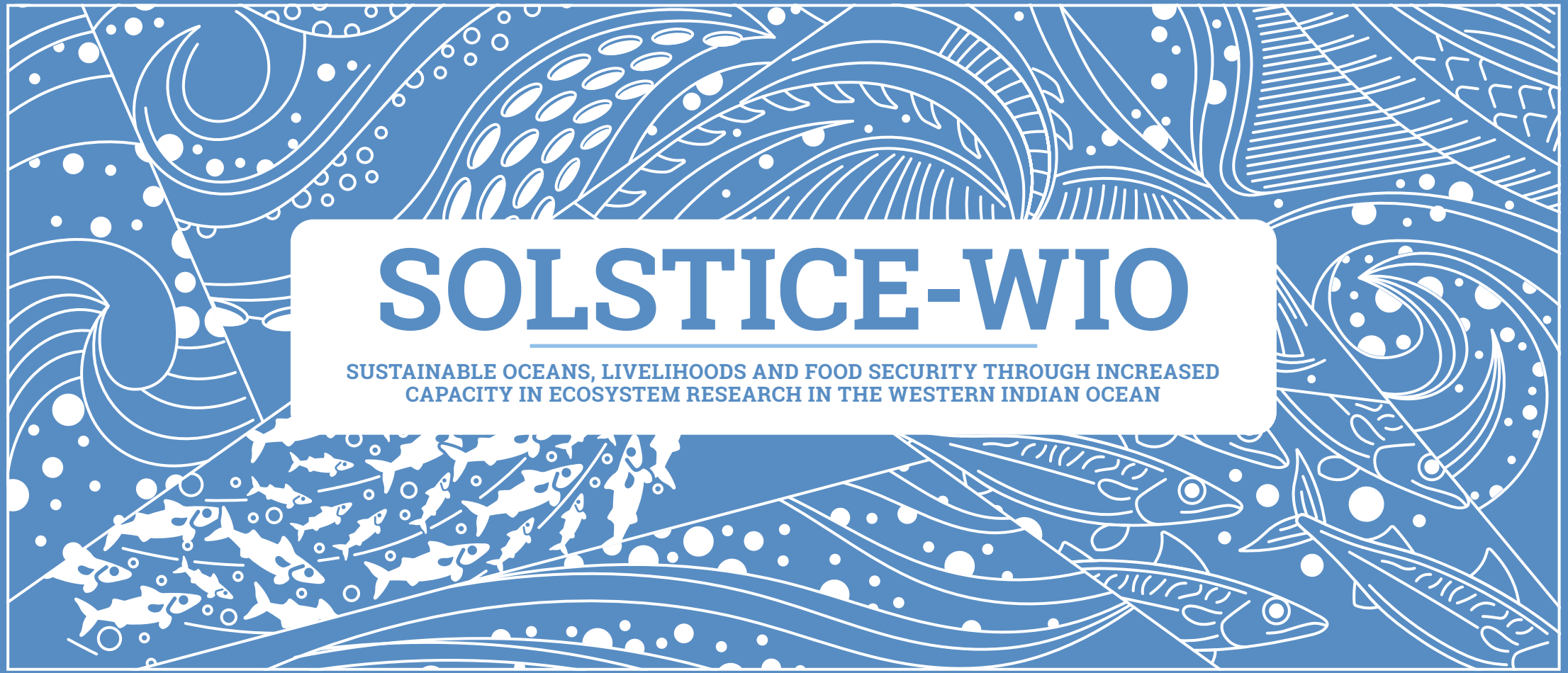

SOLSTICE-WIO
SUSTAINABLE OCEANS, LIVELIHOODS AND FOOD SECURITY THROUGH INCREASED CAPACITY IN ECOSYSTEM RESEARCH IN THE WESTERN INDIAN OCEAN

CONTENTS

SOLSTICE-WIO

FROM PHYSICS TO FISH TO PEOPLE TO POLICY

SOLSTICE-WIO (Sustainable Oceans, Livelihoods and food Security Through Increased Capacity in Ecosystem research in the Western Indian Ocean) was a four-year collaborative project funded by the UK Global Challenges Research Fund (GCRF). Launched in October 2017, it brought together recent advances in marine technologies, local knowledge and research expertise to focus on the challenges of food security and climate change impacts on marine ecosystems facing the Western Indian Ocean (WIO) region in a cost-effective way via state-of-the-art technology transfer, collaborative environmental and socio-economic research and hands-on training.

SOLSTICE-WIO combined efforts from more than thirty organisations from across the UK and WIO countries and numerous collaborators from around the world to carry out interdisciplinary research focusing on case studies in Kenya, Tanzania and South Africa. The project engaged with existing regional initiatives to collaborate with policy makers and fisheries managers to meet their information needs. It also worked with local communities to build on their understanding of the issues associated with sustainable use of marine resources and increase ocean literacy by sharing scientific information.

SOLSTICE-WIO has demonstrated its approaches to interdisciplinary research and to strengthening research capacity through case studies in Kenya, Tanzania and South Africa. These are:

- Pemba Channel (Tanzania) small pelagic fishery under climate threat
- Emerging fishery of the North Kenya Banks: the next frontier for food security
- Environmental drivers and socio-economic consequences of the South African Chokka squid fishery collapsing

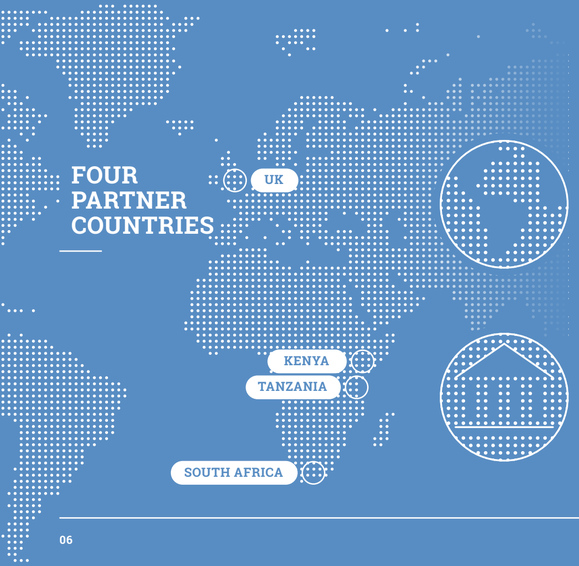
The case studies were selected by SOLSTICE-WIO partners in each of the three countries due to the socio-economic significance of the issues being addressed, their importance to low-income communities with high dependence on living marine resources and novel and previously unexploited research aspects that can benefit from use of new research technologies.

DR EKATERINA POPOVA
SOLSTICE-WIO Director

PROFESSOR MIKE ROBERTS
SOLSTICE-WIO Director

INTRODUCING SOLSTICE-WIO

Over 60 million people in the WIO region live within 100 km of the coast, with over 1 million working in the fisheries sector. The people of the WIO region are highly dependent on the ocean for economic stability, food security, and social cohesion. In recent years, the region has seen dramatic and often poorly understood reductions in key fisheries, due to the combined effects of climate change, natural ecosystem variability, overfishing and degradation of key marine habitats. Understanding and managing WIO fisheries and the impacts of recent and future changes requires a mature capacity in interdisciplinary marine research to implement an ecosystem approach to fisheries management that is built on sound environmental and socio-economic information.



FOUR PARTNER COUNTRIES

TWENTY COLLABORATING COUNTRIES

BUILDING THE SOLSTICE-WIO NETWORK

FORTY EIGHT DATASETS

PRODUCED THROUGHOUT THE PROJECT BETWEEN 2017 & 2021

THIRTY+ PARTNER INSTITUTIONS

WORKING WITH OUR PARTNERS FROM AROUND THE WORLD

THREE HUNDRED AND FIFTY+ CITATIONS

CITATIONS FOR SOLSTICE-WIO PUBLICATIONS IN 2017 - 2021

ONE HUNDRED+ PARTNERS

DEDICATED INDIVIDUALS CONTRIBUTING TO OUR GOALS

THREE THOUSAND, SEVEN HUNDRED+ PARTICIPANTS

ATTENDING OUR MASSIVE OPEN ONLINE COURSE IN THE 1ST YEAR

THIRTY+ EARLY CAREER RESEARCHERS

SUPPORTING THE NEXT GENERATION OF SCIENTISTS

FIFTEEN POLICY BRIEFS

PREPARED BY OUR TEAM OF SCIENTISTS

FORTY PUBLICATIONS

PEER REVIEWED THROUGHOUT THE PROJECT FROM 2017 TO 2021

FORTY EIGHT EVENTS

ENGAGEMENT EVENTS HELD FOR OUR STAKEHOLDERS

WORKING TOGETHER TO REACH OUR GOALS

INTRODUCING OUR PARTNERS

NATIONAL OCEANOGRAPHY CENTRE (NOC)

LEAD ORGANISATION

The NOC is the UK's leading institution for integrated coastal and deep-ocean research. With two sites, in Southampton and Liverpool, NOC undertakes and facilitates world-class agenda-setting scientific research to understand the global ocean by solving challenging multidisciplinary, large scale, long-term marine science problems to underpin international and UK public policy, business, and wider societal outcomes. The NOC is a truly multi-disciplinary centre with research that encompasses Marine Physics and Ocean Climate, Marine Systems Modelling, Ocean Biogeosciences and Ocean Technology and Engineering. The NOC manages two state of the art research ships and is home to the British Oceanographic Data Centre, the British Ocean Sediment Core Research Facility, the National Marine Equipment Pool, and Europe's largest fleet of autonomous and robotic vehicles.

NELSON MANDELA UNIVERSITY (NMU)

Based in Gqeberha (Port Elizabeth) on South Africa's south coast, Nelson Mandela University is the focal node for the South African Strategic 'Operation Phakisa' intended to stimulate the blue economy. NMU hosts the newly established South African International Maritime Institute, which serves coastal states in all of sub-Saharan Africa and acts as the hub for the Innovation Bridge between South Africa and the UK, recently established by the Newton Fund.

DR EKATERINA POPOVA

SOLSITCE-WIO DIRECTOR

"SOLSTICE-WIO provided us with a great opportunity to work on exciting interdisciplinary problems and collaborate with new research cultures. The project challenged us in many unexpected ways and helped us to further develop our technologies to address issues we had never come across before. SOLSTICE-WIO efforts in capacity development and research into issues of sustainability allowed us to make a substantial contribution to the UN Decade for Ocean Sciences (2021-2030)."

PROFESSOR MIKE ROBERTS

SOLSTICE-WIO DIRECTOR

"I have worked in the WIO my entire scientific career and know it well — the ocean, people, fisheries and cultures. I see negative changes in these that can only be ascribed to climate change. The awarding of SOLSTICE-WIO by the UK Government gave us the extraordinary opportunity to focus leading-edge scientific innovation to investigate these changes, the trends into the future, and arm the WIO governmental agencies with critical information to cope with the impending Climate Change crisis."

THE UNIVERSITY OF DAR ES SALAAM INSTITUTE OF MARINE SCIENCES (IMS)

Located in Zanzibar, Tanzania, IMS is one of the oldest marine science institutions in the WIO. Established by Government decree in 1978, IMS conducts research and training in all aspects of marine science at under-graduate, MSc and PhD level, and hosts the National Oceanographic Data Centre. The Marine Biology and Resources Management (MBRM) section focuses on biological oceanography, ocean productivity, fisheries, marine botany, marine mammals, coastal and marine resources (estuaries and mangroves, seagrass beds and coral reefs), socio-economics and resource management. The Physical and Environmental Marine Sciences (PEMS) section focuses on chemical oceanography (natural products, marine pollution, and ocean – land - atmosphere interactions), as well as physical oceanography, marine geology, geophysics and marine technology.

TANZANIA FISHERIES RESEARCH INSTITUTE (TAFIRI)

Established in 1980 to promote, conduct, and co-ordinate fisheries research in Tanzania, TAFIRI has operated independently since 1983. The institute comprises four Centres and one Substation: Mwanza Centre and Sota Substation on Lake Victoria, Kigoma Centre on Lake Tanganyika, Kyela Centre on Lake Nyasa (Malawi) and Dar es Salaam Centre on the Indian Ocean. TAFIRI's mission is to promote, conduct and manage fisheries research and consultancy for sustainable development of fisheries in Tanzania.

DR YOHANA W. SHAGHUDE

SOLSTICE-WIO PRINCIPAL INVESTIGATOR

"The Pemba Channel in Tanzania had been one of the least researched marine waters, but the SOLSTICE-WIO project paved ways for this part of the Tanzanian marine domain to be extensively studied. As the project approaches its closure, it is very gratifying to note that a considerable amount of information (interdisciplinary data sets and more than 10 publications) on various aspects of the Pemba Channel and the Tanzanian coastal waters have been generated by the SOLSTICE-WIO project."

DR BARAKA SEKADENDE

SOLSTICE-WIO PRINCIPAL INVESTIGATOR

"SOLSTICE-WIO provided an exciting opportunity to explore the deep areas of the Pemba Channel with an international biogeochemistry team onboard research vessel Angra Pequena".

WESTERN INDIAN OCEAN MARINE SCIENCE ASSOCIATION (WIOMSA)

WIOMSA is a regional professional, non-governmental, non-profit membership organization, registered in Zanzibar, Tanzania. WIOMSA is dedicated to promoting the educational, scientific and technological development of all aspects of marine sciences throughout the WIO region, with a view toward sustaining the use and conservation of its marine resources. The organization's inter-disciplinary memberships consist of marine scientists, coastal practitioners, and institutions involved in the advancement of marine science research and development. WIOMSA provides a forum for communication and exchange of information and fosters inter-institutional linkage within and beyond the region. It supports marine research by offering research grants; implements programmes to build the capacity of marine scientists and coastal management practitioners; and works to promote policy dialogue on key topics by organizing meetings and seminars on the findings and policy implications of science.

