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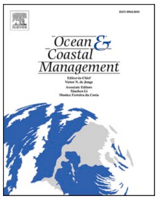

Ecological considerations for marine spatial management in deep-water Tanzania

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ABSTRACT

The United Republic of Tanzania has jurisdiction over a large marine area (223,000 km^2) of which over 92% is deeper than 200 m. These deep areas extend from, in most cases <10 km from shore, have connections to shallow and coastal marine habitats through oceanographic processes, and support important living and non-living resources, which are becoming increasingly exploited to support a valuable blue economy. Recognising the need for sustainable development, implementation of conservation and management measures in Tanzania's offshore waters has begun, with the development of coastal protected areas and marine spatial plans (e.g. the Coastal and Marine Spatial Plan for Zanzibar). As yet, the deeper areas of Tanzania have not been considered in marine spatial planning. Here we present a synthesis of available data on the habitats and biological communities of deep-water Tanzania, including new data collected in collaboration with the deep-water oil and gas industry, to provide an indication of regional-scale patterns and areas of potential importance. We also discuss the value and multiple uses of the deep ocean areas to Tanzania, and assess the ecological effects of impacts in these environments. This information is valuable to the Tanzanian government to help inform development of management measures to continue to make sustainable use of valuable deep-water resources. To facilitate uptake, we provide a series of recommendations on considering the Tanzanian deep ocean areas in marine spatial planning to boost future management of the important and sensitive offshore domain.

1. Introduction

Marine spatial planning (MSP) is an important approach for implementing successful ecosystem-based management around the world through managing the multiple uses of marine spaces (Douvere, 2008). Marine protected areas (MPA) provide a key mechanism for marine conservation (reviewed in Halpern and Warner, 2002), increasing the density, biomass (e.g. Lester et al., 2009) and diversity (e.g. Blowes et al., 2020) of organisms and improving ecosystem function (e.g. Gaines et al., 2010). Successful MSP considers the wider context, balancing biodiversity concerns and MPAs with the need to ensure economic growth while considering potential impacts of commercial activities (Douvere, 2008; Foley et al., 2010). Ecological assessments of the natural state of habitats and biota (e.g. Wedding et al., 2013), sometimes in combination with data from industry (e.g. Said and Trouillet 2020), are used to determine the conservation objectives that form the basis for MSP and the designation and evaluation of effective MPAs (Margules and Pressey 2000; Bottrill and Pressey 2012). Such data have been used in the development of MPAs (e.g. Fernandes et al., 2005), including in the Western Indian Ocean (WIO; Crochelet et al., 2016; Le Corre et al., 2012; Daw et al., 2011). Although MSP has been implemented globally, including in developing and small-island states (Lombard et al., 2019), a key barrier to implementation is limited information on the marine environment (Pınarbaşı et al., 2017). Recognising the need for sustainable development, the United Republic of Tanzania is actively exploring approaches to MSP (Permanent Mission of the United Republic of Tanzania to the United Nations, 2017), which is considered urgent to integrate management of coastal and marine resources through ecosystem-based approaches and for longer term development and investment. Conservation and management measures to date include the development of coastal protected areas and marine spatial plans, for example the integrated spatial planning for coastal and marine areas in

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Unguja (Zanzibar) Island (Khamis et al., 2017; Käyhkö et al., 2019; Levine, 2016). This planning has also included initiatives to improve data availability from a range of sources in the coastal zone, such as the Tanzania Sensitivity Atlas (TanSEA) and Zanzibar Social Environmental Atlas for Coastal and Marine Areas (ZanSea Project, 2015).

MPAs (including Marine Parks and Marine Reserves) have been established in Tanzania since the 1970s (Wells et al., 2007). These cover >13% of the continental shelf (Fig. 1) and are mostly focussed on protection of coastal and shallow habitats, including coral reefs, mangroves and turtle nesting areas (Rocliffe, 2011; Rocliffe et al., 2014). The deepest of these MPAs, Tanga Coelacanth Marine Park, extends from the coast to 150 m depth (UNEP, 2013). The mainland coast also includes the Rufiji-Mafia-Kilwa Marine Ramsar Site, added to the List of Wetlands of International Importance in October 2004. Ideally, such a network should be considered at a regional scale (Maina et al., 2020), but as is common elsewhere (Danovaro et al., 2020), the deeper water areas of Tanzania have not been considered in MSP. This is an important omission, as over 92% of the total marine area under the jurisdiction of the United Republic of Tanzania is deeper than 200 m.

The deep ocean is the world's largest habitat by volume but the least explored. It is considered to begin at water depths below 200 m, where the types of organisms, their unique morphologies and lifestyles are influenced by the lack of light, increasing pressure, and changes to available food that occur with increasing depth (Levin et al., 2019). Globally the deep sea provides vital regulating services (e.g. absorption of heat and CO_2, biological carbon pump and nutrient cycling), provisioning services (e.g. energy, mineral resources and food) and cultural services (e.g. education, aesthetic, stewardship) (Thurber et al., 2014) but its geographic separation makes it seem disconnected to the majority of the population. Increasingly research is demonstrating the connections between the deep sea and environments closer to shore.

The deep sea is connected to the surface ocean, principally through the deposition of phytoplankton into deep water as the major source of food and by the movement of organisms between shallow and deep waters. The connections between the shallow coastal zone and the deep ocean are particularly important where the continental shelf is narrow. For example, submarine canyons act as conduits for sediment (e.g. Gardner, 1989), nutrients (Fernandez-Arcaya et al., 2017) and litter (van den Beld et al., 2017) from coastal to deep water. Upwelling of nutrients supports increased primary productivity in surface waters providing feeding opportunities for large pelagic fish, sharks and marine mammals (Rennie et al., 2009).

Resources in the deep sea are attractive to industries including oil and gas, fishing and mining. Ecological assessments of deep-sea habitats have enabled management actions to protect them, potentially allowing them to recover. For example, MPA designation and adherence to fisheries closure at the Darwin Mounds (NE Atlantic) halted the loss of coral cover, but after eight years there was limited evidence of recovery in severerly impacted areas (Huvenne et al., 2016). Long-term surveys have revealed evidence for recovery over multi-decade time-scales on seamounts closed to fishing when compared to those still fished, revealing the importance of remnant populations (Baco et al., 2019). Use of the precautionary principle in MSP has been advised for deep-sea environments (Ahnert and Borowski, 2000; Halfar and Fujita, 2002), where recovery is generally slow (Baco et al., 2019; Jones et al., 2017; Stratmann et al., 2018).

The deep western Indian Ocean is increasingly exploited to support a valuable blue economy in all WIO countries (Nairobi Convention SecretariatWestern Indian Ocean Marine Science Association and CSIR, 2017). However, there is a major lack of knowledge in the deep-water biodiversity of these areas, particularly off East Africa (Wafar et al., 2011). In Tanzania, water depths increase rapidly beyond the narrow continental shelf (Masalu, 2008) and the 200 m isobath is close to land, (1–40 km; Bourget et al., 2008) (Fig. 1). The Tanzanian deep sea supports open ocean fisheries (FAO, 2007) and a developing offshore oil and gas industry (Richmond, 2016). Despite a relatively long history of exploration (Schott, 1900), the knowledge of deep-sea ecosystems off Tanzania is extremely limited (Gates 2016), hindering efforts to understand and manage its sustainable development.

Here we present a synthesis of available data on the habitats and biological communities of deep-water Tanzania, including new information collected in collaboration with deep-water oil and gas industry, to provide an indication of regional-scale patterns and areas of potential importance. Uses and users of the deep sea in Tanzania are identified and potential conflicts between them are considered. The ecological effects of impacts already observed in these mostly-pristine environments are also considered. This information is valuable to the Tanzanian government to help inform development of management measures to continue to make sustainable use of valuable deep-water resources.

2. The Tanzanian deep sea

2.1. The deep sea: a component of the wider marine environment

The majority of life in the deep sea worldwide, including the deep water of Tanzania, is dependent on the transfer of surface primary production through the water column to the deep ocean. These are habitats with low to no light, high pressure and cold temperatures (<5 °C). Many organisms in these habitats are adapted to these conditions, providing unique communities, though some, including species of conservation importance, migrate through the deep sea. Although remote, the deep sea is increasingly exploited by humans, and is impacted by climate change and pollution (Ramirez-Llodra et al., 2011).

Oceanographic, ecological and cultural aspects connect the shallow ocean, or coastal zone, to the open ocean and deep-sea environments. The East African Coastal Current and Somali current are instrumental in moving water from the open ocean to the coastal zones, providing a high degree of such connectivity off Tanzania, at timescales of less than 100 days (Popova et al., 2019). Ecological connections between the deep sea and shallower waters and coastal zones are critical to the life cycles of migrating species. Organisms such as cetaceans and turtles transit the deep sea as they travel horizontally. Vertical connections exist primarily through processes that influence global biogeochemical cycling such as the sinking of particles (e.g. Haake et al., 1993), vertical migrations of zooplankton and micronekton (Bianchi and Mislan, 2016) and through the movement of fishes through the water column, and through deep-diving cetaceans, sharks and fishes.

