



An introduction to East African Coastal Current ecosystems: At the frontier of climate change and food security

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ABSTRACT

East African marine waters, particularly those impacted by the East African Coastal Current, have a reputation for data sparsity that presents significant challenges to efforts to develop, implement, and operate effective management and governance structures to sustainably manage fisheries and the marine environment. As many coastal communities are dependent upon the ocean for livelihoods and sustenance marine resources are a central component of regional food security. However, the growing challenge of increased food insecurity in response to growing human populations, increased pressures on marine resources and the impacts of climate change is significant and improved knowledge about the marine environment is urgently required to better support decision making efforts to address this challenge. In this introductory paper we present the key findings from a series of observational, numerical and socioeconomic studies addressing issues facing marine food security in the coastal regions of Tanzania and Kenya.

1. The impending food insecurity challenge in East Africa

Coastal communities along the tropical coastlines of Tanzania and Kenya experience rates of poverty which are amongst the highest in the world (UNDP-OPHI 2020). These same communities are also dependent upon the ocean for livelihoods, sustenance, economic stability, social and cultural cohesion (UNEP-Nairobi Convention and WIOMSA, 2015). Artisanal fisheries, and small pelagic fish species in particular, play a key role in food security and provide a significant source of protein for many people (Kimani et al., 2009; Cinner and Bodin 2010; Taylor et al., 2019). This strong dependency upon local coastal fisheries means that food security is intimately tied to ecosystem variability. Whilst natural marine ecosystem variability is largely driven by the changing monsoon seasons - which induce productive coastal upwellings and significantly impact local circulation, environmental conditions and fisheries catch (Jebri et al., 2020; Jacobs et al., 2020a) - climatic forcing by the Indian Ocean Dipole (IOD) and El Nino-Southern Oscillation (ENSO) cycles also generate important longer-term inter-annual variability in these waters (Jacobs et al., 2020b). Yet this region remains one of the most poorly sampled and analysed marine domains in the world (Marsac and Everett 2020; Painter 2020), due to both restricted regional marine research capacity (IOC-UNESCO 2017) and, more recently, the challenges of

marine security (piracy) hindering international research expeditions (e.g. Dua 2015; Vespe et al., 2015). As a result, the development, implementation, and operation of effective management and governance structures required to sustainably manage fisheries and the marine environment in this region face considerable knowledge gaps.

This special issue of Ocean and Coastal Management on the “East African Coastal Current: at the frontier of climate change and food security” draws together observational, numerical and socioeconomic studies to better understand several key issues facing marine food security in the East African coastal region (Fig. 1). With more than 16 million people currently living in the coastal zone along the path of the East African Coastal Current, and with this number expected to double by 2030 due to migration towards the coast and rapid population growth rates of 2.2% yr⁻¹ in Kenya and 2.9% yr⁻¹ in Tanzania (World Bank 2020), there is an urgent need to understand the economic and social factors affecting the dependence of coastal populations on marine resources. This growing population also increases the pressure on local marine resources via increased rates of pollution, habitat destruction, and exploitation of fish stocks. Collectively these pressures increase the risk of food insecurity but they are not the only concerns facing the region. Environmental conditions in East Africa and across the wider Western Indian Ocean are also changing rapidly in response to climate change

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and the implications for both local marine resources and coastal populations are poorly understood. Rapid warming of the Western Indian Ocean in recent decades has been linked to significant declines in surface chlorophyll concentrations (Dalpadado et al., 2021), whilst projected changes in the strength of the monsoon winds over the 21st century for example, suggest wide ranging and rapidly approaching changes to the productivity of East African marine waters (Cheung et al., 2018). Equally concerning are projected reductions in marine biodiversity, fish stock depletion, and migration of species such as tuna towards cooler regions (Barange et al., 2018). Set against the background of a rapidly growing coastal population significantly dependent upon the ocean for food security, changes in regional marine productivity appear likely to present substantial socioeconomic challenges into the future. This is not just a local problem for East Africa as across the wider Western Indian Ocean over 60 million people now live within the coastal zone with many dependent upon marine ecosystems and marine resources for food security and livelihoods (UNEP-Nairobi Convention and WIOMSA, 2015; Obura et al., 2017). As the Western Indian Ocean already exhibits some of the fastest rates of environmental change in the world (Dalpadado et al., 2021), changes to key regional fisheries, particularly in response to rapidly warming ocean waters, are going to have significant implications over coming years.

