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Ocean and coastal governance in the Western Indian Ocean

Guest Editors | Louis Celliers and Shannon Hampton

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Ocean and coastal governance in the Western Indian Ocean

The West Indian Ocean Governance and Exchange Network (WIOGEN) is a MeerWissen Partnership Project, funded by the German Federal Ministry for Economic Cooperation and Development (BMZ), which supports Africa-German cooperation in marine sciences. WIOGEN is a networking platform that aims to contribute to the enhancement of the science to policy framework in the Western Indian Ocean (WIO) region. WIOGEN strives to be a trans-disciplinary coalition of researchers and policy makers working in academia, civil society and government in the region. It aims to complement other regional marine science networks by focusing on ocean governance and by bridging the social and natural marine sciences.

Ocean governance is increasingly recognised as a lever for sustainability, and one of the goals of WIOGEN is to increase awareness of ocean governance through training events and a virtual conference that was held in October 2021. There were over 300 registrations for this event that included over 50 presentations. The conference included a special session on the Participatory Development of a Regional Ocean Governance Strategy for the WIO that is being developed following a request from the countries of the Nairobi Convention at the 10th Conference of the Parties in 2021. This special issue of the Western Indian Ocean Journal of Marine Science is dedicated to the outputs of the WIOGEN conference, providing an opportunity to both experienced and early career researchers to contribute to awareness of ocean governance in the WIO. The WIOGEN project enabled early career researchers to submit to the special issue of this journal and hosted a number of writing workshops to support the writing and publication process. This is the first special issue of the journal to focus on governance challenges, and the research that supports ocean governance.

This special issue examined ocean governance from a global perspective, using policy mechanisms such as the Sustainable Development Goals (Andriamahefazafy *et al.* 2022) and Africa's Maritime Integrated Policy and Blue Growth (Guerreiro 2022). It also explores the importance of access to data and information in order to improve the science-to-policy process (Schwindenhammer *et al.* 2022).

Articles in this special issue also delved into social, ecological and economic ocean governance challenges as they pertain to certain habitat types, e.g., mangroves (Obiene *et al.* 2022); estuaries (Thoya *et al*. 2022); seagrass meadows (Malesa *et al.* 2022) and coral reefs (Okello *et al.* 2022).

In the WIO, fishing is an important social, cultural and economic activity and, concomitantly, a major challenge and opportunity for managers and decision-makers. This special issue examines the opportunities for food transformation in small-scale fisheries in the region (Mtonga *et al.* 2022, Katikiro and Mahenge 2022).

Our experience with WIOGEN has shown that there is clearly an appetite within the WIO for a better understanding of ocean governance. This extends to the educational perspective that explores formal training in ocean governance from the perspective of Mauritius as a framework for the other counties in the region (Uppiah and Appadoo 2022). This special issue, the first of many to come, highlights the importance of stepping out of disciplinary "comfort zones" and working across disciplines towards a greater degree of integration of sciences into ocean management. For example, as ocean accounting is an emerging opportunity in ocean governance for the WIO (Loureiro *et al.* 2022), a unique policy contribution that explains different ways of incorporating ocean accounting into ocean governance.

Just like the WIOGEN Ocean Governance conference was not a traditional academic conference, this special issue contains contributions from a variety of sectors and disciplines. We have included interdisciplinary studies and new formats of papers to encourage new participants in the ocean governance conversation which we hope will become increasingly common and important to the WIO region.

Louis Celliers
Shannon Hampton
Guest Editors

Sustainable Development Goal 14 in the Western Indian Ocean: a socio-ecological approach to understanding progress

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Abstract

The Sustainable Development Goals (SDGs) intend to "achieve a better and more sustainable future for all people in the world"[1]. They have become a key driver for policy and decision-making in many regions, including in the Western Indian Ocean (WIO) region. This paper analyses national and regional progress towards achieving SDG 14 in the WIO. Progress of four of the SDG 14 targets that were due in 2020 are analysed. SDG 14 has influenced regional and national policy agendas but current tools to measure this progress fail to provide a detailed picture of achievement towards each target for countries in the WIO. The paper highlights that the region has shown limited success in achieving the targets and SDG 14 targets are unlikely to be reached by 2030. The WIO region lags behind with regard to marine conservation related targets. More than half of the countries have low to average progress on SDG 14.2 on marine areas being covered by area-based management tools. Even more countries are far from achieving the 10 % coverage of marine protected areas under SDG 14.5. The region is performing better with regards to fisheries management targets with most countries classified as making average to good progress towards SDG 14.4 on sustainable stocks and SDG 14.6 on addressing harmful subsidies and IUU fishing. The diversity of the socio-economic and governance contexts in the WIO countries contributes to different levels of progress. The fairly positive ecological state of the WIO supports progress towards SDG 14. Understanding barriers to progress is fundamental to help with the prioritisation of the actions needed to meet the SDG 14 targets by 2030. Regional actors and policy-makers will need to increase their ambitions to meet the SDG 14 targets and ensure a healthy ocean and improved prospects for the region and its citizens. To account for barriers in progress towards SDG 14, the WIO region needs appropriate reporting and monitoring mechanisms and it should follow a holistic regional approach of ocean governance integrating conservation and sustainable resource use. It needs to build capacity and knowledge sharing for implementation of SDG 14 and ocean governance at various levels. Improved implementation of SDG targets will have social, economic and environmental benefits within the region.

Keywords: SDG 14, area-based management, marine protected areas, fish stocks, IUU fishing

[1] As highlighted by Resolution A/RES/71/313 adopted by the United Nations General Assembly on 6 July 2017

http://dx.doi.org/10.4314/wiojms.si2022.1.1

Introduction

Progress towards the achievement of the UN Sustainable Development Goal 14 (SDG 14) is important for the Western Indian Ocean (WIO) region considering the large number of coastal communities that rely on a healthy ocean for their livelihoods and food security (Obura *et al.*, 2017). The sustainable use of ocean resources is a priority for the blue economies of WIO countries (WIOMSA, 2018). This importance was emphasized at the UN Ocean Conference of 2022, which builds upon the first Ocean Conference of 2017, and mobilised global commitments towards funding and actions for SDG 14. Globally, the progress towards achieving SDG 14 is lagging, compared to other goals (Sturesson *et al.*, 2018; Salvia *et al.*, 2019), and there remains a substantive funding gap (Johansen and Vestvik, 2020). Despite progress on some of the different targets of SDG 14, none are close to being achieved (United Nations, 2019). For African countries, progress on SDG 14 is generally limited, with some instances of a decline in the indicators for sustainability (Salvia *et al*., 2019). This is true for some WIO countries, where challenges to achieving sustainability remain (Sachs, *et al.* 2019). Studies on SDG 14 have mainly focused on national achievements (Recuero Virto, 2018; Rivera-Arriaga and Azuz-Adeath, 2019; Gulseven, 2020). In the WIO region, SDG 14 has primarily been assessed from the perspectives of blue economies and fisheries. Benzaken (2017) discusses the implementation of SDG 14 supporting the blue economy agenda of WIO countries including Kenya, Madagascar and Seychelles. She highlighted the opportunities for countries to achieve SDG 14 through activities such as marine-based tourism or energy. Obura (2020) highlighted how achieving other SDGs represent a means to progress in the implementation of SDG 14 in the WIO. He also presented a model for the assessment of the achievement of SDGs, which is based on a narrative approach, whereby explicit tangible interactions (such as the delivery of ecosystem services), can be used to measure progress, rather than measurement of progress based on indicators. Techera *et al*. (2020) looked at the implementation of SDG 14 from the perspective of small-scale fisheries in the Indian Ocean islands. They presented the progress made by Madagascar and Seychelles in fisheries management that can contribute towards the fisheries related targets of SDG 14. Wright *et al*. (2017) propose that most of the SDG14 targets can be achieved through regional initiatives that can increase ambition, learning exchanges, and coordination. They highlight that regional governance acts as a driver for the development of integrated approaches, particularly in the context of small island developing states (SIDS) and least developed countries (LDCs), of which many of the WIO states are.

Using the example of the 10 countries of the WIO (Somalia, Kenya, Tanzania, Mozambique, South Africa, Comoros, Madagascar, Seychelles, Mauritius, France - covering Réunion and Mayotte), the paper assesses the progress of four SDG 14 targets that were due in 2020[2]. The paper has three objectives:

- It assesses the state of national achievements of SDG 14 in the WIO based on existing global databases that provide data of the four SDG 14 targets analysed according to the global indicator framework.
- It identifies the socio-ecological and political drivers behind success, or lack thereof, towards SDG 14 in the region. Using a socio-ecological system approach, the paper explores the common drivers and differences that drive progress nationally.
- It explores current literature to provide potential pathways towards improving achievement towards SDG 14 in the WIO region.

Current SDG 14 reporting is unreliable; in the past five years, countries of the WIO have submitted the voluntary SDG reviews on progress towards the targets sporadically or not at all (United Nations, 2022b). Limited availability of data prevents the effective monitoring of progress. This paper provides insights into improving regional indicator use, thereby contributing to the requirement of UN member states to develop and implement national and regional indicators to complement the global indicator framework.

[2] SDG 14.2: By 2020, sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, including by strengthening their resilience, and take action for their restoration in order to achieve healthy and productive oceans
SDG 14.4: By 2020, effectively regulate harvesting and end overfishing, illegal, unreported and unregulated fishing and destructive fishing practices and implement science-based management plans, in order to restore fish stocks in the shortest time feasible, at least to levels that can produce maximum sustainable yield as determined by their biological characteristics
SDG 14.5: By 2020, conserve at least 10 per cent of coastal and marine areas, consistent with national and international law and based on the best available scientific information
SDG 14.6: By 2020, prohibit certain forms of fisheries subsidies which contribute to overcapacity and overfishing, eliminate subsidies that contribute to illegal, unreported and unregulated fishing and refrain from introducing new such subsidies, recognizing that appropriate and effective special and differential treatment for developing and least developed countries should be an integral part of the World Trade Organization fisheries subsidies negotiation

For practitioners, this paper provides an assessment of the achievement of SDG 14 at both the national level, and regional perspective that can help target actions towards ocean sustainability and identify the needs in the WIO. This is relevant given the upcoming SDG14 review at the UN High-level Political Forum (HLPF) on the SDGs. The paper also analyses the role of socio-ecological and political drivers in achieving global goals. This can be helpful to policy makers and practitioners working on the SDGs, ocean management and blue economies in Africa. It argues that achieving the targets of SDG 14 will require the adoption of a more integrated approach when implementing policies. The ecological and socio-economic context of each country or region has significant impacts on progress and should be reflected in their policies. Social, economic and ecological impacts of policy implementation should be better integrated into decision making, monitoring and reporting associated with SDG 14.

Materials and methods

The research was based on two methods. First, progress towards the four targets of SDG 14 that expired in 2020 was assessed. Under the UN framework[3], indicators are established for each of the targets. While the overall progress of SDG 14 is published in the annual SDG progress report by the UN, data regarding progress towards each indicator at the country level is more dispersed, either through the UN platforms (not always covering all indicators[4] or all countries[5]) or through Voluntary National Reviews submitted by countries (often not submitted by all countries[6]). Independent repositories of progress also exist, although they do not always precisely align with the UN indicators or do not cover all countries for all indicators[7]. To overcome these limitations and provide a clear picture at the country level, an analysis was undertaken of publicly available databases which provided data about the indicators of the four targets of SDG 14 which were interpreted according to UN related guidelines in the UNEP Global Manual for the indicators of SDG 14.2 and SDG 14.5.

For 14.2 (Indicator: Number of countries using ecosystem-based approaches), the UNEP Global Manual (UNEP, 2021) assesses two sub-indicators. Firstly, the level of implementation of ecosystem-based approaches for the management of marine areas. It aims to capture area-based, integrated planning and management schemes in place in waters under national jurisdiction (e.g., marine spatial planning, marine protected areas, marine zoning, sector specific management plans). For this indicator the level of marine spatial planning (MSP) implementation was assessed as the most comprehensive ecosystem-based approach (Douvere, 2008; Santos *et al.*, 2019). The IOC-UNESCO MSP online database was used that presents the status of MSP processes in different countries as of 2019 (IOC-UNESCO, 2021). For countries that do not have MSP in place yet, the compendium of existing and emerging cross-border and transboundary MSP practices was used that included Large Marine Ecosystem initiatives that countries were involved in as of 2020 (IOC-UNESCO, 2021). The second sub-indicator assessed ecological parameter schemes (e.g., state of biodiversity, water quality, habitat quality, ecosystem health). For this, the 2020 Ocean Health Index database was used which provides the state of ocean health based on 10 components ranging from marine biodiversity to clean water and food provision for each country (Ocean Health Index, 2021). The use of the sub-indicator provided an indication of the health of ecosystems and marine species.

For 14.4 (Indicator: Percentage of stocks within biologically sustainable levels), the FAO has put in place a national questionnaire that has been sent to all FAO member States on a biannual basis since 2019, collecting information on national fish stocks (FAO, 2021). Sustainability of stocks is defined as stocks with abundance that are at or greater than the level that produce the maximum sustainable yield (MSY). In 2021, less than 20 countries filled in the questionnaire related to their stocks. Considering this limitation, the reconstructed catch data produced by the *Sea Around Us* (Pauly *et al.*, 2020) was used to assess SDG 14.4 as it included all the WIO countries. The *Sea Around Us* provides an assessment of national stocks of countries through its stock status plots database. The stocks (i.e., species, genus or family level of taxonomic assignment) assessed for each country are those that have been reported on for at least five consecutive years over a minimum of a 10-year period and for which catch is greater than 1,000 tonnes. For each EEZ, stocks are categorised as developing (catches ≤ 50 %

[3] Resolution A/RES/71/313 on the Global indicator framework adopted by the General Assembly

[4] See for example: https://country-profiles.unstatshub.org/

[5] For example for SDG 14.4: https://www.fao.org/sustainable-development-goals/indicators/1441/en/

[6] Available at: https://sustainabledevelopment.un.org/vnrs/

[7] See for example https://dashboards.sdgindex.org/map/goals/SDG14 or https://sdg-tracker.org/oceans

of peak catch and year is pre-peak, or year of peak is final year of the time series); exploited (catches ≥ 50 % of peak catches); overexploited (catches between 50 % and 10 % of peak and year are post-peak); collapsed (catches < 10 % of peak and year is post-peak); and rebuilding (catches between 10 % and 50 % of peak and year is after post-peak minimum) (Kleisner and Pauly, 2011). To conduct the assessment, the percentage of developing, exploited and rebuilding stocks (excluding overexploited and collapsed) for the year 2018 was combined to estimate stock sustainability. In addition to stock plots, the Marine Trophic Index (MTI) based on the *Sea Around Us* database of reconstructed catches for the period 1950-2018 was used as another indicator to measure the health of the marine resources. The MTI measures how fishing pressure in an EEZ changes the annual mean trophic level of the catch of large, exploited fishes (Pauly and Watson, 2005). The MTI indicates if high volumes of large pelagic fishes are within high trophic levels (>=3.5) or lower levels (<3.5), the latter showing that mean trophic level of the catch decreases over time.

For 14.5 (Indicator: Coverage of MPAs), the UNEP Global Manual (UNEP, 2021) also suggests two sub-indicators. First, is an assessment of the coverage of marine and coastal areas by protected areas. For this, the World Database on Protected Areas (WDPA) was used to assess each country (UNEP-WCMC and IUCN, 2022). Second is an assessment of various parameters, from coverage of important biodiversity areas to effectiveness of management, connectivity and equity within MPAs. For this second level, the key biodiversity areas database was used to determine the extent of MPAs that covered biologically important areas (BirdLife International, 2021).

For 14.6 (Indicator: implementation of international instruments to combat Illegal, Unreported and Unregulated [IUU] fishing), the FAO suggests using the degree of implementation of international instruments to combat IUU fishing as the indicator. This is based on self-reporting biannually by FAO members through an online questionnaire. The 2020 data indicates that half of the WIO countries did not fill in the questionnaire (United Nations, 2022a). To overcome this, the data from the IUU Fishing Index (IUU Fishing Index 2018); specifically the 2021 IUU Index scores relating to state action to combat IUU fishing (i.e. "response") was used. The response part of the IUU Index covers 17 indicators for countries in their capacity as coastal, flag and port states, including the adherence to international agreements set out to combat IUU fishing, reflecting what is currently assessed by the FAO.

To assess the level of achievement of each of the four SDG 14 targets, a five-level classification from 'far from achievement' (class 5) to 'achieved' (class 1) was stablished. A five level scale provides a good picture of success and lack of achievement but also intermediate levels from low to good progress towards achievement. The five levels were set across the different types of scoring and level of assessment for each indicator (Table 1).

The second method is a literature review to collect data on socio-ecological drivers of achievement and recommendations. Socio-ecological drivers were divided into five categories adapted from the 'Press-Pulse Dynamics' framework (Collins *et al.*, 2011): ecological, socio-economic, governance, external drivers and events. Events can be press or pulse. Press events were adapted as not only ecological events but also socio-political ones that are sustained and sometimes chronic events that affect the system. Pulse events are discrete but quickly affect the socio-ecological system and its functioning (ibid). To find the relevant information, a search of papers and reports with the keywords "WIO" "governance" and "management" was undertaken. The following documents have been chosen as being recent publications covering both ecological and socio-economic aspects about the 10 WIO countries in their content:

- The WIO MPA Outlook 2021 (UNEP-Nairobi Convention and WIOMSA, 2021): A regional stock-taking of MPA coverage and management effectiveness showing the progress, governance and challenges regarding MPAs and area-based management tools.

- The SOLSTICE papers (https://solstice-wio.org/outputs/peer-reviewed-publications): A set of publications about ecological processes taking place in the WIO as a region and in individual countries.

- The 2021 IUU Index report (Macfadyen *et al.*, 2021): A global report on the state of IUU fishing at the global and regional levels. This report provided information on the state of IUU fishing and related challenges faced by countries and regions, including the WIO.

Table 1. Classification used to assess the achievement of SDG 14.

Progress towards SDG 14 targets	Classification	SDG 14.2	SDG 14.4	SDG 14.5	SDG 14.6
Achieved	1	MSP covering the entire EEZ is implemented OHI 85-95	>90% of stock sustainable MTI >4.5	MPAs >10% of EEZ, with 50% of marine KBAs covered	IUU index (response) 1-1.7[1]
Good progress / Near completion for SDG 14.5	2	MSP under development, complete/approved but not implemented yet OHI 75-85	60-90% of stock sustainable MTI 3.5-4.5	MPAs = 7,5 - 10% of EEZ, with at least 50% of marine KBAs covered, or MPAs >10% of EEZ but less than 50% of marine KBAs covered	IUU index (response) >1.7-2
Average progress	3	MSP under development OHI 65-75	>50% of stock sustainable MTI 3-3.5 or <50% of stock sustainable MTI >4		IUU index (response) >2-2.5
Low progress	4	MSP at pre-planning phase OHI 60-70	20-50% of stock sustainable MTI 3-4	MPAs = 2 - 7,5% of EEZ, no matter about the percentage of marine KBAs covered, or MPAs = 7,5 - 10%, but less than 50% of marine KBAs covered	IUU index (response) >2.5-3.0
Far from achievement	5	MSP at Pre-planning/ Pilot project phase OHI <60	<20% of stock sustainable MTI <3	MPAs = 0 - 2% of EEZ, no matter about the percentage of marine KBAs covered	IUU index (response) >3

[1] Note that this target can never be truly "achieved", but that the national response to combat IUU fishing at this score range appears to be broad and very solid.

These documents were also complemented by general references to events and initiatives linked to the four SDG targets taking place in the WIO region.

Results and discussion

The assessment of the indicators of SDG 14 targets shows that WIO countries are still far from achieving SDG 14 (Fig. 1). Across the four targets analysed, only two targets, 14.5 and 14.6 were achieved by two countries (France and Mozambique). One country, the Seychelles, has seen good progress across all four targets. Two countries (Comoros and Somalia) show no to low progress towards achieving at least three of the targets assessed.

Achievement of marine protection targets (SDG 14.2 and SDG 14.5)

The majority of countries are far from achievement and show low progress towards marine conservation related targets. SDG 14.2 was assessed through the proportion of national exclusive economic zones managed using ecosystem-based approaches. The assessment of existing databases divided WIO countries into three groups - countries making low, average and good progress – but none of the countries have achieved this target (MSP implemented and high OHI score). While most WIO countries have fairly satisfactory ecological status according to the OHI, MSP processes are not well advanced with countries still developing or in the pre-planning phase of MSP. Four countries (France, Mozambique, the Seychelles and South Africa) have made good progress with the MSP process being complete, but not yet implemented, or MSP under development but with a high OHI score. Somalia is at the lowest classification for this target with the MSP process being at pre-planning stage and the ecological indicator being at an average level.

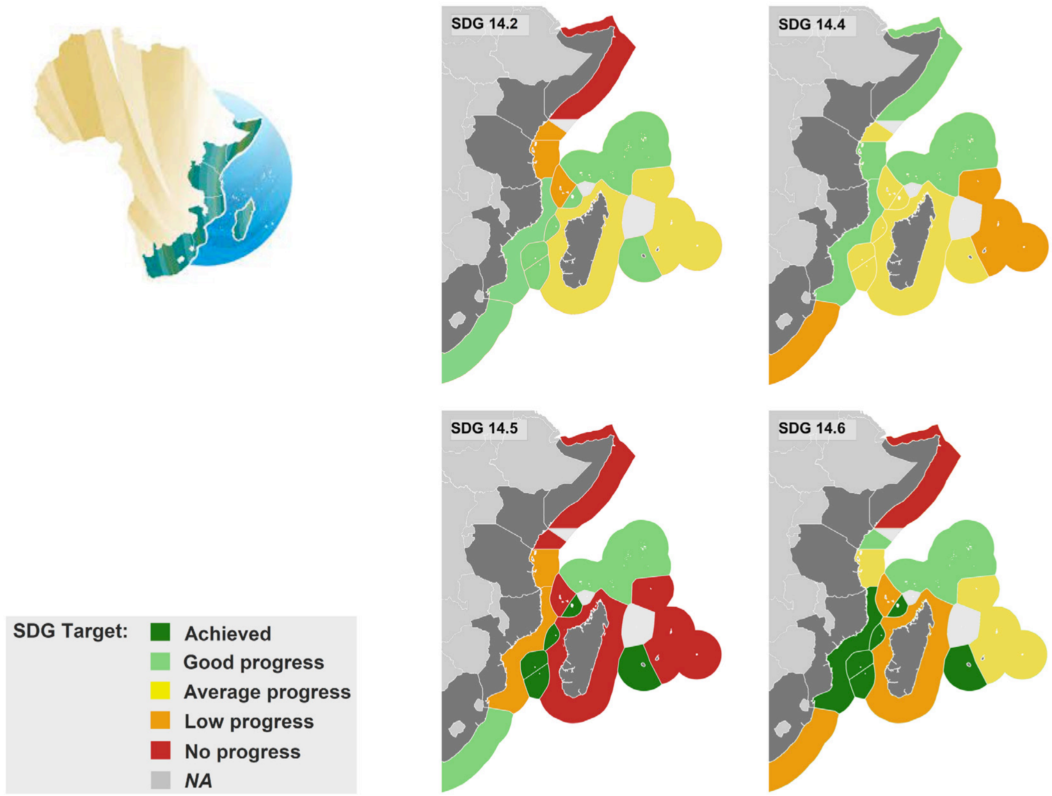

Figure 1. Map of progress on the four SDG 14 targets (14.2, 14.4, 14.5 and 14.6) in the WIO countries.

SDG 14.5 assesses the coverage of protected areas in relation to marine areas. One country (France) has achieved this target with 16,6 % of marine areas covered by protected areas including more than 50 % of marine key biodiversity areas. Two countries (the Seychelles and South Africa) are near completion having achieved more than 10 % marine protected areas coverage but with less than 50 % of marine Key Biodiversity Areas under the current coverage. The Seychelles has achieved a 32,8 % MPA coverage, France 16,6 % and South Africa 15,5 %. For France and South Africa, the protection of remote island territories has contributed to this achievement. However, they only cover between 30 and 47 % of marine Key Biodiversity Areas. Two countries (Mozambique and Tanzania) showed low progress with less than 5 % MPA coverage. The other half of WIO countries are far from achievement with less than 2 % MPA coverage. This SDG target is the one that has seen the lowest level of achievement amongst the four targets assessed.

Achievement of fisheries management targets (SDG 14.4 and SDG 14.6)

With regards to fisheries related targets, achievement of the WIO countries has been disparate with countries in all classifications from "achieved" to "far from achieved". Target 14.4 on fisheries regulation was assessed by the proportion of sustainable stocks and fisheries governance. The majority of countries (8) have been classified as making good or average progress meaning 60 to 80 % of national stocks were assessed as sustainable and with high MTI score (>3.5) (in the case of Mozambique, the Seychelles, Somalia and Tanzania) or with less than 70 % of stock being sustainable but having a MTI score (>4) (as for Comoros and France). Two countries have been classified as having made low progress towards this target as they had mainly low levels of sustainable stocks (<40 % for Mauritius and South Africa). The fish stocks of the region appear to be in a fairly good state although efforts are needed to lift all countries towards the achievement of this target. The SDG Tracker[8] highlights a decrease of 5 % of overexploited stocks in the WIO, which aligns to the overall average progress as reported in this study. Contrastingly, the SDG Index Dashboard[9] values for percentage of fish caught from overexploited or collapsed stocks showed better progress for all WIO countries but Mauritius.

[8] https://sdg-tracker.org/oceans

[9] https://dashboards.sdgindex.org/map/indicators/fish-caught-from-overexploited-or-collapsed-stocks

based on 2018 year reference, stating that for most WIO countries, this target has been achieved. The approach of this study incorporates not only the percentage of sustainable stocks, but also the impact of fishing pressure on the state of marine trophic levels. This could explain the variations between the findings of this study and those of other reporting sites.

With regards to target 14.6 which assesses the progress by countries in the implementation of international instruments aiming to combat illegal, unreported and unregulated fishing, in 2021, two countries (France and Mozambique) have achieved this target and two others (Kenya and Seychelles) are making good progress. Another 50 % of the countries have been classified as making low to average progress which means that the level of implementation of international instruments to reduce IUU fishing has not been satisfactory and actions are still required such as establishing action plans or complying to management measures to provide enough response to fight IUU fishing. This SDG target has seen the most progress amongst the four targets assessed, however, it should be noted with caution that IUU fishing is difficult to monitor and record, and that the indicators for this target focus solely on whether the measures are in place rather than their implementation. When compared to the SDG Tracker for this target, six of the 10 countries had no data to track progress in 2020, highlighting the challenge of monitoring this target.

Socio-ecological drivers of progress

As SDG 14 targets are set to be the main global framework to assess ocean sustainability, understanding the drivers behind the current levels of achievement can improve the way forward for implementation of SDG 14 targets due in 2030. Some countries have made good progress towards SDG 14.5 and 14.6. For SDG 14.5, looking at ecological drivers, the countries with good progress all have good Ocean Health Indices and average levels of MTI. This aligns with research showing that areas with good protection status in the WIO also have increased fish productivity (Osuka *et al.*, 2021).

On the social drivers, three countries (France, the Seychelles and South Africa) have more favourable socio-economic contexts (all ranked highest in the Human Development Index in the region). Some key events such as the 2018 Debt Swap in Seychelles (SSCOE, 2018; UNEP-NC and WIOMSA, 2021) can constitute pulse events that foster the increase of MPAs. The Great Blue Wall initiative (IUCN, 2021) will also be a pulse event, potentially fostering further marine protection through Other Effective Area-based Conservation Measures (OECMs) such as locally managed marine areas. Similarly, press events through long standing engagement and consistent political will towards marine conservation can help stimulate marine protection and the establishment of MPAs. This has been the case for the Seychelles, where leadership was committed to ocean conservation (State House, 2020). Similarly, press events such as the mobilisation of resources by the Nairobi Convention (the regional convention under the UNEP Regional Seas Programme) or production of data and knowledge through WIOMSA (the regional marine science association that functions as a network of marine scientists and as a regional advisory body) have contributed to the advancement of marine protection in the region. External drivers such as the increased drive towards ocean conservation, highlighted by the pledges of delegates from the 'Our Ocean' 2017 conference in Malta (IISD, 2017) and initiatives such as 30x30 campaign (Ocean Unite, 2021) can also promote and push for more actions towards marine protected areas.

Six out of 10 countries have made good progress in SDG 14.6. An ecological factor that can be considered is the state of fish stocks in the region, of which only a few are considered unsustainable (overfished or collapsed). Countries of the WIO have long benefited from support regarding fisheries governance. The 10 countries are part of the Southwest Indian Ocean Fisheries Commission (SWIOFC) where fisheries management and adoption of international frameworks are discussed and supported. Similarly, they are all party to regional fisheries management organisations such as the Indian Ocean Tuna Commission or the Southern Indian Ocean Fisheries Agreement which allow countries to implement management measures for shared fishing stocks and discuss the fight against IUU fishing. Pulse events, such as the existence of online platforms like Global Fishing Watch, allow countries to have a better oversight of fishing activities within their EEZs. Press events include past or existing regional surveillance and monitoring programmes such as Fish-i Africa (Stop Illegal Fishing, 2017) or the regional Indian Ocean Commission monitoring and surveillance programme (IOC, 2014). They provide countries of the WIO with resources to fight against IUU in the region. External drivers such as the global interest to fight overfishing (GEN, 2021) or the impact of harmful subsidies in fisheries (Sumaila *et al.*, 2021) fuel existing development towards management efforts.

Regarding the limited progress made by some countries across the four targets, an ecological look at the WIO region through the OHI, the MTI and stock data show that while marine ecosystems and biodiversity in the WIO can be considered to be at a healthy level, the high level of exploitation of fish stocks in some countries (between 30 % to 80 % of stocks being over-exploited or collapsed) puts marine resources at risk. Threats such as climate change (Cerutti *et al.*, 2020; Jacobs *et al.*, 2021), increasing marine pollution (Burt *et al.*, 2020; Kerubo *et al.*, 2020) and overfishing of species such as tunas and sharks in the broader Indian Ocean (IOTC, 2016; IOTC, 2019) all put pressure on the ecological health of the WIO and the ability for ecosystems to deliver functioning services. The connectivity of the WIO with the high seas also means that fishing activity in the high seas affects the health of marine ecosystems within the WIO region (Popova *et al.*, 2019).

On the socio-economic drivers, for the developing countries of the WIO, socio-economic and political imperatives of development and blue growth often involve extraction of natural resources undermining conservation priorities (Kiswaa, 2020; Bennett *et al.*, 2021). External drivers, such as high demand for seafood and key commercial species like tuna, also have an impact on the level of exploitation of marine resources. The unsatisfactory results in governance in the WIO countries, despite the region being highly active and supported by various initiatives, suggest that the WIO region is struggling with both implementation and with monitoring progress. Countries that are struggling to perform well now are likely to struggle in the future given the limited means and resources to implement activities towards achieving SDG 14 (UNEP-NC and WIOMSA, 2021). Persistent lack of funding and limitations in number of staff and equipment and the need for capacity development hindered WIO countries implementing MPA management (ibid) as well as the fight against IUU fishing (Macfadyen *et al.,* 2021).

There have been serious impacts and implications of the COVID-19 pandemic on all 17 SDGs in the year 2020 (United Nations, 2020). For SDG 14 this had affected enforcement, resources and capacity, and limited the ability of nations to progress towards the targets. Pulse events such as political instability can also influence direction of governments towards marine actions as national interests often change with changing governments.

In view of the different initiatives happening in the WIO, it seems that monitoring of progress could be better recorded and therefore contribute to the achievement of SDG 14 targets. For example, as of January 2022, the IOC UNESCO portal on MSP only has records of five WIO countries involved in MSP (France, Kenya, Mauritius, Mozambique and Seychelles) (IOC-UNESCO, 2021). However, other countries (e.g., South Africa and Madagascar) and the WIO region are involved in the development of national and a regional MSP (MSP Secretariat, 2020; Lombard *et al.* 2021). Furthermore, national processes towards monitoring of the achievement of targets are still limited. MPA coverage is monitored through both national submission of data for the WDPA or by regional initiatives such as the WIO MPA outlook but, beyond MPAs, national reporting on SDGs including SDG 14 is currently based on the Voluntary National Reviews which is more a list of actions undertaken by countries. In the past five years, countries of the WIO have submitted these reviews sporadically or not at all (United Nations, 2022b).

Limited availability of data prevents effective monitoring of progress. This includes, for example, data regarding OECMs that could improve the coverage of marine areas protected and help achieve both SDG 14.2 and 14.5 (Gurney *et al.*, 2021; Estradivari *et al.*, 2022). Data on fish stocks for stock assessments is also limited. The number of available stock assessments remains limited globally and not only in the WIO region (FAO, 2020; Britten *et al.*, 2021). Knowledge about stocks are available through regional assessments of the FAO, regional fisheries management organisations or, as analysed in this study, from the available assessments made by the *Sea Around Us* project.

Some external drivers such as the difficulty to implement some targets have rendered implementation challenging, and not only for the WIO countries. Target 14.2 for example promotes the implementation of area-based management including MSP and Integrated Coastal Zone Management (ICZM). However, the operationalisation of MSP is still at the development stage for most countries globally while socio-economic, institutional and political challenges have now emerged from the process (Flannery *et al.*, 2018; Santos *et al.*, 2019; Frazão Santos *et al.*, 2021). ICZM processes, on the other hand, have been in place for a long time and have presented various limitations to implementation as well (Sowman and Malan, 2018; Sabai, 2021). The same applies to Target 14.4 which aims to achieve biologically sustainable fish stocks. National capacity to undertake stock assessment is still limited (Palomares *et al.*, 2021) and initiatives to improve this by the FAO have only been taken up since 2019 (FAO, 2019).

Potential ways of improving SDG 14 reporting and implementation towards achievement in the WIO

The results above represent a reality check for the region which has been the beneficiary of various projects, assessments and initiatives for many years. Based on the most recent literature the following adjustments and improvements are suggested to the WIO region and countries.

Better appropriation of SDG 14 monitoring

To improve achievement of SDG 14, the actions taking place in the WIO, at national and regional level, need to be recorded timeously and accurately and integrated into the overall monitoring of SDG 14 achievement. At the moment, SDG 14 achievement is assessed through the UN reporting mechanism or independent studies not facilitating appropriation of the process of monitoring by countries and regions. Structures like the Nairobi Convention can serve as a platform in this process to better coordinate actions and support low achieving countries. Scientific networks such as the WIOMSA could be mobilised to gather existing data that would better monitor the actions of the WIO region towards SDG 14. The following table provides an indication of the potential data needed for all SDG 14 targets and the sources of knowledge that could be mobilised within the WIO region. The data and knowledge gathered could be consolidated at the regional level and accessed by national focal points at the ministries in charge of fisheries and marine resources management that are periodically contacted to fill out UNEP or FAO questionnaires related to the progress of the different targets of SDG 14. Providing the information to national actors can also improve the submission of data for platforms like World Database on Protected Areas monitoring progress towards SDG 14.5 and it can help countries in the submission of their voluntary reports by providing key results on different targets.

A holistic approach towards achievement: Linking conservation and sustainable use

To achieve the goals of Agenda 2030, the region needs to increase its ambition. National and regional strategies towards improving progress towards SDG 14 should address not only the direct lack of progress, but also the root causes thereof. Increasing the coverage of marine protected areas requires a focus on establishing processes and providing resources for countries to implement and monitor the effectiveness of these marine areas (Failler *et al.*, 2020; Phang *et al.*, 2020). This requires the collaboration of various stakeholders, from governments establishing policy to civil society organisations and businesses involved in implementing actions, as well as researchers providing the needed evidence for policy and decision making. The WIO has platforms such as the Science to Policy dialogue to allow this collaboration and could be mobilised towards SDG 14 achievement. Alignment of different governance and marine management processes is necessary. For example, SDGs and the CBD post-2020 biodiversity framework cover targets addressing similar issues, such as the target for marine protected areas increasing from 10 % under SDG 14.5 to 30 % under the CBD post-202 biodiversity framework target 3. Better alignment is also needed between SDG 14 targets and national and regional blue economy strategies that are burgeoning in the region. To capture all these processes, a more narrative-based approach to present achievement might be useful as it could address different SDGs (Obura, 2020) or better align blue economy strategies with SDGs needs (Niner *et al.*, 2022).

Marine protection and fisheries management need to be addressed in a more holistic way. While the distinct fisheries and marine protection SDG 14 targets perpetuate the separation between marine protection and fisheries, reduction of marine resources through fisheries presents a real threat to the state of our oceans and its people (Okafor-Yarwood *et al.*, 2022; Marsac *et al.*, 2020). Achieving SDG 14 targets related to fisheries is therefore essential to achieve an effective marine protection. Similarly, better managed marine areas can lead to a more productive ocean that could benefit fisheries (Davis *et al.*, 2019; Marshall *et al.*, 2019). Monitoring these two targets and ensuring that actions address both topics have the potential to simultaneously achieve two or more SDG 14 targets and other related SDGs (e.g., SDG 2 on food security or SDG 13 on climate action). This, however, could require making trade-offs on other SDGs such as SDG

Table 2. Targets, indicator, data and sources to monitor SDG 14 progress in the WIO.

SDG 14 Targets	Indicator[1]	Data needed to monitor progress[2]	Potential data source for the WIO
Target 14.1: Reduce marine pollution	Index of coastal eutrophication and floating plastic debris density.	Level of eutrophication Plastic flow	WIO Marine Litter Monitoring Programme
Target 14.2: Protect and restore ecosystems	The proportion of national exclusive economic zones managed using ecosystem-based approaches.	Coverage of EEZ Effectiveness of EBAs	Marine Spatial Atlas for the Western Indian Ocean IOC-UNESCO MSP database SAPHIRE Project
Target 14.3: Reduce ocean acidification	The average marine acidity (pH) measured at agreed suite of representative sampling stations.	Data on marine acidity at sampling stations	MASMA Ocean Acidification project
Target 14.4: Sustainable fishing	The proportion of fish stocks within biologically sustainable levels.	Level of sustainability of all national stocks	*Sea Around Us* database FAO assessments IOTC stock assessments Global Fishing Index
Target 14.5: Conserve coastal and marine areas	The coverage of protected areas in relation to marine areas.	Evolution of marine protected area coverage	WDPA database WIO MPA outlooks
Target 14.6: End subsidies contributing to overfishing	Progress by countries in the degree of implementation of international instruments aiming to combat illegal, unreported and unregulated fishing.	Implementation level of IUU related instruments	SWIOFC reports IUU Index
Target 14.7: Increase the economic benefits from sustainable use of marine resources	Sustainable fisheries as a proportion of GDP.	Measurement of fisheries being sustainable, proportion of small-scale fisheries into DGP	N/A Needed: a measurable definition of sustainability To be collected: Information from fisheries departments and NGOs/ local fishers
Target 14.A: Increase scientific knowledge, research and technology for ocean health	The proportion of total research budget allocated to research in the field of marine technology.	Budget information	N/A To be collected: National budgets of research institutes
Target 14.B: Support small scale fishers	Progress by countries in the degree of application of a legal/regulatory/ policy/institutional framework which recognizes and protects access rights for small-scale fisheries.	Identification of instruments and Level of implementation of access rights related instruments	N/A To be collected: Information from COAPA Information from LMMA networks
Target 14.C: Implement and enforce international sea law	The number of countries making progress in ratifying, accepting and implementing through legal, policy and institutional frameworks, ocean-related instruments that implement international law, as reflected in the United Nations Convention on the Law of the Sea.	Identification of relevant legal, policy and institutional frameworks and level of implementation	IUU index Global Fishing Index

[1] According to Resolution A/RES/71/313 on the Global indicator framework for the Sustainable Development Goals and targets of the 2030 Agenda for Sustainable Development

[2] According to the Global Manual on Measuring SDG 14.1.1, SDG 14.2.1 and SDG 14.5.1 (UNEP 2021) and the SDG indicators metadata repository (available at: https://unstats.un.org/sdgs/metadata/)

2 on poverty (Singh *et al.*, 2018) or SDG 7 on energy (Nilsson *et al.*, 2018) for example, by limiting fishing efforts in specific biodiversity areas (Hilborn *et al.*, 2021) or establishing compensation funds from biodiversity loss from fisheries (Booth *et al.*, 2021).

A tailored approach to capacity development through mutual learning

While sharing the same part of the Indian Ocean, WIO countries are socio-economically diverse. This leads to different means, resources and capabilities in both implementing SDG 14 actions and monitoring progress towards achievement. Some countries are advancing well in achieving SDG 14 and others are still struggling. Existing and future efforts in capacity development, from a regional perspective, need to consider the different needs in the region and tailor the actions needed towards SDG 14 accordingly. As regional initiatives such as the WIO Great Blue Wall (IUCN, 2021) and global funding such as from the Blue Action Fund (Blue Action Fund, 2022) continue to flow in the WIO, these need to look at the diverse and distinct needs of the WIO countries. This paper shows that WIO countries can be divided into three groups, each necessitating tailored capacity development:

- First are the high achievers such as France and the Seychelles. For these countries, capacity development in monitoring progress is key to ensure that results of projects and initiatives are counted towards achievement of SDG 14. Considering the diversity of the SDG 14 targets, coordination between various state departments is necessary and ensuring that capacity towards monitoring progress towards SDG 14 is reinforced.

- Second is the countries that are still far from achievement such as Comoros[10] or Somalia. These countries require capacity development at both implementation and monitoring levels. For implementation, as seen in the implementation of other global goals such as the CBD Aichi targets, capacity is needed at different levels from local community groups to national NGOs, governments and research entities that are often underfunded and understaffed leading to limited means available to implement actions (Phang *et al.*, 2020; UNEP-Nairobi Convention and WIOMSA, 2021). Here, investment in capacity development is needed in key processes, such as raising and maintaining financial capacity for MPAs and OECMs or increasing human resources capacity in the fight against IUU fishing. In terms of monitoring, capacity development in data production and collection remains paramount. Processes such as stock assessments or MSP are at the centre of SDG 14 and will require countries and initiatives in the region to invest in improving national capacity through supporting training.

- The third set of countries, representing more than half of the WIO, are countries that have been classified as making low to average progress, depending on the targets. For these countries, targeted actions will be needed in terms of implementation and monitoring of progress. All countries classified as displaying low progress towards achieving ecosystem-based area management (SDG 14.2), need to better record and monitor progress within initiatives such as MSP, Locally Managed Marine Areas (LMMAs) and ICZM actions. Regarding MPA coverage, most countries have not achieved this target which implies that more MPAs and OECMs are still needed within the WIO. However, ensuring effectiveness of existing MPAs/OECMs needs to remain a priority. It might also be time to question the relevance of this target for the region. While quantified targets can be useful to ensure robustness (Maron *et al.*, 2021), few countries globally achieve them – for example, biodiversity targets (Secretariat of the Convention on Biological Diversity, 2020). A more qualitative or narrative-based approach towards progress, as suggested by some authors (Rees *et al.*, 2018; Obura, 2020) could be beneficial in showing improvement of processes in marine management and protection.

Finally, regarding the sustainability of fish stocks, countries need to improve their capacity in undertaking stock assessments, support initiatives that rebuild stocks and phase out destructive fishing activities such as bottom trawling and other destructive gears. Current reporting of the IUU Index or the newly established Global Fishing Index (Minderoo Foundation, 2021) can also help countries and the WIO in targeting areas that require capacity development, such as improving monitoring, control and surveillance capacity. To coordinate these efforts, regional cooperation on ocean governance will be essential: countries making progress or those that have achieved the targets can share best practices with others and help pave the way for more SDG 14 progress in the region. Countries with average progress need to be more supported in their existing efforts. Countries far from achievement are highlighted so they can get more support from the region and the international community. This support should not be geared towards rushed achievement but better structured towards long-term improvement in all aspects of fisheries management.

[10] At the time of the revision of this paper, Comoros made the decision to expand its MPA network with three more sites, not accounted yet within the WDPA.

A cross-scale intervention for inclusion and social equity

SDG 14 provides a framework for more ocean actions or more visibility of actions undertaken in the region. Implementation of SDG 14 requires action across scales from the local managers of marine areas or fishers to the governments and those involved in regional processes. As the pressure on governments towards ocean action increases, it is essential that local actors, that are most affected by the management of the WIO and its resources, remain at the centre of processes. Inclusion and social equity need to drive the achievement of SDG 14 in both implementation and monitoring of achievement. Involvement of local stakeholders needs to go beyond participation at meetings or being beneficiaries of projects. It should ensure that local views are taken into consideration and integrated into decision-making. Processes such as MSP, for example, can be a source of conflict when, despite participation local actors feel that their views are not reflected into the outcome of the process (Flannery *et al.*, 2018; Schutter and Hicks, 2019).

As various independent assessments are being undertaken, countries and stakeholders need to be fully engaged in the process of measuring progress rather than only being data providers. A fully engaged co-production of knowledge is necessary and can pave the way for positive and equitable socio-ecological transformation (Ertör and Hadjimichael, 2020; Chambers *et al.*, 2021). Achieving SDG 14 needs be seen as an opportunity for stakeholders to have dialogues and debates on how to best advance towards a sustainable ocean. The integration of SDG14 in the development of blue economy agendas in the WIO should result in a more inclusive process and enhance blue justice (Bennett, 2018; Armstrong, 2020), creating an opportunity for the region to be a model for the rest of the world.

Conclusion

The SDGs represent the global framework for sustainable development until 2030 and potentially beyond that. As more than five years have now passed since the adoption of SDG 14, this paper reflects on implementation, monitoring and potential ways to achieve the SDG 14 targets for the WIO region. Countries of the WIO have made limited progress towards the four targets of SDG 14 analysed in this paper. Countries have struggled to achieve targets related to marine protection and area-based management (SDG 14.2 and 14.5) while progress towards fisheries related targets (SDG 14.4 and 14.6) has been more encouraging with more countries making good progress. Considering the various active projects and initiatives taking place in the region, this shows that either current efforts have been insufficient to achieve the global targets or that the region has not managed to convert its successes into the achievement of the SDG 14 targets. The paper shows the national challenges in achieving SDG 14 and how knowledge around the SDGs could be improved beyond global indicators. To achieve SDG 14, the WIO region needs to improve the monitoring of progress towards SDG 14 targets by mobilising existing data but also by potentially adapting the monitoring process to fit the diverse contexts in the WIO. In parallel to this, countries of the WIO could adapt the framework of SDG 14 targets to direct actions towards a more comprehensive approach - linking conservation and sustainable use, fostering mutual learning and ensuring inclusivity and equity in decision and policy making. As we have entered the UN Decade of Ocean Science for sustainable development that promotes science towards SDG 14, the WIO region is ideally equipped with its lively community of governments, practitioners and researchers to be a model towards SDG 14 achievement tailored to the needs and capabilities of the region.

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Africa Integrated Maritime Policy, blue growth and a new ocean governance: case studies from the Atlantic and the Indian Ocean

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Abstract

Integrated maritime and blue economy policies are changing ocean governance by introducing new policy drivers, reshaping institutional frameworks, as well as demanding new management instruments (e.g., Maritime Spatial Planning (MSP)). This started in 2007 though the European Union Integrated Maritime Policy approach, and in 2009 the Africa Union initiated a similar process, leading both to the Africa integrated maritime strategy as well as a blue economy strategy. Several countries, particularly in sub-Saharan Africa, began to look to blue economy as a booster to socioeconomic welfare and initiated the development of national strategies, together with the necessary adaptation of institutional and legal networks. Case studies address those processes at the transition from the Atlantic to the Indian Oceans, focusing on Angola, Namibia, South Africa, Tanzania and Kenya in the Southern African Development Community (SADC) region, as well as several African Small Islands Developing States (SIDS), particularly Cape Verde, S. Tomé and Príncipe, Seychelles, Madagascar and Mauritius. Findings show that all countries covered in the case studies are developing national ocean and/or blue economy strategies and adapting their governmental, institutional, and legal frameworks, although there is a deeper political impact in SIDS. Overall, these new policy drivers are leading to a new model of ocean governance by addressing integrated maritime policies and blue growth strategies, as well as introducing MSP as a new EEZ governance tool.

Keywords: Africa, SIDS, marine governance, blue economy, maritime policy, MSP

Introduction

The United Nations Convention on the Law (UNCLOS) entered into force in 1994 after a long process, triggered by the 1945 Truman Declaration, claiming the unilateral right of the United States to explore mineral resources, namely oil, within the continental shelf. This led to a strong reaction from other nations and paved the way for the 1st UNCLOS conference in 1958 (UN General Assembly, 1958), aiming to establish the global ocean governance model. Following the Lisbon 1998 World Ocean Exhibition, "*The Oceans, A Heritage for the Future*" (EXPO98), within the UN International Year of the Oceans, the World saw an explosion of new ocean science and technology. This technological evolution at the turn of the century also brought to the ocean new uses, from deep sea mining to offshore wind farms, causing a demand for maritime space, not seen since the end of World War II and the race for oil exploitation on the continental shelf.

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These new uses triggered a new ocean blue economy[1], "Blue Growth"[2] and a demand for maritime spatial planning, leading to a new challenge to ocean governance (Guerreiro, 2021). There was a need for new rules and instruments as social and political ideas about ocean resources and governance processes changed (Campbell *et al*., 2016).

The globalization of the concept and debate surrounding the Blue Economy became institutionalized at the United Nations (UN) Conference on Sustainable Development, held in Rio de Janeiro in 2012 (Rio +20), in which the themes of the oceans, its governance and the blue economy were formally discussed and were the subject of several side events (Campbell *et al*., 2013; Silver *et al*., 2015). At the 2nd preparatory meeting in March 2011 the issue of the blue economy was formally debated (IOC - UNESCO, 2011) and, at that same meeting, where the Pacific Small Island Developing States (SIDS) suggested that their development interests would be better served by blue economy, rather than green economy[3]. This idea would later be consolidated at the third SIDS conference in Apia, Samoa, on September 3, 2014, concluding that "*... Sustainable fisheries and aquaculture, coastal tourism, the possible use of seabed resources and renewable energy are among the main sectors of a sustainable ocean economy in small island developing states*" (UN, 2014b). In 2014, a UNECA report identified the key strategic areas for blue growth in SIDS to be: i) Fisheries, ii) Aquaculture, iii) Shipping and transport, iv) Tourism, v) Marine (blue) energy (fossil and renewable), vi) Pharmaceutical and cosmetic industries, genetic resources and general sea-based products, and vii) Blue carbon market (UNECA, 2014).

The specificity of SIDS has been recognized since the Rio Conference in 1992, reinforced in 1994 at the first UN Global Conference on the Sustainable Development of SIDS in Barbados. It resulted in the adoption of the Barbados Programme of Action (BPOA) which identified key areas requiring urgent action, such as climate change and sea level rise, coastal and marine resources, energy, biodiversity and tourism resources. BPOA was reviewed in 2005 and the Mauritius Strategy was adopted for further Implementation of the Barbados Programme of Action. The outcome document of Rio+20 reaffirms SIDS have placed sustainable development prominently on their agenda for twenty years and the BPOA and the Mauritius Strategy of Implementation have clearly outlined the way forward. Following this trend, the FAO in 2014 identified blue growth as a way to promote sustainable development through key sectors such as Tourism, Water, Energy, Waste and small-scale Fisheries and Aquaculture in the Blue Growth Initiative for SIDS (FAO, 2014). The World Bank reinforced this path by launching the report "The Potential of the Blue Economy: Increasing Long-term Benefits of the Sustainable Use of Marine Resources for Small Island Developing States and Coastal Least Developed Countries" in 2017, pointing out not only established sectors, such as fisheries, maritime transport, and tourism, but newer and emerging sectors and emerging industries, such as deep-sea mining, marine biotechnology, and renewable ocean energy (World Bank, 2017).

[1] There is no concrete and global definition for "Blue Economy", nor for "Ocean Economy" or "Maritime Economy", and these three concepts have been used in a wide range of situations (Lee *et al*., 2020). The Blue Economy concept was formally defined at the UN in 2014, aiming at: "improving human well-being and social equity, significantly reducing environmental risks and ecological fragilities" (United Nations, 2014a). Also, the World Bank (2014) defined Blue Economy "... a sustainable use of ocean resources for economic growth, improved livelihoods, and jobs while preserving the health of ocean." Ocean economy was also defined by the Economist Intelligence Unit (2015) as: "... a sustainable ocean economy, where economic activity is in balance with the long-term capacity of ocean ecosystems to support this activity and remain resilient and healthy". In 2019 the African Union Blue Economy Strategy considers that the concept of the Blue Economy (BE) integrates into a new approach the economic exploitation of the resources of oceans, lakes, rivers and other bodies of water and the conservation of aquatic ecosystems. It represents a basis for rational and sustainable use and conservation of natural resources (both renewable and non-renewable) and their natural habitats (AU, 2019). In 2012 the EU considered Maritime Economy as a part of the economy composed of different interdependent sectors, such as maritime transport, tourism, energy and fishing, which are based on common skills and shared infrastructures (such as ports and electricity distribution networks) and depend on the sustainable use of the sea (EC, 2012a)

[2] On SD, Rio + 20 held in Rio in 2012, a group of small island nation states (SIDs) emphasized the importance of the blue economy - that is the multifaceted economic and social importance of the ocean and inland waters and the importance of "blue growth". At the Rio + 20 conference, the Food and Agricultural Organization (FAO) supported these views and sent a very strong message to the international community that a healthy ocean ecosystem ensured by sustainable farming and fishing operations was a prerequisite for a blue growth. Since the Rio + 20 conference, the blue growth concept has been widely used and has become important in aquatic development in many nation states, regionally as well as internationally (Eikeset *et al*., 2017). Also in 2012 the EU, following the approval of its Integrated Maritime Policy / Blue Book (EC, 2007), approved the Marine and Maritime Agenda for Growth (EC, 2012a), which introduced the Blue Growth Strategy and concept, emphasizing the importance of marine areas for innovation and growth in five sectors (aquaculture, coastal tourism, marine biotechnology, energy from the oceans and deep sea mining), together with the need to support it in three main axes: i) Knowledge of the marine environment; ii) Maritime spatial planning; and iii) Integrated maritime surveillance.

[3] SD, Rio + 20 held in Rio in 2012, a new concept took center stage at the backdrop of the international financial crisis. The concept was "green growth". According to the OECD "green growth means fostering economic growth and development while ensuring that natural assets continue to provide the resources and environmental services on which our well-being relies (Eikeset, 2017).

Africa has 38 coastal states, from which 7[4] are considered SIDS, reaching collectively 13 million km^2 of the ocean space, considered as the African Maritime Domain (AMD). **Not surprisingly,** Africa was one of the first regions in the world to embrace these new policies and challenges. At the 13th Ordinary Session of the AU Assembly, African Heads of State and Government called upon the AU Commission "*to develop a comprehensive and coherent strategy*"[5] to improve African maritime security and safety standards, as well as African maritime economy for more wealth creation from its oceans and seas, ultimately ensuring the well-being of African people. At the AU level, the Africa Integrated Maritime Strategy 2050 (AIMS 2050) Strategy Task Force, was constituted on the 3rd of June 2011 and, in 2012, the AIMS 2050 (AU, 2012)[6] was issued, together with the identification that Blue Economy was vital for the development of the African continent (Republic of Seychelles, 2014).

In 2016 the United Nations Economic Commission for Africa drew up Africa's Blue Economy: A Policy Handbook (UNECA, 2016). Also, in 2016 the AU approved a key stone maritime policy instrument, the Lomé Charter on Maritime Security and Safety and Development in Africa, considering security and safety indispensables for the success of Blue/Ocean Economy[7]. Finally, the Sustainable Blue Economy Conference that took place in Nairobi, Kenya in 2018, [8] under the theme "*Developing a sustainable blue economy; increasing momentum for Africa's Blue Growth*", paved the way for the approval of the Africa Blue Economy Strategy (African Union - Inter-African Bureau for Animal Resources, 2019). The Africa Blue Economy Strategy focusses on five critical blue economy sectors, considered as thematic areas: i) Fisheries, aquaculture and ecosystems conservation; ii) Shipping, transportation and trade; iii) Sustainable energy, extractive minerals, gas, innovative industries; iv) environmental sustainability, climate change and coastal infrastructure; and v) governance.

New policies soon triggered a more profound political change at the higher level, leading several governments to create dedicated Sea/Ocean Ministries from Maritime Economy to Ocean Affairs (Guerreiro *et al*., 2021). Following this, the need for new legal and institutional frameworks, including but not limited to maritime spatial planning (MSP) became clear, as well as agencies with a clear mandate and know-how to implement policies (Ehler and Douvere, 2009). The need to improve management authorities, management capacity and resources, together with the commitment of officials and intergovernmental coordination/collaboration, was considered critical to the successful implementation of MSP (Liu *et al*., 2011). Accordingly, more and more actors stand for the need to create an authority for MSP as a guarantee of the success of the process and interface among agencies and stakeholders (Albotoush and Shau-Hwai, 2021).

The holistic approach to cross cutting sectoral policies and a new universe of stakeholders, demanded both horizontal and vertical coordination to facilitate governance, but in reality it was revealed that there is an increased difficulty in coordinating policies at the horizontal level, compared with the vertical level. Martino (2016), addressing this issue, found that some regions have developed institutions based on an inter-sectoral coordination committee or an advisory body, while others have chosen an internal proactive collaboration to resolve conflicting interests between directorates. Moreover, these regions are also extending coastal management into maritime spatial planning, trying to tackle conflicts emerging from land/sea interactions based on two different spatial planning systems and instruments (Casimiro and Guerreiro, 2019). A wide range of authorities, from fisheries to environment and ecology, maritime authorities, shipping, and harbours industries, councils and urban planning are involved in the administration of maritime and coastal space, a mishmash that Freire-Gibb *et al*. (2014) considered 'institutional ambiguity'. Peart (2017), when pointing out this increasing complexity, suggested the establishment of a governance entity with certain powers and representatives from different sectors. Several governments follow this path and have created Inter-ministerial Commissions, or similar bodies, to articulate sectoral policies.

This article addresses the impacts of the African political options for Integrated Maritime Policy and Blue Growth at the legal, institutional and government level, changing the model of ocean governance. Several case

[4] Cape Verde, Guinea-Bissau, S.Tomé and Príncipe, Mauritius, Madagascar, Comoros and Seychelles

[5] Decision [Assembly/AU/Dec.252(XIII)] adopted by the 13th Ordinary Session of the AU Assembly held in Sirte, Libya, on July 2009

[6] Formally approved in 2014

[7] Blue/Ocean Economy is defined as: sustainable economic development of oceans using such techniques such as regional development to integrate the use of seas and oceans, coasts, lakes, rivers, and underground water for economic purposes, including, but without being limited to fisheries, mining, energy, aquaculture and maritime transport, while protecting the sea to improve social weilbeing,

[8] http://www.blueeconomyconference.go.ke/

studies, focused on SIDS (e.g., Cape Verde, S. Tomé and Príncipe, Madagascar, Mauritius and Seychelles) as well as continental countries linking the transition from the Atlantic to Indian Ocean and the Large Marine Ecosystems (LME): i) Benguela Current (Angola, Namibia and South Africa); and ii) Agulhas/Somalia Current (South Africa, Mozambique, Tanzania and Kenya).

Methods

Research was performed during a 6-year period between 2017 and 2022 and followed three main criteria based on the existence of: i) Integrated Maritime Policies, National Ocean strategies and Blue Economy/Blue Growth strategies; ii) Institutional framework for maritime and marine governance; and iii) Legal framework for maritime governance and MSP. Data were obtained by: i) a comprehensive literature review carried out on scientific data bases using the key words ocean strategy, integrated maritime policy, blue economy, blue growth, maritime economy, marine governance, MSP, plus the name of the country; ii) directed search of the institutional websites; iii) specific questionnaires addressed to national authorities; iii) direct interviews, particularly in Cape Verde, Angola and Mozambique.

Information was analysed according to the following three main themes and criteria:

Integrated Maritime Policies & Blue Economy

- Integrated Maritime Policies/National Ocean Strategies
- Blue economy strategies/initiatives.

Government structure and mandates:

- Ministry/ministries with a mandate to promote blue economy and/or MSP policies;
- Institution/Agency with a mandate to develop and implement the blue economy/MSP;
- Coordinating structure for blue economy and/or MSP.

Legal Framework

- Governance of Maritime Space
- Specific legal framework for MSP.

Results

The mapping of policies, institutional and legal frameworks is summarized in Table 1, showing that although all studied countries address Integrated Maritime Policies/Ocean Strategies and Blue Growth, they do this at different levels. Nevertheless, there are clearly different stages of maturity, more evident when considering the institutional and legal framework, particularly regarding government structures and the status of implementation of MSP.

Cape Verde

Cape Verde is an archipelago situated in the Macaronesian Region of the central Atlantic and its economy depends mainly on fisheries, tourism (25 % of GDP) and services[9], these accounting for an overall value around 60 % of the GDP[10]. The country embraced blue growth and approved the: i) Chart for the promotion of blue growth in Cape Verde (2015); ii) National Blue Economy Investment Plan (2018); and iii) Programme for the Promotion of the Blue Economy (2018). The government structure was reshaped accordingly to new political drivers and a Ministry for Maritime Economy was created alongside a new agency, Directorate General for Maritime Economy, clearly empowered to enhance blue economy and develop MSP supported by the National Institute for Spatial Management articulating with the Directorate General for Marine Resources. In 2021, the new government, although maintaining the institutional framework, changed the governmental structure and maritime affairs were assigned to the Ministry of Culture, Creative Industries and Minister of the Sea[11]. Blue economy continues to be one of the priority policies with strong support from EU cooperation. Areas such as fisheries, nautical tourism and shipping, aquaculture and blue biotechnology are the core of ocean economy, on which the country depends. Ocean science is also one of the new political drivers supported by the recently created Technical University of the Atlantic, focused on ocean sciences. The legal framework on spatial planning addresses integrated coastal zone management plans, some recently approved (Guerreiro *et al.*, 2021). However, specific legislation for MSP covering the exclusive economic zone (EEZ) is still under development as well as a National Maritime Spatial Plan.

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[9] Services correspond to ISIC divisions 50-99 and they include value added in wholesale and retail trade (including hotels and restaurants), transport, and government, financial, professional, and personal services such as education, health care, and real estate services. Also included are imputed bank service charges, import duties, and any statistical discrepancies noted by national compilers as well as discrepancies arising from rescaling.

