicated how these components cluster in areas where leads have yielded positive results (Figure 3-3). These components form the core from where impacts originate and its evident that many of these occur in or near the shallow-water environment i.e. within the 1000 m isobath (Figure 3-4). Impacts over the near-field span most of the coastlines of the mainland and islands in the study area, with the far-field impacts covering most of the study area. The fields account for a decline in impact with increasing distance from the source (where applicable), and thus near-field areas have the greatest impact significance and the far-field areas have the least impact significance (Figure 3-5).

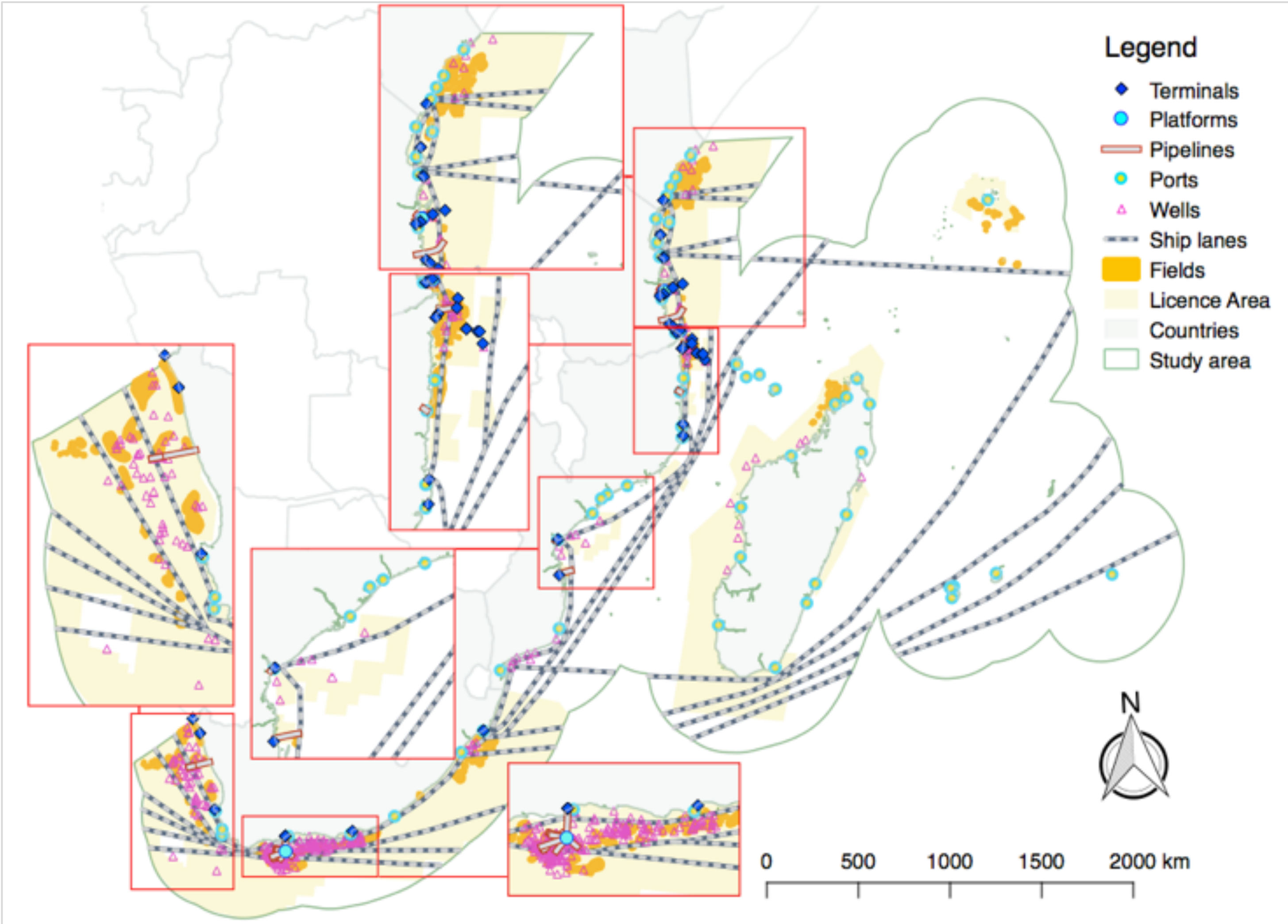

Figure 3-3 | Areas of identified or highly likely HEP components associated with the upstream industry including: i. fields; ii. licence areas; iii. wells; iv. platforms; v. pipelines; vi. ports; vii. terminals and viii) shipping lanes. The red inserts represent areas where there are clusters of HEP components.

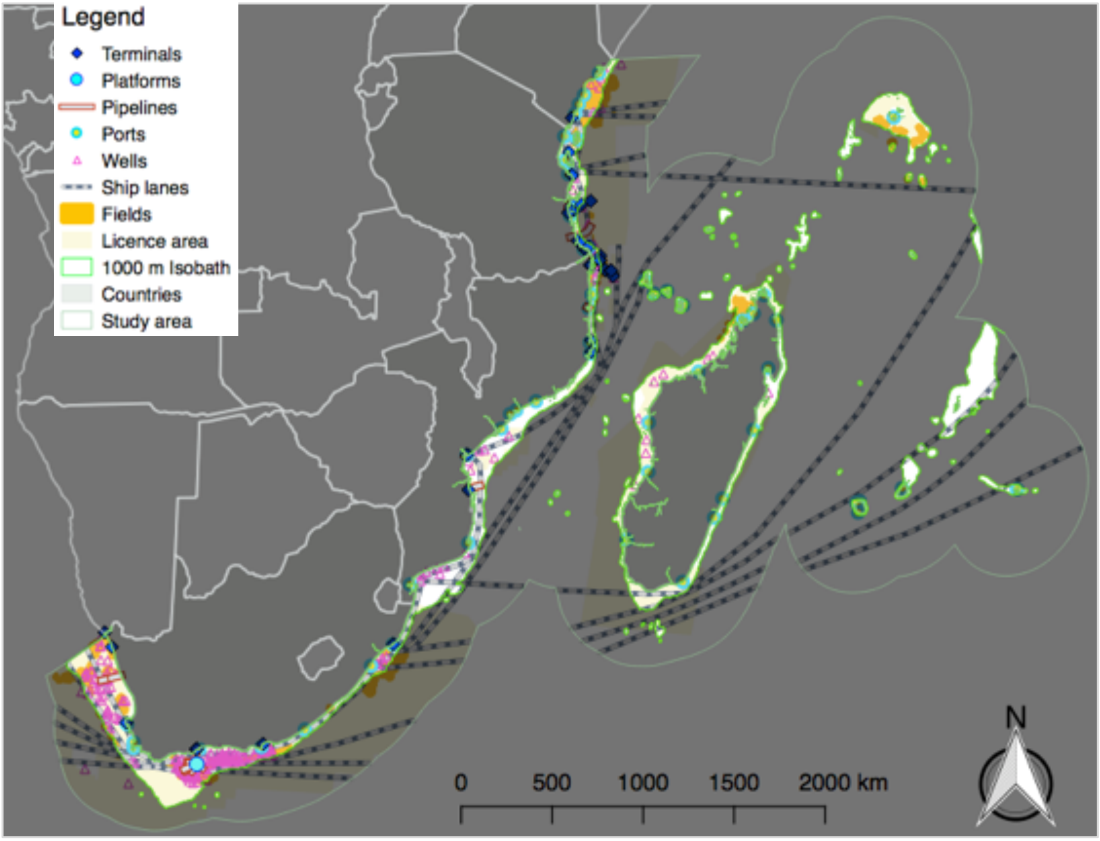

Figure 3-4 | Areas of identified or highly likely HEP within the 1000 m isobath (bright green). including: i. fields; ii. licence areas; iii. wells; iv. platforms; v. pipelines; vi. ports; vii. terminals and viii) shipping lanes.

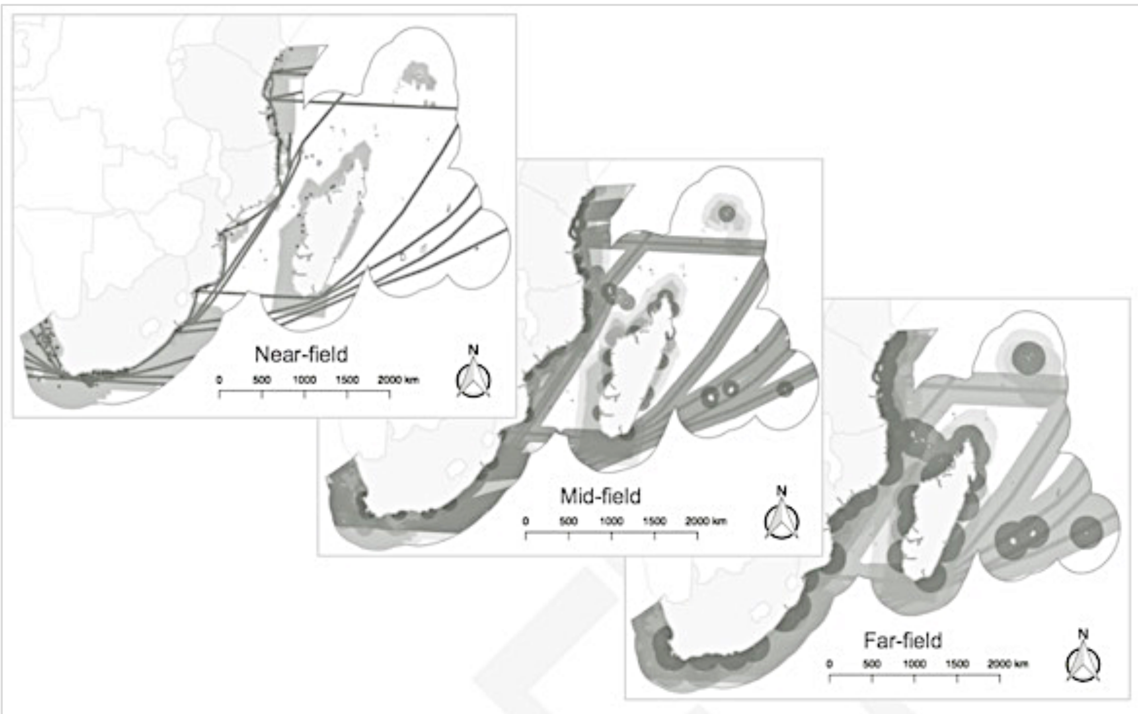

Figure 3-5 | Maps indicating the HEP components buffered by the most plausible extent for each impact category, i.e. near-, mid- and far-field zone, thereby accounting for a decline in impact with increasing distance from the source (where applicable). The different shades of grey are a function of the multiple layer overlays and therefore the darker shades of grey the more overlapping layers there are.

3.4.2 Hydrocarbon impact ratings

Of the top 28 impacts (Table 3-2), eight are associated with ports (Figure 3-9a), this assemblage of impacts associated with ports can be explained by the high likelihood of occurrence of impacts such as oil spills and ship strikes, as well as active and persistent impacts such as sediment dredging and security lighting at these key infrastructure points. Pipeline, platforms and wells each contribute five impacts to the top 28. Pipeline impacts are mostly associated with near-field construction impacts i.e. habitat destruction and noise pollution, whereas stochastic water pollution events might affect the near-field, mid-field and far-field. Impacts from platforms and wells are typically associated since permanent platforms are only established at productions wells. Therefore, the impacts as they relate to both are similar, i.e. potential water pollution, light pollution and habitat destruction, although there are aspects which differentiate these impacts in terms of ratings e.g. the complexities around establishing wells versus platforms which might lead to impacts manifesting differently (Aryee, 2013). Ship-associated impacts (four of the top 28) mostly relate to potential water pollution as vessels carrying hydrocarbons can potentially cause significant impact to sea turtles throughout the study area. Water pollution at terminals contribute the last of the top 28 impacts. The occurrence of water pollution at terminals can be due to chronic or stochastic events, which could see substantive amounts of pollutants enter the marine environment (Marsh LLC, 2014) from both on- and offshore terminals.

The top 28 impacts were split between HEP-associated impacts (ports and ships, Figure 3-11a); and HEP-only impacts (wells, platforms, pipelines and terminals, Figure 3-11b). In doing this, the overall impact layout shifted from one which encompass vast areas of the entire study area, to one where higher significance impacts become predominantly shallow-water associated within the shore and the 1000 m isobath (fields and licence areas had no impacts rated in the top 28 and were therefore excluded). This illustrated the high potential of impacts to occur in shallow-water areas, although their influence spheres are not necessarily restricted to the shallow-water environment

Table 3-2 | Impact ratings of the potential HEP impacts ranked from most (severe) to least (minimal) significant. The top 28 impacts rated as severe, major or moderate significance are bolded

***Impact**, source of impact including fields; licence blocks; wells; platforms; pipelines; ports; terminals and ship lanes; **WP (blue)**, water pollution; **LP (yellow)**, light pollution; **NP (grey)**, noise pollution; **VS (orange)**, vessel strikes; **HD (green)**, habitat destruction; **NF**, near-field; **MF**, mid-field; **FF**, far-field; **Ex high**, Extremely high; **V unlikely**, Very unlikely; **Ex unlikely**, Exceptionally unlikely; **Vr certain**, Virtually certain; **#,** score. (Appendix B provides this table arranged by impact category and type)*

Impact	Intensity	#	Duration	#	Magnitude	#	Likelihood	#	Significance	#
Port WP NF	Very high	6	Permanent	7	Ex high	13	Definite	7	Severe	91
Port HD NF	Very high	6	Permanent	7	Ex high	13	Definite	7	Severe	91
Port WP MF	Very high	6	Permanent	7	Ex high	13	Vr certain	6	Major	78
Well WP NF	High	5	Permanent	7	Very high	12	Vr certain	6	Major	72
Ship WP NF	High	5	Permanent	7	Very high	12	Vr certain	6	Major	72
Plat WP NF	Very high	6	Permanent	7	Ex high	13	Very likely	5	Major	65

Impact	Intensity	#	Duration	#	Magnitude	#	Likelihood	#	Significance	#
Plat WP MF	Very high	6	Permanent	7	Ex high	13	Very likely	5	Major	65
Port WP FF	Very high	6	Permanent	7	Ex high	13	Very likely	5	Major	65
Pipe HD NF	Moderate	4	Long term	5	High	9	Definite	7	Major	63
Ship WP MF	High	5	Permanent	7	Very high	12	Very likely	5	Major	60
Well WP MF	High	5	Semi-permanent	6	Very high	11	Very likely	5	Moderate	55
Port HD MF	Moderate	4	Long term	5	High	9	Vr certain	6	Moderate	54
Plat WP FF	Very high	6	Permanent	7	Ex high	13	Likely	4	Moderate	52
Plat HD NF	Moderate	4	Semi-permanent	6	High	10	Very likely	5	Moderate	50
Pipe WP NF	High	5	Long term	5	High	10	Very likely	5	Moderate	50
Well LP NF	High	5	Seasonal	2	Moderate	7	Definite	7	Moderate	49
Port LP NF	High	5	Seasonal	2	Moderate	7	Definite	7	Moderate	49
Well WP FF	High	5	Permanent	7	Very high	12	Likely	4	Moderate	48
Well HD NF	Moderate	4	Medium term	4	Moderate	8	Vr certain	6	Moderate	48
Ship WP FF	High	5	Permanent	7	Very high	12	Likely	4	Moderate	48
Term WP NF	Moderate	4	Long term	5	High	9	Very likely	5	Moderate	45
Plat LP NF	High	5	Seasonal	2	Moderate	7	Vr certain	6	Moderate	42
Port LP MF	High	5	Seasonal	2	Moderate	7	Vr certain	6	Moderate	42
Port NP NF	High	5	Seasonal	2	Moderate	7	Vr certain	6	Moderate	42
Pipe NP NF	Moderate	4	Seasonal	2	Low	6	Definite	7	Moderate	42
Pipe WP MF	High	5	Long term	5	High	10	Likely	4	Moderate	40
Pipe WP FF	High	5	Long term	5	High	10	Likely	4	Moderate	40
Ship NP NF	Low	3	Long term	5	Moderate	8	Very likely	5	Moderate	40
Well LP MF	Moderate	4	Seasonal	2	Low	6	Vr certain	6	Minor	36
Port HD FF	Moderate	4	Long term	5	High	9	Likely	4	Minor	36
Term HD NF	Moderate	4	Long term	5	High	9	Likely	4	Minor	36
Ship VS NF	High	5	Seasonal	2	Moderate	7	Very likely	5	Minor	35
Plat HD MF	Low	3	Long term	5	Moderate	8	Likely	4	Minor	32
Port LP FF	Moderate	4	Seasonal	2	Low	6	Very likely	5	Minor	30
Port VS NF	Moderate	4	Seasonal	2	Low	6	Very likely	5	Minor	30
Well HD MF	Low	3	Medium term	4	Moderate	7	Likely	4	Minor	28
Pipe NP MF	Low	3	Negligible	1	Very low	4	Definite	7	Minor	28
Pipe NP FF	Low	3	Negligible	1	Very low	4	Definite	7	Minor	28
Pipe HD MF	Low	3	Medium term	4	Moderate	7	Likely	4	Minor	28
Licence NP NF	High	5	Seasonal	2	Moderate	7	Likely	4	Minor	28
Field LP NF	Low	3	Seasonal	2	Low	5	Very likely	5	Minor	25
Plat LP MF	Moderate	4	Seasonal	2	Low	6	Likely	4	Minor	24
Plat HD FF	Low	3	Long term	5	Moderate	8	Unlikely	3	Minor	24
Term LP NF	Moderate	4	Seasonal	2	Low	6	Likely	4	Minor	24
Field WP NF	Low	3	Short term	3	Low	6	Likely	4	Minor	24
Field WP MF	Low	3	Short term	3	Low	6	Likely	4	Minor	24
Field HD NF	Low	3	Short term	3	Low	6	Likely	4	Minor	24
Well HD FF	Low	3	Medium term	4	Moderate	7	Unlikely	3	Minor	21
Pipe HD FF	Low	3	Medium term	4	Moderate	7	Unlikely	3	Minor	21
Term WP MF	Very Low	2	Long term	5	Moderate	7	Unlikely	3	Minor	21
Term WP FF	Very Low	2	Long term	5	Moderate	7	Unlikely	3	Minor	21

Impact	Intensity	#	Duration	#	Magnitude	#	Likelihood	#	Significance	#
Term HD MF	Very Low	2	Long term	5	Moderate	7	Unlikely	3	Minor	21
Port NP MF	Low	3	Seasonal	2	Low	5	Likely	4	Minor	20
Term LP MF	Low	3	Seasonal	2	Low	5	Likely	4	Minor	20
Ship VS MF	Low	3	Seasonal	2	Low	5	Likely	4	Minor	20
Ship VS FF	Low	3	Seasonal	2	Low	5	Likely	4	Minor	20
Licence NP MF	Low	3	Seasonal	2	Low	5	Likely	4	Minor	20
Licence NP FF	Low	3	Seasonal	2	Low	5	Likely	4	Minor	20
Field NP NF	Low	3	Seasonal	2	Low	5	Likely	4	Minor	20
Plat NP NF	Very Low	2	Seasonal	2	Very low	4	Likely	4	Minimal	16
Plat VS NF	Very Low	2	Seasonal	2	Very low	4	Likely	4	Minimal	16
Field WP FF	Low	3	Negligible	1	Very low	4	Likely	4	Minimal	16
Plat LP FF	Low	3	Seasonal	2	Low	5	Unlikely	3	Minimal	15
Port NP FF	Low	3	Seasonal	2	Low	5	Unlikely	3	Minimal	15
Port VS MF	Low	3	Seasonal	2	Low	5	Unlikely	3	Minimal	15
Port VS FF	Low	3	Seasonal	2	Low	5	Unlikely	3	Minimal	15
Term LP FF	Low	3	Seasonal	2	Low	5	Unlikely	3	Minimal	15
Term HD FF	Very Low	2	Long term	5	Moderate	7	Vr unlikely	2	Minimal	14
Well LP FF	Very Low	2	Seasonal	2	Very low	4	Unlikely	3	Minimal	12
Well NP NF	Very Low	2	Seasonal	2	Very low	4	Unlikely	3	Minimal	12
Well NP MF	Very Low	2	Seasonal	2	Very low	4	Unlikely	3	Minimal	12
Plat NP MF	Very Low	2	Seasonal	2	Very low	4	Unlikely	3	Minimal	12
Plat NP FF	Very Low	2	Seasonal	2	Very low	4	Unlikely	3	Minimal	12
Plat VS MF	Very Low	2	Seasonal	2	Very low	4	Unlikely	3	Minimal	12
Term NP NF	Very Low	2	Seasonal	2	Very low	4	Unlikely	3	Minimal	12
Term NP MF	Very Low	2	Seasonal	2	Very low	4	Unlikely	3	Minimal	12
Term NP FF	Very Low	2	Seasonal	2	Very low	4	Unlikely	3	Minimal	12
Ship NP MF	Very Low	2	Seasonal	2	Very low	4	Unlikely	3	Minimal	12
Ship NP FF	Very Low	2	Seasonal	2	Very low	4	Unlikely	3	Minimal	12
Licence VS NF	Very Low	2	Seasonal	2	Very low	4	Unlikely	3	Minimal	12
Licence VS MF	Very Low	2	Seasonal	2	Very low	4	Unlikely	3	Minimal	12
Licence VS FF	Very Low	2	Seasonal	2	Very low	4	Unlikely	3	Minimal	12
Well NP FF	Negligible	1	Seasonal	2	Very low	3	Unlikely	3	Minimal	9
Plat VS FF	Negligible	1	Seasonal	2	Very low	3	Unlikely	3	Minimal	9
Well VS NF	Very Low	2	Seasonal	2	Very low	4	V unlikely	2	Minimal	8
Pipe LP NF	Very Low	2	Seasonal	2	Very low	4	V unlikely	2	Minimal	8
Term VS NF	Very Low	2	Seasonal	2	Very low	4	V unlikely	2	Minimal	8
Licence HD NF	Very Low	2	Seasonal	2	Very low	4	V unlikely	2	Minimal	8
Licence HD MF	Very Low	2	Seasonal	2	Very low	4	V unlikely	2	Minimal	8
Licence HD FF	Very Low	2	Seasonal	2	Very low	4	V unlikely	2	Minimal	8
Field NP MF	Very Low	2	Seasonal	2	Very low	4	V unlikely	2	Minimal	8
Pipe VS FF	Negligible	1	Seasonal	2	Very low	3	V unlikely	2	Minimal	6
Ship LP NF	Negligible	1	Seasonal	2	Very low	3	V unlikely	2	Minimal	6
Ship LP MF	Negligible	1	Seasonal	2	Very low	3	V unlikely	2	Minimal	6
Ship LP FF	Negligible	1	Seasonal	2	Very low	3	V unlikely	2	Minimal	6
Field LP MF	Negligible	1	Seasonal	2	Very low	3	V unlikely	2	Minimal	6
Field HD MF	Negligible	1	Negligible	1	Neutral	2	Unlikely	3	Minimal	6
Pipe LP MF	Negligible	1	Negligible	1	Neutral	2	V unlikely	2	Minimal	4
Pipe VS NF	Negligible	1	Negligible	1	Neutral	2	V unlikely	2	Minimal	4
Pipe VS MF	Negligible	1	Negligible	1	Neutral	2	V unlikely	2	Minimal	4

Impact	Intensity	#	Duration	#	Magnitude	#	Likelihood	#	Significance	#
Term VS MF	Very Low	2	Seasonal	2	Very low	4	Ex unlikely	1	Minimal	4
Field NP FF	Negligible	1	Negligible	1	Neutral	2	V unlikely	2	Minimal	4
Field VS NF	Negligible	1	Negligible	1	Neutral	2	V unlikely	2	Minimal	4
Field VS MF	Negligible	1	Negligible	1	Neutral	2	V unlikely	2	Minimal	4
Field VS FF	Negligible	1	Negligible	1	Neutral	2	V unlikely	2	Minimal	4
Field HD FF	Negligible	1	Negligible	1	Neutral	2	V unlikely	2	Minimal	4
Term VS FF	Negligible	1	Seasonal	2	Very low	3	Ex unlikely	1	Minimal	3
Licence LP NF	Negligible	1	Seasonal	2	Very low	3	Ex unlikely	1	Minimal	3
Licence LP MF	Negligible	1	Seasonal	2	Very low	3	Ex unlikely	1	Minimal	3
Licence LP FF	Negligible	1	Seasonal	2	Very low	3	Ex unlikely	1	Minimal	3
Field LP FF	Negligible	1	Seasonal	2	Very low	3	Ex unlikely	1	Minimal	3
Well VS MF	Negligible	1	Negligible	1	Neutral	2	Ex unlikely	1	Minimal	2
Well VS FF	Negligible	1	Negligible	1	Neutral	2	Ex unlikely	1	Minimal	2
Pipe LP FF	Negligible	1	Negligible	1	Neutral	2	Ex unlikely	1	Minimal	2
Ship HD NF	Negligible	1	Negligible	1	Neutral	2	Ex unlikely	1	Minimal	2
Ship HD MF	Negligible	1	Negligible	1	Neutral	2	Ex unlikely	1	Minimal	2
Ship HD FF	Negligible	1	Negligible	1	Neutral	2	Ex unlikely	1	Minimal	2
Licence WP NF	Negligible	1	Negligible	1	Neutral	2	Ex unlikely	1	Minimal	2
Licence WP MF	Negligible	1	Negligible	1	Neutral	2	Ex unlikely	1	Minimal	2
Licence WP FF	Negligible	1	Negligible	1	Neutral	2	Ex unlikely	1	Minimal	2

Impact intensity i.e. the degree of damage caused by an impact, was found to have ratings of high, very high and extremely high for ~30 % of all impacts assessed. Impact intensity rated as very low or negligible accounted for ~48 % of all impacts assessed (Figure 3-6a and Figure 3-7). Consequently, based on intensity, only around a third of impacts have the potential to negatively impact on sea turtles given that they occur (likelihood) for long enough (duration). Around 52 % of impacts had a duration rated as seasonal and ~18 % of impacts had a duration rated as negligible (Figure 3-6b). This aligns with the magnitude (the sum of intensity and duration) of impacts, of which ~66 % is rated as low, or less (Figure 3-6c).