Such connectivity presents challenges for spatial management, as connectivity between areas and habitats must be considered for management actions to be effective (O'Leary and Roberts 2018; Popova et al., 2019). For example, conservation in a single area may only protect parts of a life cycle for migratory organisms. Thus, management of the coastal zone should consider impacts to the deep sea and open ocean, and vice versa. Spatial management actions should integrate across coastal, shallow and deep ocean areas, and include both the seabed and water column above it.

2.2. Discovery: deep-water exploration off Tanzania

The deep sea off Tanzania was visited by several of the first broad-scale oceanographic expeditions, with some biodiversity documented. The first appears to be the 1898–1899 *Valdivia* expedition, which sampled between Seychelles and Dar-es-Salaam (Schott, 1900) using a dredge in waters up to 5000 m deep obtaining the first observations of many deep-sea benthic and pelagic species (Chun, 1903). The John Murray *Mabahiss* expedition (1932–1934) sampled between Mombasa, Zanzibar and Sri Lanka. This expedition sampled deep-water echinoids (Mortensen, 1939), gorgonians (Cannon, 1940), bivalves (Knudsen, 1967) and fishes (Norman, 1939) amongst others. The *Galathea II* expedition (1950–1952) collected samples between Sri Lanka and the Kenyan coast, as well as from Mozambique to South Africa (Demopoulos et al., 2003) but did not sample Tanzanian waters. *Galathea II* noted

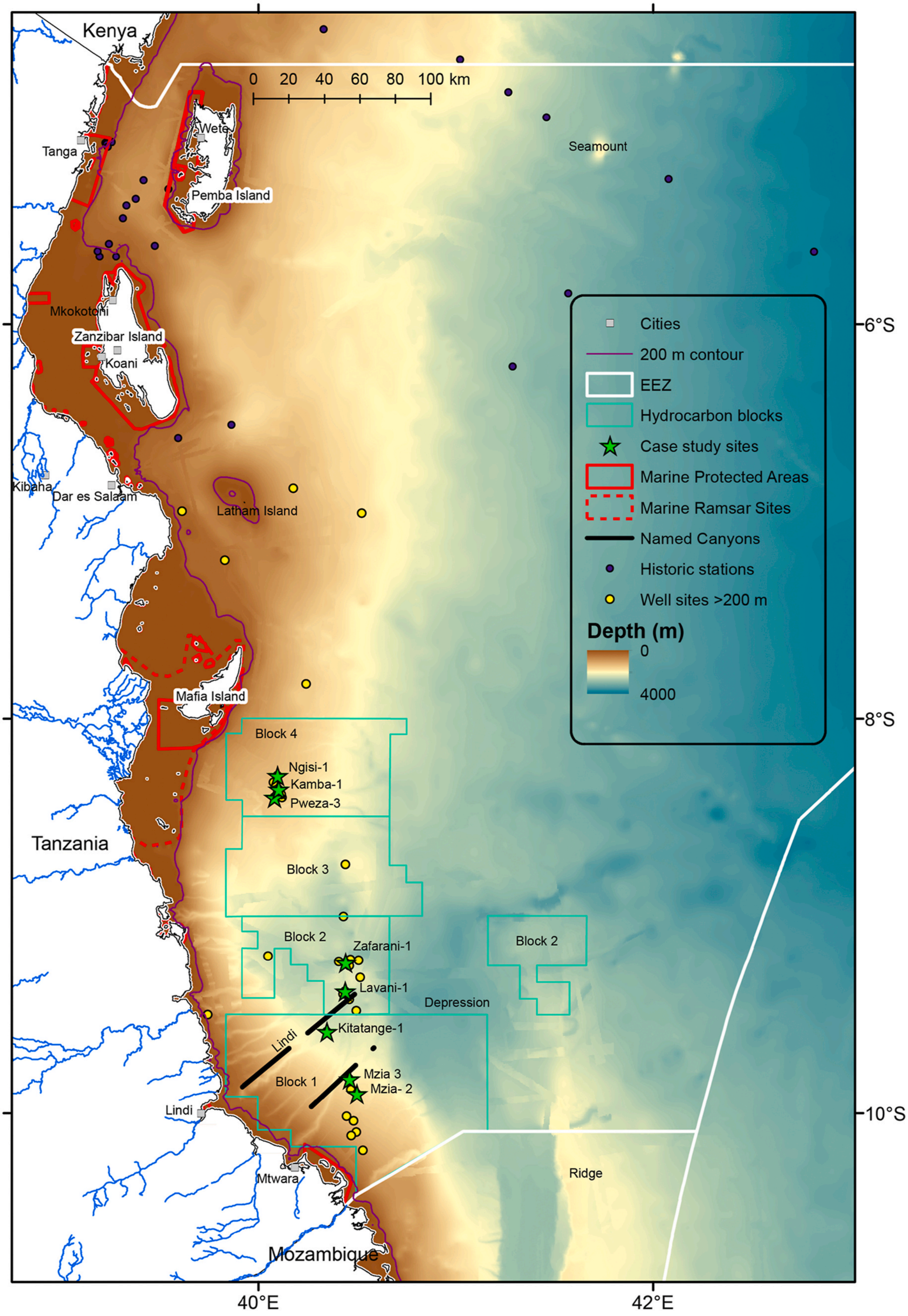

Fig. 1. Map of the Tanzania EEZ showing the seabed bathymetry, key areas of anthropogenic activity, protected areas and sites of biological exploration (eastern-most extent of EEZ excluded for presentation purposes). Data sources provided in Table 1.

large quantities of terrestrial vegetation in trawls from the Mozambique Channel to the south of this study area (Bruun et al., 1956). The International Indian Ocean Expedition (IIOE) aboard the *RV Anton Brunn* in 1962–1965 sampled between the Seychelles and Mombasa (Wyrtki, 1971) (Fig. 1). These expeditions provide important information about the fauna inhabiting specific sites in the WIO, but alone provide limited information about the spatial patterns required to support management of increased development of the blue economy.

Other work has focussed on potential impacts of resource use off Tanzania. In the 1980s the *RV Dr Fridtjof Nansen* programme carried out acoustic surveys of small pelagic and mesopelagic fishes on the continental shelf and upper slope areas and assessed the hydrographic regime (Birkett, 1978; Francis et al., 2017; Iversen et al., 1984; Sætersdal et al., 1999) (Fig. 1). More recently, observational studies of deep-sea ecology (1300–2700 m) accessed oil and gas industry infrastructure offshore Tanzania. These studies provide the first in situ observations of deep-sea organisms on the seabed and water column near offshore drilling operations in Tanzania (Gates 2016) and included new ecological information such as behaviour and distribution of deep-sea animals (Moore and Gates 2015; Gates et al., 2017a). In the most recent developments, autonomous underwater vehicle technology has been used to identify benthic environments of conservation concern at mesophotic depths (<150 m) (Osuka et al., 2021). Overall, studies of the deep ocean using modern quantitative techniques are particularly sparse.

2.3. Nature of the deep-sea environment off Tanzania

The continental shelf of Tanzania is narrow (less than 5 km) except in the vicinity of relatively shallow Mafia (Rufiji Delta) and Zanzibar channels, where the shelf reaches widths of around 40–60 km (Masalu, 2008; Bourget et al., 2008). Beyond this, the continental slope is steep (average 1.5–2°, locally >4.5°) especially along the southern part of the coastline of mainland Tanzania and less steep near major islands and along the northern part of the coastline. Of the total area of the Exclusive Economic Zone (EEZ; 223,000 km^2), over 92% is deep sea (>200 m) and 72% is deeper than 2000 m (Masalu, 2008; Weatherall et al., 2015). The steep continental slope is incised with submarine canyons (Fig. 1, Table 1), with two canyons gazetted (Lindi and Mikindani Canyons; named in GEBCO Undersea Features Names Gazetteer) and 13 large canyons reported in global databases (Harris et al., 2011). The lower slope (>2000 m) has gentler gradients (∼0.25°) and gives way to the generally flat Somalia abyssal plain. This area has three distinct morphological features within the EEZ (Masalu, 2008): a seamount (5.1°S 41.7°E; summit depth 2250 m base depth 3125 m; Yesson et al., 2011); a ridge (near 41.5°E) extending from south of Tanzania to 9°S (axis depth 1900 m) and a deep depression inshore of the ridge (60 km diameter; up to ∼3400 m depth ∼600 m deeper than surrounding seafloor). The maximum depth within the EEZ is 4106 m (Weatherall et al., 2015). Morphological features, such as seamounts, ridges and depressions, are important because they host unique species, and alter (and often increase) the biodiversity of the area above that of the abyssal plain (Clark et al., 2009; Rogers 2018; Fernandez-Arcaya et al., 2017; Priede et al., 2013).