[10] See https://pt.theglobaleconomy.com/Cape-Verde/Share_of_services/

[11] The same minister heads two different ministries. See https://www.governo.cv/governo/ministerios/ministro-da-cultura-e-industrias-criativas/

Table 1. Country governmental structures, policies, institutional and legal frameworks for Ocean strategies, Blue Economy and Maritime Spatial Planning.

Country	Ministry	Policy/strategy	Agencies	Msp	Legal instrument for msp
Cape Verde	Culture, Creative Industries and Ministry of the Sea*	Chart to Promote Blue growth Programme to Promote Blue growth	General Directorate for Maritime Economy General Directorate for Marine Resources	Underway	Under development
Angola	Agriculture and Fisheries	National Ocean Strategy	General Directorate for Maritime Affairs	Under final approval	Under development
S. Tomé e Príncipe	Planning, Finances and Blue Economy	Under development	Strategic Intelligence Unit for Blue Economy (UIE)	----------	------------
Namibia	Fisheries and Marine Resources	Strategic Plan 17/22 Namibia's Marine Resources Policy Sustainable Blue Economy Policy (draft) 2022-2031	Directorate Policy, Planning and Economics	Pre-planning complete Management Plans underway	Marine Spatial Planning National Working Group
South Africa	Environment, Forestry and Fisheries	Operation Phakisa	Department of Forestry, Fisheries and the Environment	MSP ongoing	MSP ACT
Mozambique	Sea, Inland Waters and Fisheries	Ocean Policy and Strategy	National Directorate of Maritime and Fishing Policies Blue Economy Development Fund (ProAzul)	National MSP ongoing	Law Decree establishing the legal regime for the use of maritime space
Tanzania	Livestock and Fisheries State Minister Vice President Office	------------- National Integrated Coastal Environment Management Strategy	Policy and Planning Division National Environment Management Council	----------------- MSP Projects undergoing	---------------- ---------------
Kenya	Transport, Infrastructure Housing, Urban Development and Public Works	KMA Strategic Plan 2018-22	Department for Shipping and Maritime Affairs/Kenya Maritime Authority (KMA)		---------------
	Agriculture, Livestock, Fisheries and Co-operatives	National Ocean and Fisheries Strategy	Department for Fisheries, Aquaculture and Blue Economy Kenya Marine and Fisheries Research Institute	Multi-sectoral Interagency Working Group	
Seychelles	Fisheries &Blue Economy (presently Fisheries) Environment, Energy and Climate	Blue Economy: Strategic Policy Framework and Roadmap	Department of Blue Economy	Seychelles Marine Spatial Plan Initiative	Maritime Zones Act – under development
Madagascar	Fisheries and Blue Economy Spatial Planning and Land Management	Proposal for National Strategy on Blue Economy	General Directorate for the Sea and Blue Economy General Directorate for Spatial Planning	Pre-planning	---------
Mauritius	Prime Minister's Office		Department for Continental Shelf, Maritime Zones Administration and Exploration/MSP Coordinating Committee	MSP for the exclusive economic zone of the republic of Mauritius	Marine Spatial Planning Bill under consideration by the Coordinating Committee
	Blue Economy, Marine Resources Fisheries and Shipping	Ocean Strategy underway			

* The same minister oversees two ministries, one of which is the Ministry of the Sea.

Angola

Angola has an important geostrategic position in the transition from central Africa/Gulf of Guinea to Southern Africa influenced by the Guinea Gulf Current (Angola current) in the north and the Benguela Current in the south (Angola, Namibia and South Africa). Traditionally, the economy strongly depends on oil and gas, representing almost 90 % of exports, followed by fisheries. In 2009, the Angolan government decided to embrace an Ocean Strategy and the Presidential order N°147/19 Decree from 12th August orders the development of the Angola Nacional Ocean Strategy (ENMA), the development of Maritime Spatial Planning and creates a Multisectoral Commission gathering 14 different ministries. Politically the process is headed by the head of the Civil House of the Angola President and co-coordinated by the Ministry of Agriculture and Fisheries. A General Directorate for Maritime Affairs (DNAM) was created under the Ministry for Agriculture and Fisheries and assigned the task of supporting the technical group in charge of developing ENMA and the legal framework for MSP. At the same time, pilot projects on MSP are being developed, with the support of projects financed by the Benguela Current Convention[12], which are being developed by DNAM. The Angola National Ocean Strategy was approved by the Council of Ministers in May 2022, pursuing the vision of "promoting an increase in social well-being, employment and national wealth, boosting the blue economy within a framework of sustainable development, supported by scientific knowledge and affirming Angola as a maritime reference in its geostrategic context". ENMA focuses on seven strategic goals: i) Foster and diversify the maritime economy; ii) Increase employment and professional qualifications at sea; iii) Optimize the means, instruments and mechanisms for security and maritime surveillance; iv) Promote scientific knowledge, technological development and literacy of the oceans; v) Promote and guarantee the good environmental status of the marine environment and the sustainable management of biological resources; vi) Optimize the governance model for maritime space and intersectoral coordination; and vii) Strengthen Angola's role in maritime policies both at the international and regional geostrategic contexts.

[12] The Marine Spatial Management and Governance Programme (MARISMA) of the BCLME promotes sustainable ocean use in the Benguela Current, focusing on implementing Marine Spatial Planning (MSP). See https://www.benguelacc.org/index.php/en/marisma

São Tomé and Príncipe

São Tomé and Príncipe is an archipelago in the Gulf of Guinea, off the western equatorial coast of Central Africa. Traditionally, its economy depended both on agriculture as well as fisheries and tourism. However, since 2004, a joint venture with Nigeria to explore oil reserves in waters claimed by the two countries of the Niger Delta geological province, changed this focus considerably.

Although no Ocean or Blue growth Strategy is in force, the latest government created a Ministry of Planning, Finances and Blue Economy with a specific body to promote Blue Economy – the Strategic Intelligence Unit for the Blue Economy, which has a mandate to develop a National Strategy. Although no MSP initiative recognized by IOC/UNESCO is in place, the legal framework for spatial planning considers Coastal Zone Management (ICZM) instruments.

Namibia

Namibia is the middle state of the Benguela Current Convention (BCC). Namibia's economy is strongly dependent on mining, but also on tourism and fisheries. Fisheries, benefiting from the effect of the Benguela current, is the fastest growing economic sector and the coast of Namibia is considered to be home to some of the richest fishing grounds in the world. Namibia's government and institutions are involved in several projects under the BCC, particularly on MSP. At the present the pre-planning phase of the National Maritime Spatial Plan is completed, and the management plans are underway. The Ministry of Fisheries and Marine Resources (MFMR) was given the mandate to coordinate and guide the process of institutionalising MSP, and an inter-ministerial and cross-sectoral National Working Group (NWG) on MSP was established by MFMR in 2016. The National Development Program 2017-2022 introduces the concept of "blue economy", understood to comprise existing maritime industries, such as fisheries and mariculture, shipping and transport, tourism and minerals, as well as prospective uses such as marine renewable energy, the utilization of genetic resources for bio-prospecting and other sea-based products such as seaweeds for pharmaceutical and cosmetic uses. In 2019 a Draft Sustainable Blue Economy Policy was published (MFMR, 2019) focusing on Fisheries, Tourism, Blue Biotechnology and Bioprospecting, Mining, Desalinization, Renewable energy and Blue Carbon Trading. This Blue Economy policy is supposed to enter into force for the period 2022-2030.

South Africa

South Africa has a unique geostrategic position facing both the Atlantic and the Indian Ocean with a coastline of 3 900 km including the sub-Antarctic islands. South Africa's economy is the second largest in Africa[13] and although natural resource extraction industries remains one of the main pillars, in the last three decades the economy became more diversified with a rise of the tertiary sector. The ocean economy of South Africa plays a strong role, consisting mainly of fisheries, aquaculture, tourism, transport, ports, coastal mining, and energy. The last decade showed a slowdown in the growth rate of economy and in 2014 the government launched a specific programme to reboot South Africa's economy - Operation Phakisa[14] (based on the Malaysian experience "Big Fast Results Methodology"). The aim was to tap into other sustainable alternative resources, one of which is the ocean economy. With the introduction of Operation Phakisa, it was estimated that the ocean had the potential to contribute up to R177b to Gross Domestic Product (GDP) and provide between 800 000 and 1 million direct jobs annually by 2033. With effective implementation, it was expected that these estimates will produce at least 4 % annual growth in both GDP contribution and job creation. (Odeku, 2021). The Oceans Phakisa Initiative[15] initially, under the specific programme called Ocean Economy Lab, reviewed eight industry sectors and an associated ocean governance sector for their potential in advancing the South African oceans economy. The reviewed sectors included Marine Transport and Manufacturing, Tourism, Offshore Oil and Gas, Construction, Renewable Energy, Fisheries and Aquaculture, Communication, Desalination, and the Marine Protection Services and Governance Aspect. Three industry sectors (Marine Transport and Manufacturing, Offshore Oil and Gas, and Aquaculture) and Marine Protection Services and Governance were initially selected for advancement, with two further industry sectors (Tourism and Small Harbour and Infrastructural Development) selected. Each of the Oceans Phakisa Focus Areas identified a set of target initiatives to advance their sectors within the oceans economy (Findlay, 2018). Following the implementation of Operation Phakisa (and in line with Objective 10 of the Marine Protection Services and Ocean Governance delivery area) the government approved a MSP Act, being the first African country to do so.

At the present, the National MSP Data and Information Report is finalized and provides the evidence base and knowledge collated by the National Working Group (NWG) regarding the spatial layers that are needed to embark on spatial planning. The NWG is currently identifying the spatial priorities and claims of each sector and marine activity to draft marine area plans. Furthermore, South Africa is also involved in the BCC programmes, particularly the already mentioned MARISMA project[16].

The institutional framework is led by the authority for MSP in South Africa, the Department of Forestry, Fisheries and the Environment (DFFE), which chairs the NWG. The established Directors-General Committee and Ministerial Committee on Marine Spatial Planning are comprised of 17 sectoral departments. While the MSP authority DFFE chairs the committees, the Department for Planning, Monitoring and Evaluation is the co-chair of both committees[17]. Politically the process is coordinated by an inter-ministerial committee.

Mozambique

Mozambique possesses the third longest coastline in continental Africa with over 2 700 km. The Mozambique Channel is an important source region for the Agulhas Current, which is one of the major western boundary currents flowing along the south-eastern coast of South Africa. The Mozambique Channel is also one of the two routes through which the South Equatorial Current feeds the Agulhas Current. The coral reefs of Mozambique are the southern limit of the well-developed reefs that occur along the continental shelf of the East African coast. Together with South Africa, Tanzania, Kenya and Somalia, as well as Seychelles, Madagascar, Mauritius and Comoros, Mozambique constitutes one of the hotspots of marine biodiversity of the world: the Western Indian Ocean Region. Mozambique's economy is traditionally dependent on agriculture and fisheries (10 % of GDP), whch also support exports. In the last decade, projects on exploitation of natural gas (NLG) began to shift this focus[18], despite the armed conflicts in Cabo

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[13] See https://www.statista.com/statistics/1120999/gdp-of-african-countries-by-country/

[14] See https://www.operationphakisa.gov.za/pages/home.aspx

[15] See https://www.operationphakisa.gov.za/operations/oel/pages/default.aspx

[16] See https://www.benguelacc.org/marisma-2/

[17] See https://www.dffe.gov.za/msp/structuresresponsible

[18] See https://data.worldbank.org/indicator/NY.GDP.NGAS.RT.ZS?locations=MZ

Delgado. Tourism, particularly coastal and safari tourism, has also shown a growing trend accounting for more than 6 % of GDP before the COVID pandemic[19].

Mozambique embraced blue growth and developed a National Ocean Policy and Strategy in 2017 (Resolução 39/2017) focusing on six priority sectors: i) Ports and infrastructure; ii) Maritime transport and shipping industry; iii) Fishing and aquaculture; iv) Culture, tourism and sport; v) Minerals and hydrocarbons; and vi) Energy. In 2019 a Blue Economy Development Fund (ProAzul) was created, partly financed with the incomes of the licensing of the activities in the maritime space[20]. The ProAzul is dedicated to fostering and guiding private investment for priority projects and actions in the blue economy, as well as providing assistance in drawing up business plans, as well as economic and financial advisory services, among other duties. Like South Africa, Mozambique also developed its legal framework for MSP under the Law Decree 21/2017 and approved the National Maritime Spatial Plan (POEM) in May 2021[21]. The institutional framework for maritime governance is headed by the Ministry of the sea, inland waters and fisheries (MIMAIP). The National Directorate of Maritime and Fishing Policies is the agency responsible for the development and implementation of MSP.

Tanzania

Tanzania has a coastline of 1 450 km, and its territorial water includes 64 000 km2 thus making the country a significant player in regional fisheries, contributing about 2.6 % of the GDP. Following two decades of sustained growth, Tanzania reached an important milestone in July 2020, when it formally changed from low-income country to lower-middle-income country status[22]. However, Tanzania's economy strongly depends on tourism accounting for 10,9 % of the GDP in 2019[23], before the COVID 19 pandemic.

Although there is potential for blue economy development in Tanzania, a specific blue growth or Ocean Strategy has not been developed yet. The Government of the semi-autonomous region of Zanzibar recognized Blue Economy as a driver for social economic development and approved Zanzibar Blue Economy Policy[24] in 2020. This policy targeted 5 sectors to boost the region's economy and welfare: i) Fisheries and Aquaculture; ii) Maritime Trade and Infrastructure; iii) Energy; iv) Tourism; and v) Marine and Maritime Governance. The regional government also includes a Ministry for Blue Economy and Fisheries.

Tanzania has not yet developed MSP, nor a legal framework to support it, however several MSP pilot projects were developed or are undergoing, as is the case in the Rufiji, Mafia and Kilwa District with the support of WWF and the coordination of the National Environment Management Council (NEMC), which is the national authority for MSP. The National Integrated Coastal Environment Management Strategy (NICEMS) in Tanzania exists (2003 - 2025) and although 'Spatial planning' is not mentioned in NICEMS, it is recognized as having the same action plan as NICEMS. Furthermore, Tanzania is conducting a coastal and marine dataset study and developing a "Geonode Platform", which will help update its Spatial Data and Environmentally Sensitive Area maps and the Atlas Map of Tanzania Coastal Resources (onshore, offshore, terrestrial). The Northern Mozambique Channel (NMC)[25] project, aimed at designing a methodological tool for enhancing the sustainability and suitability of national MSP in NMC countries produced a situational report and a methodological tool was put in place to contribute to the development of MSP in Tanzania and Madagascar.

Kenya

Kenya has a coastline of 1 420 km and an EEZ of 142 000 km^2. Kenya's economy is the third largest in Sub-Saharan Africa behind Nigeria and South Africa. Agriculture, Forestry and Fisheries are the sectors that most contribute to Kenya's GDP, accounting for almost 25 %[26] with the fisheries sector accounting for around 5 %. The other critical sector, tourism, accounted for more than 8 % before the COVID 19[27]pandemic.

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19 Source: WTTC https://www.statista.com/statistics/1257785/contribution-of-travel-and-tourism-to-gdp-in-mozambique/

20 See https://www.proazul.gov.mz/quem-somos/

21 See https://poem.gov.mz/

22 See https://www.worldbank.org/en/country/tanzania/overview#1

23 See https://www.statista.com/statistics/1255025/contribution-of-travel-and-tourism-to-gdp-in-tanzania/

24 See http://planningznz.go.tz/doc/new/BE%20Policy-2020.pdf

25 See https://wio-c.org/projects-by-members/wwf/northern-mozambique-channel-initiative/

26 See https://data.worldbank.org/indicator/NV.AGR.TOTL.ZS?locations=KE

27 See https://www.statista.com/statistics/1219642/contribution-of-travel-and-tourism-to-gdp-in-kenya/

Although having not yet developed a specific blue growth strategy, Kenya has since 2008 a National Ocean and Fisheries Policy in place. Political priority has been given to the blue economy and a Presidential Blue Economy Task Force was created in 2017 as well as a Blue Economy Implementation Standing Committee. Kenya is a member of the High-Level Panel for Sustainable Ocean Economy. Furthermore, in 2018 the Blue Economy conference hosted with Japan and Canada, included over 16 000 participants from 184 countries, which resulted in the Nairobi Statement of Intent on Advancing a Sustainable Blue Economy[28]. A specific governmental Department on Fisheries, Aquaculture and Blue Economy was also constituted under the Ministry of Agriculture, Livestock, Fisheries and Co-operatives (Benkenstein, 2018).

Present blue economy drivers are focused on shipping, aquaculture, expansion of tourism and fishing, and expansion of port and shipping activities (new ports foreseen in Lamu and Shimoni areas).

MSP is in the stage of preplanning and a multi-sectoral Interagency Working Group has been constituted under the State Department for Fisheries, Aquaculture and the Blue Economy. The MSP planning process will involve a review of legislation and the development of policy framework which is expected to be approved by the Government. Although no legislation on MSP is being developed yet, Kenya has an ICZM Policy (2015), an ICZM National Action Plan (currently under review) and a National Spatial Plan (2015-2045). The Blue Economy Implementation Standing Committee also gives oversight to the Marine Spatial Planning process. In June 2022 Kenya co-hosted, with Portugal, the UN Ocean Conference held in Lisbon[29].

Seychelles

Seychelles is an archipelago comprising 115 islands at the eastern and south regions of the Somali area. Seychelles has the highest GDP per capita in Africa, but the economy is highly dependent on tourism and fisheries, and climate change poses long-term sustainability risks. The government of Seychelles embraced the concept of blue growth early and is strongly committed to it. The Government of Seychelles and the Government of the United Arab Emirates co-hosted the first 'Blue Economy Summit' during the Abu Dhabi Sustainability Week of January 2014, to explore ways in which the Blue Economy concept could be utilized as a tool to enable the transition of development models for island and coastal states towards sustainable development. The main output was the Abu Dhabi Declaration[30] which presented the Blue Economy concept as one that emphasizes conservation and sustainable management of oceans and complements the green economy. This conference paved the way to the critical UN Third International Conference on SIDS in September 2014, in Apia, Samoa. In 2018 Seychelles approved, the Seychelles Blue Economy Strategic Policy Framework and Roadmap[31] focusing mainly in 8 sectors: i) Coastal and Marine Tourism; ii) Sustainable fisheries; iii) Ports infrastructure and maritime transport; iv) Mariculture; v) Biotechnology and marine biological resources; vi) Oil & gas and renewable energies; vii) Digital connectivity and e-government; and viii) Enhanced trade. The governance framework was adapted, and a specific Department of Blue Economy was created, under the Ministry of Fisheries and Blue Economy, at the time.

MSP is under development and the Ministry of Environment, Energy and Climate is the leading authority, coordinating the Seychelles Marine Spatial Plan Initiative[32]. At present planning is underway, and the sectors involved in MSP are mainly biodiversity conservation, financing, fisheries, marine infrastructure, maritime security, tourism, recreation, non-renewable energy and renewable energy. Accordingly, a new Maritime Zones Act is being prepared to accommodate the new management and planning instruments.

Madagascar

Madagascar is the fifth largest island in the world and has a coastline of 5 600 km and an EEZ of 1 200 000 km^2. Its economy depends on agriculture, tourism, textile and mining industries and before the pandemic it was one of the fastest-growing economies.

The Government of Madagascar also targets Blue Economy as a critical policy to boost the economy and, in 2017, the Council of Ministers adopted the Resolution on National Framework for Blue Economy followed, in 2018, by a Proposal for National Strategy on Blue Economy, which however is not yet approved.

[28] See https://www.fao.org/fi/static-media/MeetingDocuments/SustainableBlueEconomy/3.pdf

[29] See https://www.un.org/en/conferences/ocean2022

[30] See https://sustainabledevelopment.un.org/content/documents/2983BEdeclaration.pdf

[31] See http://www.seychellesconsulate.org.hk/download/Blue_Economy_Road_Map.pdf

[32] See https://seymsp.com/

Also ongoing, with FAO support, is a project under the Finances Ministry comprising a National Plan for the Investment in Blue Economy. Preliminary drivers of Blue Economy include: i) Blue tourism and recreational marine activities; ii) Fisheries, shrimp farming and sea cucumber farming; iii) Food production and processing of marine products; iv) Marine renewable energies; iv) Innovative marine biotechnology; v) Creation and multiplication of Marine Protected Areas; and vi) Exploitation of offshore strategic resources.

Madagascar is also part of the Northern Mozambique Channel Initiative[33] and several workshops were organized with representatives from tourism, finance, economy, planning, industry, energy, environment, research, land use, fisheries and defence. Such an inclusive process aimed at developing a methodology for ensuring an enhanced integrated approach to MSP. As in Tanzania, the roadmap to MSP implementation is completed, and a methodological tool was put in place to contribute to the development of MSP in Madagascar. The Ministry in charge of Spatial Planning and the Ministry in charge of the Blue Economy, supported by World Wildlife Fund for Nature, are working together to advance MSP in Madagascar, and more particularly lately on the design of a methodological tool that aims to improve the contribution of spatial and temporal management tools to MSP. In November 2021 the actors of MSP in Madagascar met to remobilize all the stakeholders concerned and discuss how to improve the design of the MSP. Although no specific legal framework for MSP is yet developed in Madagascar, the Law on the Maritime Space (Loi, 2018) approaches integrated maritime space management and Blue Economy.

Mauritius

Mauritius, located east of Madagascar, spans 2 040 km^2 and has an EEZ covering 2 300 000 km^2. The economy of Mauritius strongly depends on Tourism making up around 24 % of GDP, while before the pandemic, fisheries accounted for around 2 % of GDP. Agriculture, textile and financial services are the other main clusters of Mauritius' economy. According to Bolaky (2020), various sectors have been earmarked by the Government for development of Blue Economy such as fishing, seafood and aquaculture, seaport related activities (investment opportunities in establishing regional trans-shipment base, bunkering, petroleum storage for re-export, ship building, repairs and allied services, ship supply and handling, ballast water treatment, ship waste treatment, home porting for cruise lines and ancillary services to vessels and the cruise industry), marine services including marine ICT, marine finance and marine biotech, deep sea-water applications, game-changer industries and the oil and gas support sector. In 2017 the World Bank prepared a report intitled "The Ocean Economy in Mauritius - Making it happen, making it last"[34] paving the way to an Ocean Strategy and in the budget of 2018-2019, it was announced that an Ocean Economy Unit will be set up with the responsibility of preparing a National Ocean Policy Paper, which is under approval. The task to develop national strategies and enhance Blue Economy is attributed to the Ministry for Blue Economy, Marine Resources, Fisheries and Shipping. Targeted areas are: i) mineral resources development; ii) ship building; iii) ship registration; iv) communication cable laying; v) pharmaceutical enterprises; vi) sustainable energy from waves and currents; vii) seaside leisure tourism; and viii) fisheries and aquaculture. MSP was developed in Mauritius and a EEZ Maritime Spatial Plan was approved, under the coordination of the national authority for MSP, the Department for Continental Shelf, Maritime Zones Administration and Exploration. However, a specific Bill for MSP is still under consideration by the MSP Coordinating Committee.

Discussion

Integrated Maritime Policies (IMP), Ocean Strategies and Blue growth proved to have a deep impact on ocean governance at four different levels: i) Policy drivers; ii) Government structures; iii) Institutional frameworks; and iv) Legal frameworks.

AIMS 2050 defines a framework of strategic actions and assumes as its final objective: "*Increased wealth creation from AMD that positively contributes to socio-economic development, as well as increased national, regional and continental stability, through collaborative, concerted, cooperative, coordinated, coherent and trust-building multi-layered efforts to build blocks of maritime sector activities in concert with improving elements of maritime governance.*" (AU, 2012). In 2015 the core objective of AIMS 2050 was formulated in Aspiration 1 in Agenda 2063 for Africa, as a priority for achieving inclusive growth and sustainable development, assuming that: "*Africa's blue/ocean economy … for continental transformation and growth, through knowledge of marine and aquatic*

[33] See https://cordioea.net/category/northern-mozambique-channel/

[34] See https://documents1.worldbank.org/curated/en/193931508851670744/pdf/120633-WP-PUBLIC-329p-Mauritius-text-10-20-17-web.pdf

biotechnology, the growth of the naval industry, the development of maritime, river and lake transport and fisheries; and exploration and exploitation of deep sea minerals and other resources" (AU Commission, 2015)

Reinforcing their position, the 3rd SIDS conference in Apia, Samoa, on September 3, 2014, concluded that "*...Sustainable fisheries and aquaculture, coastal tourism, the possible use of seabed resources and renewable energy are among the main sectors of a sustainable ocean economy in small island developing states*" (UN, 2014). Again, the AU embraced this challenge at the Sustainable Blue Economy Conference (Nairobi, Kenya, 2018) under the theme "Developing a sustainable blue economy; increasing momentum for Africa's Blue growth" (Sustainable Blue Economy Conference Technical Documentation Review Committee, 2018) paving the way for the approval of the Africa Blue Economy Strategy (African Union Inter-African Bureau for Animal Resources, 2019). The Africa Blue Economy Strategy focuses on five critical blue economy vectors, considered as thematic areas: i) Fisheries, aquaculture and ecosystems conservation; ii) Shipping, transportation and trade; iii) Sustainable energy, extractive minerals, gas, innovative industries; iv) Environmental sustainability, climate change, and coastal infrastructure; and v) Governance, Institutions and social actions. This approach is in line with the Africa Agenda 2063 (Africa Union Commission, 2015) which already highlighted that: "*Africa's Blue/ocean economy, which is three times the size of its landmass, shall be a major contributor to continental transformation and growth, through knowledge on marine and aquatic biotechnology, the growth of an Africa-wide shipping industry, the development of sea, river and lake transport and fishing; and exploitation and beneficiation of deep sea mineral and other resources*". It becomes clear that in Africa the blue economy is seen as a key driver for economic growth and job creation, overcoming the environmental sustainability dimension.

This panoply of policy instruments and drivers is reflected at the national and sub-regional levels in Africa, particularly in the Southern Africa Development Community (SADC) region. South Africa, with its key geostrategic position in the transition from the Atlantic to Indian Ocean, was a pioneer, not only by being the first African country to develop a specific legal framework for MSP, the Marine Spatial Bill (2017) but particularly, with the implementation of Operation Phakisa addressing ocean economy. According to Odeku (2021), Operation Phakisa is a clear example of how the South African government seeks to unlock the ocean economy, with the aim of fast-tracking transformation in identified priority areas, namely marine transport and manufacturing, offshore oil and gas exploration, and aquaculture, as well as marine protection services and ocean governance. Overall, the focus of Operation Phakisa is to promote economic growth and job creation.

Findlay and Bohler-Muller (2018) analysed the lessons learned from the Operation Phakisa Ocean Economy initiative and how this experience could be useful for the Western Indian Ocean region, addressing seven particular aspects relating to ocean governance, namely: i) Consolidation of ocean governance; ii) Capacity development within ocean economies, including within ocean governance; iii) Advancement of research innovation and technology; iv) Enhancement of compliance, monitoring and enforcement; v) The establishment of marine protected areas; the use of MSP and other decision support tools in ocean governance; and vii) Stakeholder engagement. One of their main conclusions highlights that it is essential that an ecosystem-based approach is followed, including MSP, by a full evaluation of ecosystem services and their associated externalities and trade-off decision-making within a sustainable ocean-governance model. These pressures on maritime space led South Africa to be the first African country to develop MSP, also making a commitment to sustainable use of the oceans. Although these policies did not impact at the government structure, a new institutional framework was put in place with a Directors-General Committee and Ministerial Committee on Marine Spatial Planning.

These types of initiatives spread at the sub-regional level, both in the Atlantic and Indian Oceans. In the Indian Ocean, the case studied countries are also part of the LMEs of the Agulhas current (east South Africa, Mozambique and the South of Tanzania) and the Somali Current (centre and north Tanzania and Kenya), as well as SIDS of the Indian Ocean. The potential for blue economy in the Indian Ocean comprises the sectors of: i) Fisheries and aquaculture ii) Marine mining; iii) Offshore oil and gas; iv) Shipping and ports; v) Marine leisure and tourism; and iv) Digital blue economy (Llewellyn *et al.*, 2016). Like South Africa, Mozambique embraced an Ocean Policy and Strategy and is betting on blue growth, supported also by an MSP legal framework. Tanzania has a recognized potential for blue growth, but seems to be behind as a result of insufficient capacity for management of marine resources and delays in marine aquaculture development hinders blue economy growth in Tanzania economy (Lyimo, 2021). Although no specific agency was created nor specific legislation on MSP developed, pilot projects are in progress and the political coordination is assured at the Vice-Presidents office level, supported by the NEMC. Kenya seems to be more committed to blue growth, with strong political support for the development of Kenya's Blue Economy with flag projects being carried out, such as the expansion of the Mombasa Port reinforcing Kenya's importance as a regional transport node. Although a National Ocean Strategy is in place and a Multisectoral Interagency Working Group is working to develop MSP, for the effective development of the Blue Economy, Kenya needs, among other things to build human resource capacity through investing in marine education and training, boost marine scientific research support the traditional industries of fisheries, aquaculture, tourism, blue biotechnology, ports and shipping, develop a Blue Economy database, resolve outstanding boundary disputes, and reduce illegal unreported and unregulated fishing (Rasowo *et al.*, 2020). In the countries which did not develop governmental departments or agencies dedicated to Ocean Governance/Economy, the ministry of fisheries and a specific agency for fisheries and blue economy lead the processes, supported by multisectoral interagency working groups.

The ecosystem approach to MSP at the sub-regional level highlights the importance of transboundary cooperation within LME's. Although transboundary cooperation at Agulhas and Somalia Current Large Marine Ecosystems (ASCLME) level is less strong and binding than is the case with the Benguela Current Convention, the existing institutional arrangements within the ASCLME system facilitate transboundary cooperation among countries, enhancing regional projects and institutions, such as the South West Indian Ocean Fisheries Project (SWIOFP); the UNEP WIO-Lab Project (Western Indian Ocean Land-Based Sources and Activities); the Seamounts Project (Applying an Ecosystem-Based Approach to Fisheries Management), among others (Satia, 2016). The ASCLME Project[35] developed a Transboundary Diagnostic Analysis (TDA) and a Strategic Action Plan, aiming to introduce an ecosystem approach to managing the living marine resources of the western Indian Ocean region, which could constitute grounds for an integrated approach to MSP at a sub-region level.

[35] See www.asclme.org

In the Atlantic, the Benguela Current region is under significant pressure for ocean space, particularly related to the abundance of economically valuable non-living marine resources, including petroleum, gas, precious stones and other minerals such as phosphate (Anon, 2014). Exploration and exploitation of these resources is a priority for all three countries of Benguela Current Convention (BCC), all pursuing blue growth to boost their economies. This exploration also leads to intense shipping, particularly from oil tankers which, together with fisheries and mariculture, contributes to increased pressure on maritime space. Angola, Namibia and South Africa developed strong cooperation aiming at an integrated approach to the governance and management of this LME, which became stronger with the entry into force of BCC in 2015 (Hamukuaya *et al.*, 2016). According to Finke *et al.* (2020), all countries have developed a similar spatial management approach, which is neither solely policy led, nor entirely zoning based, which consists of: i) general development guidelines, ii) sector development guidelines, and iii) a zoning scheme with spatial regulations. The national MSP schemes are in progress with specific legal support being considered. Although at the governmental/institutional level these policies did not lead to structural changes or the creation of new agencies, all BCC countries have put in place similar inter-ministerial and cross-sectoral mechanisms to enable the introduction of MSP and preparation of the first plans. Lead ministries and departments were identified to deal with national ocean strategies, blue growth and MSP, supported by formally established National Working Groups, also to work closely with other relevant ministries/departments and government agencies. The Nairobi Convention[36] also plays a role in assisting countries at a technical level in relation to blue economy, MSP, the SDG's and AU Agenda 2063, as was noted at the 8th Conference of the Parties in 2015 (Mahe, Seychelles). Since then, different programmes addressing these issues have been launched, in particular the Western Indian Ocean Governance Initiative (WIOGI)[37] to support the development of a Sustainable Blue Economy.

All the African SIDS studied embraced the Blue Economy as a booster for economic growth, employment and social welfare as well as a political priority. In all

[36] See https://www.nairobiconvention.org/,

[37] The project involves several countries in the region, namely: Comoros, Reunion (France), Kenya, Madagascar, Mauritius, Mozambique (Pilot Country), Seychelles, Somalia, South Africa, and Tanzania. See https://www.nairobiconvention.org/nairobi-convention-projects/wiogi/.

these countries, Ocean Strategies and/or dedicated Blue Economy Strategies are ongoing, under approval or being elaborated. Moreover, there are clear common drivers based on traditional sectors such as: i) Fisheries, ii) Tourism iii) Shipping and ports, but also focusing on value addition, value chains, exploring new and emerging sectors such as: i) Mariculture; ii) Renewable energy; iii) Biotechnology; and iv) Digital connectivity/smart trade. At the governmental and institutional level, SIDS clearly assumed blue economy as a political priority by creating dedicated ministries and governmental agencies, as is the case with Cape Verde and S. Tomé and Principe in the Atlantic Ocean. Although the latter does not yet have a structured Ocean/Blue Economy strategy, it did create a specific Unit for Blue Economy under the new ministry of Planning, Finances and Blue Economy. In Seychelles and Madagascar, specific Departments and General Directorates for blue economy were created and in Mauritius it was announced that an Ocean Economy Unit will be set up (Bolaky, 2020). MSP has also received attention from African SIDS and some legal initiatives or Pilot Projects are going on, but it has not received the same political priority, as no legal specific framework for MSP is yet in force in the studied SIDS. Nevertheless, some Maritime Spatial Plans are already underway and, once approved, will be regulatory, as is the case of Seychelles[38]. In Mauritius a Marine Spatial Planning Bill is envisaged and is under consideration by the MSP Coordinating Committee to support the implementation of MSP[39]. The Ecosystem-based approach is also being considered, as is the case of the 2012 treaties for the joint management of the Mascarene Plateau region, a submerged volcanic plateau, between Mauritius and Seychelles.

The initiatives for MSP under the Northern Mozambique Channel Initiative favour an ecosystem approach, setting specific goals for 2030[40], aimed at: i) High biodiversity value coral reef and associated ecosystems are maintained and enhanced through effective spatial management of marine uses to secure a sustainable future for coastal communities and economies; and ii) The institutional and knowledge foundations are laid for the application of multi-stakeholder-based MSP across the NMC region. Thus, although it seems not to have the same political priority as blue economy drivers, MSP and the ecosystem approach to the management of marine space are being considered and developed.

The SIDS studied clearly adapted their governmental structure to the new drivers of AIMS 50 and Blue Growth, by creating specific ministries dedicated to the Sea/Blue Economy, together with specific agencies. The continental countries, with the recent exception of Mozambique, maintained the "old" governmental structure, linked to fisheries and marine resources. However, the continental countries within SADC did develop specific agencies dedicated to maritime policy and blue growth, while putting in place inter-ministerial commissions to develop national ocean/blue economy strategies as well as MSP processes. There is direct inclusion of blue economy in the ocean governance models and institutional framework in all studied countries.

Conclusions

It is clear that Africa is moving towards development of a Blue Economy and since 2009, has not only addressed this through an Integrated Maritime Strategy but also by developing specific policies and guidelines to improve the Blue Economy, and integrate the main goals in the long-term vision for Africa in the Africa Agenda 2063, aiming at a coherent approach. Blue economy has been described as the "new frontier of African Renaissance" (Bolaky, 2020) and its potential to boost economic growth, generating employment and increasing social welfare has become clear for governments in the SADC region. Even in countries where the oil and gas sector are the major contributor to GDP, such as Angola and, lately, Mozambique and S. Tomé and Principe, the need for economic diversification and the importance of the Blue Economy is clear. These policies are more developed in the Indian Ocean, with South Africa and Mozambique and SIDS in the lead. Moreover, this policy driver is also supported by regional organizations, such as the Indian Ocean Commission[41] which launched a Regional Plan for Blue Economy in 2021[42] (CEA, 2021). However, Africa's coastal states lack financial and technologi-

38 See https://www.mspglobal2030.org/msp-roadmap/msp-around-the-world/africa/seychelles/

39 See https://www.mspglobal2030.org/msp-roadmap/msp-around-the-world/africa/mauritius/

40 See https://wio-c.org/projects-by-members/wwf/northern-mozambique-channel-initiative/

41 The Indian Ocean Commission is an intergovernmental organisation that links African Indian Ocean nations: Comoros, Madagascar, Mauritius, Réunion (an overseas region of France), and Seychelles. There are also seven observers: China, the European Union, the Organisation internationale de la Francophonie, the Sovereign Order of Malta, India, Japan and the United Nations

42 See https://www.commissionoceanindien.org/wp-content/uploads/2021/07/COI-PAREB-FINAL_29avril21.pdf

cal capacity to fully harvest ocean assets (Akpomera, 2020). The lack of skilled human resources, limited maritime security against piracy and illegal activities, and political issues, including corruption, limit the strategic use of the states' advantageous maritime resources for more locally beneficial development.

African SIDS emphasize the blue economy as a booster for their economy, mainly following FAO and World Bank guidelines (FAO, 2014; Cervigni and Scandizzo, 2017). The impact on the governmental and institutional structures and networks is greater in the SIDS, with the creation of dedicated ministries and agencies, while the "continental states" mostly opted for intersectoral commissions/working groups, with a specific ministry and agency that leads the process, both for Ocean/Blue Strategies as well as for MSP.

MSP is seen as a tool to facilitate Blue Growth and the process is supported politically. There are several encouraging signs towards the use of an ecosystem approach to MSP, with several initiatives going on at the LME level, both in the Atlantic and Indian Ocean, favouring transboundary approaches (Sacko, 2020).

Africa's vison for an Integrated Maritime Policy, which introduced the Blue Economy as the "new frontier for Africa Renaissance", has the potential to change the socio-economic approach to the maritime economy, contributing to human welfare, but this process has also triggered new horizons for ocean governance models and frameworks, at national and regional levels.

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Paradox incentive structures and rules governing sharing of coastal and marine data in Kenya and Tanzania: Lessons for the Western Indian Ocean

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Abstract

Comprehensive and timely data-sharing is essential for effective ocean governance. This institutional analysis investigates pervasive data-sharing barriers in Kenya and Tanzania, using a collective action perspective. Existing data-sharing rules and regulations are examined in respect to boundaries, contextuality and incentive structures, compliance and settlement mechanisms, and integration across scales. Findings show that current institutional configurations create insufficient or incoherent incentives, simultaneously reducing and reproducing sharing barriers. Regional harmonisation efforts and strategically aligned data-sharing institutions are still underdeveloped. This article discusses proposals to increase capacities and incentives for data-sharing, as well as the limitations of the chosen analytical framework. The debate is extended to aspects beyond institutional issues, i.e., structural data-sharing barriers or ethical concerns. Key recommendations include the establishment of more compelling incentives structures for data-sharing, increased funding of capacity-building and sharing infrastructure, and further awareness creation on the importance of data-sharing.

Keywords: data-sharing, ocean governance, collective action, institutional design, knowledge commons

Introduction

Coastal and oceanic ecosystems in the Western Indian Ocean (WIO) region sustain millions of lives and are characterised by their abundant biodiversity, which renders them immensely valuable in socio-economic and ecological terms (UNEP, 2015a). At the same time, they face various pressures related to anthropogenic activities and climate change (Diop *et al.*, 2016; Hollander *et al.*, 2020). Decision-makers are challenged with mitigating these pressures while settling space-use conflicts and considering the interests and needs of a diverse range of stakeholders. Local and national coastal management strategies also need to be harmonised to meet transboundary conservation goals in the region (UNEP, 2020). To this end, sustainability-oriented decision-making and integrated

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coastal area management would greatly benefit from accurate, up-to-date, and comprehensive marine biodiversity data (Pendleton *et al.*, 2020; UNEP, 2020; Satterthwaite *et al.*, 2021). However, the amount of available biodiversity data as well as processing and interpretation capacities are limited in East Africa and the larger WIO region (UNEP, 2015a). Effective data-sharing among researchers, policy-makers, and stakeholders is thus critically important. Efforts to make more data available and develop common sharing strategies are undertaken at various levels of operation, including data-sharing policies, regulations, and voluntary initiatives within and among state agencies, research institutes, and environmental organisations (UNEP, 2020). Despite these endeavours, further barriers to data-sharing persist and urgently need to be addressed by scientists, decision-makers, and environmental managers (Pendleton *et al.*, 2019; Satterthwaite *et al.*, 2021).

This article aims to examine prevailing institutional barriers to data-sharing, building on findings of a qualitative exploratory study which was conducted to investigate data-sharing practices in coastal East Africa (Schwindenhammer, 2020). Data-sharing is a complex activity and involves various forms of information exchange among actors, within or across different sectors, i.e., research, politics, industry, and civil society. Findings from the exploratory study suggest that considerably different and even contrasting normative views of *what* data-sharing should entail and *how* it should be organised exist. This, despite a common understanding of its importance in general. Effective, equitable, and harmonised sharing practices in East Africa and the larger WIO region are yet to be further developed and refined (Ibid., Schwindenhammer *et al.*, 2021). This analysis focuses on rules regulating data-handling practices in academia and research, and ways in which the current institutional design might prevent or complicate data-sharing. Implications of data-sharing for marine ecosystems sustainability and regional ocean governance are discussed. A collective action theory perspective (Ostrom, 1990) is used to investigate these issues and propose options for more productive exchange at the nexus of science, policy, and management. With this analysis, the authors intend to contribute to existing data-sharing recommendations for decision-makers and scientists in the WIO region (UNESCO-IOC, 2019; Schwindenhammer *et al.*, 2021). This article mainly focuses on data-handling practices in science and academia, while remaining conscious that these may differ in interaction with other sectors.

Background on data-sharing in the WIO region

Data and information concerning the state of key species and ecosystems in coastal and marine environments of the WIO region are important to inform decision-making (UNEP, 2020; Satterthwaite *et al.*, 2021). As such, the sharing of scientific products (data, information) with policy-makers is essential for ocean governance. Generally, many researchers are motivated to share their findings, e.g., to expedite scientific advancements, for collaborative purposes, to inform and educate, to increase the impact of their work, to generate funding, or to advance their career (Schmidt *et al.*, 2016; Figueiredo, 2017; Schwindenhammer, 2020). Such collaboration is vital to enhance research in data-poor countries, which have limited capacities to collect, process, and analyse data (Hollander *et al.*, 2020). Local researchers and practitioners with long-standing experience are well aware of blind spots and limiting factors for data-sharing in the WIO region. During expert workshops[1], they have underlined the need for more uniform data collection and handling approaches, increased fostering of sharing skills and capacities, and taxonomy training for non-academics working with marine biodiversity data (Schwindenhammer *et al.*, 2021). Furthermore, numerous initiatives exist to provide data and increase information flows. For example, the Nairobi Convention's Coral Reef Task Force (CRTF), which consists of two nodes of the Global Coral Reef Monitoring Network (GCRMN), has successfully compiled complementary ecological data from multiple contributors into consolidated datasets (Obura *et al.*, 2017; Gudka *et al.*, 2018). These datasets have been pivotal to recent regional reef status reporting (Ibid.) and other analyses (Obura *et al.*, 2021). Another important regional initiative is the Clearinghouse Mechanism[2] introduced by the UNEP Nairobi Convention[3], which aims to provide a regional data reference centre, facilitating data-sharing for Contracting Parties and their stakeholders in the WIO region.

[1] Workshops took place in the context of the NeDiT project, led by the Institute of Marine Sciences at the University of Dar es Salaam (IMS) and the Leibniz Centre for Tropical Marine Research (ZMT). The international partnership project aims to create a collaborative network of researchers using innovative digital technologies to inform marine resource management.

[2] Available at https://www.nairobiconvention.org/clearinghouse/

[3] The Nairobi Convention is an intergovernmental partnership between states, private sector, and civil society.

Theoretical Framework

Governing the commons

Resources can be conceptualised as different kinds of goods, e.g., public and accessible to everyone, or private and only accessible to few (Ostrom and Ostrom, 1977; Ostrom, 1990). When natural resources are shared by one or several groups, dilemmas of appropriation and provision are bound to occur. This is particularly true for *common-pool-resources*, which are freely accessible and at the same time highly subtractable, i.e., using the resource or extracting units from it will leave less for others. *Commons* are resource systems which may include several types of goods and are used by more than one individual or entity (Ibid.). For many years, commons researchers proposed that self-interested individuals were incapable of achieving collective benefits as a group, i.e., using it sustainably. This rather fatalistic assumption, most famously described by Hardin's *Tragedy of the Commons* (1968), has long served as a rationale to prescribe approaches for the governance of natural resources, i.e., through state and market instruments (Gordon, 1954; Olson, 1971; Demsetz, 1974). However, empirical findings have repeatedly indicated that communities are capable of aligning individual and group interests with regards to the use of shared resources (Ostrom, 1990; Gautam and Shivakoti, 2005; Cox *et al.*, 2010). *Collective action theory* aims to understand how such communities cooperate through self-organisation, and why some succeed in overcoming commons dilemmas whereas others do not. One of the most prominent scholars in this field, Elinor Ostrom, has identified social and ecological variables which influence self-organisation for community-based resource governance (Ostrom, 1990; McGinnis and Ostrom, 1992; Hess and Ostrom, 2007).

Data as a shared resource

Although collective action concepts generally describe dilemmas of natural resource use, for example fish stocks or forests, they may also apply to *knowledge commons* (Hess and Ostrom, 2007, p. 4). Knowledge can be understood as 'intelligible ideas, information, and data' and implies varying degrees of accessibility and possibilities for appropriation (Ibid., p. 8). Publicly available scientific data and information, which are analysed holistically across geographical and disciplinary borders, could potentially bear great societal benefits (Figueiredo, 2017). Advocates of the open science movement emphasise the increased transparency, quality, and impact that could be achieved, and stress the societal obligations of science (Elliott and Resnik, 2019; Krishna, 2020). In an ideal world, one may be inclined to envision scientific data as public goods, which are freely accessible and non-subtractable (i.e., one individual's use of data does not reduce the value to others using the same resource). Conversely, data are often understood as a common-pool resources which are rivalled in use and may be affected by collective issues such as freeriding, congestion, overuse, and conflict (Hess and Ostrom, 2007). Knowledge commons face issues such as 'commodification or enclosure, pollution and degradation, and nonsustainability', similarly to natural resources (Hess and Ostrom, 2007, p. 5; Krishna, 2020). Technological advancement throughout the last decades has rendered data a highly complex resource, creating new possibilities for sharing and collaboration, while simultaneously increasing the (perceived) risk of abuse and stealing (Hess and Ostrom, 2007, p. 14). In social environments characterised by high rivalry, i.e., competition for innovation and publications, incentives to withhold data often outweigh those for sharing. Cooperation may further be impeded by a lack of recognition and due credit, fear of data misuse, or additional efforts associated with sharing (Schmidt *et al.*, 2016, Figueiredo, 2017; Chawinga and Zinn, 2019). Researchers who have invested personal and financial resources into data collection and analysis may find themselves in a dilemma of wanting to share their findings while also collecting the rewards of their hard work (Ibid.). Even if they decide to share data, further issues may arise due to the incompatibility of different datasets that were collected under a variety of methodologies, equipment, time scales, details, or insufficient data quality (Schmidt *et al.*, 2016). When researchers lack the time and capacity to use the findings to their full extent, some data may remain unused on private servers or repositories. Such 'data loss' may also occur with digitally stored information on short-lived webpages and databases (Waters, 2007) or because of the lack of metadata describing these datasets (Chawinga and Zinn, 2019; Schwindenhammer *et al.*, 2021). Scholars have stressed the importance of preventing data loss and enclosure (Heller, 1998; Boyle, 2007; Krishna, 2020), as it may leave scarce scientific resources underused. This is particularly problematic in the context of coastal and ocean governance, in which knowledge is both scarce and urgently needed to address complex and pressing social and environmental challenges (UNEP, 2020; Satterthwaite *et al.*, 2021). Efforts are currently in place to mitigate against losing datasets by making global databases more robust to accept all data types and formats, e.g., the Ocean Biogeographic Information System (OBIS) (De

Pooter *et al.*, 2017) and the World Register of Marine Species (WoRMS) (Vandepitte *et al.*, 2018). Given this state of data-sharing, investigating underlying institutional structures may help to better understand barriers to data-sharing and how to overcome them (Hess and Ostrom, 2007; UNESCO-IOC, 2017).

Institutional design for collective action

Collective action, such as preventing the deterioration of common-pool resources, relies on trust and reciprocity among members of a community or group (Ostrom, 1990). Social interactions are organised by *institutions*, commonly understood rules which shape responsibilities, procedures, and payoffs for individuals (Ibid.), helping them to reduce uncertainty in social environments (North, 1990). Formal rules are officially documented and enforceable, sometimes legally binding, for example laws, contracts, or directives. Informal rules are based on social norms and interpersonal agreements, usually imposed through social repercussions, e.g., affecting an individual's reputation, access to certain social spheres, or collaboration opportunities (Ostrom, 1990). In the context of data-sharing, institutions provide incentives and disincentives for individuals or entities to make their data available to others. From a multitude of empirical studies, Ostrom and her colleagues identified eight design principles for 'robust, long-enduring' institutions (Hess and Ostrom, 2007, p. 7). These principles may help explain under which conditions trust and reciprocity can be built and maintained for the sustainable use of common-pool resources. Such collective action is also relevant in the context of data-sharing. Data in shared knowledge systems often involve different usage rights and opportunities for access for various user groups, which requires appropriate institutional arrangements to foster its equitable, efficient, and sustainable use (Ibid., p. 6). This is particularly relevant in the WIO region, where decision-makers from ten countries draw on their collective marine biodiversity knowledge to govern shared ecosystems. In the following sections, Ostrom's design principles will serve as a point of reference to assess select institutional arrangements for data-sharing in

Table 1. Design principles of robust institutions for data-sharing, based on Ostrom (1990) and McGinnis and Ostrom (1992).

Principle	Meaning for Data Sharing
1. Clearly defined boundaries: Individuals or entities who have rights to withdraw units from the resource must be clearly defined, as must the boundaries of the resource itself.	Clear definition of who may access and/or use specific sets of data, as well as the extent to which these data may be used, modified, and/or shared.
2. Context-specific rules: Appropriation rules restricting time, place, technology, and/or quantity of resource units are related to local conditions and to provision rules requiring labour, materials, and/or money.	Rules affecting the distribution of costs and duties in data-sharing arrangements are closely related to the distribution of benefits and rights. These rules are tailored to the situational conditions, i.e., type of data or capacities of involved parties.
3. Collective-choice arrangements: Most individuals affected by operational rules can participate in modifying operational rules.	Those involved may participate in creating and/or revising rules of data-sharing arrangements.
4. Monitoring of compliance: Monitors, who actively audit resource conditions and participant behaviour, are accountable to the participants or are the participants.	Those monitoring data-sharing activities are accountable to other members of data-sharing arrangements or are members themselves.
5. Graduated sanctions: Participants who violate operational rules are likely to experience assessed graduated sanctions (depending on the seriousness and context of the offense) from other participants, by officials accountable to these participants, or by both.	Those who violate rules of data-sharing arrangements face sanctions which are proportional to severity and context (e.g., repetition) of the offense. These sanctions are carried out by other members or monitors of the violated data-sharing arrangement.
6. Conflict-resolution mechanisms: Participants and their officials have rapid access to low-cost, local arenas to resolve conflict among participants or between participants and officials.	Spaces and procedures exist to easily resolve conflicts related to data-sharing arrangements, i.e., among members or between members and external officials.
7. Minimal recognition of rights to organise: The rights of participants to devise their own institutions are not challenged by external governmental authorities.	Involved parties can create and enforce their own rules for data-sharing arrangements without interference from government authorities.
8. Nested enterprises: Appropriation, provision, monitoring, enforcement, conflict resolution, and governance activities are organised in multiple layers of nested enterprises.	Rules, monitoring, sanctions, and governance activities related to data-sharing arrangements need to harmonise and complement each other among user groups and across scale.

Kenya and Tanzania and to identify potential areas for improvement. Table 1 contains an overview of the eight design principles, their definitions, as well as their meaning in the context of data-sharing.

Methodology

Data collection and previous analysis

An exploratory, qualitative study was conducted for the purpose of a Master thesis in the context of the NeDiT[4] project (Schwindenhammer, 2020). In November and December 2019, thirteen interviews were conducted in Kenya (Mombasa and Nairobi) as well as Zanzibar, Tanzania. Interview partners were chosen through a combination of criterion and snowball sampling (Patton, 2002), mostly involving partners of the NeDiT project network. Professional involvement with marine biodiversity data, such as using, providing, or producing it, was the main selection criterion. Potential interview partners were either approached in person or contacted via email before arranging conversations. Data were collected through semi-structured interviews, using the ´romantic conception of interviewing´ (Roulston, 2010). This interview method served to build trust and rapport between researcher and participant, encouraging a high degree of openness and self-revelation by the latter. A semi-structured interview guide granted flexibility and conversational flow while covering all topics of interest (Patton, 2002) and allowed participants to express ideas in their own words (Flick, 2015). Interview questions were informed by previous experiences of the NeDiT project, as well as Ostrom's institutional design principles and assumptions (1990), contributing to six research objectives. These objectives were to: 1) understand the current situation of actors who produce, process, analyse, or use marine biodiversity data; 2) identify motives for sharing marine biodiversity data in different formats; 3) identify existing formal and informal rules related to the handling and sharing of marine biodiversity data and analysing the mediating role they play; 4) explore patterns of interactions between involved actors and investigate the mediating role of social norms and trust; 5) determine the willingness and capacities of involved actors to share marine biodiversity data among each other and with others in different formats; and 6) to explore which new rules and norms could be established to increase collaboration among actors (Schwindenhammer, 2020). Prior to beginning the interview, participants were informed about the procedure, the purpose of the study, and about their rights to withdraw from the interview at any time. They were advised to sign the consent form and asked permission to record the conversation on a private mobile phone. Afterwards, interviews lasted between 34 and 96 minutes. Recordings were complemented by extensive notes taken during the interview, which were reviewed and annotated with further personal impressions after each session (Patton, 2002).

After the completion of field interviews, a two-fold qualitative text analysis was conducted to identify common themes around data-sharing. Interview recordings were transcribed as post-scripts, which included a detailed account in the form of paraphrased statements while remaining close to a participant's choice of language and expressions. Whereas parts of little relevance to the research topic were shortened or omitted, particularly relevant or interesting statements were transcribed as full citations, based on the judgment of the researcher. In another step, paragraphs within these post-scripts were re-ordered by topic to facilitate coding. A free version of the qualitative data analysis software f4analyse8[5] (Evers, 2018) was employed for two rounds of coding, using a combination of deductive and inductive coding. For the first round, an initial coding frame was developed according to the interview guide and findings from the Belmont Forum Open Data Survey (Schmidt *et al.*, 2016). The initial coding frame was tested using a line-by-line method and subsequently revised to include additional categories and three *in-vivo* codes which emerged from the second round of inductive coding. The final coding frame included five main categories which encompassed statements related to: 1) motivation for sharing; 2) descriptions of what makes shared data valuable; 3) accounts of how data are shared; 4) institutions and rules; and 5) conditions which may impede data-sharing. In addition to the content analysis, a comparison of institutional contexts was conducted, using a different framework[6] which is beyond the scope of this paper. The main purpose of this additional analysis was to understand how varying institutional configurations in seemingly similar contexts could produce vastly different outcomes regarding data-sharing.

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[4] More project information available at https://www.leibniz-zmt.de/en/research/research-projects/nedit.html

[5] Version 1.0.0-beta.26 FREE for Windows, available at https://www.audiotranskription.de/english/f4-analyse

[6] The framework used was the Institutional Analysis Development (IAD Framework). More detailed information about the study may be requested from the corresponding author.

Present article

Aggregated findings of the study were systematically re-examined according to Ostrom's eight institutional design principles (1990), which were thematically grouped into four clusters, i.e., '*boundaries*', '*congruence of context, costs, and benefits*', '*compliance and settlements*', and '*integration across scales*'. Specifically, *operational rules*, which organise daily activities around resource appropriation and provision, their monitoring, as well as the enforcement of sanctions, were investigated (Hess and Ostrom, 2007).

Findings

An abundance of operational rules affects scientific data-sharing practices in Kenya and Tanzania. This section relates these rules in view of Ostrom's institutional design principles (1990). In each cluster, the interpretation of these principles in the context of data-sharing is elaborated prior to specifying examples from the study.

Boundaries

This first cluster includes findings related to principle 1 (see Table 1), which is understood as the necessity to define explicit boundaries in operational data-sharing rules. Appropriation rules indicate individuals or groups who may access certain datasets and specify ways in which these data may be used, modified, or shared with others. Whereas some datasets may be freely available to anyone, e.g., in open access formats, others may be reserved for users of a certain professional background, employees or affiliates of an institute, agency, or organisation, or for individuals involved in a project. Moreover, financial boundaries restrict data access via subscriptions or once-off payments. Limitations for data use include restrictions for specific purposes, determine the level of aggregation which may be accessed and modified (i.e., primary or compiled data), or state the appropriate form of acknowledgement given to data collectors and owners. Sustainable data use implicates sensible information-handling, with boundaries in place to protect original ideas or vulnerable species from exploitation.

Participants of the study consider boundaries established in formal sharing rules important to prevent conflict, reduce ambiguity, and create a sense of control over the data. Yet, boundaries around shared data often appear unclear and non-transparent in practice, especially in the case of openly accessible databases or repositories. In such open formats, data contributors may anticipate loss of control and authority over their data, not knowing who can access them and how they are used. Concerns about data misuse, i.e., use and reproduction without permission, for unintended purposes, or without acknowledgement, may prevent researchers from sharing data to open platforms. Alternatively, sharing information about data, e.g., via metadata declarations or data papers[7], enables contributors to establish more explicit boundaries and maintain transparency. This form of sharing is popular among contributors and data users alike, as it creates data visibility while retaining control over access and use. Direct sharing of datasets, i.e., from one person or entity to another, also allows for an unambiguous communication of boundaries through verbal or written agreements. Overly strict boundaries, on the other hand, may also constitute data-sharing barriers. Some individuals may struggle with legal constraints on data-sharing, e.g., restrictive contracts which prevent sharing or use beyond the scope of specific projects. In the WIO region, a substantial amount of data is dispersed across specialised databases of government departments, research institutes, or organisations, only accessible to employees and affiliates. Moreover, sensitive data may be confined within national borders, e.g., data containing genetic information.

Congruence of context, costs, and benefits

This cluster reports on findings with respect to design principles 2, 3, and 7 (see Table 1). Appropriation rules are suitable in the context of application, e.g., considering the appropriate extent of data accessibility, the intended group of users and their capacity to adhere to given rules, as well as local culture and customs. Moreover, provision rules assigning costs and duties in data-sharing arrangements are closely aligned with the distribution of benefits and rights, promoting rule adherence from a cost-benefit perspective and conveying equity. For example, those investing time and financial resources into the collection, treatment, or provision of data profit from their findings or receive credit when these data are used by others. Equity is promoted by applying sharing rules to everyone while considering variations according to individual needs and abilities. If possible, affected users and contributors are involved in the creation or modification of operational rules. They may possess profound information and experience to devise effective and context-specific rules, contrary to externally imposed statutes which may neglect local conditions.

[7] Searchable metadata documents, which describe a particular dataset or a group of datasets and may be published in peer-reviewed journal articles.

Furthermore, locally devised data-sharing rules may be more potent in the absence of interference from external authorities, i.e., governments.

In the study cases, scientific data-handling is often regulated by rules created in local contexts, e.g., through internal policies or directives of research institutes, organisations, or journals. For instance, researchers are frequently required to contribute data declarations or entire datasets to internal repositories of their affiliated institute upon completion of a project. These operational rules are generally appropriate for affected employees and affiliates, matching their capacities to comply and securing sensitive information. Incentives for sharing are created by making it a prerequisite for research licenses, field-work permissions, project funding, or publishing. In some situations, general data-sharing rules require some flexibility on an individual basis, e.g., for projects involving longitudinal data collection. In absence of guaranteed data protection and credit for data contributors, individuals may perceive risks and burdens of sharing as larger than its benefits, especially in highly competitive research environments. This may reduce their willingness to share data unless attribution or authorship is strictly enforced.

Creating context-specific provision and appropriation rules is often a challenge for open access databases, which have a broad user base and mostly rely on voluntary contributions. Instead, some global databases provide additional sharing incentives, such as the DOI service[8] offered by the Flanders Marine Institute (VLIZ) which hosts the World Register of Marine Species (WoRMS), African Register of Marine Species (AfReMaS) and the Ocean Biodiversity Information System (OBIS) databases. This service enables researchers to formally publish their data, so they can be traced and cited. For projects or bilateral agreements, contracts are commonly used to establish formal data-sharing rules, e.g., creating a memorandum of understanding about when, how, and with whom data collected within a funded project should be shared. Projects involving multiple partners may employ initiative-specific data-sharing agreements with each data owner to facilitate sharing, as was the case for the Nairobi Convention's CRTF ecological data compilation (Obura *et al.*, 2017; Gudka *et al.*, 2018). Assigning data coordination and management responsibilities to a trusted non-governmental intermediary in the region sustains perceived impartiality and fairness in such large projects. Rules are also commonly established informally, i.e., through interpersonal verbal agreements. Due to direct and clear communication among involved parties, contracts and informal agreements often result in high contextuality and a fair distribution of benefits. Incentives to share data are high to avoid legal or social repercussions.

Compliance and settlements

This cluster includes findings regarding principles 4, 5, and 6 (see Table 1). Compliance with operational data-sharing rules is monitored to identify and address rule violations. Ideally, compliance monitors belong to the group affected by these rules or are in some way accountable to its members, rather than uninvolved external authorities. Known and observable monitors are more likely to establish rapport with the people they oversee, fostering trust and cooperation. Moreover, monitors who benefit from sustainable data-handling practices have additional incentives to ensure rule compliance. Sanctions for violations of operational data-sharing rules are fair and enforceable, which means they are proportional to the severity and context of the offense, avoiding excessively harsh or unreasonable punishments. Disciplinary measures include the limitation or withdrawal of permissions, e.g., to publish, conduct field-work, or access repositories. Consequences could also be of a financial nature, i.e., fines or retraction of funding. Finally, spaces and procedures exist to resolve conflicts around data-sharing at low costs.