PROFESSOR JULIUS FRANCIS

SOLSTICE-WIO PRINCIPAL INVESTIGATOR

"The case study approach adopted by the SOLSTICE-WIO project proved to be a 'game-changer'. It enabled detailed studies to be conducted focusing on physical and biogeochemical drivers of targeted ecosystems or fisheries, their socio-economic significance and policy implications in the North Kenya Bank, Pemba Channel in Tanzania and Eastern Cape in South Africa. It also (and of greater importance) provided an opportunity to test new technologies, build capacity and new partnerships and to study large scale regional/global processes that may have implications to the resources in the three countries and the WIO region as a whole."

KENYA MARINE FISHERIES RESEARCH INSTITUTE (KMFRI)

KMFRI was established in 1979 as a State Corporation, which was formally recognized as a national research institution in 2013. KMFRI's mandate is to undertake research in marine and freshwater fisheries, aquaculture, environmental and ecological studies, and marine research, including chemical and physical oceanography, in order to provide scientific data and information for sustainable exploitation, management and conservation of Kenya's fisheries and other aquatic resources, and contribute to National strategies of food security, poverty alleviation, clean environment and creation of employment.

DR JOSEPH KAMAU

SOLSTICE-WIO PRINCIPAL INVESTIGATOR

"The SOLSTICE-WIO project came at an opportune moment when KMFRI was building its oceanographic research capacity, after acquiring a research vessel (RV. Mtafiti). It was also within a period when Kenya, as a country, was embracing the aspect of Blue Economy, culminating in the hosting of the Sustainable Blue Economy Conference at Nairobi, Kenya (2018). The international networking and scientific cooperation accorded by the SOLSTICE-WIO project fed into some key research capacity gaps. This enabled the Kenyan component of the project, through the application of models, to provide current and future biogeochemical insights facilitating a clearer understanding of climate change impact scenarios on the region's productivity."

COASTAL OCEANS RESEARCH AND DEVELOPMENT – INDIAN OCEAN (CORDIO) EAST AFRICA

CORDIO East Africa is a is a civil society research and conservation organisation focused on marine and coastal ecosystems in the WIO with the aim of generating knowledge to create solutions that benefit ecosystems and people. CORDIO's priority focus is on coral reefs, covering topics such as climate change, resilience, long term monitoring, artisanal fisheries, community based management approaches, mitigating climate change impacts and endangered species protection. CORDIO operates through three guiding principles: (1) Generating knowledge through applied research to find solutions to managing marine ecosystems; (2) implementing conservation action at different scales by empowering coastal communities to manage their own marine resources, by partnering with government to address national objectives, and by disseminating clear, synthesized information for decision makers; (3) Partnerships and capacity: helping to build the next generation of marine scientists and decision-makers.

DR MELITA SAMOILYS

SOLSTICE-WIO PRINCIPAL INVESTIGATOR

"SOLSTICE-WIO has brought CORDIO East Africa incredible opportunities in collaborative research with exceptional oceanography modellers at the NOC as well as access to remote camera technology for exploring deeper marine ecosystems. The modelling of our coastal ecosystems has opened our eyes to the impacts of climate change and how we need develop policy for the future. It has also helped develop solid collaborations between our research institutions within Eastern Africa."

RHODES UNIVERSITY (RU)

Rhodes University Department of Ichthyology and Fisheries Science (DIFS) is an internationally recognized, leading African academic institution that supports the study of fish and the sustainable utilization of aquatic resources through the teaching and training of students and research. With its Grahamstown partners South African Institute for Biodiversity (SAIAB) and South African Environmental Observation Network (SAEON), Rhodes University has a high concentration of fisheries related human capacity. This DIFS post-grad school trains independent, high quality students in a research-based MSc and PhD model focussing on aquaculture, biodiversity, stock assessment, fisheries governance, fisheries economics, fish ecology, social science, ecosystem studies, stock identification and fish biology as research and capacity development priorities in the region. The university has the biggest ichthyological library in the Southern Hemisphere, with subscriptions to all primary regional and international fisheries journals.

PROFESSOR WARWICK SAUER

SOLSTICE-WIO PRINCIPAL INVESTIGATOR

"From ocean gliders to ocean policy SOLSTICE-WIO has advanced our understanding of research and management of the marine environment in Southern Africa and left in place a close network of researchers and managers who will continue to push the boundaries in ensuring sustainable oceans"

UNIVERSITY OF CAPE TOWN (UCT)

The UCT School of Economics is one of the largest departments at the university, with over 3000 full time student and roughly 40 academic staff. It also contains a number of research units, one of which is the Environmental Policy Research Unit (EPRU), which seeks to enhance environmental policy-making in South Africa through rigorous policy research and extension in order to attain sustainable development and poverty reduction. EPRU is funded by the Swedish International Development Cooperation Agency (SIDA) through the Environment for Development (EfD) initiative managed by the Environmental Economics Unit at Gothenburg University.

SOUTH AFRICAN ENVIRONMENTAL OBSERVATION NETWORK (SAEON)

The oceans around South Africa play a key role in determining regional and global weather and climate patterns. The contrast between the physical variability of South Africa's east and west coasts results in exceptionally rich and diverse marine fauna and flora occurring along the coastline and on the continental shelf. Challenges in accessing the deeper regions of the continental shelf, has severely constrained progress in scientific research and our understanding of the dynamics and ecosystem functioning. The SAEON Egagasini Node for Marine Offshore Systems addresses these challenges through long-term observations and research, modelling, data dissemination and capacity development. We also engage with young learners, as well as working closely with educators, supporting and encouraging them in their efforts to incorporate marine science into the curricula.

PROFESSOR TONY LEIMAN

SOLSTICE-WIO PRINCIPAL INVESTIGATOR

EMERITUS ASSOCIATE

"SOLSTICE-WIO showed once again that sustainability isn't about keeping the resource intact; it is about people too. The risk comes because sustainability is a juggling act; fishers, firms and fish are three balls, all have to be kept in the air. If we keep too close an eye on any one ball, all three risk ending up on the floor."

DR LUCY SCOTT

SOLSTICE-WIO PRINCIPAL INVESTIGATOR

"SOLSTICE-WIO brought better understanding how environmental variability impacts food security, but also how fishers and associated sectors respond (sometimes in unexpected ways) to variability in catches and market demand. I have a new appreciation of how important transboundary approaches are in understanding the relationships between environmental and socio-economic factors in complex fisheries."

PLYMOUTH MARINE LABORATORY (PML)

PML is a Centre of Excellence in Marine Science & Technology carrying out research in the marine environment from estuaries to the open ocean. PML has an internationally recognised track record in biogeochemical cycling research, using an interdisciplinary approach to study chemical and biological processes in the ocean as well as chemical exchanges with the atmosphere. Research areas include biodiversity and ecosystem function, coastal production processes, ecosystem modelling and forecasting, long-term observations, marine biogeochemical cycles, and valuing the marine environment.

SCOTTISH ASSOCIATION FOR MARINE SCIENCE (SAMS)

SAMS is Scotland's largest and oldest independent marine science organisation, delivering marine science for a productive and sustainably managed marine environment through innovative research, education and engagement with society. Based near Oban on the Scottish west coast, SAMS marine research and teaching portfolio is diverse in topic and discipline, global in outlook, project locations and relevance, and delivered in partnership with academic, business, government, regulatory, voluntary and civic society colleagues.

DR SÉVRINE SAILLEY

SOLSTICE-WIO PRINCIPAL INVESTIGATOR

"The SOLSTICE-WIO project was a great opportunity for us to interact with other scientist in a multi-disciplinary project. The training and science delivered during the project was beneficial to all involved and the working relationships forged during the project will be the foundations of future ground-breaking work."

PROFESSOR JOHN HOWE

SOLSTICE-WIO PRINCIPAL INVESTIGATOR

"It was a privilege to be involved in the important SOLSTICE-WIO project. I really enjoyed working with colleagues from Tanzania and Kenya and making new friends in the, sometimes challenging, environment around Pemba. I hope the opportunity to use the autonomous underwater vehicles will make a difference and help bring about a sustainable use of the WIO".

HERIOT-WATT UNIVERSITY (HW)

Founded in 1821, Heriot-Watt has a rich heritage and an established reputation as a leading research-led university and provider of education around the world, ranked 1st in Scotland and 9th university in the UK for research impact. The Lyell Centre for Earth and Marine Science and Technology is a collaboration between HWU and the British Geological Survey (BGS), which aims to develop and use innovative methods and new technologies to facilitate real-world solutions to address global challenges associated with the Earth's surface, sub-surface, oceans and atmosphere.

NATIONAL AND KAPODISTRIAN UNIVERSITY OF ATHENS (NKUA)

NKUA is a research University and, as a leader since 1837, it aims to advance knowledge and educate students in sciences and arts that will best serve the nation and the community of the twenty first century. Committed to innovation and academic excellence, NKUA seeks to infuse each member of our academic community with the passion of research and knowledge gain. NKUA encourages cultivation of creativity, maturation of social and cultural sensibilities as well as critical thinking, by supporting free and open dialogue and a culture of integrity and diversity.

DR ALEX POULTON

SOLSTICE-WIO PRINCIPAL INVESTIGATOR

"Being involved in SOLSTICE-WIO has greatly expanded my outlook on marine science, embedding my science in socio-economic problems and encouraging the sharing of skills and ideas as part of successful capacity-building activity. These have been skills that I considered relatively simple to the more complex – and this has not been a one-way flow of knowledge, skills and experience – interacting with new researchers always brings cross-fertilisation and widens ones' perspective."

DR DIONYSIOS RAITSOS

SOLSTICE-WIO PRINCIPAL INVESTIGATOR

"So fascinating to work with such a multicultural group, that led to substantial new knowledge in the WIO. Visiting our partners was a life-time experience!"

GLOBAL CHALLENGES RESEARCH FUND

INTRODUCING OUR FUNDER

SOLSTICE-WIO is funded by the Global Challenges Research Fund (GCRF) which supports cutting-edge research to address challenges faced by developing countries. It is part of the UK's Official Development Assistance (ODA) and is managed by the Department for Business, Energy and Industrial Strategy.

The fund addresses the United Nations sustainable development goals. It aims to maximise the impact of research and innovation to improve lives and opportunity in the developing world.

GCRF also work in partnership with other organisations including the United Nations Development Programme (UNDP).

GCRF and its partners are supporting programmes that:

- promote challenge-led disciplinary and interdisciplinary research, including the participation of researchers who may not previously have considered the applicability of their work to development issues;
- strengthen capacity for research, innovation and knowledge exchange in the UK and developing countries through partnership with excellent UK research and researchers;
- provide an agile response to emergencies where there is an urgent research need.

GCRF themes are:

- equitable access to sustainable development;
- sustainable economies and societies;
- human rights, good governance and social justice.

UK Research and Innovation

GCRF

GCRF'S SIX GLOBAL STRATEGIC CHALLENGE PORTFOLIOS

- CITIES AND SUSTAINABLE INFRASTRUCTURE
- EDUCATION
- FOOD SYSTEMS
- GLOBAL HEALTH
- RESILIENCE TO ENVIRONMENTAL SHOCKS AND CHANGE
- SECURITY, PROTRACTED CONFLICT, REFUGEE CRISES AND FORCED DISPLACEMENT

CLIMATE CHANGE IMPACTS ON THE WORLD'S OCEANS

MARINE ECOSYSTEMS UNDER PRESSURE

The world's oceans are entering an alarming period of change and uncertainty. Human activities have increased atmospheric concentrations of greenhouse gases, and raised the Earth's average surface temperature by around 1.1°C since the start of the Industrial Revolution. There is a high level of confidence that global warming will place additional pressure on ocean ecosystems through increased sea temperatures, rising sea levels and expanding oxygen minimum zones. The greenhouse gas, carbon dioxide, is also absorbed by the ocean, where it reacts with seawater, causing the ocean to become more acidic. The impacts of anthropogenic climate change on our oceans are not things that are going to happen in the distant future. Marine ecosystems are feeling these impacts now.

Global fisheries catch is increasingly dominated by warm-water species as a result of fish migrating towards the poles in response to rising ocean temperatures. Coral reefs, the most diverse of marine ecosystems, are already experiencing mass bleaching events that are becoming both more intense and more frequent. Although climate change is a global problem, its manifestation in various regions on the planet is often unique and shaped by local factors and there are no simple solutions for adapting to climate change.

Developing adaptation options requires scientific understanding of climate change at a global scale. It also requires regional expertise, detailed knowledge about the area in question, and local understanding of the social and environmental contexts. Small-scale fisheries are dominant in the WIO. They tend to operate at a family or community level, have low levels of capitalisation, and make an important contribution to food security and livelihoods. These small-scale fisheries communities are often dependent on coastal ecosystems such as coral reefs and mangroves, both as a source of food and coastal protection, making them among the most vulnerable to the impact of climate change.

Working together, the SOLSTICE-WIO partnership combined cutting edge ocean climate projections with local knowledge and understanding of the vulnerabilities of coastal communities. The project provided a unique outlook on how the accelerating impacts of climate change may alter the WIO upwelling system, the fisheries they support and communities they sustain.