Impacts rated as virtually certain and definite comprised ~14 % of all impacts and ~54 % of impacts had a likelihood rated as unlikely or less (Figure 3-6d and Figure 3-8). Impacts rated as likely to occur amounted to ~22 %, these are impacts where the assessment was unclear if the impact is likely to occur or not, either due inherent variability associated with the impact, and/or insufficient evidence from existing studies, and/or lack of conclusive expert judgement. Around 51 % of impacts were found to currently have a minimal propensity to affect sea turtles negatively (Figure 3-6e), which is consistent throughout the ratings, given that approximately half of the impacts were grouped in the low end of the ratings scale. Although impacts rated as “minimal” or “minor” are not currently of foremost concern they should still be noted, especially those that have a predisposition for more significant impacts, e.g. gas fields, where infrastructure is likely to cluster, as is currently the case (Figure 3-3). Impacts with a significance rating of moderate or higher amounted to ~24 % of all impacts, i.e. the top 28 impacts of a 120 assessed (eight HEP components, with five impacts of three intensities) from HEP activities were spatially delineated across the study area, it's these impacts that demand the most attention because they can have meaningful negative impacts on sea turtles (Table 3-2).

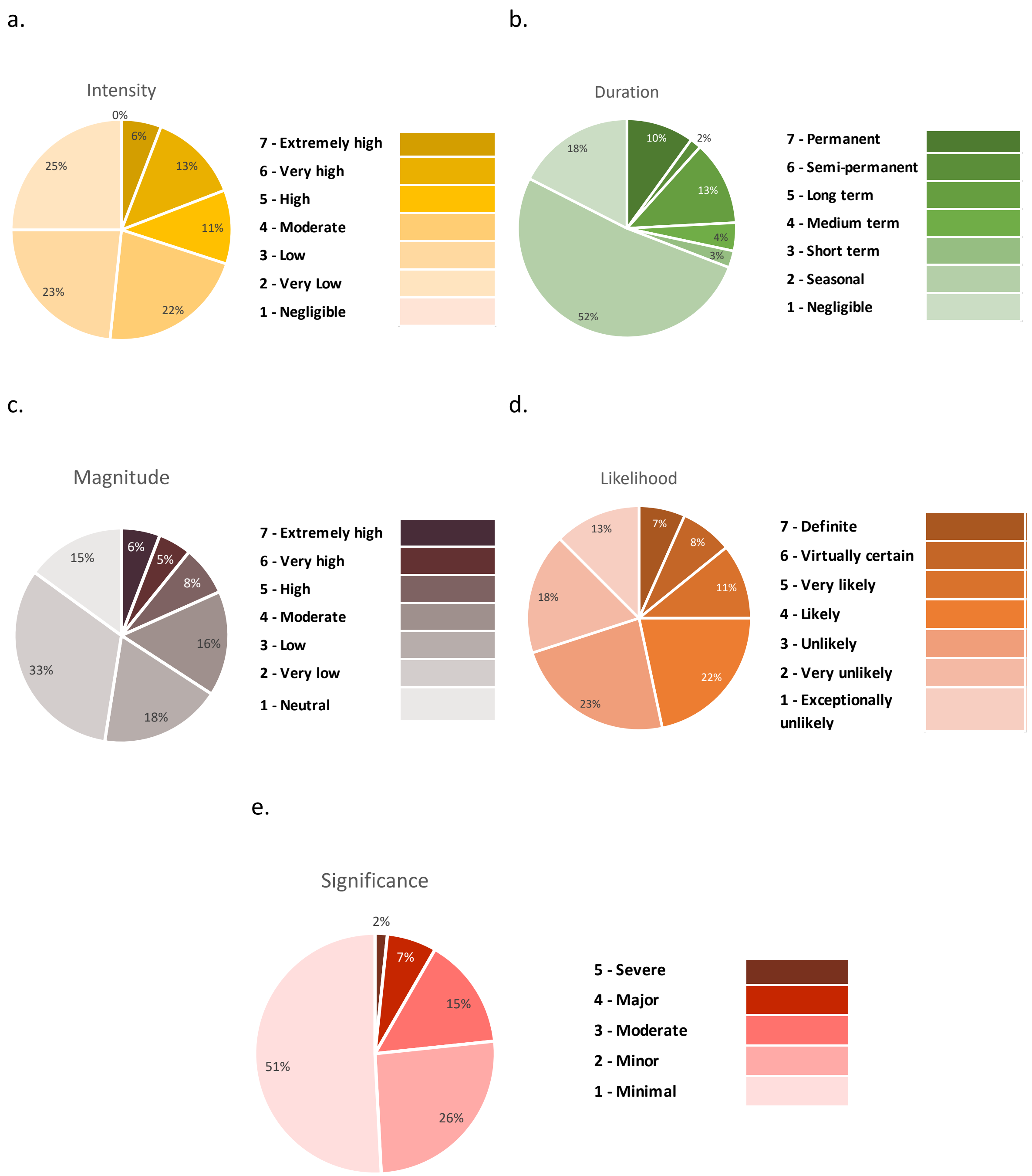

Figure 3-6 | Summary of the HEP impact ratings (n=120), including: a.) intensity; b.) duration; c.) magnitude; d.) likelihood; and e.) significance. The impact magnitude is derived from the sum of intensity and duration and the impacts significance is derived from the product of magnitude and likelihood.

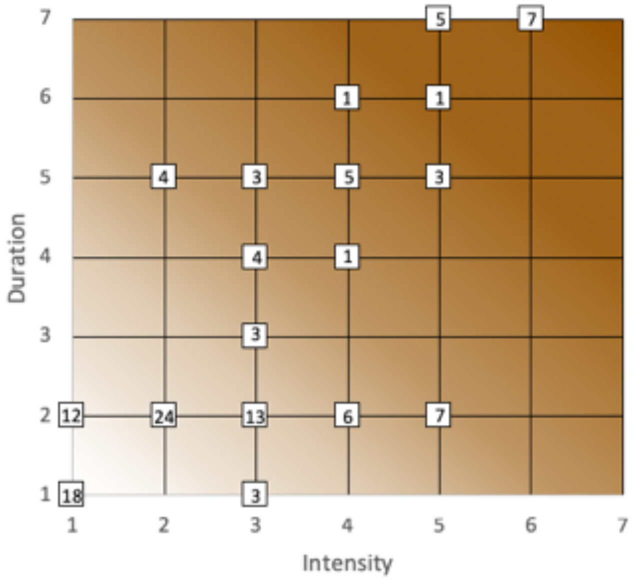

Figure 3-7 | Summary of the HEP ratings for intensity and duration, the sum of which provides the impact Magnitude. Each block in the graph provides the number impacts that are rated at the specific level of intensity and duration. This graph illustrates that as impact intensity increases so does the duration of the impact.

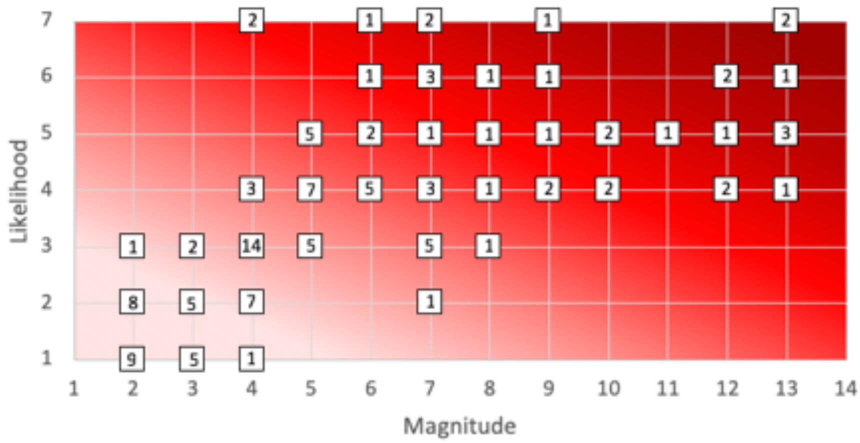

Figure 3-8 | Summary of the HEP ratings for likelihood and magnitude, the sum of which provides the impact significance. Each block in the graph provides the number impacts that are rated at the specific level of likelihood and magnitude. Impacts rated as major and severe all have a likelihood rated as likely, very likely, virtually certain or definite.

3.4.3 **Risk per impact category**

3.4.3.1 Water pollution

The impact rating results (in Section 3.4.2) highlighted the importance of the top 28 impacts identified in this study, 16 of which are related to water pollution (Table 3-2). The main contributors to potential water pollution are ports, ships, pipelines, wells and platforms, all of which cover a near-, mid- and far-field extent with only water pollution from terminals limited to near-field extent (Figure 3-10). Ports have the highest rated impact significance for water pollution (severe) of all impacts. Furthermore, ports are the only coast-associated infrastructure associated with water pollution in the severe and major categories whereas ships, wells and platforms are not necessarily coast associated, although their impacts might still reach the coast. Importantly, two of the greatest contributors to water pollution are ports (Figure 3-9a) and ships (Figure 3-9d), which are features that have in many cases been long established in the study area with impacts not confined to HEP. Water pollution had the greatest extent from source (Table 3-1), which coupled with the geographic spread of potential impact sources, means that it has the largest extent of all impacts associated with HEP (Figure 3-10a). Potential water pollution impacts encompass all of the 1000 m bathymetry and traverses all EEZ boundaries in the study area.

Other sources of water pollution include pipelines (moderate significance in the near- to far field, Figure 3-9e), which have a comparatively lower likelihood of causing a major stochastic pollution event since location of pipelines are fixed (in contrast to ships that may theoretically cause water pollution anywhere (Mazaheri, et al., 2013)) and mechanisms such as valves can be closed to limit volume of product spilled (Merv, 2012), in contrast to pollution at ports which may be challenging to contain. It's only fields and licence areas which have been assessed not to contribute to significant water pollution impacts. Water pollution in areas mapped as licence blocks or fields are currently rated as minor or minimal, but since the hydrocarbon industry will focus on developments in or adjacent these areas, it's still important to take note of their location and extent (Figure 3-9g and Figure 3-9h).

3.4.3.2 Light pollution

Four of the top 28 impacts are associated with light pollution (Table 3-2). Significant emitters of light pollution (all of moderate significance) include ports (near-and mid-field), platforms (near-field) and wells (near-field), (Figure 3-10b). These significance ratings are largely associated with the presence of safety lights at infrastructure. Therefore, ports, which are coast bound, may have a higher likelihood of impacts up to mid-field extent than platforms or wells (which are not necessarily near the coast), even though the intensity of lighting at platforms might exceed that at ports. Light pollution will have greatest impact on sea turtles in sensitive coastal areas (near nesting beaches), although the potential impact sphere might extend significantly seaward. It should also be noted that lights from ports might typically coincide with other sources of light pollution, i.e. city lights, thus only contributing to the overall light pollution, whilst wells and platforms are often far away from other light sources being the main contributors to light pollution (Figure 3-3).

3.4.3.3 Noise pollution

Areas where there is a high occurrence of shipping traffic (propeller noise) or constant noise-generating activities such as ports are rated as moderate in the near-field. Pipeline noise pollution is also rated to be of moderate significance in the near field because construction of pipelines may have substantial adverse impacts during specific seasons, especially where they bisect nesting beaches or other high-use areas e.g. from nearshore wells to onshore terminals. Seismic survey activities associated with licence blocks are rated as minor even though the near-field intensity is rated as high (Table 3-2). This is based on the short-term duration of seismic activities impacts and likelihood of these events to coincide with seasonal aggregation of sea turtles in specific areas. The area covered by licence blocks (Figure 3-10c) is vast and therefore if the duration of impacts increases, e.g. in the case of repetitive seismic activity in a confined area, the significance of potential impacts will increase substantially.

3.4.3.4 Vessel strikes

There are no vessel strike impacts in the top 28 impacts (Table 3-2). Vessel strikes are most likely to occur in or near ports (near-field) and shipping lanes (near-to far-field), both rated as being of minor significance (Figure 3-10d). The contribution of the HEP industry to vessel strikes must be viewed in context of other industries, such as transport, fishing and tourism that also contribute to potential physical impact in the same area. Additionally, the likelihood of physical impact occurring directly associated with HEP in any given area with an aggregation of sea turtles (thus seasonal duration) to such an extent that it manifests in a quantifiable negative impact is low.

3.4.3.5 Habitat destruction

Habitat destruction impacts generally occur during construction of HEP infrastructure and is closely correlated to the physical footprint of the HEP infrastructure. Consequently, near-field impacts at ports (severe) and pipelines (major) are rated of the highest significance (Figure 3-10e). The duration of habitat destruction impacts is subject to recovery after construction, yet at ports and pipelines, maintenance activities such as dredging means that impacts periodically return and therefore the duration of these impacts on sea turtles and their habitat is seen as permanent. Specifically, ports have the means of altering the near-shore environment significantly (Gupta, et al., 2005), hence the severe significance rating. Moderate significance habitat destruction impacts include wells (near-field), platforms (near-field) and ports (mid-field) making up the last five of the top 28 impacts (Table 3-2). The remainder of habitat destruction impacts are of minor or minimal significance.

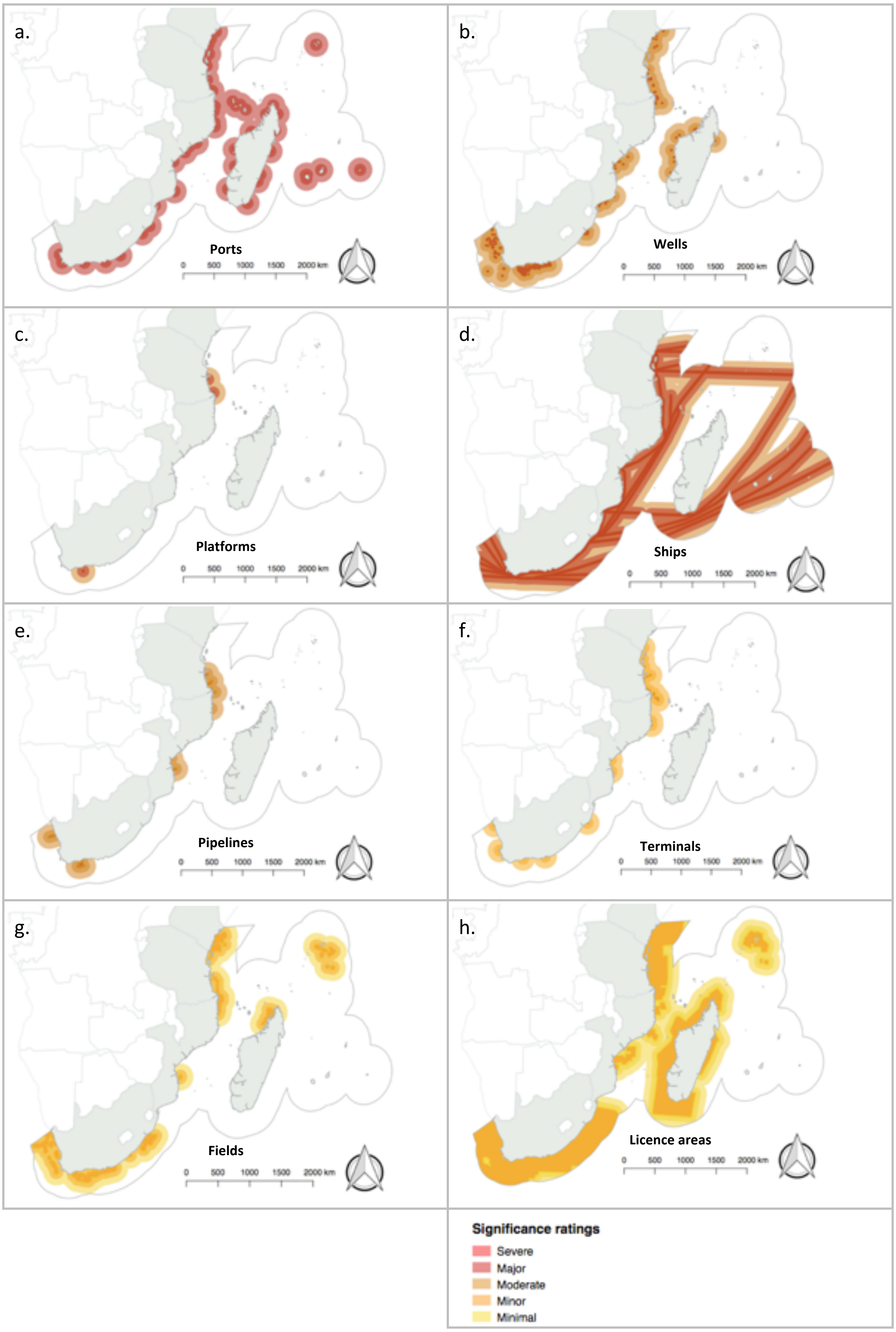

Figure 3-9 | Significance of impacts per feature type for: a.) ports; b.) wells; c.) platforms; d.) ships; e.) pipelines; f.) terminals; g.) fields; and h.) license areas. The vast extent of severe and major impacts from ports and ships are particularly evident.

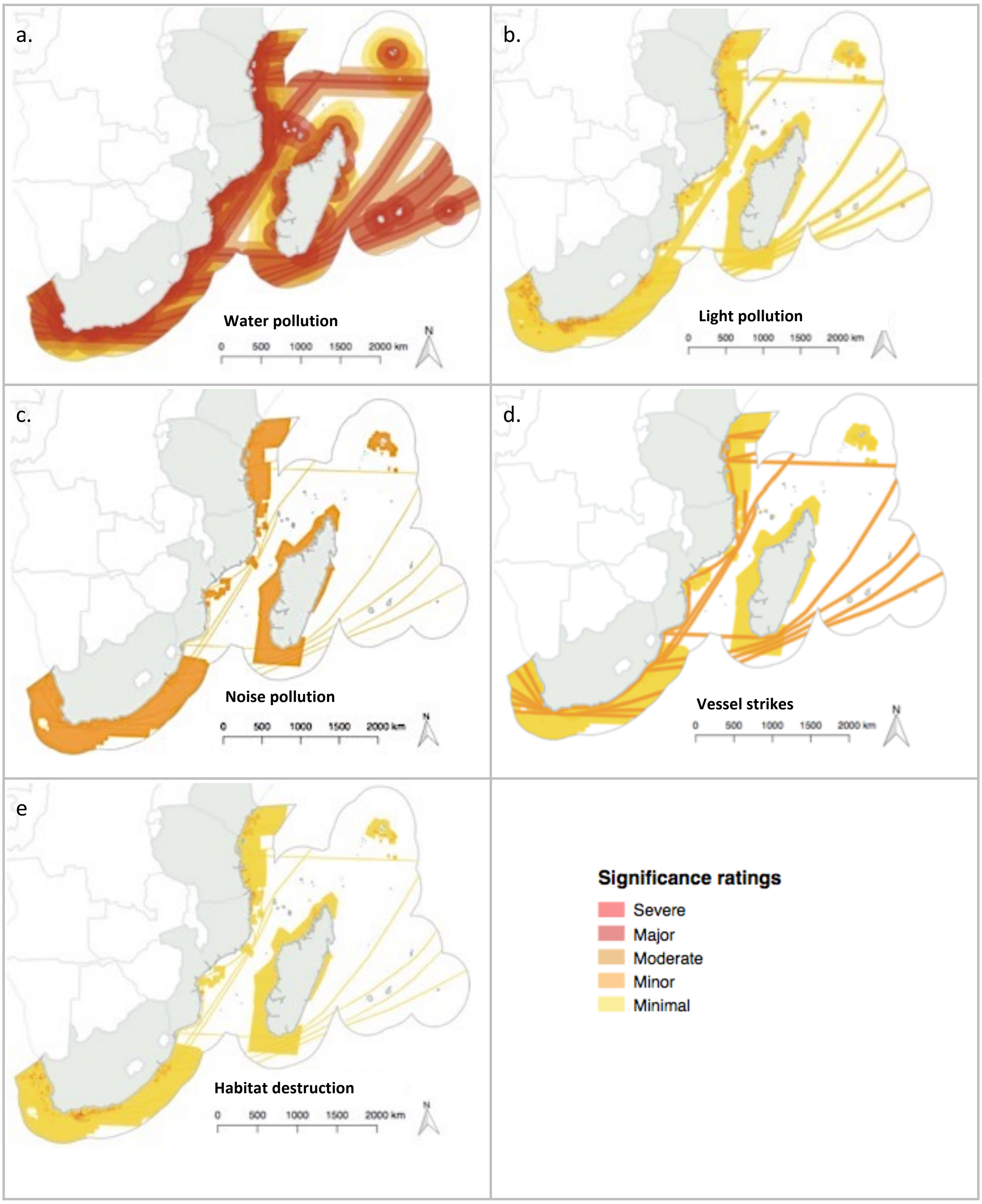

Figure 3-10 | Significance of impacts per threat type for: a.) water pollution; b.) light pollution; c.) noise pollution; d.) vessel strikes; and e.) habitat destruction. The combined water pollution impacts from all HEP infrastructure and actives are greatest in both extent and significance of all impacts.