Participants in this study generally perceive a high adherence to data-sharing rules. Ample accountability exists among people who directly interact and can observe each other's behaviour, e.g., colleagues and project partners. As data-sharing is often required prior to obtaining funding or permissions, monitoring automatically becomes a by-product of approval processes, and rules are easily enforced. Executives in research institutes have a strong interest to ensure that all scientific data are shared into their respective repository, particularly those serving a double-function as National Oceanographic Data Centres (NODCs). However, in absence of formalised rules, comprehensive monitoring and successful enforcement of data-sharing is less likely. Moreover, in settings in which data contributors and users seldom interact or stay anonymous, e.g., open access databases, individuals may attempt to avoid accountability. Monitoring through strong peer review systems

[8] Flanders Marine Institute, available at http://www.vliz.be/en/publish

may complement formal rules and create additional incentives to share, especially in competitive professional environments. For instance, the peer review screening by the WIO Journal of Marine Science (WIOJMS) enables regional reviewers acquainted with current research activities to detect plagiarised ideas or data. Disputes around data-sharing may emerge between or among individuals, organisations, or authorities. Breaching of contracts is usually followed by established protocols to settle conflicts, whereas disciplinary boards may conciliate violations of internal directives and codes of conduct. Data are often shared informally, rendering conflict resolution dependent on the personal relationship of involved parties. Although these arrangements often involve a high degree of accountability and are easily monitored, they are unsuitable to serve as reliable long-term understandings and lack standardised procedures to deal with disagreements, e.g., when relationships or conditions change.

Integration across scales

This cluster involves aspects related to the principle 8 (see Table 1), which translates to the need for data-sharing rules, monitoring, sanctions, and governance activities to harmonise and complement each other among user groups and across scale. Like puzzle pieces, different rules and regulations between individuals, organisations, authorities, and regional coordination bodies interlock and engage in the bigger picture of the data-sharing institutional landscape.

Operational data-sharing rules in the WIO region are often influenced by higher-level institutions such as national laws, e.g., decrees which require reporting of scientific data to government authorities or regulate data-sharing across borders. In Kenya, for instance, guidelines for data-sharing are provided by the National Commission for Science, Technology and Innovation (NACOSTI), which manages research activities in the country. Moreover, international data-sharing standards and obligations may prompt the creation of operational rules, e.g., through mandates of the Nairobi Convention (UNEP, 2015b), the Convention of Biological Diversity (Secretariat of the CBD, 2010, 2012, 2020) or the United Nations (UNESCO-IOC, 2014, 2019; United Nations, 2015). Norms for data-sharing in research and academia are further shaped by international frameworks, such as the 'Findable, Accessible, Interoperable, and Reusable' (FAIR) principles (Wilkinson *et al.*, 2016) or the 'CARE' principles for indigenous data sources[9]. Overall, various influences and interests have resulted in the large number and diversity of data-sharing rules and regulations in the region. Sometimes, these rules are inconsistent or even contradict each other. For instance, NACOSTI obliges researchers to report data collected in Kenya to the respective affiliation institute, including full datasets, metadata forms, research articles, or dissertations. NACOSTI further prohibits the sharing of certain findings across national borders. At the same time, these researchers may be bound to different sharing policies at their workplace or must uphold contract agreements with project donors and partners. Such legal constraints especially affect international and inter-organisational projects which conduct research on transboundary ecosystems.

Moreover, international or regional attempts to harmonise data-sharing often fall short of integrating across scale. A regional data-sharing protocol by the Nairobi Convention, for instance, would rely on voluntary commitments of signatory states. However, it may be incompatible with existing protocols in some of these states. Further, a considerable amount of research data never reaches national repositories, e.g., due to inconsistent sharing rules in institutes and organisations, or because of a shortage of data collection capacities.

Discussion

This investigation guided by Ostrom's design principles (1990) sheds light on the intricate web of social norms and formal rules for data-sharing in Kenya and Tanzania, as well as the institutional barriers which persist.

Paradoxes and payoffs

In their current constellation, institutional arrangements create incentives both for and against sharing, simultaneously reducing and creating data flow barriers. Given the pressing demand for scientific data, devising rules that are fair, realistic, and effective seems to constitute a delicate balance between creating incentives for voluntary sharing while also employing compulsory means. Although similar principles of institutional design may be applied, organising collective action for the sustainable use of shared data fundamentally differs from sharing natural resource commons. For instance, defining appropriate boundaries of access and use is often more difficult for a

[9] Global Indigenous Data Alliance, available at https://www.gida-global.org/care

dataset than for physical places, such as lakes or forests. Whereas data may be collected and processed in a specific place and by a closed group of people, boundaries become increasingly intangible as such data are shared and further handled in digital spaces. This is apparent in the difficulty to establish context-appropriate and enforceable sharing rules in large open access databases, which store data from a variety of places and contributors and have a broad, sometimes anonymous, user base. Although open sharing practices are often encouraged to reduce bureaucracy and accelerate research processes, highly contextual rules may actually produce additional administrative burdens, e.g., when specific contracts are needed for each alternative use of the same datasets.

The dispersion of scientific information across specialised databases is another example of such bureaucratic hindrances, as outsiders need to obtain permissions for data access and use. Whereas these boundaries may seem reasonable from an organisational perspective, they can impede essential collaborations and efficient data-reporting to national or regional regulatory bodies. A payoff between contextualised boundaries and streamlining of information seems inevitable if regional and international conservation goals are to be effectively supported. Informal sharing based on trust and personal relationships is frequently used to circumvent data accessibility issues and plays an important, yet ambiguous role. On one hand, these unofficial sharing pathways may serve as a foundation to develop formal agreements and build long-term professional relationships. At the same time, they can reduce transparency and awareness of existing data, reproducing the exact issues which data-sharing aims to reduce, i.e., research redundancy and information gaps. Furthermore, agreements bound to personal relationships are vulnerable to change and may even result in ownership conflicts. Thus, depending on the context, informal rules can both strengthen and undermine formal institutions.

Moreover, the incongruence of time horizons in science and governance poses another contradiction. Research and publishing are lengthy processes and scientific data may only become available after several years, whereas the information is needed immediately. Requiring data-sharing within shorter time frames would often be unattainable, as stages of data collection or processing may still be incomplete or because of inadequate personal capacities. Furthermore, premature sharing may contradict other obligations researchers have, e.g., with donors or project partners. Due to these discrepancies, research findings might become significantly delayed and cannot be used to inform policy and management decisions in a timely manner.

Perspectives for ocean governance

To facilitate regional ocean governance, i.e., achieving the Sustainable Development Goals (United Nations, 2015), the Aichi Biodiversity targets (Secretariat of the CBD, 2010), and milestones defined in the UN Decade for Ocean Science (UNESCO-IOC, 2019), data-sharing is imperative. Otherwise, the measurement of relevant indicators and mobilisation of the necessary political and financial capital to implement decisions is unattainable. In the WIO region, numerous approaches to counter the issues outlined above are starting to develop or already exist, albeit inconsistently. For instance, the growing use of metadata declarations, both for obligatory and voluntary sharing, is highly promising. Sharing metadata can constitute a valuable compromise, increasing the visibility of scientific data and transparency of their origin, while contributors retain control over access and use. This could be an especially fruitful option to encourage sharing to open access databases or from ongoing research projects.

Publishing and funding bodies possess considerable levers to shape and enforce data-sharing rules, and thus play a central role in fostering metadata availability (Chawinga and Zinn, 2019; Schwindenhammer *et al.*, 2021). Targeted policy adjustments could grant greater legal authority to NODCs and increase their capacity to act as intermediaries for the implementation of data-sharing mandates. Additionally, the inclusion of feedback mechanisms, e.g., tracing access and purpose of use, could further reduce fears of data misuse and increase voluntary sharing (Pendleton *et al.*, 2019; Chawinga and Zinn, 2019). Sharing could further be encouraged with a simplified publishing process, i.e., promoting data papers and attributing them the same significance as traditional research articles (Chawinga and Zinn, 2019; Schwindenhammer *et al.*, 2021).

Providing traceable and citable DOIs for datasets is another auspicious approach to reward frequent and swift data-sharing, especially for time-sensitive research needed to inform indicator-based conservation strategies (Pendleton *et al.*, 2019; Chawinga and Zinn, 2019). Such data citations further ensure that the data cannot be manipulated and anyone claiming them as their originators can be confirmed by the citations. Authorship crediting mechanisms in journals could further be adapted to better acknowledge the contributions of individual authors in large collaborations, contrary to the current focus on first and last authors (Li *et al.*, 2021; Devriendt *et al.*, 2022). Moreover, attention should be paid to create equitable, collaborative, and inclusive environments in diverse research teams, as a cordial work climate may positively impact data-sharing practices (Settles *et al.*, 2019). Currently, some researchers in the region have embraced collaborations for publishing global papers or regional assessments. Shared skills from these experiences spur the creation of new networks and can ultimately attract more funding as a wider group of donors and collaborators become involved. This is particularly relevant in instances in which no historical precedence for data-sharing policies exists and uncertainty about the benefits of sharing prevails.

Leonelli *et al.* (2018) stress the need to sensitise global data-sharing efforts to diverse research environments, pointing out global differences in access to digital infrastructure and highlighting the distinct challenges, concerns, and goals of African researchers. They further criticise the unequal power relations in global standards of scientific rigour and data quality, which are usually determined by countries with privileged access to technical and financial resources (Ibid.). Contextual considerations may increase the accessibility of international data-sharing spaces for researchers from low-resourced environments. To this end, donors and funding bodies could consider more flexible financing options, e.g., in the form of micro-funding for routine research activities (Rappert, 2017). Researchers should receive comprehensive data-sharing training, ideally early in their career (Chawinga and Zinn, 2019; Tanhua *et al.*, 2019; Schwindenhammer *et al.*, 2021). Chawinga and Zinn (2019) propose that researchers are educated to spend equal efforts toward data management as to research publications. Some scholars caution against imprudent data-sharing or absolute interpretations of openness (Leonelli *et al.*, 2018). Instead, they underscore the need to provide researchers with data-sharing tools that enable them to include a variety of considerations and make ethical, safe choices (Levin and Leonelli, 2017; Leonelli *et al.*, 2018). Examples for African-led initiatives prioritising ethical and adequate data-sharing include the African Open Science Platform (Boulton *et al.*, 2018) or H3Africa and H3BioNet (Leonelli *et al.*, 2018).

Limitations and further considerations

This paper highlights a few examples of data-sharing issues in the WIO region. However, these findings are not necessarily representative or generalisable for the entire region, as the empirical basis is a small qualitative sample from selected locations in Kenya and Tanzania (Schwindenhammer, 2020). Another limitation may have been the exclusive use of collective action as a theoretical perspective, as it only encompasses institutional aspects of data-sharing issues. Recalling the FAIR principles (Wilkinson *et al.*, 2016), sharing rules and directives often address data findability and accessibility, while omitting dimensions of interoperability and reusability. Comprehensive harmonisation of data-sharing efforts across scales thus exceeds the coordination of rules and should also consider structural barriers. Such obstacles include, for instance, inadequate quality, comprehensibility, or applicability of data shared for decision-making (Fisher *et al.*, 2010; Tanhua *et al.*, 2019; Schwindenhammer *et al.*, 2021); or navigation issues for other researchers wanting to use shared data (Pendleton *et al.*, 2019). Tanhua *et al.* (2019) suggest building interoperable data management systems based on existing structures, i.e., databases and open sharing infrastructures. A practical example for this is the European Marine Observation and Data Network (EMODnet)[10] effort, which provides access to European marine data from local, national, regional, and international repositories (Ibid). Additional efforts to increase the robustness of global databases, i.e., compatibility with all data types and formats, are currently in place to mitigate against losing datasets, e.g., in OBIS (De Pooter *et al.*, 2017), WoRMS (Vandepitte *et al.*, 2018), and AfReMaS (Odido *et al.*, 2022).

Others propose a combination of technical and cultural solutions, drawing from various sectors to address sharing barriers (Pendleton *et al.*, 2019). This could be in the form of 'ocean data combinatory machines', i.e., technology platforms which draw lessons from commercial online marketplaces to bring together data, researchers, and users (Ibid., p. 6). Data management systems should be built in anticipation of an increased volume of data in the near future, e.g., due to technological advances and facilitated data capture through sensors (Tanhua *et al.*, 2019). Close collaborations with sensor manufacturers could result in direct communication of metadata according to standards and conventions of the respective research community (Ibid.). Additionally, several scholars suggest incorporating

[10] More information available at https://emodnet.ec.europa.eu/en/about_emodnet#inline-nav-3.

user experience-testing when developing digital data-sharing infrastructure (Hermes *et al.*, 2019; Tanhua *et al.*, 2019; Volentine *et al.*, 2021).

Furthermore, a holistic reassessment of research priorities may be needed to avoid a mismatch of research efforts and conservation needs (Fisher *et al*., 2010), or a lack of research data use in policy-making (Aggestama and Mangalagiu, 2020). Such insights could be yielded from a focus on the co-production of knowledge and expertise (Wyborn *et al.*, 2019). Participatory methods, i.e., collaborative or transdisciplinary research designs, could highlight the perspectives of all relevant stakeholders, create more equitable data collection processes, and produce actionable data for decision-making (Berkes *et al*., 2000; Cinner *et al.*, 2009; Glass and Newig, 2019; Norström *et al.*, 2020). Lastly, a substantial amount of financial capital is necessary to build and maintain data-sharing capacity-building and infrastructure. This should be considered when allocating financial priorities in projects, as well as in organisational, national, or international budgets (Leonelli *et al.*, 2018; Chawinga and Zinn, 2019; Schwindenhammer *et al*., 2021).

Conclusion

This article intends to contribute to a more profound understanding of institutional data-sharing barriers in the WIO region and their implications for regional ocean governance. For this purpose, a collective action theory lens was applied, using Elinor Ostrom's institutional design principles (Ostrom, 1990) as an analytical framework to review existing data sharing-rules and how they interact. Data-sharing is commonly believed to be a matter of ethical obligation, fairness, and proper scientific conduct. However, this social norm does not always translate into the routines of people who work with marine biodiversity data. Current institutional configurations often create insufficient or incoherent incentives for sharing. In absence of clear, enforceable, and fair rules, competitive professional contexts tend to promote non-collaborative data-handling practices. Existing initiatives to harmonise data-sharing practices in the region still have little directly measurable effects on more effective coordination, as links to strategically align data-sharing institutions across governance levels are still underdeveloped. Overall, three key messages emerged from the findings of this paper. Firstly, more compelling incentives for individual and organisational data-sharing must be established. A transformation of the reward system in scientific professional circles could tie benefits and career advancement to timely and transparent sharing, e.g., promoting data papers or DOIs for datasets. Measures to make project funding or publishing contingent on data-sharing have also proven successful in encouraging open data practices. Secondly, capacity-building and infrastructure for data-sharing should be considered more prominently when allocating fiscal budgets for projects, institutes and organisations, or constituencies. Thirdly, further awareness creation on the importance of data-sharing among researchers, publishers, and funding bodies is essential. A sharing culture should be nourished in all research environments, with lessons learned from successful regional collaboration examples.

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Variations in community perceptions of ecosystem services within the Tana River estuary, Kenya: Implications for ocean governance

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Abstract

Coastal communities in the Tana estuary, Kenya, rely on a variety of economic sectors linked to ecosystem services, including small-scale fisheries (SSF), commercial prawn fisheries, and tourism. Despite its environmental and social importance, the estuary has been negatively impacted by overexploitation, pollution, and climate change. As a result, developing integrated management approaches for this area is a priority. The integrated approach to ecosystem services (ES) evaluation has widespread support because it emphasizes people's views of ecological value to human well-being and aims to provide a solution to the rapid depletion of our planet's natural resources. This study applied mixed methods to understand the perspectives of the communities on ES. It was hypothesized that perceptions of ES differ across communities with different socioeconomic characteristics, and this hypothesis was tested in two communities (Ozi and Kipini) that share the same ecosystem but have different socioeconomic characteristics. Kipini is an area near the ocean, whereas Ozi is a rural area further upstream. Differences were noted in the valuation of cultural services, while there were similarities in provisioning and regulating services. Mangroves, other trees, and river systems were considered to have higher ES provision than the ocean, floodplains, and settlement areas. The Ozi community ranked the ocean higher than the Kipini community, even though Ozi was located further upstream from the ocean; consequently, the perception that communities benefit more from resources that they are close to could be false. The relevance of using social ES identification to determine the distribution of benefits from coastal ES is highlighted in this study and will be beneficial for informing decision-making and developing all-inclusive governance structures.

Keywords: land use, land cover (LULC), local knowledge, socio-cultural values, rural communities, socio-ecological systems, ecosystem services evaluation

Introduction

There is increasing pressure on global coastal zones, especially in fragile ecosystems such as estuaries, where multiple activities such as fisheries, agriculture, and tourism combine to make these areas vulnerable to degradation. Ecosystem protection efforts to preserve the productivity and quality of coastal ecosystems are needed for the sustained provision of ecosystem services (ES) for human wellbeing to coastal communities. ES are the benefits people obtain from ecosystems. These are categorized as provisioning services (food, water, timber); regulating services (climate regulation, flood control, water quality); cultural services (recreational, aesthetic); and supporting services (soil formation, photosynthesis, and nutrient cycling) (MEA, 2005). Management interventions are especially needed in developing countries, where societal expectations have forced the need for rapid economic

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expansion, driving environmental concerns to the bottom of the priority list. Rural communities whose livelihoods depend on sectors that rely on ecosystem quality, such as fishing and tourism, have been harmed because of the environmental deterioration of coastal zones (Owuor *et al.,* 2017). Creating management measures to protect and increase these ecosystem services would be beneficial to such communities.

Effective management strategies must be developed in such a way that they have no negative impact on community well-being; otherwise, such management approaches in rural coastal regions result in a vicious cycle of environmental degradation and poverty (Pelletier *et al.,* 2019). Understanding the socio-economic value of ecosystems to various user groups is critical for resource management and governance. It aids in the understanding of resource use patterns and the benefits of coastal ecosystem services to the different user groups.

Mapping and valuing ES can help the understanding of the complex socio-economic and environmental importance of coastal ecosystems to a wide range of users (Asah *et al.,* 2014; Grêt-Regamey *et al.,* 2015). Creating maps of ES and assigning a value to the ES using community participation highlights the importance of individual ecosystems, and how it can be utilized as part of a community-based decision-making process. This approach has been used to understand ecosystems globally, such as the Mida creek in Kenya (Owuor *et al.,* 2017) and the St. Lawrence estuary in Canada (Jacob *et al.,* 2021). In these cases, the approach proved to be effective in highlighting the importance of ecosystems to different user groups, which can help guide decision-makers in the conservation and management of such complex ecosystems.

The Tana River estuary is one of East Africa's most important estuarine wetlands. Because of its extensive mangrove area, the estuary offers essential ecosystem services such as biodiversity preservation for endangered species, pollution mitigation, cultural services, and food production, notably for small-scale fishers (Manyenze *et al.,* 2021; Mwamlavya *et al.,* 2021). The Convention on Wetlands of International Importance designated the area as an important ecological and bird reserve in 2012 (Ramsar, 2012). Despite the critical importance of the area, human activities such as conversion of mangroves into farm areas, mangrove overexploitation for timber and firewood, overfishing, poor land use and agricultural practices and interruption of water flow from upstream (Samoilys *et al.,* 2011; BirdLife International, 2016) continue to impact this estuary.

Kenya has a well-developed coastal and marine protection governance structure, but it lacks an estuary-specific integrated management plan (Momanyi, 2016) .The National Oceans and Fisheries Policy (GoK, 2008), Forest Conservation and Management Act (2016) (GoK, 2016a), the Wildlife Conservation and Management Act (2013), (GoK, 2013a) (which also applies to mangrove regions and coastal forests), and the Integrated Coastal Zone Management Policy 2013 (GoK, 2013b) are all currently used to manage the estuary (Momanyi, 2016).

The Kenyan government is speeding up efforts to improve the Tana estuary's long-term management, including funding studies that will aid in determining the value of ecosystem services to various user groups (van Beukering *et al.,* 2015). Several studies have been conducted in this area, although the majority of them have concentrated on a single issue, such as fisheries (Fulanda, 2003; Munga *et al.,* 2016), socio-economics (Odhiambo-Ochiewo *et al.,* 2016), and ecosystem biodiversity (BirdLife International, 2016; Samoilys *et al.,*, 2011). Fewer studies, (e.g., van Beukering *et al.,* 2015), have provided an in-depth assessment covering social, cultural, economic and ecological aspects for a multi-disciplinary overview of the Tana River estuary. This research intends to close this gap by giving more comprehensive assessments of the region by mapping and contrasting ES across various user groups (Ingram *et al.,* 2012).

Understanding how and why ES decisions differ between societies and social groups has important implications for environmental management since it can help identify conflicting values and winners and losers in various circumstances (Daw *et al.,* 2011; Lapointe *et al.,* 2019). Different impressions of ES have been documented in both urban and rural groups (e.g., Shi *et al.,* 2016; Lapointe *et al.,* 2019). This might be due to the community's reliance on the environment – communities that rely on ecosystems for direct revenue are more likely to engage in ecosystem protection and maintenance (Lindsey *et al.,* 2007).

This study applied an integrated approach (Yang *et al.,* 2015) to examine local community perceptions on the ES provided by the Tana River estuary on the north coast of Kenya. Two distinct communities, Kipini and

Ozi, which share the same ecosystems, although one is located farther upstream with limited access to amenities such as roads, electricity, and piped water, were the basis of this assessment. Because of the socioeconomic and geographical contrasts between the two communities, the study was able to investigate how socioeconomic position and ecosystem access influenced the residents' views of ecosystem services. This will address the current gaps in the knowledge needed to understand how these communities interact with this ecosystem, which will have ramifications for the Tana estuary's governance, management, and conservation.

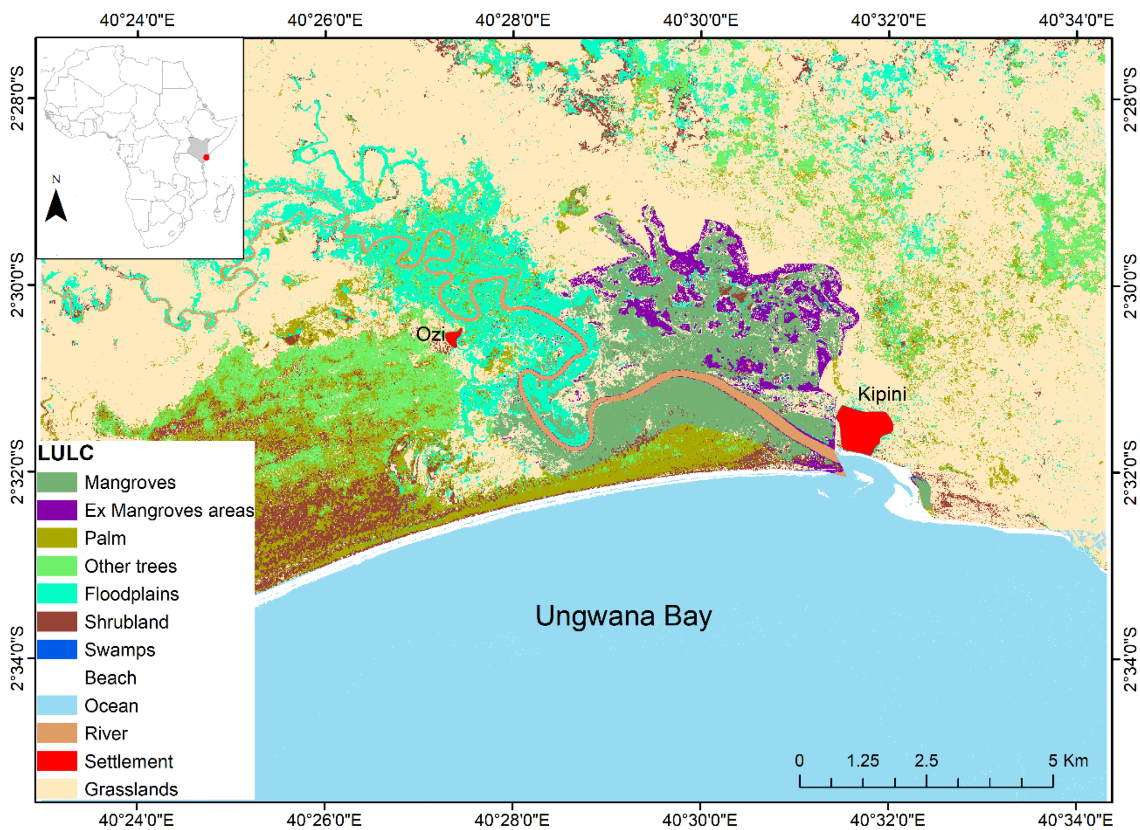

Figure 1. Map showing the location and main land use cover classes along the Tana estuary, and the location of study sites of Kipini and Ozi.

Material and methods

Study area

Tana River is the longest river in Kenya. Its estuary contains a diverse range of habitats, including mangroves, deltas, estuaries, and beaches, which sustain a wide range of fish, trees, and birds (van Beukering *et al.*, 2015). This study focused on the settlements of Kipini and Ozi in the Tana River estuary. Kipini is closest to the river mouth while Ozi is situated approximately 20 km upstream from Kipini (Fig. 1). Coastal and marine fisheries are one of the most significant economic activities in Kipini's peri-urban population, with artisanal fishers and artisanal catch rates among Kenya's highest (Abila, 2010; GoK, 2016b). Ozi is a rural village, with most of its residents reliant on riverine agriculture and fishing (van Beukering *et al.,* 2015).

Data collection and analysis

Data was collected through household surveys and focus group discussions and was combined in a matrix approach with Land Use Land Cover (LULC) mapping to understand the perception of ES by the two communities. LULC is the classification of human activity and natural components on the landscape over time using recognized scientific and statistical techniques. Remote sensing software approaches, such as supervised and unsupervised classification, are used for LULC classification (Di Gregorio, 2005).

Household survey

Structured interviews were conducted in the communities to obtain data on the demographics, the use of the different ecosystems in the area, and the ES they provided to the community. There are 801 households

Table 1. List of LULC classes and ES used for ranking during focus group discussions on ES scores.

LULC classes	ES Services		
	Provisioning services	**Regulating services**	**Cultural services**
-Mangroves -Other vegetation -Palm trees -Settlement -Beaches -River/stream -Open inshore Ocean **-Floodplains**	-Firewood -Charcoal -Construction poles/timber -Fishing gears -Honey -Medicine -Fisheries -Wild foods, -Palm wine	-Erosion protection -Carbon sequestration -Flood protection -Nutrient regulation	-Education and research -Cultural shrines -Recreation and tourism -Intrinsic values

in Kipini town and 389 in Ozi village, according to the population census (GoK, 2019). A systematic sampling design was utilized to select a total of 146 households, including 71 from Kipini (8.9 % of homes) and 75 from Ozi (19.3 % of households). The survey's target data included characteristics on home location, gender and age of the household head, household size, livelihood activity, education level, monthly revenue from livelihood activities, as well as fishing and agricultural assets.

Focused group discussion with LULC matrix

Data from the household survey helped with the identification of key LULC types based on the activities and ecosystem types mentioned by the respondents. These were used to guide the development of the LULC maps and collection of training data for a supervised classification in ArcGIS 10.5 of a Sentinel 2 satellite image obtained in August 2017. Level-1C Sentinel products are images that have already undergone preprocessing, including geo-referencing, extraction of top of atmosphere (TOA) reflectance and cloud masking. Key informants (community group leaders) from the area helped in identification of key areas where the different LULC was identified on Google Maps, and these were used as collection points of data for the LULC supervised classification training. The community leaders represented all key groups, including women, youth, fishermen, and opinion leaders.

The LULC classes were combined with ES, based on the definition by Kandziora *et al.* (2013). The matrix from this combination was presented to respondents for ranking/scoring using the Likert scale. The participants were asked how important each ecosystem type was for providing ES. Ranking was done after a discussion among the participants and after consensus reached. Valuing ranged from 1 (low) to 5 (high) (Burkhard *et al.*, 2009). The matrix is shown in Table 1 and a summary of the methodological approach is shown in Figure 2.

Two focus group discussion workshops were conducted in Kipini and Ozi in April 2017. All the relevant stakeholders in natural resources management

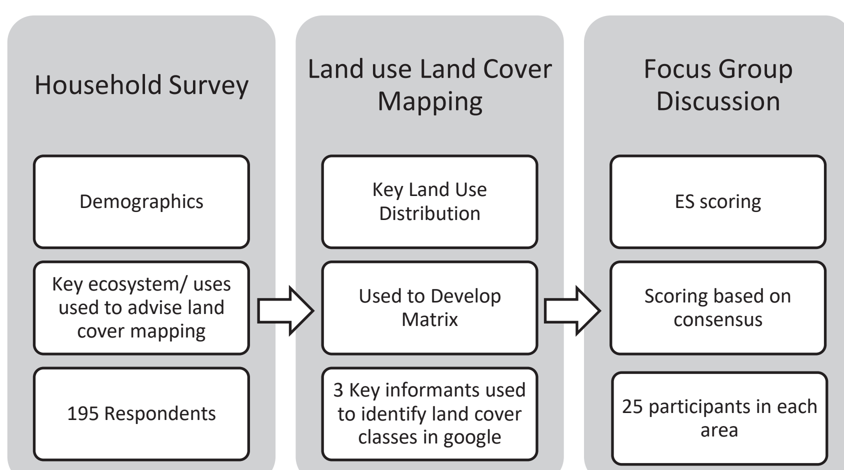

Figure 2. Summary of the methods used to collect data, the activities undertaken and the relationship between them.

were invited to participate, including the Kipini and Ozi Beach Management Units, the Kipini Community Conservation Management Forum, and the Ozi Community Conservation Association. Both workshops were attended by 25 people and took approximately three hours. The workshops were held on two consecutive days. Participants were asked to assess the LULC's importance based on a map of ecosystems.

Data analysis

Data were plotted to evaluate the difference in perception between the two areas for each of the ES classes (provisioning, regulation, and cultural services). Only questions on the socio-economic differences between the two groups were collected from the household surveys for this research. The data from the focus group discussion was used to show differences in ES perception. For proximity of the villages to the LULC, the LULC maps were converted to 100 m pixels, and the distance from the center of each pixel to villages was calculated; box plots were used to show variations in the distances of each pixel to the villages. The non-parametric Wilcoxon rank-sum test was used to compare the ranking by the two communities for the different LULC classes.

Results

The most significant source of income for the residents of Kipini was fishing, which was followed by farming and trading. Farming of rice, bananas and mango was the primary source of income in Ozi, followed by fishing and trading. Between the two communities, there were considerable educational disparities, with Kipini having more educated people than Ozi. However, there were no substantial financial differences between the two villages (Fig. 3).

Mangroves, palms, and floodplains are among the LULC types found in the Tana estuary. Mangroves predominate closer to the river mouth, whereas farmlands on the floodplains predominate farther upstream (Fig. 1). Distance / proximity of the two settlements of Kipini and Ozi to the various LULC classes vary. Kipini is near the coast and mangroves, but Ozi is nearer to other LULC classes like palm trees and floodplains. Kipini was closer to the areas with evident cut mangroves than Ozi (Fig. 4).

Variation in ES scores between Kipini and Ozi

Both the Kipini and Ozi community indicated that mangroves and other trees provide the following ecosystem services: firewood, charcoal, erosion protection, carbon sequestration, cultural shrines, education, and research, whereas the inhabited places supported minimal ecosystem services (Fig. 5). The relevance of the LULC class differed; for example, while Ozi participants identified eight ecosystem services originating from the ocean (cultural shrines, education and research, fisheries, flood protection, intrinsic values, medicine, nutrient regulation, recreation, and tourism), Kipini participants listed three ES (fisheries, intrinsic values, recreation, and tourism). Another noticeable variation was the significance of floodplains, where Ozi participants indicated eight

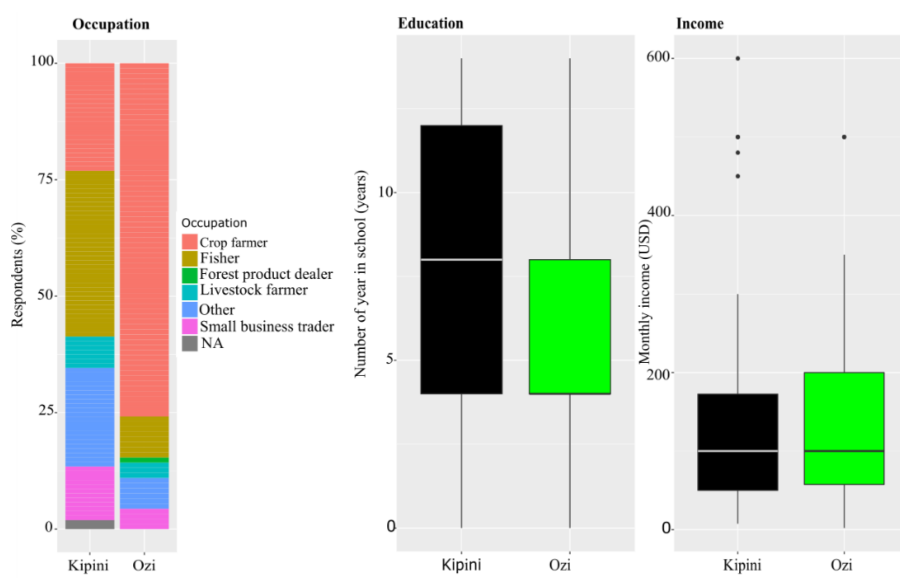

Figure 3. Stacked bar chart (occupation) and box and whisker charts (education and income) characterising the populations living in Kipini and Ozi.

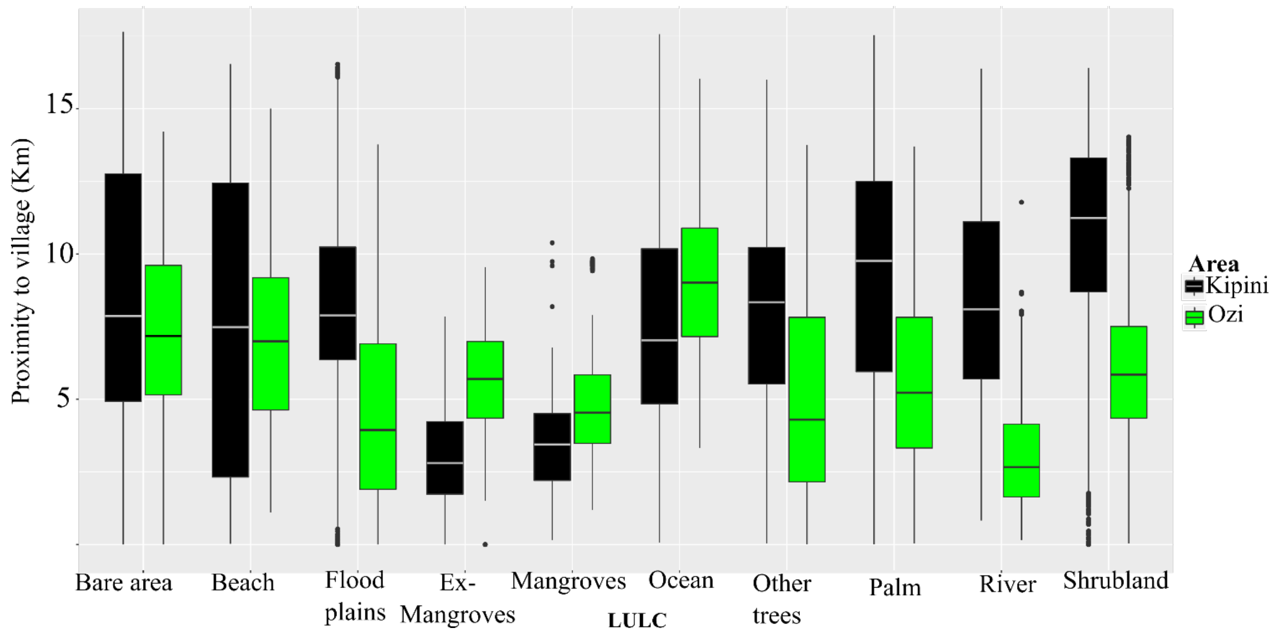

Figure 4. Box and whisker chart showing the proximity of Kipini (Black) and Ozi (green) to the different LULC classes. (Proximity is defined as the distance of each LULC pixel from the village).

important ecosystem services (firewood, construction poles, fisheries, intrinsic values medicine, recreation and tourism, nutrient regulation, and wild foods) that they draw from this land cover compared to three (erosion protection, fisheries, and nutrient regulation) for Kipini participants. Despite Kipini being significantly closer to the beach area, the Ozi participants identified more cultural uses for the beach area, such as cultural shrines, recreation, and intrinsic values (Fig. 5).

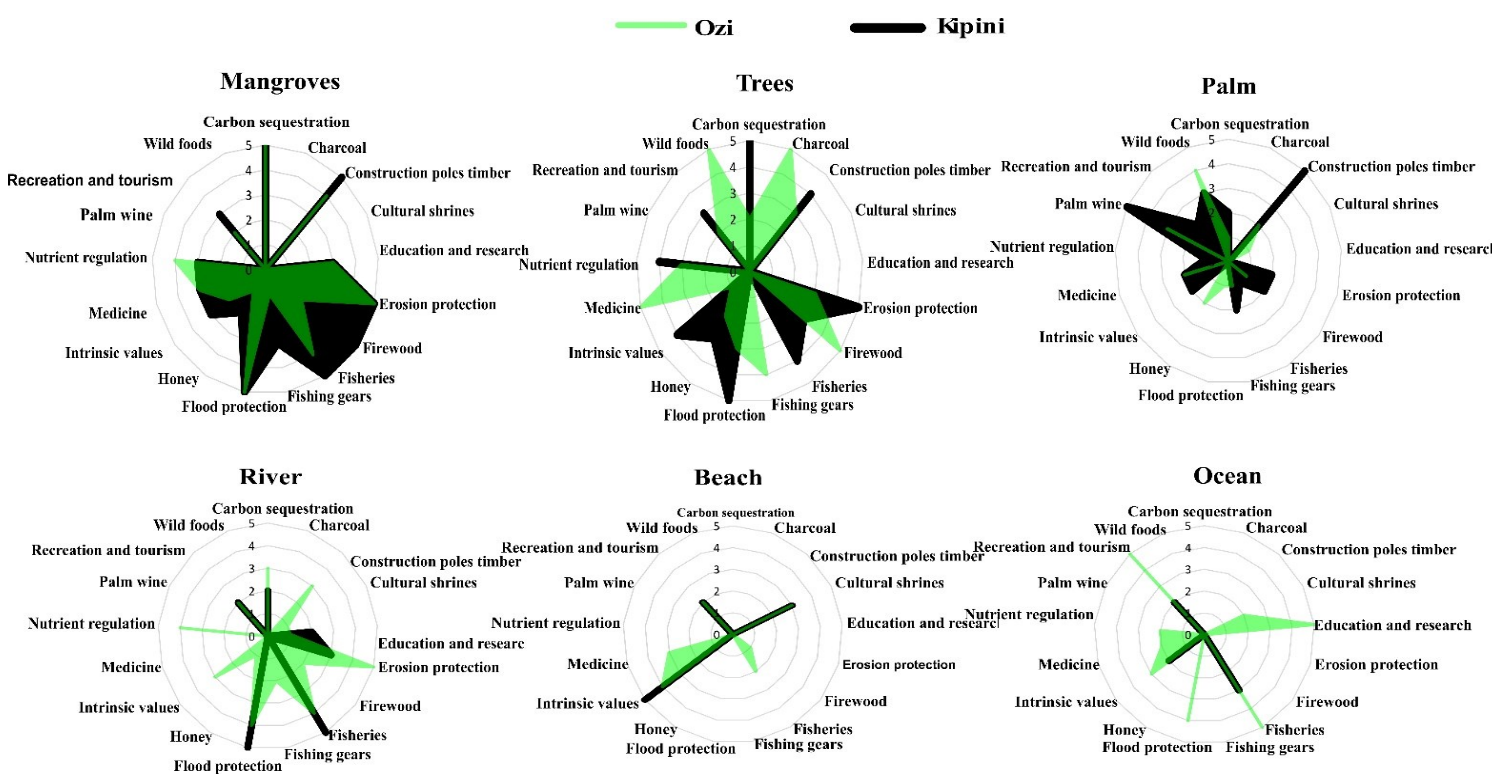

Figure 5. Spider charts comparing the differences in perception of the value of ES derived from the different habitat types, by participants from Kipini (in black) and Ozi (green).

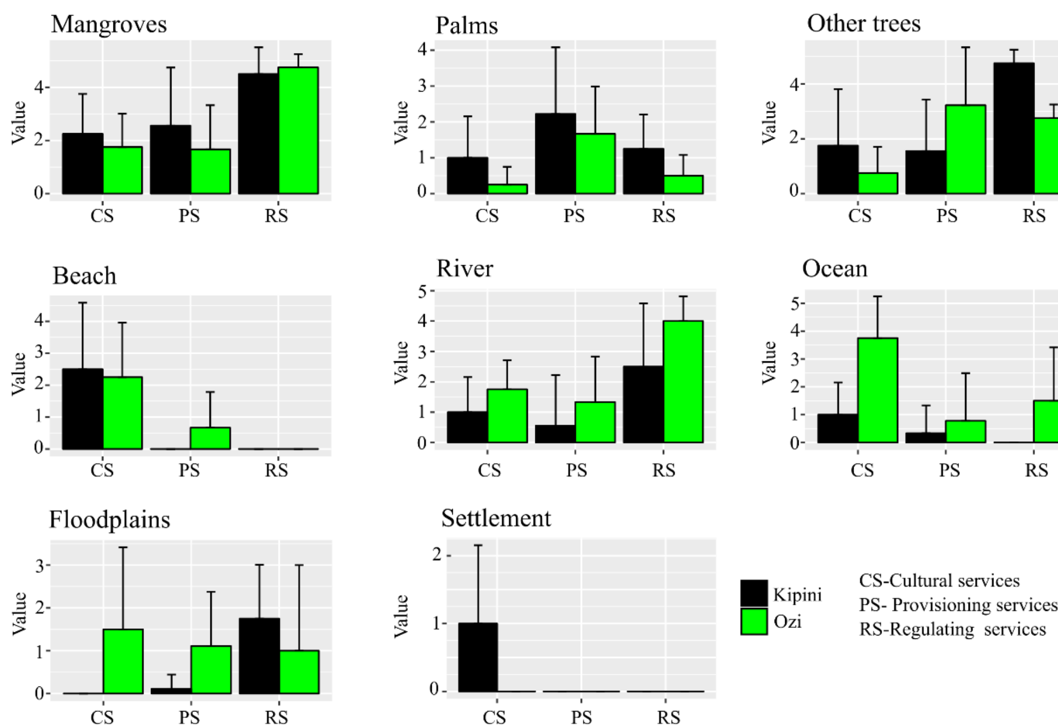

Figure 6. Bar charts showing the difference in perception of the importance of the different ecosystem for provision of the different categories of ES between Kipini (black) and Ozi (green) communities.

Other trees, palms, rivers, beaches, and flood plains scored highest in value, while ocean and settlement scored lowest. Other trees received the highest scores from Ozi, followed by mangroves, river, ocean, flood plains, and palms with the beach receiving the lowest score. Carbon sequestration, construction poles, timber, flood and erosion prevention, firewood, fishing equipment materials, and wild fruits are among the top ranked uses of other trees (Fig. 6). The Wilcoxon rank-sum test indicated a difference in ranking between the two locations for the river and ocean LULC classes (Table 2).

Discussion

This study sought to find whether there was a difference in the assessment of ecosystem services in the Tana estuary between two community groups (Kipini and Ozi). The Tana estuary provides a variety of ES to the two communities assessed, including carbon sequestration, construction poles, timber, flood and erosion prevention, firewood, fishing equipment materials, and wild fruits, highlighting the importance of this ecosystem to the community. The study found that there were variations in the identification and scoring of the ES by the two communities. ES

Table 2. Test results (p-values, 95 % confidence level.) of the Wilcoxon rank-sum test (W) for the difference of means of Kipini and Ozi scoring of the importance of the different ecosystems.

Land Cover/Ecosystem	W	p
Beach	138	0.32
Floodplains	122	0.13
Mangroves	0.4457	0.44
Other trees	199	0.22
Palm trees	199	0.22
River	106	0.05
Ocean	111.5	0.05
Settlement	180	0.163

derived from mangroves, palm trees and other trees had the highest scores from the Kipini community, while ES derived from other trees, mangroves, and the river received the highest scores from the Ozi community. The variation in the scoring of ES could be attributed to the difference in the cultural and economic activities connected with these two communities; farming was the primary source of income in Ozi, while fishing was the primary source of income at Kipini.

The Tana estuary communities have shown that, through the ES approach, they can identify benefits derived from the estuary. It is not the provisioning services but the regulating services that received the highest scores overall, followed by cultural services. The Kipini community assigns high scores to the regulating services from mangroves and other trees, while the Ozi community values those from mangroves and the river. The highest scoring of regulating services for mangroves is for flood protection (both communities), erosion protection, and carbon sequestration. Previous studies have shown that coastal erosion is a major concern for many coastal areas in Kenya and that mangroves can offer coastal protection against erosion, storm surges, and floods (Kairu and Nyandwi, 2000; Zhang *et al.,* 2012). The mangroves in the Tana estuary, as well as other vegetation, provide flood protection. The river is essential to the Ozi community because it provides water for agriculture. Floods occurs mostly upstream, affecting Ozi more than Kipini, which is largely shielded from river flooding by mangroves and dunes.

The ecosystems in the Tana estuary also provide important cultural ES to the communities. For the Ozi community, it is the ocean (cultural shrines, traditional medicine, intrinsic values), the beach (intrinsic values, medicine, cultural values), and mangroves (medicine, education, recreation). For the Kipini community, it is mainly the beach (intrinsic values, cultural values, recreation), mangroves (recreation, medicine, intrinsic values), and other trees (intrinsic values, recreation). The Ozi community is more rural with limited access to amenities such as hospitals and good road networks, therefore the majority of the residents use traditional medicine from mangroves and other trees (leaves, fruits, bark, and roots) for stomach disorders, fever, the removal of hookworms and fly eggs, and warding off bad spirits (Rönnbäck *et al.,* 2007). This explains why its residents gave high scores for the provision of these ES.

Furthermore, the communities' perceptions of the cultural benefits provided by floodplains and settlements differ. Floodplains were valued by residents of Ozi for their intrinsic and recreational worth, however Kipini did not score this habitat. Ozi did not award any scores for settlement (manmade places inhabited by people), but Kipini appreciated it for recreational and educational benefits. These findings could be because Kipini is a peri urban area with more buildings that provide social services, such as churches and schools, being in place compared to Ozi which is more rural with limited amenities. The Ozi community are closer to floodplains, thus their importance. This shows that certain ecosystem services are only accessible near the ecosystem that delivers them. Additionally, inhabitants of the Kipini village appear to utilise nearby recreational possibilities (settlement and the beach) rather than traveling inland to the floodplains for pleasure.

This finding, on the other hand, contradicts the scores given to the ocean. Even though Ozi is located inland and distant from the ocean, the community identified more uses of the ocean and ranked these higher than Kipini, particularly for recreational activities, flood prevention and nutrient management. Since they rely heavily on the ocean for fishing, it was expected that residents of Kipini would place a higher value on the ocean than Ozi. While fishing is the most valuable provisioning service provided by the ocean for Kipini, Ozi placed a considerably greater value on the ocean in general (Fig. 4). Fishing is the most significant source of food for Kipini, followed by mangroves and other plants. Palm trees and mangroves were also valued for their ability to provide fishing gear. The Kipini community is dominated by fishermen (Fig. 3), suggesting that socioeconomic considerations could determine the emphasis given to certain ES. Ozi is more rural, with limited access to roads and no access to power or gas. As a result, the score for using mangroves and other trees for charcoal and fuel in Ozi (Fig. 5) is higher, as this is their only source of energy for cooking. Furthermore, Ozi places higher importance on the provisioning service of wild food, as its harvest supplements the farming activities taking place in this village.

These results support previous research by Daw *et al.* (2011) and Lapointe *et al.* (2019) that indicate that various groups of people benefit from ecosystems in different ways, which could be impacted by their activities, access and socioeconomic position. Most of the disparities in community perceptions of ES in the

Tana estuary may be explained by their position and availability to the supplying ecosystems, as well as the communities' socio-economic culture. These hypotheses, however, do not account for all the evidence, such as the importance of the ocean to riverine Ozi community members.

Conflicts can emerge when one community's use of the ES has a negative impact on the provision of ES to the other. The cutting of mangroves by the Ozi community, for example, could have an influence on the Kipini people's food security as mangroves are fish spawning grounds. Furthermore, provisioning and regulating service trade-offs are sometimes made at the price of regulating services. This puts all ES at risk, because regulatory services are frequently related to the long-term supply of cultural and provisioning services (Turkelboom *et al.,* 2015). The estuary's ecosystems are interrelated, and activities in one area of the estuary can have an impact on ecosystem functioning and ES provisioning in other regions. Unsustainable agricultural practices by Ozi farmers on the floodplains could result in increased nutrient introduction into the ocean, posing a threat to Kipini fishermen. At the same time, because the Ozi community derives many cultural and regulating ES from the ocean, this could impact them too. To manage such an interconnected system as the Tana estuary, it is critical to bring the two communities together as stakeholders to establish ways that can promote activities that ensure equitable sharing of the resources from the ecosystem (Turkelboom *et al.,* 2015). This study creates a platform for developing integrated management objectives for the region, considering trade-offs to minimize possible conflicts, by explaining the value of distinct ecosystems to the two most significant groups in the lower Tana estuary. The information can be used to develop governance frameworks for the estuary.

Because estuaries are located at the land-ocean interface, governance frameworks that explicitly handle this interaction while also encompassing land and ocean-based sources of pollution and degradation are required (Momanyi, 2016). Analyzing the distribution of ES, who benefits from terrestrial and coastal services, and which activities have negative effects on ES is a critical first step in building suitable governance frameworks for the area. Area or place-based management is critical, as is management based on integrated evaluations that incorporate several types of information (e.g., social, cultural, local, traditional, and scientific knowledge) (Haas *et al.,* 2021).

Conclusions

This study highlights how the resource users' perceptions of ES from the different LULC classes found in the Tana estuary varied by location of the respondent and the type of LULC, such as mangroves, floodplains, and ocean. These findings provide a baseline for the importance of the different LULC classes found in the Tana estuary, therefore, showing the need for consideration of different landscapes in resource use planning and the need for integrating the preferences of the different resource users. Similar perceptions about provisioning and regulating services among respondents can be leveraged to reinforce participatory management and governance of the Tana estuary. The study also provides a knowledge sharing forum for the different resource users on the importance of the different LULC classes hence fostering an understanding on the need to conserve these ecosystems. The findings can be applied to the implementation of estuary management plans, community-based natural resources management programmes and activities within the Tana estuary or other estuaries in the Western Indian Ocean region.

Acknowledgements

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Understanding of Sustainable Development Goals among communities living adjacent to mangroves in Kenya

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Abstract
Mangroves are among the most productive ecosystems, known for their diverse provisioning, regulating, supporting and aesthetic services. The ecosystem directly supports livelihoods and ensures food security and nutrition of people through its ecosystem services (ES) such as wood, fish and medicines while protecting them by stabilizing shorelines, reducing flooding, and mitigating climate change and natural disasters such as tsunamis. In so doing, the ecosystem promotes several sustainable development goals (SDGs) and co-benefits several others. This relationship however remains under explored with limited studies on the co-benefit scenarios and the cognitive views of mangrove resource users. This paper highlights gaps in knowledge of the role of mangroves in development and the implications on ecosystem governance. The study analysed the 'ideal' scenario presented in secondary data in comparison to community perspectives on mangrove-related development. Bearing in mind the complexity of the concept of sustainability, development was categorised at local, national and international levels, and community members were asked to mention any known links to mangrove ES at any of the three levels. Results indicate that 45.4 % (n=166) of the community understood the roles of mangroves in development. The majority (79.5 %) were able to link the ecosystem to local (village level) development, 43.1 % to both local and national development while only 13.5 % could link the ecosystem to local, national, and international development. Forty-three per cent (n=157) of the community did not know of the relationship between mangroves and development while 11.6 % (n=43) felt that mangroves do not contribute to development. The study further disaggregated this knowledge socio-demographically, highlighting opportunities for enhancing governance, conservation and the use of mangrove ecosystems in Kenya.

Keywords: mangroves, community knowledge, synergies, sustainable development goals, governance

Introduction
In 2015, the United Nations formalised 169 targets with 230 indicators to gauge development under 17 Sustainable Development Goals (SDGs) (United Nations, 2015; Singh *et al*., 2017). The SDGs incorporated themes from poverty and hunger alleviation (SDG 1 and SDG 2), to environmental sustainability (SDG 7, SDG 13, SDG14 and SDG15), good health and sanitation (SDG 3 and SDG 6), promotion of equality, justice and education (SDG 10, SDG 5, SDG 16 and SDG 4) and sustainable infrastructure and economic growth (SDG 8, SDG 9, SDG 11, SDG 12) all supported under SDG 17 which seeks partnerships for the goals. The SDGs represent an ambitious effort to improve the lives of the world's poor and marginalized communities through a multi-sector approach (Wood *et al*., 2018). Embedded in the goals is an aim to rebuild and strengthen the integrity and function of ecosystems to secure the

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benefits they provide to both current and future generations (United Nations, 2015; Obura, 2020).

Mangroves are critical in this discourse for their social, ecological, and economic functions (FAO, 2007). The ecosystem provides habitat and nursery grounds for fish and other biodiversity (Field *et al.*, 1998; Kathiresan and Qasim, 2005), wood products and medicinal resources for coastal communities (Huxham *et al.*, 2017). Mangroves also capture and store carbon in their above and below ground components while buffering hinterlands against strong waves and storms (Alongi, 2012; Kuffman *et al.*, 2014). Additionally, mangrove areas are important cultural and aesthetic sites (Shilabukha, 2018).

Considering their broader contribution to the SDGs, exploitation of mangrove goods and services like timber, honey and aesthetics contributes to SDG 1 and SDG 8, eradicating poverty and creation of employment (Huxham *et al.*, 2017). Habitat and biodiversity supporting services provide food for SDG 2 (eradicating hunger) while supporting life for SDG 14 (life for marine biome), and SDG15 (life on land), (Wood *et al.*, 2018). Medicinal mangrove species and other therapeutic qualities of mangroves contribute to SDG 3 (improving health) (UN-DESA, 2017; Wood *et al.*, 2018). Carbon capture and storage link them to SDG 13 (climate action) (Chow, 2018), while their water regulating, and hazard barrier attributes makes them relevant for SDG 6 (clean water) and SDG 11 (sustainable coastal cities) respectively (UN-DESA, 2017).

Despite this critical value, mangroves have experienced a net loss in cover in recent decades, and what remains is highly threatened (Walters, 2003; Thomas *et al.*, 2017). About one fifth of the global mangroves have been lost since 1980, due to anthropogenic stressors, including over-extraction and deforestation from infilling, drainage and conversion of forest areas to aquaculture and agriculture (Walters, 2003; Thomas *et al.*, 2017). This decline has negatively impacted coastal communities and threatens to increase the vulnerability of small-scale fisheries which depend heavily on coastal habitats. As a result, at least 45 countries have mentioned mangroves in their national plans to tackle climate change (Deng *et al.*, 2022), 28 in their restoration pledges, and approximately 62 countries in their national biodiversity plans (IISD, 2019). Kenya has lost approximately 20 % of its mangrove cover since 1980 (Abuodha and Kairo, 2001; Government of Kenya, 2017) and now prioritises mangrove habitats in its commitments to climate change mitigation and biodiversity conservation (Government of Kenya, 2018). The country is committed to reducing its greenhouse gas emissions by 30 % by 2030, and to increase forest cover to at least 10 % of the land area (Government of Kenya, 2018). The latter has seen the introduction of protection efforts including a ban on mangrove logging (Government of Kenya, 2017; Government of Kenya, 2018). Coupled with efforts to enhance community based natural resource management (CBNRM), the country appears to be making steps towards Agenda 2030, but how do such efforts resonate with the primary resource users?

Studies show a close relationship between environmental sustainability and the quality of governance (Friess *et al.*, 2016) which, according to Lockwood *et al.* (2010) are reflected in eight principles - legitimacy, transparency, accountability, inclusiveness, fairness, integration, capability, and adaptability. Although these principles provide a suitable framework for analyzing governance effectiveness, the complexity of assessing the eight principles within a smaller scale and fitting them with the SDG framework remains a challenge. As a result, different schools of thought have developed simplified assessment frameworks, such as procedural justice, that emphasize the understanding of stakeholder engagement throughout the decision-making process (O'Beirne *et al.*, 2020). Procedural justice advocates for openness and inclusivity in decision making from inception to implementation as reflected in socio- demographic characteristics.

Here we apply the tenets of procedural justice in understanding effectiveness in mangrove governance as reflected in community knowledge. We present the community perspective on the role o of mangrove in development in comparison to an 'ideal' scenario presented in the literature as a step towards assessing the effectiveness of mangrove governance frameworks in Kenya. Community perspectives can provide useful insights into governance frameworks by providing a comparison between community identified needs and current regulations (Shirkhorshidi, 2013; Bennett and Dearden, 2014)

Material and methods

Study area

The study was conducted in Vanga, a fishing location on the south coast of Kenya. Vanga is located at 4°39´00"S and 39°13´00"E along the trans-boundary area between Kenya and Tanzania. The site was chosen because of its geographical proximity to mangrove forests and the dependence of the adjacent communities on fisheries as their main source of livelihood (Kenya National Bureau of Statistics, 2013). Four villages within Vanga Location (Vanga, Jimbo, Kiwegu, and Majoreni) were sampled in the study (Fig. 1). Fishing, subsistence farming, small-scale businesses, and mangrove harvesting are the main economic activities in the area (Kenya National Bureau of Statistics, 2013).

Assessment of the relationship between mangroves and SDGs

The relationship evaluation framework of Singh *et al.* (2017) was operationalized (Fig. 5) in mapping the relationship between mangrove ecosystem services (ES) and the SDGs. Mapping of the relationships was done through a series of secondary data reviews.

Secondary data sources included reports, journal essays, internet sources, and book chapters related to ES and the SDGs. The focus of these reviews was to compile a matrix representing the ES and SDG targets. During the review, SDG targets were translated *verbatim* as presented in the texts of the SDG blueprint while the relationship assessment was in-depth, leading to an array of co-benefits. For instance, although specific targets like halting biodiversity loss refer directly to biodiversity support, the service was not only limited to biodiversity-related targets but assessed from the broader perspectives of poverty and hunger alleviation, good health and sanitation, environmental sustainability and promotion of equality, justice, education and infrastructure development. This information was then compiled into a comprehensive matrix of the "ideal" relationship between mangroves and SDGs for expert review (Appendix 1). The "ideal" relationship was contextually defined as the desirable link between mangroves and SDGs as envisioned in the SDG blueprint. In the ideal situation, social dynamics play harmoniously

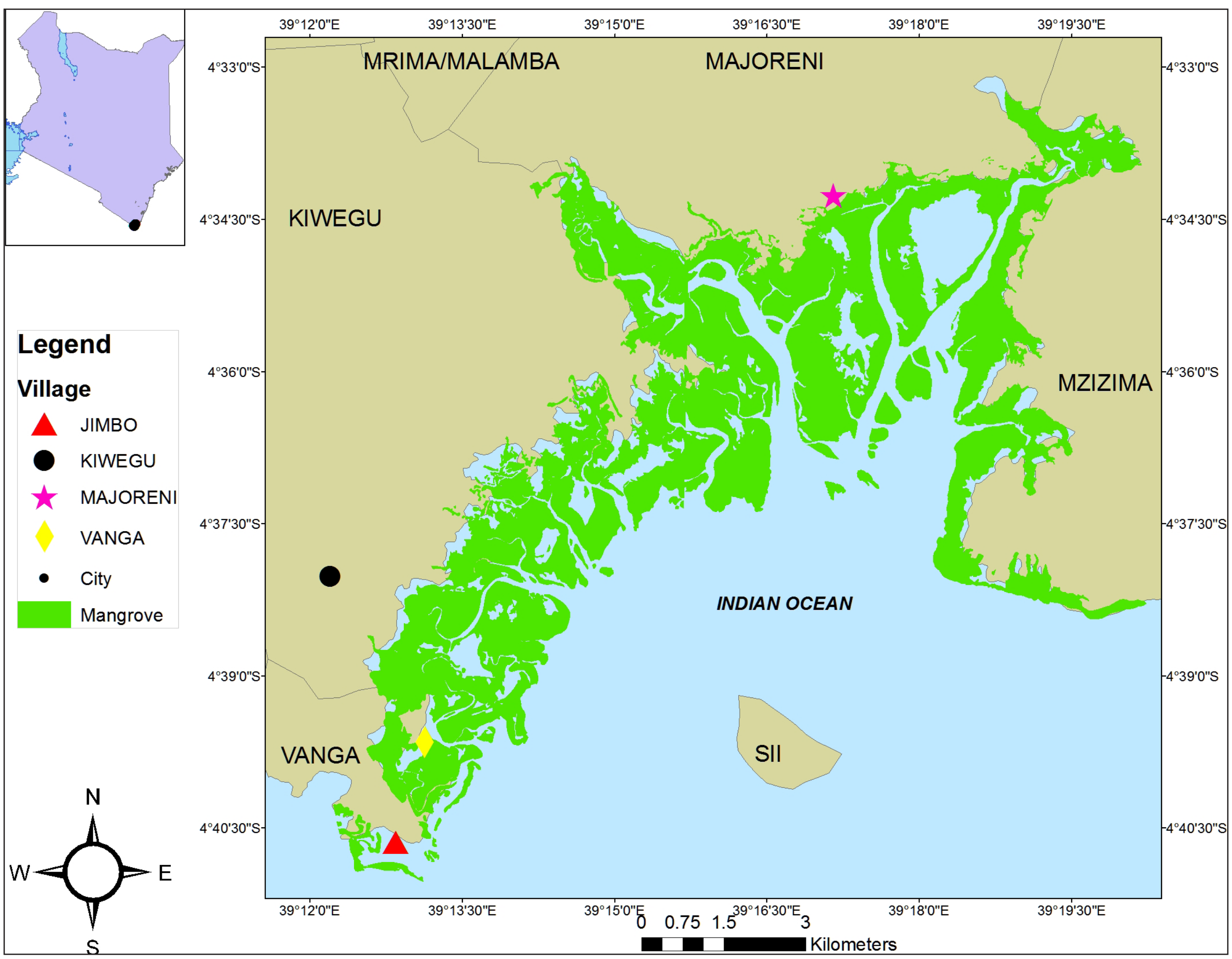

Figure 1. A map representing the study area showing the study sites, Jimbo (red triangle), Kiwegu (black circle), Majoreni (pink star) and Vanga (yellow diamond). The extent of mangroves is highlighted in green.

with the ecological needs to present sustainable development outcomes.