Table 1
Sources of data.

Parameter	Data provider	Link
Submarine Canyons	GEBCO Undersea Features Names Gazetteer	https://www.ngdc.noaa.gov/gazetteer/
Tanzanian Marine Protected Areas	World Database on Protected Areas	https://www.protectedplanet.net/country/TZ
Marine Ecoregions	Spalding et al. (2007)	https://www.marineregions.org/downloads.php
Bathymetry	GEBCO 2020 gridded bathymetry	https://www.gebco.net/data_and_products/gridded_bathymetry_data/
Offshore oil and gas wells	Tanzania Petroleum Development Corporation	http://tpdc.co.tz/deepwells.php
Tanzania Sensitivity Atlas (TANSEA)	Institute of Marine Sciences, University of Dar es Salaam	http://195.154.41.216/tansea/
Deep-sea observations	SERPENT Project	https://archive.serpentproject.com/view/countries/tanzania.html

2.4. The importance of canyons in Tanzania

Submarine canyons incise the continental shelf globally (Harris et al., 2011). In East Africa, this occurs from Somalia to South Africa and Madagascar (Bang 1968; Coffin and Rabinowitz 1988; Wiles et al., 2019). Canyons have high habitat heterogeneity, which often create hotspots for biodiversity (De Leo et al., 2010). The canyons of the KwaZulu-Natal shelf edge off South Africa have been the subject of geological study (Green and Uken 2008; Green 2011) owing, in part, to the recognition of their importance as coelacanth habitats (Venter et al., 2000). The canyons on Tanzanian continental slope are thought to be tributaries to a giant deep-sea valley 10 km wide and 70 m deep (the Tanzania channel), some 800 km from the Tanzania coast, one of the largest known submarine valleys (Bourget et al., 2008). In the North East Atlantic, studies of submarine canyons have revealed diverse epibenthic megafauna (Huvenne et al., 2012) including important cold-water coral habitats (Morris et al., 2013). Local scale processes can cause upwelling at the canyon head, which may increase productivity and support pelagic fauna (Rennie et al., 2009). In addition to providing habitat for unique faunal communities (Robertson et al., 2020), canyons play an important role in the transport of materials, and the circulation and ecological connectivity between the coastal zone to the deep sea (Fernandez-Arcaya et al., 2017; Pohl et al., 2020).

3. Deep-sea observations in Tanzanian waters

To augment the scarce environmental and biological data available for the Tanzanian deep sea, data from a recent series of expeditions carried out through the SERPENT Project (Gates et al., 2017b) are included here. These illustrate the diversity of deep-sea life that can be readily observed on or near the seafloor off Tanzania. These data were obtained using a remotely operated vehicle (ROV) and baited time-lapse camera deployments at eight deep-sea (1330–2580 m depth) hydrocarbon wells in blocks 1,2 and 4 off Tanzania (Fig. 1, Table 2).

3.1. Seabed environment

Seabed water temperature at the study sites decreased from 4.9 °C at the shallowest site (1330 m) to 2.1 °C at the deepest site (2580 m). Through the water column, temperature decreased with depth from around 28 °C in the surface waters (e.g. Moore and Gates., 2015), therefore differences among the sites reflect the increasing depth (Table 2). Dissolved oxygen was lowest (75.76 μmol l^{-1}) at the shallowest site (1330 m) and highest (162.6 μmol l^{-1}) at the deepest site (2580 m) (Table 2) reflecting reduced oxygen concentration in the water column profiles to approximately 1000 m before increasing to the seabed, similar to sites off Kenya to the north (Duineveld et al., 1997).

The seabed sediment surface at the study sites was soft, with lebensspuren such as burrows, mounds and holothurian deposits (Fig. 2 a & i). The sediment was a calcareous deep-sea ooze comprising coccoliths from Coccolithophore species *Emiliania huxleyi* (Lohmann) W.W.Hay & H.P.Mohler, 1967*, Gephyrocapsa oceanica* Kamptner, 1943, *Calcidiscus leptoporus* (G.Murray & V.H.Blackman) Loeblich Jr. and Tappan, 1978, *Discosphaera tubifer* (Murray & Blackman) Ostenfeld, 1900 and *Umbilicosphaera* sp. indet., as well as planktonic foraminifera and diatoms. Bedforms were visible on the seafloor at most sites. At Zafarani, for example, video transects crossed bedform features such as shallow channels and depressions. Such bedforms are typically formed by high

Table 2

Summary of environmental and biological characteristics of SERPENT exploration sites. The sites are ordered north (Ngisi) to south (Mzia). These sites were all visited between 2012 and 2016. A total of 6–10 ROV transects covering an average of ~4000 m^2 of seabed were carried out at each site.

Site	Ngisi-1	Kamba-1	Pweza-3	Zafarani	Lavani	Kitatange	Mzia-3	Mzia-2
Lat (deg)	−8.285	−8.359	−8.399	−9.237	−9.392	−9.58	−9.828	−9.901
Lon (deg)	40.095	40.667	40.08	40.44	40.441	40.07	40.458	40.596
Depth (m)	1330	1377	1380	2580	2400	2325	1788	1624
Distance from shore (km)	82	86	85	88	86	66	72	76
Licence Block	4	4	4	2	2	1	1	1
Seabed water temp (degrees C)	4.9	4.1	4.3	2.1	2.5	–	3.3	3.6
Dissolved oxygen (μmol l^{-1})	75.76	95.93	–	162.6	160.27	–	111.25	108.15
Seabed salinity	35.16	35.03	–	35.10	35.08	–	35.05	35.09
Sediment grain size (μm) 0–3 cm (Volume weighted mean)	462.3	–	–	76.9	65.6	–	–	189.7
Mean undisturbed total megafaunal density (ind ha^{-1}) (sd)	81 (15)	42 (20)	157 (36)	128 (20)	99 (18)	82 (56)	106 (19)	29 (0.7)

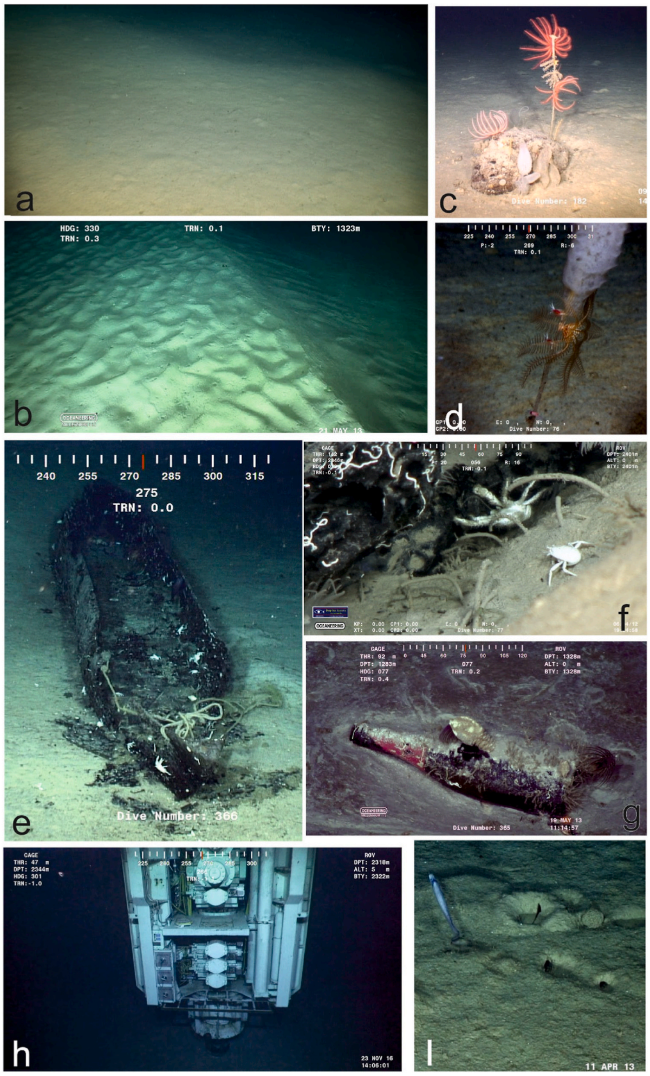

Fig. 2. Example images of deep-sea habitats and features occurring off Tanzania. a) representative soft sediment at deeper sites, b) bedforms observed at the Ngisi site, aligned northwest to southeast at approximate intervals of up to 20 m, c) hard substratum supporting a diverse assemblage of sessile invertebrates, d) biogenic structures (glass sponge stalk) supporting epifauna (crinoids), e) a sunken traditional canoe observed at 1330 m water depth, f) close up image of fauna colonising sunken wood, g) marine litter as substratum for sessile invertebrates, h) the blow-out preventer at a deep water hydrocarbon well in Tanzanian waters, i) example of bioturbation of sediments.

current events (Masson et al., 2004). The Ngisi site was notable for its distinct ridge-like bedforms (Fig. 2 b) aligned northwest to southeast at approximate intervals of up to 20 m. Sediment samples showed grain size was coarser at Ngisi than other sites (Table 2) and observations from ROV video suggested this varied over the bedform features (Fig. 2 b).