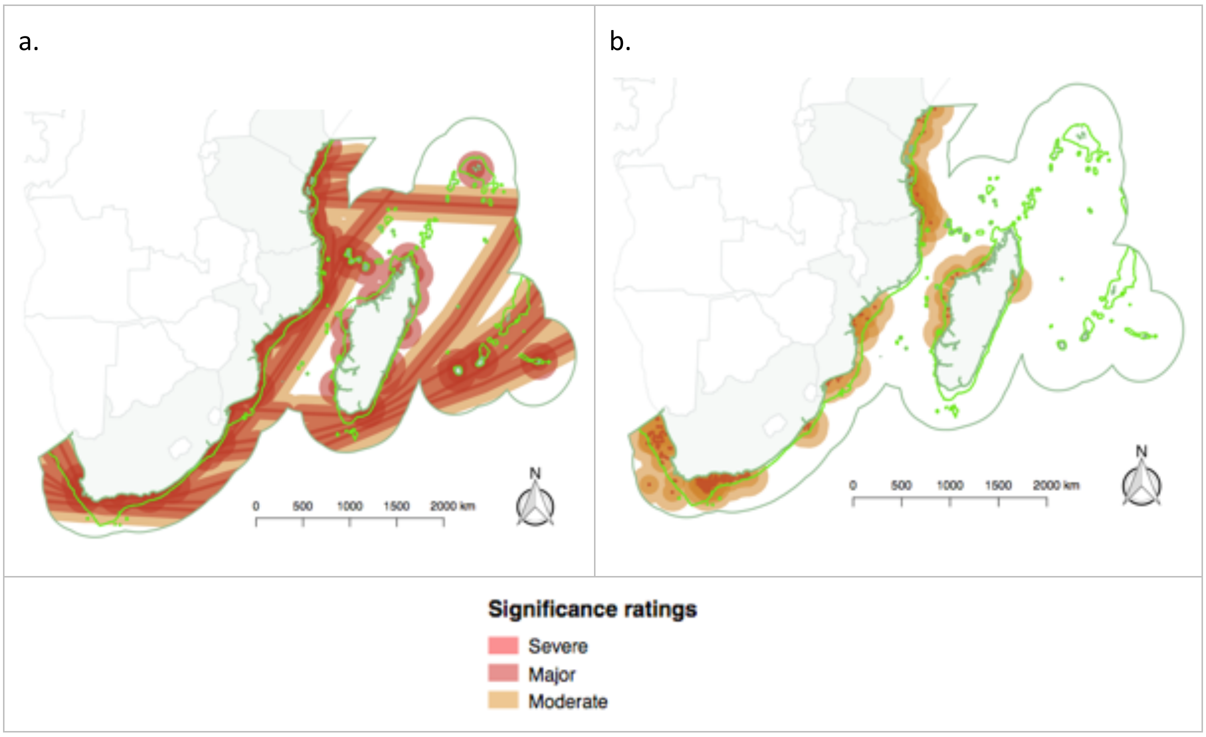

Figure 3-11 | The top 28 impacts rated as severe, major and moderate significance for: a.) of ports and ships; and b.) wells, platforms, pipelines, terminals (fields and licence areas had no impacts rated in these categories and were therefore excluded). A 1000 m isobath (bright green) was included to define the shallow-water environment. Note the high potential of impacts to occur in shallow-water areas.

3.5 Discussion

Adult sea turtles spend a significant part of their lives in the neritic zone (Maxwell, et al., 2011; Shimada, et al., 2016) for feeding and breeding, and thus are particularly at risk in these areas (Shimada, et al., 2017). This risk is exemplified by the findings in this study, which indicate that the area from shore to the 1000 m isobath (defined as shallow-water) of all countries in the study area are significantly and for a large part wholly exposed to potential impacts from the HEP industry. Therefore, the notion that an overlap in space use between the HEP activities and sea turtles in the shallow-water environment exists is sustained. Additionally, this study established that potential HEP impacts of major significance also cover large expanses of the study area beyond the 1000 m isobath, i.e. the deep-water zone. Sea turtles, which are highly migratory (Lutz & Musick, 1997), are bound to traverse these areas of potential impact. Moreover, juvenile sea turtles are completely sea-bound for the first few of years of their life (Briscoe, et al., 2016), may be wholly at risk during these so called “lost years”. The potential threat to sea turtles from HEP is thus both in the neritic and oceanic environment, but to quantify this potential threat as an actual threat comparison will have to be made with sea turtle distribution.

The space-use overlap between sea turtles and HEP is ongoing based on the expansive extent of impacts from existing infrastructure, such as ports, and activities, such as hydrocarbon-associated shipping i.e. tankers using ship lanes or vessels transporting infrastructure components. Considering that impacts associated with ports and ship lanes pose the most significant potential risk to sea turtles’ these aspects are viewed as the main cause of the space-use conflict between sea turtles and hydrocarbon HEP, both in the shallow- and deep-water environment. Ports are coast associated and the potential water pollution threat around ports (Valdor, et al., 2014) holds impacts of major significance to sea turtles. As is the case with West and Central African ports, ports in the SWIO study area face numerous environmental challenges often underpinned by legacies, which did not give much attention to environmental considerations (Barnes-Dabban, et al., 2017). Ship lanes are areas where high volumes of vessel traffic occur and the potential pollution impact from these areas are thus subject to temporal considerations, e.g. daily and seasonal traffic peaks (Xiao et al., 2013) as well as the inherent stochastic nature of major pollution events. Ship lanes are not coast associated and span large parts of the study area, as do potential pollution impacts associated with them. The potential pollution impacts from these two sources are of note since they may invariably influence all sea turtle life stages throughout their range.

Dissociating impacts from ports and ship lanes from other hydrocarbon impacts illustrated an overall shift in impact footprint from one which include vast areas of the entire study area to one where impacts of higher significance become predominantly shallow-water associated. A clear decrease in significance is seen with increase in distance from the shore, which also holds true for an increase in depth. Considering what is known regarding impacts related to ships i.e. the unpredictable nature of pollution events and the great extent at which they might occur (ITOPF, 2017), it would be difficult to argue that any area within the study area is safe from pollution events. Therefore, representing the potential pollution impact from ships through the study area as homogenously severe risk portrays a plausible scenario, which would be worsened in shallow-water and nearshore priority areas for sea turtles. This makes coast-associated impacts the main geographic distinction, especially in light of the impact extent of water pollution from ports. These variable scenarios emphasise the importance of understanding potential multi-faceted impacts and the need to address each on their own merits.

3.5.1 Why water pollution is the worst

In consideration of the worst historical HEP pollution incidences, pollutants dispersed hundreds and even thousands of kilometres from the point of origin. In the case of oil pollution, examples include 1969 Union Oil Company spill off the coast of California, which released a ~2,071 km2 oil slick, the 2010 British Petroleum Gulf of Mexico spill affecting ~6,317 km2 (Aryee, 2013) and 2002 Prestige spill off Spain where ~30,000 km2 was affected (Sanchez, et al., 2006). Although the vast majority of catastrophic spills are in the form of crude oil, the products of natural gas could also hold similar catastrophic results as recently (2018) shown by the Iranian tanker Sanchi, which sank in the East China Sea with 136,000 metric tons of natural gas condensate on board. Subsequent to the results of this study, it’s clear that the extent of potential pollution impacts in the study identified all coastal zones to be at risk. This poses a significant challenge to ocean zoning in the SWIO to reduce conflict between ocean-based HEP and sea turtles, because ultimately sea turtles will be at risk throughout the coastal zone, which inherently means no HEP will be able to take place without potentially impacting sea turtles negatively. Consequently, the proposed blue growth, which aims to improve human well-being and social equity, while significantly reducing environmental risks and ecological scarcities (Pauli, 2010; Obura, 2017a) will not be plausible if the *status quo* approach to HEP continues.

Although impacts from pollution are addressed separately to habitat destruction, it is noted that pollution itself may cause habitat alteration and in severe cases, destruction. Pollution events might destroy significant portions of critical foraging habitat (Loya & Rinkevich, 1980; Jackson, et al., 1989; Haapkyla, et al., 2007) and transform nesting habitat (Lauritsen, et al., 2017). This substantiates why numerous studies on HEP impacts have highlighted the need for holistic environmental assessment through Life Cycle Analysis (LCA) (Salter & Ford, 2001) and the strong emphasis placed on a need for interdisciplinary environmental analysis of HEP. However, in one of the most recent catastrophic oils spill, the Deepwater Horizon Spill in the Gulf of Mexico, the rig was exempted by the US Interior Department from having a detailed environmental impact study done since preliminary studies found that that a massive oil spill was unlikely. The decision to give BP's lease at Deepwater Horizon a "categorical exclusion" from the National Environmental Policy Act of 1907 (NEPA) is symptomatic of how impacts may be down played to favour oil companies and protection for vulnerable populations limited (Osofsky, et al., 2012). This emphasises that although the potential significance of impacts might be negated due to a low likelihood of occurrence, such an occurrence might still be of great consequence. The consequence of the Deepwater Horizon spill is that, to this day, species such as loggerhead turtles are impacted by habitat destruction linked to an event that happened more than eight years ago (Lauritsen, et al., 2017).

3.5.2 Habitat destruction, plucking away at nature

Habitat destruction resulting from oil and gas developments are numerous, typically associated with construction activities and to a lesser extent, maintenance during operation (Wilson, et al., 2002; Kadafa, 2012a). Accordingly, habitat destruction has a comparatively low significance when likened to other impacts, yet due to the intensity of these impacts (van't Hof, T., 1983; Fabricius & Wolanski, 2000; Hitchcock & Bell, 2004), it might be significantly detrimental to sea turtles over a near-field extent. One of the key limitations when it comes to the assessment of impacts on habitat are the complexities related to separating impacts occurring at different spatiotemporal scales (Chabanet, et al., 2005). Habitat destruction, as direct impact from HEP activities, are largely determined by the footprint size of the stressor and impact on the near-field environment. Activities which have large footprints, e.g. pipeline construction, or where multiple small impacts occur in a confined area, e.g. exploration drilling in a gas field, are therefore more likely to cause a greater extent of habitat destruction. Nevertheless, impacts over vast majority of a pipeline route may be deemed insignificant to sea turtles or their habitat, yet areas where the pipelines move near or onshore might see notably significant impacts (Iversen & Stokke, 2009).

The context of the specific habitat and importance thereof is of the utmost significance since impact significance is not necessarily an exact measure of the impact consequence. Certain types of development impacts may be relatively confined and short lived if undertaken with the needed due diligence e.g. construction phase lighting impacts, whilst others e.g. pipeline construction near nesting beaches might have significant impacts on sea turtles. The same development might have a completely different impact on seagrass, where systems might recover over a relatively short period with the aid of rehabilitation (Di Carlo, 2004). Other impacts may have a long-term persistence, i.e. construction and subsequent dredging of a port shipping canal, which not only destroys the immediate habitat, but also ensures that there is little to no recovery since the impact is chronic and re-occurring (Erftemeijer, et al., 2012). Habitat destruction is often closely associated with other impacts such as water pollution, which may destroy sea turtle feeding habitat or exclude them from certain feeding or breeding areas. Similarly, well points and terminals far offshore might impact on low diversity substrate and those near shore, which might impact on coral reefs and seagrass beds, which are of high diversity and conservation importance (Peter & Robert, 2008; Unsworth & Cullen, 2010).

The propensity for hydrocarbon clusters to develop as finds are proven may lead to substantial habitat destruction in the SWIO, with several such clusters identified throughout the study area. International examples of these cluster developments include the Gulf of Mexico (BOEM, 2010), Persian Gulf (Pratt, et al., 1997) and Niger Delta (Kadafa, 2012b). Once finds are made, different role players enter specific geographies to exploit the resource, e.g. drill their own wells, erect their own terminals and lay their own pipelines. Even though oil concession contracts may incentivise oil companies to decrease the number of wells, and other HEP infrastructure components, the driver behind this largely remains economic incentives (Ing, 2014). This may lead to significant impacts on habitats, such as fragmentation and altering their functioning permanently (Cordes, et al., 2016), ultimately leading to significant degradation due to multiple adverse impacts (Laurance, 2010). The likeliness of this happening is particularly high in areas identified as fields, since these areas represent geographies with geologies containing major hydrocarbon-bearing deposits. Fields thus represent areas where further exploration and possible development of reservoirs, well-drilling and platform installation may materialise (Iyer & Grossmann, 1998). In the study area, the gas fields around the Rovuma basin in southern Tanzania (Mahanjane, 2014) is a key example of where the HEP industry might lead to significant impacts, as happened in the Niger Delta (Kadafa, 2012a). Both northern Mozambique and southern Tanzania border this gas field with proven reserves (numerous wells have been drilled to date with estimates of recoverable reserves in Mozambique at 85 tcf (trillion cubic feet) and Tanzania at 18 tcf) on both sides of the border (Ledesma, 2013). Projects are currently underway by several hydrocarbon companies to establish HEP infrastructure on both sides of the border (Ledesma, 2013; ERM & Impacto, 2014) and licence blocks have been established by governments of both countries bordering their respective EEZs.

3.5.3 **Light pollution, and lost hatchlings**

The impacts of light pollution are fairly well studied in terrestrial ecosystems, yet marine habitats have received comparatively little attention (Davies, et al., 2014). Over the past decade there has been growing concern over light pollution as it effects every part of the marine environment from the deep sea to intertidal and sublittoral ecosystems (Godard-Codding & Bowen, 2010). Light pollution from oil and gas developments are well documented (Longcore & Rich, 2004; Davies, et al., 2014) with sources including safety lights on platforms and processing facilities as well as gas flares and several other sources. Sea turtles are affected by light pollution both on land and at sea throughout their life cycle. It's specifically ecological light pollution, which alters natural light regimes in terrestrial and aquatic ecosystems (opposed to astronomical light pollution which obscures the view of the night sky), that may impact negatively on sea turtles (Longcore & Rich, 2004). The most well documented scenario pertaining impacts on sea turtles from light pollution are the substantive impact on sea turtle hatchlings. Hatchlings rely on visual cues to orient themselves seaward, which renders them vulnerable to light pollution through disorientation (Godard-Codding & Bowen, 2010). This in turn may lead to increased energy expenditure, dehydration and predation (Godard-Codding & Bowen, 2010; Wilson et al., 2018). Adult female sea turtles are also influenced by light pollution in areas where they rely on visual cues to navigate, or where they abandon nesting attempts due to avoidance of areas with excessive artificial light, both scenarios might lead to further indirect adverse effects on individuals as well as the specific populations (Godard-Codding & Bowen, 2010).

Lighting on HEP infrastructure such as platforms, terminals and ports are seen as necessary safety requirements as is the process of flaring gas. These light sources also cause light pollution, which may have significant impact on sea turtles if it occurs near sensitive areas, i.e. nesting beaches, and therefore it's of utter importance that these impacts be identified and proactively mitigated (Thums, et al., 2016). If this is not done the effects of light pollution could be major e.g. light pollution arising from a paper mill in Turkey with similar safety lighting to those used at petroleum terminals led to more than 60 % of loggerhead turtle hatchlings not reaching the surf (Godard-Codding & Bowen, 2010). Light pollution is seen as one of the more manageable anthropogenic disturbance impacts (Whitherington & Martin, 2003) and given our increased knowledge on how light impacts on sea turtles its negative impacts should clearly be lessened. In saying this, there is high degree of complexity associated with measuring and assessing light pollution at receptor points, albeit that the exact measurements are not needed to mitigate this impact. A case has been made that through appropriate management of light, the prohibition thereof is not required (Whitherington & Martin, 2003). In addition, the regional context and existing levels of light pollution in the study area should be born in mind when considering the contribution made by HEP. This is especially true in urban areas where skylines can present crooked silhouettes which result in inconstant cues to female turtles looking for nesting beach access (Godard-Codding & Bowen, 2010). However, since many of the new proposed HEP developments in the SWIO will be situated in rural areas far from other significant light sources this impact may be exacerbated. This may lead to potential desertion of nesting attempts if turtles become aware of people prior to oviposition and increased risk of interference since there may be a greater likelihood of approach towards more visible animals by humans and predators (Godard-Codding & Bowen, 2010).

3.5.4 Noise pollution in a complex soundscape

Disturbance of sea turtles from both Cheloniidae and Dermochelyidae families is very poorly understood, especially the cause-and-effect mechanisms that underpin disturbance, with little research been undertaken (Nelms, et al., 2016). One of the major disturbance factors affecting sea turtles is noise. Noise impacts on turtles differ between those that lead to behavioural response and those that directly cause physiological impacts i.e. loss of hearing, injury or even death in extreme cases (Hawkins, et al., 2014). Whilst noise impacts that directly cause death and injury are rare and associated with noises of significant amplitude i.e. air gun blast from seismic surveys (Nelms, et al., 2016) or blasting during decommissioning of rigs (Hawkins, et al., 2014), these events may still impact on sea turtles. Nevertheless, since noise pollution primarily causes behavioural responses (Samuel, et al., 2005), it is seen as a disturbance impact. Noise pollution is an aspect often overlooked when it comes to oil and gas developments, probably because the complexity of the natural world's soundscape and how different species perceive sound are poorly understood. Noise impacts that lead to avoidance behaviour because of disturbance is however prevalent throughout the exploration and production phases of the oil and gas industry (Nelms, et al., 2016). Noise emitted from oil and gas activities affect two very distinct environments i.e. air and water, each with a unique soundscape. Studies on juvenile green sea turtles have shown that they react to different threshold ranges in air and water (Piniak, et al., 2016), and although turtles spend the majority of their life in water, critical portions of their life cycle occur on land.

Noise pollution is an intrinsically difficult aspect to quantify since it is receptor driven (Radtke, 2016). To account for relative loudness perceived by the human ear, an A-weighting in decibel (dBA) is undertaken, yet for sea turtle's several studies have shown that the use of the A-weighting curve underestimates the role low frequency noise plays in loudness annoyance (St. Pierre & Maguire, 2004). Since sea turtle hearing is confined to lower frequencies below 1000 Hz, they are able to hear the low-frequency sound emitted underwater by anthropogenic sources (Samuel, et al., 2005). Ultimately studies using A-weighting curves are rendered irrelevant since it has been shown that this can lead to misjudgement of physical and other effects associated with low frequency noise (St. Pierre & Maguire, 2004). In recent reviews of management guidelines pertaining environmental impacts from the deep-water oil and gas industry, it's apparent that potential effects of sound on marine mammals, fish and invertebrates remain poorly understood even though evidence exists that the effect thereof may be significant (Cordes, et al., 2016). Furthermore, there is also no differentiation between above and below water noise, yet considering that sound travels 4.3 times faster in air than water (Wong & Zhu, 1995), this might have important implications on sea turtle response to this stressor. Typically, noise impacts will be based on potential sound pressure levels at the receptor location, which is subject to modelling and monitoring. In the sound exposure guidelines for sea turtles (and fishes) compiled by the Acoustical Society of America (ASA), it is clearly stipulated that currently there are insufficient data to quantify to what distances sea turtles might be influenced (Hawkins, et al., 2014). This has far-reaching consequences for the mitigation of noise impacts on sea turtles in the SWIO, since there is very little in the line of empirical evidence on the effects of noise on sea turtles that will be able to substantiate species-specific mitigation measures.

Seismic surveying is one aspect that has been identified as a significant contributor to marine noise and it has been shown that extreme noises like those emitted by seismic airguns may impact sea turtles negatively (Nelms, et al., 2016; McCauley, et al., 2017). What is known is that sea turtle's response to these extreme noises include behavioural responses such as avoidance (McCauley, et al., 2017), and when areas critical for the species persistence are routinely avoided the impacts may shift to one of major significance. Sea turtles are however one of the groups that are severely understudied when it comes to potential noise impacts (Williams, et al., 2015; Nelms, et al., 2016). The potential extent of sea turtle disturbance from seismic surveys in the study area is great considering the vast extent of licence areas proclaimed by governments, but due to the short duration of disturbance events, such as extreme noise, the net significance is likely low. However, disturbance impacts become more important when it's in close proximity to focal areas and the duration of the impact is increased by persistent renditions of the disturbance factor in the same field of influence. As seismic surveying in the study area intensifies, so does the likelihood of these negative impacts on sea turtles.

3.5.5 The not so fleeting nature of ship strikes

Impact with vessel keels or props, which cause harm to sea turtles, are by default related to areas where vessels and sea turtles frequent. This is a density-dependant interaction (Curtis & Moore, 2013). Although chance meetings between a shallow-swimming sea turtle and a vessel in the open ocean is not impossible, the likelihood is fairly low. Therefore, areas with high vessel traffic can be considered potentially dangerous to sea turtles, especially if they coincide with areas where sea turtles congregate i.e. nesting beaches or feeding areas of high productivity. Similarly, because structures like drilling platforms often attract sea turtles (Gitschlag & Herczeg, 1994), specimens in close proximity of these structures are in potential danger of being struck by vessels. There is great difficulty in quantifying what additional traffic related to HEP developments would bring to the study area since there are numerous other industries such as fisheries, tourism and transport that already contribute to these impacts (World Bank IEG, 2015; Obura, 2017a). Vessels used by HEP have no distinct differences to vessels used in other sectors and thus no differentiation is made among industries. Although possible impacts are vast in extent, the low intensity and likelihood of these impacts mean that the likelihood of them causing detrimental impacts on sea turtles remains low.

However, with ever increasing maritime traffic (Obura, 2017a), consideration should be given to a holistic view on impacts on marine life emanating from the maritime transport industry.

3.5.6 Limitations of the study

Fraser, et al., (2006) in a study on the impact of oil and gas pollution on sea birds found that one of the major gaps in environmental assessment studies were that assessment methods were not species specific and therefore deemed inadequate to prescribe suitable mitigation measures (Fraser, et al., 2006). The method used to estimate significance in this study clearly established priority areas, which are at higher risk of significant impacts and spatially occupy a larger extent, yet it's of utmost importance to note that areas not mapped to be subject to any impacts may still be impacted upon by stochastic events e.g. hydrocarbon spills from ships. The limitations of this study are based on a lack of scientific studies on the spatial extent at which impacts such as light and noise pollution affect sea turtles and behavioural response of sea turtles to these impacts.

Due to the gaps in scientific literature on how sea turtles are affected by anthropogenic impacts, especially from HEP, undertaking analysis of the hydrocarbon components on a case by case basis is a must to undertake rigorous decision making. Here, a multi-criteria decision-making analysis with specialists from both the environmental (sea turtle) field, oil and gas (HEP) field and marine spatial planners would prove invaluable to both sectors in refining and validating results. This study and ratings were undertaken by the author and therefore there is substantial room for increasing the robustness of the assessment results by incorporating a larger group of assessors. Nevertheless, the assessment was undertaken based on a large body of peer reviewed and grey literature pertaining the potential impacts of HEP on sea turtles.

3.5.7 The value of a species- and industry-specific assessment

The study focussed on what can be described as developing hydrocarbon industry. This will likely see an increase in impacts to sea turtles directly linked to the HEP, as well as those that cumulatively contribute to existing pressures. The reality is that the sea turtles in the study area have already been impacted upon by other sectors through the same stressors identified for HEP i.e. water pollution (Hoarau, et al., 2014), light pollution (IUCN/UNEP, 1995), habitat destruction, noise pollution (UNEP-Nairobi Convention and WIOMSA, 2015) and ship strikes (Okemwa, et al., 2004). Therefore, the emphasis on sea turtle protection cannot be directed at only the HEP industry but should rather be met by proactively identifying areas that cannot be put at risk from any industry e.g. nesting beaches. Historically, this has been proven to be near impossible for the global HEP industry to do, due to challenges such as inadequate baseline information, failure to incorporate environmental justice into planning and statutory provisions that are partial to oil companies (Lopez, 2010; Osofsky, et al., 2012). It's therefore not coincidental that the often-overlooked complexities of assessing and mitigating impacts first become apparent once detailed analysis is undertaken, often too late or in retrospect of impact manifestation. What this study has found is that ~70 % of all potential HEP impacts on sea turtles could be avoided if seasonality of sea turtle movement and critical life stages are included as species-specific HEP mitigation. Consequently, understanding the spatiotemporal overlap of sea turtles and potential HEP impacts are fundamental to determining pro-active mitigation measures.

It has been shown that contextual sensitivity of the research topic is strongly associated with replication success (Van Bavel, et al., 2016) and therefore undertaking a species-specific assessment, akin to this study, might hold more value from a replicability perspective than assessments undertaken on project specific basis. A species-specific approach for sea turtles has been successfully undertaken by the fisheries industry to reduce turtle bycatch (Pooley, 2007; Wallace, et al., 2008; Wallace, et al., 2013b). Notwithstanding the success of the fisheries industry in prioritising limited conservation resources toward managing the most substantial impacts on sea turtle populations (Wallace, et al., 2013a), species-specific impact assessments at a regional (strategic) level is a rarity. There are only a few examples of similar approaches undertaken in an effort to conserve species under threat, e.g. the strategic assessment to aid conservation of sea turtles in the Adriatic Sea (Štrbenac, 2015). Moreover, species-specific assessments are often retrospective of impacts, e.g. the strategic framework for sea turtle restoration activities post the Deepwater Horizon oil spill (DWH Trustees, 2017), which is far from ideal considering the global state of sea turtle populations. It's therefore motivated that any approach which would assist in better quantifying potential future issues pertaining a species in need of conservation and managing risks towards such populations be deemed a positive step toward safeguarding them.