Assessment of community perceptions of the relationship between mangroves and SDGs

Community perceptions were disaggregated by age, gender, level of education, and period of residence in the study area while development was categorized into local, national and international levels. Local development was limited to village boundaries, national development to the country boundaries while international development was development beyond national boundaries. Considering the complexity of sustainability, community members were asked to generally mention the link between mangroves and development at local, national and international level. Sustainability principles were then applied to the responses to assess their perceptions of the link between mangroves and the SDGs.

The study adopted a cross-sectional design employing simple random sampling. Daniel's (1999) sampling formula, reviewed in Daniel and Cross (2018), was used to determine the sample size of the study:

$$= \frac{N \times X}{X + N - 1}$$

Where, X = Zα/2 *p*(1-p) / MOE2 (Zα/2 is the critical value of the normal distribution at α/2, e.g., when the confidence level for this study is 95 %, α is 0.05 and the critical value is 1.96), MOE is the margin of error, p is the sample proportion (50 % for this study), and N is the population size) (Daniel and Cross, 2018). This study used a questionnaire survey, focused group discussions (FGD), and secondary data review.

A total of 366 respondents were sampled for the survey. FGDs involved men and women categorized by age groups (youths and elderly). Each FGD consisted of 8-12 individuals of the same gender and age group.

Hypothesis and statistical tests

The null hypothesis for the study was that socio-demographic factors influence knowledge of the synergies and trade-offs. Spearman's correlation was used to test the null hypothesis with knowledge of the relationship between mangroves and the SDGs as the dependent variable and sociodemographic factors as the independent variables. The r-value (relationship) was determined using the formula:

$$Rs = 1 - \frac{6 \sum d2}{n3 - n}$$

p=Spearman's rank correlation coefficient
*d*2=difference between the two ranks of each observation
n=number of observations

Spearman's *rho* is a statistical framework for non-parametric test of the association between two variables, where the value r = 1 means a perfect positive correlation and the value r = -1 means a perfect negative correlation (Prion and Haerling, 2014). This has been used in a wide range of socioeconomic studies to determine the relationship between trends and phenomena. We based our analysis on the practical guide in Akoglu (2018) in assessing the correlation coefficient between independent and dependent variables of this study.

Data processing

Qualitative data was transcribed and coded according to themes of the study using Atlas.ti7 then analyzed and presented in rich narratives. Quantitative data was analyzed using descriptive and inferential statistics and presented in graphs and tables.

Results

Sociodemographic characteristics of the study area

The sample size of the study included 56.4 % (n=206) female and 43.6 % (n=160), male participants. Forty-eight percent of the sample population were the heads of households, while 52 % were close relatives to the head of households living within the households and contributing to household income. The highest proportion of the respondents (49.3 %) were aged 18-35 years, 42 % aged 35-60 years while 8.7 % were aged over 60 years. Education standards in Vanga were low with the majority of the respondents (62.3 %) having attained only primary school education and 19.4 % no formal education. Only 18.3 % had a post-primary school education, amongst whom 1.7 % had attained tertiary education. This indicated a low transition rate to higher education levels with a 44 % disparity between community members with only a primary school education and those with at least a secondary school education. Most respondents aged over 60 had no formal education while the majority of those aged 18-35 and 35-60 had only a primary school education. Most women had a primary school education while the majority of men had at least a secondary school education (Table 1). Forty eight point six percent (48.6%) of the study population had lived in the study area for more than 30 years, 25.1 % between

Table 1. Frequency distribution of the socio-demographic characteristics of the study area.

Education			Village								
			Jimbo		Kiwegu		Majoreni		Vanga		%Aggregate (n)
			Gender		Gender		Gender		Gender		
			Female	Male	Female	Male	Female	Male	Female	Male	
			% Freq	% Freq	% Freq	% Freq	% Freq	% Freq	% Freq	%Freq	
Others/Non-Formal	Age	>60	4.3	0	2	13.6	0	10.2	1.5	7.3	4.9 (18)
		18-35	8.7	8	6.1	2.3	0	4.1	6.2	0.0	4.4 (16)
		35-60	15.2	4	20.4	2.3	6.4	6.1	13.8	7.3	10.1(37)
Primary	Age	>60	0	16	0	9.1	2.1	2.0	1.5	2.4	3.3 (12)
		18-35	34.8	40	30.7	20.5	53.2	16.3	30.8	29.3	31.4(115)
		35-60	26.1	4	38.8	34.1	19.1	18.4	40.0	24.4	27.6(101)
Secondary	Age	>60	0	0	0	0	0	0	0	2.4	0.3 (1)
		18-35	10.9	24	2	4.5	17	28.6	0	17.1	11.7(4)
		35-60	0	4	0	9.1	2.1	10.2	3.1	9.8	4.6 (17)
Tertiary	Age	18-35	0	0	0	4.5	0	4.1	3.1	0	1.7 (6)
% Aggregate (n)			64.8(46)	35.2(25)	52.7(49)	47.3(44)	49(47)	51(49)	61(65)	38.7(41)	100 (366)

20 to 30 years, 20.8 % between 10 to 20 years while only 5.5 % had lived in the area for less than 10 years.

Mangrove co-benefits

Sustainable management of mangroves results in several co-benefits with economic, social and ecological importance. 'Co-benefits' were categorised under the MEA (2005) categories of regulating, provisioning, supporting, cultural and aesthetic services. The term 'co-benefits' is contextually used to refer to the ecosystem services whose exploitation results in no trade-offs among the social, economic, and ecological benefits of an ecosystem (Fig. 2). Results indicated that 16 ES provided by mangroves have co-benefits, most of which occurred under the regulating and the cultural and aesthetic services categories (Fig. 2; Appendix 1). Under the regulating services, it was found that the ecosystem is critical in the purification of air and water, shoreline protection, as a carbon sink, for rain catchment and as a hazard barrier, protecting hinterlands from environmental hazards. Under the provisioning services, mangroves were found to be an important store of historic artifact, a source of indigenous medicine and animal feeds. The ecosystem supports small invertebrate life, bees, fish diversity, as well as an important nursery grounds for fish. Under

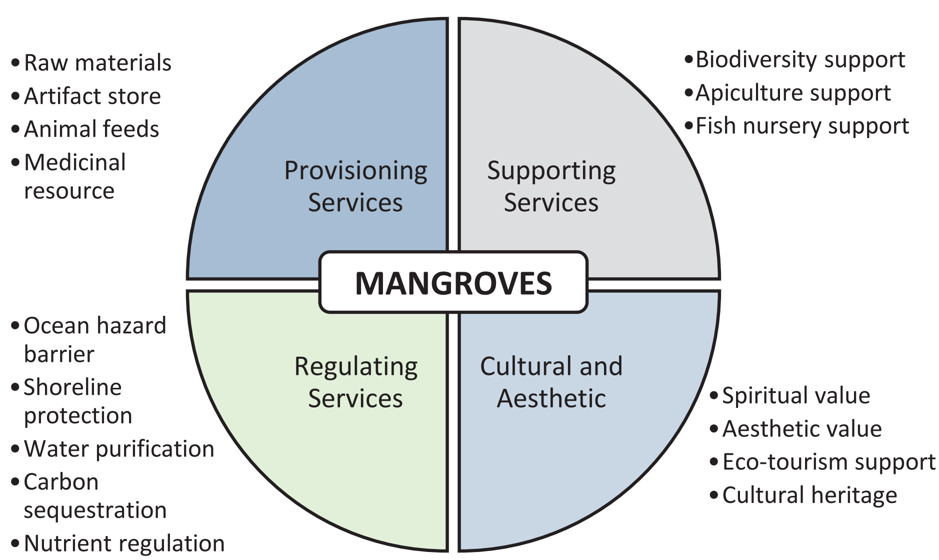

Figure 2. The mangrove ecosystem services identified by the community members of Vanga, categorized under the provisioning, supporting, cultural and aesthetics, and regulating services.

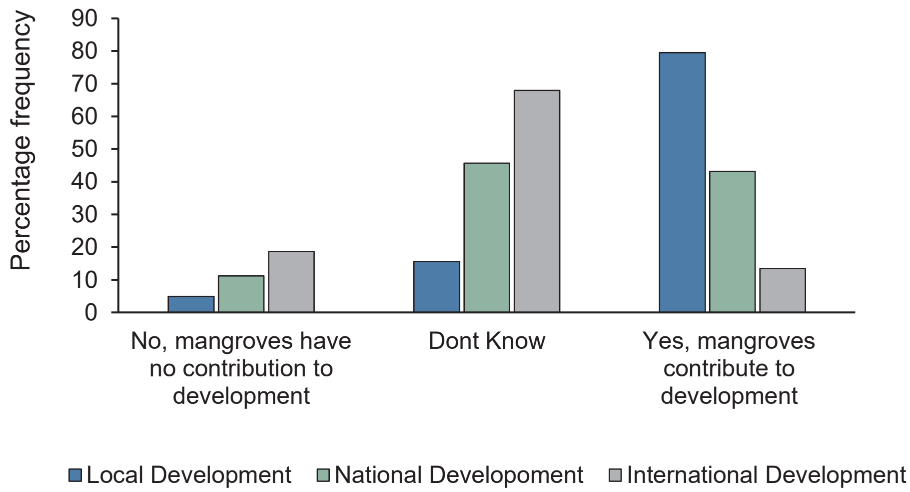

Figure 3. Community knowledge of the roles of mangroves in development. Development was assessed at local, national, and international levels represented by blue, green and grey bars respectively.

the cultural and aesthetic services, mangroves were found to be of important spiritual value with some trees acting as religious totems. They provide important sites for traditional practices and with aesthetic value, ideal for recreation and social functions (Fig. 2).

The 'ideal' link between mangrove and SDGs

The synergies

Analysis of the synergies indicated that mangroves contribute directly to the achievement of at least 14 targets of sustainable development goals, co-benefiting at least 18 targets (Fig. 5). Regulating services directly contribute to the achievement of at least 7 SDG targets, co-benefiting 9 SDGs targets. Supporting ecosystem services directly contribute to 2 SDG targets, co-benefiting at least 9 SDG targets. Cultural ecosystem services directly contribute to at least 4 SDG targets, co-benefiting at least 7 SDG targets while provisioning services directly contribute to 3 SDG targets while co-benefiting at least 2 targets (See discussion section) (Fig. 5).

The trade-offs

Unregulated exploitation of provisioning services results in a tradeoff with all the mangrove benefits (Fig. 5). This was, however, not the view among the majority of the community members who posited that '*our fore-fathers exploited this forest and so did our fathers, yet, the forest has never been depleted. The ecosystem has its natural regeneration mechanisms, hence, impossible to exhaust and should be cut in order to nourish*'. In as much as silviculture activities as pointed out by the community are important to the forest, unregulated extraction limits the ecosystem's capacity to continue providing wood products, habitat, socio-cultural services, and protective services, among other benefits.

Community knowledge of the link between mangroves and the SDGs

Community members of Vanga identified 16 ecosystem services accrued from the mangrove ecosystem (Fig. 2). A mutually inclusive analysis of community knowledge however indicated that only 45.4 % of the population knew the role of the ecosystem in development, 79.5 % of whom were able to link the ecosystem to local development, 43.1 % to both local and national development while only 13.5 % were able to link the ecosystem to local, national, and international development (Fig. 3). A large proportion of the respondents (43 %) had no idea whether mangroves contribute to development or not while 11.6 % felt that mangroves do not contribute to development in any way (Fig. 3). The largest proportion (49.2 %) of the respondents who knew the roles of mangroves in local development mentioned income generation from the sale of wood products, ecotourism, and proceeds from conservation as the main contributors, while 21 % mentioned provisioning of affordable building materials (Fig. 4)

Of the respondents who knew the roles of mangrove in national development, 40.9 % mentioned revenue generation from licensing of mangrove cutters, export of wood products, and ecotourism, while 22.6 % mentioned income generation from mangrove-related businesses. Despite having an idea of the contributions of mangroves to national development, 9.4 % of the respondents could not explain how it does but were sure it did contribute in some way.

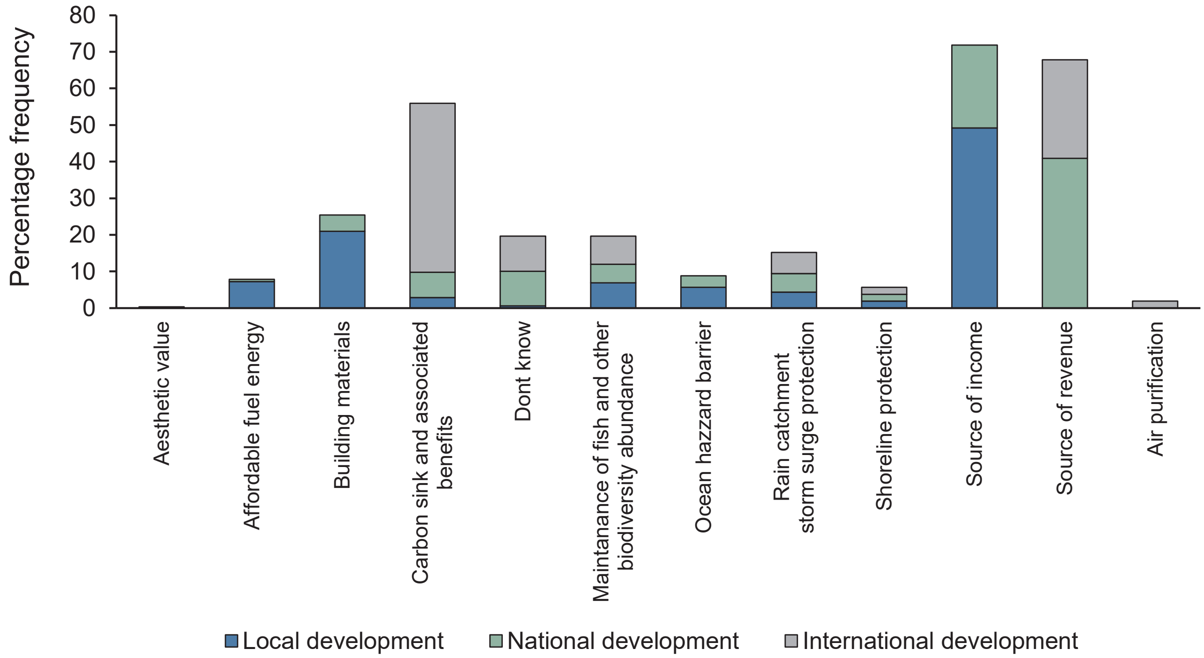

Figure 4. Community perceptions of the contributions of mangrove ecosystem services to development. The bars represent the roles of respective ecosystem services in development at local, national and international scales.

At the international level, carbon sequestration was perceived as the greatest contributor to development (46.2 %) followed by revenue from international trade in timber products and ecotourism (26.9 %). Nine percent of the respondents thought mangroves contribute to international development but were not sure how (Fig. 4). When asked how carbon sequestration contributes to international development, the most coherent response from FGDs was, '*it must be important and that's why there is a lot of international investments in the ES*'. The

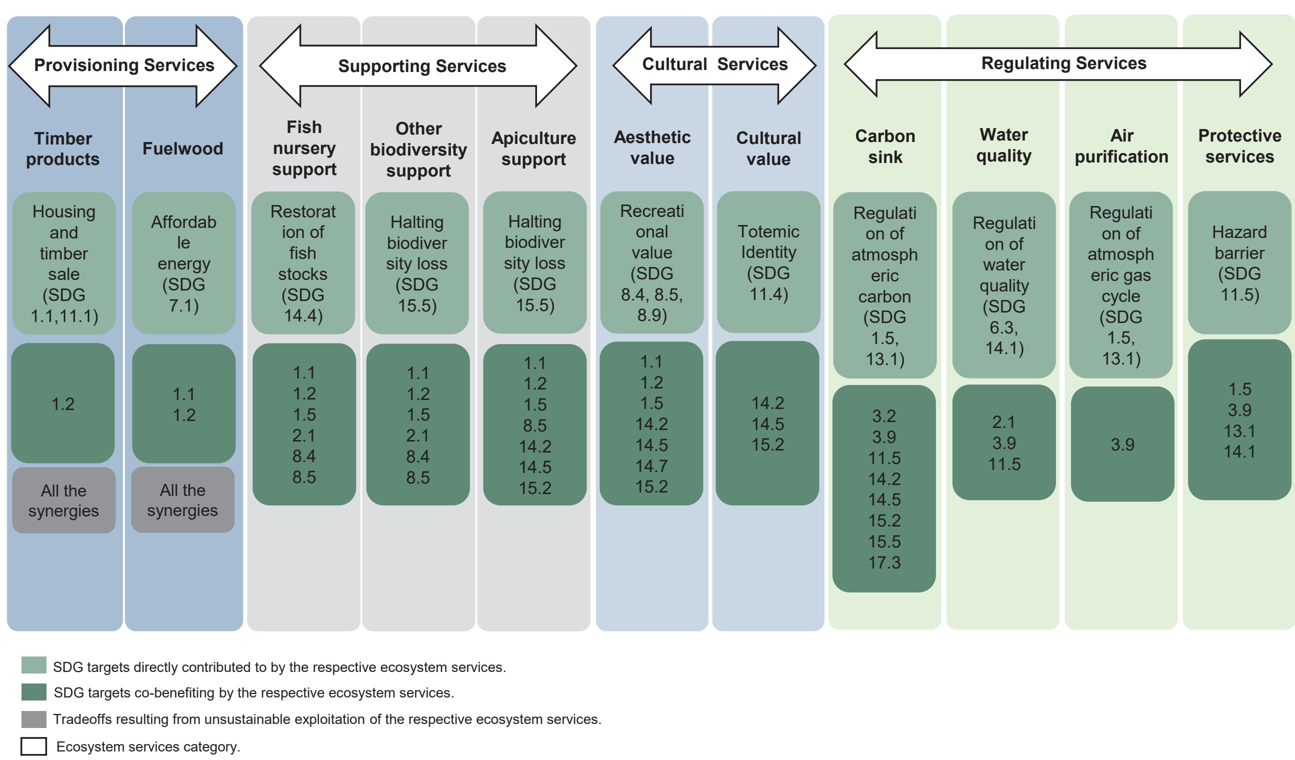

Figure 5. A relationship evaluation framework representing the mangrove-SDG co-benefits and tradeoff. Numbering represent SDG targets promoted by the respective ecosystem services. (Framework adapted from Singh *et al.*, 2017).

Table 2. A distribution table of the disaggregated co-relations between age, gender, level of education, duration of residence in the study area and the knowledge of the synergies between mangroves and development.

			Gender	Age	Education	Period of residence	Local development	National development	International development
Spearman's *rho*	**Gender**	Correlation Coefficient	1.000	-.074	-.202**	-.010	.035	.027	.010
		Sig. (2-tailed)	.	.157	.000	.849	.510	.610	.852
		n	366	366	366	366	366	366	366
	Age	Correlation Coefficient	-.074	1.000	-.351**	.329**	.042	.017	.023
		Sig. (2-tailed)	.157	.	.000	.000	.419	.748	.657
		n	366	366	366	366	366	366	366
	Education	Correlation Coefficient	-.202**	-.351**	1.000	-.137**	-.240**	-.206**	-.186**
		Sig. (2-tailed)	.000	.000	.	.009	.000	.000	.000
		n	366	366	366	366	366	366	366
	Period of residence	Correlation Coefficient	-.010	.329**	-.137**	1.000	.127*	.074	.115*
		Sig. (2-tailed)	.849	.000	.009	.	.015	.158	.028
		n	366	366	366	366	366	366	366
	Local development	Correlation Coefficient	.035	-.042	-.240**	-.127*	1.000	.388**	.193**
		Sig. (2-tailed)	.510	.419	.000	.015	.	.000	.000
		n	366	366	366	366	366	366	366
	National development	Correlation Coefficient	.027	.017	-.206**	.074	.388**	1.000	.533**
		Sig. (2-tailed)	.610	.748	.000	.158	.000	.	.000
		n	366	366	366	366	366	366	366
	International development	Correlation Coefficient	.010	.023	-.186**	.115*	.193**	.533**	1.000
		Sig. (2-tailed)	.852	.657	.000	.028	.000	.000	.
		n	366	366	366	366	366	366	366

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

majority did not know what carbon sequestration is, with most referring to it as '*the dark soil within the mangroves*' while others simply called it '*clean atmosphere*'.

A common assertion among community members that '*if not for mangroves, we would not be living where we live due to flooding and shoreline erosion'* indicated an understanding of the protective functions of mangroves. This was, however, not reflected in the link to development with shoreline protection and ocean hazard barrier ranking among the least (less than 2 % of the respondents) contributors to development (Fig. 4).

On the general views on the roles of mangroves in development, the majority of the community supported similar views that: *'Our parents paid our school fees through mangrove-related income. The forest provided timber for construction of boats for fishing, furniture, house construction, and fuel energy, and today we take our children to school thanks to the same ecosystem. To us, therefore, mangroves mean timber, fish, and a beautiful environment'.* This was coherent with the results (Fig. 4), where the majority (35.9 %) of the community members in Vanga perceive mangroves as a source of income.

Disaggregating community knowledge socio-demographically

Knowledge (dependent variable) was disaggregated by gender, age, level of education, and period of residence within the study area (independent variables). Spearman's *rho* was used to determine whether frequency of mentioning co-benefits is related to age, level of education, gender or period of stay within the study area. Results established no perfect coefficient among dependent and all independent variables (Table 2). Education however had a significant negative coefficient with the knowledge of the synergies in all development levels at $p \leq 0.01$ while migration had a significant positive correlation with knowledge at local and international level at ($p \leq 0.05$) (Table 2). This implied a significantly better knowledge of the synergies among community members with less education and better knowledge of the synergies among respondents who had stayed longer in the study area. No perfect or significant coefficients were established between gender and age with knowledge of the synergies at any development level (Table 2).

Discussion

The mangrove ecosystem was selected for its vital protective functions, social-economic elevation potentials, and its role in regulating ecological processes, which make them critical to achievement of the SDGs (Huxham *et al.*, 2017; UN-DESA, 2017; Singh *et al.*, 2017). Studies suggest that the critical nature of protecting and restoring mangroves is reflected in SDG 14 (life below water), but the ecosystem has the potential of supporting the achievement of several other SDGs (UN-DESA, 2017). The diverse nature of these benefits results in a number of co-benefits and tradeoffs contingent to community perceptions, which influence utilisation and eventuality of the development agenda (Nazarea *et al.*, 1998; Cinner and Pollnac, 2004).

Community knowledge of the synergies and tradeoffs between mangroves and SDGs

Local support strongly underpins conservation success, and is influenced by the perceptions of the impacts of governance frameworks on the community (Bennett and Dearden, 2014). Ecosystem services frameworks present viable mechanisms for assessing the effectiveness of governance, by providing mechanisms for understanding different views of local communities and their support for conservation interventions (Afonso *et al.*, 2022). This study adopted the ecosystem services framework for assessing community knowledge on the roles of mangroves in sustainable development. Results indicate that community members in Vanga have a limited understanding of the role of mangroves in development, with the majority linking the ecosystem to income and revenue generation. This reaffirms the findings by Afonso *et al.* (2022) that suggested that community members do not acknowledge the existence of ecosystem services that do not bring a direct economic benefit.

Moreover, as similarly found by Owuor *et al* (2019), that community members exhibit limited understanding of the ecosystem functionality despite having knowledge of the ecosystem services, the findings from this study show that despite identifying 16 ecosystem services (Fig. 2), community members could only explain the roles of consumable benefits in development. Critical ecosystem services like shoreline protection and ocean hazard barrier, despite being identified as vital for the existence of ocean adjacent communities, were not considered major contributors to development (Fig. 4).

Carbon sequestration, *hewa kaa* in local parlance, was however, identified as a major contributor to international development but the majority of those who mentioned this ES lacked understanding of the how this worked. The frequent reference to carbon sequestration was therefore probably a result of the proceeds from a carbon offsetting project in neighboring villages in Gazi Bay.

In the socio-demographic disaggregation of community knowledge of the roles of mangrove to development, it was found that period of residence within the study area and education significantly influence knowledge of the link between mangroves and development. Education had a significant negative correlation with knowledge of the synergies at all development levels while period of residence within the study area had a significant positive correlation with knowledge at all development levels. Cinner and Pollnac (2004) and Okello *et al* (2019) similarly found that education and migration influenced community perceptions. The negative coefficient between education and knowledge could be attributed to education-related cultural dynamics, as pointed out by the respondents in FGDs, *'the educated have no time to get dirty in the mangrove mud. Whenever they need anything from the mangroves or the ocean, they pay the uneducated casual laborers to get them on their behalf'.* The positive coefficient between knowledge and period of residence within the study area, on the other hand, is logical since longer stays imply more interactions with the ecosystem, hence a better understanding of them.

Relating community knowledge to the 'ideal' link between mangroves and the SDGs

A review of secondary data on the 'ideal' mangrove-SDG relationship indicated a gap in community knowledge. Contrary to the community perspective that was limited to income and livelihood related goals SDG 1, SDG 2, SDG 3 and SDG 8, expert analysis established greater links between mangroves and sustainable development. The influence of regulating services was found to contribute to at least 17 SDG targets, either directly or as reinforcement to co-benefiting targets. In its protective functions, the ecosystem buffers shoreline erosion, strong wave actions, storm, and other climate change related hazards (Barbier, 2016). This strengthens resilience against climate-related and other extreme events (SDG 1.2, 1.5, and 13.1), reducing health risks (target 3.9) (Singh *et al*., 2017). As an efficient carbon sink, nations can include mangrove restoration efforts towards the operationalization of integrated policies and plans for adaptation to adverse impacts of climate change (SDG 1.5, 13.1, and 13.2) (UNEP, 2015; Government of Kenya, 2018). This provides a basis for sustainable management of coastal ecosystems through carbon offsetting, promoting SDG targets 14.2 and 14.5, and hence halting deforestation and biodiversity loss (targets 15.2 and 15.5) while also contributing to the mobilization of financial resources (SDG 17.3) (Windham-Mayers *et al*., 2018; Wylie *et al*., 2016). Through water purification, mangroves control the introduction of solid waste into the ocean mitigating marine pollution (SDG 14.1 and 12.4) which improves water quality (SDG 6.3). This reduces illness and death from water pollution and related hazards (SDG 3.9 and 11.5), and biodiversity loss (SDG 15.5) which ensures nutritious food contributing towards SDG 2.1 (Diz *et al*., 2020; Diz *et al*., 2019). Air purification reduces the exposure of the poor and those in vulnerable situations from atmospheric toxic gasses (SDG 1.5, 13.1) which prevents their illnesses and deaths from air pollution-related hazards (SDG 3.9) (Fig. 5; Appendix 1).

Supporting services comprising of fish nursery and other biodiversity support maintain biodiversity abundance (Sandilyan and Kathiresan, 2012) towards achievement of SDG 14.4 and 15.5. Achievement of the two targets ensures opportunities for eradicating poverty (SDG 1.1), sufficient and nutritious food for SDG 2.1, environmentally friendly income generation by local communities (SDG 8.4 and 8.5), combating poverty and other economic shocks among local communities (SDG 1.2 and 1.5) (Diz *et al*., 2020) (Fig. 5; Appendix 1).

Cultural ES identified in this study include aesthetic and cultural values of the mangrove ecosystem. Aesthetic value creates a sense of identity with environmental beauty which provides a basis for conservation through social reciprocity (Carlson, 2005), promoting eco-tourism and employment opportunities towards SDG 8.9, 8.4, and 8.5 (Friess, 2017). This could motivate local communities to tradeoff extractive forest benefits with environmental aesthetics, enhancing sustainable management and protection of marine and coastal ecosystems (SDG 14.2) and halting ecosystem degradation (SDG 15.2), hence making steps towards conserving of at least 10 % of coastal and marine areas (SDG 14.5). By creating employment opportunities, communities are also cushioned against poverty and other economic challenges, contributing to SDG 1.1, 1.2, 1.5, and 14.7. Cultural value, on the other hand, invokes a totemic sense of belonging (SDG 11.4) that can deter degradation around cultural areas (Cooper *et al*., 2016). As in the case of Kayas of the south coast of Kenya, the fear of taboos and wraths of the spirits dissuade community members from destructive practices around the cultural sites. Mangrove areas are in the process conserved, contributing to the achievement of SDG 14.2, 15.2, and 14.5; all of which create a basis for the realization of all the benefits of mangroves within and around the cultural areas (Fig. 5; Appendix 1).

Provisioning mangrove functions, on the other hand, promote the achievement of at least 4 SDG targets and tradeoff with at least 17. Timber products provide opportunities for income generation, reducing poverty towards achievement of SDG 1.1, which potentially reduces the number of people living in poverty thus contributing towards SDG 1.2. Timber harvesting also ensures affordable housing for the local poor contributing to SDG 11.1. Fuelwood provides affordable energy for SDG 7.1, creating a market context for SDG 1.1 and 1.2. In so doing, unsustainable timber and fuelwood extraction result in ecosystem degradation which deters all the benefits of mangroves. This is worsened by the fact that these two ecosystem goods are the most valued by local community members. The community depends on wood products for house construction, income generation and primary source of fuelwood among mangrove adjacent communities (Huxham *et al*., 2017) (Fig. 5; Appendix 1).

Conclusions

Results suggest a gap in community knowledge of the roles of mangroves in development. This, his we conclude based on the perception that mangrove resources are inexhaustible and the limited understanding of mangrove benefits beyond extractible services. Moreover, the role of mangroves in development is less understood as one progresses from local level, where provisioning services are more valued, to international level where regulatory services and other indirect benefits are of greater value. As such, the adoption of procedural justice in the framing and implementation of development and governance frameworks is recommended. This means placing the primary natural resource users and their contextual socio-demographic dynamics at the center of decision making from inception to implementation.

Moreover, it is evident that development from a community perspective means livelihood and income generation. It is therefore important that governance and development strategies are sustainably refined to reflect the needs and desires of local communities to improve acceptability and cost-effectiveness. In this process, resource managers should endeavor to promote viable options to the destructive harvesting of forest products to reduced extractive pressure on the ecosystem while promoting community livelihoods.

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APPENDIX

Appendix 1. Descriptive text on the SDG targets supported by the mangrove ecosystem services.

SDG targets supported by the mangrove ecosystem services	Description	Related ecosystem service
SDG 1		
1.1	Eradication of extreme poverty	Timber products
1.2	Reduction of, at least but half, the number of people living in poverty	Fish nursery and biodiversity support
1.5	Building resilience of the poor and those in vulnerable situations and reducing their exposure and vulnerability to climate-related extreme events and other economic, social and environmental shocks and disasters	Protective functions, Carbon sequestration
SDG 2		
2.1	Ending hunger and ensuring access to sufficient and nutritious food by all	Fish nursery, Biodiversity support
SDG 3		
3.9	Substantial reduction of the number of deaths and illnesses from hazardous chemicals and air, water, and soil pollution and contamination	Protective functions, Carbon sequestration
SDG 6		
6.3	Improvement of water quality by reducing pollution	Water purification
SDG 7		
7.1	Ensuring universal access to affordable and reliable energy services	Fuelwood provisioning
SDG 8		
8.4	Progressive improvement of global resource efficiency in consumption and production, endeavoring to decouple economic growth from environmental degradation	Fish nursery and biodiversity support
8.5	Achievement of full and productive employment and decent work for all women and men, including for young people and persons with disabilities	Fish nursery and biodiversity support
8.9	Devising and implementation of policies to promote sustainable tourism, job creation, and promotion of local culture and products	Cultural and aesthetic services
SDG 11		
11.1	Ensuring access for all to adequate, safe, and affordable housing and basic services	Timber products
11.4	Strengthening efforts to protect and safeguard the world's cultural and natural heritage	Cultural and aesthetic services
11.5	Reduction of the number of deaths and people affected by disasters, including water-related disasters), co-benefiting	Regulating services, Carbon sequestration
SDG 13		
13.1	Strengthening resilience and adaptive capacity to climate-related hazards and natural disasters in all countries	Ocean hazard barrier; Carbon sequestration

SDG targets supported by the mangrove ecosystem services	Description	Related ecosystem service
SDG 14		
14.1	Prevention and significant reduction of marine pollution of all kinds, in particular from land-based activities	Regulation of water quality
14.2	Sustainable management and protection of marine and coastal ecosystems to achieve healthy and productive oceans	Biodiversity and fish nursery support
14.4	Science-based restoration of fish stocks	Fish nursery and biodiversity support
14.5	Conservation of at least 10 percent of coastal and marine areas	
SDG 15		
15.2	Promoting the implementation of sustainable management of all types of forests, halting deforestation and degradation	Cultural and aesthetic services; Carbon sequestration
15.5	Taking urgent action to halt the loss of biodiversity	Fish nursery and biodiversity support
SDG 17		
17.3	Mobilization of additional financial resources for developing countries from multiple sources	Carbon sequestration

Assessment of land-based pollution problems in Kenyan marine environments to facilitate adaptive management of coral reef systems

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Abstract

Coral reefs are sensitive to environmental perturbations, and an unprecedented decline in corals has been reported globally as a result of increasing global and local stressors including excessive input of anthropogenic nutrients. This study investigated the effect of land-based sources of nutrients (N and P) associated with sewage, on ocean water quality and the health of corals in Mombasa Marine National Park and Reserve in Kenya to inform integrated coastal zone management and ocean governance. A year-long study was conducted to determine water quality according to protocols described in Grasshoff *et al.* (2007). Coral health status was also monitored using Underwater Visual Census (UVC) to record coral reef ecological parameters. The study area's temperature, salinity, pH and dissolved oxygen were within the recommended standards for healthy coral reefs. The study indicated that land-based nutrients, Chlorophyll-*a* (*Chl a*) and total suspended solids (TSS), are the key factors affecting corals and could be the reason for the observed coral health, which ranged from fairly healthy to unhealthy. On average, nutrient concentrations were higher than recommended to maintain at least 50% coral coverage. Ammonia was the dominant form of nitrogen ranging from 0.105 to 0.4130 mg/l, while nitrate concentrations were 0.0348-0.0468 mg/l, indicating the possibility of blooming algal species in the area. Total suspended solids were above the recommended values, ranging between 33.5 and 79.3mg/l and *Chl a* 0.7114 and 1.58 µg/l. The study concluded that land-based nutrient load influenced coral reef health during the study period. It recommends that land-based pollution needs to be addressed as part of a holistic, integrated coastal zone management approach supporting practical, sustainable and legal management of nutrient discharge into the marine environment to preserve the water quality of Mombasa Marine National Park and Reserve.

Keywords: water quality, pollution, nutrient enrichment, coral health, governance

Introduction

Coral reefs play an important role in marine ecosystem functioning and service provision (Tan *et al.*, 2020; Hughes *et al.*, 2017; MEA, 2005). In recent years, corals have continued to degrade (reducing at a rate of 1-2 % per year) due to numerous anthropogenic stressors, such as overfishing, global climate change, and environmental pollution (Hughes *et al.*, 2017). The loss and degradation of coral reefs results in the loss of livelihoods of millions of people living along tropical coastlines (Hoegh-Guldberg *et al.*, 2019). It will also hamper the achievement of the Sustainable Development Goal 14 and the Aichi Target 10, which aim to reduce the pressures on coral reefs (UN-GA, 2015, CBD, 2020). Along with increasing human population and urbanisation, unregulated coastal development puts pressure on the marine and coastal environment in the Western Indian Ocean (WIO) region, including

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Kenya. These pressures include resource exploitation and discharges of poorly treated or untreated industrial, agricultural and urban wastes (ASCLME, 2012; Bhatnagar and Sangwan, 2009; Seitzinger *et al.*, 2005; Shanmugam *et al.*, 2007).

Approximately 80% of marine pollution originates from land-based sources that reach coastal waters via diffuse run-off, direct waste deposit, and atmospheric fallout (Daoji and Daler, 2004; McIntyre, 1990). Most eutrophication and organic pollution in coastal regions in the world is linked to the discharge of sewage (defined as a cocktail of waste from food preparation, dishwashing, garbage-grinding, toilets, baths, showers and sinks) effluent and dumping of sewage sludge (Okuku *et al.*, 2011). Moreover, an increase in food production due to population growth has resulted in a concentration of these nutrients on land as well as changes in the global hydrological cycle, doubling the rate at which biologically available nitrogen and phosphorus enter the marine ecosystems (Galloway *et al.*, 2004; Seitzinger *et al.*, 2005). This is compounded by poorly developed sewage waste management infrastructure and inadequate domestic waste management facilities, with much of the effluent from industries and tourist hotels emitted directly into the coastal waters (Okuku *et al.*, 2011).

Nutrients such as nitrogen (N) and phosphorous (P) are essential for supporting the productivity of coral reef ecosystems. However excessive enrichment of marine and coastal waters by these nutrients associated with anthropogenic activities can cause deleterious effects, making them one of the major threats facing coral reefs globally (Lapointe *et al.*, 2010). By stressing coral physiology and functioning through increased water temperature, increased algae cover, and seaweed development that competes with the corals for space and light, excess nutrients can cause coral ecosystems to collapse (Smith *et al.* 1981). A reduction in light penetration results in reduced zooxanthellae photosynthesis, which reduces coral productivity (DeGeorges *et al.*, 2010). Enhanced macro-algae growth can smother and kill corals (Littler *et al.*, 2006), negatively affecting them by shading/overtopping, reducing water exchange, and causing mechanical abrasion or chemical disturbance. Besides enhancing the susceptibility of coral reefs to bleaching (Mangi *et al.*, 2007), algae can also release toxins, deplete oxygen and increase the risk of bacterial and fungal infections contributing to the spread of coral diseases (D'Angelo and Wiedenmann, 2014). Lower calcification rates, reduced reproductive success, altered skeletal density, and linear extension in response to heat and light stress are some of the observed reactions of corals to elevated nutrient levels. Studies have shown that anthropogenic nutrient enrichment of reef waters contributes to the deterioration of coral reefs close to urbanised and heavily populated areas. (Fabricius *et al.*, 2003; Wagner *et al.*, 2010; Wooldridge, 2009).

To conserve marine ecosystems from land-based pollution, governance institutions should develop policies to monitor and regulate the quality and quantity of nutrients released into coastal areas. There is limited data on the link between coral health and nutrient load in the WIO. At the same time, many global marine regulations do not integrate land-based controls, making them prone to failure (Carlson *et al.*, 2019). Marine reserves tend to be static (e.g., hotspots for marine biodiversity) rather than representing the time-variant dynamics that define land-sea processes, such as contaminant flows (Stoms *et al.*, 2005, Arias-González *et al.*, 2017). These issues are among several that have hindered the design and implementation of the regulation of discharges and management of wastes from urban developments and agricultural inputs in reef catchments. This highlights the need to couple land-sea planning while recognising the complexities associated with executing ridge-to-reef conservation approaches (Carlson *et al.*, 2019; Arias-González *et al.*, 2017; Stoms *et al.*, 2005).

This study provides information on the water quality status in coral reef ecosystems. Nutrient quality and quantity and coral reef health were assessed in the Mombasa Marine National Park and Reserve in Kenya. The study also aimed to establish the relationship between water quality, in terms of nutrient concentrations, and coral reef health. This is useful for managers and decision-makers in formulating holistic and best practices in management and governance for the conservation and sustainability of coral reefs.

Materials and methods

Study area

Mombasa Marine National Park and Reserve (MMNP&R) is a marine protected area (MPA) between Mtwapa Creek and Tudor Creek in the north of Mombasa County, Kenya. It lies between 3° 57'S and 4° 9'S, and 39° 41'E and 39° 52'E, covering an area of 210 km^2. The MMNP&R, managed by the Kenya Wildlife

Services (KWS), is zoned into the Marine Park and the Marine Reserve (Fig. 1). The Park measures 10 km^2 and is open to public recreation, but extractive uses are prohibited ("no-take" zone). The Reserve measures 200 km^2, allowing public access and controlled extractive use of resources. It has coral reefs in its waters and encloses part of the lagoon, back reef and reef crest habitats of the Bamburi-Nyali fringing reef. The MPA has other critical habitats – seagrass beds, sandy beaches and intertidal flats – that are an essential source of coastal livelihoods such as fishing and tourism. The MMNP&R is adjacent to Mombasa city, making it vulnerable to numerous threats (Tuda *et al*., 2007).

The area is characterised by warm tropical conditions varying between 25 °C and 31 °C throughout the year. It experiences bimodal rainfall, with long heavy rains falling between April to July and short rains between October and December. The rainfall surface run-off transports anthropogenic pollutants into the Mtwapa Creek and the MMNP&R (Pole *et al*., 2016).

Water quality

The year-long study was carried out between September 2017 and August 2018 to measure seasonal variation in water quality and its potential impact on coral reef health. Samples were collected once a month on the first Tuesday/Wednesday of the month. Seasons were classified as short rains (September to November), dry (December to February), long rains (March to May), and cold (June to August).

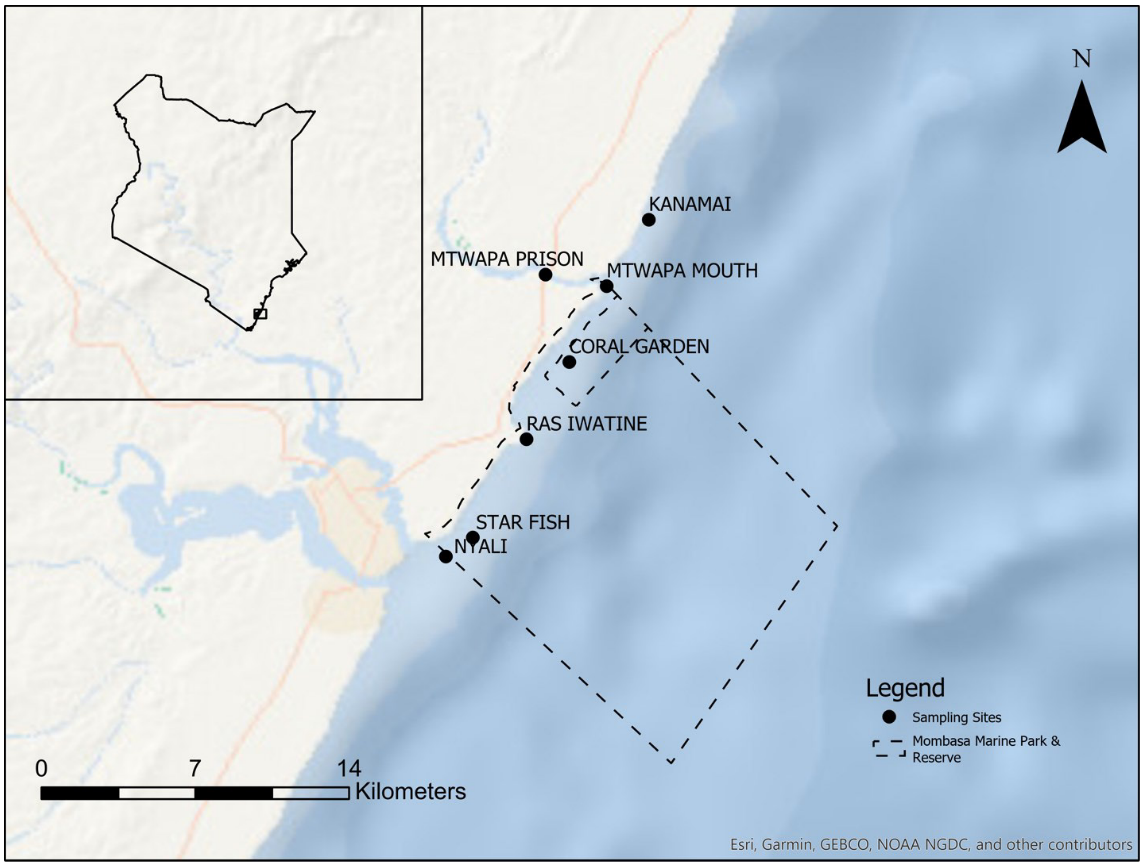

Figure 1. Map of the Mombasa Marine National Park and Reserve and sampling stations at Nyali, Star Fish, Coral Garden, Mtwapa Prison and Mouth and the control site in Kanamai.

Seven stations were selected and clustered into three distinct groups for water sample collection and coral health monitoring (Fig. 1):

- Two sampling stations in Mtwapa Creek were selected after being identified as a potential point source of nutrient input. Mtwapa Prison station is close to the Shimo La Tewa prison, where raw, untreated sewage was observed entering the Creek (Fig. 2). The Mtwapa Mouth station was chosen because it is the point where potentially polluted water from the Creek enters the open ocean and the adjacent MPA.

- Two sampling stations rich in corals in the Marine Park (Coral Garden and Ras Iwatine) and Marine Reserve (Nyali and Starfish)

- One sampling station in Kanamai served as the control site and was characterised by a low human population, less anthropogenic influence and community-led conservation efforts.

The study examined the potential effects of nutrient pollution on corals by carrying out assessments of coral reef health and water quality in terms of nutrient (N and P) quality and quantity, usually measured as *Chl a* in the water column, which is a robust indicator of increased nitrification (Brodie *et al*., 2007; Furnas *et al*., 2005). Data collection were done both *in situ* and *ex-situ.* Measurements of physico-chemical properties of the water, including salinity, temperature, conductivity, pH and dissolved oxygen (DO), were carried out *in situ* using an AZ86031 digital handheld water meter. Water quality around the reefs was further determined by focusing on priority nutrients, i.e., dissolved inorganic nitrogen (DIN) [ammonium (NH_4^+-N), nitrate + nitrite {(NO_3^- + NO_2^-)-N}] and phosphates (PO_4^{3-}-P), and Chl-*a,* with sampling and analysis done according to protocols described in Grasshoff *et al*. (2007).

Triplicate surface water (0.5 m) samples at each site were collected in pre-cleaned polypropylene sample bottles for the nutrients. The samples were fixed *in situ* with mercury chloride (HgCl) to prevent any further biological activities and kept at -20 °C until analysis. The PO_4^{3-}-P was determined using the ascorbic acid method at 885 nm, while NH_4^+-N was determined using the indophenol method at 630 nm after at least six hours. Dissolved (NO_3^- + NO_2^-)-N was determined using the cadmium reduction method and measured calorimetrically at 543 nm and Genesys 10S Vis spectroscopy (Thermo Scientific™). Triplicate samples were also collected at each sampling point for Chl-*a.* One litre (1L) of seawater was filtered through a synthetic filter (GF/C) after a few drops of a suspension of magnesium carbonate were added to prevent acidity on the filter. The filter was drawn dry, removed and folded in half using forceps, then stored and fastened in a vial for storage in a freezer at -20°C until analysis. The pigments were extracted from the filter in 90% acetone. Their concentration was estimated spectrophotometrically at selected wavelengths of 750 nm, 664 nm, 647 nm, and 630 nm using a Genesys 10S Vis spectroscopy (Thermo Scientific™).

The same volume of 1L of the sample was passed through a prepared, pre-weighed filter paper. The filter was then dried at 104 ± 1°C. After drying, the filter was reweighed, and the TSS was calculated. For all the analyses, procedural blanks were included. The accuracy and consistency of the analytical procedures were determined by analysing check standards (which had an absorbance at the middle range of the calibration curve) analysed after every ten samples.

Coral health

Of the seven sampling stations, only four had coral reefs (i.e., Ras Iwatine, Coral Garden, Nyali and Starfish). The coral health status was monitored monthly using an aquatic survey, which entails the Underwater Visual Census (UVC) method to monitor and record coral reef ecological parameters. The point intersect method was used to record benthic substrates along a 40 m permanent line transect laid parallel to the reef crest. Benthic substrates were recorded at every 1 m interval in 10 categories of hard coral, soft coral,

Figure 2. photos of the point of pollution where raw sewage is released into Mtwapa Creek (left) and filtered concentrated Total Suspended Solids (TSS) from water samples collected from the same sampling site (right)

seaweeds, seagrass, coralline algae, rubble, sand, bare rock, and *Halimeda* spp. as described by Obura and Grimsditch (2009). Percentage coral cover value was obtained by simply dividing the total number of point intercept records belonging to hard corals by 40, which is the total number of valid point intercept records for all the substrates at the transect, multiplied by 100.

The basic bleaching and mortality monitoring level developed by CORDIO (Kawaka *et al.*, 2016) for monitoring coral reefs in Eastern Africa was modified to include healthy, partially bleached, and fully bleached categories only and used to assess coral health conditions. Coral bleaching was evaluated using a 40 m permanent line transect laid parallel to the reef crest. Each coral colony intercepting the 40 m permanent transect was counted and classified into three bleaching categories. The percentage value of each bleaching category was obtained by dividing the total number of line intercept records belonging to a given bleaching category by the total number of corals intercepting the 40 m line transect.

Trophic state index (TSI) classification

The trophic state index (TSI), developed by Carlson (1977), is used to measure the water quality of water bodies. It has three states: **oligotrophic** (low primary productivity due to nutrient deficiency); **mesotrophic** (intermediate level of productivity); or **eutrophic** (high biological productivity due to excessive nutrients, especially nitrogen and phosphorus, and can support an abundance of aquatic plants). This study used the trophic status measured by Carlson's trophic state index (CTSI) which examines several criteria such as the oxygen concentration, species composition of the bottom fauna, concentrations of nutrients, and multiple measures of biomass or production as multi-parameter indices computed from the three interrelated water quality parameters of Turbidity (Secchi disk depth - SDD), chlorophyll-*a* concentration (Chl-*a*), and total phosphorous (TP) concentration as described by EPA (2000) and Carlson *et al*. (1977). The water bodies are classified as oligotrophic, mesotrophic or eutrophic based on the values of CTSI.

Data analysis

Microsoft ® Excel 2010 was used to tabulate all the parameter data obtained, after which the different variables from different stations were subjected to quantitative analysis. One-way Analysis of Variance (ANOVA) at p-value = 0.05 was computed using the Statistical Analysis System (SAS) to determine the variations between and within sampling stations and over time. Analysis of the means was computed using a t-test at a $p = 0.05$ significant level. A comparison of the levels of different nutrients with threshold levels for various nutrients was then made against standard water quality variables criteria.

PAST Statistical Package (Version 2.10) was used for the Shannon-Wiener Index ranking that considered species diversity (H') and species richness (MI) indices. Shannon-Weaver's diversity index, H' (Ortiz *et al*., 2016) was calculated as $H' = - \Sigma Pi \log2Pi$, where Pi was the frequency of presence for I species. MI was calculated according to Margalef (1961): $MI=(S-1)/\ln N$, where S was the number of identified species for the total counted colony (N). The variable data was used to carry out correlation and multivariate analysis between other physical variables using Canonical correspondence analysis (CCA) (Orfanidis *et al*., 2007). Carlson's TSI was calculated using the following formulas, ignoring the negative results:

a. TSI for Chlorophyll-a (CA)TSI = 9.81In Chlorophyll-a(ug/L) +30.6
b. TSI for Secchi depth (SD)TSI = 60 -14.41In Secchi depth (Meters)
c. TSI for Total phosphorus (TP)TSI = 14.42 In Total phosphorous (µg/l) + 4.15

where TSI is Carlson's Trophic State Index, and In is Natural logarithm;
Carlson's trophic state index (CTSI) = [TSI (TP)+TSI(CA)+TSI(SD)]/3
With TP and Chlorophyll-a measured in micrograms per litre (µg/L), and SD transparency in meters.

Assumptions

The study was carried out to investigate the impact land-based nutrient loads would have on marine systems, with corals being used as indicator species. While there are many factors such as human activities within the study area that impact coral reef health, the focus of this study was on nutrient concentrations. Temperature was also considered as it is a standard parameter when analysing water quality. The study did not consider previous bleaching events, rather focusing on the parameters that were measurable during the study period. The results and conclusions presented here are those observed during the study period. Furthermore, the study recognizes the need for continuous monitoring to establish long term coral health parameters and differentiate chronic and acute impacts of nutrient load on coral reef health.

Results and discussions

Water quality

The physico-chemical properties of the sampling sites showed that the average monthly temperature ranged from 22.7 ± 10.0 to 28.2 ± 0.1 °C observed at Nyali and Mtwapa Prison. Studies conducted by Hoegh-Guldberg (1999) in similar coral ecosystems show similarities to the study area and describe these temperature ranges as ideal for coral's optimal growth (Hoegh-Guldberg and Bruno, 2010). Typically, the temperature range for the formation of corals is 18 – 36 °C, with the optimal temperature between 22° and 28 °C (Wilkinson, 1999; Hubbard, 1997). Further studies have found that photosynthesis pathways in zooxanthellae are impaired at temperatures above 30 °C; this could activate the dissociation of coral/algal symbiosis. Based on these figures, it can be concluded that the deterioration of coral health due to water temperature was unlikely in the study area during the study period. However, the comparatively higher temperatures observed at Mtwapa Prison, an area receiving untreated sewage effluents from Shimo la Tewa Prison, indicate the influence of sewage pollution on coastal water temperatures. Physico-chemical properties and nutrient concentrations of water samples collected from Mtwapa creek and MMNP&R are summarised in Table 1.

The average pH observed during the studies ranged from 7.7± 2.7 to 8.5 ±0.1. This is within the global average of the world's open oceans ranging from 7.9 to 8.3± 0.1 (Gagliano *et al.*, 2010; Hoegh-Guldberg *et al.*, 2007). There was a slight variation in salinity between the stations. The Mtwapa Prison station had the lowest salinity of 32.4 ± 9.2 ppt, while Ras Iwatine, located in the Marine Reserve, had the highest value of 39 ± 8.4 ppt of salinity. Studies have shown that most reef-building corals require saline water ranging from 28.7 — 40.4 PSU (Guan *et al.*, 2015), demonstrating that the salinity in the study area is ideal for the growth and development of corals and is therefore not a limiting factor for coral health.

Dissolved oxygen (DO) showed a wide variation ranging from 6.0±2.1 mg/l to 15.7± 5.9 mg/l. The highest value was recorded in Ras Iwatine (MMNP&R) and the lowest at Mtwapa Mouth (Creek). Table 1 shows that the areas with high nutrient concentrations (Mtwapa Mouth and Prison) had lower concentrations of DO (6.0 mg/l and 6.3 mg/l), respectively. These stations are located in the Creek and are closest to the point source of pollution. Similarly, Ras Iwatine recorded lower levels of nutrients (0.0387 mg/l) and high DO levels (15.7 mg/l). During the study, there was no statistically significant correlation between DO and the measured nutrient concentrations (p-value > 0.05). Other studies found that excessive amounts of nitrogen and phosphorous have been linked with the reduction of DO in marine water systems to the point of causing hypoxia (Dodds, 2006). However, all stations had levels higher than the recommended standard of 4 mg/l (Shanmugam *et al.*, 2007) (Table 2). This implies that DO did not contribute to the deterioration of coral health in MMNP&R during the study period (Table 2).

Table 1. Mean physico-chemical and nutrient concentrations in water samples collected at the seven sampling stations in Mtwapa creek, Mombasa Marine National Park and Reserve.

	Control	Mtwapa creek		Marine Park and Reserve				
	Kanamai	Mouth	Prison	Coral Garden	Nyali	Starfish	Ras Iwatine	Average
Temp (°c)	27.8±1.17	27.7±1.19	28.2±1.28	27.9±1.32	22.7±10.00	27.9±1.27	27.9±1.66	27.5
pH	8.5±0.12	8.5±0.10	8.4±0.14	8.5±0.10	7.7±2.71	8.5±0.08	8.5±0.11	8.5
DO (mg/l)	8.3±2.40	6.3±1.88	6.0±2.10	7.5±2.44	14.28±11.2	7.4±2.39	15.85±15.7	9.1
Sal (ppt)	36.1±0.63	36.0±1.21	32.4±9.23	36.4±0.26	32.7±11.50	36.4±0.30	39.0±8.43	36.1
TSS (mg/l)	99.0±33.1	45.3±13.6	46.4±11.8	30.9±4.1	68.9±23.6	42.3±15.9	58.9±20.7	55.5
Chl-a (µg/l)	5.257±4.403	1.237±0.658	1.146±0.673	0.900±0.564	0.755±0.448	0.710±0.199	0.692±0.207	1.068
PO_4 (mg/l)	0.014±0.0028	0.022±0.0044	0.03±0.0109	0.014±0.0031	0.03±0.0146	0.022±0.0213	0.011±0.0171	0.021
(NO_3^-+NO2-) -N (mg/l)	0.0426±0.0139	0.0408±0.0165	0.0407±0.0234	0.0348±0.0238	0.0468±0.0245	0.0409±0.0145	0.0387±0.0125	0.0408
NH_4^+-N (mg/l)	0.2338±0.0527	0.2496±0.069	0.2283±0.0547	0.2371±0.0805	0.2602±0.0853	0.2234±0.0437	0.2142±0.0351	0.2352

Table 2. Coastal water quality standards that are safe for swimming and support aquatic life (Shanmugam *et al.*, 2007).

Water quality parameters	Standards
pH	7.8–8.3
Temperature (°C)	30
Total Suspended Sediments (TSS)	<25 mg/l
Dissolved Oxygen (DO)	>4 mg/l
Nitrate/Nitrite (NOx)	<10 mg/l
Phosphorus as Phosphate (PO_4^{-3})	<0.1 mg/l
Chlorophyll-*a* (Chl *a*)	<15 mg/l

Total suspended solids (TSS) affect coral reef growth (Parwati *et al.*, 2014). Effects of sedimentation on the coral reef are a significant factor that results in the smothering and death of corals during the recruitment process (Fabricius *et al.*, 2003). The results for TSS ranged from 33.7 mg/l in the Mtwapa Mouth to 79.3 mg/l at Coral Garden, with an average of 55.5 mg/l across all seven stations. As shown in Table 2, the TSS across all stations is higher than the recommended standards of <25 mg/l (Shanmugam *et al.*, 2007). These values suggest that the high TSS levels in the study area could contribute to the deterioration of coral health during the study period. Proper sewage treatment to remove suspended solids, organic matter and nutrients is necessary before the effluent is discharged into aquatic bodies (Rono, 2017).

Nutrients

The net primary production of photoautotrophs in the ocean depends on nutrient availability, with some nutrients limiting phytoplankton biomass production in a system at a given time. The water quality in marine regions can directly or indirectly be adversely affected by land-based and water-based anthropogenic activities, with most of the pollutants finding their way into the marine environment from land-based activities through sewerage drainage systems from the discharge of poorly or untreated wastewater. These activities can result in elevated nutrient concentrations (primarily nitrogen and phosphorus), leading to eutrophication. The increase in toxic algal blooms could cause the death of benthic fauna and can be a threat to human health and could limit recreational activities (Moreno-Díaz *et al.*, 2015; Pole *et al.*, 2016), which is a concern for Mombasa Marine National Park and Reserve.

The mean nutrient concentrations observed in the Mtwapa creek were NH_4^+ - 0.253 ± 0.069 mg/l, (NO_3^- + NO_2^-)-N 0.042± 0.017 mg/l, PO_4 - 0.028 ± 0.004 mg/l

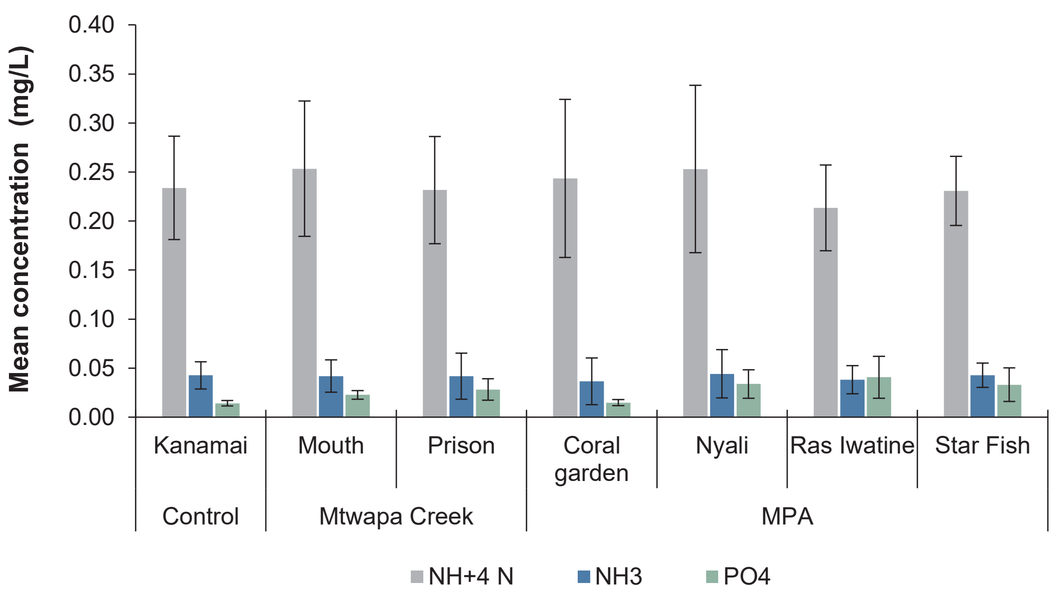

Figure 3. Mean ± standard deviation concentration of nutrients (dissolved inorganic nitrogen and phosphates) at the sampling stations.

at the Mtwapa Mouth station and NH_4^+ - 0.042 ± 0.055 mg/l, (NO_3^- + NO_2^-)-N 0.25 ± 0.023 mg/l, PO_4 - 0.023 ±0.011mg/l at Mtwapa Prison. The results for the MPA stations ranged from 0.213 ± 0.044 - 0.253 ± 0.085 mg/l for NH_4^+, 0.037 ± 0.014 - 0.044 ± 0.025 mg/l for (NO_3^- + NO_2^-)-N, and 0.014 ± 0.003 - 0.041 ± 0.021 mg/l for PO_4 (Fig. 3).

1. Dissolved Inorganic Nitrogen (DIN)

DIN is composed of ammonium (NH_4^+-N), Nitrate plus Nitrite (NO_3^- + NO_2^-)-N. These forms of nitrogen are readily available to phytoplankton and often control the formation of blooms (Caffery *et al.*, 2007). The range of NH_4^+ was consistent throughout the study period, showing minimum variability across the sampling stations, ranging from 0.105 mg/l (Kanamai) to 0.4130 mg/l (Nyali). It was noted that there was some seasonal variation of NH_4^+ (Fig. 4). The highest levels were recorded between April and August 2018, during and after the long rain season. Statistical analysis of variance confirms no significant differences in NH_4^+ levels between the stations throughout the year.

