SOLSTICE

October 2021

Livelihoods from the Ocean: How science and technology can contribute to their sustainability in Tanzania

SCIENCE INTO POLICY REVIEW

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Key Messages:

Through its 20+ peer-reviewed scientific publications, The SOLSTICE programme has brought new understanding of Tanzania's marine ecosystems helping to build WIO marine science research capacity.

SOLSTICE has demonstrated that the application of cost-effective remote-sensing data and ecosystem models will go a long way to overcome the current lack of in situ data collection.

SOLSTICE has made a strong case for continued investment in AUV technology, and scaling-up as skills and experience within the research community.

This Science into Policy Review is primarily designed to help national decision-makers in Tanzania to understand the options potentially available to their scientific advisors for generating the knowledge required to inform the development of sustainable fisheries livelihood and food security policies. It is anticipated that development cooperation partners, as well as national and international NGOs, will also benefit from learning more about what options exist to affordably increase Tanzania's home-grown marine ecosystem research capacity and scientific outputs. The content of this review is based on the work of the SOLSTICE programme in Tanzania and describes what the Programme achieved and what recommendations resulted from it

Eating fish (and shellfish) nourishes the body

Eating fish (and shellfish) nourishes the body with nutrients including vitamins, minerals, and omega-3 fatty acids. Collectively referred to as *micronutrients*, they are critical to human health and a deficiency increases the risk of child mortality but also of reduced cognitive development and impaired immune functionality, leading to an increased burden of disease[1].

However, recent data indicates that the diets of as many as 137 million people across East Africa are lacking in sufficient micronutrients as well as animal proteins (Golden et al., 2016). In Tanzania, a 2015/2016 survey indicated that **more than 30% of the population were estimated to be undernourished**, the growth of more than 40% of

[1] National Development Vision 2025 for mainland Tanzania and Vision 2020-2050 Blue Economy for Zanzibar

children under-5 years of age was stunted, while more than 50% of young children were anaemic. Given that Tanzania's population is expected to double by 2050 the challenges for individual households to secure adequate nutrition will only increase and, therefore, so will the pressure on marine (and other) ecosystems, pressures that will be amplified by climate change (Taylor et al., 2021; Jacobs et al., 2021).

However, Tanzania's marine ecosystems are still productive and remain a critical source of nutrition for a significant number of Tanzania's people (Sekadende et al., 2020). And because of ever-more rapid and sophisticated trade routes across the continent of Africa, the beneficiaries of this productivity are not only coastal communities, but also include those living in the interior of the country, and even neighbouring countries, located far from the coasts and the marine ecosystems themselves. At the same time, there are tens of thousands of livelihoods that depend, to varying degrees, on the fisheries derived from the WIO. On the mainland and in Zanzibar there are probably more than 100,000 fishers (both men and women, fishing and foraging from boats and on foot), while there are likely to be at least another 250,000 people involved in supporting the fishery with fuel, equipment, and investments and in processing, selling, and transporting the various products derived from the fishery. Fisheries are expected to continue to play a crucial role in both economic growth and supporting food security on both the mainland and in Zanzibar. It is crucially important therefore that Tanzania safeguards its marine ecosystems; this entails both maximising our understanding of how these ecosystems function and ensuring that optimum policies are in place to manage their exploitation.

Safeguarding the livelihoods generated from the ecosystems of the Western Indian Ocean requires support and interventions across a number of policy arenas including trade, business development and employment, tourism, as well as resource-use management. These policies may be informed by numerous sources and stakeholders including communities, local governments, business and by legitimate political objectives. But marine scientists should also routinely participate and contribute their expertise, providing as the UN puts it '***The Science we Need for the Ocean we Want'***[2].

For this to happen requires appropriate knowledge-sharing mechanisms, but of primary importance is an improved scientific understanding of these ecosystems in the first place. The acquisition of knowledge of complex marine ecosystems tends to be expensive and time-consuming, often requiring a time-series of data, observation platforms (such as research vessels) and the work takes place in the demanding marine environment. But it also requires advanced technology and advanced analytical techniques. For many developing economies such *marine research infrastructure* is not yet routinely available, especially with so many other, competing demands for financial support across the spectrum of social and economic development.