GLOBAL FOOD SECURITY

THE GROWING ROLE OF THE MARINE ENVIRONMENT

Food security is a major global challenge that is expected to escalate due to population growth and the accelerating pace of climate change. The Food and Agriculture Organisation (FAO) of the United Nations defines food security as:

> *"when all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life."*
> **1996 WORLD FOOD SUMMIT, ROME DECLARATION ON WORLD FOOD SECURITY**

With expanding populations and subsequent increasing demand for food, some scientists have suggested relying on fish to feed the 9 billion people expected to inhabit the planet by 2050. Currently, around 821 million people are affected by food deprivation or chronic undernourishment, and almost 90 percent of global marine fish stocks are either fully exploited or overfished. Given the spotlight placed on fish to provide an adequate food supply to the growing global population, it is important to assess the role of fish in food security.

Estimates suggest that between 30 and 60 million people in the WIO's coastal communities are dependent on the coastal environment for goods, services, livelihood and income. However, data for many fisheries are underreported, especially in less regulated small-scale fisheries. SOLSTICE-WIO research on marine food security has helped to shed light on these communities that are not accurately represented in national statistics, but are highly dependent on the ocean.

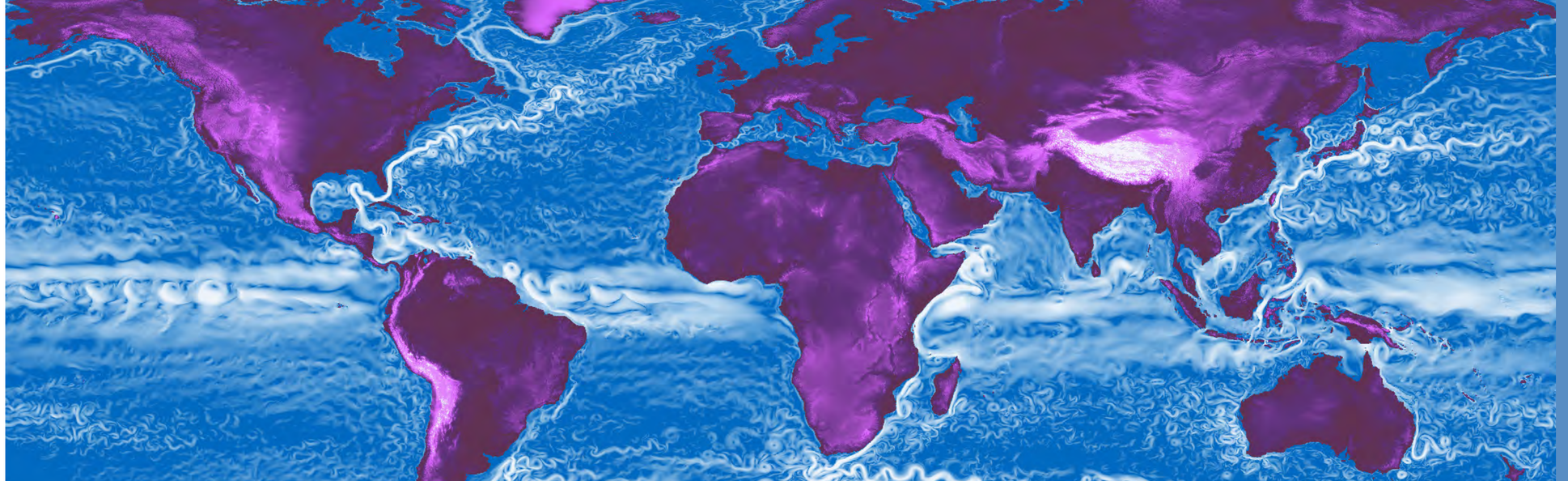
MARINE TECHNOLOGIES FOR SOCIETAL CHALLENGES

COMBINING MARINE ROBOTICS, SATELLITE DATA AND MODELS

SOLSTICE-WIO has deployed a combination of marine robotics, remote sensing and ocean models in the shelf waters of Kenya, Tanzania and South Africa to show how these can be used for cost-effective monitoring and predictions in data poor areas.

- Marine autonomous systems are becoming ever more reliable and easy to use for environmental observations – at a fraction of the cost of a research ship.
- Earth observation satellites monitor the oceans daily, collecting a wide range of marine data - most are freely available from global archives.
- Ocean models of increasingly high resolution make it possible to explore regional ecosystem dynamics, gain insights into reasons for variability and change, and deliver predictions to inform policy development, resource management and adaptation to future change.

Through extensive fieldwork, capacity development, data analysis and research publications, the project has demonstrated how these technologies can form the basis for environmental research and monitoring programmes to deliver decision making support for marine policy development and resource management.



UN SUSTAINABLE DEVELOPMENT GOALS

GLOBAL ACTION FOR A SUSTAINABLE FUTURE

The Sustainable Development Goals (SDGs) were adopted by all member states of the United Nations, in September 2015. They encapsulate a new understanding about holistic development, balancing economy, society and the environment. The SDGs express a vision of a fair, just and inclusive world that provides for all people into the future.

> *"What is special about the SDGs in the Western Indian Ocean is that this is the region with very high levels of poverty in the coastal zone so that dependence on marine ecosystem services is very high. Here, the SDGs are very helpful in ensuring that the rights and access for local communities to sea food and ocean resources are maintained and that the development which we desperately need is done in a way that doesn't cause environmental decline in the region and also doesn't take rights away from people."*
>
> **DAVID OBURA** DIRECTOR OF CORDIO EAST AFRICA

However, it is no simple matter to achieve all the goals simultaneously, and if we try and focus on just one or a few of the SDGs, others may be negatively affected. This highlights a fundamental challenge for the SDGs – that there are often trade-offs between the goals. The SDGs are said to be "whole and indivisible", meaning that they must be addressed in concert.

> *"We have to consider trade-offs between the SDGs because this is the reason they are necessary. If you try and maximize a single goal, for example food production (this is what humanity was doing for centuries), it leads to agricultural and fishing practices which are damaging to the environment. The trade-offs between producing food and maintaining a healthy environment are the sorts of things we need SDGs to help us balance."*
>
> **DAVID OBURA** DIRECTOR OF CORDIO EAST AFRICA

Understanding all the complex interactions between the SDGs needs accurate information. For the marine environment, ensuring a balance between fishing and ocean health requires information from many sources on many factors. In multidisciplinary projects like SOLSTICE-WIO, working with stakeholders and Governments to identify the key questions and needs for information and how ocean data services and products can be developed to meet these needs, gets us closer to achieving the UN Sustainable Development Goals.

WORKING IN PARTNERSHIP

In research dedicated to societal challenges, balancing the interests of scientists from different research cultures, institutions, disciplines, at different career stages, with varying political agendas and cultural differences is not easy. And yet an equitable partnership can be defined as a partnership where each member's benefits outweighs the challenges such a partnership brings.

Building an equitable partnership of all project partners was key to the success of SOLSTICE-WIO, and very much tied to its capacity strengthening activities. The partnerships we developed were characterised by transparency, joint ownership, and mutual responsibility and benefits for all partners. In project terms, this was embedded from the outset through co-design of the case studies and joint decision making at every step of the project.

HARNESSING THE POWER OF COLLABORATION

THE SOLSTICE-WIO NETWORK

Scientific networks are at the centre of all international programmes, especially those concentrated around “wicked problems” such as food security and sustainability. Well-organised networks harness capacity to solve shared but complex problems by unifying scarce resources, through the creation of Capacity Development opportunities, and by development of common knowledge and understanding.

The term “Network” is highly subjective, and so is the notion of what constitutes “network strength”. SOLSTICE-WIO defined its network as an output-based collaboration where two researchers become connected if they have co-authored a peer-reviewed paper.

Through more than 40 peer-reviewed publications in 2020-21 produced by more than 30 collaborating institutions, SOLSTICE-WIO built an international and interdisciplinary network focused around the challenge of food security, sustainable use of living marine resources and impact of climate change on marine communities. Its key characteristics include research excellence, sustainability (ability to secure future funding) and the potential to address complex problems (research capability). The ultimate ambition is for this to grow and evolve into a global network, as SOLSTICE-WIO data sets, models and ideas continue to be exploited by the global research community in the years to come.

- **A** AUSTRALIA
- **B** CANADA
- **C** DENMARK — ONE PAPER LED
- **D** FRANCE — TWO PAPERS LED
- **E** GERMANY
- **F** GREECE
- **G** INDIA — ONE PAPER LED
- **H** IRELAND
- **I** ISRAEL
- **J** ITALY
- **K** JAPAN
- **L** KENYA — FIVE PAPERS LED
- **M** MALAYSIA
- **N** MOZAMBIQUE — TWO PAPERS LED
- **O** NEW CALEDONIA
- **P** NORWAY
- **Q** RÉUNION
- **R** SAUDI ARABIA
- **S** SOUTH AFRICA — SIXTEEN PAPERS LED
- **T** SPAIN
- **U** SWEDEN
- **V** TANZANIA — FIVE PAPERS LED
- **W** UK — SEVENTEEN PAPERS LED
- **X** USA

THE FUTURE OF OCEANOGRAPHIC RESEARCH
OUR EARLY CAREER RESEARCHERS

SOLSTICE-WIO supported great career development opportunities for Early Career Researchers (ECRs) both in the WIO countries and in the UK. More than 50 outstanding early career researchers have been supported via fellowships, travel grants, exchange visits, capacity development workshops and training programmes, participation in the fieldwork campaigns and mentoring. Here we are proud to introduce a cohort of SOLSTICE-WIO ECRs who led the first wave of project peer reviewed publications in 2020-2021 working in close international collaboration.

DR ZOE JACOBS

Dr Zoe Jacobs is a Biogeochemical Ocean Modeller, in the Marine Systems Modelling group at the National Oceanography Centre in Southampton, UK. She is interested in what drives productivity in the ocean and in understanding how this will be affected under future climate change scenarios.

As part of the SOLSTICE-WIO project, Zoe has used models in conjunction with satellite remote sensing to investigate what drives the productive regions that sustain fisheries in the WIO areas off North Kenya Banks and Agulhas Bank. She also used forward projection models to identify key regionally important climate stressors over the East African Coastal Current.

Zoe is also passionate about capacity development. She served as an Early Career representative on the Project Leadership Team, led the SOLSTICE-WIO Capacity Development work package as well as the Massive Open Online Course (MOOC) international mentoring team. One of the most memorable SOLSTICE-WIO experiences was the visit to the fishing village and market in Zanzibar with Dr Narriman Jiddawi – her wealth of knowledge is astounding.

SOLSTICE-WIO PUBLICATIONS

Jacobs, Z.L., et al. (2021) Key climate change stressors of marine ecosystems along the path of the East African coastal current, Ocean Coast Manag., doi: 10.1016/j.ocecoaman.2021.105627.
Jacobs, Z.L., et al. Drivers of productivity on the Agulhas Bank and the importance for marine ecosystems. Deep-Sea Res. Part II Top. Stud. Oceanogr. (In Review).
Jacobs, Z. L., et al. (2020) Shelf-break upwelling and productivity over the North Kenya Banks: The importance of large-scale ocean dynamics. J. Geophys. Res. Oceans, doi: 10.1029/2019JC015519.
Jacobs, Z.L. & Jebri, F., et al. (2020) A major ecosystem shift in coastal East African waters during the 1997/98 Super El Niño as detected using remote sensing data. Remote Sens., doi: 10.3390/rs12193127.
Jacobs, Z.L., et al. Retention properties of the Agulhas Bank and their relevance to the chokka squid life cycle. Deep-Sea Res. Part II Top. Stud. Oceanogr. (In Review)

DR FATMA JEBRI

Dr Fatma Jebri is a research scientist in Satellite Oceanography within the Marine Physics and Ocean Climate group at the National Oceanography Centre in Southampton, UK. Fatma is passionate about investigating links between ocean biological and physical processes using Earth observations in synergy with model outputs and fisheries data. She enjoys coding and data analysis, with a particular interest in multivariate statistics and machine learning.

As a member of the SOLSTICE-WIO project team, Fatma used ocean remote sensing observations to study marine ecosystem variability in the WIO. Additionally, she worked on capacity building through scientific and technical support of WIO partners who were using remote sensing in their research.

Being part of a multidisciplinary project such as SOLSTICE-WIO has reshaped her perception of ocean research. When addressing a hypothesis or a question, she now thinks about the potential socio-economic impacts that research has, beyond purely scientific curiosity. SOLSTICE-WIO also offered Fatma a memorable human experience, in getting to know the amazing collaborators and building connections with scientists and students from different backgrounds.

SOLSTICE-WIO PUBLICATIONS

Jebri, F., et al. (2020) Interannual monsoon wind variability as a key driver of East African small pelagic fisheries. Sci. Rep., doi: 10.1016/j.dsr2.2020.104813
Jebri, F., et al. (2022) Unravelling links between squid catch variations and biophysical mechanisms in South African waters, Deep-Sea Res. Part II Top. Stud. Oceanogr., doi: 10.1016/j.dsr2.2022.105028
Jacobs, Z.L. & Jebri, F., et al. (2020) A major ecosystem shift in coastal East African waters during the 1997/98 Super El Niño as detected using remote sensing data. Remote Sens., doi: 10.3390/rs12193127
Jebri, F., et al. Machine learning and Earth observation reveal the dynamics of productive upwelling regimes over the Agulhas Bank, Remote Sens. Environ. (In Review)

HELLEN KIZENGA

Hellen Kizenga is an early career marine scientist from the WIO and an assistant lecturer at the University of Dar es Salaam, Tanzania. She holds a BSc in Microbiology and a Master's degree in Marine Sciences from the University of Dar es Salaam and recently completed the NF-POGO Centre of Excellence in Observational Oceanography training programme at the Alfred Wegener Institute, Germany.

Hellen's research interests focus on primary productivity (phytoplankton) and small pelagic fish species. She applies skills in remote sensing, in-situ observation, and social sciences to ensure that scientists collaborate with traditional knowledge in generating information on the sustainability of marine and coastal resources. Her passion for remote sensing applications formed part of her collaboration with the SOLSTICE-WIO project, in which she investigated biophysical controls on the Mackerel fish catch in the Pemba Channel. This project has been key to boosting her career through training on using remote sensing products, analysis, and manuscript production.