Nitrates plus nitrites (NO_3^- + NO_2^-)-N concentrations were lowest in Coral Garden (0.0348 mg/l), and the highest was recorded at the Nyali sampling station (0.0468 mg/l). The lowest amounts of (NO_3^- + NO_2^-)-N concentrations were recorded between November 2017 and April 2018 (0.0074-0.1169 mg/l). Similarly, the highest levels were recorded between July and August 2018 (0.0321-0.0987 mg/l), after the long rain season (Fig. 5). There were no statistically significant differences (p-Value = 0.9853) of (NO_3^- + NO_2^-)-N levels between the stations throughout the year.

2. Phosphates

Phosphorus is a limiting nutrient, particularly in tropical and subtropical estuarine and marine systems (Caffery *et al.*, 2007). Phosphates in the water samples ranged from 0.0138 mg/l in Coral Garden to 0.0430 mg/l in Ras Iwatine. There was a large seasonal variability across all stations, with peak amounts of phosphates recorded in October 2017, January and April 2018. This was more pronounced for Ras Iwatine and Nyali (spikes in January and April 2018) and Mtwapa Prison, which showed a spike in October 2017 (Fig. 6). The analysis of variance confirms that there are no significant differences in phosphate concentrations (mg/l).

*3. Chlorophyll-*a

Chlorophyll-*a* measures the green pigments in photosynthesising algae in the marine environment. The recommended scale for Chl-*a* in the marine environment ranges from good (<15 µg/l), fair (15-30 µg/l), and poor (>30 µg/l) (Shanmugam *et al.*, 2007). Ras Iwatine

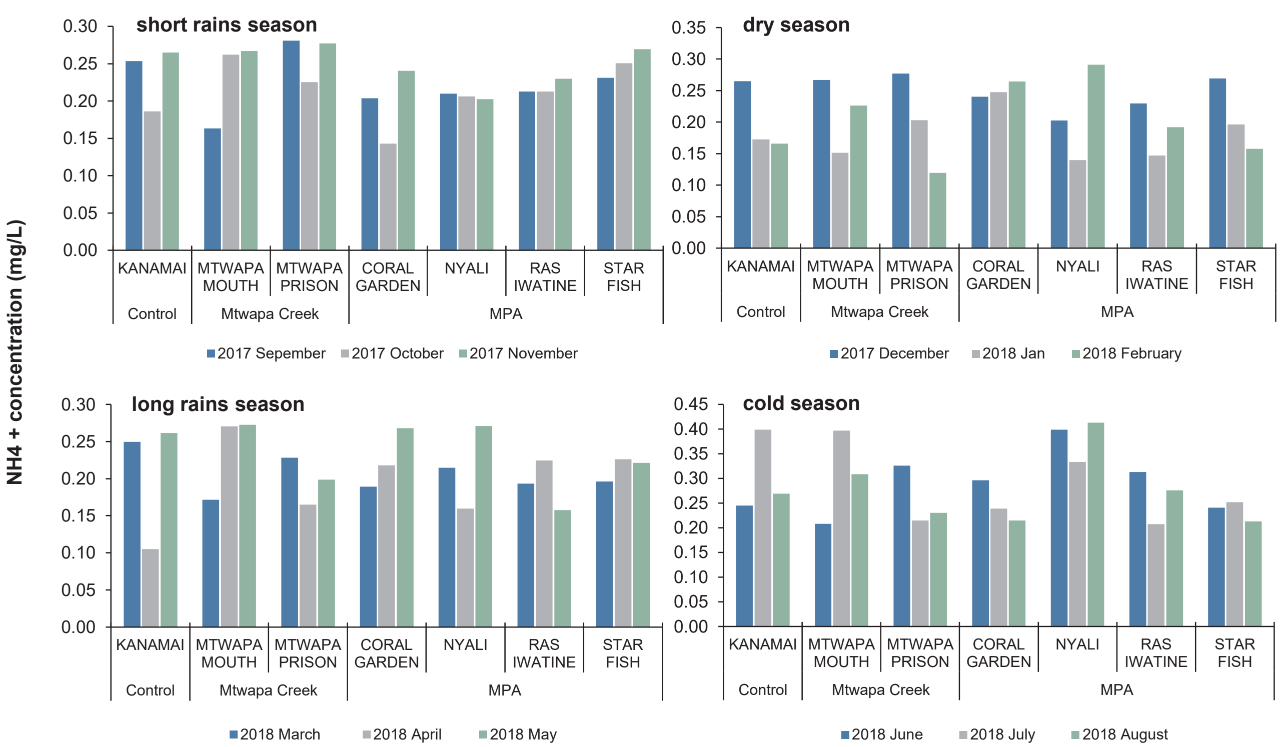

Figure 4. Monthly and seasonal variations of ammonium (NH4 +) concentration from September 2017 to August 2018 at each sampling station.

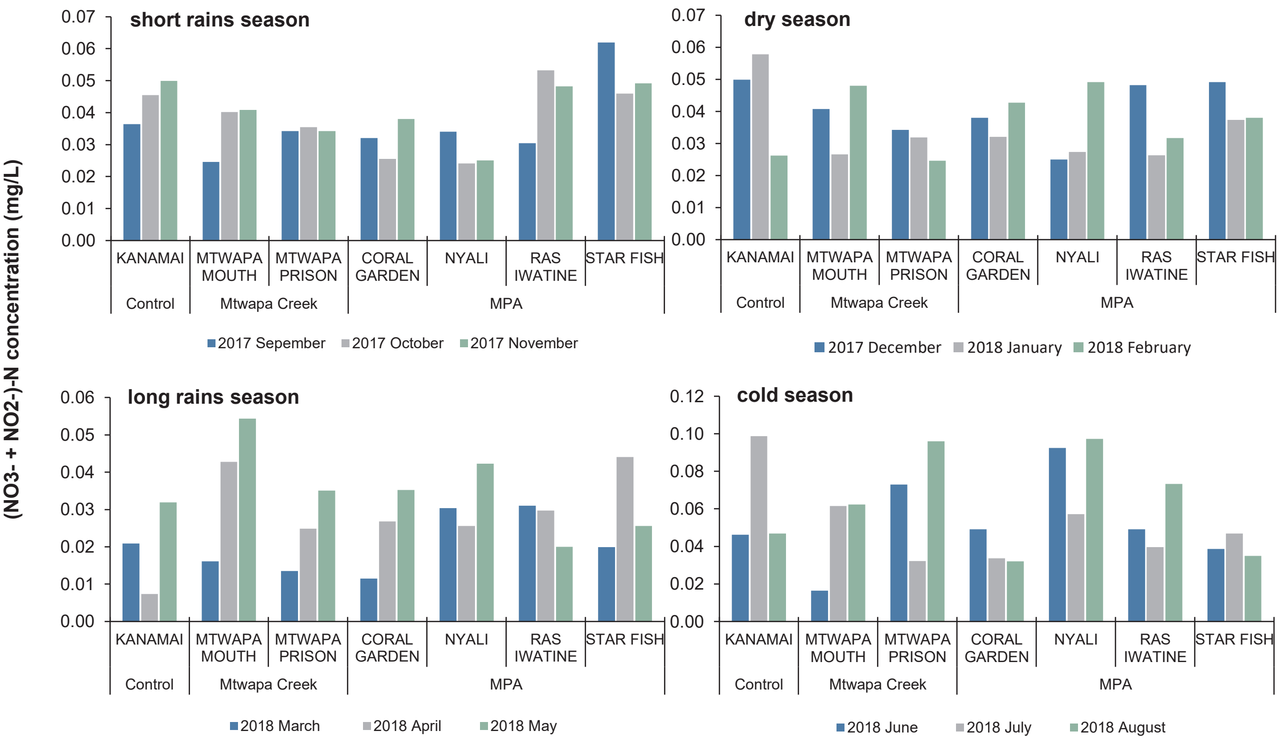

Figure 5. Monthly and seasonal variations of nitrates plus nitrites from September 2017 to August 2018 at each sampling station.

recorded the lowest average Chl-*a* amount of 0.7114 µg/l while Mtwapa mouth (Creek) had the highest value of 1.4942 µg/l. The levels of Chl-*a* appeared to be highest in the MPA stations close to the Mtwapa creek: Coral Garden (1.58 µg/l); Ras Iwatine (0.7114 µg/l); and the control site of Kanamai (0.9591µg/l). This was also demonstrated when the seasonal variability of Chl-*a* was analysed (Fig. 7). April and August 2018 had the highest concentrations of Chl-*a* across all sampling stations (Fig. 7). Statistical analysis showed that, based on

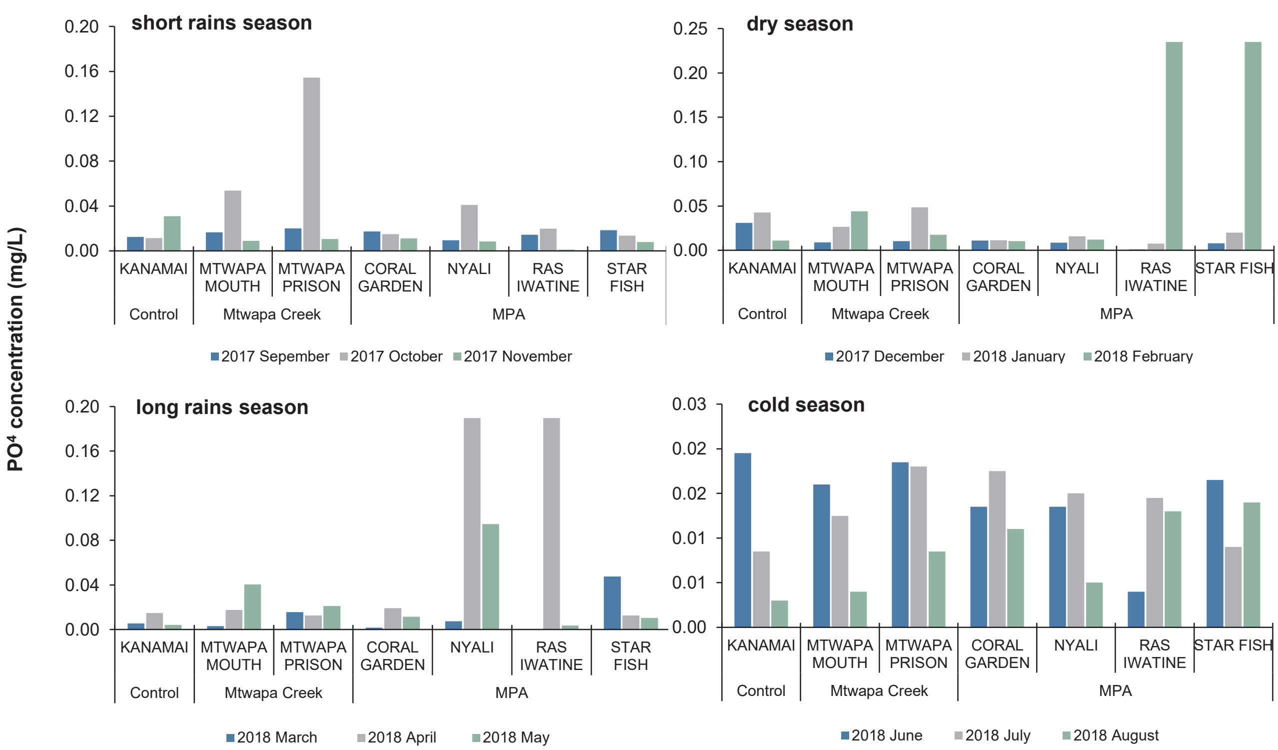

Figure 6. Monthly and seasonal variations of phosphates from September 2017 to August 2018 at each sampling station.

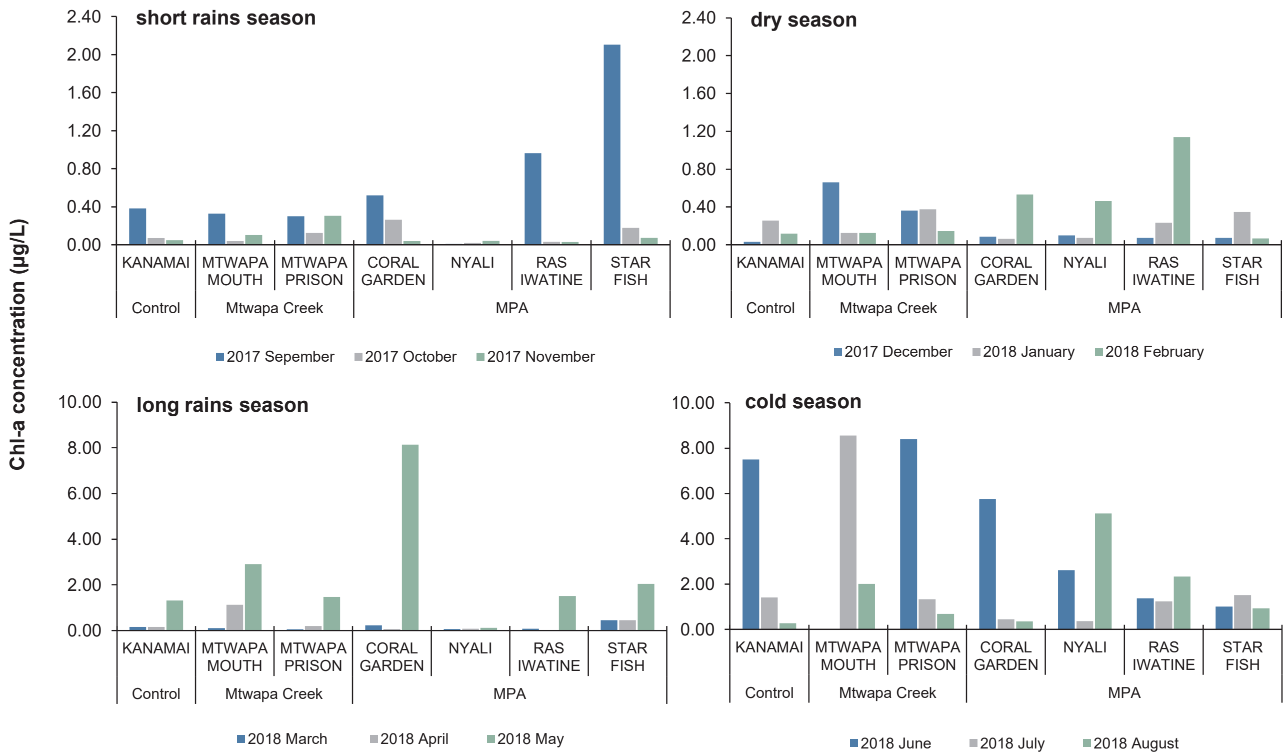

Figure 7. Monthly and seasonal variations of Chl-*a* in µg/L from September 2017 to August 2018 at each sampling station.

a p-value >0.05 in all sampling stations, there was no significant variance in Chl-*a* between the stations. Even though there was no significant difference in the level of all nutrients in the seven regions, Ras Iwatine, Nyali and Starfish had less Chl-*a* than the other four regions.

Kinjo (2017) presented a set of nutrient concentrations needed to maintain at least 50% coral reef coverage in a given area (Table 3). While the average amount of phosphates (0.021 mg/l) and nitrates + nitrites (0.0408 mg/l) were below the coastal water standards (Table 2), they are still higher than the concentration required to maintain 50% coral coverage (Kinjo 2017). These results suggest that, while the concentrations of these nutrients could not be harmful to most aquatic life, they would negatively impact corals. These observations are supported by Passy *et al*. (2016). who found that terrigenous nutrient delivery into the ocean increases with the degree of eutrophication, which is sensitive to agricultural practices and wastewater treatments at the level of the watersheds. The over-enrichment of nutrients can result in toxic algal blooms, shellfish poisoning, coral reef destruction, and other harmful outcomes. Other studies have also observed a correlation between elevated nitrogen concentrations, increased phytoplankton densities and coral bleaching (Wagner *et al*., 2010; Wooldridge, 2009; D'Angelo and Wiedenmann, 2014).

Enrichment of reef environments with dissolved inorganic nitrogen is considered a threat to the survival of corals. For those corals living in symbiosis with dinoflagellates (*Symbiodinium sp.*), enrichment can cause phosphorus starvation of the algal symbionts that can be caused by skewed nitrogen (N) to phosphorus (P) ratios (Rosset *et al*., 2017). Nutrient enrichment plays

Table 3. Environmental guidelines for coral reef conservation for acceptable levels of P and N to maintain 50 % of coral coverage as highlighted by Kinjo (2017). The observed averages in the study areas and their molar ratios.

Water quality parameters	Water quality is required to maintain 50% of coral coverage	Observed averages	Moles (uM)
Phosphates	<0.006 mg/l	0.021 mg/l	0.00022
NO_3	<0.01 mg/l	0.041 mg/l	0.00066
N:P molar ratio			3: 1

Table 4. Carlson's trophic state index (TSI) classification calculated from Chlorophyll-*a* (Chl-*a*) and total phosphorous (TP) concentration, ignoring the negative results.

Sampling Station		TSI (Chl-*a*)	TSI classification	TSI (TP)	TSI classification
Control	Kanamai	13.15	Oligotrophic	-57.29	Eutrophic
Mtwapa Creek	Mouth	27.35	Oligotrophic	-50.41	Eutrophic
	Prison	28.10	Oligotrophic	-47.35	Mesotrophic
MPA	Coral garden	30.47	Oligotrophic	-56.62	Eutrophic
	Nyali	32.19	Mesotrophic	-44.70	Mesotrophic
	Ras Iwatine	33.05	Mesotrophic	-42.03	Mesotrophic
	Star Fish	32.80	Mesotrophic	-45.03	Mesotrophic

Note: the scale of 0-30 TSI = oligotrophic, 31-49 TSI = mesotrophic and 50-100 TSI= eutrophic represent the trophic state classifications in reference to Carlson (1977) and KDHE (2001).

a role in determining coral reef resilience and overall health (Brodie *et al*., 2009; D'Angelo and Wiedenmann, 2014; Fabricius, 2005; Furnas *et al*., 2005; Koop *et al*., 2001). The ratio of N:P indicates the limiting nutrients for primary photosynthetic production in the marine environment. The approximate range of N:P ratios required for healthy coral reefs is from 4.3:1 to 7.2:1 (Smith *et al*., 1981; Crossland *et al*., 1984; Furnas *et al*., 1995). The results recorded in this study showed an N:P ratio of 3:1, which is a lower ratio than those recommended by the previous studies. This lower ratio suggests that there is a higher concentration of phosphorous than nitrogen in the study area, which would negatively impact the health of corals. This is further supported by a study by Larned (1998) that concluded that higher concentrations of phosphorus, rather than nitrogen, are the primary limiting nutrient to coral and macroalgae productivity.

Carlson's TSI classification

According to Carlson (1977), the changes from oligotrophic to eutrophic do not occur at sharply defined places or at the same location or rate. This implies that water bodies can be considered oligotrophic by one criterion and eutrophic by another. This is evident in the results from the current study in Table 4, where TSI classifications based on Chl-*a* differ from those based on total phosphorous concentrations.

The results based on Chl-*a* concentration show that the control site and the sampling stations in the Creek fell under oligotrophic TSI classifications. Except for Coral Garden (oligotrophic), the MPA sampling stations were all mesotrophic. The TSI classification based on concentrations of total phosphorous ranged from mesotrophic (Mtwapa Prison, Nyali, Ras Iwatine and StarFish) to eutrophic (Kanami, Mtwapa Mouth and Coral Garden).

Coral Health

Ras Iwatine and Nyali had the highest average count of healthy corals (615) along the transect, followed by Coral Garden (608) and then Starfish (192). Coral Garden had the most partially bleached corals (16),

Table 5. Interpretation of benthic survey results based on Kawaka *et al*. (2016).

	Unhealthy	Fair	Healthy
Recommended levels according to Kawaka *et al*. (2016)	1% live coral cover >21% algae cover **Characteristics:** mainly rubble, broken, dead coral, bleached coral covered by algae	15-30% live coral cover 6-20% algae cover **Characteristics:** soft corals begin to grow on bare rock, and some live coral. an increasing proportion of live and soft coral, less rubble, dead and bleached coral	>30% live coral cover 0-5% algae cover **Characteristics:** high proportion of live & soft coral, very little rubble or bare rock, no brown or green algae covering coral
Observed Results	≈2% Live (soft) coral. ≈22% macroalgae	≈17% live (hard) coral	

followed by 15 in Ras Iwatine, 11 in Nyali, and then five in Starfish. In comparison, 19 corals were fully bleached in Coral Garden, 18 in Nyali, 17 in Starfish and 15 in Ras Iwatine. The mean percentage cover for hard coral in Mombasa National Marine Park and Reserve between October 2017 to September 2018 was ≈17%, while soft coral was ≈2%. Seaweed cover, which included macroalgae, was ≈22% during the same period. Other benthic substrates covered were *Halimeda* with ≈1%, Coralline algae with ≈5%, sand with ≈6%, seagrass with ≈11%, bare rock with ≈22%, rubble with ≈16% and other with <1%. Benthic substrate cover did not vary significantly from month to month (p-Value = 0.123). However, there was no consistent trend in the benthic substrate cover over the monitoring period. This inconsistency could be attributed to slow reef recovery after the 2016 bleaching event which affected Kenya's coral reefs. During the study period, there was no mass bleaching in the area (or elsewhere on the Kenyan coast).

Based on the study's results, it was inferred that the coral reef health in MMNP&R was fair to unhealthy (Table 5). While the health of the hard, live corals in the study area can be considered fair, it was still below Kenya's average coverage of 20% (Kawaka *et al*., 2016). A report on coral health by Gudka *et al*. (2018) shows similar results of hard live corals of 26±9.1% following the bleaching event of 2016 in Mombasa.

Diversity Indices

The highest number of coral types recorded in this study was hard corals with 461 individuals, compared to the soft corals, with 89 individuals. The most dominant type was the soft corals with average ***Dominance_*** (***D*** 0.16 ± 0.06) compared to the hard corals with an average ***Dominance*** (***D***=0.07± 0.02). Based on the individuals recorded in various study sites, the Coral Garden had the highest diversity indices (H = 2.9) for the hard corals and the lowest diversity indices (H = 1.7) for soft corals (Table 6). On the other hand, the soft corals were low in percentage coverage, accompanied by a significant percentage coverage of macroalgae (tell-tale signs of eutrophic conditions), indicating unhealthy corals (Table 7).

Kanamai's (control) soft coral diversity index showed a positive canonical correspondence (H= 0.11), while the hard corals diversity index negatively correlated to the other physico-chemical parameters. Different results were found in the highly impacted Mtwapa Mouth station; the hard and soft coral diversity (H= -36.84, -38.12, respectively) negatively corresponded to the other physico-chemical parameters. The positive

Table 6. Principal component Canonical correspondence of the physico-chemical parameters and the Shannon-Wiener (H) diversity indices of the hard and soft corals recorded at the sampling sites.

	Control	Mtwapa Creek		MPA			
	Kanamai	Mouth	Prison	Coral garden	Nyali	Ras Iwatine	Starfish
	PC 3	PC 1	PC 2	PC 4	PC 5	PC 6	PC 7
DO (mg/l)	2.96	-25.40	-13.57	-0.78	1.12	0.11	-0.41
pH	-1.30	-29.74	-7.81	-3.21	0.74	0.58	0.35
Temp (°c)	4.28	12.41	18.19	-2.71	-0.48	1.48	-0.66
Cond (µs)	9.20	64.60	50.12	-4.63	2.68	-0.50	0.03
Sal (ppt)	8.20	33.47	25.64	-2.29	1.65	-0.38	0.30
Chl-a (mg/m³)	-6.70	-44.54	-17.27	-4.21	-0.21	-1.03	-0.83
TSS (mg/L)	-28.74	101.10	24.14	-0.12	-3.15	0.00	0.10
NH+4 N (mg/l)	-3.63	-48.23	-18.57	-3.64	0.52	0.06	0.33
NH3 (mg/l)	-3.68	-48.67	-18.84	-3.67	0.48	0.04	0.31
PO4 (mg/l)	-3.66	-48.70	-18.87	-3.67	0.48	0.05	0.32
Hard Corals (_I)	5.89	191.51	-50.47	3.31	1.52	0.01	-0.02
Hard Corals (_H)	-0.41	-36.84	6.98	5.82	0.59	0.06	0.11
Hard Corals (_D)	-0.40	-41.91	7.72	7.14	0.39	-0.16	-0.12
Soft Corals (_I)	18.37	0.77	-2.20	-0.67	-7.27	-0.25	0.14
Soft Corals (_H)	0.11	-38.12	7.06	6.27	0.54	0.12	0.19
Soft Corals (_D)	-0.48	-41.73	7.72	7.06	0.39	-0.17	-0.14

Table 7. Shannon-Wiener (H) diversity indices of the hard and soft corals recorded at the MPA sampling sites.

	Hard Corals			Soft Corals		
MPA	**Individuals**	**Shannon_H**	**Dominance_D**	**Individuals**	**Shannon_H**	**Dominance_D**
Coral garden	120	2.87	0.06	12.00	1.70	0.24
Nyali	132	2.78	0.06	16.00	2.19	0.13
Ras Iwatine	151	2.68	0.07	39.00	2.33	0.11
Starfish	58	2.56	0.10	22.00	2.02	0.19

canonical correspondence of the hard and soft coral diversity to other physico-chemical parameters in the MPA ranged from H= 0.06- H= 5.82 and H= 0.12- H= 6.27, respectively (Table 5).

Management of nutrient discharges

Land-based pollution needs to be addressed as part of a holistic, integrated coastal zone management approach supporting practical, sustainable and legal management of nutrient discharge into the marine environment to conserve corals. Efforts have been made to address land-based activities by formulating Strategic Action Plans (SAPs) to address the challenges of increased coastal water pollution in the Western Indian Ocean region (Pole *et al.*, 2016). Several methods to reduce nutrient discharge have also been developed around the world that can be adopted in Kenya (Aloe *et al.*, 2014). Encouragement of environmentally benign and economically viable technology, raising awareness and developing capacity for wastewater management are some methods for reducing effluent discharge. Kenya can follow the lead of many countries that have adopted Direct Toxicity Assessment (DTA) or Whole Effluent Toxicity (WET) testing to assess and manage effluents, leachates and contaminated ambient waters in marine and freshwater environments. These DTAs can serve as early warnings for the implementation of management actions and also provide a direct measure of toxicity and bioavailability of mixtures whose chemical composition is unknown (Pole *et al.*, 2016). Other available management options include land-based buffer zones along flow paths developed by Weller *et al.* (2011). Finally, Kenya should ensure the implementation of policy, legal, regulatory and institutional frameworks to protect and manage the coastal environment from land-based pollution. These frameworks would be an integral part of the country's ocean governance strategy.

Conclusions and recommendations

The study found that the land-based nutrient load would influence coral reef health during the study period. The temperature during the study period was within normal ranges and was deemed to have little impact on coral health. The physico-chemical parameters of the study area and their effects on coral health were established. Nutrient quality and quantity were assessed and found to be higher than the recommended standards. This impacted the coral reef health within Mtwapa creek and MMNP&R , which was established to be fair to unhealthy. It was observed (and corroborated anecdotally) that despite efforts by KWS to manage MMNP&R, land-based pollution continues along the coastline. While it is easy to pinpoint the sewage discharged by the Shimo La Tewa prison as a point source of pollution, there are other diffuse and point sources of pollution along the coastline. Due to financial and technical limitations, the different sources were not considered in the study. While other direct human activities in the marine space contribute to coral health, the study did not consider them. More robust studies should be carried out in the future to include all these factors, including pollution from land-based sources.

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Structural complexity of seagrass and environmental variables as a determinant of fish larvae assemblages in tropical coastal waters: Implications for seagrass management and conservation

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Abstract

Anthropogenic activities including climate change affect the development of structural complexity in seagrass and the state of environmental variables. It remains unclear whether these variables, alone or in combination, have an important influence on fish larvae assemblages. This study examined the influence of the structural complexity of seagrass meadows and various environmental variables on fish larvae assemblages in tropical coastal waters of Tanga, Tanzania. The study was conducted in four *Thalassia hemprichii* dominated seagrass meadows from June 2019 to January 2021. Multiple regression analysis indicated that the structural complexity of seagrass (canopy height, seagrass cover, and shoot density) and environmental variables (dissolved oxygen, temperature and salinity) were the foremost predictors for fish larvae assemblages; abundance and richness (R^2 = 0.75, p = 0.0185, R^2 = 0.54, p = 0.0396, respectively). Based on these findings, the structural complexity of seagrass and environmental variables are both important determinants of fish larvae assemblages in tropical coastal waters. The findings suggest that reducing anthropogenic activities that affect the development of structural complexity of seagrass and negatively impact environmental variables in seagrass meadows through more effective governance would result in increased production of fish larvae in meadows and, as a result, increased fish recruitment in tropical coastal waters.

Keywords: seagrass, fish larvae, assemblages, coastal waters, anthropogenic stress

Introduction

Anthropogenic activities, including climate change, are increasingly affecting the health and function of seagrass meadows (Dunic *et al.,* 2021), with significant impacts on the recruitment of fish stocks (Waycott *et al.*, 2009; Brodie and De Ramon N'Yeurt, 2018; Hedberg *et al.,* 2019). Threats directly affecting the health and functions of seagrass meadows include destructive fishing methods such as drag-net fishing, the use of beach seines, ring nets, gleaning, trampling, pulling or pushing boats towards deeper waters, surface rain runoff, and excessive nutrient and sediment fluxes from activities related to agriculture (Gullström *et al.,* 2008; Erzad *et al.,* 2020). Also, increased populations of grazers, such as sea urchins, can cause local overgrazing of seagrasses. Increases in grazers are associated with overfishing of predatory fish that feed on sea urchins (Eklöf *et al.,* 2008). These threats underscore the need for effective conservation and governance to address the pressures that impact the ecosystem function of seagrass meadows in coastal waters.

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Seagrass meadows are important fishing and nursery grounds for a variety of fish species (Nagelkerken *et al.,* 2000; Gullström *et al.,* 2008; Unsworth *et al.*, 2019). They are distinguished by an abundance and diversity of fish larvae, which play an important role in recruitment of fish stocks in coastal waters (Cullen-Unsworth and Unsworth, 2016; Unsworth *et al.,* 2019). While relatively high abundance of fish larvae in seagrass meadows is often attributed to the availability of prey (Vonk *et al.,* 2010), the structural components of seagrass meadows could diminish predator foraging efficiency (Lugendo *et al.,* 2007; Muhando and Rumisha 2008; Hedberg *et al.,* 2019) and be important in attracting fish larvae seeking refuge (Gillanders, 2006; Lugendo *et al.,* 2007; Gullström *et al.,* 2008; Jones *et al.,* 2021; Tarimo *et al.,* 2022). The degree of structural complexity in seagrass meadows is influenced by the local environment (Huwer *et al.,* 2016), which also has an impact on the fish larvae assemblages. Furthermore, seagrass plays a crucial role in combatting climate change (Uku *et al.,* 2022), ensuring food security, protecting coastlines, and biodiversity enhancement (Nordlund *et al.,* 2016; Brodie and De Ramon N'Yeurt, 2018).

Seagrass cover, shoot density, canopy height, length and width of leaves, and number of leaves per shoot are used as a structural complexity measure or indicators, and have been shown to decrease with disturbance in previous studies (Hedberg *et al.,* 2019; Jones *et al.,* 2021; Mwaluma *et al.,* 2021). Research on how the complexity of seagrass structures affect fish larvae assemblages is lacking. A few studies in the Western Indian Ocean (WIO) region have examined the impact of seagrass complexity on juvenile, sub-adult, and adult fishes but not on fish larvae (Gullström *et al.,* 2006; Palmqvist *et al.,* 2013; Hedberg *et al.,* 2019; Jones *et al.,* 2021). Other studies focused on seasonal patterns of fish larvae in mangrove creeks, and inshore seagrass meadows (located adjacent to mangroves) (Lugendo *et al.,* 2007; Tarimo *et al.,* 2022). In other geographical areas, studies focused on the complexity of vegetated areas on fish larvae distribution and variability (Rappe *et al.,* 2013; Erzad *et al.,* 2020). Despite these studies, there is limited information on the impact of tropical seagrass structural complexity alone or in conjunction with environmental variables on fish larvae assemblages, making it difficult to determine which characteristics are crucial for setting management priorities (Molina *et al.,* 2020). The present study was designed to examine the relative importance of seagrass structural complexity and environmental variables on fish larvae assemblages (abundance and family richness) in tropical coastal waters. The explicit hypotheses was tested that abundance and family richness of fish larvae are determined by (1) seagrass structural complexity (seagrass percentage cover, shoot density, and canopy height), and (2) environmental variables (temperature, dissolved oxygen, pH, salinity, and water depth).

Methodology

Study site description

The study was conducted in Kitanga (ST1), Fungu ya Kaangoni (ST2), Nyonza (ST3), and Mwamba Karange (ST4), situated on the north coast of Tanzania (Fig. 1). The selection of sites was based on the presence of seagrass meadows influenced by varying degrees of anthropogenic disturbance, affecting the development of seagrass structural complexity. In general, seven seagrass species were present in the surveyed areas of which *Thalassia hemprichii* was dominant. The data collected were for the single species *Thalassia hemprichii,* based on the finding of Jones *et al.,* (2021) that seagrass diversity (both functional and species) had minimal effect on fish assemblages. Therefore, in this study it was decided to concentrate on the single dominant species.

These sites experience varying degrees of anthropogenic disturbances that impact on the development of seagrass structural complexity. Fungu ya Kaangoni (ST2) and Mwamba Karange (ST4) were characterized by reduced intensity and frequency of fishing, and anthropogenic activities that impact on seagrass beds, as well as natural factors like the influence of seasonal streams inflow, which brings sediments from land sources, as these sites are comparatively far from the coastline (about 10 km away from the coast). Kitanga (ST1) and Nyonza (ST3) are located nearshore, where the majority of damaging fishing practices (e.g., drag nets) are carried out and streams flow directly into these sites, bringing sediments and wastes from agricultural and industrial activities and contribute to impacts on these sites. While Nyonza (ST3) is influenced by the Kisare stream, Kitanga (ST1) is influenced by the Koreni stream. These streams transport domestic waste, sediment from land-based operations, nutrients, or fertilizers from sisal estates during the rainy season. Furthermore, these sites are impacted by fishing activities (the use of ring nets, gleaning, beach seines and other fishing methods), trampling, and pulling or pushing boats towards deeper waters.

The study sites are influenced by southeast and northeast monsoon winds (Peter *et al.,* 2021), which affects water temperature, wind, rainfall, water circulation, wave action, and biological processes. The southeast monsoon season (SEM), from May to September, is characterized by strong winds (blowing relatively strongly from the southeast towards the northwest, at a speed of about 9 ms^{-1}), heavy rains, and low air temperatures. The northeast monsoon season (NEM), from November to March (Peter *et al.,* 2018), is characterized by steady winds (blowing from the northeast towards the southwest at about 5 ms^{-1}), short rainy periods, and high air temperature (Peter *et al.,* 2021). Field surveys

Field sampling and laboratory procedures

Environmental variables, including temperature, salinity, pH, dissolved oxygen, and water depth were measured directly in the field. Temperature and dissolved oxygen (DO) were measured using a thermometer with a temperature sensor and a DO meter (ECOSENSE DO 200A), respectively. Salinity was measured using a refractometer (RS 20). The pH was recorded using a pH meter (HANNA S8128) and water depth was recorded using an echo sounder (speed tech instrument 4308055). All equipment used were handheld.

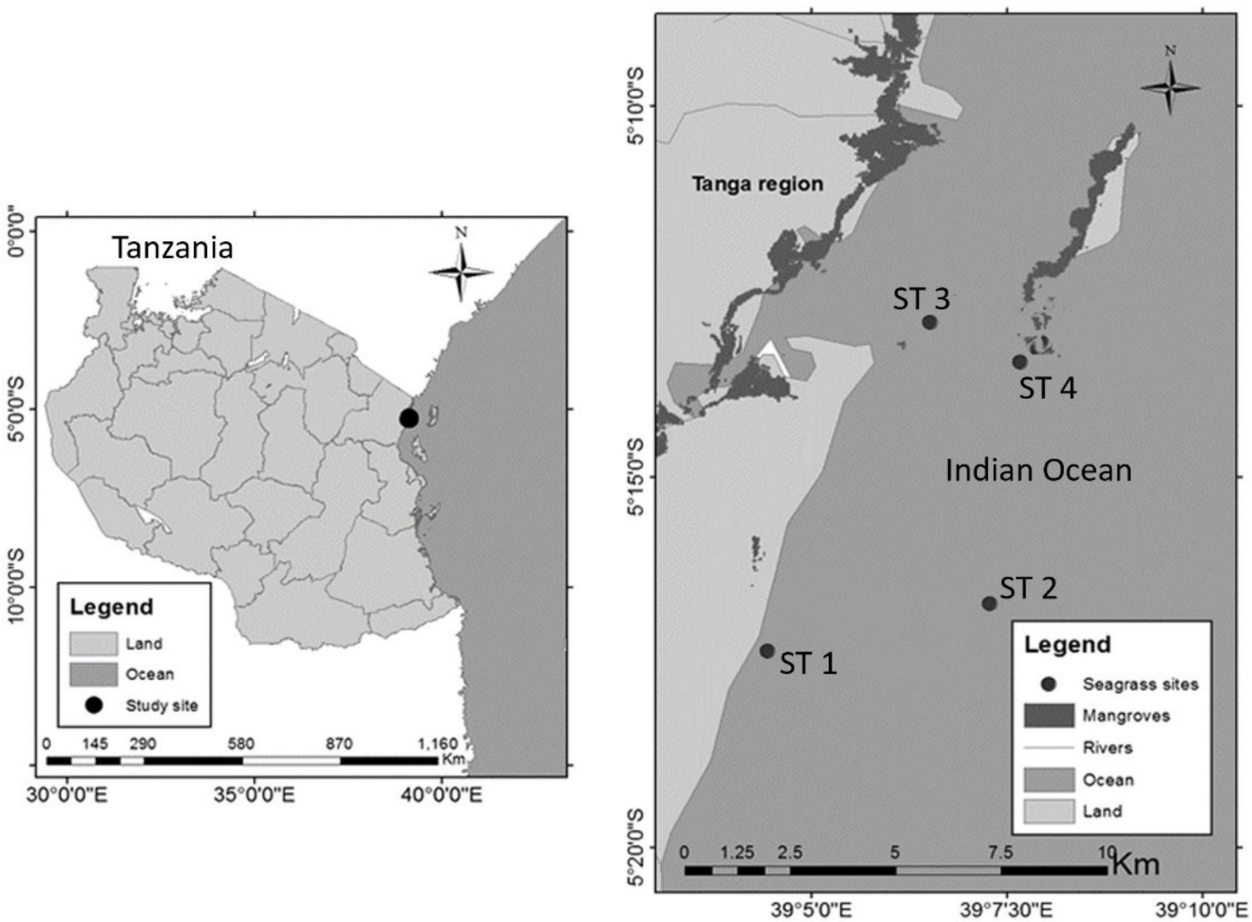

Figure 1. Map showing the study sites: the black dot on the map of Tanzania shows the general location of the sampled area, which is then expanded on the map on the right-hand side, giving the exact locations of the four sites. Where ST1 - Kitanga, ST2 - Fungu ya Kaangoni, ST3 – Nyonza, ST4 - Mwamba Karange.

in seagrass meadows were conducted during spring low tides while fish larvae sampling was conducted over the seagrass meadows during the corresponding high tides. During the SEM, sampling was conducted for four months; June and August (2019) as well as July and September (2020). During the NEM season, sampling was also conducted for four months; December (2019), February and November (2020) as well as January (2021).

At each seagrass meadow site, two transects were established perpendicular to the shoreline covering upper, middle, and lower zones. These transects were set 100 m apart to capture site representation. On each transect, three plots in each zone were randomly selected using a 0.25 x 0.25 m quadrat, for nine plots in total. In each quadrat, data for seagrass cover, canopy height, and shoot density were recorded. Seagrass species were identified *in situ* using field manuals appropriate for the region (Richmond, 2002). Shoots of the dominant seagrass species, *Thalassia hemprichii,* were counted and then used to estimate shoot density. Seagrass shoot density was determined as the number of individual seagrasses in a quadrat, which was expressed in a square meter area (m^2) (Erzad *et al.,* 2020). Seagrass percentage cover of *T. hemprichii* was determined by visual estimate using 0.25 x 0.25 m quadrats (Saito and Atobe, 1970). Within the quadrat, canopy height of *T. hemprichii* was measured using a ruler (30 cm).

Fish larvae samples were collected by towing an ichthyoplankton net (mesh size of 500 µm, mouth diameter of 0.5 m and a total length of 2.5 m) fitted with a hydro-bios mechanical flow meter to calculate the volume of water passing through the net. The net was towed behind the boat over seagrass meadows dominated by *T. hemprichii* as close to the canopy as possible, ranging between 0.75 and 6 m depth and maintained in surface waters at approximately 1 meter per second current speed for 15 minutes to concentrate fish larvae samples. After each tow, the fish larvae samples were decanted into 200 mL plastic bottles then immediately fixed with 75% ethanol solution and transported to the laboratory for further analysis. In the laboratory, fish larvae samples were drained and a fresh 75% ethanol solution was added. The separation of fish larvae from the entire sample was carried out under a stereomicroscope. Using the available taxonomic guides of Mwaluma *et al.* (2014) and Leis and Carson-Ewart (2000), each fish larvae specimen was identified to family level.

Data analysis

Before statistical analyses, the assumption of homogeneity of variance was checked by using Shapiro-Wilk's test at the significance level of $p < 0.05$. Fish larvae abundance and environmental variable data were $\log_{10}(x+1)$ transformed when necessary based on the values of skewness. This was carried out using R statistical programming version 4.1.2 software. When the data remained heteroscedastic despite transformations, hypotheses were rejected at alpha levels lower than the p-values of the Shapiro-Wilk's test. Data of seagrass structural complexity measurements (i.e., percentage cover, shoot density, and canopy height) and fish larvae abundance were analyzed using Analysis of Variance (ANOVA) to compare the means and state significant differences, followed by Tukey's *post hoc* test in the four sites. A two sample t-test was used to test the seasonal difference between the SEM and the NEM seasons. Multiple linear regression analysis was used to explore the relative importance of various continuous variables: seagrass structural complexity (percentage cover, shoot density, and canopy height); and environmental variables (temperature, dissolved oxygen, pH, salinity, and water depth) on fish larvae assemblages. Moreover, before the analysis, all predictor variables were checked for collinearity. The data for testing the response of fish larvae abundance and fish family richness were grouped into two distinct groups: (1) seagrass structural complexity; and (2) environmental variables. Given that multiple variables were included within the two categories, Principle Component Analysis (PCA) was performed using the prcomp() function in R and the values for PC1 were extracted and exported to create a single variable accounting for the majority of the variance. Afterwards, PCA values accounting for the majority of variance to do multiple linear regression were used to evaluate the influence of seagrass structural complexity and environmental variables on fish larvae assemblages. The approach constructed a linear model from the analyses of the principal component instead of the original values of the predictors to avoid the redundancy and multicollinearity between them.

Linear mixed-effects were used to explore the relative importance of three seagrass structural complexity variables and five environmental variables on two fish response variables; fish larvae abundance and fish family richness. Multivariate analysis of the fish larvae assemblage was performed using PRIMER ver. 6.1.2 software (Plymouth Routines in Multivariate Ecological Research) (Clarke and Warwick, 2001). Two-way crossed analysis of similarities (ANOSIM) was used to test for differences in fish larvae assemblages among sites. Patterns of similarities were visualized using non-parametric multidimensional scaling (nMDS) based on the Bray-Curtis similarities measure (a well-suited similarities index since it does not require exclusion of rare species or family), calculated by means of square root-transformed data. The similarity of percentages (SIMPER) procedure was carried out to determine which fish larvae family contributed most to dissimilarities among the different study sites. To determine the degree of correlation between 2 independent distance (dissimilarity or similarity) matrices, the Mantel test was applied whereby a randomization technique to test whether dissimilarity matrices of fish assemblages and habitat variables (i.e., seagrass structural complexity, environmental

Table 1. Average values (± SE) of environmental variables in the study sites and season. Where, ST1 - Kitanga, ST2 - Fungu ya Kaangoni, ST3 – Nyonza, and ST4 - Mwamba Karange. SEM - southeast monsoon, and NEM - northeast monsoon seasons.

Sites/Season	Environmental variables				
	Temperature (°C)	DO (mg/L)	pH	Salinity (psu)	Depth (m)
ST1	27.69 ± 0.39	6.5 ± 0.36	8.60 ± 0.12	35.30 ± 0.24	3.80 ± 0.32
ST2	27.50 ± 0.38	7.39 ± 0.36	8.61 ± 0.15	35.88 ± 0.35	3.23 ± 0.42
ST3	27.65 ± 0.38	6.115 ± 0.38	8.58 ± 0.11	35.0 ± 0.30	3.19 ± 0.26
ST4	27.76 ± 0.39	6.70 ± 0.42	8.68 ± 0.11	35.95 ± 0.39	3.24 ± 0.60
p value	$p = 0.29$	$p = 0.06$	$p = 0.19$	$p = 0.23$	$p = 0.27$
SEM	26.59 ± 0.20	7.78 ± 0.30	8.56 ± 0.05	36.02 ± 0.28	3.18 ± 0.25
NEM	28.65 ± 0.27	6.77 ± 0.30	8.63 ± 0.03	35.19 ± 0.16	3.21 ± 0.25
p value	6.4e-06***	0.00186**	0.0207*	0.00426*	$p = 0.12$

variables) showed association among sites (Mantel, 1967). Distance matrices based on $X^{0.25}$ transformed fish larvae data (abundance and family richness) were calculated based on Bray-Curtis similarities, whereas distance matrices of *z* transformed habitat and environmental variables were made on Euclidean similarities measures.

Results

General description of environmental variables, fish larvae assemblages and seagrass structures

Variations in environmental variables in the different seagrass meadow sites and seasons are presented in Table 1. There were no statistically significant differences in environmental variables among sites ($p > 0.05$). However, a two-sample t-test revealed a significant seasonal difference in environmental variables ($p < 0.05$), except for the depth, as presented in Table 1. During the SEM season, dissolved oxygen, and salinity levels were higher than during the NEM season. Temperature and pH, on the other hand, were significantly higher in the NEM season than in the SEM season. In the present study, there were no significant seasonal differences in fish larvae assemblage and seagrass structures between SEM and the NEM ($p > 0.05$) (Table 2).

Seagrass habitat structure varied among *T. hemprichii*-dominated seagrass meadows (Fig. 2). For structural complexity variables (mean seagrass percentage cover, and canopy height), there was a significant difference among seagrass meadow surveyed sites ($p = 0.000$, $p = 0.022$ respectively). In contrast, estimates of the mean shoot density were comparable with no significant differences among sites ($p = 0.16$). There was significantly higher seagrass cover at sites ST2 and ST4 than ST1 and ST3, while canopy height was significantly higher at sites ST1 and ST3 than at ST2 and ST4.

A total of thirty-eight (38) fish larvae families were identified (Fig. 3). One-way ANOVA showed a significant difference ($p = 0.013$) in fish larvae abundance (number of individual families per m^3) among study sites (Fig. 4). The Tukey's *post hoc* test revealed highest values at ST1, ST2 and ST4, while lowest values were recorded at ST3. There was no significant difference in fish larvae abundance at seagrass sites ST1 and ST4 ($p = 0.14$). Statistically, fish larvae abundance at seagrass sites ST3 and ST2 were significantly different from each other ($p = 0.041$). Also, the two sample t-test revealed no significant difference in fish larvae abundance and fish family richness between SEM and NEM seasons ($p = 0.31$,

Table 2. Average values (± SE) of fish larvae assemblages and seagrass structures between southeast monsoon (SEM) and the northeast monsoon (NEM) seasons.

Variables	Season		
	SEM	NEM	*p value*
Seagrass % cover	39.47 ± 0.39	40.83 ± 0.40	0.34
Shoot density	396.59 ± 1.24	455.85 ± 1.33	0.12
Canopy height	5.55 ± 0.15	5.67 ± 0.15	0.42
Fish larvae abundance (Ind/ 100m³)	5.06 ± 0.14	3.68 ± 0.11	0.31
Family richness	4.93 ± 0.13	3.68 ± 0.11	*0.199*

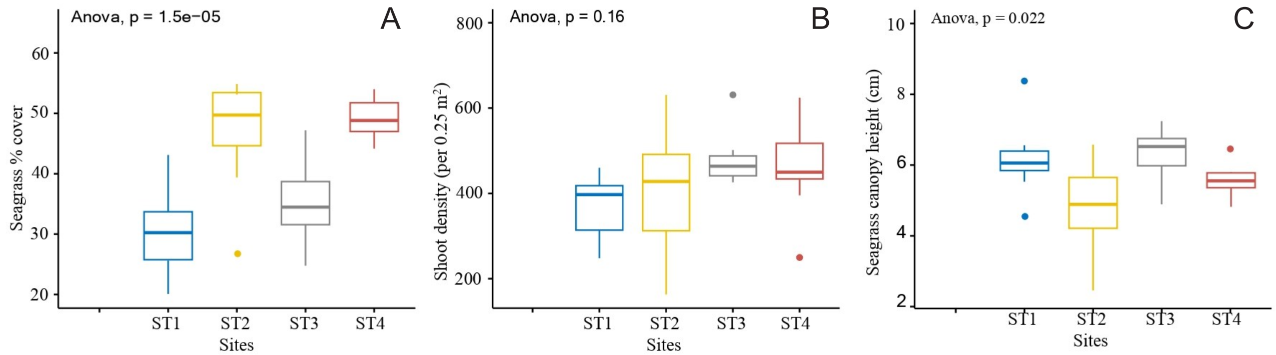

Figure 2. Boxplot showing seagrass habitat structure among the study sites. ST1 - Kitanga, ST2 - Fungu ya Kaangoni, ST3 – Nyonza, ST4 - Mwamba Karange.

p = 0.199 respectively) (Table 2). There was a significant variation in fish larvae family richness among the study sites (p = 0.031). Tukey's *post hoc* test revealed the highest and the lowest values at sites ST1 and ST4 (p = 0.034). While lower values were observed at seagrass sites ST2 and ST3 (p = 0.45), high family richness was observed at ST4 and ST1. The dominant fish larvae families identified throughout the study were Scaridae, Syngnathidae, Labridae, Sphyraenidae, Belonidae, Clupeidae, Carangidae, and Bleeniidae.

The influence of seagrass structural complexity and environmental variables on fish larvae assemblages

Principle Component Analysis (PCA) was performed to extract variables accounting for the majority of the variance (Fig. 5). In the PCA of seagrass structural complexity, PC1 accounted for 52.9% of the variation while PC2 accounted for 32%. All seagrass variables contributed to PC1 which was positively correlated with canopy height and shoot density, and were negatively correlated with seagrass percentage cover. For environmental variables, PC1 accounted for 39.8% while PC2 accounted for 23.6% of the variation and each had substantial factor loadings on PC1. For environmental variables, dissolved oxygen and depth were positively correlated while temperature, salinity, and pH were negatively correlated on PC1. From the multiple linear regression analyses, combined seagrass structural complexity variables (seagrass percentage cover, canopy height, and shoot density) and environmental variables (temperature, dissolved oxygen, pH, salinity, and depth) significantly predicted fish larvae abundance (R^2 = 0.756, p = 0.0185; Table 3). Also, the same result was observed on fish family richness whereby all predictors statistically significantly predicted fish larvae families (R^2 = 0.54, p = 0.0396; Table 3).

Using individual variables in one model, multiple linear regression analyses of seagrass percentage cover, canopy height, and shoot density variables statistically, they significantly predicted fish larvae abundance

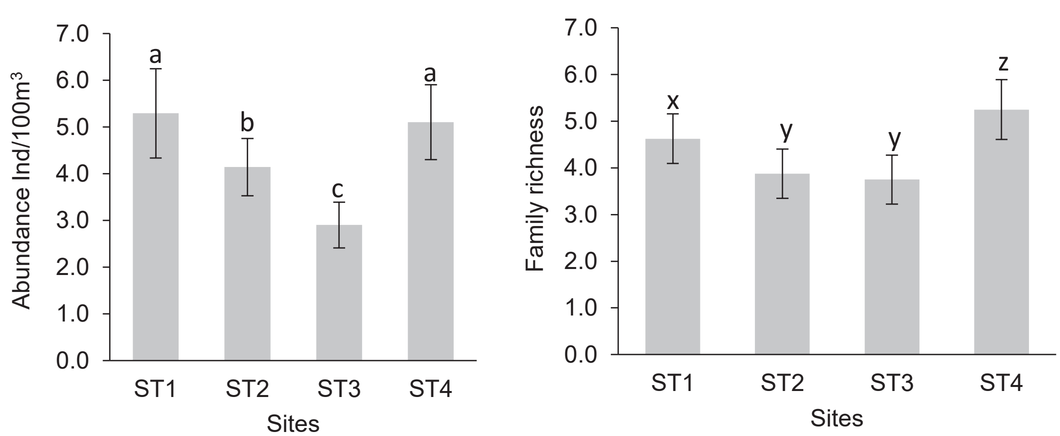

Figure 3. Fish larvae abundance and family richness among meadows at the four sites (Where, ST1 - Kitanga, ST2 - Fungu ya Kaangoni, ST3 - Nyonza, and ST4 - Mwamba Karange). Note that bars with the same letters (a, b, c, x, y, z) indicate values which are not statistically different at p < 0.05 within the same group.

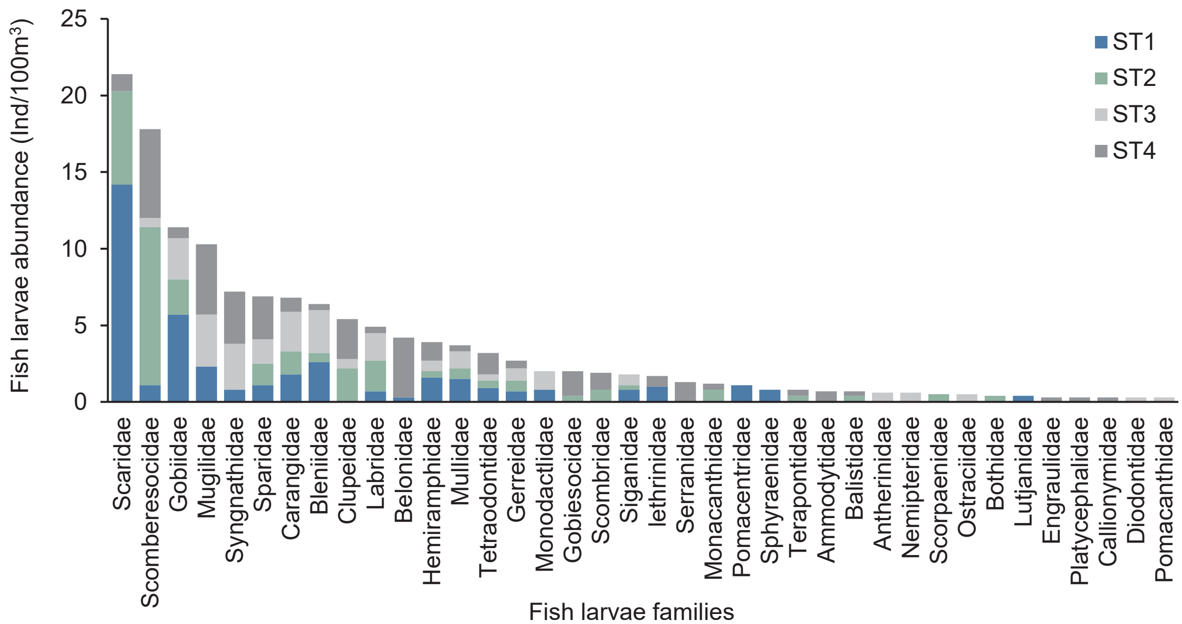

Figure 4. Dominant fish larvae family abundance among sites (Where, ST1 - Kitanga, ST2 - Fungu ya Kaangoni, ST3 - Nyonza, and ST4 - Mwamba Karange).

(R^2 = 0.72, p = 0.011). Canopy height and shoot density positively predicted fish larvae abundance and it was significant (p = 0.03, p = 0.045; Table 4). Likewise, a significant negative prediction by seagrass percentage cover on fish larvae abundance was observed (p = 0.005; Table 4). In terms of fish family richness, only canopy height was a significant positive predictor of fish family richness (p = 0.012), while shoot density and seagrass percentage cover showed a positive prediction on family richness but were not statistically significant (p = 0.15, p = 0.95, respectively).

Environmental variables showed a statistically significant prediction on fish larvae abundance (R^2 = 0.54, p = 0.032). Temperature and dissolved oxygen were significant predictors of fish larvae abundance (p = 0.04, p = 0.026, respectively). Furthermore, pH was shown to be a positive predictor of fish larvae abundance (p = 0.88), and a negative predictor of fish richness (p = 0.75), but not significantly. Other predictor variables such as salinity and depth negatively predicted fish larvae abundance, however, they were not statistically significant (p > 0.05). Multiple linear regression analyses of seagrass structural complexity significantly predicted fish larvae family richness (R^2 = 0.65, p = 0.0124). Predictor variable canopy height had a significant prediction of fish larvae family richness (p = 0.012) while shoot density and seagrass cover

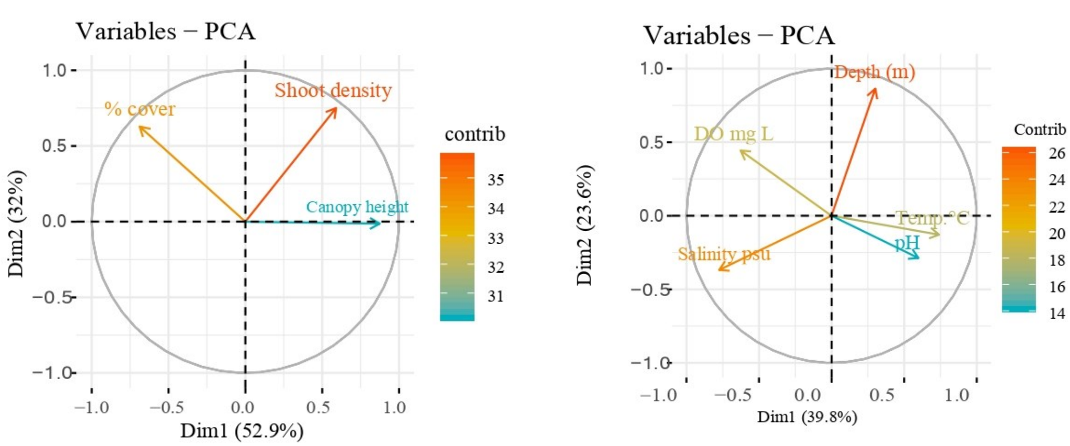

Figure 5. Principle Component Analysis (PCA) plots showing the variation in seagrass structural complexity and environmental variables on fish larvae assemblages.

Table 3. Results of multiple linear regression analysis showing combined seagrass structural complexity and environmental variables extracted from PCA accounting for the majority of variance for predicting fish larvae assemblages.

Dependent variable	Predictor variables	Estimate	Std. Error	t value	Pr(>|t|)	R^2	p- value (overall model)
Fish larvae abundance	Intercept	1.40811	0.68	2.060	0.0485 *		
	Seagrass structural complexity	0.7689	0.081	9.426	0.00 *	0.756	0.0185 *
	Environmental variables	0.140	0.122	2.6244	0.062.		
Family richness	Intercept	0.674	2.815	5.337	0.00 *		
	Seagrass structural complexity	0.484	0.805	2.288	0.0296 *	0.54	0.0396 *
	Environmental variables	0.228	0.121	1.19	0.09851.		

Table 4. Results of multiple linear regression analysis showing variables significantly predicting fish larvae abundance and family richness.

Dependent variable	Predictor variables	Estimate	Std. Error	t value	Pr(>|t|)	R^2	p- value (overall model)
Fish larvae abundance	Intercept	4.31	1.98	2.17	0.051.		
	Seagrass % cover	-0.14	0.041	3.43	0.005*		
	Shoot density	0.17	0.030	2.16	0.045.	0.72	0.011*
	Canopy height	0.61	0.90	0.67	0.03*		
Fish larvae abundance	Intercept	84.19	75.36	1.12	0.27		
	Temp (°C)	-1.03	0.90	-1.15	0.026*		
	DO (mg/L)	1.62	0.81	1.99	0.04*	0.54	0.032 *
	pH	1.17	7.41	0.16	0.88		
	Salinity (psu)	-1.98	1.26	-1.57	0.13		
	Depth (m)	-0.50	0.60	-0.83	0.41		
Family richness	Intercept	4.17	3.92	1.06	0.30		
	Seagrass cover	0.20	0.5	0.02	0.98		
	Shoot density	0.046	0.030	1.510	0.159	0.65	0.0124*
	Canopy height	0.41	0.13	2.99	0.012*		
Family richness	Intercept	78.30	45.05	1.738	0.116		
	Temp (°C)	-1.08	0.46	-2.37	0.03*		
	DO (mg/L)	0.38	0.41	0.93	0.36		
	pH	-1.20	3.76	-0.32	0.75	0.73	0.013*
	Salinity (psu)	-1.27	0.64	-2.00	0.04*		
	Depth (m)	-0.26	0.30	-0.85	0.40		

NB: Significance difference at: $p < 0.05$ *

Table 5. Fish families contributing (by > 5%) to dissimilarities (cumulative limit of 68%) among sampling sites (legend described in Fig. 1) in the SIMPER analysis on fish larvae abundance.