2. Synthesis of results

2.1. Fisheries and coastal communities

Small pelagic fisheries are a nationally important resource in

Tanzania yet they are also heavily exploited (Anderson and Samoily 2016; Sekadende et al., 2020). Knowledge gaps about the fishery (e.g. stock size, exploitation rate, vulnerability, seasonality) present considerable difficulties to efforts intended to improve sustainable management practices and ultimately protect this resource. For example, fishers knowledge that key species experience seasonality in abundance and distribution is probably more widely known than are the underlying causes for this seasonality. Fisheries catch data from Unguja Island (Zanzibar Archipelago) shows that mackerel landings from eastern Pemba Channel peak during the southeast monsoon months, a period typically accompanied with cooler sea surface temperatures, higher chlorophyll concentrations and increased marine primary productivity, yet investigation of the causal links is limited. Such unknowns led Kizenga et al. (2021) to explore the links between mackerel catch and local oceanographic conditions, and to demonstrate that mackerel catch is indeed sensitive to local biophysical factors being positively (negatively) correlated with surface chlorophyll (temperature) and thus prone to natural variability over both seasonal and interannual timescales. Environmental factors were also found to be important for ichthyoplankton distributions in Kenyan waters. Based upon the results of a synoptic large-scale survey across the North Kenya Banks, Mwaluma et al. (2021) identified strong thermal controls on fish larval distribution patterns. This study also found high larval abundances out to the shelf edge and indications of a nursery ground for several high value migratory fish species (e.g. tuna). Such information increases the need for greater management protection across the North Kenya Banks, which is currently an unregulated region, whilst the clear presence of thermal controls on larval distribution suggests that sustainable long-term

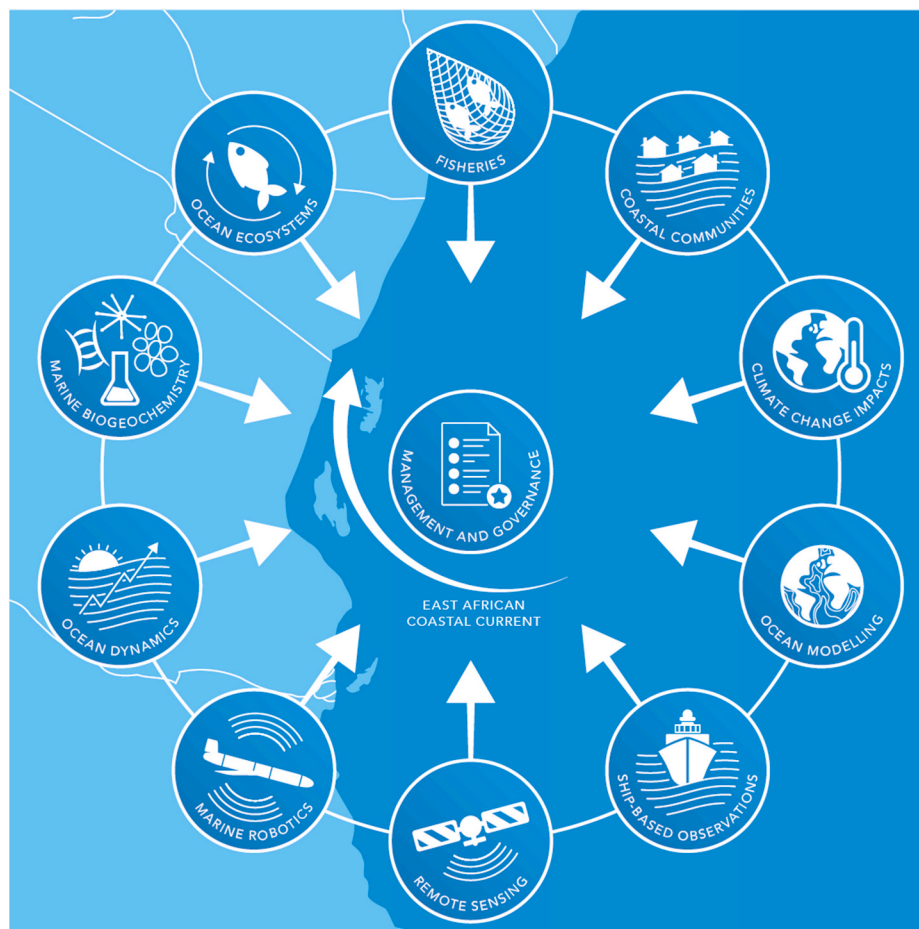


Fig. 1. Illustration of how marine management and governance challenges in the East African region are supported by interdisciplinary research efforts utilising advanced observing technologies.

management of the fisheries resource must address risks associated with current and future ocean warming trends (Kamau et al., 2021). Indeed, Blue Economy initiatives to expand access to, and increase exploitation of, marine resources across the North Kenya Banks region must carefully consider and adapt to future climate induced changes (Kamau et al., 2021). Similarly, in reviewing the latest data and information available on small pelagic fisheries in Tanzania, Sekadende et al. (2020) highlighted the potential impacts climate change could have on regional fisheries using the small pelagic fishery of Pemba Channel as an illustrative example of the wider Western Indian Ocean region.