[2] United Nations Decade of Ocean Science for Sustainable Development 2021-2030

The Sustainable Oceans, Livelihoods, and food Security Through Increased Capacity in Ecosystem (SOLSTICE) programme operated across much of the Western Indian Ocean (WIO) between 2017 and 2021. In Tanzania, SOLSTICE engaged with significant numbers of the country's marine scientists and institutions, as well as drawing on additional expertise and technology from UK and South Africa. The research was particularly focused on the Pemba Channel and its nationally important fishery for small pelagic species. In describing the strategies employed by SOLSTICE, the reader is reminded of, or introduced to, affordable ways of advancing marine science. And in highlighting some of the achievements of SOLSTICE, the reader is informed of some of those advances, the details of which can be followed up on the SOLSTICE programme website.

There already exists a large reservoir of open-access, remote-sensing data to explore.

Remotely sensed data are continuously generated by environmental monitoring satellites and their analysis can provide insight into the functioning and status of WIO marine ecosystems. SOLSTICE researchers have mobilised some of these data, including outputs from the Copernicus Marine Environment Monitoring Service (CMEMS) of the European Commission, the Ocean Colour Climate Change Initiative Project (OC-CCI) for satellite-derived data on the concentrations of chlorophyll-a (referred to as *Chl-a*, a proxy measure for ocean productivity) and the Jet Propulsion Laboratory/NASA *MUR MEaSUREs* project for data on sea surface temperature (SST). SOLSTICE coupled these data with freely available climate change and biogeochemical climate response models developed by various research teams around the world to enrich their outputs.

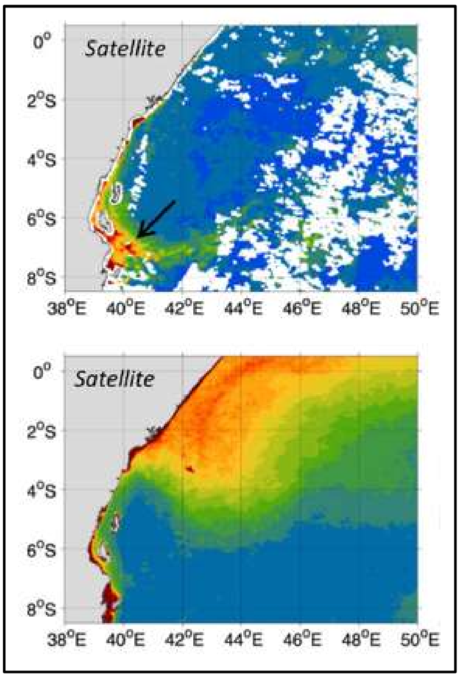

Figure 1: The spatial distribution of Chl-a concentrations in February, 1998 (an El Niño year, top image) compared to the average over the period 1998-2015. Red indicates the highest concentrations, blue the lowest (Source: Jacobs et al. 2020).

The remote-sensing datasets, in some cases supported by additional data collected in the field, or *in situ*, have helped to establish how, and to what extent, the various elements of Tanzania's coastal and high seas ecosystems interact and ultimately how this may determine marine fisheries productivity for the country.

For example, by mining *historical* satellite data UK, South African and Tanzanian scientists working together under the umbrella of SOLTICE (Jacobs et al., 2021) were able to develop complete an analysis which demonstrated that a short-lived but significant ecosystem shift took place in the WIO during the 1997/98 *El Niño* event (a periodic event originating in the eastern Pacific Ocean). For Tanzania, this was characterised by a dramatic *increase* in local productivity (**Figure 1**); conversely the fisheries of the North Kenya Banks were *adversely* affected. More specifically, the distribution of tunas (which continuously search for highly productive areas of the ocean) was quite different compared with previous and subsequent years, as observed by the changed distribution of the distant water fishing nation (DWFN) tuna fleets observed locally in 1998. The analysis showed that not only are oceanographic processes in the WIO are dynamic but also that variation is a natural phenomenon, which may be driven by processes originating half-way across the world, as well as by more *local* factors.