S/N	Fish larvae families	% contribution to dissimilarities
1	Scaridae	14.2
2	Syngnathidae	10.8
3	Labridae	10.0
4	Sphyraenidae	8.2
5	Belonidae	7.3
6	Clupeidae	6.9
7	Carangidae	5.6
8	Bleeniidae	5.5

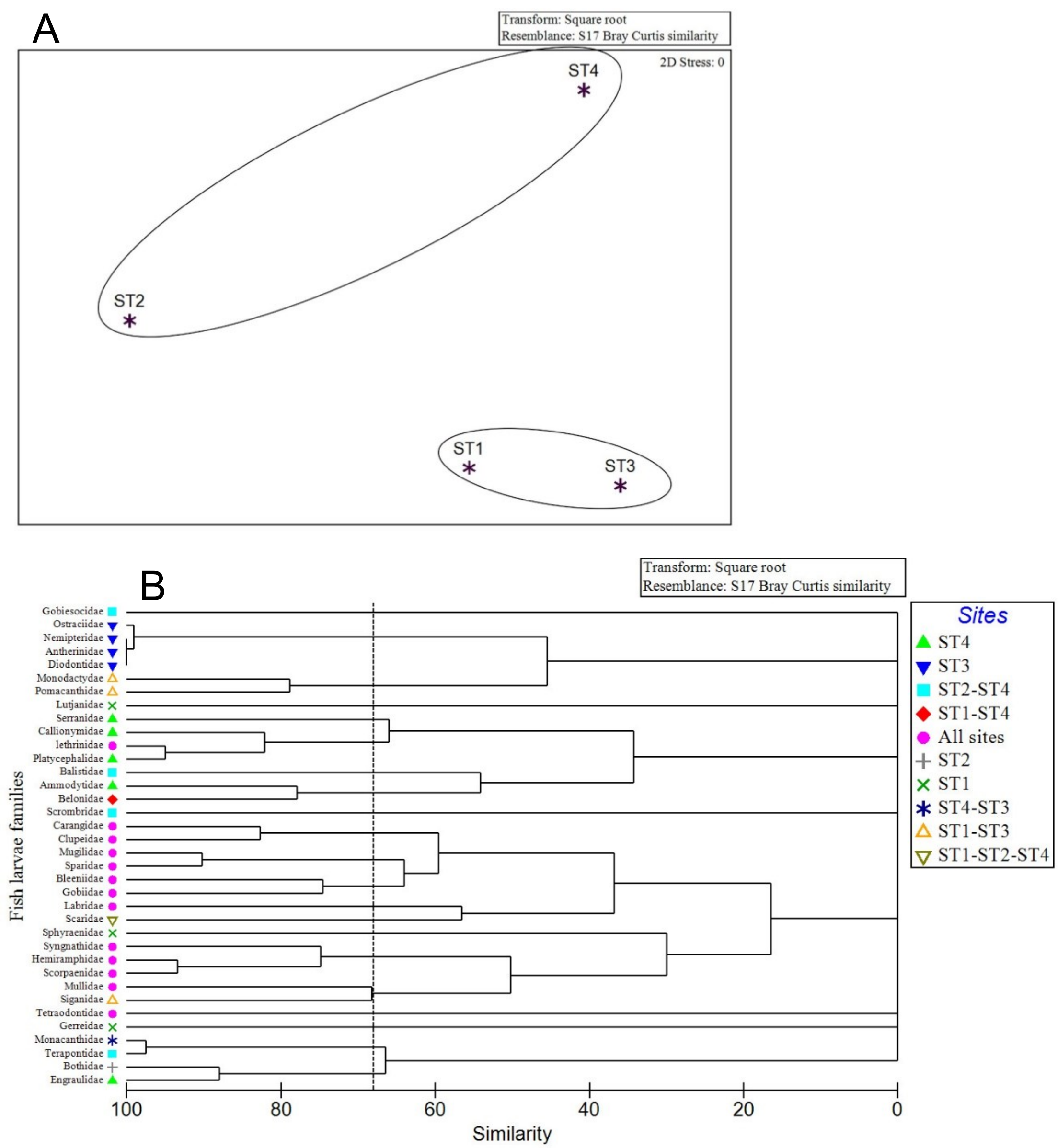

Figure 6. (a) Non-parametric multidimensional scaling (nMDS) ordinations of fish larvae assemblage structure, separated into sites (Abbreviations are as in Fig, 1.); and (b) Dendrogram plot showing similarity for fish larvae families/sites.

showed a positive prediction of fish larvae family richness, but they were not statistically significant ($p > 0.05$). On the other hand, environmental variables significantly predicted fish larvae family ($R^2 = 0.73$, $p = 0.013$). Temperature and salinity were found to be negatively correlated with fish larvae family richness ($p = 0.03$ and $p = 0.04$, respectively). Dissolved oxygen positively correlated with fish larvae family richness while pH and depth gave a negative correlation, but all were not statistically significant ($p > 0.05$; Table 4).

Multivariate patterns of fish larvae assemblages

Two-way crossed ANOSIM analyzing fish larvae assemblage structure revealed significant separation among sites (global R = 0.80, $p = 0.001$) and support the patterns in the non-multidimensional scaling (NMDS) ordination plots (Figs. 5a and 5b). Pairwise (between habitat) site comparisons showed that two sites, ST1 and ST4, were significantly different from each other ($p < 0.05$). SIMPER analyses showed that the most abundant fish larvae families were Scaridae, Sphyraenidae, Gobiidae, Sparidae, Labridae, Clupeidae, Carangidae, Belonidae, and Syngnathidae, which are all seagrass residents. These were also the families that contributed most to dissimilarities in the fish larvae assemblage structure among study meadow sites (Table 5). The study was further confirmed by nMDS analysis that reflected the analogous pattern of grouping among the sites as observed in the cluster analysis (Figs. 6a and b). The group average similarity between sampling sites ST1 and ST3 showed a similar pattern, comprising 80% similarity (Fig. 6a). Furthermore, sites ST2 and ST4 formed a separate group of less than 50% as shown in Figure 6 (a and b). The stress value was less than 0.1, which is a good ordinance pattern and a perfect description of the observed data for distances between sample sites. Both plots are based on the Bray-Curtis similarities index using square-root-transformed fish larvae abundance data.

Discussion

Environmental variables

Distribution of fish larvae within seagrass nursery areas differ between families and species, and depend on environmental variables (Palmqvist *et al.,* 2013). Environmental variables play an important role in fish larvae assemblage structure (Molina *et al.,* 2020). Fish larvae are distributed across a wide range of environmental conditions, yet the presence or abundance of some families or species is limited by factors such as dissolved oxygen, pH, temperature, salinity, and water depth (Gullström *et al.,* 2008). The variation in environmental variables is influenced by a range of factors including climatic, hydrological, geological, and anthropogenic stress (Hedberg *et al.,* 2019). From the present study there was no differences in the water temperature, dissolved oxygen, pH, and salinity among the sites; this lack of variation may have been caused by constant water mixing, and the patterns of the current within the relatively shallow tropical seagrass habitat (Perez-dominguez *et al.,* 2006). The seasonal difference in environmental variables are commonly related to seasonal monsoonal weather (most pronounced in the upper layer of the water column) and oceanographic conditions (McClanahan, 1988). The average water temperature in this study was higher during the NEM season due to longer exposure to sunlight radiation (McClanahan, 1988).

Additionally, in the SEM, lower temperatures are caused by strong winds that cause deep mixing, thereby bringing colder waters to the surface (Peter *et al.,* 2021). There was a significant seasonal variation in dissolved oxygen, and pH was higher during the SEM than the NEM season. Similarly, salinity was slightly higher during the SEM than during the NEM season, probably due to surface runoff caused by the rains during the NEM, which is supported by the work of Giering *et al.,* (2019) and Peter *et al.,* (2021). During the NEM season, however, pH was slightly higher than during the SEM season, presumably due to runoff from nearby agricultural areas carrying organic wastes (Levinton, 2001; Dhanam *et al.,* 2016).

Effect of seagrass structural complexity on fish larvae assemblages

Previous studies have identified that individual factors, such as the characteristics of seagrass meadows (Palmqvist *et al.,* 2013; Zerrato and Giraldo, 2018; Jones *et al.,* 2021; Mwaluma *et al.,* 2021) and environmental variables (Reynalte-tataje *et al.,* 2012; Molina *et al.,* 2020), affect the spatial patterns and variability in seagrass fish larvae assemblages. The present study showed that, when looking at abundance and richness, a number of predictor variables affect fish larvae assemblages in tropical coastal waters. In terms of seagrass structural complexity, it was discovered that seagrass cover, shoot density and canopy height all have a significant impact on fish larvae abundance, while canopy height has a significant impact on family richness. These findings concur with those of Gullstrom *et al.,* (2008) and Jones *et al.,* (2021), who observed that the seagrass cover and canopy height, which served as a measure of the complexity of the seagrass, had an impact on fish abundance and richness in coastal waters. The abundance of fish larvae and family richness were found to be strongly related to the canopy height of the seagrass meadows. One explanation for the strong positive relationship between canopy height and fish larvae abundance and family richness is that a higher seagrass canopy provides shelter, which leads to a higher survival rate by providing protection from predators (Unsworth *et al.,* 2019; Tarimo *et al.,* 2022). Furthermore, a higher seagrass canopy height supports a variety of fish larvae species because of reduced currents which favor organic matter deposition that support high primary productivity and enhance food availability (Arshad *et al.,* 2012).

Hedberg *et al.,* (2019) found that fish larvae assemblages increased with seagrass canopy height. Similar results were also reported by Palmqvist *et al.* (2013) and Jones *et al.* (2021), attributing the increased fish abundance to their ecological function as nurseries and shelter. Similarly, Erzad *et al.* (2020) noted the abundance of fish larvae in seagrass ecosystems is influenced by shelter availability. This supports the current findings that high canopy height provides shelter and food availability (Gullstrom *et al.,* 2008). It has been reported that greater fish abundance was observed in seagrass species with lower shoot density (Jones *et al.,* 2021), which contrasts with the current findings that an increase in seagrass shoot density could result in an increased fish abundance; however, the Jones *et al.* (2021) study was based on juveniles and adult fishes, whereas the current findings are based on fish larvae.

Seagrass cover had a positive relationship with family richness but a negative relationship with fish larvae abundance. Such a negative relationship might be due to other factors such as reproduction patterns and fish species preferences (Tarimo *et al.,* 2022), which were not investigated in the current study. This is in contrast to previous studies, which discovered that seagrass cover is an important factor in determining fish assemblages regardless of fish larvae stage (Arshad *et al.,* 2012; Erzad *et al.,* 2020). However, Rappe *et al.* (2013) reported that the validation of such a relationship is only possible in areas with high seagrass species richness and fish assemblages. Additionally, in contrast to earlier studies by Gullstrom *et al.,* (2008), Rappe *et al.,* (2013) and Jones *et al.,* (2021), the relative significance of seagrass habitat structure that was dominated by *T. hemprichii* was apparent in in the present study.

This implies that high seagrass percentage cover, shoot density, and canopy height attract more fish larvae families to occupy an area. These findings are similar to that of Jones *et al.* (2021) who reported that the complexity of seagrass with extensive coverage, and high leaf canopy provide strong shelter capacity and a variety of food resources. Moreover, high seagrass cover attracts various fish species because of the avoidance of predators and wide space for forage. These results are supported by Gullström *et al.* (2006) and Jones *et al.* (2021), who also found that high cover and canopy height is a harbour for a variety of faunal assemblages and support greater fish diversity and richness. Therefore, seagrass cover, shoot density and canopy height influence fish larvae richness. Overall, a complex canopy structure (high canopy height, long and more numerous leaves, but moderate shoot density) had greater fish richness as observed, and shoot density predicted fish larvae families richness, similar to what was reported previously (Rappe *et al.,* 2013; Erzad *et al.,* 2020; Jones *et al.,* 2021). Generally, seagrass structural complexity provides a favorable environment for fish larvae survival and recruitment (Gullström *et al.,* 2008; Ramli *et al.,* 2013).

Effects of environmental variables on fish larvae assemblages

Regression analysis revealed that environmental variables influence fish larvae abundance and family richness. When combined and using PCA values however, there was no significant influence on fish larvae assemblages, but when treated separately there was an influence. This means that the fish larvae abundance and family richness can be determined by the environmental variables. However, other factors need to be taken into account. Average water temperature was negatively correlated with the abundance of fish larvae and family richness. This could imply that an increase in temperature affects the fish larvae assemblage, abundance and family richness (Zerrato and Giraldo, 2018). Temperature influences the physiological processes in seagrass and fish larvae growth (Nordlund *et al.,* 2016; Mwaluma *et al.,* 2021). The average water temperature in the seagrass ecosystem in the study sites was around 27.15 °C, which is deemed ideal for fish larvae growth and survival and for the photosynthesis process of seagrass (Erzad *et al.,* 2020). The DO was found to positively predict fish larvae assemblages. According to Perez-dominguez *et al.,* (2006), DO is positively correlated with fish assemblages because a seagrass meadow provides oxygen and contributes to fish larvae survival and recruitment in the habitat. Similar findings were reported by Unsworth *et al.,* (2019).

pH had a negative correlation with family richness, but a positive correlation with fish larvae abundance. According to Molina *et* al. (2020) this could be due to differences in sensitivity and responses among fish families. Moreover, a small shift in pH can have significant impacts on fish larvae assemblages. The negative relationship between fish larvae assemblages and salinity could imply that fish larvae cannot tolerate a wide range of salinity (Arshad *et al.,* 2012). Similar results were reported by Zerrato and Giraldo (2018). Another predictor variable, depth, was negatively correlated with fish larvae abundance and family richness. The most likely explanation for this is that the majority of the fish larvae reside in nearshore habitats in shallow waters. This is in contrast with previous findings which show juvenile, subadult, and adult individual fish to be positively correlating with water depth (Jones *et al.,* 2021). This is due to fact that the occurrence of post larvae fish primarily depends on the tidal regime and species-specific mobility (Tarimo *et al.,* 2022). Large fish have a preference for slightly deeper subtidal seagrass habitats which provide a suitable environment for foraging and increased space for protection against predators (Gullström *et al.,* 2008; Jones *et al.,* 2021). This disparity could be explained by the fact that the current investigation was based on fish larvae, which are small and with limited mobility. Additionally, it is necessary to carry out an extensive comparable study that would include all fish life histories in the seagrass ecosystem in order to assess and contrast their diversity and abundance under various tidal regimes.

Relative importance of seagrass structural complexity and environmental variables

Seagrass structural complexity and environmental variables influence the fish larvae assemblage abundance and richness. Multiple regression analysis indicated that seagrass structural complexity (canopy height, seagrass cover, and shoot density) was the foremost predictor of fish larvae assemblages in tropical coastal waters. This was followed by variables related to the environment (temperature, dissolved oxygen, and salinity). The current study found that both seagrass structural complexity and environmental variables are important for fish larvae assemblages in coastal waters, and that conservation efforts should take both into account.

Cluster analysis and general patterns of fish larvae assemblage among sites

The hierarchical cluster analysis showed variation in fish larvae assemblages among study sites. The distribution of fish larvae families was closely associated with the environmental variables and seagrass structure (Mwaluma *et al.,* 2021). A similar pattern of grouping among the sites in hierarchical cluster analysis and nMDS in the present study is in line with Arumugum *et al.*, (2016). In their observations, these authors stated that the nMDS plot revealed the same groups as a cluster, which was again demonstrating the variations in different sampling sites. In contrast to ST3 and ST4, where there was unequal dispersion, the group average similarity across sampling sites ST1 and ST3 showed a comparable pattern, suggesting that most fish larvae families are the same and were distributed equally in the two sites. This might be due to tidal and water current fluctuation differences for distributing fish larvae in different areas as reported by Erzad *et al.,* (2020).

This study showed that the structure of fish larvae assemblages varied spatially among seagrass meadows dominated by *T. hemprichii,* displaying high fish larvae abundance and family richness at ST2 and ST4 sites. These sites are relatively far from the coast (about 10 km) experiencing lower intensity of degradation. This is in contrast to ST1 and ST3, which were near the coast and experience high intensity of degradation from fishing activities, such as the use of beach seines, ring nets and boat anchorage over seagrass beds. Similar results were reported by Palmqvist *et al.* (2013) where fish assemblages varied with seagrass localities and were primarily driven by the large differences in numbers of juvenile seagrass residents and coral-seagrass associated fish of all life stages. Given that the area with the highest severity of degradation also had the fewest fishes, it may be connected to the present findings. Within the group of fish larvae families identified, most individuals were herbivores, in particular the seagrass-grazing parrotfish, these provide an important trophic link within the seagrass food web and the reason why spawning occurs in habitats with extensive coverage of seagrass. This implies that trophic interactions affect fish larvae abundance in a complicated way, with parent fish preferences for food and shelter, species and life stage-specific interactions, and coastal habitat connectivity, all playing a role (Hedberg *et al.,* 2019; Jones *et al.,* 2021).

Implications for management and governance

The findings presented here will be of broad interest to fisheries managers, researchers, and other relevant stakeholders, including responsible authorities to ensure effective management and conservation of seagrass and adjacent coastal ecosystems. It has been observed and reported that one of the most direct adverse effects on seagrass beds is the damage caused by fishing or recreational boat activities (e.g., the use of beach seines, cutting by propellers, propeller wash, anchor and mooring damage, and boat groundings), which could result in significant localized impacts on the physical integrity of seagrasses (Turner and Schwarz, 2006; Jones *et al.,* 2021). Propeller scarring, for example, can result in a continuous line of seagrass damage, fragmenting the seagrass bed and increasing the vulnerable bed edge to erosion, thereby leading to more scouring and deepening of the scoured area. As a consequence of increased seagrass bed fragmentation, fish larvae and associated animal communities are increasingly affected. The potential long-term negative impact of destructive fishing practices and boat activities on seagrass meadows has long been known, and the cumulative effects of such events can result in large-scale loss of seagrass beds in nearshore coastal areas. However, these activities have been largely overlooked by researchers and little is known about the extent to which anthropogenic activities affect most seagrass structural complexity.

This study was carried out in a Marine Protected Area (MPA), where the current fishing management measures are insufficient and only cover a small area close to Tanga Coelacanth Marine Park (TACMP), leaving a large portion of the "protected area" unprotected, with limited monitoring, control, and surveillance of fishing vessels. The current management strategy is to reduce the fishing pressure. But, from field observations, there were many anthropogenic threats to seagrass meadows in the study area, which are overlooked and sometimes are not well managed, especially in the nearshore habitats. These include the use of ring nets, gleaning, beach seines, trampling, and pulling or pushing boats towards deeper areas at low tide via the seagrass beds. Anchoring activities in the study area both negatively influences seagrass health and reduces complexity, and in turn affects fish dispersal and recruitment which then impacts fisheries productivity (Hedberg *et al.,* 2019). These anthropogenic stresses are frequently overlooked but impact the ecological functioning of seagrass coastal habitats. This study provides important baseline observations which can guide the development of fisheries management plans and governance strategies for activities in marine protected and adjacent areas. The study indicated the importance of seagrass complexity and environmental variables in ensuring fish larvae growth and survival and contribution to overall fish recruitment. This suggests the need for greater seagrass protection and emphasizes the importance of conservation efforts within the MPAs. Moreover, there is a need for improved knowledge on the impact of anthropogenic stresses on coastal habitats to inform management and conservation development planning and governance (Mwaluma *et al.,* 2021). Nevertheless, in the WIO region, climate change is another threat to habitats and it is necessary to improve understanding of the present coastal habitats how climate change will impact fisheries productivity alongside efforts to prepare adaptation for those future changes (Jacobs *et al.,* 2020; Sekadende *et al.,* 2020; Mwaluma *et al.,* 2021).

Conclusions and recommendations

The structural complexity of seagrass beds and environmental variables are determinants of fish larvae assemblages in these coastal habitats. The abundance and diversity of fish larvae are determined by seagrass structural complexity, (canopy height, shoot density, and seagrass cover), and environmental variables (temperature, dissolved oxygen, pH, and salinity) which influence fish larvae assemblage in tropical coastal waters. The study recommends that shallow coastal habitats, including seagrass meadows, should be prioritized for conservation and governance efforts in order to protect critical habitats for fish larvae, which help to maintain robust coastal fish stocks and viable coastal fisheries, which is the main occupation of the coastal communities.

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Recent rise in exploitation of Tanzanian octopuses: a policy and management challenge

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Abstract
The artisanal octopi fishery is important for the coastal communities in Tanzania. In this work the octopi landing data from the United Nations Food and Agriculture Organization (FAO), Ministry of Livestock and Fishery Development (MLFD) and trade statistics from Comtrade of the United Nations were analysed. The FAO dataset show that from 1980 to 2017 annual octopi landings stayed below 2000 tons until 2018 when the catch increased to 2864 tons, and doubled to 5,687 tons in 2019. FAO datasets show large catches in 1995, 2003 and 2019, with 2019 recording the largest catch. For both Comtrade and MLFD export statistics, approximately 5,818 and 2,254 tons of octopi were exported globally from 2018 to 2020 with an equivalent value of approximately 13 and 19 million US$ respectively. Portugal was the largest importer of Tanzanian octopi, followed by Turkey, Italy, Spain, Netherlands, Israel, France and Panama. The current management interventions relating to octopi are presented, including the challenges needed to be addressed for sustainability of the octopi fishery. Voluntary octopi closures indicated some signs of success, but an in-depth assessment of the associated effects is required. The study recommends a need for verification mechanisms to ensure consistency of FAO and MLFD statistics, stock assessments, *in-situ* research on recruitment patterns of octopi, as well as innovation and research in designing sustainable fishing gear to support development of policies for sustainability.

Keywords: artisanal, fishing, sustainability, trade

Introduction
Octopi forms an important fishery for coastal communities along the coast of Tanzania and the Western Indian Ocean (WIO). In mainland Tanzania approximately 150 tons (10 % of the total landing) is consumed by the local community annually, and a significant proportion (nearly 1500 tons, or 90 %) is exported to the international markets mostly in Europe and Asia (Guard and Mgaya, 2002; Rocliffe and Harris, 2016). To ensure the effective governance and sustainability of the fishery, it is important to understand the biology of the species involved, the socio-economic impacts of the fishery and conduct catch assessments from time to time to better inform fishery management.

Artisanal octopus fishers use gleaning, spears, traps, trawlers and pots (Van Nieuwenhove *et al.*, 2019). Gleaning is a technique applied mostly by women and children where they walk along the exposed shores and reefs during low tide hunting for octopus using sharp sticks.

The Tanzanian artisanal octopus fishery grew over the last decades due to a rise in international market demand and price paid for octopus (FAO, 2017).

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In turn, the artisanal fishermen responded by increasing fishing effort and changed their focus from local markets to also supply the international markets (Humber *et al.*, 2006). TANPESCA, Bahari Foods and Alphakrust are the main companies on the mainland annually, equivalent to about US$ 6.8 million (Rocliffe and Harris, 2016). The important international buyers during the same period were Portugal, Italy, France, Mauritius and Spain.

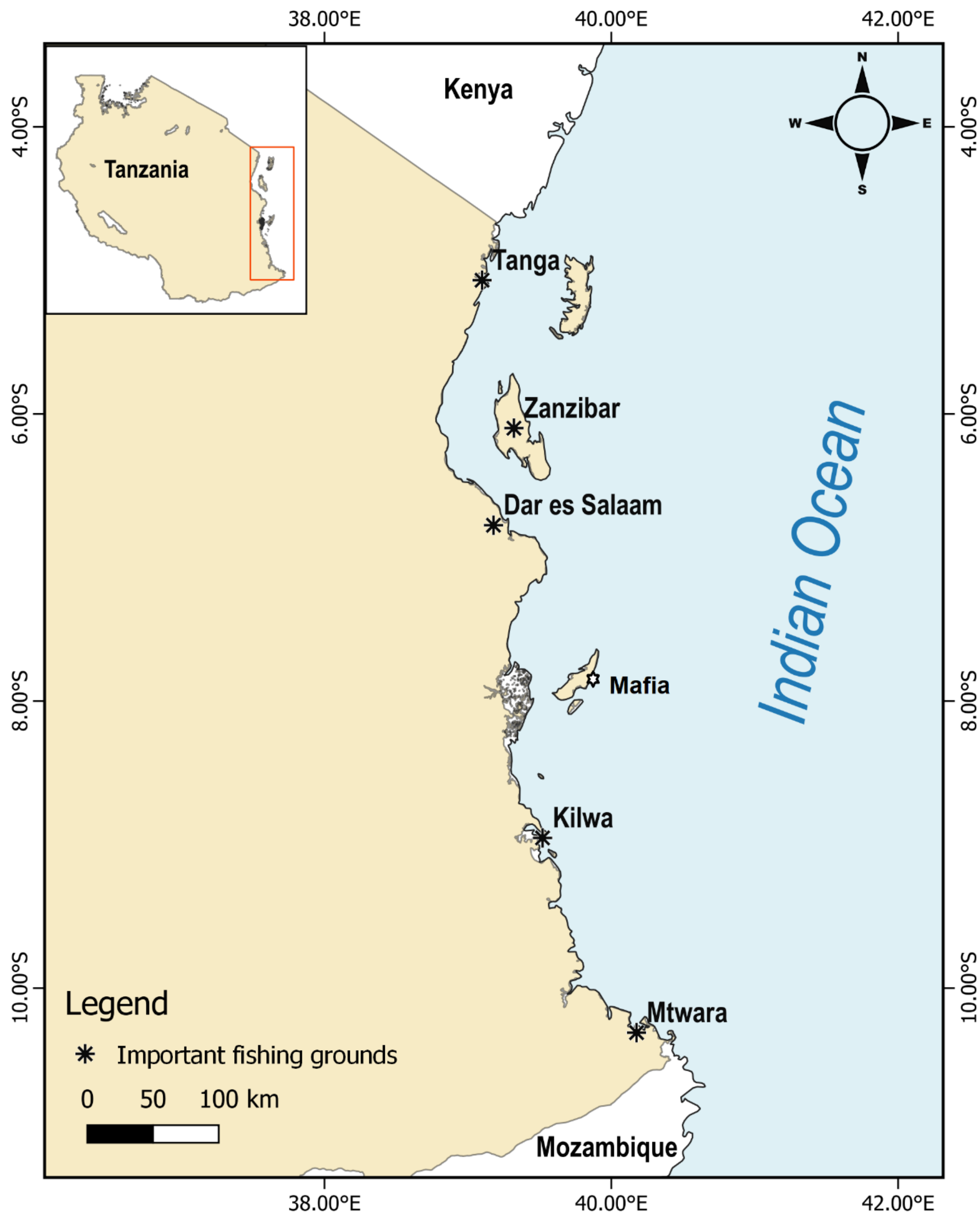

Figure 1. The coastal waters of Tanzania where the data originated. Some of the important octopus fishing grounds are concentrated in the sites marked with an asterisk, and include Tanga, Zanzibar, Dar es Salaam, Mafia, Kilwa and Mtwara.

that buy octopus from artisanal fishers, process and export to foreign markets (Anderson, 2014 as cited in Rocliffe and Harris, 2016). Information on recent (2018 - 2020) annual exploitation rates is lacking. Previous reports indicate that from 2008 to 2012 Tanzania exported approximately 1,500 tons of octopi In Zanzibar however, the main market is tourists and a smaller proportion (about 10 %) of the catch gets exported elsewhere (Pandu, 2014 as cited in Rocliffe and Harris, 2016). Due to its dependency on the tourism market, the octopus fishery in Zanzibar was severely impacted by the Covid-19 pandemic.

Perry *et al.* (1999) proposed three types of management strategies to safeguard the cephalopod fisheries: (i) catch regulation; (ii) size/sex limits; and (iii) control of fishing. As opposed to the large-industrialized fisheries, the artisanal octopus fishery consists of hundreds of fishers, making it challenging to implement effective management. Hence, in developing countries a combination of the three strategies is applied.

In Tanzania the octopi catch usually includes the two main species: the big blue octopus *Octopus cyanea* Gray, 1849; and the common octopus *Octopus vulgaris* Cuvier, 1797 (Guard, 2009; Pandu, 2014). *O. cyanea* is the larger species with a reported mean and maximum weight of 6 kg and 11.7 kg respectively (Guard and Mgaya, 2002). *O. cyanea* dominates the catch and can make up to 99 % of overall octopus landings (Guard and Mgaya, 2002). Research on life history, growth dynamics and the reproduction cycle of *O. cyanea* indicates that a time window (s) exist where short-term closures can have a positive effect on the fishery; especially when the females are nesting and during the period which the growth is exponential (Van Heukelem, 1973; Caveriviere, 2006; Raberinary and Benbow, 2012). Thus, several experimental periodic octopus closure initiatives were established at sites in Tanzania and in other areas of the WIO. Reports show that the closures resulted in increased catch and income in the communities, although these benefits disappeared a few days after the opening (Benbow *et al.*, 2014).

This study analysed the octopi catch statistics from the Food and Agriculture Organization of the United Nations (FAO) between 1908 and 2019, annual octopus landing from the Ministry of Livestock and Fishery Development (MLFD) of the United Republic of Tanzania, and the octopus export statistics provided by Comtrade of the United Nations to report on the exploitation rates, trading, and recommendations to avoid misinformation and improve consistency of the data. Furthermore, the study explored the current management tools in place, and gaps that need to be closed to improve sustainability of the octopus fishery.

Methodology

Study area

The study assessed octopus landings and export data from Tanzania (Fig. 1). The country's waters are under the influence of the East African Coastal Current (EACC) flowing from the south toward the north of Tanzania. The region is affected by monsoon winds. The southeast (SE) monsoon occurs between May and September, and the northeast (NE) monsoon prevails from November to March (McClanahan, 1988). The country contains reef patches and shores supporting several fisheries and significant biodiversity. The main artisanal octopus fishing grounds are located in Kilwa, Mtwara, Mafia, Zanzibar and Tanga (Fig. 1; Anderson, 2014 as cited in Rocliffe and Harris, 2016).

Fisheries and octopus trade statistics

Octopus fisheries catch data were obtained from the FAO catch statistics (https://www.fao.org/fishery/statistics/, retrieved on 6 May 2021). The portal contains octopi catch data recorded between 1980 and 2019. Furthermore, the octopi export trade data were obtained from the United Nations Comtrade database (https://comtrade.un.org/data, accessed on 13 June 2021). All octopi product codes that represent octopus were selected in the Comtrade database search. The items included: 1. code 030751 for live fresh, or chilled octopus; 2. 030752 for frozen octopus; 3. 030759 for dried, salted, in brine or smoked, cooked or not before or during the smoking process; and 4. code 160555 for prepared or preserved octopus. To assess the consistency of the dataset records from the FAO and Comtrade databases, the available annual octopus fishery statistic reports from the fishery department in Tanzania were consulted (MLFD 2003; 2008; 2011; 2013; 2014; 2015; 2016; 2018; 2019; 2020). The reports contained annual octopus landing and general yearly exported amounts that were used for validation and comparison.

Octopus fishery management in Tanzania

Existing relevant national management tools such as the Fisheries Act number 22 of 2003, the Fisheries Regulations of 2009 (G.N. No. 308), The Fisheries Regulations Amendment (GN.No. 492 of 3/7/2020) and the Fisheries Policy of 2015 were reviewed. An intensive literature review was conducted to provide a better understanding of the areas that need more attention to achieve sustainability of the octopus fishery.

Results

Octopus fishery and landings

FAO reports total catch for the whole of the United Republic of Tanzania, including the landings from the Zanzibar archipelago and Tanzania mainland. The total catch reported by FAO is therefore combined from the two territories (Fig. 2). Results show that the octopi catch in Tanzania increased from 483 tons in 1990 to 5,687 tons in 2019. Tanzania remained the top producer of octopi in the whole of the WIO region followed by

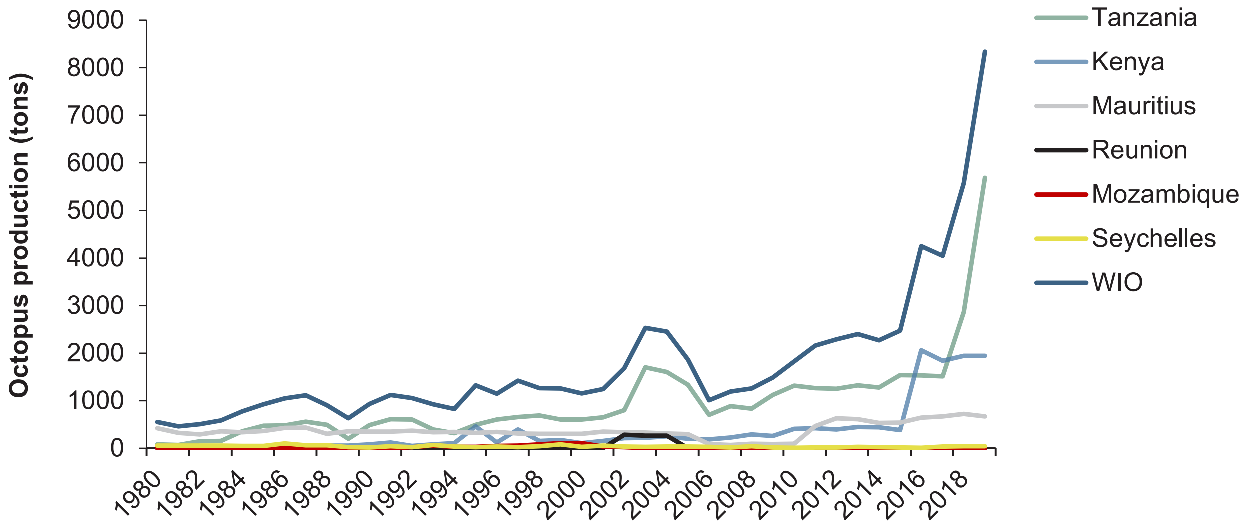

Figure 2. Octopus landing in Tanzania and the WIO region covering the period between 1980 and 2019. Source: FAO Fisheries and Aquaculture Department portal (https://www.fao.org/fishery/statistics/, retrieved on 06th May 2021).

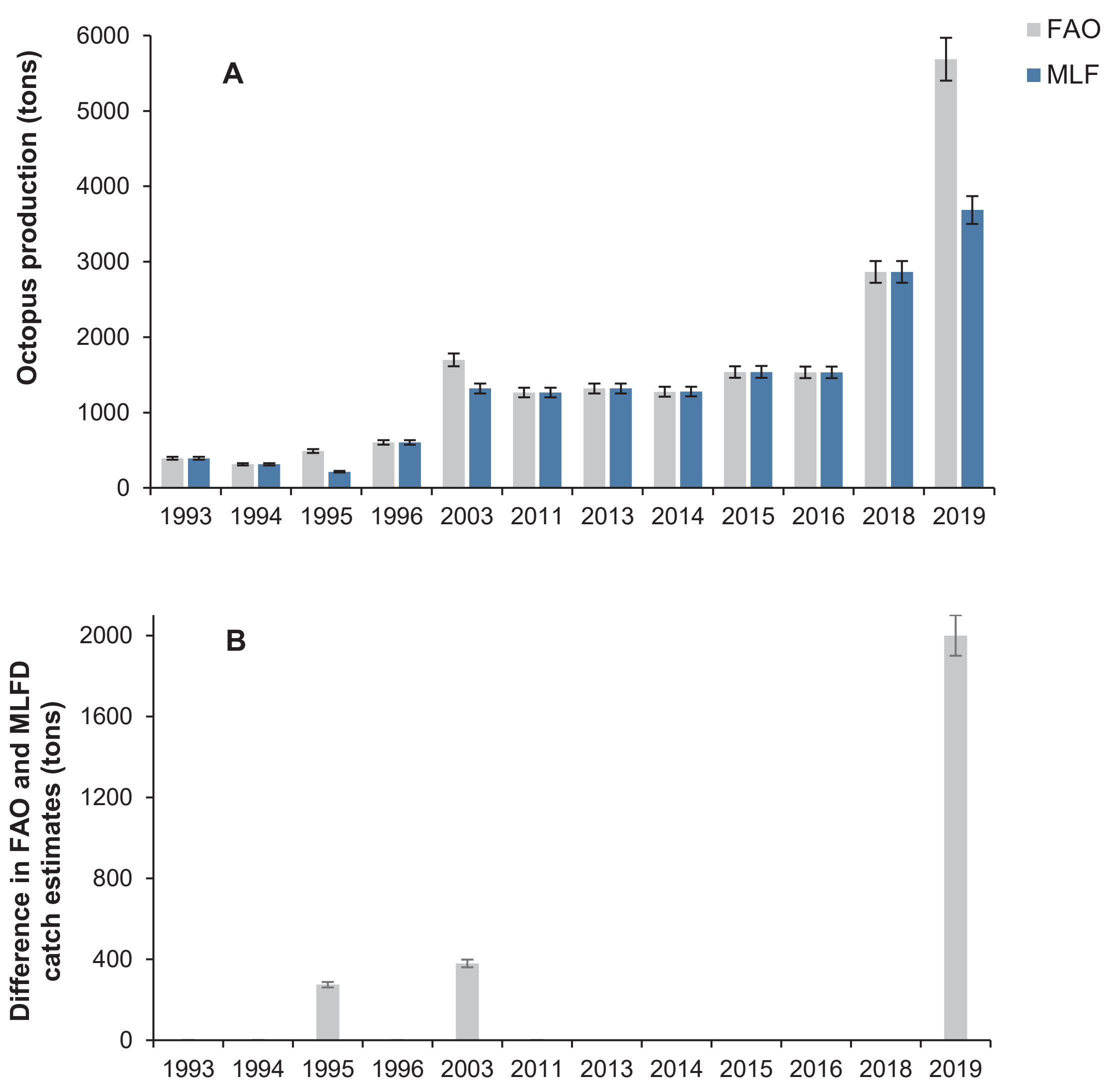

Figure 3. [A] Octopus catch statistics as reported by the Ministry of Livestock and Fisheries Development (MLFD) and the FAO Fisheries and Aquaculture Division. [B] The differences in catch between the two reporting entities. Note that there were notable catch discrepancies in 1995, 2003 and 2019. In 2019 for instance the FAO reported around 2000 tons higher than the MLFD. Sources: MLFD and FAO Fisheries and Aquaculture Division.

Kenya and Mauritius. In Tanzania, octopi production peaked at 1,700 tons in 2003, before decreasing to 703 tons in 2006. Since then, the landings rose steadily, reaching 1,251 tons in 2012, 2864 tons in 2018, and increasing rapidly to 5,687 tons in 2019.

The comparison between the records from FAO and MLFD are presented in Figure 3. Both datasets indicate increased octopi exploitation in the years 2019 and 2020. However, there are discrepancies in the data from the two reporting agencies. In 2019 FAO reported an annual catch production of approximately 5,687 tons and the MLFD recorded approximately 3,687.08 tons of octopus, with over 2000 tons difference. Notable differences in reporting were also found in the years 1995 and 2003 (Fig. 3).

Export market

The export data from the United Nations Comtrade platform covering the years 2021 to 2017 are presented in Table 1. According to Comtrade, Tanzania exported approximately 677, 1,681 and 3,460 tons in the years 2020, 2019 and 2018 with values of 3,384,721, 8,699,260 and 1,323,378 US$ in those years respectively. Thus, between 2018 and 2020 a total of 5,818 tons of octopus were exported from Tanzania to elsewhere, with

Table 1. Top countries importing Tanzania octopi per year from 2018 – 2021. Data were retrieved from Comtrade 2022 of the United Nations and the MLFD (MLFD 2018; 2019; 2020).

Year	Partner	Comtrade		MLFD	
		Quantity (Kg)	Trade value	Quantity	Trade value
2021	Portugal	310920	2370971		
	Italy	58968	533255		
	Turkey	19225	138204		
	Kenya	1290	4536		
	United Kingdom	11	31		
	Sub-total	**780828**	**6094003**	**N/A**	**N/A**
2020	Portugal	291409	1509280		
	Turkey	23036	68040		
	Spain	21060	105300		
	Kenya	1785	6729		
	Uganda	1200	2960		
	Sub-total	**677014**	**3384721**	**373,090**	**5,205,979**
2019	Portugal	833900	4327187		
	Turkey	4660	13980		
	Kenya	2010	7951		
	Rwanda	75	510		
	Sub-total	**1,681,290**	**8699260**	**1,048,580**	**14,164,387**
2018	Portugal	700202	193476		
	Israel	288840	12473		
	Netherlands	191254	25378		
	Spain	156002	12931		
	Turkey	116000	80033		
	Italy	105300	67785		
	Sub-total	**3,459,620**	**1,323,378**	**832,340**	**10,692.53**
2017	Portugal	671820	2828852		
	Italy	168930	705654		
	France	24000	231360		
	Panama	21060	63180		
	Turkey	13000	32500		
	Sub-total	**1,799,914**	**7,732,430**	**N/A**	**N/A**

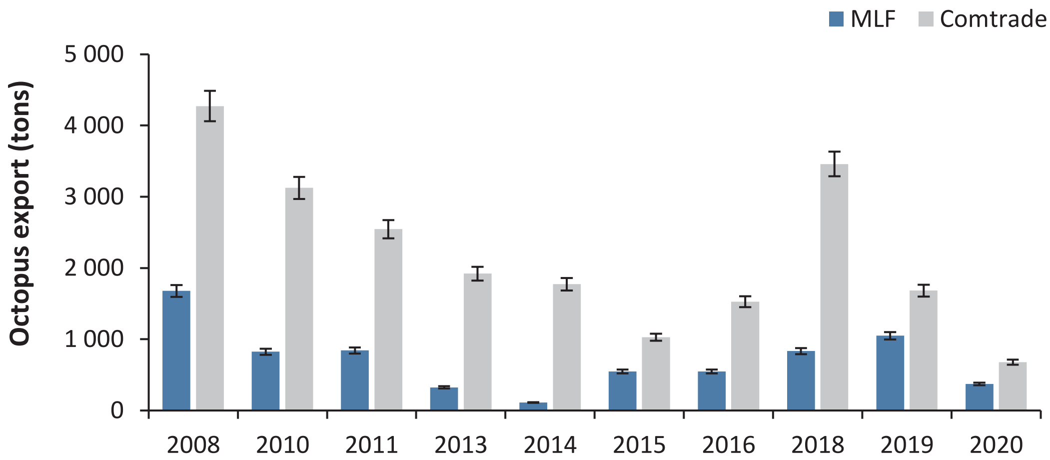

Figure 4. Recorded octopus exports (tons) as reported by the Comtrade and the MLFD. Note that the MLFD is consistently lower than the Comtrade data during this period, with the largest difference of approximately 2500 tons in 2018.

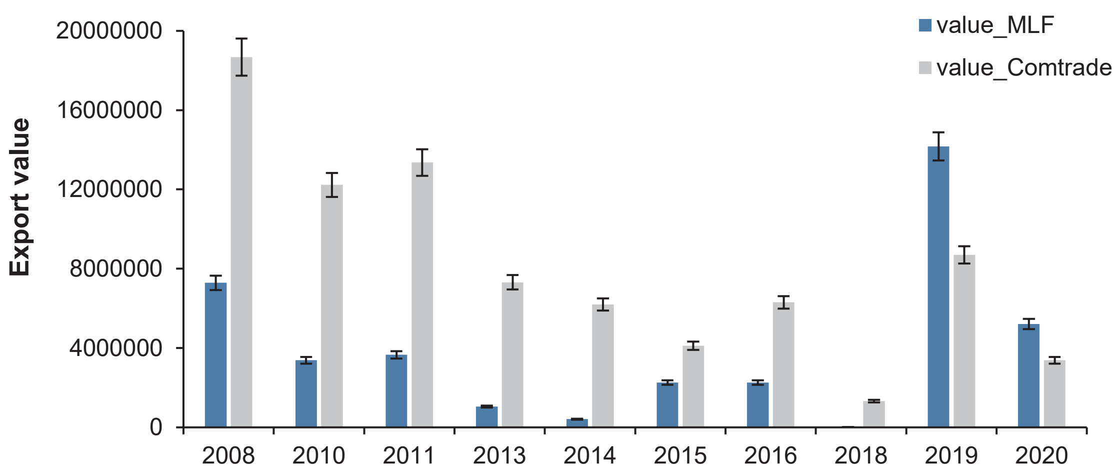

Figure 5. Octopus export values as reported by the Comtrade and the MLFD. The MLFD started recording larger values for octopus exports compared to Comtrade in 2019 and 2020. This is the period for which the MLFD recorded a larger catch of over 2000 tons.

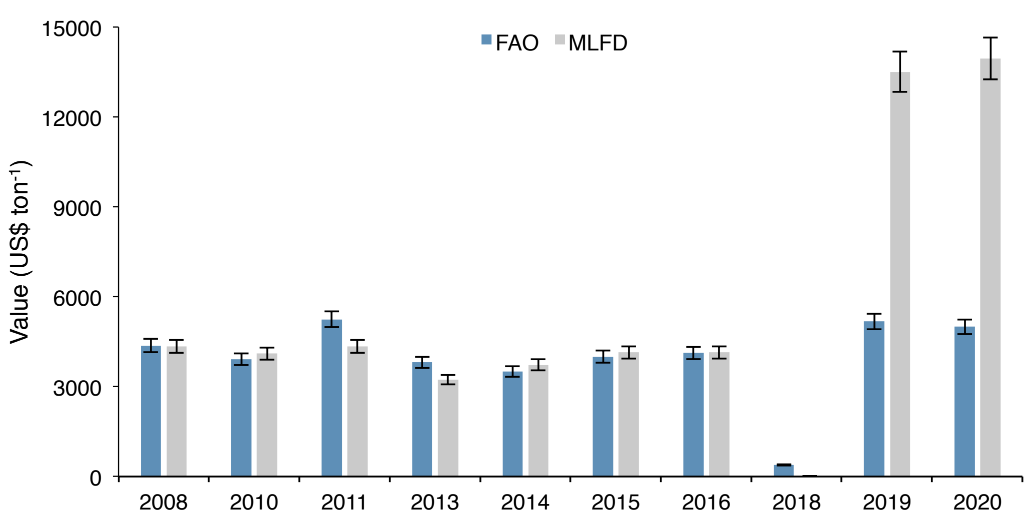

Figure 6. The value (US$) per ton of exported octopus recorded by FAO and the MLFD.

an equivalent value of around 13 million US$. The MLFD datasets reported estimated amounts of 373, 1,048 and 832 tons with values of 5,205,979, 14,164,387 and 10,692.53 US$ consecutively in these same years (Fig. 5). Therefore, a total of 2,254 tons of octopus valued at an estimated 19 million US$ were exported to other countries from 2018 to 2020. For both reporting entities, the amount exported was smallest in the year 2020, mainly due to the Covid19 pandemic. In the past five years, Portugal remained the leading importer of the Tanzanian octopi, reaching nearly half the total export amount in 2019 (Table 1). The other important importers between 2017 and 2020 were Turkey, Italy, Spain, Netherlands, Israel, France and Panama. In addition, a small proportion of octopi were shipped to the regional market in Eastern Africa reaching Kenya, Uganda and Rwanda.

The differences in the annual exported amount reported by Comtrade and MLFD is illustrated in Figure 4. The annual exports recorded by Comtrade were consistently larger than the MLFD. Both datasets

Table 2. Summary of octopus fishery management interventions and effectiveness

Intervention	Remark on effectiveness
Size limit: The Fisheries Regulation 59 (1) and its amendments of 2020 established an octopus fishing and handling size limit of 500 g. The regulation 59 (3) provides that no person shall trade or export processed octopus below the limit of four hundred and forty grams.	The fishing techniques are non-selective. Although exporting industries follow the rule, the undersized octopus are consumed locally.
Closed Season: The Fisheries Act No 22 of 2003 Section 17 (g) gave mandate to the Minister of Fishery to establish closed seasons, prohibit certain fishing techniques and species of fish. In some communities, the closure can be initiated voluntarily by the respective village upon agreement among themselves.	Closed seasons by top-down mandate is implemented mostly in other fisheries, the voluntary community octopus closure is now popular in Tanzania.
Management Zones: The Fisheries Regulation of 2009 in the Section 17 provided a mandate to the minister to initiate measures to ensure sustainable management of the fishery such as prohibition of fishing in certain areas. The regulation allows the minister to initiate controlled areas such as critical and potential breeding areas.	The regulation is essential, providing room for immediate conservation actions when a potential critical area is identified for biodiversity protection.
Access to Fishing (licensing): The Fisheries Act No 22 of 2003 in the Section 22 established a license requirement for anyone before undertaking fishery activities such as fishing, marketing, processing and or production of fishery related products. The license is provided by the Director or authorized officer. Requirements of license apply also to the fishing vessels and traders.	The regulation has succeeded to control fishing, but a more detailed examination is required to assess the effectiveness. For instance, children also collect octopuses at low spring tide, as a part of cultural practices.
Compliance and law enforcement: Fisheries Act No 22 of 2003 in the Section 17 gives mandate to the minister to take necessary measures to ensure sustainability of the fishery resources, the interventions related to enforcement, monitoring and surveillance. Section 32 (1) provides for the establishment of the surveillance and control unit. It also directs mechanisms that enhance participation of communities and other entities through agreements in national, regional and international arena.	Law enforcement has been challenged by limited resources (boats, fuel, and compensations), and capacity of the surveillance team in the villages to ensure reefs are well protected against unsustainable fishing practices.
Co-management arrangements (the Beach Management Units or BMUs): Fisheries Regulations, 2009 (13) provides for the establishment of the co-management structure from within the members of the fishing community to assist in activities like surveillance, control and catch inspection. Their roles also extend to data collection on 10 days of every month.	A good participatory approach, but the infrastructure and capacity of BMUs needs to be enhanced to improve their contribution to sustainability.
Marine Protected Areas: Marine Parks and Reserves Act No. 29 of 1994 (Section 8 (2) and Section 10 in particular provides a guide to establish the Marine Protected Areas (MPAs) for conserving biodiversity or at areas displaying features of significance such as historical, scientific or critical habitat values.	The approach is amongst the successful approaches, but more research and activities to enhance resilience of the ecosystems are needed.
Octopus fishing closure: These are self-driven participatory approaches when the community agree to implement a closure in their respective reef (s) with the goal of obtaining an improved yield and enhancing ecological benefit. They can be a pathway toward more concrete actions like establishment of new Marine Protected Areas.	The system worked best in remote areas with less population pressure. A more detailed assessment of the social-ecological benefits is needed. Program leads should use the best available science on recruitment of octopus for best results.

showed a difference of approximately 2000 tons between the years 2008 and 2013 (Fig. 4). In 2018, there was a discrepancy of over 2500 tons between the data reported in MLFD (832.34 tons) and Comtrade (3,459.62 tons) databases. There was a reduction in the exported catch recorded by the two entities in the years 2019 and 2020, which is likely a result of the Covid 19 pandemic. While Comtrade reported higher values of octopi per ton traded between the years 2008 and 2018, the MLFD recorded higher values per exported octopus (tons) in 2019 and 2020 (Fig. 6).

Existing governance tools and arrangements for octopus fishery management in Tanzania

The octopus fishery in Tanzania is mainly guided by the Fisheries Act number 22 of 2003, the Fisheries Regulations of 2009 (G.N. No. 308) with its amendments (GN.No. 492 of 3/7/2020) and the National Fisheries Policy of 2015. The Fisheries Act established a co-management system within the local communities called Beach Management Units (BMUs). The BMUs have been given a mandate to oversee the fishery in the fishing grounds and their respective landing sites in consonance with higher level fisheries management plans (Fisheries Act number 22 of 2003) and in consultation with the respective fishery officers. Their roles include collection of catch data, monitoring, control and surveillance, among others. As one of the control measures of fisheries that also applies to octopi, the Fisheries Act of 2003 requires that any person(s) conducting fishing activities should have a valid licence in accordance with the Act and Regulation.

To ensure sustainable exploitation of octopuses, the Fisheries Regulations of 2009 established a recommended allowable minimum octopus size of 0.5 kg (MLFD, 2009). The regulation is however not often enforced, and authors referred to it as 'voluntary' (Sauer *et al.*, 2021). One of the challenges is that the methods used by fishers remained non-selective, such as the use of spears (Table 2). In most cases, fishers can injure or even kill undersized octopuses when they are still in the den before knowing the size, and therefore they don't find it logical to discard the octopus smaller than the size limit. Thus, individuals below the recommended weight are often harvested. The National Fisheries Policy of 2015 provides a guide for enhancing sustainable fisheries and management of aquatic resources. It provides the pathway for fishery control measures for sustainability, processing, value addition and trade.

Discussion

Octopus exploitation and trading

In this study it was found that, based on both data sets, the catch was above 2000 tons in 2018 and 2019. These findings differ from the Rocliffe and Harris (2016) where the FAO datasets from 2008 to 2012 were analysed, and showed that the annual octopi catch in Tanzania was below 2000 tons, yet still showed the important contribution of octopus to the economy and coastal livelihoods (Rocliffe and Harris, 2016).

Larger octopus landings in the FAO as compared to the MLFD datasets could be a result of lack of validation and/or random errors. The recent increase in catch could be due to elevated fishing effort over time and/or enhanced data recording (FAO 2017; Van Nieuwenhove *et al.,* 2019). However, these findings should be treated with caution because catch statistics from MLFD, FAO and Comtrade are likely conservative estimates (Rocliffe and Harris, 2016). The octopus fishery in Tanzania is affected by illegal, unregulated and unreported fishing. Thus, under-reporting of the catch makes it difficult to track the fishery products to meet certification and traceability requirements. The reported estimations are considered as underestimations, and more effort needs to be made to support catch recording at various fishing sites in Tanzania. Data challenges and underestimation has been a challenge in various fishing localities in the world, and reconstruction of the data could be an option to address this (Bultel *et al*., 2015). Belhabib *et al.* (2015) for instance, re-analysed catch records provided by the Republic of the Gambia to the FAO and found that the corrected catch data was double the original reported values.

In this study it was found that the major importers of octopus between 2018 and 2020 were Portugal, Italy, France and Spain, in addition to The Netherlands and Israel which were not reported by the previous study (Rocliffe and Harris, 2016). This indicates an expansion of the Tanzanian octopus market with implications for fishery management and sustainability.

Inconsistence in the MLFD and FAO datasets

In this study there were discrepancies in the catch statistics data as reported by the FAO and the MLFD. But because MLFD supply these data to the FAO, the observed difference could be caused by lack of good coordination between these bodies in providing the best estimates for octopus production, and limited validation, verification and inspection. There is also a challenge with regards to octopus species identification, with reports suggesting that *Octopus cyanea* constitute over 90 % of landings (Guard and Mgaya, 2002) which also includes species like *O. vulgaris*, the MLFD statistics recognize only the white-spotted octopus *O. chromatus.* The FAO regard the whole octopi catch as the big blue octopus *O. cyanea*, but *O. vulgaris* has been found in Tanzania and other cryptic species exist in the WIO region (Guard and Mgaya 2002; Van Nieuwenhove *et al.,* 2019).

As for many other artisanal fisheries, the octopus fishery in Tanzania can be regarded as data deficient and there is no available traceability system to track, measure and record all octopus caught at various fishing villages. Because the MLFD reports rely on the BMUs who collect all fishery and octopus data on ten days on average per month, it is suggested that the octopus exploitation in the country is likely larger than the amount presented in this work.

Filling the gaps toward sustainability

While there has been progress toward improving sustainability and certification of the octopus fishery in Tanzania (Rocliffe and Harris, 2016), further work is required to achieve social, economic and ecological goals. Although the Fisheries Act 22 of 2003 controls fishing activities through licences, there is a risk that without accurate understanding of octopi stocks, more licences could be granted than the stocks can sustain (MLFD, 2009; Rocliffe and Harris, 2016). There is therefore a need for better science to inform management on estimates of stocks abundance and the number of fishers (fishing effort) allowed, to avoid overexploitation. Although the fishers were advised to use wooden sticks for fishing to protect the health of consumers, a large proportion of fishers still use iron rods (Guard and Mgaya, 2002; Sauer *et al*., 2021; Robertson *et al*., 2018). The use of fishing pots has been recommended as a more sustainable and selective fishing method that can avoid smaller individuals (Sobrino *et al*., 2011), but preliminary findings from recent trials conducted at Kilwa by the Tanzania Fisheries Research Institute (TAFIRI) showed that the pots did not capture any octopus (Bigeyo pers. comm.), and more experiments are being undertaken to further understand this.

Although the voluntary periodic octopus closures enabled community empowerment and participation in the fishery (Emery *et al*., 2016), there is need for dedicated research to guide the process. The voluntary octopus fishing closures at Jojo and Songosongo, for instance, started without any reliable scientific evidence on the spawning and recruitment pattern of octopus (Silas, 2022). The timing for most of the of the fishing closures conducted in Tanzania did not align well with the available scientific evidence. Octopus recruitment occurs year- round. Guard (2003) reported that *O. cyanea* recruitment peaks occurred in September, with a second smaller aggregation in February, and through subtracting the estimated number of days before recruitment they estimated that the respective brooding periods were in June and December. Recently, Silas *et al.* (2021) documented two major recruitment peaks, in May and July for Jibondo and Bwejuu sites (Mafia archipelago) respectively. Both Guard (2003) and Silas *et al.* (2021) recruitment peaks and spawning were within the May – September period. Therefore, to attain the maximum positive effect, an octopus closure should be scheduled for between May and September. Through modelling the influence of environmental variables on octopus catch, Chande *et al.* (2021) recommended that the closure should begin one month earlier (April to July) and reopening should be in October and March after a successful recruitment. Thus, the traditional octopus fishery closure can be implemented during inter-monsoon (April) throughout the SE monsoon (May to September) period. However, there is a need for further experimental research on the influence of environmental variables on recruitment using field data and models. Understanding the effect of environmental variables on recruitment of octopuses using predictive modelling and more accurate data can help to better inform practitioners about the correct timing for the most successful octopus closure.

Measuring success of the octopus closure initiative can be challenging without clear predetermined metrics. Lindkvist *et al.* (2019) collected expert opinions in the WIO on how they defined successes of the past periodic octopus closure and concluded that all practitioners, including academia, viewed successes in three categories: economic, ecological and social. Economic success was viewed as a result of an increased income, economic conditions and trade opportunities in the communities. Ecological success was defined by increases in variables such as catch, individual size and catch per unit effort, in addition to positive effects on other marine species. Social success included acceptance by the coastal community, reduced conflicts and improved governance. Data should be collected from both closed and open access sites to document the 'true' success of the experimental closure efforts in each category. Octopus catch increased after three months of closure at Songosongo, for instance (in 2018 and 2019), with large catches (10 and 19 tons respectively) after only a few days of harvesting (WWF, 2018). The benefit sharing was an issue because of intrusion of fishers from other nearby localities (Silas, 2022). The significant increase in catch could have been as a result of increased fishing effort of the fishers from the nearby villages. Furthermore, men are more involved in octopus fishing at relatively high waters using diving gears than women (Vanier, 2022). If an octopus fishing closure aims to establish a social success regarding gender equity, the program would need to incorporate these dimensions in measuring the associated positive effect. Clearly predefined goals (or metrics) and design would be needed to establish successes and compare the activities associated with closure against other possible applied management approaches.

Finally, improving marketing structure and infrastructure across the value chain can enhance the economic benefit in the local communities. During the octopus reopening at Kilwa, approximately 5 tons of the harvested octopus spoiled due to lack of readily available cooling facilities (WWF, 2021). In addition, the price during reopening at the landing beach and locally available markets reduced by approximately 8.8 %, from 1.83 US$ to 1.62 US$ (Silas, 2022). A management strategy that includes periodic closures should consider immediate and long-term risks, and the impacts on market prices.

Recommendations

With increasing fishing effort, driven by both local consumption and international markets, it is suggested that there should be a permanent plan to effectively collect and monitor the octopus catch and trade data. Because the information derived from the MLFD, FAO and Comtrade likely represent underestimates, there is a risk of overexploitation and misunderstanding the contribution of the octopus fishery to the economy and livelihoods of Tanzania. Determining the size of the octopus stock at different sites can guide fishery management towards preventing overfishing. This will require resources to collect more accurate catch and effort data, and to develop robust models with fewer assumptions and a better understanding of seasonal changes in stocks (Otero *et al*., 2005; Sauer *et al*., 2021).

Increasingly, there are trained data collectors, apart from BMUs, at the landing sites but most are not permanent and are subject to the duration of projects and programmes. The authors recommend that the government continues recording the octopus export trading data and make it publicly available. Without this, it would be difficult to ensure and maintain the sustainability of the fishery. There is a need to strengthen the enforcement and awareness of fishery regulations to ensure fishers comply with the existing laws and policies. Although fishers found it challenging to preselect specimens that were below the recommended size when the octopus was in a den, some fishers still harvest small octopus intentionally.

Conclusions

The study identified discrepancies in the catch statistics as reported by the FAO, MLFD and Comtrade. According to the FAO the annual octopus landings remained below 2000 tons until 2018 when the catch increased to 2864 tons, and to 5,687 tons in the year 2019. Both MLFD and FAO provided a signal of increasing exploitation of Tanzanian octopus but FAO recordings were higher in several years, particularly in 1995, 2019, and 2003. In 2019 FAO reported over 2000 tons higher than the MLFD recordings. The differences were also observed in the exported amount and values, with Comtrade and MLFD recorded a total of around 5,818 and 2,254 tons of octopus from 2018 to 2020 with an estimated value of 13 and 19 million US$ respectively. The existing interventions for octopus fishery management have had some degree of success, but work is needed in improving management infrastructure, data collection, research, innovation towards more sustainable selective fishing methods, law enforcement and improving capacity of the BMUs. While the octopus fishery closure could have ecological successes, they work best in less populated villages, and social and ecological successes require established regional metrics or guides for evaluation. The study recommends increasing investment to support BMUs in octopus management, ensure continuous data collection, verification and validation of the statistics between FAO and MLFD before reporting, and stock assessment to determine the exploitation status of the octopus at various fishing villages to inform the authorities to take the necessary measures to improve the fishery governance.

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Small pelagic marine fisheries for food sovereignty? The case of the *dagaa* fishery at three coastal sites in Tanzania

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Abstract

To implement effective ocean governance, development of policies and management strategies needs to incorporate input from communities that will be impacted by the decisions. People engaging in small-scale fisheries and aquaculture mobilize themselves in anticipation of various challenges, for example, food sovereignty. Food sovereignty is the right for people to access healthy and culturally appropriate food that is produced through ecologically sound and sustainable methods. Little attention has been paid to documenting and understanding the struggles and efforts of small-scale fishers to ensure their own food sovereignty. In the Western Indian Ocean region, and Tanzania in particular, there has been a limited number of initiatives among coastal fishers that seek to transform food systems. To better understand these initiatives, this study was designed to examine collective actions undertaken in pursuit of food sovereignty among small pelagic fishers at three landing sites on the coast of Tanzania. Collection of primary data involved a survey of 206 individuals, 25 key informant interviews, 3 focus group discussions and participant observation. Secondary data was also collected from official fisheries records and published materials to supplement the primary data. The study revealed limited current capacity of the small pelagic fisheries to satisfy local demand of fish for food security and sovereignty purposes due to increased fish trade supplying markets beyond the study sites. The prospects of satisfying an increasing fish demand from existing production systems are limited. Small pelagic fisheries need to be linked to the global food system through appropriate mechanisms to allow them to contribute meaningfully to food security and sovereignty.