Her memorable experience is meeting and working with a very committed, hardworking oceanography expert, Dr Fatma Jebri from the National Oceanography Centre who has continued to be a great mentor.

SOLSTICE-WIO PUBLICATIONS

Kizenga, H.J., et al. (2021) Variability of mackerel fish catch and remotely-sensed biophysical controls in the eastern Pemba Channel, Ocean Coast Manag., doi: 10.1016/j.ocecoaman.2021.105593

KENNEDY E. OSUKA

Kennedy Osuka is a fish ecologist and fisheries scientist interested in understanding linkages between marine habitats and fish communities. As a research scientist at CORDIO East Africa working under the Fish and Fisheries programme, since 2010, Kennedy developed great interest in artisanal fisheries research, coral reef resilience, management and conservation. At CORDIO he contributed in the development of responsible fisheries and building resilience to climate change policies for small-scale fisheries of the Kenyan coast.

Kennedy's current PhD research at the Department of Environment and Geography, University of York, seeks to contribute towards the application of marine robotics to produce habitat and biotope mapping of shallow (0-30 m) and mesophotic (30-150 m) habitats of the Pemba Channel in Tanzania. The study will provide information to support conservation and management of the seascape. His work also feeds directly into questions on sustainability and food security and threats of climate change. His research interests are aligned to finding innovative solutions to problems around ecological and social resilience to climate change, environmental conservation, and policy and governance.

SOLSTICE-WIO PUBLICATIONS

Osuka, K.E., et al. (2021) Characteristics of shallow and mesophotic environments of the Pemba Channel, Tanzania: Implications for management and conservation, Ocean Coast Manag., doi: 10.1016/j.ocecoaman.2020.105463

Osuka, K.E., et al. (2021) Protection outcomes for fish trophic groups across a range of management regimes, Mar. Pollut. Bull., doi: 10.1016/j.marpolbul.2021.113010

DAMARIS MUTIA

Damaris Mutia is an early career scientist in the field of Physical Oceanography at the Kenya Marine and Fisheries Research Institute in Mombassa. She holds a Bachelor of Science in Physics from the Jomo Kenyatta University of Agriculture and Technology. Her main research interests span operational oceanography, ocean modelling, understanding ocean circulation and ocean heat budgets. In building her ocean sciences career, she has participated in both national and international training in the field of Physical Oceanography.

Through the early career scientist capacity-building aspect of the SOLSTICE–WIO project, Damaris has gained skills in remote sensing and data analysis techniques. This training enabled her research into the contribution of the Tana River discharge to productivity in Ungwana Bay (on the Kenyan coast), which has now been published in a Special Issue of Ocean and Coastal Management.

Her most memorable SOLSTICE-WIO experience was travelling to Plymouth, in the UK, for a month-long exchange programme. This allowed her valuable experience through spending time with scientists a Plymouth Marine Laboratory carrying out data analysis and manuscript preparation.

SOLSTICE-WIO PUBLICATIONS

Mutia, D., et al. (2021) Productivity driven by Tana River discharge is spatially limited in Kenyan coastal waters, Ocean Coast Manag., doi: 10.1016/j.ocecoaman.2021.105713

SIXOLILE MAZWANE

Sixolile Mazwane is currently studying for a PhD at Nelson Mandela University, Gqeberha, South Africa as part of the SOLSTICE-WIO project.
Her interests are in pelagic ecosystems with an emphasis on phytoplankton dynamics and primary production. She worked with phytoplankton during her undergraduate degree, looking at the growth responses of phytoplankton from ephemeral wetlands. More recently, her work has focused on biological oceanography, investigating the phytoplankton biomass and primary production on the Agulhas Bank on the southern coast of Africa.

Sixolile is interested in remote sensing and the use of satellite data (Chlorophyll, sea surface temperature, photosynthetically active radiation, etc.) to understand phytoplankton dynamics in shelf seas ecosystems. Her research provides many of the fundamental biological datasets used in the South African case study which are relevant to efforts determining productivity at higher trophic levels.

I benefited from SOLSTICE-WIO in terms of collaborating with different scientists, travelling outside of my country, and getting experience on different data analysis methods.

SOLSTICE-WIO PUBLICATIONS

Mazwane, S.L., et al. Seasonal and long-term stability of Net Primary Production on the Agulhas Bank, 1998 - 2018. Deep-Sea Res. Part II Top. Stud. Oceanogr. (In Review)

SARAH TAYLOR

Sarah Taylor is a passionate Environmental Economist from South Africa, where she gained her Bachelor of Business Science degree at Rhodes University. She is particularly interested in valuation of natural capital and interactions between natural resources and economies. She gained skills in econometric modelling during her Master's degree in Economics at Nelson Mandela University, during which she assessed the relationship between economic growth and climate change on marine food security. Sarah's current research interests are in the use of ocean accounting and bioeconomic models as policy tools for sustainable ocean economy growth.

Sarah has found SOLSTICE-WIO to be an incredible experience for both her academic and personal growth. She has particularly valued the connection to researchers from so many different disciplines, which has expanded her thinking beyond economics. One of her most memorable experiences was walking alongside Dr Narriman Jiddawi through the fish markets in Tanzania as Narriman explained how fishing is the heartbeat of the coastal communities. This experience breathed life into her research on marine food security and made Sarah more determined to continue working towards achieving science into policy.

SOLSTICE-WIO PUBLICATIONS

Taylor, S.F.W., et al. (2021) The complex relationship between asset wealth, adaptation, and diversification in tropical fisheries, Ocean Coast Manag., doi: 10.1016/j.ocecoaman.2021.105808
Taylor, S.F.W., et al. (2019) Measurement and implications of marine food security in the Western Indian Ocean: an impending crisis? Food Secur., doi: 10.1007/s12571-019-00971-6

LISA HANCKE

Lisa Hanke is an oceanographer with more than 15 years' experience in the practical aspects of metocean data collection and project management for both marine science campaigns and the offshore energy industry. She is a technically minded and hands-on individual with extensive experience in the design and deployment of deep-water mooring systems, weather buoys and other oceanographic survey equipment. Her early scientific career focused on mesoscale circulation and connectivity in the in the Mozambique Channel and the shelf regions off the South African south coast.

Lisa is currently pursuing a PhD in Ocean Science at Nelson Mandela University under the SOLSTICE-WIO South African case study. Her work investigates the circulation and temperature structures on the Agulhas Bank through in situ measurements, and specifically the dynamics associated with an upwelling filament that enhances productivity on the interior of the central Agulhas Bank.

The SOLSTICE-WIO programme has provided Lisa with opportunities for travel and interaction with international scientists through the Remote Sensing and GIS workshop in Zanzibar and a visit to the NOC.

DR STEPHEN KELLY

Dr Stephen Kelly is an early career Ocean Modeller working in the Marine Systems Modelling group at the National Oceanography Centre. His main research interest is in marine connectivity, specifically, how spatially separated areas of ocean are connected by ocean currents.

Stephen studied physics to Master's level, before taking up oceanography for his PhD studies. During his PhD, Stephen specialised in Lagrangian modelling of the Arctic Ocean. As part of the SOLSTICE-WIO team, he has transferred his focus to Indian Ocean. His current research involves characterising connectivity pathways and timescales across the WIO. He has also contributed to particle-tracking experiments as part of the SOLSTICE-WIO project.

Stephen's favourite part of the project was the opportunity to work with a range of amazing colleagues on a selection of different topics, rather than having a single narrow focus. He has found working on an interdisciplinary project has widened his academic horizons. Stephen has found it particularly rewarding to see how his work can complement the socio-economic side of the SOLSTICE-WIO project, ultimately addressing problems that affect people's lives.

DR JULIANE WIHSGOTT

Dr Juliane Wihsgott is a physical oceanographer with a strong interest in biophysical interactions. As a member of the international SOLSTICE-WIO team, Juliane is investigating the biophysical interactions that sustain the coastal fisheries of South Africa, Tanzania and Kenya, and their sensitivities to climate change. She is part of a team collecting new observations using ocean robots. She then combines these observations with data from ocean models to identify key physical controls on primary productivity.

In addition to the scientific objectives within the SOLSTICE-WIO project, there is a strong emphasis on building research capacity among our project partners in the WIO. This is something Juliane feels passionate about, and she has actively sought to transfer her skills by presenting training in processing and interpretation of observational ocean data products.

Juliane's SOLSTICE-WIO highlight was taking the first ever turbulence measurements in the Pemba Channel, Tanzania with fellow early career researchers, Rachel Sabuni and Violeth Swai. She found their enthusiasm to gain new knowledge and acquire new skills remarkable.

HOSTING A GLOBAL CLASSROOM

"OCEAN SCIENCE IN ACTION" A HIGHLY SUCCESSFUL MASSIVE OPEN ONLINE COURSE (MOOC)

The course, named Ocean Science in Action: Addressing Marine Ecosystems and Food Security in the Western Indian Ocean, introduces learners to innovative marine technologies and their applications used to tackle the challenges of the sustainable management of marine ecosystems. Since its launch on 5 October 2020, the MOOC, which is freely available through Future Learn, has had significant global reach, with 3700 enrolments from 140 countries to date.

The four-week course is designed for people working within marine related industries, such as fisheries, both in the WIO and those who study this ocean region. It is also more widely relevant to those with an interest in ocean management and conservation, the technology used to study the ocean, and the impact of accelerated climate change on the marine environment. The MOOC features over 30 videos, introducing learners to innovative marine technologies and their application in tackling the challenges of sustainably managing marine ecosystems.

Using case studies from the SOLSTICE-WIO project, the course illustrates how marine science is applied to the sustainable management of marine ecosystems and how this can contribute to global efforts in meeting the UN Sustainable Development Goals and the challenges of the Ocean Decade 2030.

Building upon this success the SOLSTICE-WIO MOOC is also now being promoted by Future Learn as part of their effort to create the world's most comprehensive climate change social learning curriculum as part of the COP26 initiatives. This exciting endeavour includes courses from leading industry and academic institutions all of which provide learners with the skills and knowledge required to work towards combating climate change and achieving the four major goals of COP26:

- Secure global net-zero by mid-century and keep 1.5°C within reach;
- Adapt to protect communities and natural habitats;
- Mobilise finance;
- Work together to deliver.

As part of the SOLSTICE-WIO legacy, the MOOC will continue to be available via Future Learn.

OVER THIRTY VIDEO LECTURES

3500+ INTERACTIVE COMMENTS

FIVE STAR USER RATING

THREE MARINE TECHNOLOGIES

INTERNATIONAL EARLY CAREER SCIENTIST MENTORING TEAM

FOUR CASE STUDIES SET IN THE INDIAN OCEAN

THE MOOC IS VERY HIGHLY RATED BY LEARNERS AND HAS RECEIVED SOME GREAT REVIEWS:

"A very informative and engaging course that I really enjoyed. The content was highly detailed and I enjoyed studying such topical and fascinating case studies. Thank you!"

"Informative and wonderfully interactive."

"I really enjoyed this course. The content, although complicated was conveyed in an easy-to-understand way, and the quizzes along the way really helped with comprehension. I feel that I've expanded upon my basic knowledge of marine ecosystems and can't wait to continue my learning journey."

140 COUNTRIES
WITH LEARNERS

ADDRESSING SIX OF THE UN SUSTAINABLE DEVELOPMENT GOALS

CONTRIBUTING TO THE UN DECADE OF OCEAN SCIENCE PRIORITY AREAS

3700+ TOTAL LEARNERS → 54% → **2000+** ACTIVE PARTICIPANTS → 33% → **600+** FULLY COMPLETE

BUILDING CAPACITY TO ADDRESS FUTURE CHALLENGES

WORKING WITH THE NEXT GENERATION OF WIO SCIENTISTS

The SOLSTICE-WIO international partnership carried out an extensive capacity building programme to support and expand partner countries' activities that address national challenges of sustainable development and international initiatives, such as the UN Sustainable Development Goals and the UN Decade of Ocean Science for Sustainable Development (2021-2030). These activities also ensured alignment with the UK Aid Strategy, in particular to strengthening resilience and response to crises, tackling extreme poverty and helping the world's most vulnerable people.

SOLSTICE-WIO capacity strengthening activities came in many forms, from workshops and training courses enabling scientists to access, analyse and interpret data, to "on-the-job" training during multiple fieldwork campaigns, which included research cruises and marine robotic missions. With research excellence being at the heart of all capacity development activities, SOLSTICE-WIO also provided extensive training and support for early career researchers leading to publication of peer-reviewed papers in international scientific journals.

STATISTICS

7 INTERNATIONAL INSTITUTIONS	**5** WORKSHOPS & TRAINING COURSES DELIVERED	**5** "ON THE JOB" FIELDWORK TRAINING SESSIONS	**76** PARTICIPANTS FROM SIX COUNTRIES
12 EXCHANGE VISITS RESULTING IN TWELVE FIRST AUTHOR PAPERS	**22** PAPERS WITH AFRICAN LEAD AUTHORS	**13** PAPERS LED BY AFRICAN EARLY CAREER RESEARCHERS	**100+** CO-AUTHORS FROM WIO COUNTRIES

MAKING AN IMPACT

Across the WIO region more than 60 million people are dependent upon coastal and marine ecosystems for their food security and livelihoods. This coastal population is expanding and faces serious challenges due to habitat destruction, over exploitation of decreasing resources and the accelerating impacts of climate change on marine ecosystems. Together, these point to a looming humanitarian disaster across the region. Governments have little information upon which to base their response, and moreover, often have insufficient capacity and infrastructure to initiate the necessary research and planning.