Rocks were observed on the seabed at all sites with the exception of the two deepest sites in Block 2 and were most prevalent at Pweza-3 and Kitatange-1 (e.g. Fig. 2 c). Some biogenic structures provided further habitat heterogeneity. At the deeper sites, tall, dead hexactinellid sponge stalks were common, (e.g. 57 observed at Lavani and 27 at Zafarani). At both sites the sponge stalks, likely *Monorhaphis* sp. indet, provided structures to raise invertebrates including Amathillopsid amphipods (Lorz and Horton, 2021) and crinoids above the seafloor facilitating feeding opportunities (Fig. 2 d and 3 b).

Occasionally items of litter were encountered on the seabed e.g. aluminium cans, rope and glass, which also provided a surface for epifaunal organisms to colonise (Fig. 2 g). A remarkable encounter at Ngisi-1 was the remains of a dugout canoe traditionally used by artisanal fishers in East Africa (Fig. 2 e). Naturally occurring terrestrial wood and other vegetation were observed at most sites and supported deep-sea organisms such as squat lobsters (Fig. 2 f), reflecting observations of terrestrial vegetation in deep-sea trawls in the Mozambique Channel in the *Galathea II* expedition (Bruun et al., 1956).

3.2. Deep-sea fauna

The ROV observations revealed a diverse community of deep-sea organisms (Figs. 3 and 4). A total of 116 morphospecies were recorded in quantitative video surveys across the eight study sites comprising one category for protozoans (Xenophyophorea), 85 metazoan benthic megafaunal invertebrates (e.g. Fig. 3), seven benthopelagic invertebrates and 23 fish (e.g. Fig. 4). Observations from baited time-lapse camera deployments at a subset of the sites revealed scavenging organisms that perform an important ecosystem function in the redistribution of nutrients in the deep sea. These included invertebrates such as lithodid crabs (Fig. 2n) and fishes, primarily deep-sea sharks (*Centrophorus* sp., Fig. 4j), Chimaera (*Hydrolagus* sp. Fig. 4n) and macrourids (Fig. 4s & t). Total abundance of organisms observed in quantitative video transect surveys outside visible seabed disturbance from hydrocarbon drilling (including large protists, Xenophyophorea) varied among sites from 29 ind ha^{-1} at Mzia-2 in Block 1 to 157 ind ha^{-1} at Pweza-3 in Block 4.

Variations in habitat type influenced the communities observed. The soft sediment supported motile deposit feeding echinoderms such as holothurians (Fig. 3u, v, w & x) and echinothuriid sea urchins (Fig. 3s & t). It also provided habitat to sessile organisms such as xenophyophores (Fig. 3a) and hexactinellid sponges (Fig. 3b, c, d & e). Hard substratum was less frequent but supported sessile epifaunal organisms such as sponges and soft corals (Fig. 2c).

At a broader scale, there were patterns in species present between sites (Fig. 5). Some taxa, such as a morphotype of hexactinellid (glass

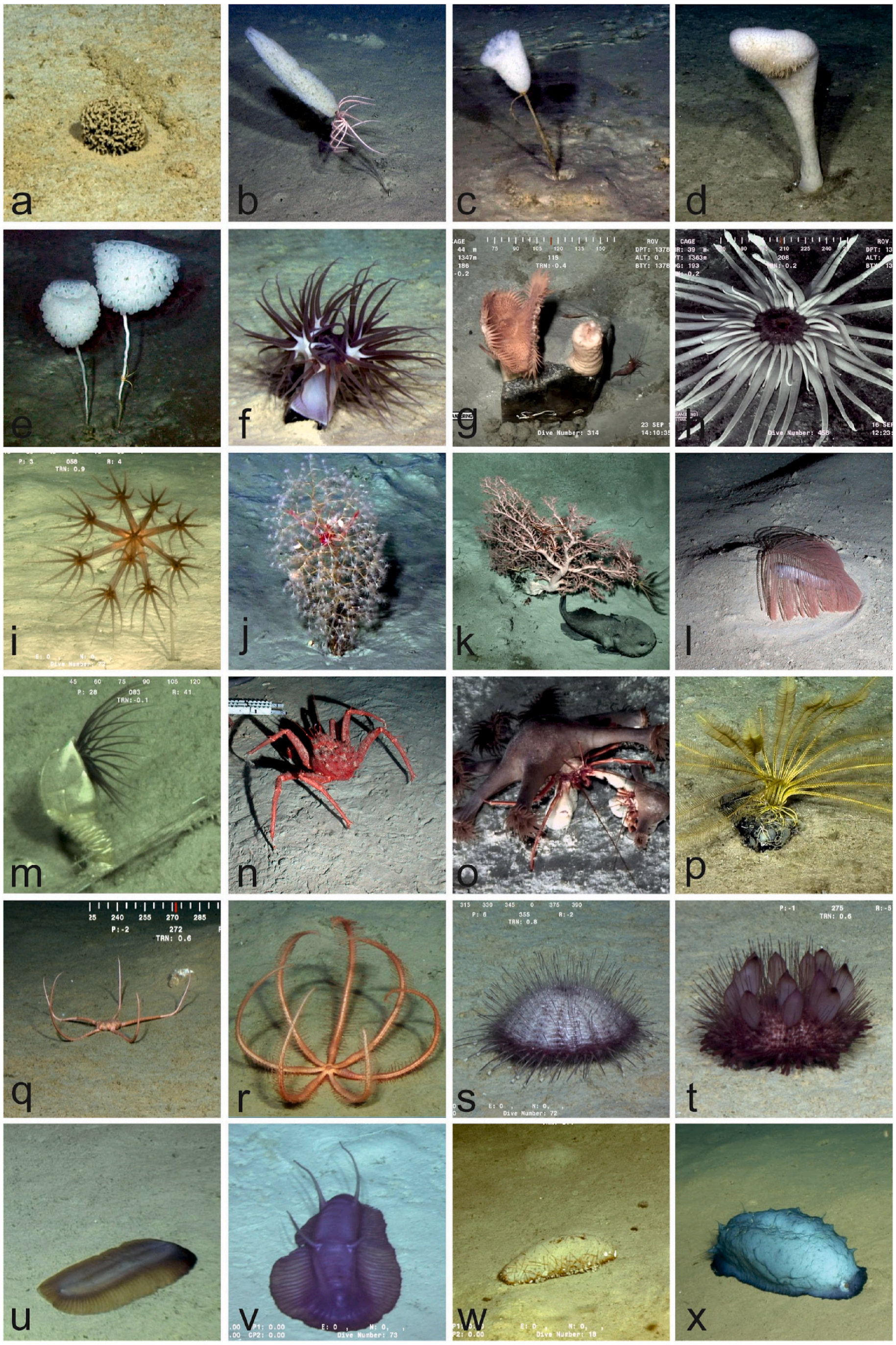

Fig. 3. Example images of deep-sea invertebrates occurring off Tanzania. Xenophyophores: a) *Syringammina* sp., Hexactinellid sponges: b) *Monorhaphis* sp., c) *Hyalonema* sp., d) *Platylistrum* sp., and e) *Saccocalyx* sp., Cnidarians: f) *Actinernus* sp., g) venus flutrap anemone, likely *Actinoscyphia* sp., h) a large (30–50 cm) unidentified anemone, i) the pennatulid (sea pen) *Umbellula* sp., j) a chrysogorgiid soft coral with associated chirostylid decapod crustacean, k) bubblegum coral, likely *Paragorgia* sp. with "blobfish" *Psychrolutes* sp. l) antipatharian "black coral", *Schizopathes* sp. Crustaceans: m) barnacle (Scalpellidae), n) stone crab *Neolithodes* sp. attending baited camera experiment, o) two *Parapagurus* sp. hermit crabs with associated *Epizoanthus* sp., Echinoderms: p) Commatulid crinoid *Glyptometra* sp., q) unidentified ophiuroid (brittle star), r) Brisingid sea star, s) *Tromikosoma* sp. t) *Phormosoma* sp., u) and v) *Benthodytes* sp., w) *Mesothuria* sp., x) *Benthothuria* sp.

sponge) *Hyalonema* sp., (observed at 7 of the 8 sites) and a large penaeoid decapod, likely *Cerataspis* sp. (all locations) were shared across multiple sites. Others were more specific. The unusual "grid-eye" fish *Ipnops* sp. (Fig. 4w) was encountered at all sites in Block 1 and 2 but not observed at the three sites in Block 4, while *Umbellula* sp. (Fig. 2i) was only encountered at the three deepest sites. Broadly there were similarities between sites in the same block or at similar depth. Three of the four sites in Block 1 and Block 2 were dominated by xenophyophores. Examination of specimens indicated they were *Syringammina* sp. Two of the three sites in Block 4, including Pweza-3 (the site with greatest faunal abundance), were dominated by white coiled corals, likely of the genus *Radicipes* (Fig. 5).