Keywords: small-pelagic fishery, dagaa, food sovereignty, governance, interviews, marine resource

Introduction

Fishing and fisheries associated activities are important on many fronts (Herrón *et al*., 2019): providing fish for food and nutrition security (Villasante *et al*., 2022), income (March and Failler, 2022), employment (Okafor-Yarwood *et al*., 2022) and sustaining livelihoods (FAO, 2020). Recently, there has been an effort to integrate fisheries into ocean governance strategies and blue economy growth without compromising the health status and sustainability of the ecosystems supporting them (Ayilu *et al*., 2022; Cohen *et al*., 2019). Fisheries are diverse, including for example large and small pelagics, inshore, reef, estuarine and riverine fisheries, and management needs to be adapted for the specific fishery and people involved in it. Small pelagic fisheries constitute a large share of fish landings and drive production in the marine sector (March and Failler, 2022; McClatchie *et al*., 2018; Sekadende *et al*., 2020; Stephenson and Smedbol, 2019). The small pelagic fishery is one of the most challenging marine sectors to manage because of the widespread fishing effort and open access into the fishery, and the fact that a large proportion of coastal communities are dependent on this fishery for food, employment and income (Cushing *et al*., 2019). However, a lack of appropriate storage and processing facilities causes post-harvest losses, creating a problem for the overall supply and access of fish for food, especially for poor households (Akande and Diei-Ouadi, 2010).

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The marine fisheries sector in the Western Indian Ocean (WIO) region plays a significant role in the development of coastal economies (Obura *et al*., 2017). Although precise data is still lacking, best estimates indicate that more than 25 million people in the WIO region could be directly or indirectly dependent on artisanal fisheries for their livelihoods (Taylor *et al*., 2019). In 1997, the Food and Agriculture Organization (FAO) declared that the WIO had great fisheries potential, but since then the total landings appear to have leveled off, despite an increase in fishing effort (Groeneveld, 2016). This decline has been attributed to several factors, including increasing competition for dwindling stocks, excessive and destructive fishing methods (Jury *et al*., 2010; Silas *et al*., 2020). In particular, excessive and destructive fishing methods result in habitat destruction and high levels of by-catch and discards, which has led to a decline of marine resources and biodiversity in the region (UNEP-Nairobi Convention and WIOMSA, 2015). This situation has put the livelihoods and food security of more than 25 million people living in the coastal areas of the region at risk (Jebri *et al*., 2020). Marine fisheries in most WIO countries are composed of artisanal and small-scale fisheries (Palmer *et al*., 2021), predominately in inshore waters. Habitats such as coral reef, mangrove creeks, seagrass beds, and sand banks are where most fishing efforts are concentrated (Jiddawi and Öhman, 2002; Robertson *et al*., 2018). Fishers also fish further offshore in search of small and large pelagics, as well as tuna and tuna-like species. Small pelagic fish commonly captured in WIO countries include species of sardine, anchovy and mackerel (Sekadende *et al*., 2020). Other diverse species are caught depending on where fishing takes place and oceanographic characteristics (Jacobs *et al*., 2021; Kizenga *et al*., 2021).

Attempts to regulate fishing in the WIO region through the implementation of marine protected areas and gear restrictions, are beset with challenges (Mwaipopo *et al*., 2010; Vousden and Stapley, 2013). These challenges include a lack of sufficient scientific data and expertise, which are complicated by economic and socio-political realities (Ochiewo, 2015). Fisheries statistics such as catch, the number of fishing vessels and fishers are limited in most WIO countries (Kadagi *et al*., 2021). Tanzania and other countries make use of fisheries frame surveys that provide fisheries statistics but these are not conducted regularly due to financial constraints. The regional State of the Coast Report for the WIO (UNEP-Nairobi Convention and WIOMSA, 2015) states that nearly all the countries in the region cannot adequately assess their marine resources and lack the financial capacity and technical expertise to manage them effectively. The lack of reliable data, analytical capacity and advice presents a barrier to decision making. Knowledge of the stock status, trends, potential productivity of a stock, and socio-economic implications of the fishery, is vital to the design of responsible fisheries management interventions and sound policy making yet many of the fisheries stocks have not been assessed (Obura *et al*., 2017).

National fisheries institutes in some WIO countries have been mandated to collect routine fisheries data but this data is frequently underutilized or of poor quality. Records are sometimes misplaced, or the data is inaccurately captured, with no means of validating its authenticity due to the lack of an efficient digital data transmission system (Robertson *et al*., 2018; Robertson and Midway, 2019). Thus, even though data exists, it will often remain unused. The analysis of the data may also be based on inappropriate metrics and methods, which hinder the formulation of relevant policies for the sector.

Available information suggests that small pelagic fish make up the largest proportion of fish caught in the WIO and contribute to the largest proportion of employment in the WIO's fisheries sector (Sekadende *et al*., 2020). Estimates indicate that nearly one-third of marine fish catch in Tanzania are comprised of small pelagic fish (Breuil and Bodiguel, 2015; MLF, 2020). However, some scholars argue that the landings have been largely underestimated and that most stocks lack scientific assessment.

In the WIO region, small pelagic fish are predominately caught using locally made fishing vessels and different gear types and offer diverse benefits to local communities (Kizenga *et al*., 2021; Sekadende *et al*., 2020). For example, in Tanzania, this fishery plays a significant role in food security and nutrition and creates over 8,000 employment opportunities for people directly engaged in small pelagic fishing and ancillary activities (MLF, 2020). The vast majority of landings are dedicated for human consumption (MLF, 2019). A few fish processing facilities have been established along the Tanzanian coastline. There are no reliable records on the proportion of landings that go towards supporting the fishmeal and fish oil industries. There is a trade network where small pelagic fishes are exported through both formal and informal channels to neighbouring countries such as the Democratic Republic of Congo (DRC), Zambia and Kenya (Ibengwe *et al*., 2022).

The size of the catch from small pelagic fisheries is also reported to have increased in recent years (MLF, 2020). For example, in Zanzibar, catch of small pelagic fish has increased to 13,000 tonnes, according to the 2020 statistics (Ministry of Blue Economy and Fisheries, 2021). In mainland Tanzania, fish landings for small pelagics totaled 7,690 tonnes in 2011 and 8,053 tonnes in 2020 (MLF, 2020). Despite its large contribution to annual landings and being an important source of food, the current economic performance of small pelagic fisheries is believed to be far lower than could be possible given the available resources in Tanzania. There are records of initiatives that have recently taken place to safeguard fisheries from further decline (Andriesse *et al*., 2022). One of these initiatives includes prioritizing the development of a management plan for small marine pelagic fisheries. The outcome of this includes a recent initiative by WWF Tanzania Marine Programme to develop a local area management strategy to guide the management and sustainable use of the small pelagics through the established Collaborative Fisheries Management Areas in the Rufiji/Mafia/Kilwa (RUMAKI) seascape. An ocean governance framework that promotes sustainable fisheries management and incorporates the needs of local stakeholders, is essential to maintain fisheries and their roles in food security and sovereignty.

Coastal fisheries in Tanzania have been managed through the licensing of fishers and vessels, marine fishery management plan, and input and output controls. Inadequate information of fishery resources and associated value chains hampers understanding of the role of small pelagic fisheries in improving food and nutrition security, as well as promoting food sovereignty. The aim of this study was therefore to investigate how small pelagic fisheries, particularly for sardine (i.e., *dagaa* in local Franca), add to the overall food status and sovereignty. Achieving a better understanding of the ways through which small pelagics contribute to food sovereignty in small-scale fisheries is essential in enhancing science-based advice to

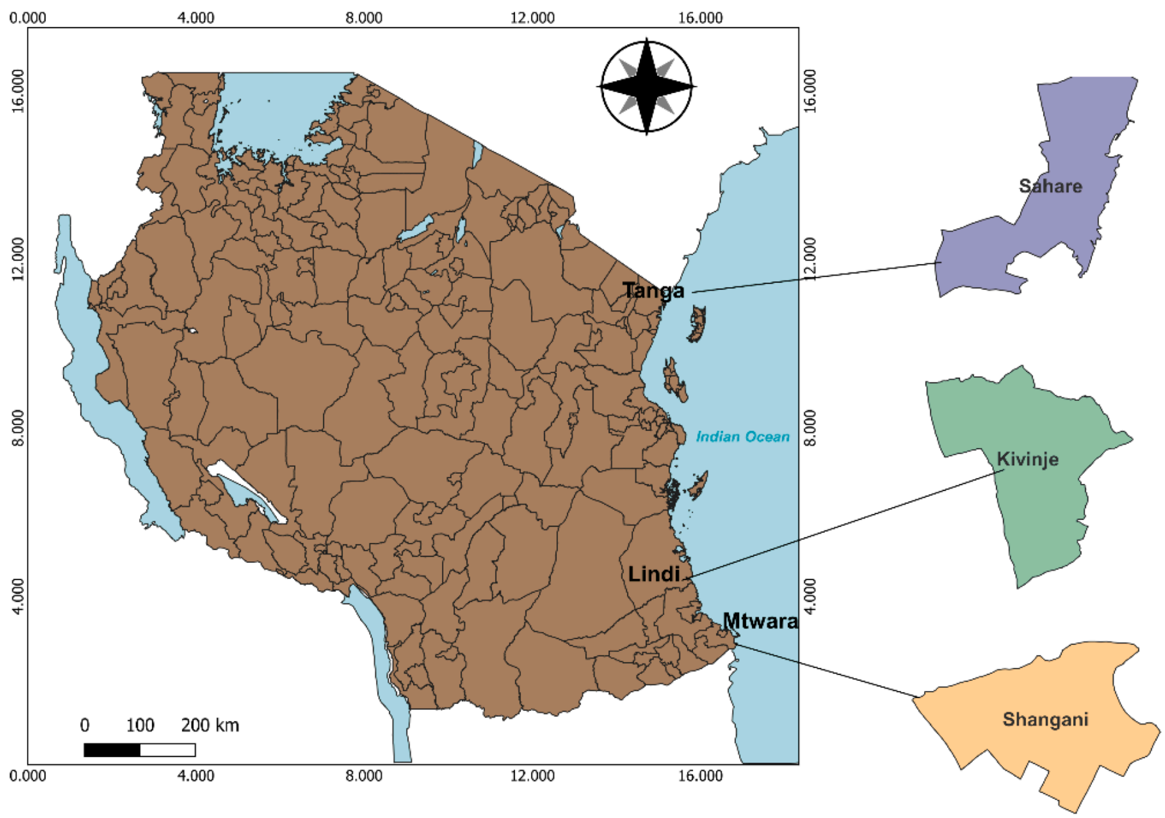

Figure 1. Three landing sites where small-scale fishing takes place, located in three coastal districts in Tanzania: Shangani (Mtwara district in Mtwara region), Kivinje (Kilwa district in Lindi region) and Sahare (Tanga district in Tanga region).

fisheries management (Arthur *et al.*, 2022). It would also provide information for policy makers to plan and put policies in place to prevent future degradation of marine resources.

Materials and methods

Study area

The study focused on three landing sites located in three coastal districts in Tanzania: Shangani (Mtwara region); Kivinje (Lindi region); and Sahare (Tanga region), as indicated in Figure 1. The sites serve small-scale fishers (resident and migrant), who target small pelagic fishes and link with fish trade networks including traders and processors from both domestic and international markets (MLF, 2020, 2019). Infrastructure for fish processing at these sites is often inadequate, and the sites have few sanitary facilities for fishers and visitors. Fish play a significant role in the diet of people living in the study sites—fish consumption in and around these sites is relatively greater than in many regions of Tanzania (MLF, 2020). However, fish and fishery product consumption in mainland Tanzania is below the world and sub-Saharan Africa average (Ochiewo, 2015).

Data collection

A survey was administered to 206 individuals (Table 1) between July and December 2019 to obtain information to better understanding the role that small pelagic fisheries play in promoting food security and sovereignty. Respondents for the survey were randomly selected individuals involved in fishery-related activities in the study sites. With the help of a fisheries official, researchers engaged with a Beach Management Unit (BMU) at each of the study sites to identify a list of individuals engaged in various fisheries-related activities at that landing site. Every third individual was selected from a list prepared by the BMU office at each site. The research did not apply convenience sampling to select respondents as this can result in visiting individuals more than once, reducing efficiency. The survey involved face-to-face interviews in the sampled study sites. The survey was achieved mainly by visiting respondents at the locations they had selected, usually at landing sites (as the majority spent much time of the day there), or at a BMU office. This was important to ensure privacy and comfort for respondents. Some individuals, particularly in Kivinje-Kilwa, were interviewed at their homes.

The survey was designed to collect perceived knowledge of respondents on small pelagic fisheries. It consisted of Likert scale, numerical and open-ended questions. Prior to the start of the field work, the survey was pre-tested with 10 individuals at Kunduchi fish landing site located in the Kinondoni district. Pre-testing allowed researchers to make the appropriate adjustments to the survey and clarify questions where necessary, before conducting interviews with the target population. The survey was conducted in Kiswahili language with five trained researchers. The average time spent for a survey interview was between 35 and 50 minutes. In addition to the survey, a research team noted down their observations in order to assess fisheries related activities as they took place. Observations included, but were not limited to, the processing of fish caught, women carrying fish from boats to auction site using large plastic containers, fish mongers purchasing fish directly at the auction, repair of fishing gears, and small-scale businesses on the shore. Observations concentrated on fish prices, marketing and sales of fish, processing, transport and governance issues (e.g., payment of levies and other fees). The purpose of noting down these observations was to enable researchers to better identify and understand interactions involved in the supply chain of small pelagic fish from the boat to consumers. Observations also supported researchers in developing further lines of questioning during interviews and informal interactions with the fisher communities.

The study included interviews with key informants. The 25 key informants were drawn from local leaders, fishers (resident and migrant), fish traders and processors, porters, business, BMUs, conservation practitioners, district fisheries officials, and fisheries and marine resource-based NGOs working in the study areas. Key informants were chosen from communities based on their experience in fishing activities. Special consideration was given to informants who had lived in their areas long enough to remember changes and developments that have occurred in the fishery sector. A snowball sampling technique was applied to select key informants. The number of participants grew by referral until the desired sample size was reached. Key informant interviews were designed to allow participants to share their personal experiences and opinions regarding small pelagic fisheries and to note how they perceive small pelagic fisheries are changing. Key informant interviews were important in gathering information on stakeholders' understanding on the journey of small pelagic fishes from boat to consumers, key actors in the supply chain of these fishes, management and institutional issues related to small pelagic fisheries, and the role small pelagic fisheries play in the contribution of food consumed by the local households. The use of follow-up questions made it easy for the informants to relate their experiences of small-pelagic fisheries to the overall fisheries activities. Researchers also interviewed stakeholders to ascertain the current status of small pelagic fisheries including utilization, processing, trade, marketing, management and food value. Key informants were interviewed where they preferred, including their homes or private settings in landing sites, and in some cases, at local offices such as BMU offices. Interviews lasted between 40 and 60 minutes. All informants gave oral consent prior to the interviews. As in the questionnaire survey, Kiswahili language was used during key informant interviews. As the majority of key informants were not comfortable for the interviews to be recorded, notes were taken instead.

One focus group discussion including 6 to 10 participants was organized in each of the three study sites. The aim of the discussion was to compliment and verify information from the surveys and key informant interviews. Participants were drawn from stakeholders engaged in small pelagic fisheries. Priority was given to women participants to ensure coverage of their concerns and knowledge. The focus group discussion lasted between 50 and 70 minutes.

Data analysis

As described by Braun and Clarke (2006), the study made use of thematic analysis to identify patterns of meaning in line with the research objectives. Quotations from key informants and focus group discussions were labelled but participants were given pseudonyms. Confidentiality was one of the requirements for ethics clearance. All completed surveys were entered into MS Excel and then converted to SPSS for data analysis.

Results

Socio-demographic characteristics of survey respondents

Table 1 provides socio-demographic characteristics of the survey respondents. Of the 206 respondents, the majority were male (80 %) and 20 % were female. All respondents participated in diverse livelihood activities including fishing, trade, farming and other sea-based activities such as processing and transporting of fish.

Consumption of small pelagic fishes

A variety of names were used for small pelagic fish species in the responses during the survey. Most of the names were local/vernacular such as *dagaa mchele, dagaa papa, dagaa lumbuga, dagaa vibua, and dagaa*. Key informants, especially fisheries officials, as well as scientists knowledgeable of the fisheries commonly found in the study sites were consulted to clarify ambiguity

Table 1. Main socio-demographic characteristic of survey respondents.

Characteristics	Variable	Landing sites			Overall (%/n=206)
		Shangani (%/n=65)	Kivinje (%/n=93)	Sahare (%/n=48)	
Gender	Female	9	19	13	41
	Male	56	74	35	165
Age group (years)	18-30	15	17	17	49
	31-50	29	49	25	103
	>50	21	27	6	54
Education	No schooling	5	9	4	18
	Primary	46	64	37	147
	Secondary	12	19	3	34
	College/Vocational	2	1	4	7
Main occupation	Fisher	17	32	21	70
	Farmer	1	11	8	20
	Fish trader	19	25	12	56
	Fish processor	18	9	3	30
	Porter	7	9	3	19
	Waged job	2	5	1	8
	Other	2	1	0	3

around species names. Naming of the types of fish was not straightforward and was affected by location and socio-cultural background. Consensus was reached by a large proportion of respondents (68 %) that sardines (Clupeidae) (referred collectively as *dagaa*) was the most landed and consumed small pelagic fish in the study sites, followed by anchovy (Engraulidae), mackerel (Scombridae) and other species (Fig. 2). One key informant emphasized that *dagaa* are commonly classified into two groups; *dagaa mchele* and *dagaa lumbuga* as summarized below:

> *[...] it is possible to hear different names for dagaa. Essentially, these all would mean the same product. Both types of dagaa can be boiled and salted or sun-dried. People will tell you the famous dagaa is dagaa nyama, but I tell you this is the same as dagaa mchele. In other areas especially hinterland like Newala they call it dagaa lumbuga. Different names, but still implying the same product* (KII5_140819)

Dagaa was said to be the most consumed fish because of its availability and lower prices compared with other fish species. When asked to identify consumption of these fishes across different income groups (low, middle and high), more than 70 % of survey respondents said that small pelagic fish species are more frequently consumed by low-income households compared to large pelagic species such as tuna and king fish. Larger fish, in their opinion, cost more than low-income households can afford. Many focus group discussion participants claimed that the fact *dagaa* is seen as a convenient fish food for low-income households is indisputable. This assertion was also supported during the focus group held at Shangani in Mtwara:

> *The thing here is not preference. You see, everywhere here is dagaa, this is what is commonly landed and the catch is often bigger than for other fishes. Many people here lack steady sources of income, and we classify ourself as poor. Our option is on dagaa, at least we can afford. We cannot go for changu or tuna [big fishes]. Those are for a few people who are well off and the vast majority is taken by traders who carry it to rich people in Dar es Salaam, although those people don't know where this fish has originated from (FGD 1_ 081219)*

Approximately 45 % of key informants said that over 70 % of small fish landed is consumed locally, both within their areas and outside their areas. The remainder is transported by traders to neighboring countries, particularly the Democratic Republic of Congo (DRC). Survey respondents older than 50 years suggested that fishing activities have changed over time, as has fish eating habits and preferences. Their opinion was that small fishes such as *dagaa* were seen as inferior fish species and only few people would prefer for them. This too was captured in a focus group discussion where a 65 years old man, identified as a seasonal fisher/fish trader, said that before the early 1980s, fish resources were abundant and often people preferred large fish to small fish:

> *Local fish has been the most frequently consumed protein, and not beans! Things have changed, you can't imagine. During that time [1980s], nobody would choose dagaa*

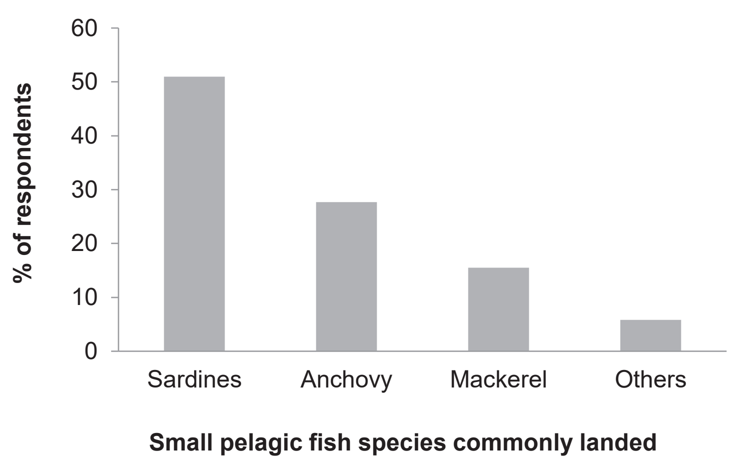

Figure 2. Proportion of small pelagic fish commonly landed across all three study sites, including sardine (Clupeidae) (referred to collectively as dagaa) as the most commonly landed and consumed small pelagic fish, followed by anchovy (Engraulidae) and mackerel (Scombridae).

Table 2 Selected questions to gauge responses on issues related to production of small pelagic fisheries

Question	Most likely (%, n)	Likely (%, n)	Neither likely nor unlikely (%, n)	Unlikely (%, n)	Most unlikely (%, n)
Current consumption of small pelagic fish might increase if fisheries resources management are improved	7.28% (15)	44.66% (92)	35.92% (74)	11.17% (23)	0.97% (2)
Financial and technical support to groups of small pelagic fisheries would improve their production efficiency	48.54% (100)	27.18% (56)	4.85% (10)	12.62% (26)	6.80% (14)
Fisheries governance initiatives will succeed to safeguard the interest of small pelagic fisheries	3.40% (7)	14.56% (30)	27.67% (57)	44.17% (91)	10.20% (21)

as this was seen as a sign of being poor. But now, dagaa is like gold, many people here can't even afford it. It has now turned to be an attractive commodity. Frequency of consuming fresh fish has declined; you now see in our market over there we even sell sardine from Lake Victoria (FGD2_171219)

Both the Kilwa Kivinje, Shangani and Sahare interviews and participant observation indicated a lack of activities and initiatives by both government and non-governmental groups to promote small pelagic fisheries through facilitation such as extension services to fishers, training on processing and marketing, as well as creating an enabling environment for access to fishing gears and vessels. According to informants, it is not easy to identify the origin of these small pelagic fishes given that some could be brought from fishing grounds located in northern Mozambique and sold at local landing sites. This was also noted by one key informant in Kivinje:

It is clear that there is fish deficit. Fishers are poor, cannot access loans to purchase big fishing nets and motorized boat. They [government] see us dependent on dagaa, but no help has been channeled to improve dagaa fishery. [...] you may think that they feel dagaa is not a preferred fish, but this is our food and also, we make money to cover our needs from it (KII18_140819)

Over 80 % of survey respondents mentioned that small pelagic fish landed are destined for human consumption. A few respondents (8 %) were aware of the use of small fishes for producing fishmeal. When asked if they knew or have heard about a fishmeal and fish oil industry along the coast, the answer was no. During focus group discussions in Sahare, in Tanga, some participants were aware of fish feed producing industries located in Dar es Salaam but there was uncertainty.

I know one industry; I forget the name but is located in Mbezi beach area. I heard that they buy sardines from lake to produce fishmeal. I have never heard or seen any trader here buying sardines with the intention of selling to such industries. It could be, but I have no proof (FGD3_281219)

When asked about price of small pelagics relative to other fish species, the majority of respondents (54 %) indicated that most often fish like *dagaa* would be cheaper than finfish such as king fish, emperor, tuna, barracuda and other large fish. This too was noted by one key informant who explained that it is common to see women buying dagaa and selling them elsewhere in small piles for approximately Tsh 1,000–2,000 (US$ 0.4–0.8 as of 2021 exchange rate). There is often a profit margin, as reported during focus group discussions, when these women sell processed *dagaa*.

Interestingly, key informants said that when large fishes are available at lower prices, people prefer them. Many respondents (Table 2) were pessimistic with regard to whether actions would be put in place to ensure better performance of small pelagic fisheries for both food security and sovereignty.

Demand for small pelagic fish as food

The survey indicated that fish is a major component of the human diet in the study sites. Although district level official records on fisheries do not include figures that indicate existing demand and supply of fish, or their species, for human consumption, information from interviews and observation suggests that demand outstrips production. The majority of survey respondents (78 %) said that fish for consumption, within their area, is locally sourced but once landed it is traded as part of broader trade and distribution systems. Interestingly, 60 % of survey respondents agreed that fish may not be obtained when needed.

Key informants indicated that fish are bought with cash from fishers or from markets and that *madalali* (middlemen) buy directly from fishers and are able to pack fish in ice boxes and transport them for greater profit to distant markets, including Ferry (Kigamboni) fish market in Dar es Salaam. This decreases the fish available to locals. The lack of infrastructure such as refrigerators, was repeatedly mentioned during focus group discussions and interviews as a limiting factor to purchasing fish in bulk. Discussions revealed that processing methods such as salting, boiling, drying or frying are not commonly preferred by consumers:

> *"People want fresh fish. Those further from the sea are the ones that will run to buy dried or fried fish, but for us here we are very much interested with freshy fishes. [...] Seasonality has also its own role, suppose you dry dagaa during bumper season, who are you expecting will buy them? Only fresh will suit customers" (FGD3_281219)*

Fresh fish are preferred but participants of discussion groups agreed that dried and fried fish are also consumed. The majority of survey respondents said that the diversity of small fish species in their diet is low compared to the past 10–20 years (Fig. 3). Processed fisheries products, such as smoked small fish, were rare. In one discussion, it was learned that smoking these types of fish is uncommon given taste preferences and that smoking *dagaa* without spoilage can be difficult.

Less than 15 % of survey respondents agreed that fish landed in their areas meet the demand, while 70 % said that the supply is low, and that people have adapted and buy vegetables or meat products to substitute fish. Nonetheless, it was clarified in the Shangani focus group discussion that the inflow of people from fish-eating cultures into coastal areas has caused an increase in fish demand. Nearly three-quarters of participants in this discussion group perceived a deficit in meeting fish demand and attributed this to decline in catch, influx of fish traders who transport fish to the hinterland markets, price and losses incurred when fish are landed prior to reaching consumers as noted in the following excerpts:

It is good if large fishing vessels are not licensing here to prevent them getting much which they don't sell in our markets. If they sell here, the price is high, we cannot afford. Yet problems are still there, fishers use traditional wooden boxes which are not effective in keeping fish afresh resulting into fish spoilage. People here process these fish in different styles they are known to them, it is not uniform because they have not been trained. What you see is a trader packing fish here and before they reach a market in Nachingwea they are already spoiled (FGD2_17919).

We don't smoke dagaa, only few households would do it. Smoking may reduce taste and, in some instances, cause spoilage. I also think it is because we have never smoked dagaa not because of their size, I guess it is our traditional. There could be a likelihood to start and see how is going to appear (FGD1_081219)

In the survey results, 50 % of respondents were of the opinion that current consumption of fish was low compared with the past 2–3 decades, and 67 % said that on average they consume fish (irrespective of type, but mostly small fishes) two times in a week. Clarification

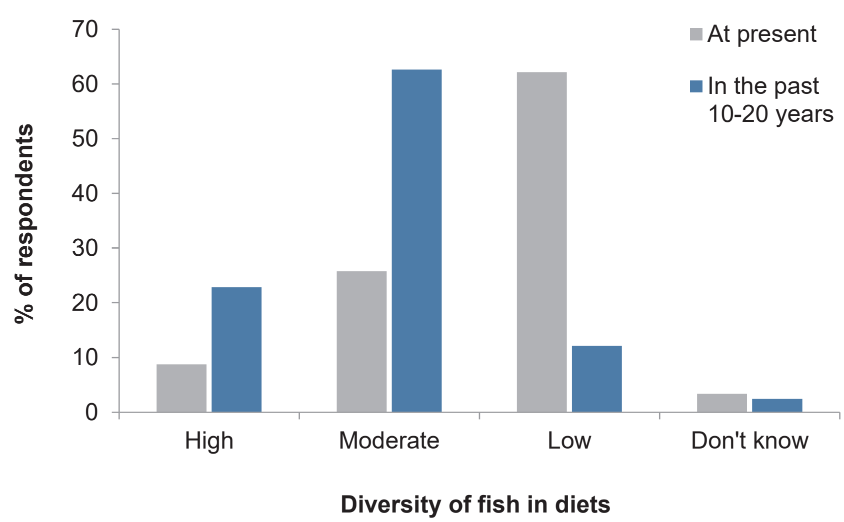

Figure 3. Responses to the question on how diversity of fish in human diets is perceived to differ from the present to what it was 10-20 years ago in the study sites.

Figure 4. Response to the question on where losses of small pelagic fish occurs before reaching markets or households. Adulteration occurs when harmful chemicals are added to preserve fish.

from key informants revealed that the attitude of local residents towards fish consumption was positive and they have a good understanding on the importance of fish food for their nutritional requirements and health.

Level of fishing effort for small pelagic fishes

A review of secondary sources, including annual government fisheries reports, showed that the current levels of fishing in many coastal areas is unsustainable (MLF, 2020). However, the status of small pelagic species is not well understood (Anderson and Samoilys, 2016; Mwaipopo and Mahongo, 2020). Despite contributing an important source of livelihoods and food security, few catch statistics clearly showed the levels of effort for small pelagics.

More than 90 % of survey respondents ranked fishing as the primary occupation of people in the study sites. Focus group discussions and interactions during field work revealed few opportunities for the residents to engage in other economic sectors. A discussion held at Sahare indicated that fishing effort is increasing and the current management approach (i.e., licensing and prohibiting gear and vessels) has not been able to curtail this increase. Sixty percent of respondents said that fishers go fishing on average two days per week. Most engage in the ring net or purse seine fishery which mainly target small pelagic fish. They work mainly as crew members because they cannot afford to buy their own fishing gear and vessels. Most of these fishers lack access to financial services and are not organized into groups that could be easily connected to donors and funding schemes. One key informant explained that a ring net fishing crew may attract up to 70 people, suggesting a high level of fishing effort in unrestricted fishing grounds. The rapid increase in fishing effort does not, however, seem to be satisfying an increasing demand from existing production:

> *With these gears and vessels, where efficiency is low, we won't meet the growing demand of fish. Our crew members cannot find new fishing areas because the vessels they use are poor and sometimes are not propelled by engines. Going to new fishing areas is also a weird thing, because in our place here [Kivinje] there are many people from all over Tanzania. How then you leave here pretending you are going to fish where people have relocated because there is no fish available there (FGD3_ 281219)*

Losses of small pelagic fish products

Across the three study sites survey respondents were interviewed to examine their understanding on fish product losses occurring from boat to consumers. In most instances, survey respondents and discussion participants explained that the small pelagic fishery experienced losses caused by spoilage during the season where the catch is high. The main causes were associated with limited or absence of processing capacity and methods that could adapt to significantly increased volume of catch. The other obvious loss mentioned during focus group discussions and interviews was attributed to discoloration, which according to 50 % of survey respondents happens when fishes are dried in the rainy season. Awareness of fish product losses and their associated economic and ecological impacts was high among survey respondents. Nearly 60 % of respondents agreed that they have experienced one type of post-harvest loss (Fig. 4) whereas 45 % were able to mention the causes of the losses.

A focus group discussion held in Kivinje revealed that the extended time taken from when the fish is caught to when it is transported from the landing site to markets is responsible for huge losses. Key informants suggest that these losses result in demand for fish outstripping supply:

> *It takes time as fishers would need to travel even up to 6 hours from where they have captured fish. They lack ice boxes or any materials that could preserve their catch. [...] you see those trucks parked over there! Waiting for fish to be auctioned, then they transport to different markets. This too affects the quality of fish and reduces availability of fish to consumers (FGD2_171219)*

Despite losses along the fish value chain mentioned during interviews, some key informants pointed out that not all catches are wasted. They gave examples where fishers or fish traders mix deteriorating fish with better quality fish or sell at lower prices:

> *Nobody would be happy to incur losses. They mix up. Look, how will you know if the dagaa you are bargaining is all good, as it is being sold in a bucket. We are not happy with this, but there is nothing we can do except bearing the loss (KII24, 191019)*

All but six key informants (n=25) reported that a large percentage of small pelagic fishes caught in the study sites are processed with methods that might compromising the quality of the fish. Sun drying, boiling and salting and deep frying were the most common processes observed in all study sites. Smoking was occasionally seen in Kivinje. Sun drying was ranked as the processing activity most often caried out (56 %), followed by boiling and salting (28 %) and deep frying (16 %). Approximately 65 % of survey respondents felt that losses are a barrier for them meeting their fish food demand and negatively impact their income. The research found few initiatives in place to transform these methods and support the transition to modern processing methods.

Discussion

The present study discovered an increasing number of people participating in small pelagic fisheries using rudimentary fishing gears and vessels in Tanzania. The catch is either consumed locally or transported to different markets, including across the border to DRC, Zambia and Kenya (Ibengwe *et al.*, 2022). Following the decline in fish resources, small pelagic fishes, especially *dagaa*, is now seen as an affordable fish for the majority of poor households in coastal Tanzania and beyond. Yet, few initiatives have been developed to modernize the fisheries sector, and improve efficiency. The existing small pelagic fisheries in Tanzania do not seem to satisfy the demand and is influenced by lower prices and availability and a growing number of consumers and markets. This poses problems for food and nutrition security and hinders the prosperity of the sector to develop food sovereignty which goes beyond food security to include culture, knowledge systems and ecosystem dynamics.

Other regions of the world have increased their food sovereignty through improvement in their fisheries sector. These include movements to improve food supply chains to support household consumption of fish and sales of fish to earn income (Levkoe *et al.*, 2017). Emphasis has also been put on acknowledging the origin of fisheries products through certification (Bellchambers *et al.*, 2016; Nyiawung *et al.*, 2021).

Although efforts have already been undertaken to develop and implement management plans for some fisheries, including prawn, octopus as well as small and large pelagic fisheries, not all fisheries are adequately managed in Tanzania (Bradford and Katikiro, 2019; Gates *et al.*, 2021; MLFD, 2013; Silas *et al.*, 2022). In areas where fisheries management plans have been developed, the use of fishers to collect data and information relevant for monitoring and management plans has been valuable to support food sovereignty. Fishers, in such cases, are provided with important training and instruments, and act as stewards of their own resources despite having a limited voice in political decision-making. Despite their importance in recording the catch landed, inadequate support by both governmental and non-governmental actors for small pelagic fisheries in Tanzania has affected the capacity of the fishery to meet increasing human consumption and self-management.

The current situation in Tanzania does not indicate that this sub-sector will be able to supply fish in the quantity needed to meet demand. This may have negative repercussions on the small pelagic fish value chain, and affect a number of actors along the chain from fishers to consumers. In the recent past, *dagaa* are crossing borders, with consequences for decreasing fish availability for local household consumption and making it a competitive food commodity (Ibengwe *et al.*, 2022). In regions where government fisheries initiatives have succeeded, e.g., Asia Pacific, to safeguard the interests of the small pelagic fisheries, their role in food security and sovereignty has grown (Ba *et al.*, 2017; Cook *et al.*, 2021; Tezzo *et al.*, 2021). In Tanzania, fisheries management interventions have been less successful, likely as a result of their pilot study nature and only covering limited areas along the Tanzanian coastline.

One approach that has been effective in addressing management in small pelagic fisheries is focused on marketing channels. In several regions of the world, this has been carried out to bolster existing management options, such as gear restrictions and closed seasons. In Bangladesh, for example, the ecosystem approach to fisheries management has led to signs of ecosystem recovery (Islam *et al.*, 2022). Similarly, in the Philippines, fish aggregative devices (FADs) have shown to increase average catch by about 5 kg (Palm *et al.*, 2021). However, FAD projects are not a long-term ecosystem approach to sustainable management given their shortcomings such as scarcity of required expertise, high cost of equipment, attraction of illegal fishers (Onyango *et al.*, 2021) as well as the lack of planning, monitoring and research needed to understand and fulfill their potential in nearshores (Bell *et al.*, 2015).

In this study, fishers prefer to sell their catch for financial gain, leaving the poor where fishing is taking place with limited access to fish or, when fish is available, unaffordable prices. Governance mechanisms could be put in place to support local communities, for instance prohibiting large sales to hinterland markets during low fishing seasons. These communities lack alternatives and eventually are forced to change their dietary needs, as seen in recent years where they opt for vegetables and beans instead of fish. This contributes to their food security but compromises the idea of small pelagic fish for food sovereignty. The economic value of small pelagic fishes in Tanzania is hidden by unrecorded 'export' of these fishes, to common markets in DRC and other countries. These fishes are transported 'illegally' to various areas, crossing borders without proper permits. The lack of data on this trade limits the actual recorded economic value of the fishery but indicates possibilities for expanding the incomes of fishers and traders of these species, which is one step toward food sovereignty.

It is important that any approach aimed at strengthening food sources, as with pelagic fisheries in this case, is set within the locally specific context, and that it recognizes the dynamic nature of food sources, as any number of complex factors are likely to impede the success of the approach. In order to identify interventions that will help to achieve sustainable food systems, an understanding is first needed of the existing context in which people exist (Arthur *et al.*, 2022). We need to understand how poor coastal communities are responding to pressures on their food security and livelihoods, how they are engaging with the coastal environment and what drives their livelihood choices. This information is the foundation on which we can then work with communities to sustainably enhance ocean governance policies that improve their livelihood opportunities whilst not degrading the coastal environment.

Limited data on the production and consumption of small pelagic fishes was a main limitation of this study. The study has relied on recording the perspective of respondents in interviews and focus group discussions as well as the extrapolation of information from the limited reports and research available. Future studies need to focus on specific species of small pelagic fish and trace the value chain from production to consumption as a way to examine who will consume these fish in future. Furthermore, governance frameworks and policy recommendations for improving the role of fish in food security need to be streamlined in the current and potential fisheries management strategies. Barriers to the performance of the small pelagic fishery, including poor growth in the overall fisheries sector, should receive policy attention and prioritization in research.

Conclusions

It is evident that the existing production and marketing channels for marine small pelagic fishes in Tanzania are inadequate to promote food security and sovereignty. Urgent measures are required including integrating fisheries in the overall food production systems. Transformation in small scale fisheries is also important for creating a supportive environment for small scale fishers to be self-sufficient from the fish they catch. It became evident that the majority of people engaging in the small pelagic fish production chain lacked the skills to take the fishery forward on their own and that there was a need to support the process. There is a need to support small pelagic fisheries operations including processing, packaging, transportation, from skills development to business planning, and the development of markets. This requires long term commitment from both the public and private sector. Most of the fishing units in the small pelagic fishery are generally small enterprises and these require an initial capital investment or startup cost. Many fishers do not have access to micro-credit services to finance these initial costs. For small pelagic fisheries in Tanzania to contribute to satisfying current demand of fish there is a need to support the development of skills to run these enterprises with relevant technical and financial management skills. There has been a lack of support to move the small pelagic fishery from a subsistence activity to a profitable economic opportunity for communities. Improving working conditions of fishers engaged in small pelagic fisheries as well as creating a favourable environment to support their activities would promote the role of this fishery in food sovereignty.

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Appendix

Questionnaire used in the survey

1. Demographic characteristics
(name, gender, age, occupation, size of household, occupation)
2. Have you ever heard about small fishes?
(1=Yes; 2=No; 3=Don't know)
3. If the answer is yes, how informed are you about small pelagic fish and fisheries in your area?
(1=Very; 2=Somewhat; 3=Little)
4. Access to small fish in diets in the past 10-20
(1=Increased, 2=same, 3=decreased, 4=Don't know)
5. hat has led to increased demand for small fish
(1=Population growth; 2=Urbanization; 3=globalized food trade; 4=Others, please mention)
6. Diversity of fish in your diet
(1=High; 2=Medium; 3=Low, 4=Don't know)
7. Preferences of small fish compared to large fish e.g., reef, large pelagics) in diets
(1=High; 2=Medium; 3=Low; 4=Don't know)
8. Source of small fish supply in your diets
(1=Domestically produced; 2=Imported; 3=Don't know)
9. Would you be willing to modify your diets following decline in availability of fishes you were used
(1=More willingly; 2=Willingly; 3=Neutral; 4=Unwillingly; 5=More
10. Fish represent an important part of your diet
(1=Strongly agree; 2=Agree; 3=Neutral; 4=Disagree; 5=Strongly disagree)
11. On average, how often do you eat small fishes?
(1=Almost every day; 2=3 to 5 servings in a week; 3=1 to 2 servings in a week; 4=1 to 2 servings in a month; 5=Less than a serving (1) per month; 6=Never/I don't eat small fishes
12. Where do you go often to buy small fisheries?
(1=Directly from fishers/landing site; 2=Fish traders/Local market; 3=Frozen fish market 4=Others (specify)
13. Among the seafood you buy, which one do you buy most frequently?
(1=Reef fish; 2=Small fish; 3=Large fish; 4=Other)
14. When you buy small fish, you prefer
(1=Fresh; 2=Dried; 3=Frozen; 4=Fried; 5=Canned)
15. What are the most important criteria when you buy seafood/fisheries products?
(1=Price; 2=Freshness; 3=Taste and texture of the seafood; 4=Eating familiarity; 5=Other)
16. How often do you try seafood that is new or unfamiliar to you?
(1=Frequently; 2=Sometimes; 3=Rarely; 4=Never)
17. Vessels that participate in small pelagic fishery
18. Main target species in small pelagic fishery
(1=Sardines; 2=Mackerel; 3=Anchovy; 4=Other)
19. Primary management measures for the small pelagic fishery are through:
(1=Licensing; 2=Closed seasons; 3=Closed fishery; 4=Gear and vessel restrictions; 5=Total allowable)

20. Who is eating pelagic fish now
(1=Low income; 2=Middle income; 3=High income; 4=All income groups, 5=Don't know)?
21. How important is fish in your diet
(1=Important; 2=Moderate; 3=Not important)
22. Who will be eating fish in the future
(1=Low income; 2=Middle income; 3=High income; 4=All income groups, 5=Don't know)?
23. Current consumption of pelagic fishes might increase if fisheries resource management are improved
(1=Most likely; 2=Likely; 3=Neither likely nor unlikely; 4=Unlikely; 5=Most unlikely
24. To what degree do you think you would benefit from not fishing small fish?
(1=Not benefit; 2=Small; 3=Medium; 4=Big benefit; 5=Don't know)
25. Do you think that not fishing/consuming certain small fishes is a good way to maintain fish around here?
(1=Don't know; 2= Completely disagree; 3=Disagree somewhat)
26. Do you think that other fishers would agree to not fishing small fishes?
(1=Don't know; 2= Completely disagree; 3=Disagree somewhat; 4=Neutral; 5=Agree somewhat; 6=Completely agree)
27. Do you think fish products are good for your health?
(1=Yes; 2=No; 3=Don't know)
28. Fish distribution facilities
(1=Foot; 2=Motor cycle; 3=Bajaj; 4=Bicycle; 5=Mkokoteni; 6=Motor vehicle)
29. Estimated amount of catch landed per boat at present
(1=Big; 2=Low; 3=Moderate; 4=Don't know)
30. Estimated amount of catch landed per boat in the past 10-20 years
(1=Big; 2=Low; 3=Moderate; 4=Don't know)
31. Any mechanism to favour poor households in the management of SPF
(1=Strongly agree; 2=Agree; 3=Neither agree nor disagree; 4=Disagree; 5=Strongly disagree)
32. Fisheries government initiatives have succeeded to safeguard the interests of the SPF
(1=Yes; 2=No; 3=Don't know)

Ocean Governance: A tertiary educational perspective in the Mauritian context

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Abstract

Ocean governance provides for the norms and tools needed to ensure the sustainable use and management of marine resources. In order to implement effective ocean governance and tools, there is a need to train all stakeholders involved in the management and sustainable use of ocean resources. This is where education, particularly tertiary education, has an important role to play. The objective of this paper is to examine the contribution of tertiary education in promoting good ocean governance. The paper assesses the role and current involvement of a tertiary education institution, the University of Mauritius, in enhancing ocean governance in Mauritius. The findings will demonstrate that, although ocean governance modules are incorporated in some undergraduate and postgraduate programmes offered at University level, a more interdisciplinary approach and further collaboration is needed to promote training in this field.

Keywords: education, tertiary institutions, ocean governance, ocean resources

Introduction

The contribution of the oceans to the development of humanity cannot be underestimated. According to Gee (2019), many societies and civilizations were built based on the oceans and the resources they provide. Today, there is unanimous agreement by states that the ocean and its resources have to be protected. Post-World War II, steps were taken by the United Nations to ensure that there was a global agreement which regulates how countries use and benefit from the ocean. In 1982, the United Nations Convention on the Law of the Sea was signed, and the Convention became effective in 1994. This Convention, also referred to as the Constitution of the Sea by Maltese Ambassador A Prado (UN General Assembly, 1967), provides for the three major features it regulates: first the Convention provides for the extent of national sovereignty over the seas and oceans; secondly it elaborates on the navigational rights of ships and aircrafts; and finally it ensures environmental protection.

This essay examines how the University of Mauritius, through its courses and research, contributes to the sharing of knowledge about ocean governance. The objective of this paper is to share the educational tools that the university uses to transmit knowledge about ocean governance to various stakeholders, thereby playing an important role in the discourse around ocean governance in Mauritius.

As more and more countries voiced their views and interests to ensure further protection and sustainable use of the oceans and its resources, the United Nations and its various agencies developed further agreements and strategies to ensure the sustainable use of the oceans. In 1992, through the United Nations Conference on Environment and Development (Chapter 17 of Agenda 21) and the 2002 World Summit on Sustainable Development, countries were required to devise and implement ocean and coastal government and policy approaches. In 2015, the Sustainable Development Goals (SDG) were developed and attention was drawn to the oceans, with SDG 14: 'Life below water'. This SDG encourages countries to take the necessary actions to protect the ocean and seas by ensuring the sustainable use of marine resources.

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Ocean governance can guide countries in this endeavor. Although there is no universally accepted definition of the term ocean governance, many commentators have put forward that ocean governance relates to a set of norms, rules and practices that regulate maritime activities with a view to protect the marine ecosystem and reap economic benefits from the use and exploitation of marine resources (Singh and Ort, 2020). According to Bailet (2002), ocean governance involves three elements: a legal foundation, an institutional framework and mechanism of implementation.

At national, regional and international levels, the international community as well as individual states have taken steps to implement Bailet's (2002) three elements of ocean governance. Several laws, conventions and international institutions have been created over the years to encourage the sustainable use and management of marine resources and activities at sea. Several ocean governance mechanisms have been created to ensure the effective management of marine resources. Examples of governance norms and tools include, *inter alia*, environmental impact assessments, the ecosystem-based approach, sustainable development, marine protected areas, and marine spatial planning.

One element within the ocean governance discourse which requires attention and analysis is education. Education plays a central role in the management and use of marine resources. The sharing of knowledge and experience, whether from a scientific, environmental and legal perspective, encourages maritime stakeholders to become aware of the importance of the sea and how and why it should be protected.

In Mauritius, research is being carried out on the ocean governance tools and norms that can be used to sustainably manage and exploit marine resources. One aspect of the Mauritian ocean governance discourse, which has not been extensively researched, is how the tertiary education sector can contribute to educating and training the various stakeholders in achieving sustainable ocean governance and creating awareness about the law of the sea.

The teaching of ocean governance at the University of Mauritius (UoM) and its role in knowledge sharing is elaborated here, illustrating how UoM can strengthen its role in being a service provider in knowledge building of ocean governance in Mauritius.

The 2017 United Nations Conference to support the implementation of the Sustainable Development Goal 14, promoted educating people on ocean governance matters. During the conference, the United Nations Education, Social and Cultural Organisation (UNESCO) presented the "Ocean Literacy for all: A global strategy to raise awareness for the Conservation, Restoration and Sustainable Use of our Ocean" as a voluntary commitment for States to create public awareness on ocean related issues among their population (UNESCO, undated). This initiative illustrates the international motivation and will to educate people on ocean matters.

In the ocean governance context, where skilled and knowledgeable individuals are important for the implementation of ocean governance norms and tools, providing for formal classes and pedagogical instruments to individuals is crucial.

Santoro *et al.* (2017) recognised the importance of developing an educational framework that would include ocean sciences into national and state standard curriculum in the United States so that students would learn the role that the ocean plays in economic growth, national maritime security, protecting ocean health and the improvement of quality of life.

As Santoro *et al.* (2017) points out, having a formal or even an informal educational framework which expands on ocean-related matters has various advantages. For example, students are able to understand the role of the marine environment in supporting and sustaining marine species. The students are better aware of the importance of marine biodiversity and actions to be taken to protect the marine ecosystem and its functionality.

Worldwide, universities are offering courses, trainings, and capacity building on ocean governance (e.g., University of Malta, Masters in Ocean Governance). Tertiary education institutions (TEIs) provide not only an environment for sharing knowledge and skills, but also the vocational and practical aspects of ocean governance to prepare students for the future workplace. Through this, tertiary educations institutions play a central role in transmitting knowledge and technical skills pertaining to ocean governance.

Kullenberg (2010) emphasizes the importance of education in promoting the sustainable use and management of ocean resources in order to reap socio-economic benefits such as employment, food security and poverty alleviation. Tertiary education institutions provide a platform where students and academics can undertake research and participate in national discussions on the importance of ocean governance and how the implementation of ocean governance norms and tools can contribute to the socio-economic development of a country.

The UoM is the first TEI to include law of the sea and ocean governance in one of its curricula in Mauritius. UoM delivers several programmes concerned with ocean governance at the Faculty of Science and Faculty of Agriculture. There are three programmes that have been offered through the Department of Biosciences and Ocean Studies that have law of the sea and ocean governance components. The first programme is a 3-year undergraduate BSc Marine Environmental Science programme where students follow a 90-hour module on law of the sea and ocean governance. The module deals with the historical background and evolution of the law of the sea, the concept of ocean governance and institutional framework of ocean governance and marine spatial planning. The cohort size in these programmes since first offered in 2019 range from 22 to 30 students.

There are two Masters programmes, namely MSc Marine Science and MSc Coastal and Ocean Management which have been offered or on offer. The first Coastal and Ocean Management cohort, with 13 students, graduated in 2017. In this MSc, law of the sea and ocean governance forms a core module of 12 credits. In this module topics include major coastal and marine environmental laws and policies, maritime zones, and technical and analytical frameworks and concepts of ocean governance, law of the sea and marine policy. In the MSc Marine Science, there is a 6-credit module called Marine Resources and Law of the Sea. The law of the sea component focuses on marine environmental law and shipping laws, the economics of the ocean, international conventions and agreements, rights and responsibilities of states in various zones of the ocean, fisheries and non-living resources vessel nationality and jurisdiction maritime security maritime boundary delimitation and baselines, marine environment and dispute settlement mechanisms.

Research in ocean science is conducted by a number of PhD candidates at the UoM both at the Faculty of Science and Agriculture. The studies conducted could include ocean governance components if they are dealing with management of marine biological resources. Furthermore, academics are increasingly conducting research in the field of ocean governance in the Mauritian context.

The UoM is the only tertiary education institution in the country to offer tailor-made undergraduate and postgraduate programmes based on ocean related matters. Although the UoM is the leading institution in Mauritius to provide for undergraduate and postgraduate courses on ocean related matters, ocean governance is still a novel concept in the country and the university can further enhance its pedagogical contribution in this field. The UoM can further strengthen its contribution to ocean governance locally, regionally and internationally.

Education plays a fundamental role in the ocean governance arena. Tertiary education can provide the necessary knowledge and practical skills required for good ocean governance.

Recommendations

At university level, there is a need to move towards a more multi-disciplinary and interfaculty approach for research and teaching. For example, at the UoM, the Faculty of Sciences, through its Department of Biosciences and Ocean Studies, offers courses on ocean governance and management.

Ocean governance is inherently a multidisciplinary and transdisciplinary endeavor and this should be reflected in training programmes on the subject. Courses and programmes should be created where academics from different faculties can contribute based on their expertise. For instance, in Mauritius the government is implementing the Blue Economy concept and courses and programmes combining management, economics and law, for example, can be developed at university level in order to be in line with governmental initiatives and contribute to expertise on new topics.

By encouraging exchanges between the UoM and other universities in the region, students throughout the Western Indian Ocean could benefit from the course and contribute to regional ocean governance understanding. Furthermore, the University can partner with regional and international organizations to contribute to, and benefit from, trainings and workshops that the partners provide. Collaboration between academics of the UoM and academics from other universities in the region will promote research, build capacity, and ensure the transfer of knowledge and technology among academics in the region. The UoM provides a model that can be adopted and expanded to other countries in the region to develop undergraduate, Masters and research programmes in ocean governance.

The UoM has the potential to contribute to ocean awareness and the understanding of ocean governance at all levels of society. By collaborating with the Mauritius Institute of Education, which is the authority that trains primary and secondary school teachers, academics can train these teachers on ocean-related matters and thus encourage the inclusion of ocean studies in school curricula. This will improve the understanding of ocean issues at all educational levels. In addition, the UoM could organize trainings and short courses targeting governmental agencies, NGOs and local coastal communities on ocean related matters, such as environmental protection, shipping and maritime activities and the potential of the sea to contribute to economic growth.

Conclusion

The importance of effective ocean governance is gaining recognition worldwide. There is a need to educate people about ocean governance and how its norms and tools are important in protecting and sustainably using marine resources. Various international organizations, such as the United Nations and its agencies, have recognized the important role of education and how it can be a tool to promote ocean governance. Worldwide, universities are developing curricula which take into consideration ocean governance elements such as the law of the sea, environmental impact assessments or marine spatial planning. By including these tools in curricula the knowledge and skills necessary for the implementation of a well-functioning ocean governance framework are created and nurtured. In Mauritius, the UOM, through its various undergraduate and postgraduate programmes, has included elements of ocean governance in its curriculum. However, in order to further enhance knowledge about ocean governance in the country, the university should encourage a multidisciplinary approach and collaborate with regional and international organizations. Training in ocean issues should start from primary and secondary school because having a population educated on ocean matters in Mauritius and regionally will ensure that decisions and actions taken will promote good governance and sustainable marine resource use, thus contributing to the protection of the marine environment for future generations.

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Every account counts for sustainable development: lessons from the African CoP to implement ocean accounts in the Western Indian Ocean region

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Abstract

The Western Indian Ocean (WIO) is critical in supporting the social and economic development of the nations it borders. To safeguard the various opportunities it provides, it is essential to adopt sustainable ocean development models that balance ocean wealth and ocean health. Such models depend on evidence-based and adaptative ocean governance underpinned by holistic social, environmental and economic indicators. The ocean accounts framework provides a standard accounting structure to integrate social, economic and environmental information in alignment with relevant international statistical standards such as the System of National Accounts and the System of Environmental-Economic Accounting. Applying such a framework produces integrated indicators against which changes can be assessed and measured. These indicators also inform decision-making and support the prioritisation of areas requiring further attention by highlighting data deficiencies, ocean governance gaps and under-explored research areas. The framework encompasses and links several systems of accounting that can be used based on specific priorities. However, three initiation points have been identified that can be further expanded and concatenated into other accounts encompassed by the framework. This publication provides practical guidelines to start implementing national, regional or local ocean accounts, following the Global Ocean Accounts Partnership Technical Guidance on Ocean Accounting. It is further complemented by amendments proposed by the African Community of Practice based on lessons learned during the implementation of ocean accounts pilots across the WIO region. Compiling ocean accounts is an adaptative and iterative process and should be constantly ameliorated and adjusted to local contexts and priorities. However, efforts should be made to maintain coherence with the framework and international standards.

Keywords: ocean accounts framework, ocean governance, data integration, statistical standards

Introduction

The ocean supports various human activities, which are rapidly growing due to advances in science and technology (Virdin *et al.*, 2021)while progress toward achieving international goals for ocean conservation and sustainability is lagging. In this context, the private sector is increasingly recognized as having the capacity to hamper efforts to achieve aspirations of sustainable ocean-based development or alternatively to bend current trajectories of ocean use by taking on the mantle of corporate biosphere stewardship. Here, we identify levels of industry concentration to assess where this capacity rests. We show that the 10 largest companies in eight core ocean economy industries generate, on average, 45% of each industry's total revenues. Aggregating across all eight industries, the 100 largest corporations (the "Ocean 100". The expansion of ocean resource-use results in increased pressures on coastal and marine ecosystems (Golden *et al.*, 2017). To balance the needs and interests of ocean stakeholders (with often competing priorities) with the sustainable use of ocean space and resources, it is critical to balance ocean health, wealth and economic development considerations (Gacutan *et al.*, 2022) economic, and environmental considerations when addressing complex policy challenges and achieving strategic objectives, such as conservation targets, or sustainable and ocean-based economic development agendas. Like many common environmental assets, oceans have been impacted by a history of imperfect governance resulting in substantial negative consequences for these important socio-ecological systems. Aligning and managing multiple trade-offs between policy targets for the management of human activities in the marine domain has been increasingly attempted using Marine Spatial Planning (MSP. The balance between various stakeholders' interests and the definition of ocean sustainable development strategies depends on trade-off analyses that are better achieved when underpinned by evidence-based decision-making (Findlay *et al.*, 2020).

The contribution of ocean economies to social and economic development is particularly important for the nations of the Western Indian Ocean (WIO), with its 22.3 million km² of ocean and supporting around 60 million people living in coastal areas (within 100 km of the shore) (Obura *et al.*, 2017). According to the most recent report on the economic contribution of ocean goods and services based on living marine ecosystems (thus excluding activities not dependant on ecological functioning, such as shipping and mining), the total ocean assets were estimated to value at $333.8 billion (Obura *et al.*, 2017).

As a result of such importance and the transboundary nature of resources, numerous regional research collaboration and governance programmes were established to support sustainable ocean management, such as the South West Indian Ocean Fisheries Project (SWIOFP), the UNEP WIO-Lab Project, the Strategic Action Programme for the protection of the Western Indian Ocean from land-based sources and activities (WIO-SAP), the Agulhas and Somali Current Large Marine Ecosystems (ASCLME) project, the South West Indian Ocean Fisheries Governance and Shared Growth Project (SWIOFish) among others (Satia, 2016). Notably, the ocean sustainable development agenda within the WIO region is reflected by the establishment of numerous regional institutions, partnerships, and intergovernmental organisations focusing on supporting multistakeholder engagement (including governments, civil society and academia) and improving ocean governance, such as the Nairobi Convention and its Conference of Parties and Protocols, the South West Indian Ocean Fisheries Commission, the Western Indian Ocean Marine Science Association (WIOMSA), the Western Indian Ocean Governance Exchange Network (WIOGEN) or the Western Indian Ocean Commission / Commission de l'Océan Indien (COI) (Vousden, 2016). Furthermore, most Western Indian Ocean nations are Member States of the Indian Ocean Rim Association (IORA).

Within the 'governance for ocean sustainable development' arena, ocean accounts provide a powerful tool to guide the systematic and consistent compilation of environmental, economic and social information. These are from numerous sources across and between ocean environments and the human use thereof, using international statistical standards (GOAP, 2021a, Gacutan *et al.*, 2022). The power of diverse information is enhanced through integration by using a variety of established accounting systems and satellite accounts relevant to ocean systems (Supplementary Table SM1). Included in these are: the System of National Accounts (SNA) (United Nations, 2008) and aligned Ocean Economy Satellite Accounts (OESA) (Colgan, 2016); the System of Environmental-Economic Accounts – Central Framework (SEEA – CF) (United Nations *et al.*, 2014); andw the System of Environmental-Economic Accounts – Ecosystem Accounts (SEEA – EA) (UNSD, 2021). These and other accounting systems currently being tested and adapted (e.g., Social Accounts, Governance Accounts, and Pressure and Risk Accounts) can be integrated into an Ocean Accounts Framework (OAF) by compiling groups of tables of stocks and flows (Fig. 1, Supplementary Table SM2). For example, the flows of goods and services from ecosystems to economic sector supply and use, and the resulting benefits to social systems link ecosystem accounts, ocean economy accounts and social accounts in one direction. Conversely, the pressures of economic resource-use activities on ecosystems and the resultant natural state change and impacts link social, economic and ecosystem accounts in the opposite direction.

The information compiled through the groups of tables on a regular basis and the systematic linkage between stocks and flows from various accounting systems result in robust knowledge products. These

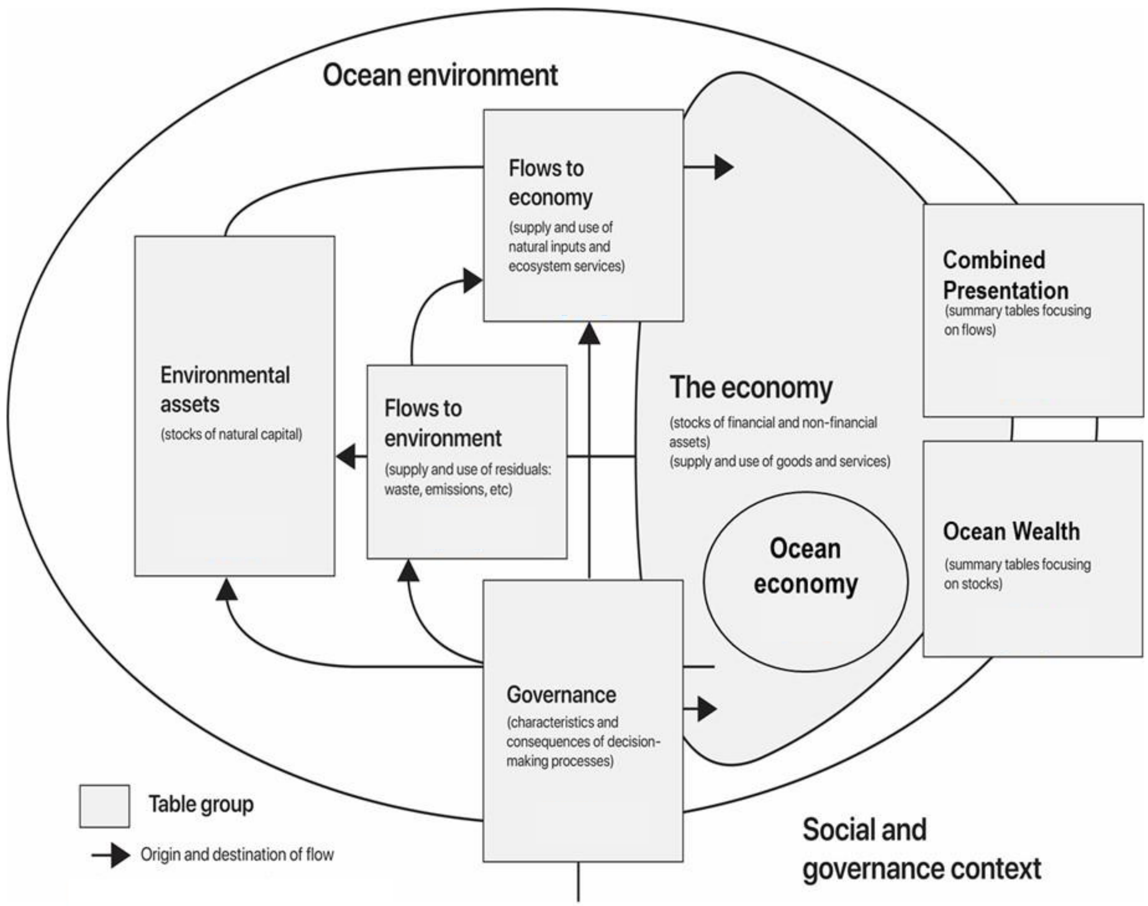

Figure 1. General structure (groups of stocks and flows, as tables) of the Ocean Accounts Framework adapted from the Technical Guidance on Ocean Accounting (GOAP 2021a).

include statistics and indicators for monitoring and reporting ocean resource uses (including benefits and costs), the equitable and inclusive share of the benefits of such use, ocean wealth and ocean health (Fenichel et al., 2020). As a result, ocean accounting data provides a foundation to support development planning, including the definition of goals and strategies for ocean sustainable development within expanding ocean economies. Ocean accounting data also underpin informed decision-making processes, including ocean governance and adaptive policy development cycles across social, economic and environmental domains, the management of the ocean space, the definition and monitoring of protected areas, and the designation and allocation of investments by sector, social groups or locations. It can also facilitate ocean monitoring and assessment, highlighting gaps in knowledge of statistics, governance and research, identifying areas requiring prioritisation; and finally, it enables the incorporation of data-heavy information systems arising from technological advances in ocean sciences.