SOLSTICE-WIO focused on the GCRF Challenge "Equitable access to sustainable development" (challenge area: "Secure and resilient food systems"). The project was also strongly aligned with the GCRF challenge "Sustainable economies and societies" (with relevance to all four challenge areas: sustainable livelihoods; resilience; sustainable communities; sustainable resources). SOLSTICE-WIO addressed these challenges via research Case Studies set up in three developing countries (South Africa, Kenya and Tanzania), where food security amongst the poorest coastal communities is of pivotal importance.

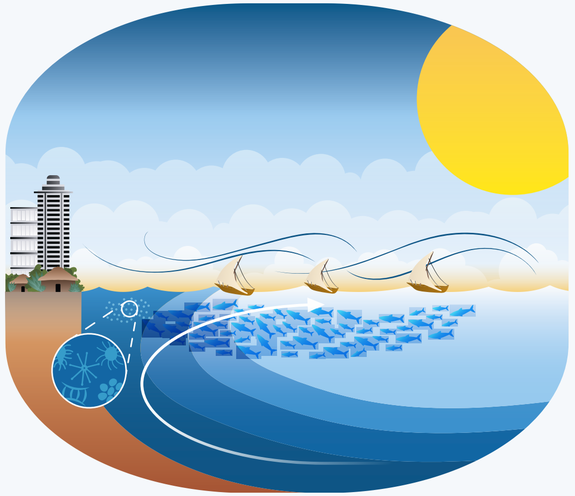
OCEAN UPWELLING
AT THE CROSSROADS OF OCEAN DYNAMICS AND SOCIO-ECONOMICS

At the core of SOLSTICE-WIO research is coastal upwelling, one of the key processes by which deep, nutrient-rich ocean waters are brought to its sunlit surface, thus sustaining rich and productive fisheries.

The major permanent upwelling systems or Eastern Boundary Upwelling Systems (there are four such systems on Earth) sustain the most productive ecosystems in the world and have received a huge amount of international research attention. In contrast, seasonal upwelling systems experience upwelling for only part of the year. Despite this seasonality, these upwelling systems can still be highly productive and are very important for regional fisheries.

Seasonal upwelling systems, despite being extremely important to the food security of millions of people engaged in the small scale and artisanal fisheries that they sustain, are severely understudied, especially along the coastlines of developing countries. All seasonal upwelling systems have unique features in terms of their underlying ocean dynamics, complex ecosystems, and the fisheries they support. These cascade into the intricate social fabric of the associated supply chains, conflicts of interest, cultures rooted in the marine environment and the emerging feedbacks between their social and ecological components.

Seasonal upwelling systems can also be highly variable in time and space and are beginning to exhibit the first signs of climate change impacts leading to regime shifts, tipping points and emergence of new socio-ecological systems. More generally, upwelling systems are also "windows into the deep ocean" and are the places where acidification and deoxygenation will manifest first.



OCEAN UPWELLING AND THE UN SUSTAINABLE DEVELOPMENT GOALS
A COMPLEX INTERPLAY BETWEEN MULTIPLE SDGs

Coastal upwellings and the ecosystems they sustain SDG 14 provide key services and benefits to people. These services directly support millions of jobs in multiple economic sectors SDG 8 in coastal and distant states, by providing living-resource for extraction. Direct benefits are mediated through fish catch SDG 12, supporting jobs, income and value chains SDG 8 sustaining use of living resources SDG 12, and facilitating provision of transport and infrastructure SDG 9 in rural areas and in cities SDG 11, with many urban centres beginning their ancient history around the rich fishing grounds.

Through these multiple benefits, coastal upwellings contribute to reducing hunger SDG 2 and poverty SDG 1, thus improving health SDG 3 directly through provision of food rich in nutrients including vitamins, minerals, and omega-3 fatty acids and indirectly, by providing a source of income. In tropical countries, upwelling-based fisheries and the supply chains they sustain are especially important for social cohesion, strengthening gender SDG 5 and social equality SDG 10. Income from fisheries, especially in the hands of women, translates to education for children SDG 4. Ocean upwelling ecosystems are interconnected with the life on land SDG 15 via their social components, as continuous degradation of land based ecosystems often result in mounting pressure on the marine ecosystems through increased migration to the coast in societies at the frontier of food insecurity SDG 2. Diplomatic and armed conflicts over fishing rights have been common throughout human history. Responsible and sustainable exploitation of shared stocks based on cooperation at all scales, from villages to nations, ensures community stability and thus reduces the root causes of armed conflict SDG 16.

However, overfishing results in pressures that may drive decline in the health of upwelling systems SDG 12. Upwelling systems act as "windows into the deep ocean" and are the places where acidification and deoxygenation will manifest first. They are also places where water temperatures will remain cooler for longer. This means that some upwelling systems and their neighbouring communities are especially vulnerable to the early onset of climate change impacts, whilst other systems may act as climate change refugia SDG 13.

Managing these complex socio-ecological systems requires appropriate awareness and knowledge SDG 4, governance mechanisms SDG 16, international research partnerships and participation and investments by a wide variety of stakeholders SDG 17.

ENHANCING UPTAKE OF CUTTING-EDGE SCIENTIFIC RESEARCH IN POLICY DEVELOPMENT

GENERATING ACTIONABLE KNOWLEDGE

Interdisciplinary research is increasingly called upon to provide actionable evidence for sustainable development. Enhancing research uptake into management and policy is one of the key objectives of the GCRF projects. However, there are many barriers to the effective communication of science into policy, as policy processes are complex, multifactorial and nonlinear, whilst decision-making is shaped by many factors including cultural and institutional values, availability of resources, personal expertise, pragmatic political considerations and traditions. SOLSTICE-WIO has shown that researchers are able to overcome these barriers.

In supporting policy uptake of SOLSTICE-WIO research, the project has engaged with the WIO LME SAPPHIRE programme (The Western Indian Ocean Large Marine Ecosystems Strategic Action Programme Policy Harmonisation and Institutional Reforms) executed by the Nairobi Convention and implemented by the United Nations Development Programme (UNDP) with Global Environment Facility (GEF) funding.

Both the SAPPHIRE and SOLSTICE-WIO projects are facilitating the development of policy relevant material by Kenyan and Tanzanian national teams. The uptake of science into policy is outlined in the SOLSTICE-WIO Science to Policy Action plan, facilitated by WIOMSA, which enables research outputs to be taken up into national, regional and transboundary policy processes in the WIO region. These complementary initiatives are designed to inform the science-to-policy process and to bring fisheries and environmental research activities closer together in the WIO. This effort provides an excellent example of Governments utilizing focused support from diverse sources whilst working towards priority issues in their respective countries.

Syntheses of the policy relevant messages arising from SOLSTICE-WIO research are presented in a series of 'Summaries of Policy-Relevant Information' available on the SOLSTICE-WIO project website*:

KENYA

- Accelerating climate change impacts on Kenya's marine ecosystems – what to be prepared for?
- Importance of ocean upwelling at the North Kenya Banks for the migratory fish species of the WIO region
- The key features of the North Kenya Banks upwelling and a need for a risk-based approach to fisheries management

TANZANIA

- Towards a joint management of the living resources in the Pemba Channel:
  - Part 1: Oceanographic underpinning.
  - Part 2: Accelerating Climate Change impacts on marine ecosystems in Tanzania – what to be prepared for?
  - Part 3: Joint management of the small pelagics in the Pemba and Zanzibar Channels
- Data management for ocean governance: Marine information sharing for improved ocean governance and national policy development

*solstice-wio.org/outputs/policy-briefs

EAST AFRICAN COASTAL CURRENT ECOSYSTEMS
AT THE FRONTIER OF CLIMATE CHANGE AND FOOD SECURITY

A SPECIAL ISSUE OF OCEAN AND COASTAL MANAGEMENT

The East African Coastal Current (EACC) flows along the coastlines of Tanzania and Kenya encompassing a largely oligotrophic environment, which is nonetheless characterised by rich and diverse marine ecosystems and habitats. More than 60 million people currently live along the EACC coastline, a number expected to double by 2030. Some EACC coastal communities experience the highest rates of poverty in the world. These communities are highly dependent on the ocean for economic stability, food security, and social cohesion.

Strong fluctuations in key fisheries occur in the region, due to the combined effects of climate change, natural ecosystem variability and overfishing. Understanding and managing fisheries under the growing threat of climate change impacts and food insecurity in the region requires good understanding of the marine environment, key environmental controls on local ecosystems and economic and social factors affecting the dependence of the coastal population on marine resources. However, the EACC region is one of the most poorly sampled and analysed marine domains in the world, due to both restricted regional marine research capacity, in recent years, and the challenges of marine security (piracy) impeding international research expeditions. In this Special Issue, SOLSTICE-WIO presents observational and modelling studies addressing research challenges related to the EACC region.

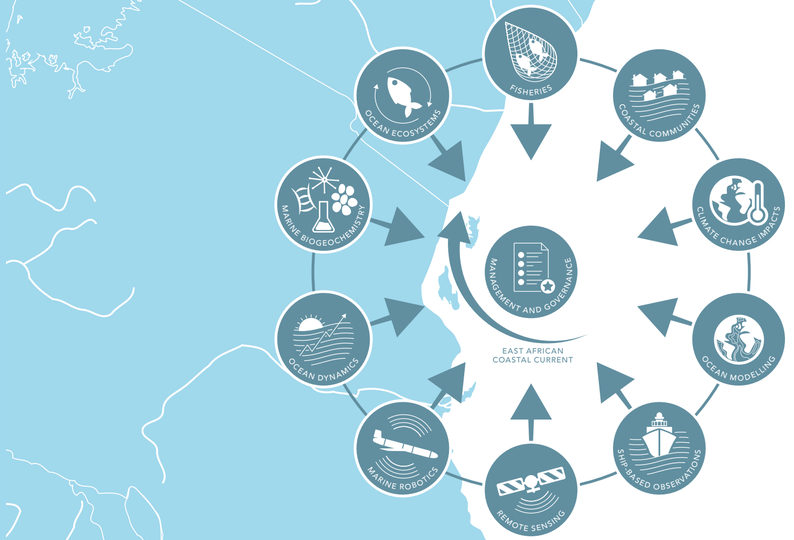
DR STUART PAINTER
MANAGING GUEST EDITOR

Dr Stuart Painter led the guest editorial team during production of a Special Issue in Ocean and Coastal Management on East African Coastal Current ecosystems. He is a Biological Oceanographer and Biogeochemist in the Ocean BioGeosciences group at the National Oceanography Centre, UK. He is interested in how ocean productivity is influenced by nutrient cycling and by biophysical interactions. As part of the SOLSTICE-WIO project, Stuart led fieldwork in Tanzania to study the marine environment of Pemba Channel to better understand the spatial variability in biogeochemical properties within a region that is an important focus for small pelagic fisheries.

Stuart was part of the Project Leadership Team and contributed to the MOOC programme and to a wide range of capacity development activities in the area of marine biogeochemistry.

"This Special Issue is the output of a great collaborative effort between researchers in Tanzania, Kenya, South Africa and the UK. With studies focused on interdisciplinary problems in poorly understood marine waters it is particularly pleasing to see African early career researchers take leading roles in addressing problems with immediate societal implications"

DR STUART PAINTER



STATISTICS

14 PAPERS ADDRESSING CHALLENGES OF THE EACC REGION

40 CO-AUTHORS FROM LEAST DEVELOPED COUNTRIES

7 PAPERS LED BY AFRICAN RESEARCHERS

62 CITATIONS IN 2021

3 PAPERS LED BY AFRICAN EARLY CAREER RESEARCHERS

79 INTERNATIONALLY COLLABORATING CO-AUTHORS

DYNAMICS OF AGULHAS BANK, SOUTH AFRICA

ECOSYSTEM SHIFTS AND FUTURE TRENDS IN THE SQUID FISHERY

A SPECIAL ISSUE IN DEEP-SEA RESEARCH PART II: TOPICAL STUDIES IN OCEANOGRAPHY

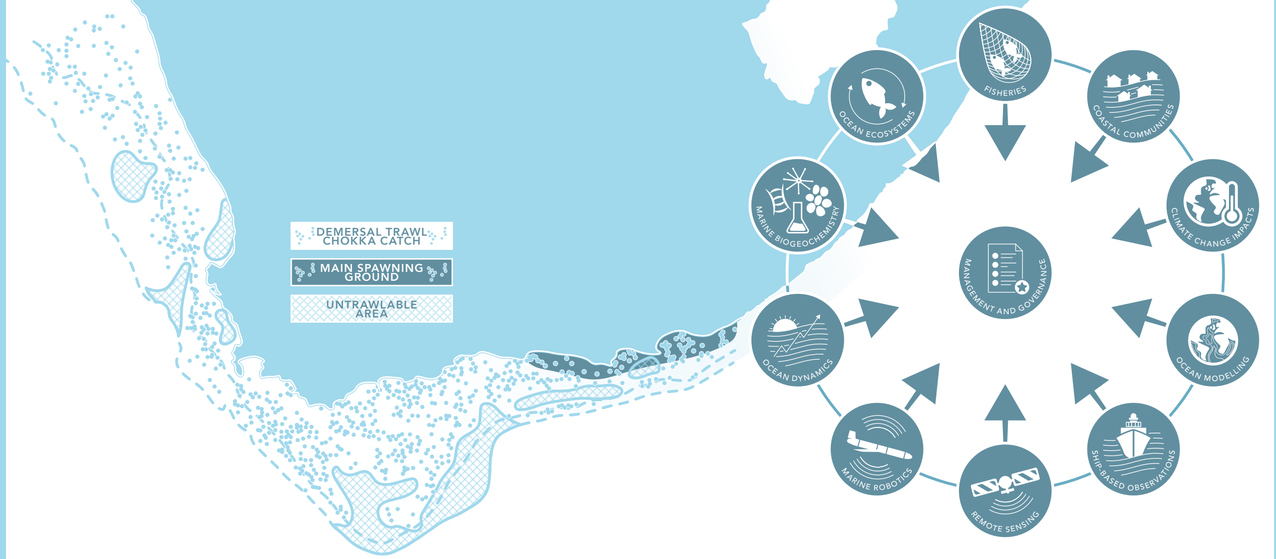
In South Africa, the chokka squid fishery is a mainstay to the impoverished Eastern Cape Province and some 35,000 people who depend on its earnings. It differs from the East African fisheries in that this fishery comprises both modern freezer vessels (122) and fishers (2,400) who catch the squid with hand-lines. Fishers are paid for their daily catch, which, although small on annual tonnage compared to other fisheries in South Africa, fetches top prices in European markets. This makes it the 4th most valuable fishery in the country. Unfortunately, from time to time, catches fall drastically (~80%), causing great socio-economic hardship for both the industrial side of the fishery and the fishers and their dependents.