In the western Indian Ocean the seasonal monsoon drives phytoplankton blooms (Lévy et al., 2007). Variation in export flux can drive seasonal and inter-annual changes in deep-sea benthic megafaunal communities (Bergmann et al., 2011; Billett et al., 2001) but temporal changes were not assessed here. While this dataset is limited it does suggest that there is variation in the megafaunal assemblages offshore Tanzania at different spatial scales.

4. Societal importance of the open ocean and deep sea in Tanzania

Anthropogenic use of the deep WIO is increasing. For Tanzania these uses are primarily for fisheries, mineral resources and conservation. Further offshore, in areas beyond national jurisdiction, industries such as deep-sea mining (Jones et al., 2020) may also impact Tanzanian waters (Popova et al., 2019). The impacts of these activities in the

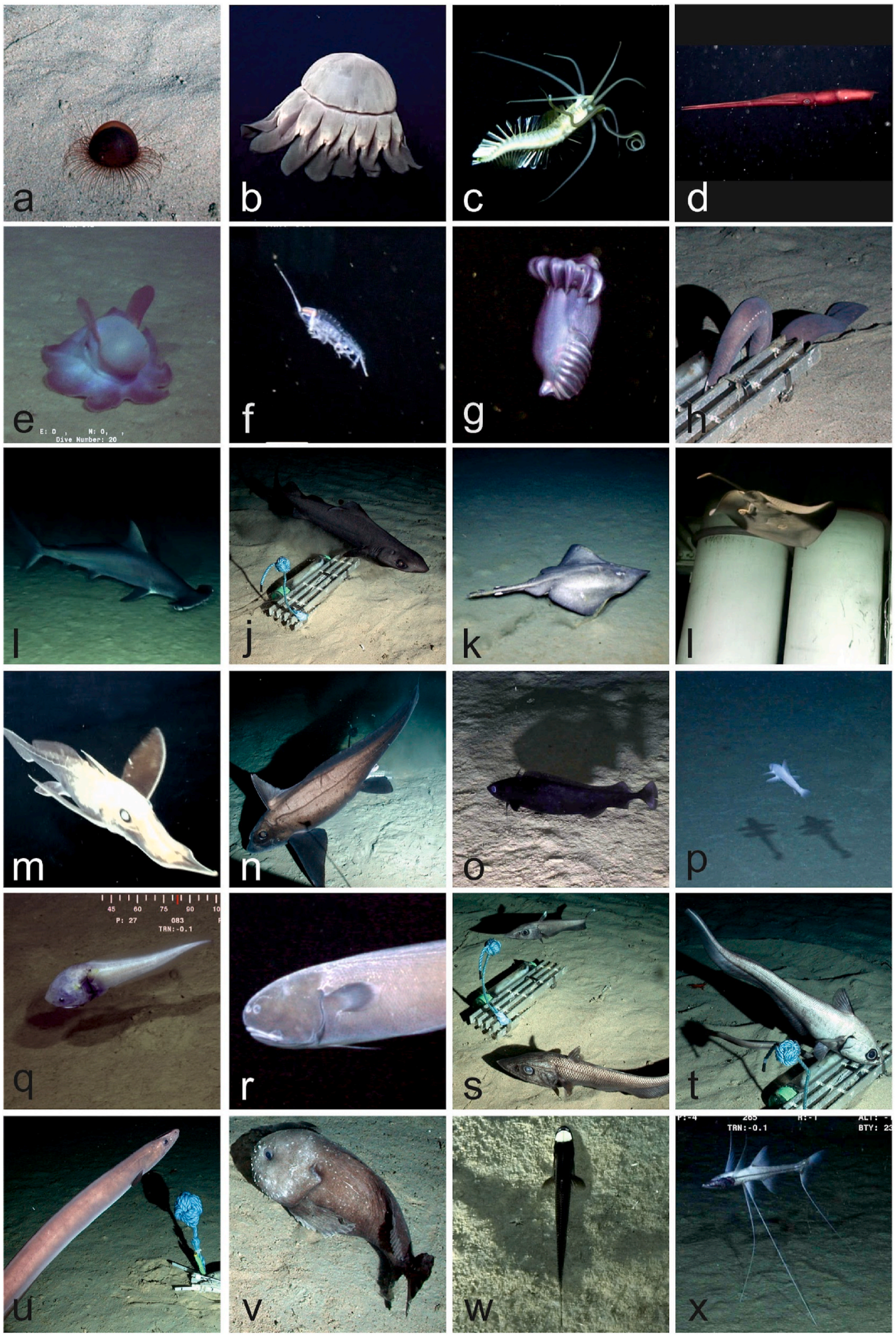

Fig. 4. Example images of fishes and benthopelagic invertebrates in the deep sea off Tanzania from in situ ROV video and baited time-lapse camera observations; a) small jellyfish frequently observed close to the sediment, likely *Benthocodon* sp. b) Large unidentified jellyfish, c) "Squid-worm" *Teuthidodrilus* sp., d) Whiplash squid (*Echinoteuthis* sp.), originally collected as part of the *Valdivia* expedition to the Indian Ocean, e) Dumbo Octopus (*Grimpoteuthis* sp.), pelagic amphipod *Cystosoma* sp., g) swimming holothurian *Enypniastes* sp., h) Hagfish (*Eptatretus* sp.) attracted to a baited camera experiment, i) deepest known observation of Scalloped Hammerhead (*Sphyrna lewini*), j) deep-sea shark *Centrophorus* sp. attracted to baited camera experiment, k) deep-sea skate, *Bathyraja* sp., l) unknown species of legskate observed near a subsea structure at a hydrocarbon drilling site (Family Anacanthobatidae), m) Longnose chimaera (Family Rhinochimaeridae), n) Ghost shark, *Hydrolagus* sp. attracted to a baited camera, o) *Antimora rostrata*, an occasional visitor to baited camera experiments, p) deep-sea lizardfish *Bathysaurus* sp. just before landing on the seabed, q) An ophidiiform or cusk eel, the "Bony-eared assfish" *Acanthonus armatus*, r) another cusk-eel, likely *Bassozetus* sp., s) one of several species of macrourid observed at baited camera experiments (likely *Coelorinchus* sp.), t) another macrourid, *Coryphaenoides* sp., u) Synaphobranchid (Cutthroat) eel, v) Blobfish (*Psychrolutes* sp.), w) Grideye (*Ipnops* sp.), x) Tripodfish *Bathypterois* sp.

Tanzanian EEZ have not been investigated but if activities expand the potential for impacts increases. Effective and integrated spatial management approaches can help limit the effects of these and reduce the potential cumulative impacts of multiple activities in the same area (Stephenson et al., 2019), involving all stakeholders in the management process.

4.1. Fisheries

In Tanzania 21% of a total population of 58 million (World Bank, 2019) resides in the coastal zone. An estimated 50,000 people are engaged in some form of marine harvesting (van der Elst et al., 2005), most of whom are engaged in artisanal fishing close to shore. Artisanal and subsistence fishing is dominated by local and migrant fishers (Wanyonyi et al., 2016) but there is limited data on fishing effort for these fisheries (Temple et al., 2018). Although shallow water, these small pelagic fisheries (<200 m depth) can be sustained in places by upwelling from deeper waters, such as the Pemba channel (e.g. Sekadende et al., 2020; Painter et al., 2021).