Such a holistic approach is critical as nations recognise the need to move beyond economic data alone to drive informed decision-making and governance processes (Stiglitz *et al.*, 2018). Be that as it may, establishing ocean accounts can be intimidating in their scope. As an integrated framework, it requires a range of data, information and knowledge from a variety of stakeholders and agencies. The critical role of multidisciplinary teams and the need for collaborative stakeholders' engagement outside their areas of expertise could result in hesitation or resistance to engaging with ocean accounts. Notably, since the OAF is fundamentally an assemblage of accounts as modules, it is often not necessary or possible for the entire process to be resolved from the outset. Selected accounts can be compiled based on specific policy questions, governance needs, national priorities, data availability, and technical capacity. While the concurrent full compilation of ocean accounts is not required, it is critical to ensure the employment of a common framework so that individual systems and flows within the OAF can be integrated later.

Accordingly, all assembled data must be organised in specific and standard structures that enable: a) spatial and temporal comparisons; b) spatial or temporal disaggregation for informed management processes, including the development of indicators; and c) ensuring that accounts can be expanded to integrate other accounting systems over time.

Although accounts within the OAF can be selected depending on the questions and targets to be addressed, there are clear initiation points of the accounting processes that align with the accepted or established accounting systems. For example, policy demand could prompt the compilation of marine ecosystem accounts from an environmental perspective, natural capital accounts from a resource-use and supply perspective, or ocean economy satellite accounts from an economic perspective. Additionally, the novel ocean accounts areas extending existing international standards (i.e., social, pressure, risk, impact, or governance accounts) still depend on compiling at least one established accounting system.

This paper presents a concise stepwise approach to start the development of ocean accounts. It draws on the Global Ocean Accounts Partnership Technical Guidance for Ocean Accounts (GOAP, 2021a) and is complemented by adaptations to the guidance proposed and validated by the African Community of Practice (ACoP), resulting from practical experience through the implementation of ocean accounts across the WIO region. To fully understand how to develop and use ocean accounts, it is recommended that the GOAP Technical Guidance for Ocean Accounts is consulted, which details how to apply the statistical framework, integrate information, and use the results to address policy priorities.

Key initial steps

Certain initial and iterative steps (Fig. 2) are required before implementing ocean accounts and initiating the compilation of information. *Step I is the engagement with stakeholders* to define and identify the focus and scope of the accounting process (similar to the development of most ocean governance tools). The formulation and/or the identification of policy priorities and/or governance gaps to be addressed and the selection of the accounting area (as defined by policy needs or existing jurisdictional boundaries) is a priority. Additionally, depending on the scope, this step may require identifying ecosystems, ecosystem services and natural capital assets; determining resource uses, economic sectors and activities, supply and use of natural, built, and human capital;

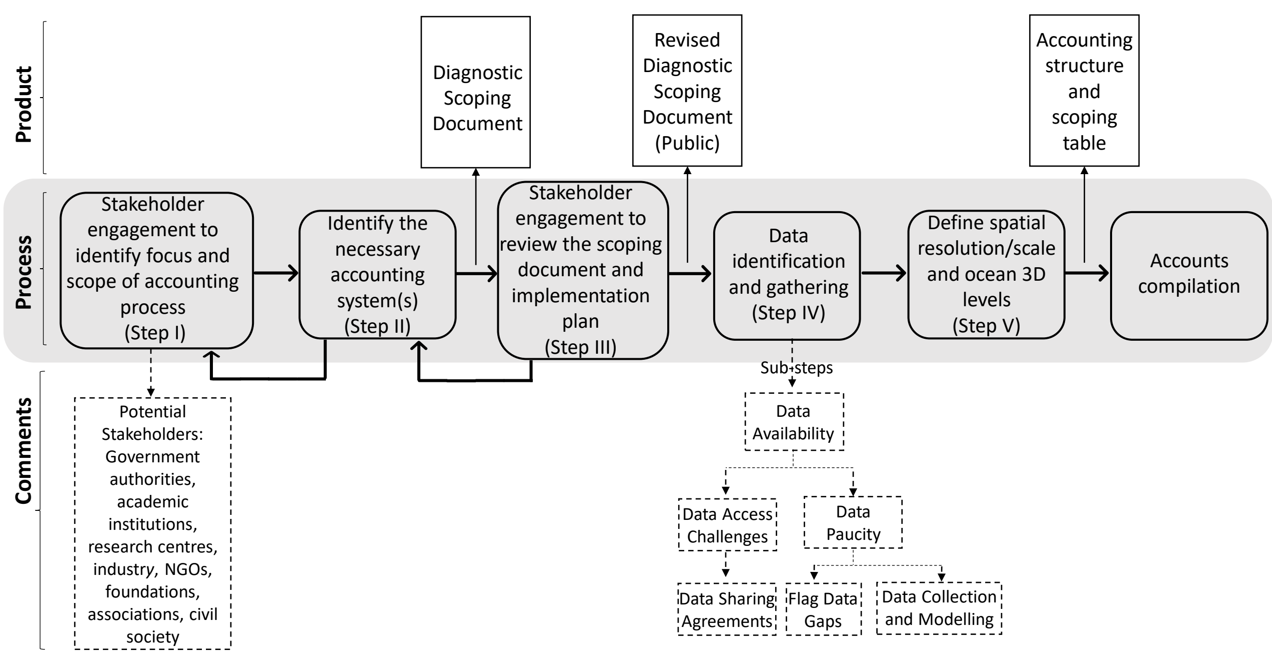

Figure 2. Initial and iterative steps before compiling the information for incorporation into selected ocean accounts. The blocks in the grey area evidence each step of the initial process (before the implementation of ocean accounts *per se*). Product blocks represent the outputs of specific steps. Comments and sub-steps are identified below in the dashed blocks.

and identifying and quantifying pressures, risks and impacts of resource use activities.

In Step II, the accounting systems (within the OAF) that require consideration to address the focus and scope (defined in step I above) in an integrated manner is identified. This includes the scoping and scaling of the process and selection of the top-down (economic demand use-driven) *vs* bottom-up (environment supply-driven) approaches.

Steps I and II conclude in a diagnostic scoping document that outlines the road map for the ocean accounting process outlined by the Ocean Accounts Diagnostic Tool (Supplementary Table SM3). This diagnostic tool guides a structured dialogue among data users, data producers and data holders to advance the strategic implementation of ocean accounts (GOAP, 2021b). Of particular importance is the recognition that the value of ocean accounting is critically boosted by the continuity and repeatability of accounting periods, resulting in ongoing indicators.

In Step III, there is another process for engaging with stakeholders to identify the components, subcomponents, assets, ecosystem services, and flows of ocean economy resource-uses and activities and facilitate two-way information flows of input data gathering and output product sharing. This engagement should provide stakeholders with a 'voice' to instil public and citizen confidence in the process while opening space for a bottom-up perspective that includes indigenous knowledge and values (Gacutan *et al.*, 2022).

Step III results in a Public Scoping Document (identified as the revised scoping document) that reviews and adapts the diagnostic scoping document (from steps I and II) to ensure that all the necessary activities and resources-uses are included.

Step IV is a comprehensive data identification and collection exercise, including identifying data availability, scarcity, and access challenges to address the relevant scope of the accounting process. Where data paucity is identified, data gaps must be flagged, and data collection and modelling can fill critical gaps. For example, physical and biogeochemical features (e.g., waves and currents, vertical convection, temperature, depth, species abundance) can be obtained through remotely sensed data or numerical modelling and can be further used to define ecosystem typology or condition, quantify assets, evaluate pressures, etc. (Moore *et al.*, 2019; Chai *et al.*, 2020). However, it is also important to recognise that developing such models can be challenging due to the dynamic and irregular quality of ocean characteristics and because model construction, reliability and validation are also data-dependent (Fujii *et al.*, 2019). The feasibility of data collection must also be assessed and the methodology defined. Where data access is an obstacle, data sharing agreements (including consideration of proprietary data) may be used to overcome such challenges. Integral within this step is identifying the available data architecture and software to accommodate big ocean data and liaising with global ocean accounting practitioners to draw on their data management experiences to ensure data architectural availability and compatibility.

Finally, in Step V, the spatial resolution and scale of available data required for accounting are defined. This includes the three-dimensional approaches to ocean resolution, e.g., surface, water column, and seafloor, or epipelagic, mesopelagic, bathypelagic, abyssal-pelagic, and hadopelagic, among other appropriate level definitions. Of particular importance is the establishment of relevant basic spatial units[1] (BSUs) at the appropriate spatial scale, bearing in mind that coarser resolution through aggregation has advantages over disaggregation.

Steps IV and V should result in a clear scoping table that identifies the diagnostic scoping process and the public process (Supplementary Table SM4). These final steps should also result in defining the accounting structure and identifying the systems and flows that will be incorporated into the process. It is important to bear in mind that the defined accounting systems used within the framework may need to be expanded, and other accounting systems might need to be integrated with time. In addition, it is critical to prioritise appropriate metadata approaches and strategies to ensure confidence in data used during steps IV and V.

Potential entry points for developing ocean accounts

Each of the accounts encompassed by the OAF can be compiled individually or as part of a set of selected accounts, depending on the particular policy questions or governance needs to be addressed. This allows for the definition of specific indicators that are relevant to different processes and goals. The integration between accounting systems depends

[1] the smallest spatial element underlying the accounting process.

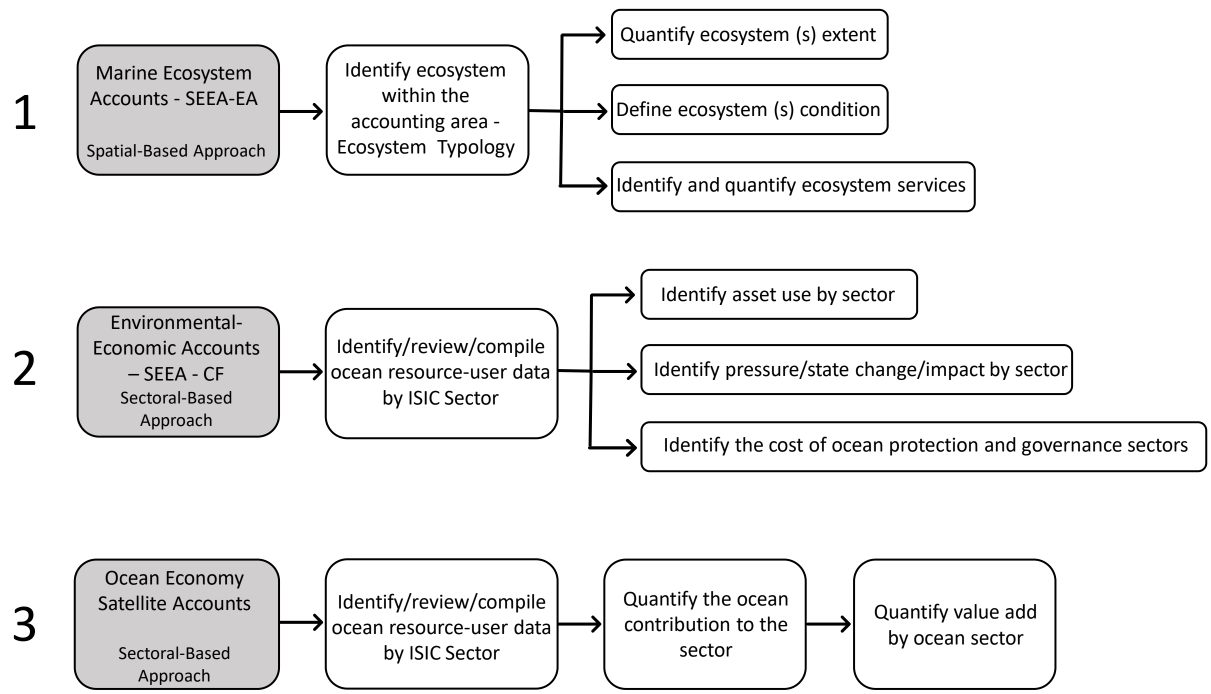

Figure 3. The three possible entry points (grey boxes) to compile ocean data through the ocean accounts framework for the WIO region. System of Environmental-Economic Accounts – Ecosystem Accounts (SEEA – EA); Environmental-Economic Accounts – Central Framework (SEEA – CF); International Standard Industrial Classification of All Economic Activities (ISIC).

on identifying flows between the different accounting systems being compiled, enabling the conversion of information, such as from physical natural capital supply flows to monetary economic supply flows. Accordingly, different accounting systems can be used as starting points for developing an ocean accounts, and the steps to be followed depend on the accounts to be compiled (Fig. 3).

It is recommended that one of the already established statistical standards encompassed by the OAF is utilised as a starting point, as those have specific and well-defined guidelines: Marine Ecosystem Accounts, Environmental-Economic Accounts, or Ocean Economy Satellite Accounts.

Marine Ecosystem Accounts

This starting point can be prioritised when the governance gaps or policy questions to be addressed are related to natural capital and profit being carried out at a spatial scale. It enables identifying and quantifying the stocks of natural resources and the flows of goods and services from ecosystems to society. Following the OAF guidelines, these flows can be further linked to economic, social, governance and risk components. The approach described in this section (Fig. 4) is an ocean-focussed adaptation of the SEEA - EA guidelines (UNSD, 2021), and further details can be found in the original document and at the GOAP Technical Guidance on Ocean Accounting (GOAP, 2021a). The SEEA - EA, as a subset of environmental-economic accounting, follows international standards to monitor the ecosystem's extent and condition and their supply of ecosystem services to sectors of the economy, government and households.

The steps for the Marine Ecosystems Account are presented below:

a. Define the ecosystem accounting area for which the information will be compiled.

b. Identify the ecosystem types occurring in the accounting area within each BSUs. Ideally, qualifying ecosystem typologies require empirical biophysical data that consider the highly dynamic nature of ocean processes, the porosity of ocean boundaries and the three-dimensional nature of the ocean space. Accordingly, ecosystem typology can use two complementary approaches: oceanographic biophysical and geochemical characteristics (empirical or modelled) or Earth Observation (EO) approaches by analysing satellite imagery and related ground-truthing. Although using EO

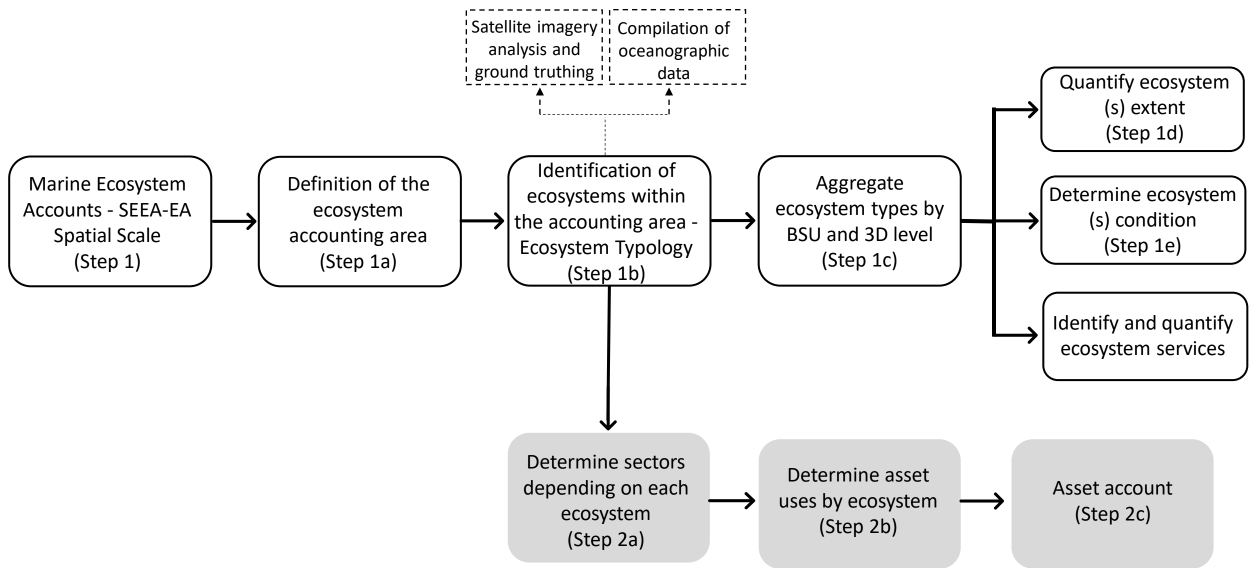

Figure 4. Stepwise approach for the development of Marine Ecosystem Accounts. Each step is defined by a block (solid line). The dashed blocks represent potential ways of classifying ecosystem types. Grey blocks represent steps linked to the System of Environmental-Economic Accounts – Central Framework (SEEA - CF) component of Environmental accounts. System of Environmental-Economic Accounts – Ecosystem Accounts (SEEA – EA); Basic Spatial Unit (BSU).

approaches requires skilled professionals that may not be available, partnering with regional and international organisations and prioritising capacity building in this area can help overcome this challenge. Moreover, whilst ground truthing can be expensive, the costs and time investment associated to *in loco* ecosystem mapping would be much higher. The IUCN Global Ecosystem Typology (Keith *et al*., 2020) allows for consistency across accounting processes in different accounts compilation. It is also important to consider consistency in typology with the SEEA – CF, Land Accounts, and the SEEA – EA ecosystem extents for terrestrial and freshwater ecosystems. When using oceanographic data, it is necessary to compile and interrogate biophysical ocean variable data (either empirical and/or modelled) (see, for example, the Global Ocean Observing System (GOOS) Essential Ocean Variable (EOV) categories provide a comprehensive array of the types of data that may be incorporated) to assess data availability at observed and modelled scales (Supplementary Table SM5, column 1 for each BSU). These variables should be compiled within a consistent time frame (e.g., quarterly, as in Supplementary Table SM5 (line 8) for variables expected to have temporal variation (e.g., temperature)) and for each of the BSU 3D levels considered in the study. The 3D levels should be defined at a relevant scale, with as many levels as required to address the accounting scope (e.g., Surface, Epipelagic, Mesopelagic, Bathypelagic, Seafloor).

c. Aggregate the ecosystem typology information by 3D level and BSU (Supplementary Table SM6). The ecosystem types identified may be composed of discrete and isolated patches. Depending on the focus and scope of the accounting process, such patches may be aggregated in different management units of the same ecosystem type, thus having their information compiled individually.

d. Quantify and evaluate the extent (as a measure of stock) of each ecosystem type identified (and ecosystem type unit when relevant) by 3D level and BSU (Supplementary Table SM7). Ecosystem extent is commonly measured in terms of area (e.g., km^2, ha), but other measurement units can be defined (e.g., volume). After that, the extent of each ecosystem is consolidated through the aggregation by type (and type unit where necessary) for the accounting period (Supplementary Table SM8), with the opening account arising from the closing account of the previous period.

e. Evaluate the opening and closing condition (as a relative measure of change) of each ecosystem type (and type unit) for the opening and closing accounting period (Supplementary Table SM9). The condition can be qualified using various parameters that can be defined according to the information available and the characteristics of each specific ecosystem type. Examples include developing indicators based on biotic and abiotic attributes through various frameworks (Smit *et al.*, 2021).

The SEEA – EA includes ecosystem services accounts in which each ecosystem's physical and monetary supply of ecosystem services in the accounting area are identified and quantified. This step is not described here, but further information can be obtained from the SEEA – EA guidelines (UNSD, 2021).

Environmental-Economic Accounts (aligned to the SEEA – CF)

The compilation of environmental-economic accounts aligned to the SEEA – CF enables the quantification of monetary and physical aspects of natural or non-produced material supply (e.g., wild fish) to the economy (La Notte and Rhodes, 2020). Commencing through this component should be prioritised when identifying and quantifying the use or depletion of natural resources (renewable or non-renewable) and the costs of management activities by economic sectors. This approach focuses primarily on discrete environmental assets and their relationship to the economy (as opposed to the focus on ecosystem assets through the SEEA - EA), identifying and quantifying: 1. stocks and flows of ocean assets (e.g., fish); 2. the positive input flows of residuals from economic sectors to the environment, allowing the identification of pressures resulting from such flows and the linkage among these pressures to ecosystem condition and extent changes (as part of the Ecosystem Accounts- Step 1); and 3. the expenditure of countries on ocean protection and governance as Environmental Activity Accounts. Notably, as this approach also identifies pressures and their connection to governance tools, it evaluates policy efficacy, contributing to adaptative policy cycles. Accordingly, when starting the compilation by environmental-economic accounting, it is possible to link the natural capital asset used by economic or other human activity, to the ecosystems and spatial units related to the provisioning of each asset, thus connecting this step to step 1 above (Fig. 5).

The steps for the Environmental-Economic Account are presented below:

a. Identify spatially determined sectors of the ocean economy by the International Standard Industrial Classification of All Economic Activities (ISIC) code (UNSD, 2008) using or potentially using resources from each ecosystem type (and type unit) by BSU and 3D Level (Supplementary Table SM10). Furthermore, non-market sectors and non-use values should be included, even if their value is qualitative instead of quantitative (e.g., bequest value of heritage sites or dugong populations).

b. Determine the environmental assets provided to each resource-use sector by ecosystem type responsible for supporting them (Supplementary Table SM11). Non-market assets (i.e., consumed by people but not traded in markets) such as wildlife viewing, snorkelling, or surfing can also be identified and related to the ecosystem type, BSU and BSU level supporting them.

c. Account for the environmental assets by quantifying opening stock, alterations and closing stocks as a percentage in each ecosystem related to the asset's maintenance and/or production (Supplementary Table SM12). For example, the ecosystem contributions to a fish stock may hypothetically extend across estuarine (nursery habitat), pelagic water column (feeding habitat) or subtidal reef (breeding habitat).

d. Identify the environmental assets used ("economically produced") by each economic sector and specific industry, quantify their stocks (e.g., a fish stock assessment), the resource use allocation (e.g., a fish stock total allowable catch (TAC)) and supply (e.g., catch) to the economic sectors and industry evaluated (Supplementary Table SM13). Note that this will result in a table for each asset contributing to a specific sector and/or industry.

e. Identify the produced and human capital, intermediate consumption, and natural capital utilised by economic sectors and subsectors. Such capital utilisation indicates "effort" utilised in resource supply (Supplementary Table SM14). The costs of resource-use components and the asset use of 2b (physical and monetarised values) may be incorporated to identify contributions to resource rents.

f. Accounting for economic sector risks to the environment can be performed by identifying and determining residuals and / or pressures arising from each resource use sector specified in step 2a (linked to Supplementary Table SM10). This

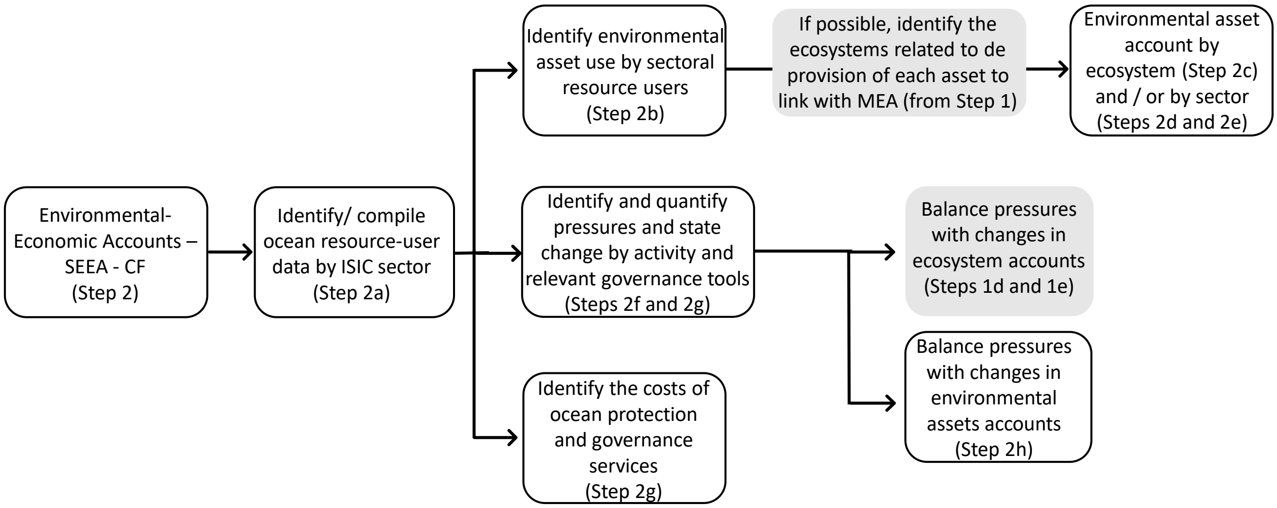

Figure 5. Stepwise approach for developing Environmental Economic Accounts aligned to the System of Environmental-Economic Accounting – Central Framework (SEEA – CF). Each step is defined by a block (solid line). Grey blocks represent a possible way of expanding this component, linking them to other systems of the Ocean Accounts Framework, e.g., Marine Ecosystem Accounts (MEA).

step can be expanded using the Driver-Pressure-State-Impact-Response (DPSIR) conceptual framework or another framework from its family, such as the DAPSI(W)R(M), which includes **D**rivers of basic human needs that require **A**ctivities that lead to **P**ressures and consequently to **S**tate change on the natural system, thus leading to **I**mpacts (on human **W**elfare), requiring **R**esponses (as **M**easures) (Elliott *et al.*, 2017) physicochemical processes and socio-economic systems. An increase in competing marine uses and users requires a holistic approach to marine management which considers the environmental, economic and societal impacts of all activities. If managed sustainably, the marine environment will deliver a range of ecosystem services which lead to benefits for society. In order to understand the complexity of the system, the DPSIR (Driver-Pressure-State-Impact-Response. These frameworks are used to identify the relationships between human activities and ecosystems (i.e. social-ecological systems), link the causes and effects of processes and their management, as well as the resulting (or potential) outcome of policies (Elliott and O'Higgins, 2020). In this guide, following the DAPSI(W)R(M) model, it is considered that ocean resource use activities (i.e., sectors and industries) lead to pressures on marine and coastal ecosystems (e.g., pollution, overfishing, introduction of exotic species). Such pressures are the agents of state change to natural systems that result in impacts on social systems. Accordingly, the following broad categories of state change and impact are identified: 1. Loss of Ecosystem Structure, Function or Productivity (EP); 2. Biodiversity Loss (B), or 3. Provisional, Regulatory or Cultural Ecosystem Service Loss (ES) (Supplementary Table SM15). Notably, information on such state changes and impacts depends on recurrent environmental monitoring or assessment as part of the accounting process. When linking this component of the SEEA-CF to the SEEA-EA through the OAF, it becomes possible to identify and measure the flows from the economic pressures (as pressure flows) to the environment and specific ecosystems and assets by identifying the activities that affect ecosystem extent (Supplementary Table SM8) or condition (Supplementary Table SM9), as well as associated asset stocks. Pressures (including residuals) and impacts may be linked to governance tools and support the assessment of their efficacy in pressure, status change and impact mitigation, and social accounts by identifying the implications of such pressures and state change on human welfare (qualitatively and / or quantitatively).

g. Quantify (if possible) pressures identified in step 2f.

h. Balance (if possible) pressure identified in step 2f with changes in ecosystem condition or extent (steps 1d and 1e) and environmental assets accounts (step 2b).

Environmental activity accounts under the SEEA-CF can be used to measure the costs, benefits and efficacy of environmental management and protection by identifying the "spend" on environmental management practices and requirements to address anthropogenic pressures / state changes identified in step 2f and, or any natural disaster change – such changes may be intertwined where there are anthropogenic drivers of natural change. Such "spend" may include, for example, the non-commercial maritime services of education, training and research technology and innovation, ocean governance activities, defence and maritime security, marine protection services, maritime information and communication service, safety at sea and environmental remediation services.

Ocean Economy Satellite Accounts (OESA)

The OESA uses the same principles and structures of the SNA but provides a discrete group of exclusive ocean-related sector accounts (Colgan, 2016). As such, this component is a good starting point when requiring economic metrics to quantify the contribution of ocean sectors to the economy to support decisions about investment, spending, and macroeconomic management. This component of the OAF provides macroeconomic indicators that are essential to measure and track the economic component related to the ocean's economic contribution to the industry sectors. Accordingly, the relevant steps of the Ocean Economy Satellite Accounts are as below (Fig. 6):

a. Identify sectoral-determined market resource supplies to economic sectors arising from consumptive and non-consumptive use of living and non-living resources as ISIC-defined sectors (UNSD, 2008) and Central Product Classification products (UNSD, 2015).

b. Balance sectors and products of step 5a with steps 2a and 2b.

c. Develop an ocean economy Supply and Use table (SUT) for ocean industry sectors/products (Supplementary Table SM16) from existing monetary SUTs of the System of National Accounts (SNA) to determine sectoral gross value add (GVA) and gross output of ocean sectors over the accounting period (Supplementary Table SM16).

d. Develop appropriate Input-Output tables (IOTs) for the ocean industry sectors / products from the SUTs of step 5c (Supplementary Table SM17). This step will require the development of a production matrix and use tables for imports and domestic outputs and their transformation to IOTs based on technology or sales structure assumptions. The selection of the type of IOTs (product by product versus Industry by Industry) depends on the objective of economic analysis.

e. Develop computable general equilibria (CGE) models for analyses dependent on ocean decision support requirements (for example, the development of scenario planning for Marine Spatial Planning needs). This optional step enables the advancement of a descriptive assessment to an analytical approach.

f. Align SUTs and IOTs with physical supply identified within the SEEA – CF accounts (Step 2b) to develop Physical Supply and Use tables (PSUTs) (Supplementary Table SM18) and other potentially relevant tables

After starting the compilation of information through the OAF by any of the three entry points mentioned above, it is possible to expand to other accounts of the OAF according to the specific needs and priorities motivating the accounting exercise. It is possible to add different information and improve the reliability

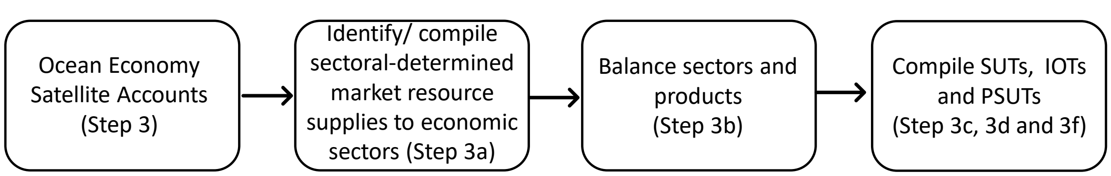

Figure 6. Stepwise approach for developing Ocean Economy Satellite Accounts. Supply and Use table (SUTs); Input-Output tables (IOTs); and Physical Supply and Use table (PSUTs).

of the statistics and indicators generated over time. The critical aspect is to ensure that the data is entered coherently to keep the links between the systems and enable spatial and temporal comparisons.

Conclusions

The importance of the ocean to humans is undeniable. Accordingly, it is crucial to shift many processes towards sustainable and inclusive strategies for the ocean's economic development, thus maintaining coastal and marine ecosystems' structure and functioning, ocean health, and pursuing the equitable provision of ecosystem services from which humans benefit. That is highlighted within the WIO region by the various blue economy programmes and initiatives under implementation, for instance, the Go Blue[2] partnership in Kenya, the ProAzul[3] in Mozambique, the Mauritius Blue Economy Initiative, the Seychelles National Blue Economy Strategic Framework and Roadmap[4], the three IORA Blue Economy declarations[5], and others (Elza, 2016, Doyle, 2018, Overbeeke *et al*., 2022).

Within such a "Blue Economy" transformation, where local, national, regional, global and even international organisations aim at prioritising ocean sustainable development, it is necessary to weigh and manage various (often conflicting) interests (Bennett, 2018). This complex task requires evidence-based and adaptative ocean governance underpinned by multidisciplinary indicators (Brodie Rudolph *et al*., 2020, Voyer *et al.*, 2021) such as those provided by ocean accounting. Implementing ocean accounts is critical to supporting long-term and well-distributed use of ocean opportunities through a consistent, standardised, holistic framework that integrates environmental, social, and economic data. As such, the OAF supports a process for monitoring drivers of change (including climate change and ocean resource use) and how they affect the environment, economy and society. This includes their current effects and impacts, the extended (or prolonged) consequences, and how decisions now affect future opportunities. The OAF also underpins tracking and reporting on the progress toward achieving the SDGs. Such a framework for accounting also supports strategic and planning decisions and the choice of appropriate investments for sustainability. Finally, an OAF supports regulatory decision-making, including the grant of concessions, permits and licenses for ocean-related activities; and the evaluation of cost-benefit trade-offs. Accordingly, implementing OA enables the long-term monitoring of ocean health and wealth.

Bearing in mind the emerging use of ocean accounts in the WIO region, this stepwise guide facilitates the implementation of national ocean accounts. It identifies potential entry points for the implementation of ocean accounting and explains how to compile and integrate marine ecosystem accounts, natural capital accounts and OESA. Novel systems are being piloted, and the processes for their implementation will be described in future publications. Additionally, due to the modular nature of the OAF, countries that already have accounting programmes in place can use them as a starting point to further advance ocean accounting. Examples in the WIO region include the development of Natural Capital Accounting in Madagascar and South Africa (Driver *et al.*, 2015, Onofri *et al.*, 2017), the evaluation of the ocean economy in Mauritius (Scandizzo *et al*., 2018), and blue carbon accounts in Tanzania and Mozambique (Gullström *et al.*, 2021). The selection of the entry point will, of course, depend on aspects such as the policy questions or governance gaps to be addressed (following a demand-driven workflow), local capacity, data and infrastructure available (data-driven workflow), stakeholder engagement and input (particularly on the initial iterative steps (Fig. 2)), programmes already in place, etc. (GOAP, 2021a).

The implementation of ocean accounts presents challenges such as those related to data (availability, accessibility, sensitivity, sharing and acquisition – particularly from often silo'ed data holders), stakeholder engagement and the lack of human capacity and appropriate experience across all environmental, economic and social domains (Halderen *et al.*, 2020). To identify solutions to arising issues, overcome challenges and improve the framework, the GOAP supports the development of several ocean accounts pilot studies around the globe and promotes collaboration, information exchange, and partnership. Through these pilots, some enabling factors for successful implementation were identified and included the careful execution of the initial iterative steps in collaboration with various stakeholders, the production of a comprehensive scoping report, and the prioritisation of an initially small focal area to be further scaled up.

[2] https://www.goblue.co.ke/

[3] https://www.proazul.gov.mz/

[4] https://seymsp.com/resources/blue-economy-roadmap/

[5] https://www.iora.int/en/priorities-focus-areas/blue-economy

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Supplementary Material

Table SM1. Established accounting systems and satellite accounts relevant to ocean systems. Source: OECD Glossary of Statistical Terms (https://stats.oecd.org/glossary/index.htm). *Not defined within the OECD Glossary for Statistical Terms; definition based on Jolliffe *et al.* (2021) and Chang *et al.* (2021).

Term	Acronym	Definition
System of National Accounts	SNA	The internationally agreed standard set of recommendations on compiling measures of economic activity. The SNA describes a coherent, consistent, and integrated set of macroeconomic accounts in the context of a set of internationally agreed concepts, definitions, classifications, and accounting rules.
System of Environmental-Economic Accounting	SEEA	The System for integrated Environmental and Economic Accounting is a satellite system of the SNA that comprises four categories of accounts. The first considers purely physical data relating to flows of materials and energy and marshals them as far as possible according to the accounting structure of the SNA. The accounts in this category also show how flow data in physical and monetary terms can be combined to produce so-called “hybrid” flow accounts. Emissions accounts for greenhouse gases are an example of the type included in this category. The second category of accounts takes those elements of the existing SNA which are relevant to the good management of the environment and shows how the environment-related transactions can be made more explicit. An account of expenditures made by businesses, governments, and households to protect the environment is an example of the accounts included in this category. The third category of accounts in the SEEA comprises accounts for environmental assets measured in physical and monetary terms. Timber stock accounts showing opening and closing timber balances and the related changes over the course of an accounting period are an example. The final category of SEEA accounts considers how the existing SNA might be adjusted to account for the impact of the economy on the environment. Three sorts of adjustments are considered: those relating to depletion, those concerning so-called defensive expenditures and those relating to degradation.
Satellite Account	-	Satellite accounts provide a framework linked to the central accounts and enable attention to be focussed on a certain field or aspect of economic and social life in the context of national accounts; common examples are satellite accounts for the environment, tourism, or unpaid household work.
Ocean Economy Satellite Account*	OESA	A satellite account that measures all economic activity directly dependent on oceans, including activities that use ocean resources as an input (e.g., fishing), produce products and services for use in the ocean environment (e.g., shipbuilding) and depend on the ocean due to geographic proximity (e.g., coastal tourism, warehouses that service ports).
Tourism Satellite Account	TSA	Provides a basic system of concepts, classifications, definitions, tables, and aggregates linked to the standard tables of the 1993 System of National Accounts from a functional perspective. This system has been developed to measure tourism’s economic impacts on a national economy on an annual basis.

Table SM2. Summary of the groups of stock and flow tables used by the Ocean Accounts Framework (OAF). Source: GOAP (2021).

Table Group	Summary
Environmental asset* (natural capital)	Records the physical status and condition, and monetary value of environmental assets (natural capital), including minerals and energy, land and soil, coastal timber, aquatic resources, other biological resources, water, and ecosystems, including biodiversity. *For the OAF, the environmental assets are focused on marine and coastal (ocean) assets.
Flows to economy (supply and use of ocean services, including goods)	Records inputs from marine and coastal environmental assets to the economy, including ocean-related materials (abiotic and biotic), energy, water, and ecosystem services. These inputs can be recorded in terms of physical quantities and monetary value.
Flows to environment (residuals including ecosystem impacts)	Records, in physical units, the outputs from the economy to the ocean environment, including solid waste, air emissions, water emissions, and impacts on ecosystems.
Ocean economy (as a contribution to the broad economy)	Records the monetary value of production, consumption, accumulation, imports, and exports in economic sectors deemed relevant to the ocean and non-market services in comparison to the broad economy (e.g., national economy). The economy is reflected in the Ocean Accounts as users of ocean services and suppliers of residuals (pollutants) and activities that affect the ocean.
Governance	Records a range of information (physical status, monetary value, and/or qualitative status) concerning collective decision-making about oceans, and the wider social and governance context in which such decisions are made. The information recorded in governance tables includes the status and/or value of protection and management of ocean environment, the "environmental" goods and services sector of the ocean economy; relevant taxes and subsidies; applicable laws and regulations; health, poverty and social inclusion; risk and resilience; and ocean-related technologies. Inclusion of health, poverty, and risk management may require a separately identified social account to address inclusivity within the overall account framework.
Combined presentation	Records a "report card" of summary information (physical quantities, monetary value, and/or qualitative status) and indicators concerning the flows of benefits and costs (the latter broadly defined as maintenance and restorations costs, disservices and externalities) between the ocean environment and the economy. This information includes but is not limited to: the share of Gross Value Added / Gross Domestic Product attributable to the ocean economy; ocean resource rents; depletion, degradation and adjusted net savings relevant to oceans; contributions of oceans to human well-being (employment, sense of place) that are not recorded in the SNA; and relevant information concerning health, poverty and social inclusion.
Ocean wealth	Records summary information (in terms of physical quantities and/or monetary value) concerning a country's (or other region's) stock of ocean wealth, including relevant stocks of environmental assets recorded on a SEEA balance sheet; economic/financial assets recorded on an SNA balance sheet; a subset of environmental assets that are defined as "critical" according to agreed criteria; the resource life of environmental assets; and relevant societal assets such as education and health systems.

Table SM3. Ocean Accounts Diagnostic Tool (Version 3, June 4, 2021). Source: https://www.oceanaccounts.org/ocean-accounts-diagnostic-tool/

Diagnostic Component	Practical Actions
Statement of Strategy and Policy Priorities	Document national visions and priorities related to the ocean, the environment, biodiversity, sustainable development, and green/blue economy, including managing natural assets and flows of services from them.
	Link priorities to environmental concerns, such as pollution or overfishing.
Institutions	Identify stakeholders, including producers and users of related information (government agencies, academia, NGOs, international agencies), but also other groups such as civil society that can benefit from improved information.
	Identify relevant institutional mechanisms currently in place.
	Review the role of the National Statistical Office to highlight the advantages of integrating information and approaches across the National Statistical System.
Knowledge	Identify key national data sources that can be used as a basis for further development.
Progress	Understand what progress has already been made in developing ocean data, statistics and accounts, and other environment statistics and accounts.
Context	Identify related statistical development activities that could benefit (and benefit from) ocean accounts initiatives.
Priorities	Determine the priorities for action to develop selected ocean accounts.
Constraints and opportunities	Assess (a) constraints to implementing specific ocean accounts and (b) opportunities for immediate actions to address these constraints.

Table SM4. Example of a scoping table containing the general information about the accounting process. The reference to annexures in column two exemplifies the need to link this scoping table to other relevant detailed documentation. 'Accounting period' refers to the start (open) and end (closing) dates of the accounting process, while 'temporal resolution' refers to the frequency in which accounts will be performed (periodicity). 'BSU', in the section' spatial information' means 'basic spatial unit', and the spatial 3D Levels or Zones selected are examples as different depth levels may be chosen. Cells in grey are null (empty) by definition.

Accounts Information	
Account Name:	
Type of Account(s):	
Compiled by:	
Compiled for:	
Addressed Imperatives:	
Data Providers	
Datasets	
Stakeholders	
Area Description	
Northern Boundary:	
Western Boundary:	
Eastern Boundary :	
Southern Boundary:	
Coastal Buffer Inclusion:	
Accounting Period	
Open Date:	
Close Date:	
Temporal Resolution within accounting period (y/n):	
Spatial Information:	
Finest BSU Spatial Resolution:	
GIS Spatial Software Environment:	
Projection:	
Number of Spatial 3D levels:	
Spatial 3D Levels	**Depth**
Sea Surface	
Epipelagic	
Mesopelagic	
Bathypelagic	
Seafloor	
Sub-seafloor	

Table SM5. Raw data table of ocean biophysical variables applied for each basic spatial unit (BSU). The variables and their categories, the spatial 3D levels or zones, and the temporal interval selected are examples and may vary depending on the project scope.

BSU Number

BSU-All Levels

Biophysical Province:

Depth:

Substrate Type:

BSU Individual Levels

3D Level		Surface				EpiPelagic				MesoPelagic				Bathypelagic				SeaFloor				Sub-Seafloor			
Time frame		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Physical Variables	Ocean surface heat flux																								
	Ocean surface stress																								
	Sea ice																								
	Sea state																								
	3D Level height																								
	Salinity																								
	Temperature																								
	Currents																								
Biogeochemical Variables	Dissolved organic carbon																								
	Inorganic carbon																								
	Nitrous oxide																								
	Nutrients																								
	Oxygen																								
	Particulate matter																								
	Stable carbon isotopes																								
	Transient tracers																								
Biological Variables	Fish abundance and distribution																								
	Coral cover and composition																								
	Invertebrate abundance and distribution																								
	Macroalgal cover and composition																								
	Mangrove cover and composition																								
	Macrofauna abundance and distribution																								
	Microbe biomass and diversity																								
	Phytoplankton biomass and diversity																								
	Seagrass cover and composition																								
	Zooplankton biomass and diversity																								
Other	Ocean colour																								
	Ocean Sound																								

Table SM6. Ecosystem typology characterised at each basic Spatial Unit (BSU) and respective 3D level. Ecosystems separated in various disconnected patches were identified as individual units (u).

3D level BSU	Sea Surface	Epipelagic	Mesopelagic	Bathypelagic	Seafloor
1	Type 1 (u1)	Type 1 (u1)	Type 1 (u1)	Type 1 (u1)	Type 1 (u1)
2	Type 3	Type 3	Type 2	Type 2	Type 2
3	Type 4	Type 4	Type 4	Type 4	Type 4
4	Type 1 (u2)	Type 3	Type 3	Type 3	Type 3
5	Type 1(u2)	Type 1(u2)	Type 1(u2)	Type 1(u2)	Type 1(u2)
6	Type 1(u2)	Type 1(u2)	Type 1(u2)	Type 1(u2)	Type 1(u2)
7	Type 3	Type 3	Type 2	Type 2	Type 2
8	Type 4	Type 4	Type 4	Type 4	Type 4
9	Type 2	Type 4	Type 4	Type 4	Type 4
10	Type 2	Type 4	Type 4	Type 4	Type 4
11	Type 2	Type 4	Type 4	Type 4	Type 4
12	Type 1(u2)	Type 1(u2)	Type 1(u2)	Type 1(u2)	Type 1(u2)
13	Type 3	Type 3	Type 2	Type 2	Type 2
14	Type 3	Type 3	Type 2	Type 2	Type 2
15	Type 4	Type 4	Type 4	Type 4	Type 4
16	Type 3	Type 2	Type 2	Type 2	Type 2
17	Type 4	Type 4	Type 4	Type 4	Type 4
18	Type 4	Type 4	Type 4	Type 4	Type 4
19	Type 2	Type 4	Type 4	Type 4	Type 4
20	Type 1(u3)	Type 1(u3)	Type 1(u3)	Type 1(u3)	Type 1(u3)

Table SM7. Ecosystem extent accounts of each ecosystem type identified at the accounting area by 3D level and basic spatial units (BSUs). Ecosystems separated in various disconnected patches were identified as individual units (u).

3D level (e.g., Sea Surface)			
Ecosystem Type	**BSU**	**Extent (km²)**	**Total Extent**
Type 1 (u1)	1		
Type 1 (u2)	4		
	5		
	6		
	12		
Type 1 (u3)	20		
Type 2	9		
	10		
	11		
	19		
Type 3	2		
	7		
	13		
	14		
	16		
Type 4	3		
	8		
	15		
	17		
	18		

Table SM8. Ecosystem extent accounts for each ecosystem type's opening and closing stocks identified in the accounting area. Ecosystems separated in various disconnected patches were identified as individual units (u). Examples of factors affecting additions and reductions to opening and closing extent stocks are provided.

	Ecosystem Types					
	Type 1 (u1)	Type 1 (u2)	Type 1 (u3)	Type 2	Type 3	Type 4
Opening stock						
Managed expansion						
Natural expansion						
Reclassifications						
Discoveries						
Reappraisals (+)						
TOTAL addition						
Managed regression						
Natural regression						
Reclassifications						
Extractions/harvesting						
Reappraisals (-)						
State change regression						
TOTAL reduction						
Closing stock						

Table SM9. Ecosystem condition accounts for each ecosystem type's opening and closing stocks identified in the accounting area. Ecosystems separated in various disconnected patches were identified as individual units (u). The opening and closing conditions of each specific indicator can also be determined.

	Ecosystem Types					
	Type 1 (u1)	Type 1 (u2)	Type 1 (u3)	Type 2	Type 3	Type 4
Opening condition						
Indicator 1						
Indicator 2						
Indicator 3						
Closing Condition						
Indicator 1						
Indicator 2						
Indicator 3						

Table SM10. The ocean market, non-market and resource use, and non-use value contributions of each ecosystem type are identified at the accounting area by basic spatial unit (BSU) and 3D level

BSU	BSU Level	Ecosystem Type		Market Uses				Non-Market and Non-Use Values		
			Sector	e.g., Fishing/ Aquaculture		e.g., Offshore oil and gas				
			Description	Marine Fishing	Marine Aquaculture	Extraction of crude petroleum	Extraction of natural gas	Direct Use	Indirect Use	Non-Use Value
			ISIC Code	0311	0321	0610	0620	e.g., Non-Market Recreation or cultural ecosystem services	e.g., Regulatory Ecosystem Services	Existence or Bequest Values
			Ocean share of the sector	Full	Full	Partial	Partial			
1	1									
1	2									
1	3									
1	4									
1	n									
2	1									
2	2									
2	3									
2	4									
2	n									
3	1									
3	2									
3	3									
3	4									
3	n									

Table SM11. Assets provided by each marine ecosystem type to advance ocean sector by BSU and 3D level.

BSU	3D Level	Ecosystem Type	Sector	e.g., Marine fishing			
			Industry	e.g., Trawl		e.g., Pelagic Purse Seine	
			Asset	Hakes	Kingklip	Sardine	Anchovy
1	1						
1	2						
1	3						
1	4						
1	n						
2	1						
2	2						
2	3						
2	4						
2	n						
3	1						
3	2						
3	3						
3	4						
3	n						

Table SM12. Environmental asset account with the opening and closing stocks at each ecosystem type that contributes to asset's maintenance and/or production. Ecosystems separated in various disconnected patches were identified as individual units (u). Examples of factors affecting additions and reductions to opening and closing stocks are provided.

		Ecosystem Type (may extend across ecosystem levels)					
		Type 1 (u1)	Type 1 (u2)	Type 1 (u3)	Type 2	Type 3	Type 4
Asset 1	**Opening stock**						
	Managed expansion						
	Natural expansion						
	Reclassifications						
	Discoveries						
	Reappraisals (+)						
	TOTAL addition						
	Managed regression						
	Natural regression						
	Reclassifications						
	Extractions/harvesting						
	Reappraisals (-)						
	State change regression						
	TOTAL reduction						
	Closing stock						

Table SM13. The extent and supply of natural capital assets to the economic sector. This table links the ecosystem supply of identified natural capital to economic supply or use by industry sectors in a natural capital accounting process. Cells that are grey shouldn't be filled.

Sector: e.g., Marine fishing Industry Asset: e.g., Wild fish	Stock / Asset extent	Resource Use Allocation	Resource Use = Economic Supply	Totals
Opening stock				
Managed expansion				
Natural expansion				
Reclassifications				
Discoveries				
Reappraisal Additions				
Total addition				
Managed regression				
Natural regression				
State change regression				
Reclassifications				
Reappraisals Reduction				
Extractions / harvesting				
Total reduction				
Closing stock				

Table SM14. Account structure for produced and human capital and intermediate consumption and natural capital assets utilised by economic sectors and industry. The balance of this account could identify the resource rent for the particular asset.

Sector: e.g., Marine Fishing Industry Asset: e.g., Wild fish	Human Capital	Built Capital	Intermediate Consumption	Resource Supply	Totals
Human Capital					
Opening Stock					
Additions					
Reductions					
Closing Stock					
Built Capital					
Opening Stock					
Investment					
Depreciation					
Closing Stock					
Intermediate Consumption					
Item 1					
Item 2					
Item 3					
Permitting and Licencing					
Fees					
Natural Capital					
Opening Stock					
Additions					
Resource Use					
Other Reductions					
Closing Stock					
Resource Rent					

Table SM15. Pressures and the resultant state change and impact from ocean resource use activities, the ecosystem indicators related to such factors and the identification of relevant governance tools. Illegal, unreported and unregulated fishing (IUU)

Activity	e.g., Marine Fishing	State Change/ Impact Categories		State Change/Impact Indicators			
				Ecosystem	e.g., Type 1 (ul)	Ecosystem	Type 2
Pressure		Ecosystem Structure, Function or Productivity Loss (EP); Biodiversity Loss (B), and/ or Provisional, Regulatory or Cultural Ecosystem Service Loss (ES).	Mitigation/ Management Plan and/or Governance Mechanisms in place (Yes/No) and identify Extent Change (Positive / Negative / Null)	Condition Change (Positive / Negative / Null)	Extent Change (Positive / Negative / Null)	Condition Change (Positive / Negative / Null)	
Chronic Production Pressures/Impacts							
1	**Extraction**						
1a.	Physical extraction						
1a1.	Freshwater extraction						
1b.	Biological extraction						
1b1.	Bycatch or Incidental						
1b2.	IUU						
2	**Pollution**						
2a.	CO^2 emission						
2b.	Chemical						
2c.	Acoustic						
2d.	Physical						
2e.	Light						
3	**Habitat Loss**						
3a.	Physical Habitat Loss						
4	Invasive Species						
4a.	Transport/Introduction						
4b.	Facilitation/Spread						
Acute Production Pressures							
5	**Pollution Events**						
5a.	Oil spill						
5b.	Hazardous Casualty						
5c.	Contaminants Runoff						
6	Habitat Loss Events						
Chronic Consumption Pressures							
7	CO^2 emission						
8	Waste Production						

Table SM16. Ocean Economy Supply and Use table (SUT) for ocean industry sectors and products. Cells that are grey shouldn't be filled.

<table>
<tr><th colspan="6">Supply</th></tr>
<tr><td></td><td>Domestic Industry Production</td><td colspan="2" rowspan="2">Import</td><td colspan="2" rowspan="2">Total</td></tr>
<tr><td></td><td>Industry Sector (e.g., by ISIC)</td></tr>
<tr><td>Product Types (e.g., by CPC)</td><td>Output by Product and by Industry</td><td colspan="2">Imports by Product</td><td colspan="2">Total Supply by Product</td></tr>
<tr><td>Total</td><td>Total Output by Industry</td><td colspan="2">Total Imports</td><td colspan="2">Total Supply</td></tr>
<tr><th colspan="6">Use</th></tr>
<tr><td></td><td>Intermediate Use by Industry Sector</td><td colspan="3">Final use by category</td><td rowspan="2">Total</td></tr>
<tr><td></td><td>Industry Sector (e.g., by ISIC)</td><td>Final Consumption</td><td>Gross Capital Formation</td><td>Export</td></tr>
<tr><td>Product Types (e.g., by CPC)</td><td>Intermediate Consumption by Product and Industry</td><td colspan="3">Final Uses by Product and by Category</td><td>Total Use by Product</td></tr>
<tr><td rowspan="4">Value Add</td><td>Wages</td><td colspan="3" rowspan="4"></td><td rowspan="4">Value Add</td></tr>
<tr><td>Taxes on Production</td></tr>
<tr><td>Operating Surplus</td></tr>
<tr><td>Total Value Add</td></tr>
<tr><td>Total</td><td>Total Output by Industry</td><td colspan="3">Total Final Use by Category</td><td></td></tr>
</table>

Table SM17. Product by product Input-Output table (IOT). Cells that are grey shouldn't be filled.

<table>
<tr><th></th><th colspan="3">Homogenous units of production</th><th colspan="3">Final Use Categories</th><th rowspan="2">Total Use</th></tr>
<tr><th></th><th>Sector 1 Products</th><th>Sector 2 Products</th><th>Sector 3 Products</th><th>Final Consumption</th><th>Gross Capital Formation</th><th>Exports</th></tr>
<tr><td>Sector 1 Products</td><td colspan="3" rowspan="3">Intermediate Consumption by Product and by Homogeneous Units of Production</td><td colspan="3" rowspan="3">Final Uses by Product and by Category</td><td rowspan="3">Total Use by Product</td></tr>
<tr><td>Sector 2 Products</td></tr>
<tr><td>Sector 3 Products</td></tr>
<tr><td>Value Added</td><td colspan="3">Value Added by Components</td><td colspan="3"></td><td></td></tr>
<tr><td>Imports for Similar Products</td><td colspan="3">Total Imports by Product</td><td colspan="3"></td><td></td></tr>
<tr><td>Supply</td><td colspan="3">Total Supply by Homogeneous Units of Production</td><td colspan="3">Total Final Use by Category</td><td></td></tr>
</table>

Table SM18. Example of a Physical Supply and Use Table (PSUT). Cells that are grey shouldn't be filled.

Supply							
		Industries Industry Sectors (e.g., by ISIC)	Imports	Final Consumption	Gross Capital Formation	Environment	Total
Products	Product types (e.g., by CPC)	Output produced by Industry	Imports by Product				Total Supply by Product
Natural Resource Uses	Consumptive Use of Living Resources					Flows from the Environment	Total supply of Natural Capital
	Non-consumptive Use of Living Resources						
	Use of Non-Living Resources						
	Ocean Space						
Pressure / Residual	Unsustainable Extraction	Pressures / Residuals generated by Industry		Pressures / Residuals generated by Final Consumption	Pressures / Residuals generated by Capital Formulation / Decommission	Flows to the Environment	Total "supply" of Pressures / Residuals
	Pollution						
	Invasive Translocations						
	Habitat Degradation						
	Climate Change						

Use							
		Industries Industry Sectors (e.g., by ISIC)	Exports	Final Consumption	Gross Capital Formation	Environment	Total
Products	Product types (e.g., by the Central Product Classification (CPC) Version 2.1)	Intermediate Consummation of Products by Industry	Final uses by Product and Category				Total Use by Product
Natural Resource Uses	Consumptive Use of Living Resources	Natural Capital Resource Use					Total Natural Capital Use
	Non-consumptive Use of Living Resources						
	Use of Non-Living Resources						
	Ocean Space						
Pressures / Residuals	Unsustainable Extraction	Mitigation of Pressures / Residuals generated by Industry			Accumulation of wastes / effluent		
	Pollution						
	Invasive Translocations						
	Habitat Degradation						
	Climate Change						

Supplementary material references:

Chang J, Jeong SB, Kim T J (2021) Development of Ocean Economy Satellite Account in Korea. Journal of Ocean and Coastal Economics 8 (2): 1-21. [doi: 10.15351/2373-8456.1148]

GOAP (2021) Technical guidance on ocean accounting v.1.0 — detailed guidance for account compilers, data providers and end users. Global Ocean Accounts Partnership [https://www.oceanaccounts. org/technical-guidance-on-ocean-accounting-2/]

Jolliffe J, Jolly C, Stevens B (2021) Blueprint for improved measurement of the international ocean economy: An exploration of satellite accounting for ocean economic activity. OECD Science, Technology and Industry Working Papers 2021/04, OECD Publishing, Paris. [doi: 10.1787/aff5375b-en]

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Any queries should be sent by e-mail to the Editorial Secretariat: wiojms@fc.ul.pt; jppaula@fc.ul.pt; mmcravo@fc.ul.pt.

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All manuscripts submitted to the Western Indian Ocean Journal of Marine Science are accepted for consideration on the understanding that their content has not been published elsewhere and is not under consideration by any other journal. Manuscripts and all illustrations should be prepared according to the instructions provided below. Submissions will be subject to a pre-review by the Editor-in-Chief or a member of the Editorial Board and those that fall within the remit of the journal, make a substantial contribution to the field of research, and are in the correct style and format, will be sent for review. Manuscripts that do not meet these criteria will be rejected. Every manuscript will be double-blind reviewed by at least two referees competent in the field of interest.

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[1] https://www.ajol.info/index.php/wiojms/login

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- Files of maps (pdf, tiff or jpeg) in high resolution.

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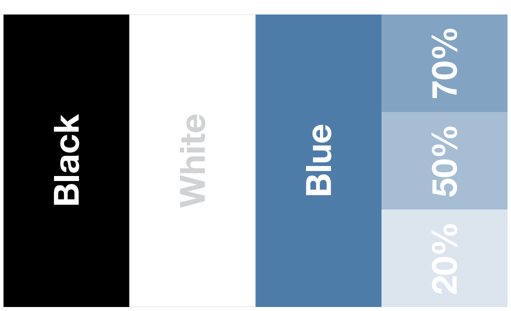

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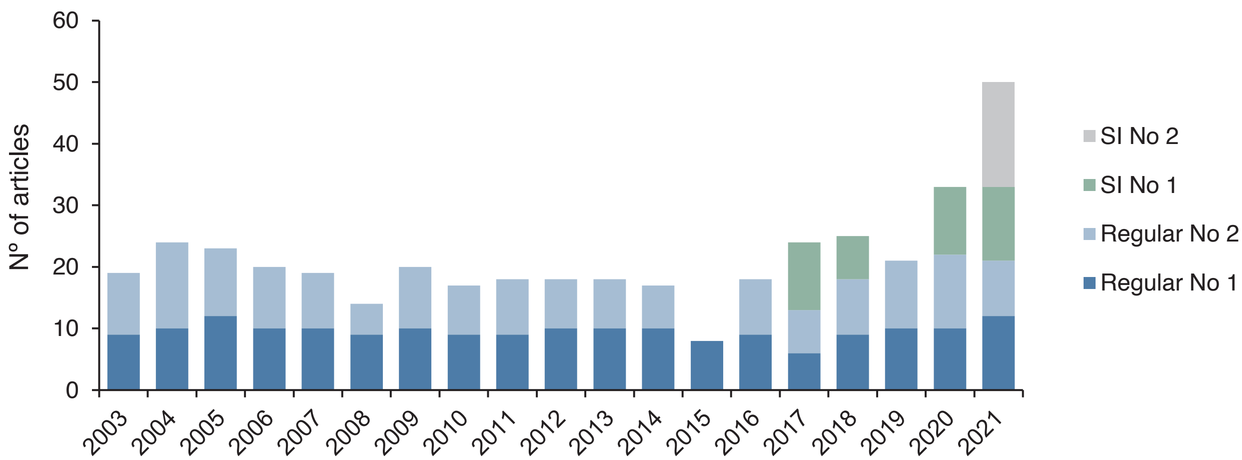

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