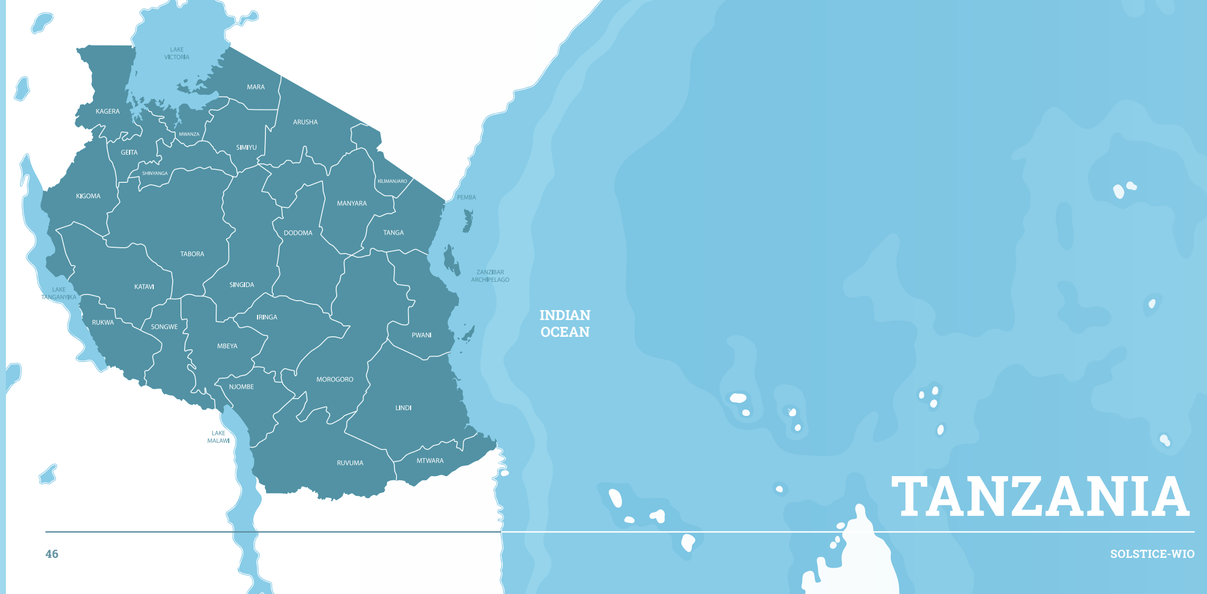
Chokka squid live in one of the most dynamic, contrasting shelf environments found anywhere in the world — the Agulhas Bank — nested at the southern tip of Africa between the warm and powerful Agulhas Current and the massive Benguela upwelling system on the west coast. Consequently, it has always been thought that these crashes are caused by extraordinary environment conditions — either during spawning or at the time of recruitment when the tiny squid paralarvae are most susceptible to starvation. In trying to understand the root-causes of these catch crashes, SOLSTICE-WIO innovatively combined marine robotics, modelling, remote sensing, field observations and socio-economic studies to reveal key processes underpinning the dynamics of the Agulhas Bank and the impact on catch crashes.

LAUREN CARTER
MANAGING GUEST EDITOR

Lauren Carter was the Managing Guest Editor for the South African Special Issue published in the scientific journal Deep-Sea Research Part II. Lauren holds Honours degrees in both English and Social Science. She has been in the forefront of publishing for some 20 years and is based in Cape Town.

> *"From a Managing Guest Editor's view point, SOLSTICE-WIO (SA) has been an amazingly successful multi-disciplinary project. Not only has it harnessed research capabilities in UK and South African institutions and synergised northern and southern scientists, it has also provided a unique and fertile environment for young South African postgraduate and early career researchers to grow."*
>
> LAUREN CARTER





TANZANIA

SMALL FISH WITH A BIG MISSION

SMALL PELAGICS OF THE PEMBA CHANNEL

Small pelagic fish are important for local communities in the Zanzibar Archipelago and mainland Tanzania as a source of food security, nutrition and livelihood support. This diverse group includes mackerel, sardines and anchovies and can be found in schools over the continental shelf or in bays and deep lagoons with nutrient rich waters. Small pelagics are more abundant during the southeast monsoon, when stronger winds drive upwelling that brings nutrient rich water to the surface.

Despite its importance for coastal economies, there is a lack of data and information about the small pelagic fishery of Pemba Channel, which hampers effective management. Using marine robotics, modelling, remote sensing, field observations and socio-economic studies, SOLSTICE-WIO has identified the key environmental and anthropogenic drivers of the main species and addressed how climatic pressures may influence this fishery in the years ahead.

A UNIQUE TRANS-DISCIPLINARY DATASET FOR COASTAL TANZANIA

TANZANIA DATASETS

SOLSTICE-WIO completed a major interdisciplinary field campaign covering the coastal zones and shelf waters of Tanzania. The resulting data set includes physical, biogeochemical, biological and socio-economic data collected in the coastal regions and shelf waters of mainland Tanzania and the main offshore islands.

In addition to ship-based fieldwork in the Pemba Channel, three key, cost-effective, mature technologies were used to complement traditional observation techniques. Satellite remote sensing, numerical ocean models and autonomous robotic technologies were used to efficiently deliver near real-time environmental data to support the ship effort. Fieldwork on land documented the coastal socio-economic, governance, and local knowledge systems of the fishing communities of Unguja, Pemba and Mafia Islands and the mainland region of Tanga to understand local resource-use patterns and local responses to social, economic, political, and ecological change. This data set has been extensively analysed by the SOLSTICE-WIO project partners in papers published in the Special Issue of Ocean and Coastal Management (East African Coastal Current ecosystems: at the frontier of climate change and food security).

AN INTERNATIONAL RESEARCH TEAM

79 RESEARCH SCIENTISTS AND ENGINEERS

26 RESEARCH INSTITUTIONS

14 PROJECT PAPERS DEDICATED TO THE CASE STUDY

SHIP-BASED OBSERVATIONS

43 PRIMARY SAMPLING STATIONS

103 PHYTOPLANKTON SAMPLES

1,487 BIOGEOCHEMICAL SAMPLES

80 ZOOPLANKTON NET HAULS AND SAMPLES

SOCIO-ECONOMIC SURVEY

4 ISLAND AND MAINLAND FISHING COMMUNITIES SURVEYED

>290 SOCIAL SURVEY RESPONDENTS

MODELLING AND REMOTE SENSING

21 MODELS

>90 MODELLED VARIABLES

5 PAPERS USING MODELLING

15 REMOTE SENSING DATASETS

5 PAPERS USING REMOTE SENSING

GLIDERS

46 GLIDER PROFILES

>11,000 MEASUREMENTS OF TEMP, SALINITY & DISSOLVED OXYGEN

>180 LAB-ON-CHIP NUTRIENT MEASUREMENTS

>11,000 MEASUREMENTS OF CHL-A FLUORESCENCE & OPTICAL BACKSCATTER (BY GLIDER)

BENTHIC ROBOTIC MISSION GAVIA AUV

>64,000 BENTHIC PHOTOGRAPHIC IMAGES

>35,000 MEASUREMENTS OF TEMP, SALINITY & DISSOLVED OXYGEN

7 ROBOTIC AUV MISSIONS FOR SEABED MAPPING, COVERING 75KM

The data are archived in the British Oceanographic Data Centre (bodc.ac.uk) and are freely available to the international research community.

A COMMUNITY-LED PROJECT
VALUING LOCAL KNOWLEDGE

A key success of the SOLSTICE-WIO project in Tanzania was early engagement with local fisheries communities to seek their advice and input into the design and focus of fieldwork activities. Led by regional research partners the process of holding regular dialogue, meetings and information sharing sessions with several coastal communities allowed not only for refinement of research objectives, but also for improved co-design and co-delivery of fieldwork activities in order to maximise the impact of research outcomes. With the underlying research case studies themselves designed and co-led by local experts who were able to blend local community concerns, interests and knowledge with institutional strategic objectives and national policy requirements, we have helped local communities engage with the scientific process and improved the chances of local knowledge being entrained into policy development.

A key example of the value of community engagement was the programme to discuss use of marine robots in coastal waters. This pre-deployment effort to educate and inform fishing communities about the purpose of such technologies resulted in positive changes in attitudes towards marine robots with increased understanding and acceptance of such technologies for monitoring the marine environment.

> *"The SOLSTICE-WIO project has strengthened capacity in the Western Indian Ocean region of the students and researchers working to addressing challenges of food security and sustainable livelihoods for coastal communities in the Pemba channel. Personally, I have enjoyed working with local communities and learning from them as well as understanding their problems and sharing scientific information resulting from SOLSTICE-WIO research through various documentary videos and leaflets in Swahili which they can understand easily"*
>
> **DR NARRIMAN JIDDAWI** STATE UNIVERSITY OF ZANZIBAR

ANTICIPATING AND MANAGING CLIMATE CHANGE IMPACTS ON SMALL PELAGICS
RESEARCH HIGHLIGHT

Management of the small pelagic fisheries of Tanzania, like many other small scale fisheries across the WIO region, face increased challenges from a changing climate. In this review paper, an international team of scientists led by Baraka Sekadende from the Tanzania Fisheries Research Institute merged recent improvements in understanding of the region's oceanography with the latest data and information on Tanzania's small pelagic fisheries to provide a comprehensive assessment of the potential impacts of climate change on the fishery.

Climate change will likely have both direct and indirect impacts on the fishery, due to a combination of factors including inter-species differences in preferred habitats, behaviours and life history strategies, meaning that the onset of climate change impacts will be varied in both time and space. A warmer ocean however may also see changes to regional ocean circulation and marine productivity resulting in geographic shifts in the distribution of small pelagic species away from current fishing grounds, a change that would impact not only national but regional fishing communities.

The study also makes clear that several key knowledge gaps exist which complicate efforts to produce reliable future projections. In particular, concerns over the accuracy of fisheries exploitation rates and biomass data, the implications of uncertainties associated with climate change projections, and the inability to adequately predict the impacts of anthropogenic factors, emerge as critical unknowns providing directions for future research efforts and highlighting the challenges faced by fisheries managers in planning for the future.

Sekadende, B., et al. (2020) The small pelagic fishery of the Pemba Channel, Tanzania: What we know and what we need to know for management under climate change. Ocean Coast Manage., doi:10.1016/j.ocecoaman.2020.105322

PUTTING MARINE ROBOTS AT THE HEART OF FUTURE OCEAN OBSERVATIONS

RESEARCH HIGHLIGHT

Our community engagement programme in East Africa has demonstrated how marine robots have the potential to transform ocean research for developing nations, offering a viable alternative to expensive research infrastructure, such as ships. The programme engaged with regional fisheries managers and researchers as well as six Tanzanian coastal communities. Together we tested and assessed the potential and readiness of WIO nations to adopt autonomous technologies to meet marine research priorities and ultimately increase capacity to help meet food security and ocean sustainability challenges.

The project (which was designed using local infrastructure and researchers where possible) introduced multiple marine robots fitted with a range of sensors to the waters around the Zanzibar Archipelago of Tanzania. The robots provided new seafloor maps and ocean measurements to improve understanding of the how the ocean supports local fisheries. We also provided education to surrounding coastal communities around the role of marine robots to address natural concerns that might prevent them accepting new technologies into local waters.

Following extensive engagement over four-years, the findings showed positive changes in attitudes towards marine robots and increased understanding and acceptance of such technologies. We were also able to demonstrate a significant increase in capacity and confidence of regional scientists through the short-term provision of equipment, skills and training. Educational materials and engagement activities were also shown to increase the acceptance by local fishing communities of new technologies entering coastal waters, offering a template for future comparable community engagement programmes.