Total hours offshore fishing effort by all vessels with automatic identification systems (AIS) in 2016 (Global Fishing Watch, 2021; Kroodsma et al., 2018) indicates activity in large parts of the Tanzanian EEZ, albeit in low density. Broadly there is some overlap with areas of other offshore activity such as oil and gas exploration (Supplementary Fig. 1). Tuna fishing is important to food security in Tanzania (Chassot et al., 2019), and is undertaken within the EEZ, though the deep-water potential for the fishery is largely unknown. The local fleet, mostly sail-powered small vessels, is restricted to operating close to shore. Open

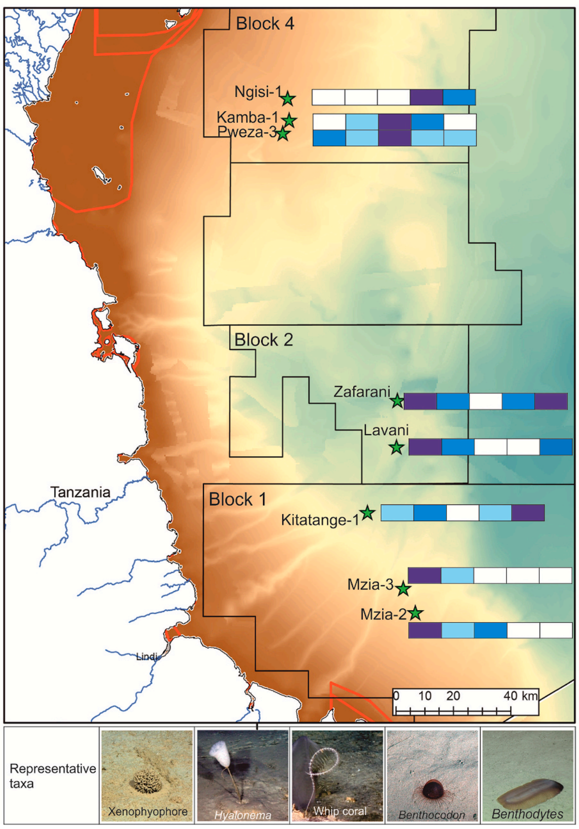

Fig. 5. Map of the southern part of the Tanzanian EEZ showing relative abundance of selected shared species at the observation sites. Order of images at the bottom of the map represent the bars at each site. The colour of each square represents relative abundance: Purple = most common, dark blue = common, light blue = uncommon, white = absent. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

ocean fisheries, such as those for tunas and other highly migratory species, are of high value but largely exploited by international fleets (van der Elst et al., 2005). The Deep Sea Fishing Authority is responsible for the management and development of tuna fisheries resources in both mainland Tanzania and Zanzibar, for the issuance of licences, carrying out surveillances and combating illegal, unreported and unregulated fishing.

The importance of the deep-sea fisheries resources to Tanzania are reflected by the recently enacted Deep Sea Fisheries Management and Development Act of 2020 (repeals the Deep Sea Fishing Authority Act of 1988 and its 2017 amendments), which is designed to improve the administration of the DSFA and fisheries conservation. This new law, which will also be applied in Zanzibar, aims to introduce fisheries research in the EEZ and implement regional conservation and management measures (United Republic of Tanzania, 2020).

Fishing for deep-water demersal fishes such as the orange roughy (*Hoplostethus atlanticus*) and the black orio (*Allocytus niger*) has occurred in the WIO, but these were focussed on the Madagascar Ridge (south of Madagascar) in depths of 500–1500 m. These deep-water fisheries are highly unsustainable and collapsed after less than 2 years (van der Elst et al., 2005). Mozambique and South Africa also have established trawl fisheries for deep-water prawns (*Haliporoides triarthrus, Aristeus virilis, Aristeus antennatus* and *Aristaeomorpha foliacea*), langoustines (*Metanephrops mozambicus*), spiny lobsters (*Palinurus delagoae*) and deep-sea crabs (*Chaceon macphersoni*) (Everett et al., 2015). Longstanding surveys have shown that species of commercially valuable deep-water (100–600 m depth) prawns (*Heterocarpus woodmasoni, Penaeopsis balsi, Penaeus marginatus*) and spiny lobster (*Linuparus somniosus*) are the most abundant crustaceans off Tanzania (Birkett, 1978; Everett et al., 2015; Iversen et al., 1984; Sætersdal et al., 1999). However, it is thought that these deep-water crustacean species could not support a viable fishery off Tanzania at present (Everett et al., 2015).

There is increasing pressure on fish stocks throughout the region, including open-ocean species. Declines in open-ocean fish abundances may be exacerbated by climate-related fluctuations, for example those associated with ENSO events (Marsac and Le Blanc, 1999). Marine fisheries accounted for approximately 0.25% of GDP in 2018, while marine and freshwater fish provided 30–60% of protein consumed, with higher contributions of marine fish to human diets in coastal communities (Sekadende et al., 2020). Overfishing and destructive fishing methods have reduced demersal and reef fisheries, with increased focus on small pelagic fisheries.

4.2. *Oil and gas industry*

Tanzania has a history of onshore hydrocarbon drilling dating back to 1956. Offshore drilling began in shallow water in 1973 but most offshore drilling in Tanzanian waters has taken place in deep water since 2010 (Bishoge et al., 2018). The Tanzanian seabed is divided into licence blocks with most deep-water effort focussed on Blocks 1, 2 and 4 in the south of the country's waters (Bofin and Pedersen, 2017, Fig. 1). This deep-water exploration has resulted in significant offshore gas finds, contributing to the total Tanzanian reserves estimated at 57 trillion cubic feet (Choumert-Nkolo 2018). Similar resources have been explored in Kenya and Mozambique (Demierre et al., 2015). The discovery of offshore gas reserves has potential to support economic growth in the region and change the overall mix of energy generation. In Tanzania, most domestic energy is supplied by wood burning (Lukonge and Cao 2019) and low numbers have access to electricity (37% in 2018, IEA, 2019). A long-running plan for LNG export from Tanzanian deep water is still ongoing and will likely include significant lengths of submarine pipeline extending from shore to deep water to the south of the country.

Key future government targets and measures include reduction of greenhouse gas (GHG) emissions by 10–20% by 2030 and an increase in electricity generation capacity from 1500 MW in 2015–4910 MW. Currently, gas provides more than half of power generation and is expected to expand, with the remainder from hydropower and oil, the latter used mostly for back-up generators and road transport. Expansion of hydropower and solar photo-voltaic, and potential contributions from geothermal, are envisaged as the main renewable sources in future (International Energy Agency, 2019).

4.3. *Conservation and ecotourism*

The WIO is internationally important for its populations of the coelacanth, *Latimeria chalumnae* (Obura et al., 2019). In Tanzania the scientific and conservation importance of *L. chalumnae* is recognised through the Tanga Coelocanth Marine Park. Coelacanth are large (up to 2 m long), long-lived, critically endangered fish that represent an ancient lineage of lobe-finned fishes (Nikaido et al., 2011). Coelacanths typically live in relatively deep water (100–300 m), water temperatures between 16.5 and 22.8 °C, in underwater caves on steep, rocky cliffs, emerging only at night to feed (Fricke and Hissmann 2000; Fricke et al., 1991). There is evidence for a genetically distinct northern Tanzania population of *L. chalumnae*, different to the southern populations which are more related to those in Comoros (Nikaido et al., 2011). Isolated populations are at greater risk of extinction (Arthington et al., 2016). Bathymetric study of the region has revealed potential coelacanth habitat exists more widely than they are currently reported (Green et al., 2009).

In Tanzania ecotourism is focused on terrestrial national parks, reserves and protected areas but there is also recognition of the value of marine protected areas in driving tourism (Mgonja et al., 2015). Close to the coast, coral reef MPAs have potential and offshore, Tanzania supports aggregations of marine megafauna such as whale sharks, manta rays and whales that are important internationally (Rohner et al., 2020). They support a developing marine ecotourism industry, particularly as deep-water sites are accessible close to shore. In the WIO whale sharks (*Rhincodon typus*) demonstrate high site fidelity (Prebble et al., 2018) enabling the reliable sightings needed to sustain tourism. Tour boat numbers increased between 2012 and 2018 at an important *R. typus* aggregation site, Kilindoni Bay off Mafia Island (Rohner et al., 2020). Elsewhere in the Indian Ocean whale shark tourism generates high economic value (Huveneers et al., 2017) and is increasingly well developed at other aggregation sites on the east African coast (Tibiriçá et al., 2011). The increasing tourism demonstrates a requirement for enforceable spatial management measures to preserve the aggregation and sustain the associated tourism (Rohner et al., 2020). Local aggregation sites provide the opportunity for tourism interactions, but *R. typus* makes use of open ocean environments. When in oceanic waters, *R. typus* spends ~95% of their time in epipelagic waters (depths of >200 m), but do make excursions into very deep water (max >1900 m) (Tyminski et al., 2015). In the WIO *R. typus* tagged in Mozambique aggregation sites have been documented crossing the Mozambique Channel and making regular dives to >200 m and tags being released east of Madagascar (Brunnschweiler et al., 2009). Thus, including these open ocean areas in an effective spatial management strategy may be essential to supporting ecotourism.

5. Anthropogenic impacts to the deep sea relevant to Tanzania

Anthropogenic activities can impact the deep-sea environment both directly and indirectly (Ramirez-Llodra et al., 2011; Cordes et al., 2016). As deep and shallow water environments are connected, impacts in one may transfer or have subsequent consequences on the other. Impacts and connections between habitats are important considerations for marine spatial planning. Here we describe impacts in relation to anthropogenic activities that occur in the deep sea in Tanzania.