3.6 Conclusion

Sea turtles are currently and will in the foreseeable future be at risk from HEP impacts. Through the method used to assess the potential impacts of HEP on sea turtles, the main impacts have been highlighted as well as the underlying causes of these impacts. This provides an opportunity to countries in the SWIO to prevent impacts, many of which were realised by other countries only through harsh lessons learned. Some past impacts have caused irreversible damage to the environment and to numerous species already at risk from increase anthropogenic pressures (Wallace & Saba, 2009). Many of the threats associated with HEP are already a reality in the study area and are seemingly highlighted only now that the hydrocarbon industry is set to expand in this region. The impacts ratings in this Chapter might change as our understanding of sea turtles and HEP impacts increase, yet it provides a base from which a dialogue among countries in the region can initiate planning for a future with the benefits of hydrocarbon products without compromising the environment on which they depend.

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Chapter 4 : Zoning the SWIO to reduce conflict between sea turtles and HEP

4.1 Abstract

The conflict between sea turtles and the numerous socio-economic developments in the SWIO is set to intensify as countries attempt to develop their ocean-based economies. The Hydrocarbon Exploration and Production (HEP) industry is of particular importance since many of the Southwestern Indian Ocean (SWIO) governments view it as catalyst for development. However, with these proposed developments come potential substantial ecological risk, most notably to those species already threatened, such as sea turtles. One way of mitigating this space-use conflict is through ocean zoning, which can be achieved through Systematic Conservation Planning (SCP), in this case the space-use conflict between sea turtles and the HEP industry in the SWIO. Therefore, the aim of this study was to derive biodiversity priority areas for an ocean zoning strategy for sustainable economic development of HEP in the SWIO region. The objectives included testing increasing spatial biodiversity targets of sea turtle breeding, foraging and migratory areas in three different Scenarios in relation to lost opportunity cost to the HEP industry. It's was hypothesized that coastal areas would have the highest selection priority when biodiversity targets are low, because of fixed sites such as breeding areas of relatively limited extent, and for migration and offshore areas to have the lowest selection priority, because they are large areas supporting sea turtles for only part of the time. By using Marxan, an optimisation algorithm, it was found that coastal areas had the highest selection frequency (an indication of irreplaceability) and that increased targets increased the cost of the solutions. Scenario 2 was identified as having the optimal range of targets (of 90% breeding areas, 70 % foraging areas and 20 % migratory areas) considering the cost, which was defined as a combination of the ecological condition of sites given the presence of hydrocarbon activities, and the opportunity cost to the HEP industry if areas are selected for conservation. As final outcome this study used the scenario planning outcomes (Scenario 2) to derive a preliminary ocean zoning, which highlighted areas where increased protection to sea turtles and management of the conflict between sea turtles and the HEP industry will be required. Three zones were identified based on selection frequency and these zones were grouped into nine Sea Turtle and Hydrocarbon Management Areas (STAHMAs) which should be the focus of future management of the sea turtle and HEP space use conflict.

4.2 Introduction

The global conflict between economic development and the marine environment is a growing problem as countries look to develop their ocean-based economies through the intensification and diversification of activities and industries (Katsanevakis, et al., 2015). This is superimposed on existing pressures such as climate change, which means that species and ecosystems are now facing exceptional levels of pressure and threat (Halpern, et al., 2015). At the same time, our commitment to sustainability is unprecedented, because of our increased awareness and understanding of how our livelihoods are affected by our actions. Consequently, countries are working hard towards global agreements, including the United Nations' Sustainable Development Goals (UN SDG, 2018) and the Convention on Biological Diversity (CBD) 2010 Aichi targets, in an attempt to reduce the pressure to biodiversity on our planet, and to ensure continued delivery of ecosystem services on which our planet and our own health and well-being depends (Lubchenco, et al., 2016).

One of the biggest industries in which the SWIO countries are investing is the hydrocarbon industry because of the high demand for, and lucrative economic gains from oil and gas products (Schenckery, et al., 2018). The hydrocarbon industry is seen by the SWIO governments as a catalyst to overcome many of their challenges such as a lack of development and poverty (Johnson, et al., 2017). The problem is, there is substantial uncertainty whether or not the hydrocarbon industry will indeed bring the large (albeit short-term) economic gains they are expected to (Frynas, et al., 2017), whilst also carrying considerable ecological risk (Kark, et al., 2015). Furthermore, the ecological risk is greatest to those species that are already threatened and that are likely to be exposed to these risks (Mace, et al., 2008). This risk to threatened species should be treated with caution and concern, especially given the SWIO countries commitment to achieve Aichi Target 12, i.e., to avoid further loss of already threatened species (CBD, 2010). Consequently, any potential conflict in space use between HEP and turtles, for example, needs to be avoided or mitigated.

Marine spatial planning (MSP) is defined as, "*a practical way to create and establish a more rational organization of the use of marine space and the interactions between its uses, to balance demands for development with the need to protect marine ecosystems, and to achieve social and economic objectives in an open and planned way* " (Ehler & Douvere, 2009). MSP is a more and more popular tool for resolving spatial conflicts in ocean use (Tuda, et al., 2014), and has the added benefits of being quantitative, robust, transparent (Ehler & Douvere, 2009) and amenable to scenario planning (Peterson, et al., 2003). It has been broadly used to achieve both economic and environmental objectives in countries such China and Vietnam, and as management approach for nature conservation, e.g. in Australia's Great Barrier Reef Marine Park (Ehler & Douvere, 2009). Therefore, MSP is a suitable tool to managing the conflict between sea turtles and the HEP industry in the SWIO in order to protect sea turtles as well as promote sustainable development of the HEP industry.

Systematic Conservation Planning (SCP) is a tool that can be used to identify sites of high importance to sea turtles and prioritise areas for conservation through a process that is underpinned by the principles of representation, persistence, complementarity and irreplaceability (Margules & Pressey, 2000). Furthermore, SCP can be used as a tool to design complementary networks of conservation areas at least cost (conflict) to competing uses of the same ocean space (Langford, et al., 2011). For example, areas with high conservation priority for seabirds were identified using SCP to guide evaluation of proposed sites for offshore wind energy development (Winiarski, et al., 2014). SCP is a multistage approach that consists of compiling data on the biodiversity of the planning region and reviewing existing conservation areas (Margules & Pressey, 2000) as undertaken in Chapter 2 of this study. Additionally, SCP aims to identify conservation goals for a specified planning region and select additional conservation areas (Margules & Pressey, 2000) and therefore SCP as a tool can help identify areas where conservation goals (turtles) need to be prioritized over economic objectives (HEP) if we are to safeguard these iconic, flagship species (Frazier, 2005) as part of sustainable ocean governance (Kristina, et al., 2008).

Identifying conservation areas for threatened species such as sea turtles, which have vast migratory ranges, can be a complex matter. In Chapter 2 of this study, the focus was on the role that MPAs (as a spatial protection measure) played in the conservation success of sea turtles based on breeding, foraging and migratory areas. It was identified that breeding areas (nesting and internesting areas) were of critical importance to sea turtles' persistence, a finding supported throughout literature (Mortimer, 2000; Nel, et al., 2013). Therefore, including the majority of breeding areas into conservation areas would be pivotal. Moreover, foraging habitat also plays a vital role in conservation of sea turtles (Mortimer, 2000), and aggregations of sea turtles have been shown to occur in areas where foraging habitat such as seagrass is protected (Scott, et al., 2012). The aim would thus be to conserve a large percentage of high-use foraging areas. In this study multiple scenarios with varying conservation targets for breeding, foraging and migratory areas will be assessed, through the use of SCP decision-support software. This will ultimately provide an indication of which scenarios achieved the conservation targets most efficiently, i.e. reaching biodiversity targets in the least amount of area and avoiding conflicting space uses most cost-effectively, in the specific planning context (Margules & Pressey, 2000).

This study incorporates scenario planning as part of SCP (Troupin & Carmel, 2018) where: targets and objectives are identified and defined; data are compiled; conservation targets are established; design principles are specified; existing protected areas are reviewed; and gaps in the protected area networks are identified (Ardron, et al., 2010). To implement conservation action (the objective of SCP, not part of this study) stakeholders need to be engaged in the process of selecting new protected areas and when specifying certain use zones, which will ultimately influence the implementation of conservation actions (Ardron, et al., 2010). Nevertheless, scenario planning as conservation tool can help guide decision-making in an uncertain world, allowing trade-offs among scenarios to be quantified and compared (Peterson, et al., 2003; Harris, et al., 2014). In this case, there is an industry which may exert multiple threats to sea turtles throughout their range. Therefore, a thorough understanding is required of where areas important to sea turtles are, and to what extent HEP developments might impact the species in these areas.

Ocean zoning as planning tool can theoretically be used to reduce the conflict between sea turtles and HEP in the SWIO. For example, potential ocean-use conflicts among offshore wind energy, commercial fishing, and whale-watching sectors were mitigated by identifying specific energy development zones, which prevented substantial economic losses (White, et al., 2012). Therefore, an ocean zoning strategy for sustainable economic development of HEP in the SWIO could be possible. It should be recognised that that there are currently specified zones in the SWIO, i.e. MPAs, which already exclude many uses within their boundaries. This provides an added dynamic to ocean zoning since not all the MPAs in the study area are equally important to sea turtles, e.g. the West Coast National park in South Africa, and not all MPAs exclude oil and gas activities, e.g. the Mnazi Bay - Ruvuma Estuary Marine Park (MBREMP) in Tanzania, where there are numerous gas related activities taking place (although to the detriment of sea turtles) (Machumu & Yakupitiyage, 2013).

The aim of this study is to identify priority areas for sea turtles, in the face of HEP, that could be used in an ocean zoning strategy for sustainable economic development of HEP in the SWIO region. The specific objectives are 1) to test increasing spatial biodiversity targets of sea turtle breeding, foraging and migratory areas in relation to lost opportunity cost to the HEP industry. It's hypothesized (1) that coastal areas will have the highest priority when biodiversity targets are low, because of fixed sites such as breeding areas of relatively limited extent, with migration and offshore areas to have the lowest priority, because they are large areas supporting sea turtles for only part of the time, and that migration and offshore areas will increase in priority as targets are increased. It's predicted (1) that there will be a high selection frequency of coastal sites and lower selection frequency for offshore sites, and for areas to increase as targets increase. As final outcome this study will attempt to provide a preliminary ocean zoning to highlight areas where increased protection to sea turtles and management of the conflict between sea turtles and the HEP industry will be required.

4.3 Methods

4.3.1 Study area

The study area comprises the EEZs (Flanders Marine Institute, 2018) and coastal zones of the African mainland countries in the SWIO, i.e. Kenya, Tanzania, Mozambique, and South Africa (excluding the Prince Edward Islands). The island nations included are Madagascar, Mauritius, Seychelles, Comoros, and France with Réunion and The Scattered Islands - Europa, Juan de Nova, Bassas da India, Tromelin, Mayotte, and Glorioso (Figure 4 1). These EEZs fall within the Agulhas and Somali Current Large Marine Ecosystems (ASCLME/SWIOFP, 2012) and thus form an ecologically coherent study area. Key coastal HEP infrastructure is frequently situated above the mean low water mark, which overlaps with sea turtle nesting habitat; the coastal boundary was thus mapped with a 1 km landward extent from the mean low water mark (where the EEZ ends). The study area and all data were divided into planning units of 10 km x 10 km, forming a study area of 83 491 planning units. A planning unit was classified as being inclusive of a feature if it intersected the specific data layer. The planning unit resolution was chosen as a compromise between the coarse- and fine-resolution input datasets, and is consistent with European Union guidelines (Directive 2007/2/EC) and other large-scale regional planning studies

(Kark, et al., 2009; Mazor, et al., 2014) in the absence of specific African Union guidelines (AUC, 2012). All data were mapped in the Geographical Information System (GIS) software, QGIS version 2.18.15 “Las Palmas” with GRASS 7.4.0, and projected into the European Petroleum Survey Group (EPSG) 54032, World Azimuthal Equidistant Coordinate Reference System (CRS).

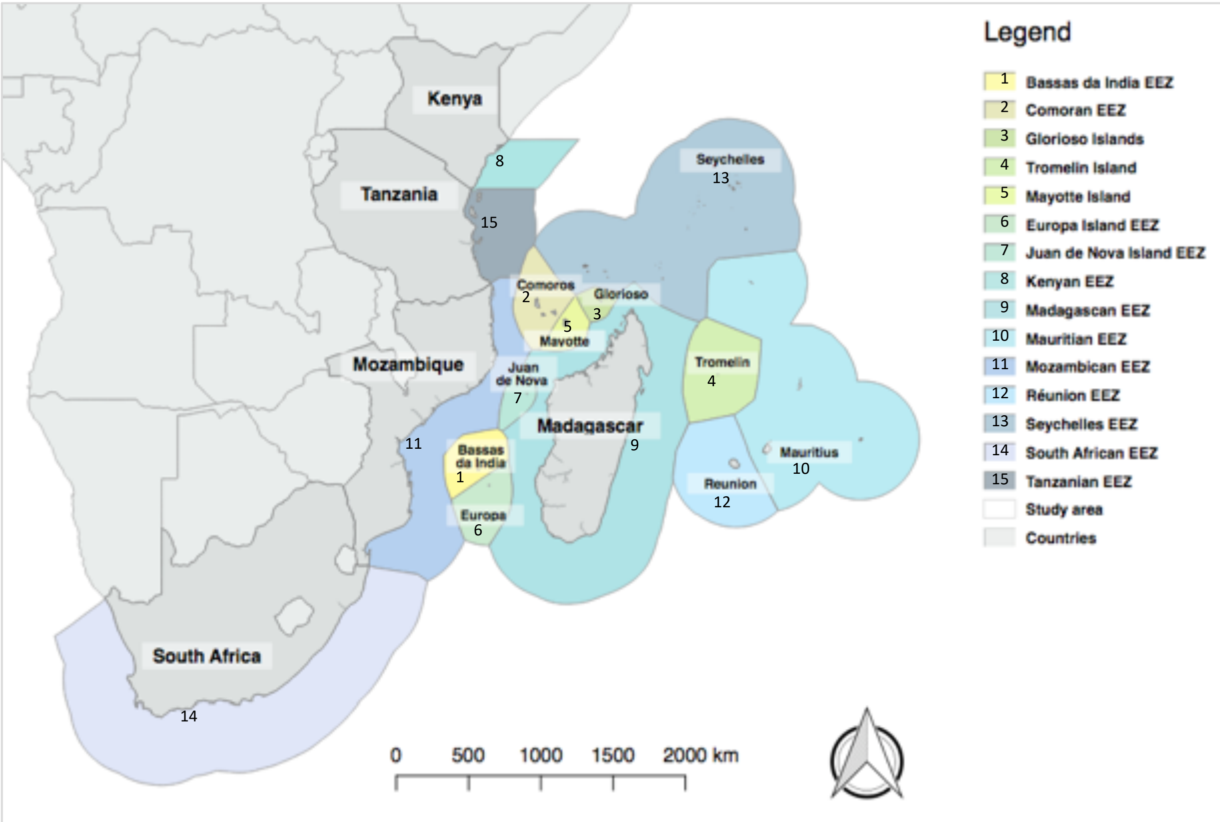

Figure 4-1 | The EEZs and territories of countries and islands in the SWIO that comprise the study area.

4.3.2 Spatial prioritization

Software useable for SCP includes Marxan (Ball et al., 2009), C-Plan (Pressey et al., 2009) and Zonation (Moilanen et al., 2009). Marxan software version 1.8.10 (Ball, et al., 2009) is used in this study, with input data prepared in QGIS, using the QMarxan toolbox version 0.3.4. Marxan is an optimisation algorithm that uses simulated annealing to select a portfolio of sites that meets user-defined targets for biodiversity features, whilst minimising costs, within a defined study area (Ardron, et al., 2010). Cost can be defined in many ways depending on the planning problem, e.g. cost can be a reflection of area, an economic cost or relative social, economic or ecological measure (Game & Grantham, 2008). In this case, cost was considered to be a combination of the ecological condition of sites given the presence of hydrocarbon activities (based on the species-specific assessment undertaken in Chapter 3 of this study), and the opportunity cost to the HEP industry if areas are selected for conservation. Areas where the HEP industry have the highest cumulative impact score (derived from Chapter 3) will have the highest cost. Therefore, Marxan will attempt to avoid selecting such (high cost) sites as part of conservation networks, in favour of sites that meet the conservation targets at lower cost. In theory, the conservation networks will change as targets in different scenarios change. To deal with these different Marxan outcomes a scenario planning approach is undertaken to explore the potential future consequences (Peterson, et al., 2003) of the HEP developments on sea turtles.

Input data for Marxan was derived from the data layers created in Chapter 2 and Chapter 3 of this study. The biodiversity features (n=12) included the breeding, foraging and migrating areas created in Chapter 2, of four sea turtle species i.e. loggerheads (*Caretta caretta*), leatherbacks (*Dermochelys coriacea*), green turtles (*Chelonia mydas*) and hawksbills (*Eretmochelys imbricata*), found in the SWIO study area (Figure 4-2a). In the absence of known or likely monetary values of fields or license areas to represent opportunity cost, the output from the hydrocarbon cumulative impact assessment from Chapter 3 was used as a surrogate, because it incorporates both existing infrastructure and likely areas of future HEP. Further, the impact significance scores also serve as a surrogate of ecological condition of the site for turtles. Consequently, each of the 120 impact layers were converted to 10 km x 10 km grid squares and assigned a value equal to the sum of all impact significance ratings per grid square (i.e. severe = 5, major = 4, moderate = 3, minor = 2 and minimal =1) (Figure 4-2b), which then cumulatively added up for each grid square, i.e. of the 120 potential impacts which could be rated up to a significance of 5 (severe) and thus cumulatively one grid square could theoretically have an impact of up to 600 (120x5).

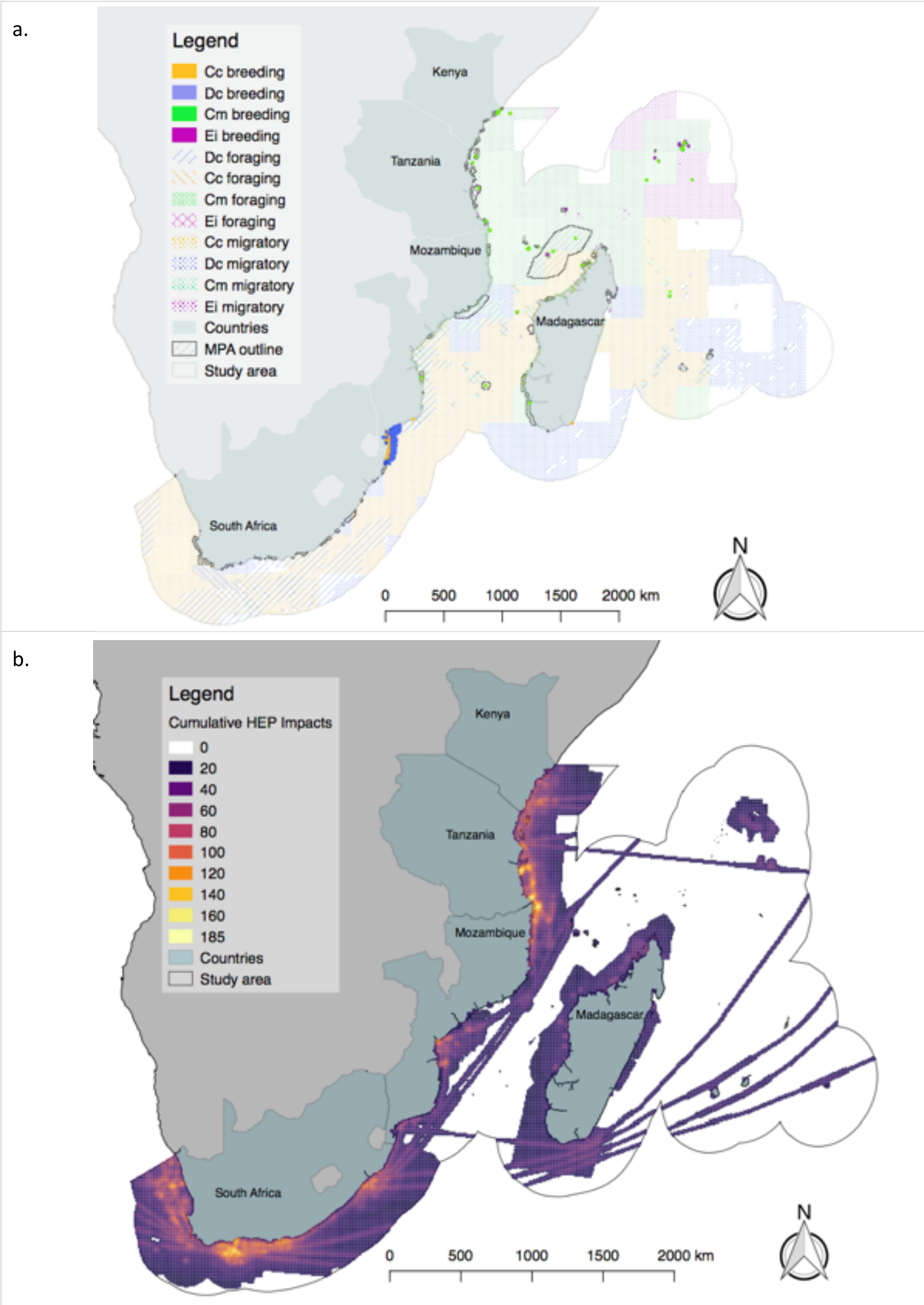

Figure 4-2 | a.) Breeding, foraging and migratory layers created in Chapter 2 for *C. caretta* (Cc), *D. coriacea* (Dc), *C. mydas* (Cm) and *E. imbricata* (EI), found in the SWIO study area. These layers were used as biodiversity features in the Marxan analysis. b.) Cumulative impacts from the HEP industry as derived from the species-specific assessment undertaken in Chapter 3 of this study. The areas with the highest scores and bright yellow colours are areas that may potentially be most heavily impacted by the HEP industry, whereas the darker areas with lowers scores will potentially be least impacted by the HEP industry. This map was used as the cost layer in the Marxan analysis.

The input parameters were calibrated according to the Marxan Good Practices Guidelines (Ardron, et al., 2010). The calibration of the number of iterations where undertaken to establish the point beyond which adding more iterations did not decrease the boundary length (km) and cost (HEP cumulative impact score) beyond that the previous number of iterations (Figure 4-3). The scenario (Scenario 2) was run 10 times each time increasing the number of iterations by an order of magnitude, i.e. 1 million, 10 million, 100 million and 1000 million (1 billion). The value selected, 100 million, was found to be the point beyond which adding more iterations, i.e. 1000 million, did not substantially reduce cost and increase efficiency (reduced border length). Zonae Cogito version 1.74. and MS Excel was used to undertake the calibration of the Boundary Length Modifier (BLM). The BLM allows controlling the solution compactness (clustering) of site selection relative to HEP cost, i.e. with an increase in BLM value, the importance of obtaining solution compactness is increased over other considerations such as cost (Game & Grantham, 2008). The calibrated BLM for the input data was derived to be 0.03 (Figure 4-4). The species penalty factor (SPF) for the algorithm was set at "1" for all runs. An SPF is a multiplier that controls the scale of the penalty that is added to the objective function if the user-defined target for a specific feature is not met, i.e. the higher the SPF in a specific scenario the more emphasis is placed on ensuring the feature targets are met (Game & Grantham, 2008).