From a food security perspective, climate change presents significant uncertainties (e.g. Jacobs et al., 2021), and whilst global fisheries catch is projected to decline during the 21st century due to the effects of climate change and increased fishing effort (Barange et al., 2018), region-specific predictions remain limited. To provide such a prediction for Kenya and Tanzania Wilson et al., (In Press) present results from a multi-species fish model that examines the impacts of climate change on fish biomass. The results, though associated with some uncertainty, suggest significant reductions in fish biomass of up to 70% in both Kenyan and Tanzanian waters by 2100, with significant reductions appearing after 2050 if climate mitigation measures are not adopted globally. Whilst these studies collectively indicate that (marine) food insecurity will likely increase during this century as the Western Indian Ocean warms, the response by fishing communities is less well understood. For example, the diversity of fish species targeted within small-scale tropical fisheries is argued to provide an adaptive capacity to insulate fishing communities from natural variability in fish catch or from the impacts of economic factors (Robinson et al., 2020). Investigation of this assumption by Taylor et al. (2021) however found that adaptive capacity was not equal amongst fishing communities. In particular, less wealthy fishers amongst Tanzanian coastal communities were found to target fewer fish species and be less able to adapt to management measures, fishery closures and natural factors impacting fisheries, whilst in contrast, wealthier fishers were more adaptive and resilient to management changes due to their ability to switch fisheries. Such insight suggests that poorer fishing communities will likely be disproportionately impacted by future changes to fish species diversity.

2.2. Mesophotic and deep-water habitats

Shallow warm-water coral reef habitats provide various environmental, cultural and economic services and support artisanal fishing activities and tourism. These habitats however face the greatest impact from natural and anthropogenic activities. Less well known are the deeper mesophotic (30–150 m) and bathyal (>200–4000 m) habitats which may help mitigate biodiversity loss. Based on a unique autonomous underwater vehicle (AUV) survey of shallow and mesophotic benthic habitats of the Pemba Channel, Osuka et al. (2021) present the first survey of mesophotic coral reefs from the Western Indian Ocean. Observations of high community biodiversity within the mesophotic environment confirm that these previously little known mesophotic communities urgently require greater conservation measures, particularly given their role as potential refugia from the impacts of climate change (Baker et al., 2016). Moving deeper, Gates et al. (2021) investigated the deep water (>200m–~4100m) benthic habitats and biological communities of Tanzania's Exclusive Economic Zone (EEZ) by utilising video footage and data captured by remotely operated vehicles (ROV) operated by deep-water oil and gas industry partners. In addition to cataloguing species diversity in the little studied deep-water regions which occupy 92% of Tanzania's EEZ, Gates et al. (2021) highlight the importance of canyons for linking shallow and deep-water ecosystems and recommend that the little studied deep-water regions should be considered within future Marine Spatial Planning activities, particularly if appropriate management of these environments is to be implemented. The studies by Osuka et al. (2021) and Gates et al. (2021) also serve to highlight the advantages that AUV and ROV technologies provide in

filling knowledge gaps about specific deep water environments, and habitat distribution and their vulnerable species.

2.3. Oceanography and marine biogeochemistry

A core focus across several studies of this Special Issue was to improve our understanding of the key mechanisms driving marine productivity and the geographical extent of their influence. Riverine discharge is one of the processes that contributes to coastal ecosystem productivity, yet for the Tana River, the largest river in Kenya, estimates of this contribution remain incomplete. In addressing this, Mutia et al. (2021) investigated the productivity impacts resulting from the Tana River discharge, finding attributable effects were largely restricted to the coastal waters of Ungwana Bay, with limited impact on productivity across the broader North Kenya Banks region. This implies riverine discharge impacts will be significant for the fisheries based in the inshore coastal waters. As productivity across the wider North Kenya Banks region remains dominated by the regional ocean circulation, this geographic distinction between inshore and offshore shelf areas has implications for water management activities on the Tana River such as river damming for hydroelectric purposes. Such activities may unintentionally impact coastal productivity and by extension nearshore commercial fisheries.

In Tanzania, Painter et al. (2021) and Sekadende et al. (2021) focussed their efforts on the Pemba Channel to describe and document many aspects of the oceanography, pelagic biogeochemistry and phytoplankton community structure within this channel. The study by Painter et al. (2021) identified a small localised upwelling feature along the western edge of Pemba Island, coincidentally a region where historic fishery distributions data has recorded elevated fisheries biomass. The parallel study by Sekadende et al. (2021) tackled the problem of phytoplankton distribution, which is generally poorly known for Tanzanian waters, but which is increasingly relevant for assessing environmental change, trophic linkages, or pollution impacts. These new data indicate low abundances of microphytoplankton (>20 µm) and no clear spatial patterns in the distribution of key species. Notably, however, several harmful phytoplankton species were identified and though abundances were low regular monitoring for these species was recommended.