5.1. *Impacts of oil and gas activities*

The environmental impacts of the deep-water offshore hydrocarbon industry are relatively well understood globally. Impacts range from local scale impacts on deep-sea ecosystems to the effects of major oil spills that could affect large areas (Cordes et al., 2016). Noise and light from ongoing activities may impact deep-sea areas. There are also changes to the use of marine areas such as increased vessel activity, construction of offshore infrastructure (McLean et al., 2017) and development of coastal infrastructure. The effect of these pressures on the ecosystems off Tanzania are not well known and should be the subject of future research as the industry develops.

Oil releases may occur from infrastructure associated with drilling and production or shipping, and releases in the deep sea can impact both the deep-sea environment and shallow water (McClain et al., 2019; Reuscher et al., 2020; Fleeger et al., 2019). The proximity of offshore oil and gas wells to canyons and the potential for spills and releases to move through the canyons has been identified (Fernandez-Arcaya et al., 2017). To help identify and respond to these risks, marine spatial planning approaches have been used in shallow waters in Tanzania. The Tanzania Sensitivity Atlas (TANSEA) highlights areas of societal and conservation concern and can be used alongside oil spill modelling and situational awareness to support emergency spill response. Nothing similar exists for the deeper ocean.

More routine impacts of oil and gas drilling include the deposition of drill cuttings and drilling mud forming a cuttings pile. Field observations at the hydrocarbon wells in the southern Tanzanian licence blocks showed evidence of smothering of the seabed sediments following the drilling operations. This is comparable with observations in the North East Atlantic (e.g. Gates and Jones 2012). The nature of the disturbed seabed at most sites was sediment with a coarser grain size overlying the background sediment. Ngisi was an exception, where the coarse background sediment particle size was larger than the overlying disturbance. Disturbed sediment had elevated levels of constituents of the drilling mud (e.g. barium) that reduced with distance from the well. The study revealed evidence of downslope transport of drill cuttings and drilling mud. For example, Mzia-3 indicated the furthest extent of seabed coverage by cuttings was to the North West, this was supported by evidence from sediment samples. Bathymetric data indicate a steep slope of 7.1° to the NW of the well site, which is near the head of a submarine canyon where downslope currents would be expected. Such disturbances typically lead to reductions in faunal numbers and biodiversity (Cordes et al., 2016).

5.2. *Impacts of fishing*

Deep-sea fishing has been increasing as stocks closer to the coasts are depleted and technologies have advanced (Victorero et al., 2018). In European North East Atlantic waters below 200 m depth, deep-sea trawling was the greatest anthropogenic impact to benthic environments by an order of magnitude (Benn et al., 2010). The consequences of benthic trawling, particularly on continental margins, can have wide reaching effects on ecosystem structure and functioning at a broad scale (Pusceddu et al., 2014). Large areas of soft sediment environments on the continental margin (e.g. >200 m depth) may be repeatedly trawled for crustaceans and fin fish (e.g. Bueno-Pardo et al., 2017) including in the Western Indian Ocean (Everett et al., 2015). This can impact the benthic density and diversity (e.g. Buhl-Mortensen et al., 2015). Important habitats such as seamounts or other cold-water coral habitats support greater abundance of fishes and may be subject to trawling (Huvenne et al., 2016; Baco et al., 2019). A major concern for Tanzania is the possible fragility of the unknown benthic habitats in deeper waters, particularly the potential for damage associated with deep-sea trawling (Clark et al., 2016).

The trawling fishery for deep-sea shrimps and other decapods in Tanzania as in many developing countries, has not been subject to management actions. In Brazil where new deep-water fishing grounds were discovered off the southeast coast, such fishing had been regarded by the Brazilian fishing authorities as exploratory (Pezzuto et al., 2006). Nevertheless, as the fleet rapidly increased and concentrated in localised profitable areas, a major concern arose regarding uncertain impacts on species and stocks that were potentially highly susceptible to fishing mortality and their respective benthic habitats (Hastie, 1995; Roberts, 2002; Large et al., 2003). Precautionary recommendations were made for an immediate interruption of the entry of new vessels in the fishery accompanied by a rotating harvest strategy, to distribute effort along the Brazilian EEZ (Pezzuto et al., 2006). A similar strategy was in place in Tanzania for many years for the inshore prawn trawler fishery, particularly in the Rufiji-Mafia Channel, which eventually collapsed because of overexploitation (Semba et al., 2016).

The industrial long-line fishery is represented by a small number of long-liners from outside Tanzania (Poseidon, 2014) which mostly set lines in deeper water for sharks and larger teleost species, usually away from the coastal reefs, though exceptions have been reported. Nevertheless, physical damage to the seabed habitats is likely to take place when lines are bottom-set, whether among shallow water coral reefs or deeper reefs.

Pelagic long-line fishing for billfish and tuna is the most widespread fishery in open-ocean systems (Worm et al., 2005), and also the source of most discards of bycatch across ocean basins, together with midwater pelagic trawling and purse seining (Crespo and Dunn, 2017). Oceanic bycatch from long-lining includes sea turtles, seabirds, marine mammals and sharks, some of which include threatened or protected species. This threat to bycatch species has led to the development of a series of potential mitigation measures aimed at maintaining viable commercial fisheries. Examples of measures include deeper setting of lines, use of circle hooks and changes to soak time or duration (see Swimmer et al., 2020). The paucity of data on long-line catches in Tanzania waters prevents any analysis to be made on bycatch species or numbers landed.

5.3. Impacts from activities in coastal and shallow marine environments

Pollution and debris are found in the coastal zone and shallow water of Tanzania, including sedimentation from catchment runoff, pollution from shipping, sewage and solid waste from human coastal settlements, and fertilizer from agricultural activities (Masalu 2000). Some of these pollutants are transferred directly to the marine environment from the shore, and others via riverine inputs to the sea, and may be transported into the deep sea. In addition, impacts from activities on the continental shelf, such as sediments suspended by fishing activity (Puig et al., 2012), can be transferred to the deep sea. Submarine canyons, particularly on narrow continental shelves enhance current flow downslope, acting as conduits of pollution and litter from coastal areas to the deep sea (Fernandez-Arcaya et al., 2017; Pohl et al., 2020). The relative importance of such transfers will be regionally dependent (UNEP, 2016).

Plastic is increasingly found in the deep sea, both in pelagic and benthic environments (Woodall et al., 2014; Pabortsava and Lampitt 2020), with potential impacts to fish (Wieczorek et al., 2018) and deep-sea organisms (Courtene-Jones et al., 2017). The transfer of material via canyon systems can lead to significant accumulations of plastics, in the canyons themselves, where high concentrations of litter and pollution have also been noted (Schlining et al., 2013; Pham et al., 2014), and on the deep seafloor (Galgani et al. 1996, 2000). Plastic has been observed in the coastal environment in Tanzania (Shilla 2019), but no studies on such impacts in the Tanzanian deep sea are available.

5.4. Impacts from climate change

Climate change is predicted to impact the Western Indian Ocean through warming, increased marine heat waves, reduced productivity and reduced connectivity in nutrient supply to the East African coast (Jacobs et al., 2021). Changes in the surface ocean can also result in impacts in the deep-sea (Jones et al., 2014), and may also alter impacts from other anthropogenic activities. Impacts of climate change have been studied in coastal and shallow water environments in Tanzania, for example for coral reefs (Ateweberhan and McClanahan 2010; McClanahan et al., 2009; Obura 2005), and mangroves (Hamad et al., 2019), with further impacts to coral reef fisheries (Cinner et al., 2012) and shallow pelagic fisheries (Sekadende et al., 2020). Climate change is anticipated to alter water flow in river basins in Tanzania (Dessu and Melesse 2013; Lalika et al., 2015), and to alter agricultural yields and practises (Rowhani et al., 2011), which could alter pollution transferred from land to the coastal ocean, and its onward transport to the deep sea. Marine reserves have benefits that may have a role in the mitigation of the impacts of climate change through carbon sequestration and storage, and help to promote adaptation through increased ecological resilience and protection of ecosystem services (Roberts et al., 2017), at least for shallow waters (Blue Carbon). To maximise these potential benefits requires careful planning of MPA design and location and management to ensure carbon sequestration and long-term integrity of carbon storage (Howard et al., 2017). These will be important when considering the deep sea in marine spatial planning (Levin et al., 2020).

6. Steps toward the inclusion of the deep sea in marine spatial planning in Tanzania

Marine Spatial Planning for the Tanzanian EEZ is in the early stages of development. Important steps toward MSP (Ehler and Douvere, 2009) have been accomplished using existing knowledge but they have a coastal focus. These include identifying needs and establishing authority, defining goals and objectives and organizing stakeholder participation. The ministry of Blue Economy and Fisheries in Zanzibar and the Ministry of Livestock and Fisheries has established teams to map the distribution and conditions of coastal resources and activities. Geographical information systems are in development that will host spatial data obtained during mapping of Environmentally Sensitive Areas. The National Spatial Data Infrastructure for Integrated Coastal and Marine Spatial Planning in Zanzibar (ZAN-SDI) (Khamis et al., 2017) and the Tanzania Marine Spatial Data Infrastructure at National Environmental Management Council with technical assistance from Institute of Marine Science have been established.