In another example, SOLSTICE reviewed a 20-year time-series of *Chl-a*, SST as well as local wind and rainfall datasets to investigate the marine productivity of the Pemba, Zanzibar, and Mafia channels (Shaghude et al., 2021). The research was able to show that there are important differences in the drivers that affect the relative productivity of the three channels. More specifically, the research showed that the three channels should each be considered as each having its own characteristic set of productivity drivers. Mafia Channel's productivity is driven by riverine inputs from the Rufiji River, Zanzibar Channel may be driven by both riverine and oceanic drivers, while Pemba Channel's productivity is dominated by oceanic drivers. However, the political and governance structures on the respective western and eastern shores of Pemba and Zanzibar Channels at least are, as far as fisheries and marine management are concerned, separate and different.

Using more recent data, a combination of remote-sensing data and fisheries catch records, SOLSTICE also investigated specific relationships between environmental parameters and the catch landed in certain fisheries; for example, the relationship between catches of *Vibua* (Indian Mackerel) and *Chl-a* and SST in one study and the relationship between a small sub-set of catch data for mixed small pelagic species and the same parameters in another (Kizenga et al., 2021). The clear demonstration of how and why fisheries catches can vary seasonally and between years can inform advocacy for the diversification of fisher community livelihoods on the one hand, and to constrain the development of fisheries as alternatives for those affected by declines in the capacity of other, terrestrial ecosystems on the other, the implications of climate change notwithstanding.

In-situ **data collection, using advanced oceanographic technology, also holds great potential** for contributing to the understanding of Tanzania's marine ecosystems. SOLSTICE provided several opportunities for technology transfer and for Tanzania's marine scientists to explore this potential. Two Direct sampling technologies were employed: one involved lowering a CTD[3] scientific instrument attached to a cable to depths of ~500 metres at pre-selected locations (or stations) in the Pemba Channel. The CTD instrument can precisely measure various properties of the water at various depths, as well as collecting samples of seawater for later analysis. These data were used to significantly improve understanding of the hydrography of the Pemba Channel, while the subsequent analysis of the seawater samples undertaken in the laboratory provided new data on nutrient levels and on the species composition of the plankton. This research provided, for example, evidence of the existence of a small upwelling of nutrient-rich cold water off the west coast of Pemba Island (**Figure 2**); upwellings play an important role in ocean primary productivity and are usually associated with significant fisheries for small pelagic species (Painter et al., 2021).

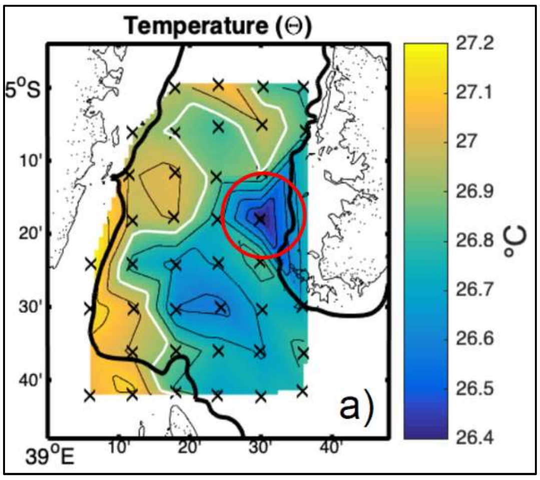

Figure 2: Location of small upwelling off Pemba's west coast (in red circle)

[3] CTD = Conductivity, Temperature and Depth. The water's salinity is determined by its electrical conductivity and depths are determined by hydrostatic pressure.

This type of knowledge could contribute to fisheries management actions; for example, focusing effort on understanding how the various upwelling processes may contribute to total fisheries production (a preliminary estimate by SOLSTICE for this specific upwelling suggests a localised increase of ˜20%). More research is clearly needed, more '*physics to fish',* as one of the SOLSTICE researchers termed it, that might suggest spatial controls on fishing effort in the upwelling zone to help conserve small pelagic fish stocks.