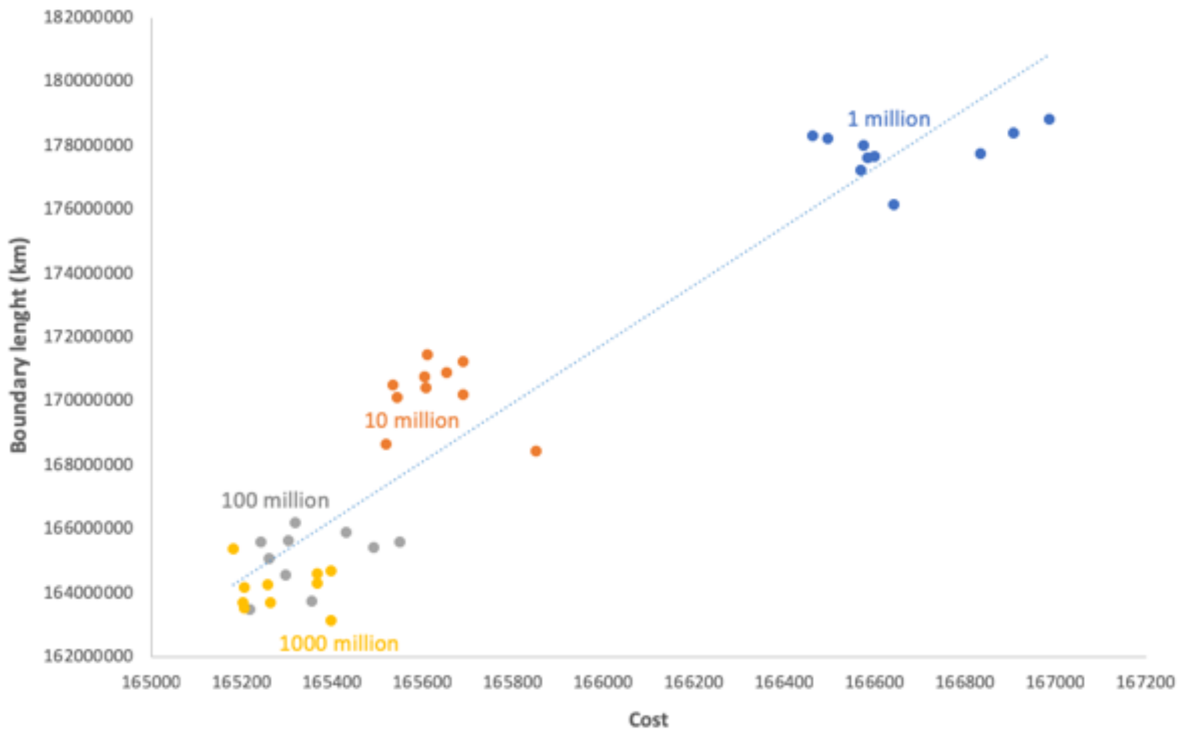

Figure 4-3 | Calibration of the number of iterations, with the value selected (100 million) at the point beyond which adding more iterations (1000 million) did not decrease the boundary length (km) and cost (HEP cumulative impact score) beyond that of the previous number of iterations.

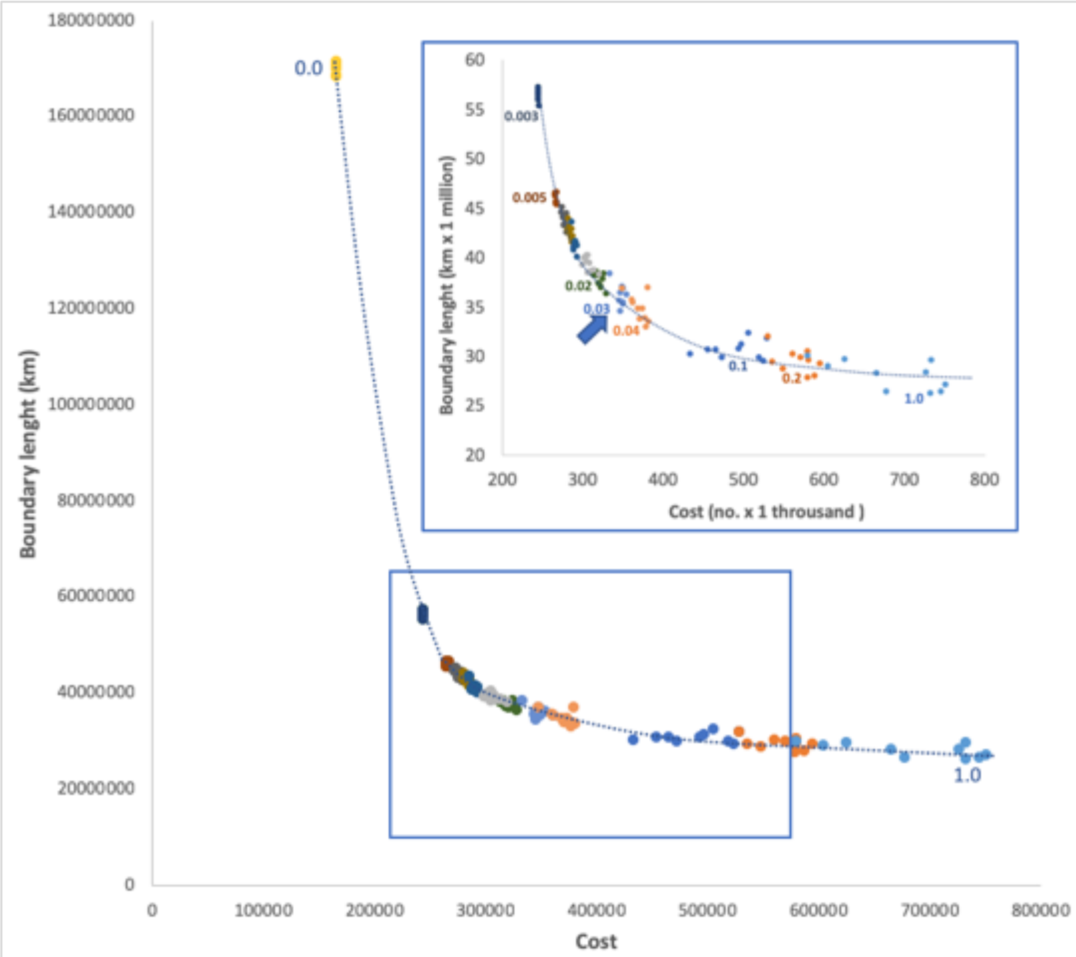

Figure 4-4 | The relationship between cost (dimensionless HEP cumulative impact score) and boundary length (km, solution compactness) as BLM increases (from X- Y), showing a BLM value ~0.03 at the approximate tangent of the fitted curve, i.e. the inflection point indicated by the blue arrow. The inflection point is the point from where an increase in boundary length rapidly increases the solution cost.

The objective of using SCP as tool is to identify sites of high importance to sea turtles and prioritise complementarity areas for conservation, which sufficiently represent areas specific to the different life history stage of sea turtles (breeding, foraging and migration areas) as well as including areas of irreplaceable value to sea turtles. Furthermore, SCP will be used to designate complementary conservation zones at the least cost (conflict) to competing uses of the same ocean space, i.e. existing and proposed HEP developments. The end goal will be to identify specific management areas referred to as Sea Turtle and Hydrocarbon Management Areas (STAHMAs) within the greater planning region to help identify areas and actions where conservation goals for sea turtles need to be prioritized over HEP.

Biodiversity targets were set for breeding, foraging and migration areas for each of the four sea turtle species in three different scenarios (Table 4-1).The migratory areas of sea turtles are vast in comparison to breeding and foraging areas, therefore targets for migratory areas were set between 10 % (based on Aichi Target 11) (Shugart-Schmidt, et al., 2015) and 30 % (based on IUCN World Parks Congress, 2014, calls for a global reserve coverage). The foraging area targets were set between 50 - 100%, based on the importance of these features for sea turtle conservation (Mortimer, 2000) and the outcomes of Chapter 2, which indicated the relative percentages of foraging areas already conserved in the SWIO by MPAs. Likewise, the breeding area targets were set based on the importance of these areas to be protected to ensure sea turtle population survival (Mortimer, 2000; Nel, et al., 2013; Harris, et al., 2015). MPAs were "locked-in" for Scenarios 1, 2 and 3, i.e. all MPAs had to be included in the solution in the these three scenarios,. Each scenario was run 100 times, with 100 million iterations per run.

Table 4-1 | Summary of scenario input parameters. Biodiversity targets are given as a percentage of breeding, foraging and migratory areas of each sea turtle species in the SWIO study area. The MPA layer was "locked-in" for Scenario 1, 2 and 3 of the Marxan algorithm, i.e. sites already in MPAs were included in the final solution by default. SPF = Species penalty factor, which was set at 1. BLM = Boundary length modifier, which was calibrated at 0.03 as trade-off between boundary length and cost to HEP.

Scenarios	Breeding ($B_{\%}$)	Foraging ($F_{\%}$)	Migratory ($M_{\%}$)	SPF	BLM
Scenario 1 ($B_{80}F_{50}M_{10}$)	80 %	50 %	10 %	1	0.03
Scenario 2 ($B_{90}F_{70}M_{20}$)	90 %	70 %	20 %	1	0.03
Scenario 3 ($B_{100}F_{100}M_{30}$)	100 %	100 %	30 %	1	0.03

4.3.3 Selection frequency outputs

The Marxan output used in this study was the "Summed solution", i.e., maps of site selection frequency, which is the number of times a site is selected across the 100 runs in each scenario. The "Summed solution" is not a solution *per se*, but it shows the areas that are mostly, frequently, infrequently, or never included in solutions. Selection frequency is therefore also an indication of irreplaceability, which reflects how important a planning unit in a reserve system is, to meet the planning objectives (Ardron, et al., 2010). Selection frequency represents the number of times a planning unit was selected as part of a good solution from all runs in a single scenario, which provides an indication of how useful a planning unit is for creating an efficient output, i.e. conservation zones. The selection frequency maps will be used to infer the change in extent of areas selected, with an increase in spatial conservation targets, in relation to lost opportunity cost to the HEP industry. It will also be used to understand where the current gaps are in the existing MPA network in relation to potential HEP impacts on sea turtles.

4.3.4 Best solution outputs

The outputs from Marxan also include the "best" solution among the runs, which will be used for comparison of the three different scenarios. This study will consider three data fields included in the "best" solution output, i.e. value, cost and planning units, to compare the outputs of the three scenarios (Table 4-1). The "value" field is the overall objective function value (value of the solved Marxan algorithm) for each run, and thus the best solution will have the lowest (most efficient), "value" score. The "value" field includes the cost, the boundary length and the penalties in each specific run (this "value" is how Marxan chooses the 'best' solution out of repeat runs). The "cost" field is the total cost of the ecological condition of sites given the presence of hydrocarbon activities, and the opportunity cost to the HEP industry if areas are selected for conservation. The "planning unit" (PUs) field is the number of planning units contained in the solution for that run. Although the cost field was used as the main indicator of the effect in changing targets between scenarios, the other fields were used to quantify what the implications are when there is a change in cost, e.g., do planning units increase or decrease as the cost increases, and how meaningful is this change in planning units in comparison to those in the other planning scenarios. Since Scenario 1 has the lowest biodiversity targets of the three scenarios, it will be used as baseline for comparison (Table 4-1). The comparison will test an increase in spatial biodiversity targets of sea turtles in relation to lost opportunity cost to the HEP industry, as well as illustrate which planning scenarios carry the lowest cost to the HEP industry.

4.3.5 Zoning the SWIO

The selection frequency outputs from Scenario 2 was used to derive a preliminary ocean zoning of the SWIO study area. The emphasis of the zoning is on mitigating the potential conflict between sea turtles and HEP, by assigning different use zones based on potential conflict in space-use between sea turtle and the HEP industry. Cognisance should be taken that this zoning is based on sea turtle-use areas only, and in context of only the HEP industry. This concept designing of focus areas for turtles could be used to inform comprehensive MSP of the SWIO, by including other stressors on sea turtles such as pelagic longline fisheries (Scott, et al., 2017, Harris et al., 2018) and other species such as cetaceans. Or it can be used to facilitate identifying finer-scale planning such as the "South-Western Indian Ocean Maritime Spatial Planning (Ocean Metiss)" project which looks to boost the economic development, by preserving the rich tropical biodiversity of the concerned territories (Ocean METISS, 2018).

The zoning is based on international examples of ocean zoning and MSP where: the HEP industry has been established (Crowder, et al., 2006; Douvere & Ehler, 2009; Game, et al., 2009); MPAs were derived with different management zones (Lombard, et al., 2007); MSP used within the SWIO study area (Grantham, et al., 2011; SMSP, 2018) and where Marxan was used to derive zones within the SWIO (McClanahan, et al., 2016). Three zones were mapped, based on Scenario 2, and included: the Red Zone based on the 80th percentile selection frequency from Scenario 2 (sites of high irreplaceability) and areas outside the 1000 m bathymetry; the Blue Zone based on the 80th percentile selection frequency from Scenario 2 (sites of high irreplaceability) and areas inside the 1000 m bathymetry. The Green Zone based on the 40th-79th percentile selection frequency from Scenario 2 (sites of moderate to high irreplaceability). The 1000 m isobath was used based on the findings of Chapter 3 which revealed the extensive nature of potential impacts on sea turtles between the shore and 1000 m isobath, of which the entire area may be impacted upon by the hydrocarbon industry. Furthermore, the 1000 m isobath provides a distinction between the shallow-water and deep-water environment which from a sea turtle and HEP perspective will require different management strategies. To facilitate the implementation of conservation measures nine geographically distinct management areas, STAHMAs, were identified. The STAHMAs include: 1.) Agulhas; 2.) Mozambique; 3.) Europa; 4.) West Madagascar; 5.) Kenya, Tanzania and northern Mozambique (KTM) Coastal; 6.) Comoros, Mayotte, Madagascar and Glorioso (CMMG) Islands; 7.) Seychelles; 8.) Tromelin; and 9.) Mascarenhas (islands in the Mascarenhas Archipelago including Reunion and Mauritius). The remainder of the study area and selection frequencies in 0-39 % were not zoned since it represents lower irreplaceability in terms of sea turtle conservation priority areas in the context of HEP. The zones were projected over the cumulative HEP impact map to establish where the remainder, if any, of the conflict areas are.

4.4 Results

4.4.1 Marxan selection frequency results

The spatial representation of Scenario 1 illustrated selection frequency patterns that were evident for Scenarios 2 and 3 as well, i.e. because MPAs were locked into the planning scenarios, there was a high selection frequency around these features (Figure 4-5). In Scenario 1, the biodiversity targets were the lowest of all three scenarios (Table 4-1), and Marxan notably selected planning units near MPAs because it could attain these planning units more efficiently and thus increase the complimentarily of new conservation areas with existing MPAs. The sites selected in Scenario 1 were spread out along the coast from South Africa to Kenya, as well as southeast Madagascar. Exansive areas selected include the EEZs of Mayotte and Glorioso Islands (which are proclaimed MPAs), as well as the water around Mauritius and vast feeding grounds offshore (south) of South Africa (Figure 4-5a). Areas not included in the high selection frequency categories, i.e. below 40th percentile include the Sofala bank in central Mozambique towards Beira as well as a marked “channel” around Reunion Island (along the northwest of the Mascarene Archipelago).

Scenario 2 had increased biodiversity targets and although the same trend around MPA selection could be seen, an increase in selection frequency of foraging areas, especially offshore was noticeable (Figure 4-5b). This included vast feeding grounds offshore (south) of South Africa as well as offshore areas around central Mozambique and around the islands of Reunion and Mauritius. Scenario 3, which had the highest biodiversity targets, i.e. all of the breeding and foraging areas and the largest percentage of migratory areas (30 %), showed an increase in connectedness between the coastal regions highlighted and offshore areas (Figure 4-5a and b). Also, notably large areas around Tromelin, Reunion and Mauritius were selected, these areas present an overlap in species migratory areas, and thus with the increase target for migratory areas, the Marxan algorithm selected these high-value areas (Figure 4-5c). Notably the coastal area in central Mozambique not selected in Scenario 1 was selected in Scenario 2. This essentially created a conservation corridor spanning from the north coast of South Africa towards the coastal and offshore areas of the Nampula Province in Mozambique. However, it did not include the Quirimbas Archipelago in northern Mozambique but did include the area around Mnazi Bay in southern Tanzania. Other areas of note included the islands of Europa, Reunion and Mauritius as well as Tanzania islands Pemba, Mafia and Songo Songo.

Scenario 3 essentially expanded on the areas described in Scenario 2 since it selected for 100% of all breeding and foraging areas. What was notable in Scenario 3 is the areas not selected which include the vast areas around Seychelles. What is apparent from Scenario 1, 2 and 3 is that there is a marked increase in area with an increase in biodiversity targets, which is to be expected given the increase biodiversity targets. It's especially important to note that the increases in sea turtle migratory targets have the most substantial influence on the increase in spatial extent of selected areas, based on the specific targets set in each scenario. This is because migratory areas in general are an order of magnitude larger (number of planning units) than foraging areas and two orders of magnitude greater than breeding areas. For example, *C. mydas* has 236 planning units that represent all breeding areas and 39622 planning units that represent migratory areas, as such an increase of 1 % in migratory areas would mean an increase of ~396 planning units (more than the total amount of breeding planning units).

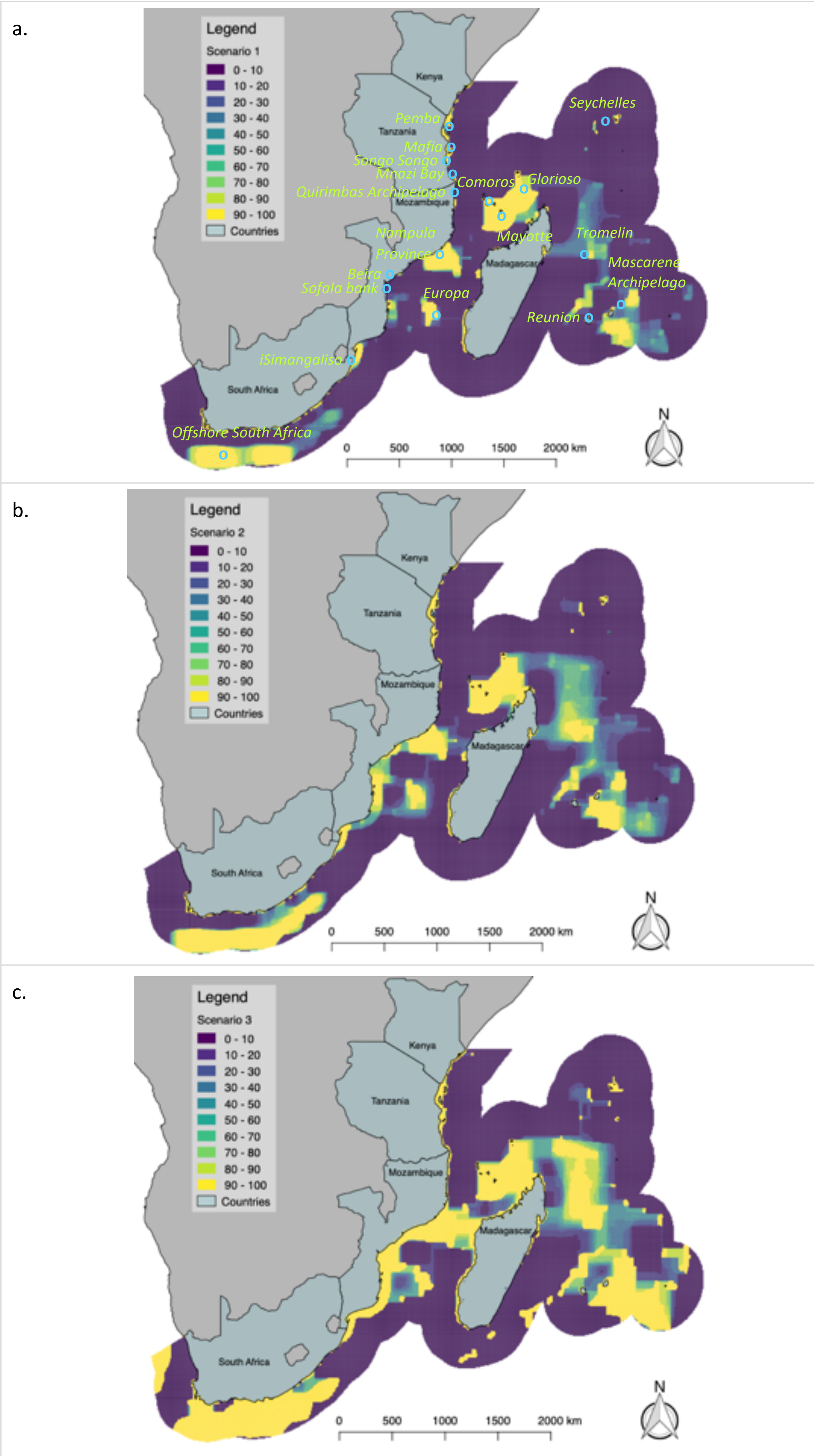

Figure 4-5 | Selection frequency maps for: (a) Scenario 1, $B_{80}F_{50}M_{10}$; (b) Scenario 2, $B_{90}F_{70}M_{20}$; and (c) Scenario3, $B_{100}F_{100}M_{30}$ (See Table 4-1 for scenario details). Areas mentioned in discussion are proved in figure (a).

4.4.2 **Best solution**

In the “best” solution output, the “value” field increased by 26.52 % in Scenario 2 and 84.65 % in Scenario 3, (Figure 4-6) when measured against the baseline (Scenario 1). The “cost” field increased notably for Scenarios 2 (54.60 %), and 3 (161.4 %). The number of planning units selected increased notably for Scenarios 2 (72.16 %) and 3 (152.60 %). In summary, there is a marked increase in cost to the HEP industry with an increase in biodiversity representation targets. The best solution in Scenario 3 was double the size of Scenario 2 (based on planning units) but cost more than triple the amount. In all three scenarios, the targets were met without having to increase the SPF.

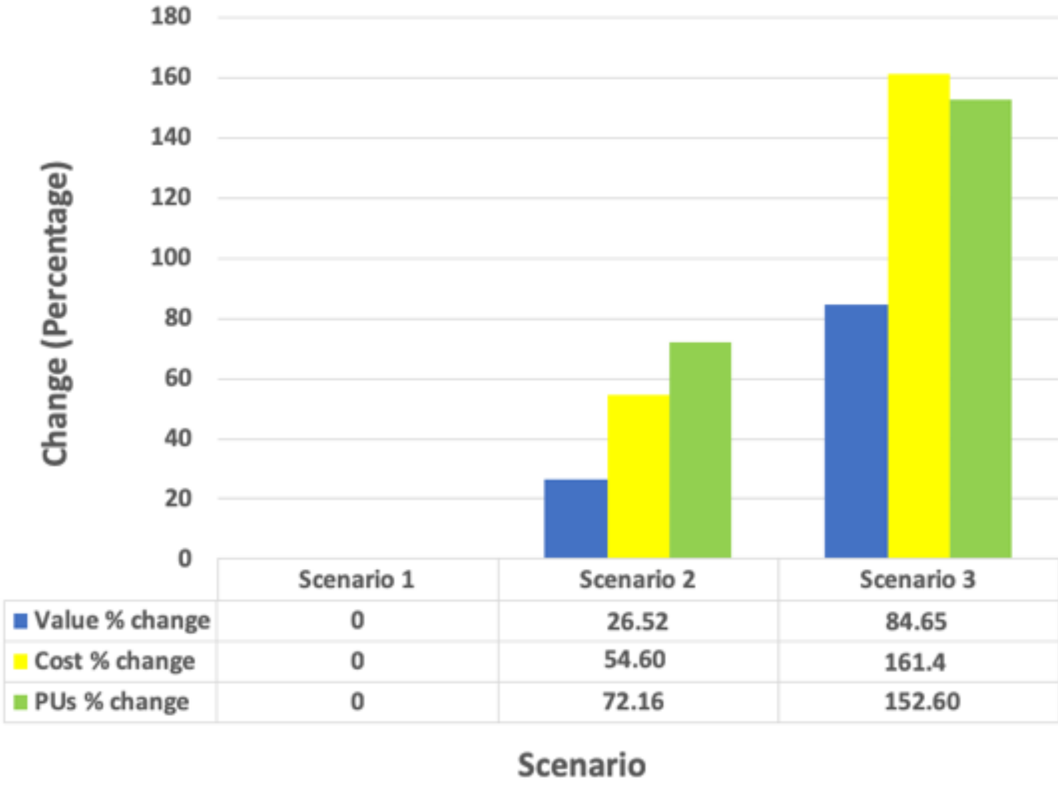

Figure 4-6 | A percentage wise comparison of the outputs of the “Best” solution run in each of three scenarios assessed. Scenario 1 is the baseline for comparison, and hence the “0” values for each field. The percentage in each field indicates an increase (percentage change) in the field amount compared to the baseline. The outputs include; “Value”, which is how Marxan chooses the best solution; “Cost”, which provides the cost of reaching the biodiversity targets; and “Planning Units” (PUs), the number of units required to reach the biodiversity targets.