Establishment of information protocols, data collection and analysis, extent of expected impacts in order to preserve ecosystems and avoid conflicts, and establishment of an information communication protocol (e.g. Tanzania marine and coastal atlas) as well as education and awareness programs are incomplete because of a lack of resources (personnel, financial and facilities). As more marine spatial information is revealed and resources mobilised, deep-ocean information will be linked with shallow water activity locations through MSP, interfaced with GIS-based thematic maps and internet-based atlases. This will be followed by analysis of existing conditions, including findings and recommendations from this review.

6.1. Biogeography/biodiversity and marine spatial planning

The observations presented here demonstrate variation in the Tanzanian deep-sea ecosystem, each site with some unique aspects to their biodiversity (Table 1, Figs. 2 and 5). This variation was observed at the scale of oil and gas license blocks. Morphological features in the Tanzanian EEZ, including canyons, ridges, depressions and a seamount, suggest that further variation exists at a broader scale. The hydrographic variability, steep slopes and exposed hard substratum associated with such features likely provides habitat for a variety of deep-sea faunal communities. At a finer scale, increased faunal diversity associated with habitat heterogeneity such as hard substratum, biogenic structures and transient food falls such as wood from terrestrial sources. This variety of ecosystems illustrates the heterogeneity of the Tanzanian deep sea, an important consideration when integrating the deep sea in to MSP.

Regional biogeographies indicate different provinces may be represented in the Tanzanian EEZ (e.g. Longhurst, 1998; Spalding et al., 2007), which should be considered in MSP. The data presented here were not designed with the intention of ground truthing regional biogeographies, and are not sufficient to do so. However, such regional patterns are supported by oceanographic patterns, particularly the position of the East African Coastal Current (Painter, 2020). Models suggest strong connectivity between coastal areas and those further offshore (Maina et al., 2020), which are highly seasonally variable (Popova et al., 2019). Depth-related zonation of communities is suggested from observations presented here, as occurs globally (Carney, 2005). Knowledge from other areas suggests that the morphological features identified will be important to regional heterogeneity, connectivity between shallow and deep waters, and understanding human impacts to these features and the Tanzanian deep sea more generally. This information should be included in MSP. To better understand the variety of deep-sea habitats, further study should also target points in shallower and deeper water, in habitats with differing seabed characteristics (e.g. hard substrate) and closer and further from shore.

Although there is considerable uncertainty and knowledge gaps about biological diversity in the deep WIO off Tanzania, this lack of knowledge should not preclude the inclusion of the deep sea in MSP, as some techniques could identify important areas with existing data. For example, bathymetric/habitat mapping could be used to identify areas of particular types of habitat, which could be overlain with spatial information about users, using an ecosystem services approach (e.g. Dove et al., 2020; Manea et al., 2020; Outeiro et al., 2015). In the event that data are not available or data from elsewhere suggest the importance of a habitat type, a precautionary approach can be taken (Cooney, 2006).

Decision-making then favours conservative environmental outcomes over exploitation, in combination with data from other similar habitats, industries and locations or global tools (e.g. Martin et al., 2015) in preliminary MSP, until sufficient data can be collected. In future, regular reviews and revisions of the MSP could allow it to evolve to include the best available data. However, the evaluation of recent data hinges on its accessibility to regulators, in addition to information about current and potential future uses and their impacts.

6.2. *Potential for conflict between users and uses of the deep sea in Tanzania*

Conflicts between users and uses of the environment are often obvious in the coastal zone and shallow water. Previous conflicts in the use of coastal and marine resources in Tanzania have been documented between tourism, conservation, fisheries, aquaculture, seaweed cultivation, sand and mineral mining, shipping, agriculture and terrestrial industry related to pollution and discharges, and increased pressures on coastal resources from human population increases (Masalu 2000; Khamis et al., 2017; Staehr 2018). Conflicts were also noted within sectors, such as between artisanal and commercial fisheries (Masalu 2000), between communities, such as local communities and migrant fishers (Wanyonyi et al., 2016), and between government agencies and departments that regulate these resource users (Masalu 2000). These are exacerbated by wider pressures, such as climate change and invasive species (Staehr 2018).

Conflicts over resource use also exist for deep-sea habitats, and include many similar types of uses. Potential conflicts include between stakeholders that directly interact with the deep sea, such as deep-sea fisheries, oil and gas development and conservation. For example, oil and gas impacts may affect fish and shellfish populations, catches and the sustainability of a fishery, while noise impacts from this activity may alter organism movement and communication. Conversely, deep fishing equipment could damage oil and gas infrastructure. Supplementary Fig. 1 indicates some potential use of similar marine areas by both fisheries and offshore hydrocarbon industry. Conflicts are also likely between these direct users of the deep sea and users of coastal and shallow marine areas, from which indirect impacts originate. Examples include pollution from agriculture, terrestrial industry, shipping and increased coastal human population (e.g. sewage and solid waste) impacting deep fisheries and conservation areas (e.g. MPAs). Conversely, tourism may be based around marine organisms that move between the shallow and open ocean, such as turtles, sharks or cetaceans, where they may be adversely impacted by offshore development, for example. Again, conflicts may be exacerbated by more generalised impacts, such as climate change.

Marine spatial planning in Tanzania has addressed conflicts between users and uses of the marine environment in coastal and shallow marine areas (e.g. Käyhkö et al., 2019; Masalu 2000). Thus, robust marine spatial planning that includes the deep sea would also involve the resolution of such conflicts, for example by coordination or zonation of users, through consultation with stakeholders. It would also consider temporal aspects and exacerbation by wider impacts, such as climate change.

6.3. *Stakeholder engagement*

In an analysis of success and failure of marine protected areas globally, stakeholder engagement was consistently identified as the most important factor affecting success or contributing to failure (Giakoumi et al., 2018). Stakeholder engagement is therefore a key step toward successful MSP that must run through the process, and methods will vary depending on many factors (Ehler and Douvere, 2009). The deep sea presents particular challenges to effective stakeholder engagement because of its remote nature and high cost of access limiting those operating in there. In Tanzania, like most parts of the world, there is a requirement for increased capacity for local scientists to engage with their deep-sea environments. Initiatives are underway to encourage this (Howell et al., 2020), including through the UN Decade of Ocean Science for Sustainable Development 2021–2030. Greater engagement with industries that operate in deep water could help identify important habitats if data were made publicly accessible (Levin et al., 2019). In the case of shallow waters this has already taken place to a certain extent with the development of the ZanSEA and TanSEA sensitivity Atlas programmes.

7. Recommendations

1) The deep sea should be included in marine spatial planning and environmental management in Tanzania. In the first instance the features and habitats identified in this review can be included in MSP documentation. This should be followed by the designation of MPAs that include deep water, and the consideration of deep-sea users and uses, and potential conflicts between them, when licensing or zoning activities. Marine spatial planning in Tanzania should consider the connections between the coastal zone, shallow water and deep marine habitats. It should be integrated across users, as has been done for the implementation of Coastal Zone Management in Zanzibar (Käyhkö et al., 2019). It should also integrate across existing marine spatial planning work, and with regional marine spatial planning activities, such as those in neighbouring countries to address shared uses (e.g. Chassot et al., 2019), as has been done for marine habitats in west Africa (Finke et al., 2020; Kirkman et al., 2019).
2) More data are needed on the Tanzanian deep sea to inform management. These data could be gleaned from multiple sources, and combined and synthesized for a complete understanding of the area. Use of relevant data from other parts of the world could be used to indicate where the precautionary principle should be applied, e.g. where known features might indicate valuable resource or areas of interest for conservation. Industry (such as oil and gas) could make non-proprietary data available to enhance knowledge of Tanzanian marine environments (e.g. Levin et al., 2019); this could be required by regulators. These data could include bathymetry, photographs and video, samples and specimens, or analyses and results from such studies. Dedicated deep-sea research programmes could also provide data, particularly on areas not covered by industry, or focusing on specific habitats, such as canyons or seamounts, or in MPAs. Data should meet FAIR Principles (Findability, Accessibility, Interoperability, and Reusability) to ensure reuse and future value if possible (Wilkinson et al., 2016).
3) Increased capacity building and public education regarding the deep sea is needed to assist government and regulatory authorities in making sound decisions, to increase research into the Tanzanian deep sea and its connections to the coastal zone, and to inform stakeholders and the public of its importance. Similar arguments for capacity building and public education about coastal and shallow water environments, and understanding the connectedness of these habitats have been made (Masalu 2000; Khamis et al., 2017), so initiatives could be expanded to involve all marine habitats.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ocecoaman.2021.105703.

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