Figure 3: Deployment of a Teledyne Webb Slocum underwater glider during SOLSTICE

The other technology made available through SOLSTICE was autonomous underwater vehicles (AUVs, Palmer et al., 2021). AUVs can gather data on a diversity of variables, over a range of geographical areas and over time periods of a few hours or weeks, even extending to months, with or without the need for constant human operational control. AUVs possess technology permitting them to simultaneously measure ocean chemistry, temperatures, currents, and bathymetry. This capacity, as well as their navigability and relative ease of deployment, dramatically increases scientists' access to the ocean and therefore our collective understanding of key components of marine ecosystems, their natural variability and how they may be changing due to human activities.

The SOLSTICE team deployed two types of AUV; a Teledyne Gavia offshore surveyor (Osuka et al., 2021), a propeller-driven AUV, was deployed with various modules including a seabed-mapping sonar and a camera with strobe light and capable of operating to 500m depth. Two models of *glider* were also deployed (**Figure 3**) with various arrays of CTD instruments, nutrient sensors, and echo-sounders. These instruments provided the research team with new insights into how oceanic waters mix as they enter the Pemba Channel. In addition to the further developing knowledge on the macro-oceanography of coastal Tanzania, the AUVs also opened-up to research ecosystem components that were previously little known, such as the *mesophotic zone* situated between ~30m and ~150m depth.

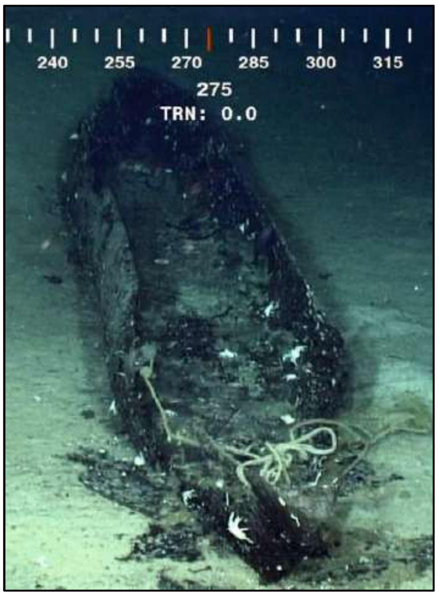

Figure 4: The remains of an mtumbwi canoe, located at a depth of 1,330m.

All of this comes at a financial cost that is relatively affordable compared to the costs of a similarly equipped research vessel, and new, even cheaper mini-AUVs will soon be available and a prototype of one (produced by *ecoSub Robotics*) was demonstrated during the Programme. While the costs of such AUVs are *relatively* cheap, they still demand a certain investment to purchase and maintain, and in the skills required to effectively use them with minimum risk of loss. A regional facility or centre of excellence may be an effective way to share costs in East Africa, in much the same way that various centres, research vessels and equipment was pooled under SOLSTICE itself.

As with remotely-sensed data, *in situ* data from other sources may also be explored from a new perspective or for a specific region of the ocean. For example, SOLSTICE gained access to deep-sea ecological data generated by the global SERPENT programme (Gaits et al., 2021). SERPENT developed a partnership with the oil and gas industry to use their exploration platforms (to mount time-lapse cameras) and deep-sea remote-operated (ROV) technology. In addition to cataloguing species diversity and highlighting the linkages between shallow and deep-water ecosystems (**Figure 4**), the imagery also permitted SOLSTICE researchers to identify specific effects of drilling operations off the coast of Tanzania, including the localised smothering of the seabed by drill cuttings and drilling mud.

However, climate change effects on Tanzania's marine ecosystems and their fisheries are likely to be significant. Probably the most significant area of research undertaken by SOLSTICE, whilst still using its parsimonious approach to sourcing data and applying existing ecosystem and ocean models, was to describe some of the specific *changes* that are likely to be observed in the WIO due to climate change. For example, at the macro-scale, SOLSTICE looked at the major ocean and coastal currents that directly affect the WIO and Tanzania (i.e. the North East Madagascar Current/NEMC and East Africa Coast Current/EACC) and which drive ocean mixing, the transport of nutrients etc (Jacobs et al., 2021).