2.4. Climate change impacts

The potential impacts of future climate change on the marine environment of the Western Indian Ocean remain poorly documented yet are of significant concern (Roxy et al., 2020). In this Special Issue, the question of how East African marine ecosystems may respond during the 21st century to various climate stressors (e.g. rising temperatures, increased frequency and duration of marine heatwaves, reduction of primary production, increased stratification, changing ocean currents, ocean acidification and deoxygenation) was investigated by Jacobs et al. (2021) who found significant consequences for marine ecosystems following widespread warming of up to 5 °C by 2100 under the extreme RCP8.5 scenario. Marine heatwaves - periods of unusually elevated ocean temperatures - are projected to become more common and more intense as early as the 2030's. Conservation, particularly of coral reef habitats, and ocean management policy more generally, therefore urgently requires the incorporation of climate change adaptation measures to ensure the sustainability of marine resources in the face of accelerating climate change.

2.5. Marine robotics

Marine robotic platforms are an increasingly familiar component of research programmes and several of the studies described in this special issue actively utilised such technologies to deliver their science. Gates et al. (2021) took advantage of ROV technologies already deployed in

Tanzania's EEZ to improve the understanding of deep-water habitats, whilst Osuka et al. (2021) utilised the GAVIA AUV platform (e.g. Macdonald et al., 2016; Howe et al., 2019), specifically transported into the region for the SOLSTICE-WIO project, to undertake the first survey of mesophotic corals. Such studies demonstrate the potential of marine robotics as useful tools for monitoring the marine environment. However, despite widespread interest in the use of marine robotics to enhance regional marine science the still high cost of robotic technologies as well as the advanced skillsets required for their deployment, operation and data analysis means that they are largely unavailable to many researchers. Another uncertainty is their security in the field as coastal communities have had little exposure to these technologies and are increasingly likely to come across these instruments in their daily activities. In examining the readiness of coastal communities to accept the use of robotic technologies Palmer et al. (2021), found a wide range of attitudes within artisanal fishing communities ranging from deep suspicion to curious indifference. Promisingly, however, community attitudes could be significantly improved via early intervention and specifically via community engagement programmes prior to robotic deployments.

3. Management and policy implications

Whilst it is widely recognised that approaches to governance and management of the marine environment and its resources varies widely across the Western Indian Ocean region, it is also acknowledged that improved governance and management will be greatly aided by the increased availability of reliable and relevant data on both the physical environment and the social and economic relationships between people and the marine environment (UNEP 2020). Data sparsity, however, presents significant challenges for describing not only basic environmental conditions but also impacts efforts to manage marine resources under a changing climate. The new results presented in this special issue represent a substantial step in providing a solid body of knowledge to underpin existing and future management and policy development. While the knowledge gap in East African marine waters still remains large, two key areas where data can already aid governance efforts are adaptation to climate change and fisheries management.

3.1. Adaptation to climate change

The marine environment in Kenya and Tanzania, and indeed across the Western Indian Ocean, is entering a period of rapid change and uncertainty due to the effects of anthropogenic climate change. It appears highly likely that there will be considerable socio-economic implications for coastal populations (Jacobs et al., 2021, Wilson et al., In Press). Key impacts are reduced marine productivity and temperature-induced migration of key fish species and/or degradation of key habitats (e.g. coral reefs). To plan and adapt for the worst of these impacts, climate change impacts on marine ecosystems need to be fully integrated into strategic plans for marine food security, blue economy and fisheries policies.

3.2. Fisheries management

Fisheries management plans currently vary in their scope, effectiveness, and level of enforcement. Tanzania and Kenya have differing requirements for specific local fisheries as well as complementary requirements for shared transboundary fisheries. In Tanzania, management of the small pelagic fishery of Pemba Channel is jointly managed by Mainland Tanzania and Zanzibar under different policies (Sekadende et al., 2020). As the stock is a shared resource that is influenced by the same oceanographic and climatic factors, there are grounds for the establishment of joint collaborative management arrangements. Such a change would be beneficial to overall efforts to ensure sustainability of this resource.

However, due to the complex legislative arena under which fisheries are currently managed in Tanzania, initial steps towards joint collaborative management protocols should begin with activities that do not require legislative changes. This includes co-ordination of monitoring efforts, data collection procedures and/or data management arrangements. In Kenya, meanwhile, there is a clear risk that ambitions to increase exploitation of the North Kenya Banks fisheries may proceed faster than efforts to develop and implement clear management structures that ensure sustainable exploitation. The fact that local communities are currently not well capacitated to exploit fisheries on the outer continental shelf provides a window of opportunity to develop and implement management plans and policies that ensure sustainable development providing jobs and improving livelihoods for the population.

Declaration of competing interest

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

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