4.4.3 **Zoning the SWIO to mitigate impacts from HEP on sea turtles**

The selection frequency output from Scenario 2 was used to derive a preliminary ocean zone (Figure 4-7). The final zoning map consisted of three zones. Three zones were mapped, based on Scenario 2, and included: the Red Zone based on the 80th percentile selection frequency from Scenario 2 (sites of high irreplaceability) and areas outside the 1000 m bathymetry; the Blue Zone based on the 80^{th} percentile selection frequency from Scenario 2 (sites of high irreplaceability) and areas inside the 1000 m bathymetry. The Green Zone based on the 40^{th}-79^{th} percentile selection frequency from Scenario 2 (sites of moderate to high irreplaceability). The 1000 m isobath was used based on the findings of Chapter 3 which revealed the extensive nature of potential impacts on sea turtles between the shore and 1000 m isobath, of which the entire area may be impacted upon by the hydrocarbon industry. Furthermore, the 1000 m isobath provides a distinction between the shallow-water and deep-water environment which from a sea turtle and HEP perspective will require different management strategies. The 1000 m isobath was used indicatively, and exceptions were made to the delineation of zones, e.g. the offshore zone south of South Africa where some of the zoned areas fell within considerably shallower depths. In the Blue and Red Zone certain HEP activities will be excluded and those that are permissible will occur under strict mitigation and monitoring measures, these measures are further explored in the Discussion section of this study. In the Green Zone HEP activities will also be excluded but the mitigation measure will in general be less intensive. The remainder of the study area was not zoned since it represents lower value areas in terms of irreplaceability and therefore lower importance to meet conservation objectives.

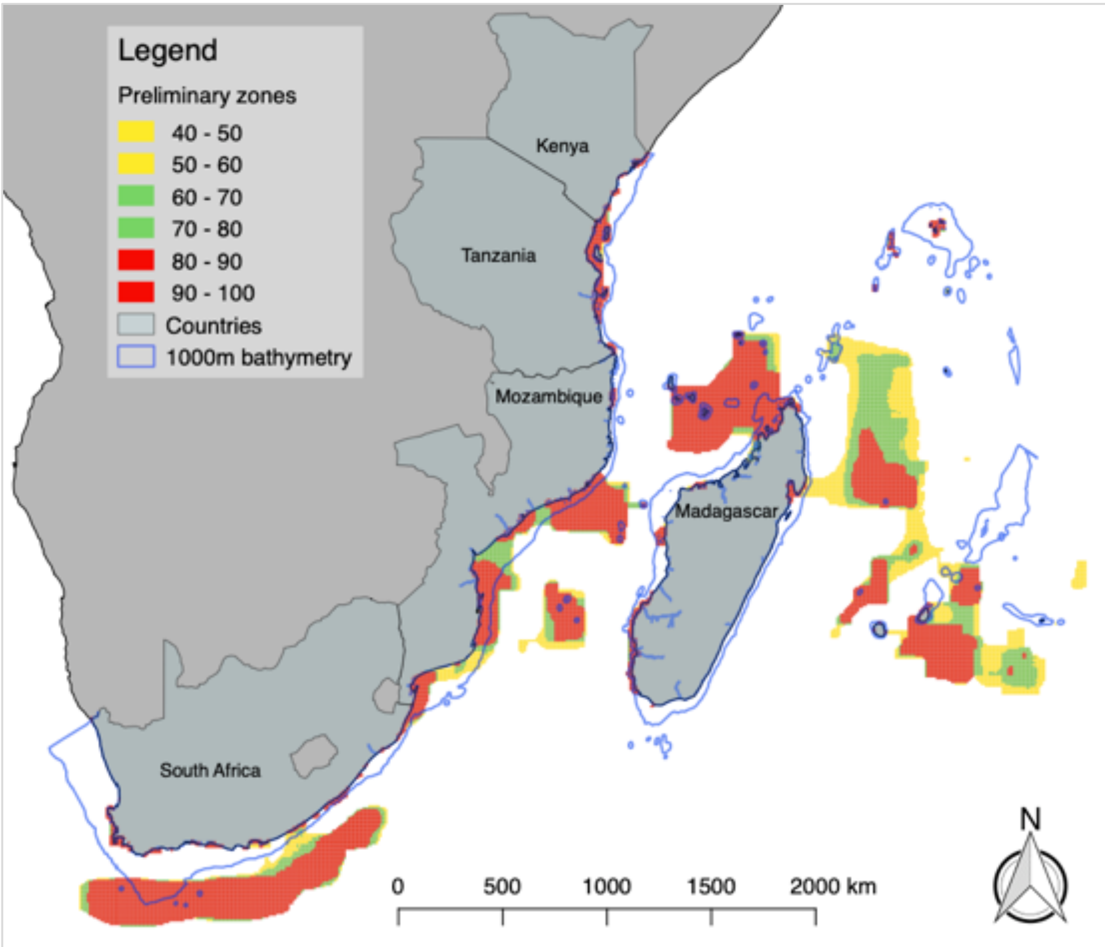

Figure 4-7 |a.) Preliminary zones based on the selection frequency output of Scenario 2. The red zones form the core area to be protected with the green and yellow areas indicating areas important for connectivity reasons and functioning as environmental support areas adjacent core areas. The blue line indicates the 1000m isobath which was used to distinguish between the shallow-water and deep-water zones.

The cumulative HEP impact map was overlaid by the three zones, which indicated that some high cost HEP areas could be avoided, yet certain key areas for sea turtles substantially overlapped with the identified zones (Figure 4-8). Consequently, the zoned areas where divided into nine STAHMAs, namely: 1.) Agulhas; 2.) Mozambique; 3.) Europa; 4.) West Madagascar; 5.) KTZ Coastal; 6.) CMMG Islands; 7.) Seychelles; 8.) Tromelin; and 9.) Mascarenhas. The STAHMAs represent areas that could be grouped together in distinct geographies (irrespective of EEZ or country boundaries) and where specific management and mitigation measures could be undertaken to reduce the conflict between sea turtles and HEP (Figure 4-9, Figure 4-10 and Figure 4-11).

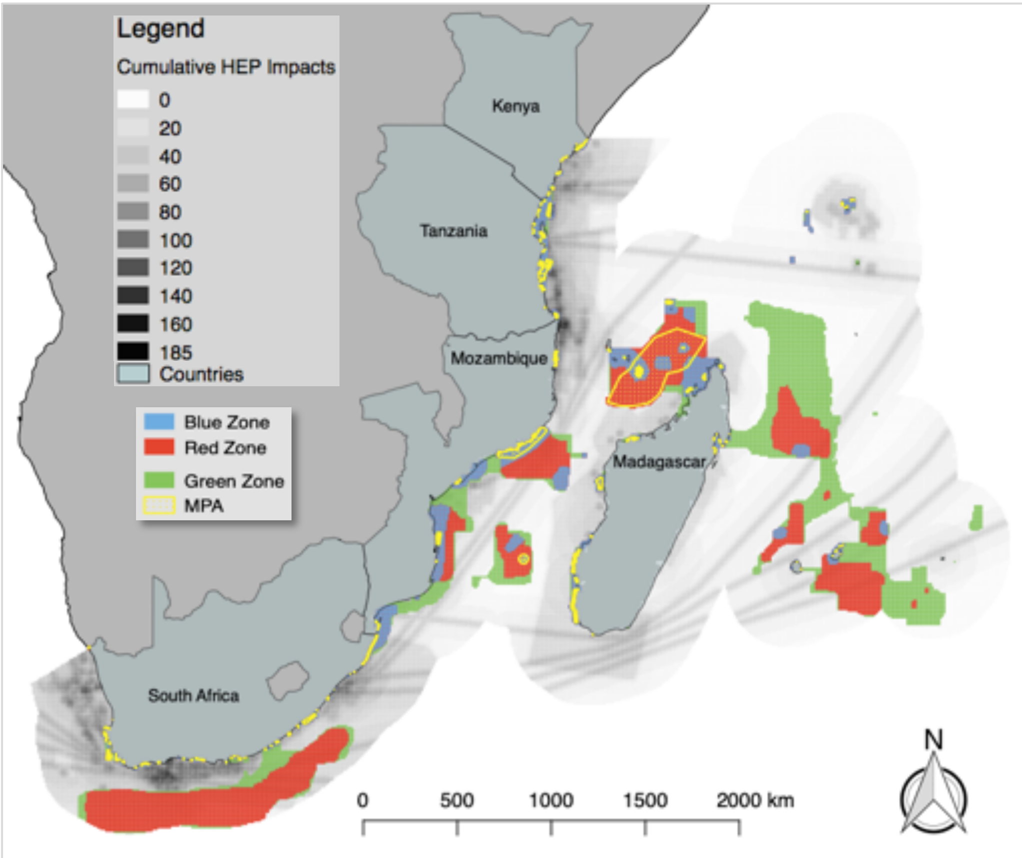

Figure 4-8 | The cumulative HEP impacts overlaid by the final zoning as illustrated in Figure 4-9. The dark areas indicate the highest cumulate HEP impacts. The area where the proposed zones overlap the dark areas from the HEP is where the remaining conflict in ocean use will be highest.

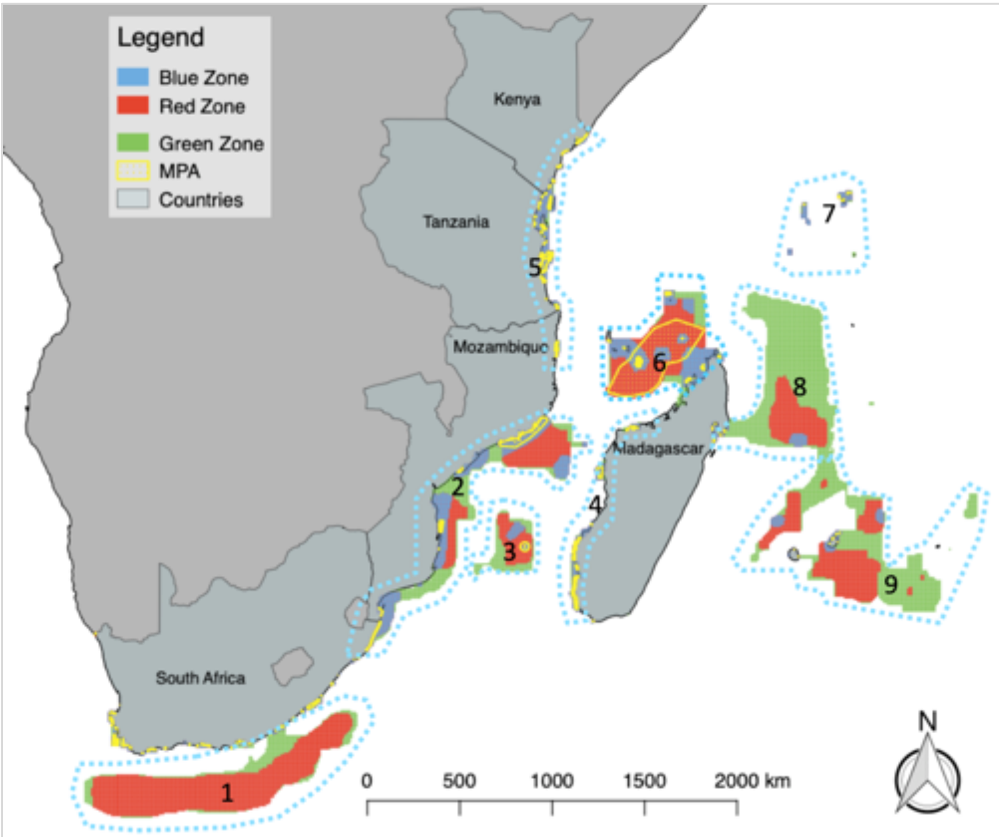

Figure 4-9 | The final zoning comprised three zones. The Red Zone included the 80th percentile selection frequency from Scenario 2 outside the 1000 m bathymetry. The Blue Zone included the 80th percentile selection frequency from Scenario 2 inside the 1000 m bathymetry. The Green Zone included the 40th-79th percentile selection frequency from Scenario 2. The rest of the area was not zoned. The zoned area where divided into nine STAHMAs (indicated by the light blue dotted line), including: 1.) Agulhas; 2.) Mozambique; 3.) Europa; 4.) West Madagascar; 5.) KTM Coastal; 6.) CMMG Islands; 7.) Seychelles; 8.) Tromelin; and 9.) Mascarenhas.

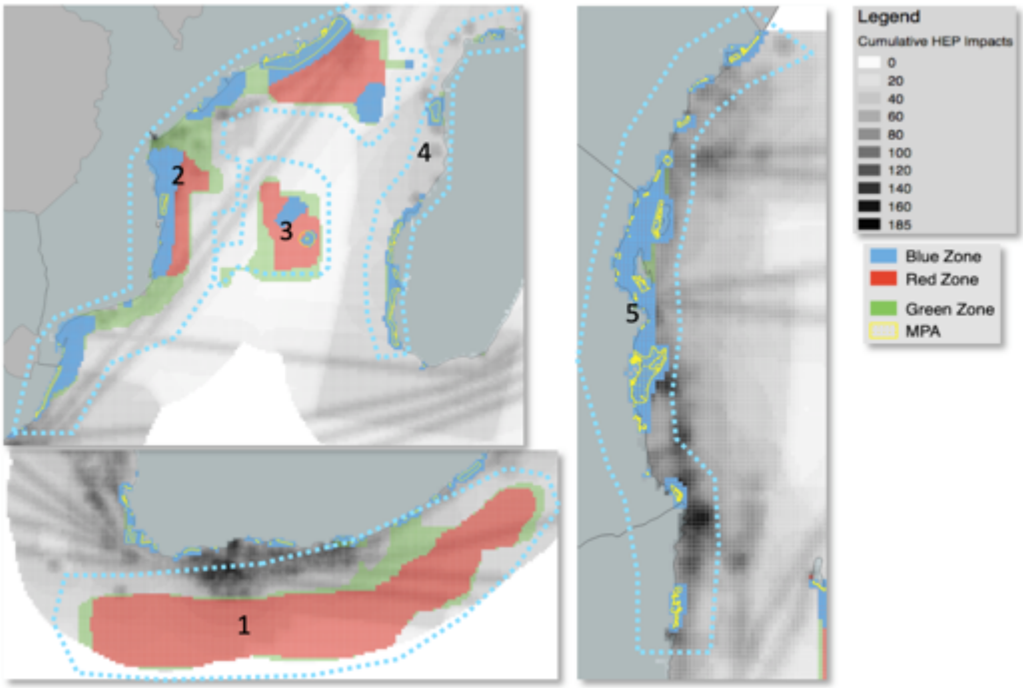

Figure 4-10 | STAHMAs 1 to 5 in relation to the cumulative HEP impacts, namely: 1.) Agulhas; 2.) Mozambique; 3,) Europa; 4.) West Madagascar; 5.) and KTM Coastal.

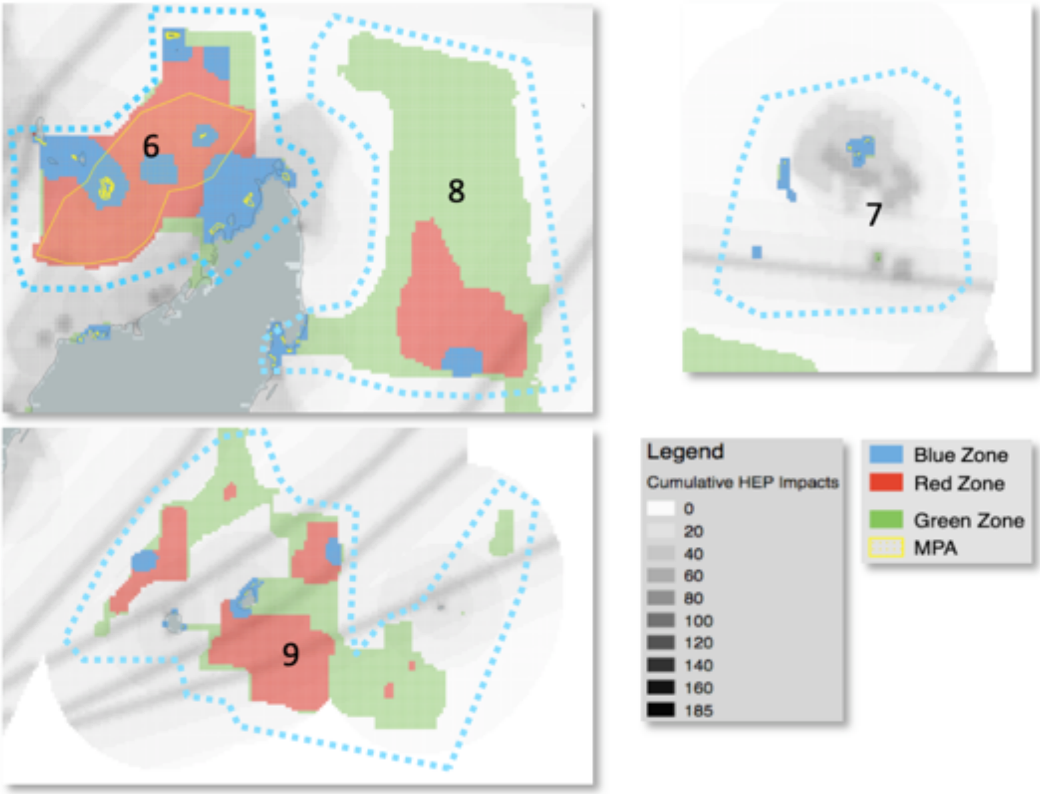

Figure 4-11 | STAHMAs 5 to 8 in relation to the cumulative HEP impacts, namely: 6.) CMMG Islands; 7.) Seychelles; 8.) Tromelin; and 9.) Mascarenhas.

4.5 Discussion

4.5.1 Priority areas for sea turtles in the SWIO

The aim of this study was to derive priority areas for sea turtles that could be used in an ocean zoning strategy for sustainable economic development of HEP in the SWIO region. This was done by testing increasing spatial biodiversity targets of sea turtles breeding, foraging and migratory areas, in three different scenarios, and in relation to cost (cost, being a combination of the ecological condition of sites given the presence of hydrocarbon activities, and the opportunity cost to the HEP industry if areas are selected for conservation). In each of the planning scenarios, the spatial biodiversity targets for sea turtles were met at the lowest cost to the HEP industry by using SCP. The results showed that there was a marked increase in planning units selected (and increase in area) with an increase in biodiversity targets, and that there was a substantive increase in cost to the HEP when compared to the baseline (Scenario 1).

In Scenario 1, it was evident that coastal areas were of the highest priority to sea turtles due to the high biodiversity targets set for breeding areas, which are strictly coast associated and foraging areas, which are strongly coast associated. Furthermore, most MPAs in the study area are situated along the coast, and since these were locked-in for Scenario 1 the Marxan selection frequency output strongly connected these coastal areas. As biodiversity targets increased, so did the inclusion of migration and offshore areas, i.e. in Scenario 2 and Scenario 3. These areas have lower priority because they are large areas supporting sea turtles for only part of the time. A considerable portion of the spatial increase in each scenario could be attributed to an increase in biodiversity target for migratory areas, since a small percentage increase in biodiversity targets for migratory areas translated in a proportionately (when compared to breeding and foraging areas) large increase in required planning units. However, because the migratory areas are so vast and because the Marxan algorithm promoted compactness of selected sites, the migratory areas selected were strongly associated with breeding and foraging areas. This spatially manifested into clearly identifiable priority areas for sea turtles in each of the scenarios tested. However, given a real-world application of SCP, it would be more likely that biodiversity efforts be directed at breeding and foraging areas than migratory areas. This conservation trade-off between key life history stages is underpinned by the reality that resources for biodiversity conservation are limited and therefore need to be spent where it will attain the most value (Douvere & Ehler, 2009).

4.5.2 Mitigating impacts on sea turtle through ocean zoning

A further aim of this study was to identify and optimise the priority areas for sea turtles, in order to use it in an ocean zoning strategy. Although the high cost areas could be avoided in some instance, certain key areas for sea turtle biodiversity still overlapped with the identified HEP impact areas. In the preliminary ocean zoning, three distinct, yet complimentary areas were zoned. In the Red and Blue Zones HEP certain activities will be excluded and those that are permissible will occur under strict mitigation and monitoring measures. These zones form the core conservation area for sea turtles within the STAHMAs and therefore all measures will have to be species specific. This will require mandatory planning and monitoring of sites prior to any decisions being made on whether establishment of specific HEP infrastructure is permissible. This will be particularly important in areas of conflicting use, e.g. areas where there are potential high cumulative impacts from the HEP industry, such as the Rovuma Basin (Ledesma, 2013).

The Blue Zone includes areas from the shore to the 1000 m isobath and therefore typical mitigation measures would consider the proximity to sensitive coastal areas such as nesting beaches and feeding grounds. Mitigation measures could include; no-go areas or buffers around sensitive areas for construction or operation of HEP associated infrastructure or activities; limiting seismic survey activities during times sea turtles aggregate in specific areas; and effectively managing light sources near coastal areas to reduce impact on hatchling sea turtles (Witherington & Martin, 2000). There may also be restrictions or requirements for specific activities pertaining the HEP industry, i.e. establishing a sea turtle exclusion field prior to construction activities and monitoring for potential sea turtle activity during construction (SRK, 2016); or measures such as speed regulations in coastal waters near areas of sea turtles aggregation (Hazel, et al., 2007). Furthermore, contingency plans, e.g. pollution control plans and protocols, in case of far field impacts from, e.g. major pollution events, will have to be set in place for Blue Zones to ensure that remedial operations commence swiftly and with purpose in order to reduce impact on the areas biodiversity (Kark, et al., 2015).

The Red Zone includes areas deeper than the 1000 m isobath (unless else specified or mapped) and therefore typical mitigation measures would consider activities like shipping traffic which could cause physical harm to sea turtles by ship strikes, potential pollution near sensitive area, e.g. seamounts, and noise pollution impacts through seismic surveying. Mitigation measures would need to consider spatiotemporal considerations of sea turtle movements as to avoid congregations of sea turtles in high productivity areas when undertaking specific activities. It might also be warranted that certain activities be completely prohibited in certain areas, such as establishing deep water drill rigs in areas where there is a high failure risk due to oceanic conditions. Aspects such as light pollution, which would need to be strongly mitigated in the near shore areas of the Blue Zone, would not be an issue in the Red Zone since there is no empirical evidence that suggest light from HEP activities would have a negative impact on sea turtle that far offshore.

In the Green Zone similar measures will be undertaken as with the Blue and Red Zones. However, these measures will be less intense and generally allow a larger range of HEP activities to take place if it can be proven that through mitigation impacts on the sea turtles will be kept to within an acceptable limit of residual risk. Furthermore, it's motivated that areas within all three zones, per STAHMA, should be the focus of finer scale planning, to specify exactly what activity can take place and what the area specific monitoring requirements should entail. This will allow for adaptive management of these priority areas, ultimately allowing for the right decisions to be made in terms of sea turtle conservation and sustainable economic development of HEP in the SWIO region.

The three zones will have to managed in a manner complementing existing MPAs, where the *status quo* management will continue with specific focus on the needs of sea turtles, where they occur. MPAs in this study represent areas where sea turtles are already theoretically conserved, yet due to differences in conservation goals, planning and management (Agardy, et al., 2011) not all MPAs protect sea turtles equally (Harris, et al., 2015). The value of MPAs as spatial protection tools for sea turtles have been proven (Scott, et al., 2012; Harris, et al., 2015), yet there are MPAs in the SWIO where sea turtles are not provided sufficient protection. For example, due to gas exploration activities in MBREMP (Tanzania), strong flare lights and noise pollution created by generators were pointed out as being a major contributor to sea turtle hatchlings decreasing from 2,122 in 2004, to 514 in 2006 (Machumu & Yakupitiyage, 2013). These activities are in strongly conflict with the protection of sea turtles and the MPA goals in general, and were ascribed to be a result of "weak impact assessments or assessment teams that are trying to protect the interest of multinational proponent rather than the impacted people and/or environment" (Machumu & Yakupitiyage, 2013). This scenario emphasises why zoning MPAs as a specific sea turtle zone in the context of HEP is important, since activities which may impacted on sea turtles should strictly be excluded from MPAs.