Although the research team used a relatively high emissions scenario, known as RCP8.5 (under which there will be little or no significant reduction in greenhouse gas emissions), the results are nevertheless useful to reflect on. For example, north of latitude 5°S (Dar es Salaam is at 6.8°S) the EACC is projected to strengthen due to increased wind speed, while south of 5°S it may shift offshore. The likely outcome is a reduced transport of nutrients into the Pemba and Zanzibar Channels, an increase in SST, and a decreased level of primary production; these changes are already taking place but are likely to accelerate by the middle of this century, in just 30 or so years (**Figure 5**).

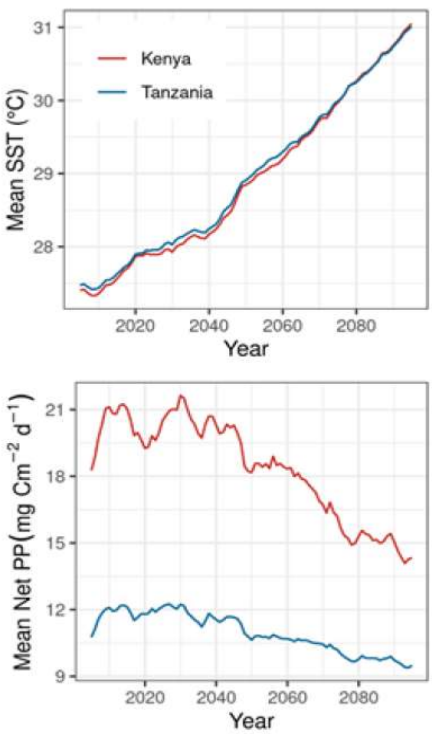

Figure 5: Potential changes to temperature and primary productivity of the WIO due to climate change.

Unsurprisingly, marine fisheries are also likely to undergo significant change, the relative extent of which are partially dependent on the physiology and behavioural ecology of the individual species of fish and plankton on which the system is based. Across the board there are unlikely to be many winners. For example, the larger tuna species are expected to be significantly affected by increased SST and reduced primary productivity but may be able to shift their geographical distribution, while nearshore neritic and reef species will be significantly impacted by the loss of live coral-reef ecosystems. Although the RCP8.5 scenario is very much the worse-case scenario, climate change is inevitable, but the extent of this change is still subject to policy decisions taken now. But in any event, what is clear is that an ecosystem that is in *good shape* will be more resilient whatever the emissions scenario.

So, what next? Our major recommendations:

Satellite observations of *Chl-a* or SST seem a long way from the world of a *nahodha* and his crew auctioning his night's catch to eager processors and traders on a perilously over-crowded boat at six o'clock in the morning! How can the outputs from SOLSTICE's research and, perhaps equally importantly, the strategies and approaches of the Programme be applied in future to support marine policy and fisheries management and therefore positively impact the lives of these fishers and others in the sector?

The SOLSTICE programme has made an important contribution in this regard for two reasons: through its 20+ peer-reviewed scientific publications it has brought new understanding of Tanzania's marine ecosystems to the policy-making table as well as helping to build WIO marine science research capacity ***and*** it has demonstrated how this can be achieved efficiently and within a realistic budget, even by just using or re-using the abundant data that already exist. This section will reiterate a few strategic key points, recommendations if you wish, that augment those that can be found in the publications themselves.

1. **Use existing and open-access data wherever possible:** SOLSTICE has proven the potential value (and efficiency) of exploring existing datasets, although there is an urgent need to augment these with additional *in situ* data collection. And SOLSTICE has also shown where there are important information gaps. Initial steps were taken to describe seasonal and inter-annual variability, but data remain scarce and the nature of the interactions between them remains to be clearly understood, but ***the application of cost-effective remote-sensing data and ecosystem models will go a long way to overcome the current lack of in situ data collection (e.g. Jebri et al., 2020)***. Without appropriate skills to ask the right questions and then undertake robust analyses, all the data in the world is not going to be especially useful. The building of the necessary research capacity, as undertaken during SOLSTICE, remains a critical step in developing the overall marine science research infrastructure for Tanzania.