> *"Robotics and autonomy are often promoted as the solution to many of the world's problems, offering the potential to make things cheaper, more efficient and more accessible. Ocean and climate research*

> *is embracing such technologies, with autonomous ocean drifters, submarines and surface vehicles now established as a common component of the Global Ocean Observing System (GOOS) and providing a low carbon alternative for ocean science.*
>
> *The results also demonstrate the value of coastal community engagement as part of the technology transfer process, ensuring that local communities, such as artisanal fishing communities that are likely to share the same space as these technologies, are willing to accept a shift in research approaches by national agencies."*
>
> **DR MATTHEW PALMER** CHIEF SCIENTIST
> MARINE AUTONOMOUS AND ROBOTIC SYSTEMS, NATIONAL OCEANOGRAPHY CENTRE

> *"It was indeed a great pleasure to host the marine robotic research in the Pemba Channel. The marine robotic research in the Pemba Channel, unique in Tanzania; no similar research had previously been conducted in Tanzanian waters. Following the success of the marine robotic research and other SOLSTICE-WIO oceanographic research in the Pemba Channel, IMS formulated other oceanographic research addressing the tuna and tuna like species, which had been among the least researched fish species in Tanzania."*
>
> **DR YOHANA SHAGHUDE** SENIOR LECTURER
> MARINE GEOLOGY AND OCEAN REMOTE SENSING, INSTITUTE OF MARINE SCIENCES, UNIVERSITY OF DAR ES SAALAM

The findings of the international robotics team, as well as recommendations for future missions and investment into robotic technology in comparable regions that include low-income countries are outlined in the publication

Palmer, M.R., et al. (2021) Marine robots for coastal ocean research in the Western Indian Ocean, Ocean Coast Manag. doi: 10.1016/j.ocecoaman.2021.105805

SOCIO-ECONOMIC SURVEY IN COASTAL TANZANIA

RESEARCH HIGHLIGHT

Fishers' ability to adapt to climate change impacts depends on individual circumstances, including financial and physical access to different fisheries. Species and livelihood diversification have been suggested as key climate change adaptation strategies in tropical fisheries. Species diversification strategy involves targeting multiple species instead of one and requires access to multiple gear types, as well as larger vessels that allow access to habitats in both shallow and deeper waters. Livelihood diversification strategy involves promoting fishers to target multiple species and to hold jobs in different industries outside of fishing. A survey by the SOLSTICE-WIO international team led by Dr Narriman Jiddawi and Prof Shankar Aswani in four coastal fishing communities in Tanzania (Tanga, Pemba, Unguja, and Mafia) assessed economic dependency on small-scale fisheries, fishing portfolio strategies, and adaptive capacity.

The survey found that fishers' households consume fish approximately six times a week, which is mainly supplied by their own catch. The majority of fishers already hold jobs outside of fishing including farming, livestock, and small business activities. However, not all fishers are able to target multiple fisheries and species because multiple gear types and larger boats are not affordable for all fishers. Fishers reported that underdeveloped markets in coastal communities are threatening livelihoods and industry growth. The survey findings indicated the need for pre- and post-harvesting processes to shift small scale fisheries away from mainly subsistence-based services to increase adaptive capacity of the costal population.

Taylor, S.F., et al. (2021) The complex relationship between asset wealth, adaptation, and diversification in tropical fisheries. Ocean Coast Manag. doi:10.1016/j.ocecoaman.2021.105808

THE IMPORTANCE OF THE DEEP SEA IN TANZANIA

RESEARCH HIGHLIGHT

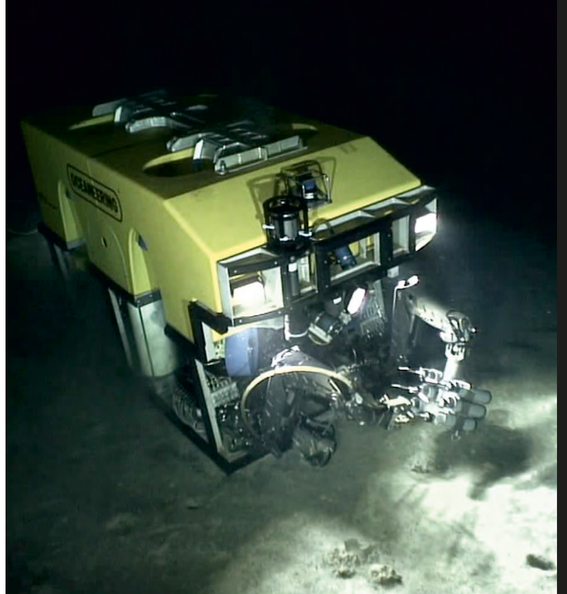
The United Republic of Tanzania has jurisdiction over a large marine area (223,000 km^2) of which over 92% is deeper than 200 m. These deep areas can be close to shore (1 – 40 km), include habitats such as submarine canyons and host important living and non-living resources, which are increasingly exploited to support a valuable blue economy, including through open ocean fishing and deep-sea oil and gas exploration and production.

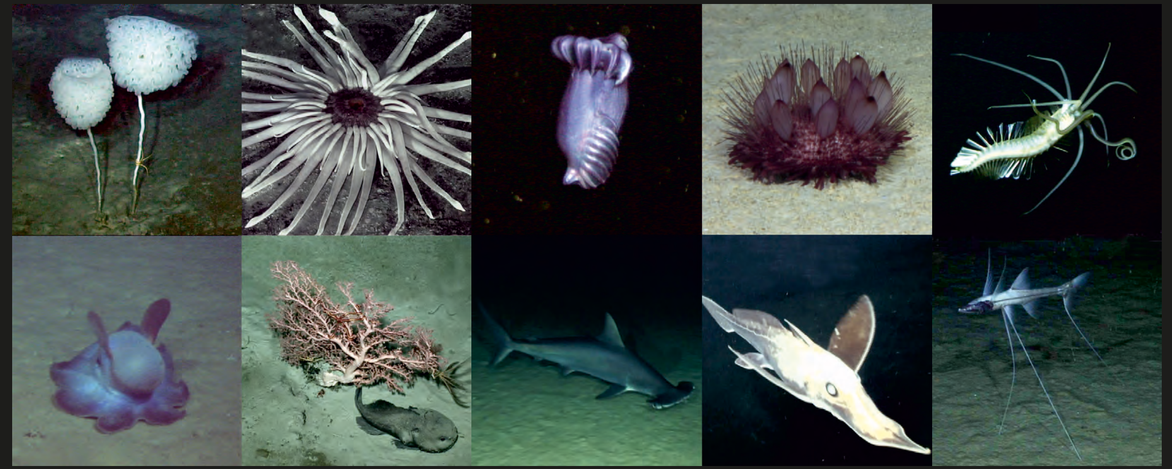
Research is increasingly showing important links between the shallow, coastal ocean and the deep sea but despite Tanzania's well-developed protected areas and marine spatial plans in shallow water, deeper areas of the EEZ have not been considered in marine spatial planning. This is particularly important in Tanzania where a large part of the continental shelf is very narrow.

Gates et al presented a synthesis of available data on the habitats and biological communities of deep-water Tanzania, including presentation of some new data from Remotely Operated Vehicle surveys that show the first in situ observations of animals living at over 1000 m water depth in Tanzania. The paper provides evidence of a diverse deep-sea environment, indication of regional-scale patterns and areas of potential importance.

This information is valuable to the Tanzanian government to help inform development of management measures to continue to make sustainable use of valuable deep-water resources. To facilitate uptake, the paper provides a series of recommendations from this work to inform marine spatial planning in deep water.

Gates, A.R., et al. (2021) Ecological considerations for marine spatial management in deep-water Tanzania, Ocean Coast Manag., doi:10.1016/j.ocecoaman.2021.105703





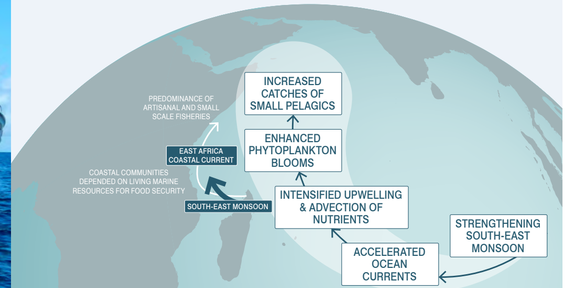
SMALL FISH, SMALL ROBOTS, BIG AMBITIONS
RESEARCH HIGHLIGHT

Autonomous underwater vehicles (AUVs) are revolutionising the way in which many branches of marine science are carried out. They have already demonstrated their value in oceanographic, geological, and ecological studies around the globe. The various datasets that AUVs are capable of generating may have particular relevance in the conservation and sustainable management of marine ecosystems.

The SOLSTICE-WIO Tanzania field campaign provided an opportunity to demonstrate and test the use of AUVs in a management and conservation role, focussing on operations within the Pemba Channel Conservation Area (PECCA). A Teledyne Gavia Offshore Surveyor AUV was operated at PECCA, fitted with a seafloor imaging camera, a geoacoustic system providing both swathe bathymetry and seafloor characterising data, and an oceanographic sensor package recording salinity, temperature, depth, and oxygen concentration. These multiple datasets were combined in an assessment of the distribution of fish, corals, and algae over the photic and mesophotic reefs of the conservation area.

Kennedy Osuka, of Coastal Oceans Research and Development - Indian Ocean (CORDIO) East Africa, Kenya, who led the research, gave the AUVs the 'thumbs up', saying "they showed great potential for mapping the photic and mesophotic coral ecosystems, and should certainly be considered for the collection of monitoring data, not least for tackling these under-researched ecosystems in the Western Indian Ocean". Kennedy's research highlighted the presence of particularly diverse biological communities on deep rock walls, that may be worthy of specific conservation measures, and that these are very challenging environments to access and study by conventional means.

Osuka, K.E., et al. (2021) Characteristics of shallow and mesophotic environments of the Pemba Channel, Tanzania: Implications for management and conservation, Ocean Coast Manag., doi:10.1016/j.ocecoaman.2020.105463



THE IMPORTANCE OF MONSOON WIND STRENGTH FOR SMALL PELAGIC FISHERIES
RESEARCH HIGHLIGHT

Small pelagic fish, which include herring, shads and anchovies, play an important role in the food security of many coastal populations. Catches of such fish however, are notoriously difficult to predict as they are renowned for strong variability and instability in stock size in response to environmental variability and also for their high mobility resulting in seasonal 'runs' along the coast.

Understanding the environmental causes of variability in the yields of small pelagic fish is particularly important for East African coastal communities where small pelagic fisheries provide food security, livelihood support and economic stability. Such information is also of value for agencies involved in food resource planning. Using observations and computer model outputs, international team of researchers led by Dr Fatma Jebri from the National Oceanography Centre (UK) found that interannual variability in small pelagic fisheries yield over an 18-year period could be linked to changes in phytoplankton biomass which in turn could be related to interannual variability in the strength of the monsoon winds.

The emergence of monsoon wind strength as a key factor behind interannual variability in small pelagic fisheries yield is a significant finding allowing planners to anticipate years with high or low yields and thus prepare coastal populations for periods of poor catches. The study highlights that the Southeast monsoon wind strength over the south tropical Indian Ocean is the main driver of year-to-year variability in fishery yield, thus providing an indicator for the likely performance of this key fishery. However, this study also makes clear that anomalous fisheries yields can and do result during years of strong El-Niño / La-Niña events, a Pacific Ocean based climatic oscillation with global implications, now including food security implications for East African communities.

Jebri, F., et al. (2020) Interannual monsoon wind variability as a key driver of East African small pelagic fisheries. Sci. Rep., doi:10.1038/s41598-020-70275-9

KENYA

EMERGING FISHERY OF THE NORTH KENYA BANKS

THE NEXT FRONTIER FOR FOOD SECURITY

The North Kenya Banks fishery is expected to spur economic growth for local communities. If well managed, it could help achieve national development goals, including poverty alleviation and wealth creation. Sustainability requires informed management interventions, but there is only scant information on the ecological status and drivers of the fishery.

Using modelling, remote sensing and field observations, we have:

- explored processes related to productivity and resilience of the ecosystems supporting the fishery;
- identified the main drivers of variability and change;
- provided the fishery managers and Government with the key information on functioning of this important upwelling ecosystem.

INTERDISCIPLINARY APPROACHES TO DATA COLLECTION

NORTH KENYA BANKS DATASETS

SOLSTICE-WIO partnered with KMFRI to undertake a large-scale oceanographic survey of the North Kenyan coastal zone including the strategically important North Kenya Banks using the R.V. Mtafiti, Kenya's dedicated marine research vessel. Using state of the art equipment including a miniature Remotely Operated Vehicle (ROV), the cruise set out to study the marine environment and fisheries resources of the North Banks in support of Kenyan Government initiatives to expand fisheries activities in these waters.

The North Kenya Banks in particular are not well studied thus the activities of this cruise have added much to our knowledge of the area. The resulting data set, which includes physical, biogeochemical, biological and fisheries data, contributes to KMFRI's strategic objectives in support of the Kenya National Oceans and Fisheries Policy. Aspects of this data set have been analysed as part of SOLSTICE-WIO activities in papers published in the Special Issue of Ocean and Coastal Management ("East African Coastal Current ecosystems: at the frontier of climate change and food security").

AN INTERNATIONAL RESEARCH TEAM

24 RESEARCH SCIENTISTS AND ENGINEERS

11 RESEARCH INSTITUTIONS

8 PROJECT PAPERS DEDICATED TO THE CASE STUDY

SHIP-BASED OBSERVATIONS

42 PRIMARY SAMPLING STATIONS

42 PHYTOPLANKTON SAMPLES

162 BIOGEOCHEMICAL SAMPLES

42 ZOOPLANKTON NET HAULS AND SAMPLES

MODELLING AND REMOTE SENSING

21 MODELS

15 REMOTE SENSING DATASETS

>90 MODELLED VARIABLES

6 PAPERS USING MODELLING

5 PAPERS USING REMOTE SENSING

A MAJOR ECOSYSTEM SHIFT CAUSED BY A SUPER EL NIÑO

RESEARCH HIGHLIGHT

The North Kenya Banks are regarded as a region capable of sustaining a rich fishery, which would boost Kenya's economy. The reversal of the Somali Current during the Northeast monsoon season (Dec-Feb) causes water to flow away from the North Kenya Banks, initiating the upwelling of cold, nutrient-rich water that enhances productivity over the region. This seasonal upwelling may sustain offshore fisheries.