Zoning different use areas will negate many substantial impacts, but it will not resolve all potential conflicts between industry and sea turtles. Hence, the rest of the SWIO study area was purposefully not zoned to keep focus on the irreplaceable biodiversity areas for sea turtles, even though further areas of sea turtle importance have been identified. The fact that these areas were not zoned does not absconded ocean users from the overarching legislated protection measures that are currently in place, whether it be international, regional or local level. Nor does it negate the need for protection of smaller isolated sea turtle populations, which were potentially excluded from analysis in this study. The reality is that ocean and its users are numerous and complex, and therefore comprehensive ocean zoning of the SWIO to explicitly deal with the cumulative and interactive effects of multiple stressors will have to be undertaken (Halpern, et al., 2008).

4.5.3 The STAHMAs

The STAHMAs were created to deal with the complexities that arise where either the Blue, Red or Green Zones overlap with high cost (impact) HEP areas. The Agulhas STAHMA is situated offshore of South Africa and includes vast offshore foraging grounds of *C. caretta* and *D. coriacea* (Harris, et al., 2018). The Agulhas STAHMA consists only of Red and Green Zones since it does not include any coastal areas. The area between the Agulhas STAHMA and the South African shoreline includes numerous HEP developments such as the Oribi and Sable oil fields in the Bredasdorp Basin, which has been exploited since the mid 1990's (Burden & Davies, 1997). This area also includes the major shipping routes around the coast of South Africa. Since the Agulhas STAHMA does not include and coastal areas mitigation of impacts such as light pollution will be unnecessary. The Marxan analysis did not include the 20 new MPAs for South Africa (approved on 25 October 2018). Nonetheless, the Agulhas STAHMA partly includes several of these newly established MPAs, included the Southeast Atlantic Seamounts (Protea Seamounts MPA), Browns Bank Complex, Southwest Indian Seamounts and the Agulhas Front. As the name of these MPAs suggest the area includes numerous seamounts, which could be associated with high productivity feeding grounds for *D. coriacea* (Santos, et al., 2007).

The Mozambique STAHMA stretches from the north coast of South Africa toward the Nampula province in Mozambique (ending just before Nacala). This STAHMA includes, the Sofala banks offshore from Beira in Mozambique, which has been identified as a conservation hotspot for *D. coriacea* due to a rare aggregation of the species that forage in these high productivity waters for extended periods (Robinson, et al., 2016). The aggregation of these *D. coriacea*, that migrate from nesting grounds in South Africa (Robinson, et al., 2016), overlap wholly with the nearshore *Empresa Nacional de Hidrocarbonetos* (ENH) block "Buzi" and offshore Sasol block "Sofala" (Deloitte, 2018) as well as the impacts zone from the Port of Beira, which is set for major expansions in the near future (CoM, 2018). The Mozambique STAHMA includes numerous MPAs including the expanded iSimangaliso Wetland Park (South Africa), Ponta do Ouro Partial Marine Reserve, Bazaruto National Park, Primeiras and Segundas Environmental Protection Area and Quirimbas National Park. These MPAs are strongly associated with the Blue Zones. The area also two Red Zones, one offshore from Bazaruto and the other offshore from the Primeiras and Segundas Environmental Protection Area (Nampula Province). The species maps specific maps created in Chapter 2 indicates that this area support important breeding areas of *C. caretta* and *D. coriacea* (Nel, et al., 2013; Harris, et al., 2015) in the south of the STAHMA as well as several *C. mydas* breeding areas along the Mozambique coast (Williams et al., 2017). This STAHMA also includes important feeding grounds for *C. caretta* and *D. coriacea* (Harris, et al., 2018) as well as vast expanses of coral, mangrove and seagrass areas which area potential feeding grounds for *C. mydas* and *E. imbricata* (Bjorndal, 1997; Gaos, et al., 2012).

The West Madagascar STAHMA stretches from the Baie de Baly National Park in the north to Barrière de Corail Nosy Ve Androka Park in the south. The entire West Madagascar STAHMA is strongly associated with coastal MPAs and all are within the Blue Zone. The Madagascar coast has seen lesser offshore hydrocarbon finds than some of the African main land countries, but none the prospecting continues, most likely spurred on by the finds offshore of Tanzania and Mozambique (IRESA, 2012; Nobert, 2016). Madagascar will also use ships to transport bituminous (tar) sand from Bemolanga, and heavy oil from Tsimiroro (Nairobi Convention Secretariat, 2012) to international markets. The marine transport of hydrocarbons would have to be strictly governed in and around the zoned areas of the West Madagascar STAHMA. The species-specific maps created in Chapter 2 indicates that this area support some breeding areas of *C. mydas* as well as vast expanses of coral, mangrove and seagrass areas, which area potential feeding grounds for *C. mydas* and *E. imbricata* (Bjorndal, 1997; Gaos, et al., 2012).

The CMMG Islands STAHMA include the Comoros which have no official MPAs, Mayotte Marine Nature Park (which includes the whole Mayotte EEZ), the Glorioso Marine Nature Park (which includes the whole Glorioso EEZ) and the north-western part of Madagascar, which include the Ankarea, Ankivonjy and Ambodivahibe MPAs. The CMMG Islands STAHMA consist of Blue Zones essentially connected via a single vast Red Zone and two Green Zones, which indicate the value of this are to sea turtles and the need to strongly mitigate or decline any proposed HEP activities. This area has not been the focus of the HEP industry, but the section north-western of Madagascar has been identified as a potential oil and gas field (Infield, 2018). The area also includes vast expanses of coral, mangrove and seagrass areas which, area potential feeding grounds for *C. mydas* and *E. imbricata* (Bjorndal, 1997; Gaos, et al., 2012). The CMMG Islands STAHMA support breeding areas of *C. mydas* and *E. imbricata* (SWOT, 2018).

The KTM Coastal STAHMA includes the Rovuma Basin where potentially the most significant gas finds of the last decade in the SWIO have been made. This area is on the border of Tanzania and Mozambique, where offshore concessions are owned by international oil and gas companies, i.e. Anadarko and Ente Nazionale Idrocarburi (ENI) (Deloitte, 2018). The area to south of the Rovuma Basin in the Quirimbas Archipelago has the largest *C. mydas* nesting populations in Mozambique

(Videira, et al., 2008), yet apart from the Quirimbas National Park it does not fall within any of the preliminary zoned areas. This can possibly be attributed to the high cost of the area based on the numerous HEP developments proposed for the area between the park and the Rovuma Basin. However, the area to the north of the Rovuma Basin, i.e. the MBREMP is recognized as an important foraging, breeding and nesting area for *C. mydas* and *E. imbricata* (Muir, 2004), this area has been included in the Blue Zone. The fact that the MBREMP has already been established meant that it would be more valuable from a sea turtle conservation perspective to expand this MPA than to conserve equally high value areas in the Quirimbas Archipelago. However, as discussed in Chapter 2, having an MPA without enforcement does not promote conservation and therefore neither will expanding MBREMP since there are already HEP activities taking place within the MPA.

The KTM Coastal STAHMA also includes the area around Songo Songo in Tanzania which is earmarked by the large Songo Songo gas field and includes several offshore wells, a gas processing plant and pipeline from Songo Songo Island to Dar es Salaam (200 km to the north) (Williams, 2009), as well as noteworthy developments planned for the greater area, e.g. Kiliwani North licence area (AMINEX PLC, 2016). The Songo Songo archipelago, including Mafia Island Marine MPA, host important nesting sites for *E. imbricata* and *C. mydas*, and foraging grounds of *C. caretta* that nest in the north of South Africa (Muir, 2004). All the above-mentioned fields have active gas or oil production wells, and in most cases further exploration is underway to further exploit these resources (Williams, 2009; AMINEX PLC, 2016; Deloitte, 2018). Most of this part of the KTM Coastal STAHMA either falls within the Blue Zone or are mapped as MPAs. Thus, specific attention will have to be given to very strict mitigation measures.

The Seychelles STAHMA consists of only Blue Zones around the main islands. Considering the importance of these islands and the adjacent waters the zoning could be considered to be under representing this particular area. However, the newly approved Amirantes Group and Fortune Bank Area of Outstanding Natural Beauty will restrict almost all human activities (Seychelles Government, 2018) and should therefore be considered in future assessment pertaining HEP. Furthermore, the area includes the Aldabra Atoll (Seychelles) which has been one of the sea turtle's conservation success stories of the region and must therefore be protected from any possible HEP impacts (Mortimer, et al., 2011).

The Tromelin and Europa STAHMA both represent islands centred with Blue Zone surrounded by a Red and Green Zone. The Mascarenhas STAHMA includes the islands of Reunion and Mauritius. This STAHMA has formed an evident channel between Reunion and the Bulin and La Pérouse seamounts, most likely due to the cost of the shipping that moves through the areas. The Tromelin, Europa and Mascarenhas STAHMA supports some breeding areas of *C. mydas* (SWOT, 2018) and potential coral feeding grounds. Al. three these STAHMA fall outside of the major proposed HEP developments in the SWIO. However, as indicated in Chapter 3 even areas not directly targeted by the HEP industry might still be impacted by far-field impacts from, i.e. ship and port pollution associated with the HEP industry. In these areas it would be pertinent that contingency plans be drawn up in case of major pollution events even though the islands themselves don't have an established HEP industry.

It's evident that all sea turtle species in the SWIO may be impacted by the existing and future HEP industry, and of particular importance is that sea turtles may be impact on in vastly different geographies, during different life-history stages. Accordingly, finer scale studies will have to be undertaken in STAHMAs where conflict between sea turtles and HEP persist. However, the regional context of the impacts on migratory species such as sea turtle will always have to be considered, e.g., it's evident that *C. caretta* and *D. coriacea*, which are well protected during nesting iSimangaliso Wetland Park World Heritage Site in South Africa (Nel, et al., 2013a) might be impacted upon in key foraging areas by HEP developments in Mozambique and Tanzania.

The motivation for finer scale studies and spatial planning in STAHMAs due to the overlap in some sea turtle use areas, and areas of existing and proposed HEP development, will be underpinned by the ability of the studies and plans to be implemented. There have been numerous cases of where developments have undermined vulnerable coastal social ecological systems in eastern Africa (Bunce, et al., 2010), i.e. the gas project in the centre of MBREMP, which fuels electricity plants powering Mtwara town, yet has had a marked adverse impact on marine life, including sea turtles (Machumu & Yakupitiyage, 2013). Hence, the crux of matter is that implementation of mitigation measures, and the monitoring thereof will ultimately be the difference between the successful conservation of biodiversity features, or the collapse of ecosystems due to unsustainable practices (Sidle, et al., 2013).

It's clear that some countries have more to "lose" and more to "gain" since the hydrocarbon resources are not spread evenly in the region, nor are the areas important to sea turtles. Considering the current problems in SWIO pertaining unresolved issues of governance and policy implementation, coupled with unrealistic local expectations on what the HEP industry might bring (African-Energy, 2015), the regional conservation of sea turtles in the context of the HEP industry will be challenging. This is especially true in context of the historical propensity for African resources to negatively affect economic growth (Basedau, 2005). However, the regional application of SCP should at least facilitate a discourse between SWIO countries on these matters. This could lead to the refinement and implementation of ocean zones and STAHMAs to manage the conflict between sea turtles and the HEP industry, in terms of an appropriate regional framework such as the Memorandum of Understanding on the Conservation and Management of Marine Turtles and their Habitats of the Indian Ocean and South-East Asia (IOSEA), which specifically aims to maintain and recover marine turtle populations by promoting cooperation among governments and other establishments (IOSEA, 2001).

This study used SCP to support MSP in order to achieve theoretical sea turtle biodiversity targets in the SWIO. Similar, studies have been undertaken in areas where there are increasing levels of fishing, mining and other human activities, all of which are set to intensify pressure on the environment through current socio-economic development initiatives (Kirkman, et al., 2019). Therefore, it's of particular importance to note large scale projects like Operation Phakisa in South Africa, which aims to unlock additional economic benefits from the ocean by significantly expand sectors such as offshore HEP (RSA, 2015). More recently the Government of Seychelles approved the "Seychelles Blue Economy Strategic Framework and Roadmap" of which one of the main outcomes is to exploring the feasibility of new and emerging maritime sectors such as offshore petroleum (Seychelles Government, 2018). Both these projects aim to align with the Sustainable Development Agenda 2030 (SDG's), Aichi Target 11 of the Convention on Biological Diversity (CBD) and the Paris Agreement on Climate Change (2015), and therefore it will be imperative that they pay specific attention to potential conflict of the HEP industry and the biodiversity in their oceans.

4.5.4 The global context of sea turtle conflict with HEP developments

The potential impact from HEP on sea turtles is not only important to the species in the SWIO RMUs, but also globally due to declining numbers (IUCN, 2018). Similarly, loss of potential HEP products might have international consequences for first-world countries such as the United States of America and the People's Republic of China, who are actively competing for access to the SWIO's resources to stabilise their dependencies (Frynas & Paulo, 2006). Thus, the conservation efforts must be weighed up against the demand for energy globally (considering oil and gas will be exported to east and west), and in context of other energy sources such as renewables, which are making their way in to the energy mix of the region (Bugaje, 2004; Deichmann, et al., 2010).

The hydrocarbon sector, being a truly global industry, has shown remarkable growth in corporate codes of conduct pertaining to their social and environmental impact, thus current day sectoral obligation to the environment is much greater than it was in the past (Frynas, 2005). The onus of resource exploitation in the African context should thus be, at least in part, placed on the multi-national companies, which will be exploiting the SWIO hydrocarbon resources (PWC, 2013; Deloitte, 2014; African-Energy, 2015) for use in a global market. Furthermore, hydrocarbon companies have also embraced major international initiatives such as Kofi Annan's Global Compact and the Global Reporting Initiative (established by CERES, the Coalition for Environmentally Responsible Economies) (Frynas, 2005). It is therefore recognised that if hydrocarbon exploitation is to be undertaken in SWIO in a way that promotes economic growth, without having severe negative impacts on sea turtles and on the ecosystems in which they persist, the multi-national companies that underwrite these ventures will have to take responsibility. This is why having a regional baseline of areas important to sea turtles and potential impacts of HEP on sea turtles are so important, since it provides all entities (e.g. governments, companies, NGOs, institutes and societies) a point of departure on which they can base their assessment and advocate accountability.

Importantly, not all impacts manifest in the same way, and the specific circumstances, e.g. location of impact event, oceanic conditions, and nature of the impact may greatly influence the eventual significance of such impacts. For example, the Castillo de Bellver oil tanker sank off the coast of South Africa near Saldanha Bay carrying 252,000 tonnes of light crude oil (Wardley-Smith, 1983; Moldan, et al., 1985). Although a considerable amount (~160,000 tonnes) of oil entered the marine environment, observations during the spill and subsequent investigations indicated that environmental damage was minimal (Moldan, et al., 1985). No impact on sea turtles was recorded even though the accident took place within the distribution range of *C. caretta* and D. coriacea. In contrast, the 2010 Deepwater Horizon (DWH) oil spill saw 1,144 sea turtles visibly affected by the spill within seven months of the incident (National Commission, 2011) with indications that at least 66,199 sea turtles were likely within the spill site (Putman, et al., 2015). Subsequently, an overall mortality of 30% has been predicted for all oceanic turtles within the footprint of the DWH oil spill, in addition to those that succumbed from heavy oiling (Mitchelmore, et al., 2017). Consequently, failing to plan for specific scenarios might greatly increase the chance of these events having a lasting impact on the environment (Duinker & Greig, 2007), ultimately rendering the HEP industry unsustainable (Ite, et al., 2013).

4.5.5 The real-world application of zoning for a specific scenario using SCP

This study focussed on existing and future HEP developments in the SWIO. In the case of existing HEP developments, the zoning should help establish additional management activities specifically assigned to mitigating the conflict between sea turtles and HEP within the STAHMAs. These management initiatives should be informed by monitoring of sea turtles within the potential impact area of HEP infrastructure or activities to ultimately validate the effectiveness and need for these mitigation measures. Where future HEP developments are planned, it would be prudent to attempt avoiding conflict between sea turtles and HEP by means of spatial mitigation measures, i.e., using fine scale MSP to avoid conflicting sea use in the STAHMAs. Only where activities cannot be avoided should management activities be used to mitigate impacts on sea turtles, where it is found that these activities are permissible. Cognisance should also be taken of the changing nature of the HEP industry, since new oil and gas finds are continuously made in the SWIO (Deloitte, 2014). Therefore, the identified zones should consciously be verified as new information on both HEP and sea turtles become available, to ensure potential future conflicts are managed.

The six stages of SCP (Margules & Pressey, 2000) provides an appropriate framework for areas of improvement in this study. These improvements include, the migratory data on sea turtles, although mostly post nesting females, greatly aided in refining the outcomes of this study. Therefore, it's motivated that further tagging of sea turtles in the SWIO is essential if we are to better understand their spatial requirements and incorporate them in to spatial protection tools such as ocean zoning to achieve specific conservation goals. Telemetry data on juvenile and sub-adult sea turtles will be particularly helpful since indications are that the HEP industry could affect them differently (Shigenaka, et al., 2010) than post nesting females. Explicit population structure models to better quantify sea turtle stocks would greatly assist in the design of more efficient sea turtle conservation areas (Hamann, et al., 2010), which would ultimately support the implementation of more effective ocean zoning. Additionally, area-specific management practices within the STAHMAs should take into account which features, and species are represented, i.e. breeding, foraging and migrating, because site specific zone activity recommendations pertaining HEP may differ by feature type and possibly by species. The baseline impact or risk assessments undertaken at regional scale on sea turtles, in the face of the HEP industry, would greatly benefit from multiple expert involvement, possibly by a multi-criteria decision model (MCDM) (Teck, et al., 2010) to provide a more robust foundation of potential HEP impacts for us in SCP.

4.6 Conclusion

This study highlights how SCP, as area-based management tool, can be used in scenario planning and the relevance thereof to the greater MSP process. It also indicates the value of having regional scale biodiversity assessments (in this case for sea turtles) and cumulative impact assessments (in the case for the HEP industry) in order to undertake spatial planning. Although it is a fairly novel concept to undertake a regional cumulative impact assessment based on one industry and one group of species, and use it in a scenario planning context, it has highlighted several issues very specific to sea turtles, which might have been forgone in a multi-industry, multi-species assessment. The next step in the SCP process will be the implementation of these findings, whether it be finer scale planning in the identified STAHMAs, adopting the outcomes of this study into overarching zoning plans, or incorporating them into conservation and management plans for sea turtles, i.e. IOSEA. As information becomes available on future HEP developments in the SWIO and regional ecology of sea turtles these findings can be integrated to the produce the best available management options given the specific spatiotemporal context. In closing, this study provides a template for similar studies where the effect of a single industry on a single group of species are warranted due to the complex nature of space-use conflict between them.

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Winiarski, K. J., Miller, D. L., Paton, P. W., & McWilliams, S. R. (2014). A spatial conservation prioritization approach for protecting marine birds given proposed offshore wind energy development. Biological Conservation, 169, 79–88.

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Appendix A: Data Source References

Bourjea, J. 2014. IFREMER/Kélonia satellite tracked late juvenile loggerhead sea turtles from Réunion Island 2008-2012. Data downloaded from OBIS-SEAMAP (http://seamap.env.duke.edu/dataset/1014) on 2017-05-15.	A satellite tracking study was conducted on juvenile loggerhead sea turtles in the Indian Ocean. Eighteen individuals were fitted with transponders and tracked from Réunion Island (21.2°S, 55.3°E) in order to investigate movements and diving patterns. Nine turtles swam north towards Oman (20.5°N, 58.8°E), where one of the world's largest rookeries of loggerheads is located. Three individuals travelled south towards South-Africa and Madagascar, countries that also host loggerhead nesting grounds. Fourteen of the transmitters relayed diving profiles.
Dalleau, M., S. Benhamou, J. Sudre, S. Ciccione and J. Bourjea. 2014. Movement and diving behavior of late juvenile loggerhead sea turtles (*Caretta caretta*) in the Western Indian Ocean. Marine Biology. 161: 1835-1849.	We conducted a satellite tracking study on juvenile loggerhead sea turtles in the Indian Ocean, where they have been poorly studied up to date. Eighteen individuals were released from Reunion Island (21.2°S, 55.3°E) to investigate movement and diving patterns of late juvenile stage in the region. Eleven turtles roughly swam towards Oman (20.5°N, 58.8°E), where one of the world largest rookery of loggerheads is located. Three individuals contrastingly went southwards off the coast South-Africa and Madagascar, countries that also host loggerhead nesting grounds. Fourteen transmitters allowed the processing of animal diving profile and we observed a dichotomy between diurnal and nocturnal diving behavior with a greater number of shorter dives occurring during the day.
Halpin, P.N., A.J. Read, E. Fujioka, B.D. Best, B. Donnelly, L.J. Hazen, C. Kot, K. Urian, E. LaBrecque, A. Dimatteo, J. Cleary, C. Good, L.B. Crowder, and K.D. Hyrenbach. 2009. OBIS-SEAMAP: The world data center for marine mammal, sea bird, and sea turtle distributions. Oceanography. 22(2):104-115.	As part of Component 5 of the South West Indian Ocean Fisheries Project (SWIOFP; http://www.swiofp.net), three Loggerhead turtles (named "Lurdes", "Esperança" and "Mingas") nesting at the Ponta do Ouro Partial Marine Reserve (POPMR) were satellite tagged (Telonics Argos Marine Transmitters TAM-2639).The loggerhead turtles had contrasting migratory routes: Lurdes immediately initiated a near-shore northbound migration, travelling approximately 634 km (monitored distance) during the 15-day monitoring period and probably the turtle was poached, as the last signal from the tag was sent from 2 km inland next to a hut, closed to Baía dos Cocos in Inhambane Province, Mozambique. Mingas was monitored for 73 days and similarly traveled along the coast, all the way to Mozambique Island and across the Mozambique Channel to the NE coast of Madagascar, traversing 3,270 km (ca 2,025 km straight distance).Finally, Esperança was tracked for 2,608 km during 187 days. This turtle travelled along the coast approximately 250 km north (straight distance) of the nesting beach and reached, what is believed to be her feeding grounds on the Mozambique coast between Macaneta and Xai-Xai. This results shows that despite being protected nationally and internationally, poaching is still a serious threat to the conservation of marine turtles in Mozambique (and in the region), which warrants further efforts for their protection.
Infield (2018). Infield Systems Ltd oil and gas mapping data. Accessed 13 June 2017 to 18 October 2018.	Data used under restricted access as provided in study.