   In order to know what data (and models) are available and where they can be found, there is a need to establish a so-called **meta-database,** even if the existing datasets for Tanzania are limited in scope and detail. Such a database, just created in a simple Excel file for example, can capture information about existing datasets (for example, the subject of the data, the geographic or species coverage, the time period, its format etc.). An oceanographic and marine fisheries meta-database, fully accessible to students, NGOs, researchers, international scientists, should be established and systematically up-dated. The contents of such a meta-database, can prove invaluable to contribute to developing a research programmes of national marine science and fisheries institutions, TAFIRI, SUZA and IMS, that are charged with answering the key questions to inform policymaking and a coherent strategy for such a programme is urgently needed;

2. **A Regional Oceanographic Technology Facility:** While the costs of marine ecosystem research may at first appear daunting, there are autonomous technologies already available that are substantially cheaper to operate than a traditional ocean-going research vessel, for example. SOLSTICE has made a *strong case for continued investment in AUV technology*, and scaling-up as skills and experience within the research community. But individual institutes may be unable to afford the equipment; a solution may lie in a regional, cost-sharing (and skills sharing) approach across Tanzania and the wider WIO (Palmer et al., 2021).

3. **Explore further transboundary management partnerships:** The SOLSTICE work in the Pemba and Zanzibar Channels showed that each channel can be seen as more or less a discrete entity of ecosystem processes and marine biology (Shaghude et al., 2021). For small pelagic fish (anchovy, sardines, herrings etc.), for example, where schools of fish likely forage on both coasts and throughout the channels, some form of collaborative management or partnership across the Channels is crucial because fishers from Zanzibar and mainland Tanzania are targeting the same stocks of fish. Indeed, the management of the entire Pemba Channel, for example, might usefully be coordinated across the two legislatures by a forum or agency designed for that purpose; a prototype for which might be the United Republic's Deep-Sea Fishing Authority (DSFA). While the unique characteristics of each of the three channels also suggests that management policies will need to be somewhat tailored to each case.

4. **Act on what the science is telling you:** SOLSTICE described some aspects of the relationship between SST and *Chl-a* and the subsequent level of fisheries productivity; while it is not possible to take any action to change the nature of these relationships, it is possible to ***develop systems to provide early-warning of impending reductions in fisheries productivity*** (Jebri et al., 2020). Such a system, again perhaps developed at a regional level could give time to central and local governments to adjust their policies while, in the short-term, give fishers and traders advanced notice of possible changes and give them the time to adapt their operations. By way of example, a short-term forecast system has already been developed in the WIO for coral-reef bleaching[4]. Although confident, longer-term forecasts are required for substantive policy-related action, awareness of impending short-term change would also allow researchers to prepare to directly monitor what adaptations are made by fishers and other stakeholders in the industry, as well as any impacts of the change itself.

5. **Take an ecosystem perspective in marine conservation planning:** SOLSTICE has probed the depths of Tanzania's marine ecosystem with CTDs, AUVs and with the help of the oil and gas industry. The programme's findings highlighted the vertical connectivity of the oceans and the research teams reported on ***the necessity of integrating the mid- and deep-water elements of the ecosystems into marine and fisheries planning and policy*** (Osuka et al., 2021; Gates et al., 2021). Working with AUVs has, for example, highlighted the enhanced fish biodiversity of the walls and steep slopes of the Pemba Channel, and these observations could inform specific and localised management and conservation planning.

[4] Indian Ocean coral bleaching | CORDIO (cordioea.net)

About the lead author:

***Jim ANDERSON** is a marine fisheries specialist with 30-years of experience across temperate and tropical ecosystems, and with two decades of experience in the Indian Ocean. Jim has worked on a wide range of aspects of both industrial and artisanal fisheries management, including extensive SCUBA, ship-based and landing-site data collection, participatory resource appraisals, traditional marine tenure, policy reviews and recommendations, project management & capacity building, MCS and support to the management of MPAs. He currently lives in France, where he divides his time between fisheries and cabinet-making.*

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