Lambardi, P., J.R.E. Lutjeharms, R. Mencacci, C.G. Hays, and P. Luschi. 2008. Influence of ocean currents on long-distance movement of leatherback sea turtles in the Southwest Indian Ocean. Marine Ecologyl Progress Series. 353: 289-301.	Turtles and transmitters. Nine female leatherbacks nesting in the Maputaland Marine Reserve, on the eastern coast of South Africa, were followed through the Argos system during their post-nesting movements between 1996 and 2003. Three different models of transmitters, produced by Telonics and by the Sea Mammal Research Unit (University of St. Andrews, UK), were used. They were programmed with different duty cycles (Table 1) and placed on the carapace with harnesses (Luschi et al. 2003b). The Argos systemprovided location data classified into 6 accuracy levels, and the routes were reconstructed using all fixes and filtering out locations on land or producing ground speed values >10 km h–1 (a threshold estimated from high-accuracy locations only).
Luschi, P., A. Sale, R. Mencacci, G.R. Hughes, J.R.E. Lutjeharms, and F. Papi. 2003. Current transport of leatherback sea turtles (*Dermochelys coriacea*) in the ocean. Proceedings of the Royal Society B: Biological Sciences. 270 suppl. 2: 129-132.	Three Tracked turtles (turtles A, B, C) nested within the Maputa- land Marine Reserve, South Africa, in January 1996 and 1999. They were equipped with Argos-linked satellite transmitters (platform trans- mitter terminals (PTTs)) by a harness made of elastic cord (Hughes et al. 1998). Telonics (Mesa, AZ) PTTs were used, with sensors on board providing information about local water temperature. The tracks were reconstructed by using all localizations provided by Argos (http://www.argosinc.com/), except those (19.1%) that inferredaspeedexceeding10kmh21 orwereonland.Turtlespeed over the ground was calculated by dividing the distance between suc- cessive fixes by the time between them.
Luschi, P., J.R.E. Lutjeharms, P. Lambardi, R. Mencacci, G.R. Hughes, and C.G. Hays. 2006. A review of migratory behaviour of sea turtles off southeastern Africa. South African Journal of Science. 102: 51-58.	Over the years 1996–2003, a total of 19 female turtles (eight loggerheads and 11 leatherbacks) have been equipped with Argos-linked satellite transmitters in the Maputaland Marine Reserve, South Africa. Turtles were captured on the beach immediately after an egg-laying event, and transmitters were attached to their carapace by standard means. Several types of satellite transmitters were employed. During the years 1996–2001, transmitters manufactured by Telonics (Mesa, Arizona, U.S.A.) were used (models ST-14 and ST-6). To make batteries last longer, three of them had the on-board processor programmed with a specific duty cycle, by which they transmitted continuously for the first month after deployment and then every 5 days for the remaining time. In years 2002–03, four turtles were equipped with special transmitters (SRDL, Satellite Relay Data Loggers), manufactured by the University of St Andrews, U.K. Further details on procedures and equipment are provided elsewhere.
Luschi, P. 2012. Leatherback Tracking in South Africa. Data downloaded from OBIS-SEAMAP (http://seamap.env.duke.edu/dataset/439) on 2017-05-15.	To contribute to their conservation, the migratory behavior of these animals has been studied by satellite telemetry for several years. This species turned out to frequent widely dispersed areas ranging from the Atlantic Ocean to the Mozambique Channel, performing large-scale wandering probably due to the leatherbacks' feeding habits on macroplankton such as jellyfish and salps. These movements have been shown to be heavily influenced by the main oceanic currents and oceanographic mesoscale features occurring in the areas crossed. 9 Dermochelys coriacea; tags deployed in South Africa. Date, Begin, 1996-01-16, Date, End 2003-07-16.

Machaku, R., M. Dalleau and J. Bourjea. 2014. University of Eldoret satellite tracked green sea turtles from Kenya 2012 under SWIOFP. Data downloaded from OBIS-SEAMAP (http://seamap.env.duke.edu/dataset/1120) on 2017-05-15.	Satellites tracking of marine turtles was done to identify the main feeding sites of marine turtle nesting in Kenya and assess the interaction between marine turtle and industrial fisheries during their migration. Three nesting sea turtles were tracked from a beach in the North coast of Kenya (-3.83°S, 39.82°E). One of the turtle moved North to a known foraging creek (Takaungu), while another moved to a foraging ground on the South (Gazi). The third turtle just foraged on the near shore reef within where it was tagged.
Nel, R. et al., 2013. Ecological Risk Assessment and Productivity - Susceptibility Analysis of sea turtles overlapping with fisheries in the IOTC region., s.l.: Report to IOTC and IOSEA Marine Turtle MoU.	The number of tags accounted for in the IOTC data included *D. coriacea* (30), *C. caretta* (20), *C. mydas* (35) and *E. imbricata* (8). The IOSEA online reporting system and Seaturtle.org (http://seaturtle.org/tracking/) lists metadata on satellite telemetry and in some instances track information on sea turtles. In the majority of cases, these data come from post-nesting females. Combining information on sea turtle nesting site and post-nesting migration provide some insight into foraging habitat, which were mapped to provide an indication of adult sea turtle distributions, and so the relative size of the RMU to the IOTC region. Only presence/absence data per 2.5^{o} X 2.5^{o} grid across the IOTC region were used.
Pereira, M. A. M., Videira, E. J. S., Gonçalves, P. M. B. & Fernandes, R. S. 2014. Post-nesting migration of loggerhead turtles (*C. caretta*) from Southern Mozambique. African Sea Turtle Newsletter. 1, 48-51.	Data on nesting activity and tagged/recaptured turtles were collected by 40 to 50 marine turtle community monitors employed by the POPMR, tourism operators and civil society organizations, as well as from observations made by the POPMR staff, the latter being especially relevant to detect emergences before the beginning of the official nesting season. Marine turtle monitors patrolled the beaches every night from October to March for the season 2010-11 to 2013-14 and from September to March for the season 2014-15. The location of each emergence was obtained by the use of a handheld Garmin Etrex GPS, the odometer of the patrol vehicle, natural landmarks such as rock headlands (which intersperse the beaches and are called 'Pontas'), or marked poles (positioned every 500m), as well as other infrastructure. Marine turtles were tagged with titanium tags from the beginning of the program in 1993/94, albeit with irregular effort. These long- term datasets were used to analyse remigration intervals to have more information on each recaptured turtle as suggested by Broderick et al. (2002), Horvitz & Thompson (1952) and Thorson et al. (2012).
SWOT. (2018). State of the Worlds Sea Turtles, distribution maps for *C. caretta, D. coriacea , C. mydas and E. imbricata*. Retrieved June 1, 2018, from http://seamap.env.duke.edu/swot	Direct download from SWOT Retrieved June 1, 2018. Global distributions were generated using the citations listed below and refined by regional experts. These global distributions are coarse geographical representations of documented occurrence patterns – bounded by maximum extents – for each species. **Citations** ***Caretta caretta* - Loggerhead** Dodd (1988). Synopsis of the biological data on the loggerhead sea turtle Caretta caretta (Linnaeus 1758). U.S. Fish and Wildlife Service biological report 88(14). 110 pp. SWOT Report - The State of the World's Sea Turtles, Vol 2., (2006) 49 p.

Nichols (2007) Loggerhead sea turtle (Caretta caretta) 5-year review: summary and evaluation. National Marine Fisheries Service and US Fish and Wildlife Service 65 p

Witt et al. (2007) Spatio-temporal patterns of juvenile marine turtle occurrence in waters of the European continental shelf. Marine Biology 151:873-885

***Chelonia mydas* - Green**

Marquez (1990). Sea turtles of the world. FAO fisheries Synopsis. Volume 11, No. 125.

WIDECAST. 2009. Basic biology of the green turtle, WIDECAST network. Online at http://www.widecast.org/Biology/Green.html.

Hirth (1997) Synopsis of the biological data on the green turtle Chelonia mydas (Linnaeus 1758) U.S. Fish and Wildlife Service, biological report, 120 p

Seminoff (assessor) (2004) Global Status Assessment: Green turtle (Chelonia mydas). Marine Turtle Specialist Group Species Survival Commission, Red List Programme:71

Seminoff (2007) Green sea turtle (Chelonia mydas) 5-year review: summary and evaluation. National Marine Fisheries Service, Silver Spring, Maryland 102 pp

Witt et al. (2007) Spatio-temporal patterns of juvenile marine turtle occurrence in waters of the European continental shelf. Marine Biology 151:873-885

***Dermochelys coriacea* - Leatherback**

Eckert et al. (2009). Synopsis of the biological data on the leatherback sea turtle Dermochelys coriacea (Vandelli, 1761). U.S. Fish and Wildlife Service agency report. 183 pp.

SWOT Report - The State of the World's Sea Turtles, Vol 1., (2005) 37 p.

Tiwari (2007) Leatherback turtle (Dermochelys coriacea) five-year review. National Marine Fisheries Service & US Fish and Wildlife Service, Jacksonville, FL, 81 p

***Eretmochelys imbricata* - Hawksbill**

Witzell (1983) Synopsis of biological data on the hawksbill turtle, Eretmochelys imbricata (Linnaeus, 1766). FAO Fisheries Synopsis 137, 78 p.

Marquez (1990). Sea turtles of the world. FAO fisheries Synopsis. Volume 11, No. 125.

SWOT Report - The State of the World's Sea Turtles, Vol 3., (2007) 43 p.

Mortimer and Donnelly (2007) IUCN Red List Status Assessment: hawksbill turtle (Eretmochelys imbricata). IUCN/SSC-Marine Turtle Specialist Group, 121 p

Mortimer (2007) Hawksbill sea turtle (Eretmochelys imbricata) five-year review. National Marine Fisheries Service & US Fish and Wildlife Service, Jacksonville, FL, 93 p

Witt et al. (2007) Spatio-temporal patterns of juvenile marine turtle occurrence in waters of the European continental shelf. Marine Biology 151:873-885

SWOT. (2018). State of the Worlds Sea Turtles, RMU maps for *C. caretta, D. coriacea , C. mydas and E. imbricata*. Retrieved June 1, 2018, from http://seamap.env.duke.edu/swot SWOT. (2018). State of the Worlds Sea Turtles, nesting beach maps for *C. caretta, D. coriacea , C. mydas and E. imbricata*. Retrieved June 1, 2018, from http://seamap.env.duke.edu/swot	To generate RMUs for marine turtles, we collated and georeferenced available data from more than 1,200 papers, reports, abstracts, and other sources (available for download at http://tinyurl.com/29w4kbf),
Videira, E., M. Dalleau, J. Bourjea and M. Pereira. 2015. AICM satellite tracked loggerhead sea turtles from Mozambique 2012 under SWIOFP. Data downloaded from OBIS-SEAMAP (http://seamap.env.duke.edu/dataset/1118) on 2017-05-15.	As part of Component 5 of the South West Indian Ocean Fisheries Project (SWIOFP; http://www.swiofp.net), three Loggerhead turtles (named “Lurdes”, “Esperança” and “Mingas”) nesting at the Ponta do Ouro Partial Marine Reserve (POPMR) were satellite tagged (Telonics Argos Marine Transmitters TAM-2639).The loggerhead turtles had contrasting migratory routes: Lurdes immediately initiated a near-shore northbound migration, travelling approximately 634 km (monitored distance) during the 15-day monitoring period and probably the turtle was poached, as the last signal from the tag was sent from 2 km inland next to a hut, closed to Baía dos Cocos in Inhambane Province, Mozambique. Mingas was monitored for 73 days and similarly traveled along the coast, all the way to Mozambique Island and across the Mozambique Channel to the NE coast of Madagascar, traversing 3,270 km (ca 2,025 km straight distance).Finally, Esperança was tracked for 2,608 km during 187 days. This turtle travelled along the coast approximately 250 km north (straight distance) of the nesting beach and reached, what is believed to be her feeding grounds on the Mozambique coast between Macaneta and Xai-Xai. This results shows that despite being protected nationally and internationally, poaching is still a serious threat to the conservation of marine turtles in Mozambique (and in the region), which warrants further efforts for their protection.
West, L. 2016. Movement patterns of nesting green turtles in Tanzania. Data downloaded from OBIS-SEAMAP (http://seamap.env.duke.edu/dataset/1003) on 2017-05-15 and originated from Satellite Tracking and Analysis Tool (STAT; http://www.seaturtle.org/tracking/index.shtml?project_id=918).	Sea Sense is conducting research into the migratory behaviour of green turtles to better understand their movements and identify important foraging grounds and migratory corridors in the western Indian Ocean region. This kind of information is being used in Tanzania to develop a National Sea Turtle Status Report which will eventually feed into a National Sea Turtle Recovery Plan. To date, four satellite tags have been deployed on nesting green turtles in Mafia Island, Temeke and Pangani which are the three most important green turtle rookeries in Tanzania.

Appendix B: Impact ratings

Table A | Impact ratings of the potential HEP impacts ranked according to impact category and secondarily by impact type

Impact, *source of impact including fields; licence blocks; wells; platforms; pipelines; ports; terminals and ship lanes;* ***WP (blue)***, *water pollution;* ***LP (yellow)***, *light pollution;* ***NP (grey)***, *noise pollution;* ***VS (orange)***, *vessel strikes;* ***HD (green)***, *habitat destruction;* ***NF***, *near-field;* ***MF***, *mid-field;* ***FF***, *far-field;* ***Ex high***, *Extremely high;* ***V unlikely***, *Very unlikely;* ***Ex unlikely***, *Exceptionally unlikely;* ***Vr certain***, *Virtually certain;* ***#,*** *score.*

Impact	Intensity	#	Duration	#	Magnitude	#	Likelihood	#	Significance	#
Field HD FF	Negligible	1	Negligible	1	Neutral	2	V unlikely	2	Minimal	4
Field HD MF	Negligible	1	Negligible	1	Neutral	2	Unlikely	3	Minimal	6
Field HD NF	Low	3	Short term	3	Low	6	Likely	4	Minor	24
Field LP FF	Negligible	1	Seasonal	2	Very low	3	Ex unlikely	1	Minimal	3
Field LP MF	Negligible	1	Seasonal	2	Very low	3	V unlikely	2	Minimal	6
Field LP NF	Low	3	Seasonal	2	Low	5	Very likely	5	Minor	25
Field NP FF	Negligible	1	Negligible	1	Neutral	2	V unlikely	2	Minimal	4
Field NP MF	Very Low	2	Seasonal	2	Very low	4	V unlikely	2	Minimal	8
Field NP NF	Low	3	Seasonal	2	Low	5	Likely	4	Minor	20
Field VS FF	Negligible	1	Negligible	1	Neutral	2	V unlikely	2	Minimal	4
Field VS MF	Negligible	1	Negligible	1	Neutral	2	V unlikely	2	Minimal	4
Field VS NF	Negligible	1	Negligible	1	Neutral	2	V unlikely	2	Minimal	4
Field WP FF	Low	3	Negligible	1	Very low	4	Likely	4	Minimal	16
Field WP MF	Low	3	Short term	3	Low	6	Likely	4	Minor	24
Field WP NF	Low	3	Short term	3	Low	6	Likely	4	Minor	24
Licence HD FF	Very Low	2	Seasonal	2	Very low	4	V unlikely	2	Minimal	8
Licence HD MF	Very Low	2	Seasonal	2	Very low	4	V unlikely	2	Minimal	8
Licence HD NF	Very Low	2	Seasonal	2	Very low	4	V unlikely	2	Minimal	8
Licence LP FF	Negligible	1	Seasonal	2	Very low	3	Ex unlikely	1	Minimal	3
Licence LP MF	Negligible	1	Seasonal	2	Very low	3	Ex unlikely	1	Minimal	3
Licence LP NF	Negligible	1	Seasonal	2	Very low	3	Ex unlikely	1	Minimal	3
Licence NP FF	Low	3	Seasonal	2	Low	5	Likely	4	Minor	20
Licence NP MF	Low	3	Seasonal	2	Low	5	Likely	4	Minor	20
Licence NP NF	High	5	Seasonal	2	Moderate	7	Likely	4	Minor	28
Licence VS FF	Very Low	2	Seasonal	2	Very low	4	Unlikely	3	Minimal	12
Licence VS MF	Very Low	2	Seasonal	2	Very low	4	Unlikely	3	Minimal	12
Licence VS NF	Very Low	2	Seasonal	2	Very low	4	Unlikely	3	Minimal	12
Licence WP FF	Negligible	1	Negligible	1	Neutral	2	Ex unlikely	1	Minimal	2
Licence WP MF	Negligible	1	Negligible	1	Neutral	2	Ex unlikely	1	Minimal	2
Licence WP NF	Negligible	1	Negligible	1	Neutral	2	Ex unlikely	1	Minimal	2
Pipe HD FF	Low	3	Medium term	4	Moderate	7	Unlikely	3	Minor	21
Pipe HD MF	Low	3	Medium term	4	Moderate	7	Likely	4	Minor	28
Pipe HD NF	Moderate	4	Long term	5	High	9	Definite	7	Major	63
Pipe LP FF	Negligible	1	Negligible	1	Neutral	2	Ex unlikely	1	Minimal	2
Pipe LP MF	Negligible	1	Negligible	1	Neutral	2	V unlikely	2	Minimal	4
Pipe LP NF	Very Low	2	Seasonal	2	Very low	4	V unlikely	2	Minimal	8

Impact	Intensity	#	Duration	#	Magnitude	#	Likelihood	#	Significance	#
Pipe NP FF	Low	3	Negligible	1	Very low	4	Definite	7	Minor	28
Pipe NP MF	Low	3	Negligible	1	Very low	4	Definite	7	Minor	28
Pipe NP NF	Moderate	4	Seasonal	2	Low	6	Definite	7	Moderate	42
Pipe VS FF	Negligible	1	Seasonal	2	Very low	3	V unlikely	2	Minimal	6
Pipe VS MF	Negligible	1	Negligible	1	Neutral	2	V unlikely	2	Minimal	4
Pipe VS NF	Negligible	1	Negligible	1	Neutral	2	V unlikely	2	Minimal	4
Pipe WP FF	High	5	Long term	5	High	10	Likely	4	Moderate	40
Pipe WP MF	High	5	Long term	5	High	10	Likely	4	Moderate	40
Pipe WP NF	High	5	Long term	5	High	10	Very likely	5	Moderate	50
Plat HD FF	Low	3	Long term	5	Moderate	8	Unlikely	3	Minor	24
Plat HD MF	Low	3	Long term	5	Moderate	8	Likely	4	Minor	32
Plat HD NF	Moderate	4	Semi-permanent	6	High	10	Very likely	5	Moderate	50
Plat LP FF	Low	3	Seasonal	2	Low	5	Unlikely	3	Minimal	15
Plat LP MF	Moderate	4	Seasonal	2	Low	6	Likely	4	Minor	24
Plat LP NF	High	5	Seasonal	2	Moderate	7	Vr certain	6	Moderate	42
Plat NP FF	Very Low	2	Seasonal	2	Very low	4	Unlikely	3	Minimal	12
Plat NP MF	Very Low	2	Seasonal	2	Very low	4	Unlikely	3	Minimal	12
Plat NP NF	Very Low	2	Seasonal	2	Very low	4	Likely	4	Minimal	16
Plat VS FF	Negligible	1	Seasonal	2	Very low	3	Unlikely	3	Minimal	9
Plat VS MF	Very Low	2	Seasonal	2	Very low	4	Unlikely	3	Minimal	12
Plat VS NF	Very Low	2	Seasonal	2	Very low	4	Likely	4	Minimal	16
Plat WP NF	Very high	6	Permanent	7	Ex high	13	Very likely	5	Major	65
Plat WP FF	Very high	6	Permanent	7	Ex high	13	Likely	4	Moderate	52
Plat WP MF	Very high	6	Permanent	7	Ex high	13	Very likely	5	Major	65
Port HD FF	Moderate	4	Long term	5	High	9	Likely	4	Minor	36
Port HD MF	Moderate	4	Long term	5	High	9	Vr certain	6	Moderate	54
Port HD NF	Very high	6	Permanent	7	Ex high	13	Definite	7	Severe	91
Port LP FF	Moderate	4	Seasonal	2	Low	6	Very likely	5	Minor	30
Port LP MF	High	5	Seasonal	2	Moderate	7	Vr certain	6	Moderate	42
Port LP NF	High	5	Seasonal	2	Moderate	7	Definite	7	Moderate	49
Port NP FF	Low	3	Seasonal	2	Low	5	Unlikely	3	Minimal	15
Port NP MF	Low	3	Seasonal	2	Low	5	Likely	4	Minor	20
Port NP NF	High	5	Seasonal	2	Moderate	7	Vr certain	6	Moderate	42
Port VS FF	Low	3	Seasonal	2	Low	5	Unlikely	3	Minimal	15
Port VS MF	Low	3	Seasonal	2	Low	5	Unlikely	3	Minimal	15
Port VS NF	Moderate	4	Seasonal	2	Low	6	Very likely	5	Minor	30
Port WP FF	Very high	6	Permanent	7	Ex high	13	Very likely	5	Major	65
Port WP MF	Very high	6	Permanent	7	Ex high	13	Vr certain	6	Major	78
Port WP NF	Very high	6	Permanent	7	Ex high	13	Definite	7	Severe	91
Ship HD FF	Negligible	1	Negligible	1	Neutral	2	Ex unlikely	1	Minimal	2
Ship HD MF	Negligible	1	Negligible	1	Neutral	2	Ex unlikely	1	Minimal	2
Ship HD NF	Negligible	1	Negligible	1	Neutral	2	Ex unlikely	1	Minimal	2
Ship LP FF	Negligible	1	Seasonal	2	Very low	3	V unlikely	2	Minimal	6
Ship LP MF	Negligible	1	Seasonal	2	Very low	3	V unlikely	2	Minimal	6
Ship LP NF	Negligible	1	Seasonal	2	Very low	3	V unlikely	2	Minimal	6
Ship NP FF	Very Low	2	Seasonal	2	Very low	4	Unlikely	3	Minimal	12
Ship NP MF	Very Low	2	Seasonal	2	Very low	4	Unlikely	3	Minimal	12
Ship NP NF	Low	3	Long term	5	Moderate	8	Very likely	5	Moderate	40
Ship VS FF	Low	3	Seasonal	2	Low	5	Likely	4	Minor	20
Ship VS MF	Low	3	Seasonal	2	Low	5	Likely	4	Minor	20

Impact	Intensity	#	Duration	#	Magnitude	#	Likelihood	#	Significance	#
Ship VS NF	High	5	Seasonal	2	Moderate	7	Very likely	5	Minor	35
Ship WP FF	High	5	Permanent	7	Very high	12	Likely	4	Moderate	48
Ship WP MF	High	5	Permanent	7	Very high	12	Very likely	5	Major	60
Ship WP NF	High	5	Permanent	7	Very high	12	Vr certain	6	Major	72
Term HD FF	Very Low	2	Long term	5	Moderate	7	Vr unlikely	2	Minimal	14
Term HD MF	Very Low	2	Long term	5	Moderate	7	Unlikely	3	Minor	21
Term HD NF	Moderate	4	Long term	5	High	9	Likely	4	Minor	36
Term LP FF	Low	3	Seasonal	2	Low	5	Unlikely	3	Minimal	15
Term LP MF	Low	3	Seasonal	2	Low	5	Likely	4	Minor	20
Term LP NF	Moderate	4	Seasonal	2	Low	6	Likely	4	Minor	24
Term NP FF	Very Low	2	Seasonal	2	Very low	4	Unlikely	3	Minimal	12
Term NP MF	Very Low	2	Seasonal	2	Very low	4	Unlikely	3	Minimal	12
Term NP NF	Very Low	2	Seasonal	2	Very low	4	Unlikely	3	Minimal	12
Term VS FF	Negligible	1	Seasonal	2	Very low	3	Ex unlikely	1	Minimal	3
Term VS MF	Very Low	2	Seasonal	2	Very low	4	Ex unlikely	1	Minimal	4
Term VS NF	Very Low	2	Seasonal	2	Very low	4	V unlikely	2	Minimal	8
Term WP FF	Very Low	2	Long term	5	Moderate	7	Unlikely	3	Minor	21
Term WP MF	Very Low	2	Long term	5	Moderate	7	Unlikely	3	Minor	21
Term WP NF	Moderate	4	Long term	5	High	9	Very likely	5	Moderate	45
Well HD FF	Low	3	Medium term	4	Moderate	7	Unlikely	3	Minor	21
Well HD MF	Low	3	Medium term	4	Moderate	7	Likely	4	Minor	28
Well HD NF	Moderate	4	Medium term	4	Moderate	8	Vr certain	6	Moderate	48
Well LP FF	Very Low	2	Seasonal	2	Very low	4	Unlikely	3	Minimal	12
Well LP MF	Moderate	4	Seasonal	2	Low	6	Vr certain	6	Minor	36
Well LP NF	High	5	Seasonal	2	Moderate	7	Definite	7	Moderate	49
Well NP FF	Negligible	1	Seasonal	2	Very low	3	Unlikely	3	Minimal	9
Well NP MF	Very Low	2	Seasonal	2	Very low	4	Unlikely	3	Minimal	12
Well NP NF	Very Low	2	Seasonal	2	Very low	4	Unlikely	3	Minimal	12
Well VS FF	Negligible	1	Negligible	1	Neutral	2	Ex unlikely	1	Minimal	2
Well VS MF	Negligible	1	Negligible	1	Neutral	2	Ex unlikely	1	Minimal	2
Well VS NF	Very Low	2	Seasonal	2	Very low	4	V unlikely	2	Minimal	8
Well WP NF	High	5	Permanent	7	Very high	12	Vr certain	6	Major	72
Well WP FF	High	5	Permanent	7	Very high	12	Likely	4	Moderate	48
Well WP MF	High	5	Semi-permanent	6	Very high	11	Very likely	5	Moderate	55