The strength, spatial extent and exact timing of this feature varies from year-to-year. There was only one year over the last ~30 years where this seasonal upwelling did not occur at all, 1997-98. This coincided with a super El Niño and positive Indian Ocean Dipole event where considerable changes in the winds over the Indian Ocean led to the reorganisation of major ocean currents that impacted the East African coast. Ultimately, the super El Niño caused the offshore flow of waters, normally positioned next to the North Kenya Banks , to shift more than 300km southwards to reside off the coast of Tanzania. This resulted in chl-a concentrations (an indicator of productivity) reaching an all-time low over the North Kenya Banks, while in waters off the coast of Dar es Salaam chl-a concentrations reached their highest ever for this time of year for this time of year.

The likely negative impacts on local fish stocks in Kenya, affecting fishers' livelihoods and food security, and the temporary increase in pelagic fishery species' productivity in Tanzania, caused by the shift in the position of upwelling, is discussed in an international study led by Dr Zoe Jacobs and Dr Fatma Jebri from the National Oceanography Centre, UK. The research team suggested that this major ecosystem shift may be repeated in the coming years with the accelerating impact of climate change. Thus, preparedness for potential scenarios of low productivity and its impact on fisheries, is an important part of risk-based management of the North Kenya Banks fisheries.

Jacobs, Z.L. & Jebri, F., et al. (2020) A major ecosystem shift in coastal East African waters during the 1997/98 Super El Niño as detected using remote sensing data. Remote Sens., doi: 10.3390/rs12193127

MANAGEMENT CHALLENGES FACING FISHERIES ON THE NORTH KENYA BANKS

RESEARCH HIGHLIGHT

Small-scale marine fisheries are significant in the provision of coastal food security, and estimated to provide about 90% of Kenya's marine fish catch, with the vast majority of this taken from coastal waters. However, marine fisheries contribute less than 5% to Kenya's national fish catch and this is considered low compared to neighbouring countries. Initiatives exist to sustainably increase the exploitation of Kenya's marine resources, but such efforts face numerous challenges. In reviewing these challenges an international team of researchers, led by Dr Joseph Kamau from the Kenya Marine and Fisheries Research Institute, focused attention on the North Kenya Banks, an important extension of the East African continental shelf and an area that is currently largely unprotected by existing fisheries management plans but is expected to see increased exploitation in future.

A key difficulty facing fisheries managers is that efforts to expand existing coastal fisheries offshore essentially equates to the creation of a new fishery with no previous history of working with the strong seasonal and interannual variability of key oceanographic features which control recruitment and retention of the important commercial species. Dr Joseph Kamau and co-authors explore how limitations in basic knowledge of ocean processes influencing fisheries (such as shelf break upwelling, regional circulation and climate change impacts on marine primary production and fisheries distribution patterns) require urgent attention from researchers and stakeholders alike if the offshore fisheries are to be sustainably exploited.

Kamau, J.N., et al. (2021) Managing emerging fisheries of the North Kenya Banks in the context of environmental change. Ocean Coast Manag., doi:10.1016/j.ocecoaman.2021.105671

SOUTH AFRICA

SOUTH AFRICAN CHOKKA SQUID FISHERY COLLAPSES

ENVIRONMENTAL DRIVERS & SOCIO-ECONOMIC CONSEQUENCES

The collapse of the chokka squid fishery in 2013 had a devastating effect on the Eastern Cape Province, one of the most impoverished provinces in South Africa. A similar crash occurred in 2001 but the reasons for these collapses remain unknown. One explanation held by local fishers is that the collapses resulted from unusual shifts in the ocean.

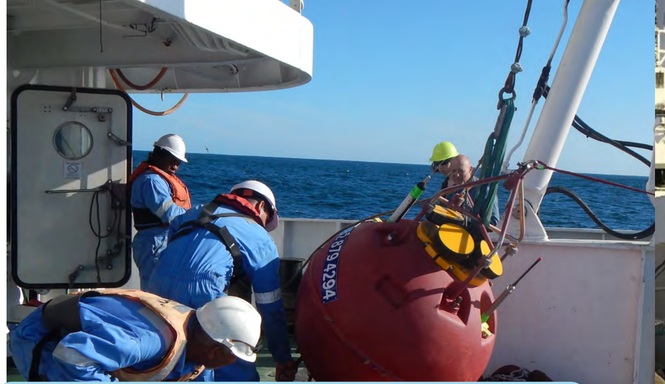
The SOLSTICE-WIO South African Case study was aimed at identifying the key environmental and anthropogenic factors controlling the dynamics of the Agulhas Bank ecosystem. Results of this huge international effort have helped explain the reasons for the main fishery collapses and have paved the way for development of an early warning system to alert the fishery and Government of future crashes.

OCEAN AND SOCIO-ECONOMIC DATA ADDRESSING SQUID FISHERY COLLAPSES

THE AGULHAS BANK DATASET

Over 2018–2019, SOLSTICE-WIO completed a major interdisciplinary field campaign which underpinned research analysis of the environmental drivers of the chokka squid catches. The resulting data set included physical, biogeochemical, biological and socio-economic data collected on the Eastern and Central Agulhas Bank and in the coastal fishing towns and harbours of Gqeberha (Port Elizabeth) and Cape St Francis. In addition to two cruises aboard the South African research vessel RV Ellen Khuzwayo, three key, cost-effective technologies were used to complement traditional observation techniques. Satellite remote sensing, numerical ocean models and autonomous robotic technologies were used to efficiently deliver near real-time environmental data to support the ship effort and compliment the data analysis and synthesis.

This data set has been extensively analysed by the SOLSTICE-WIO project partners in papers under publication for the Special Issue of Deep-Sea Research Part II "Dynamics of the Agulhas Bank, South Africa – ecosystem shifts and future trends in the squid fishery". The collected data and samples also supported PhD studies in physical oceanography, biogeochemistry and ocean productivity.



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SHIP-BASED OBSERVATIONS

52 PRIMARY SAMPLING STATIONS

58 PHYTOPLANKTON SAMPLES

1,177 BIOGEOCHEMICAL SAMPLES

96 ZOOPLANKTON NET HAULS AND SAMPLES

SOCIO-ECONOMIC SURVEY

4 ISLAND AND MAINLAND FISHING COMMUNITIES SURVEYED

101 SOCIAL SURVEY RESPONDENTS

MODELLING AND REMOTE SENSING

21 MODELS

>90 MODELLED VARIABLES

7 PAPERS USING MODELLING

15 REMOTE SENSING DATASETS

5 PAPERS USING REMOTE SENSING

GLIDERS

>3,700 GLIDER PROFILES

>450 LAB-ON-CHIP NUTRIENT MEASUREMENTS

>1.6M MEASUREMENTS OF TEMP, SALINITY & DISSOLVED OXYGEN

>325,000 MEASUREMENTS OF CHL-A FLUORESCENCE & OPTICAL BACKSCATTER (BY GLIDER)

The data are archived in the British Oceanographic Data Centre (bodc.ac.uk) and are freely available to the international research community.

INITIATING A CENTRE FOR MARINE AUTONOMY

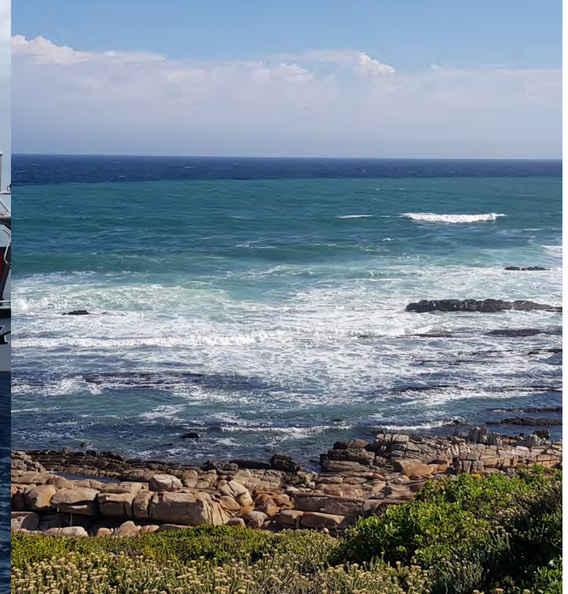
LAYING THE FOUNDATION FOR MARINE ROBOTICS IN THE WIO

Few developing countries have the resources to own and operate research vessels. This is particularly the case in the WIO where ships struggle to survey the narrow and shallow shelf waters of the continental shelves of the nine WIO counties. Marine robotics offer a real solution to these problems as they are relatively inexpensive, compared to ships, and easy to deploy.

SOLSTICE-WIO has played a major role in demonstrating these technologies in both the Tanzanian and South African Case Studies and in initiating a Marine Robotics Centre at the new Ocean Science Campus at the Nelson Mandela University (NMU), in Gqeberha (Port Elizabeth). The strong local logistical support and the existing UK-South Africa-WIO wide research network made NMU the natural hub for marine robotics in the WIO.

The WIO-Autonomous Marine Operational Systems (AMOS) Centre, operating under the NMU Faculty of Engineering, is new and still in the process of developing its capabilities. It aims to have three functions:

1. Support WIO-wide research through the deployment and operation of off-the-shelf robotics such as gliders,
2. Stimulate innovation in marine robotics, i.e. design and build new robots in collaboration with the NOC in the UK,
3. Provide postgraduate training for the wider WIO region. Already three newly-designed prototypes have been built engaging five registered MSc and PhD postgraduate students.



VALUING OUR OCEANS

ENGAGING WITH OCEAN ACCOUNTS IN SOUTH AFRICA

In working towards improving Ocean Governance, SOLSTICE-WIO embraced the new, emerging field of Ocean Accounts.

The oceans are central to the livelihoods, health and survival of billons of people around the world. However, the ocean is warming, acidifying and loosing oxygen due to the impacts of climate change. Hotspots of biodiversity, such as mangroves, coral reefs, and seagrass meadows, are under significant threat, and an estimated one-third of all fisheries are now over-exploited. To reverse the damage that society has inflicted on the world's ecosystems we must change the way we think, act and measure economic success to protect and enhance our prosperity and the natural world.

The Ocean Accounts Framework (OAF) falls within a newly emerging systems approach that provides a way to facilitate this process. It involves the field of natural capital accounting which strives to develop a means to value the natural environment and its resources, and aligns data maintained by national statistical offices and finance ministries. This enables countries to go beyond GDP and to measure contributions from the ocean economy.

In the WIO, South Africa has taken the lead in pioneering the OAF by initiating the Ocean Accounts Community of Practice project, led by NMU*, which brings together scientists across several research disciplines from various institutions, including the Nelson Mandela University, Cape Peninsula University of Technology, SAEON, University of the Western Cape and the Human Sciences Research Council. SOLSTICE-WIO leads a work package that assesses how OAF can best measure and assist in managing risks within the ocean space — especially those risks associated with fisheries in South Africa.

*https://www.algoabayproject.com/ocean-accounts-framework

BUILDING CAPACITY IN CRITICAL SKILLS

TACKLING THE 2013 SOUTH AFRICA CHOKKA SQUID CRASH

SOLSTICE-WIO established a PhD training programme at Nelson Mandela University's (NMU) newly-built Ocean Science Campus to develop critical skills needed to tackle marine ecosystem research and detect ecosystems shifts.

Understanding the fluctuations and, in extreme cases, collapses of marine ecosystems, requires a formidable research capacity in physical, biogeochemical and biological oceanography. These specialised fields of expertise need to be supported by state-of-the-art technologies that include ocean models, satellite observations, marine robotics and specialised equipment such as the artificial intelligence-driven underwater zooplankton profiler. But fisheries are not so much about fish as they are about people, necessitating the integration of fisheries and socio-economic studies into the biogeophysical sciences in order to unify the human-ecological system. It is only with this full suite of expertise that a fishery can be managed in a sustainable way.

The Ocean Science Campus was built to facilitate research and training in marine science and advance NMU into becoming a truly relevant regional university capable of addressing societal challenges such as food security. Capacity building in these fields has been a primary pillar of SOLSTICE-WIO.

Eight SOLSTICE-WIO PhD candidates, seven of whom were women, enrolled in the Ocean Science and Marine Food Security research group in 2018. Their research topics were intended to underpin the SOLSTICE-WIO South African case study research plan and included ocean physics, phytoplankton, zooplankton, benthic nepheloid layer dynamics, fisheries modelling, social dynamics and food security. Students were co-supervised by senior research scientists from both NMU and the UK with exchange visits, training courses, collaborative workshops and one-on-one coaching in presenting results for publishing in the peer-reviewed scientific journals.

> *"In a challenging educational climate, the collaborations offered within SOLSTICE-WIO gave the opportunity for the Nelson Mandela University post-graduate students to grow in a stimulating environment and gain skills from their interactions with the other project partners."*
>
> **DR MARGAUX NOYON** BIOLOGICAL OCEANOGRAPHER AND ECOSYSTEM FUNCTIONING SPECIALIST IN ZOOPLANKTON ECOLOGY, NELSON MANDELA UNIVERSITY

DYNAMICS OF THE AGULHAS BANK AND THE SQUID FISHERY
RESEARCH HIGHLIGHT

Chokka squid, *Loligo reynaudii*, is a cephalopod closely related to the cuttlefish and octopus. It is sold in restaurants as 'calamari', mostly in Spain and Portugal, and is highly prized for its texture and flavour.

Chokka squid are found over much of the west and south coasts of South Africa. They concentrate in the shallower coastal waters of the Eastern Cape where they form large aggregations to spawn. It is during this time that the 122 fishing vessels, carrying 2400 fishers, make their catch. Landings vary considerably on a monthly and annual basis, with fisher earnings reflecting these fluctuations. Times of extended poor catches, as in 2013, result in severe economic hardship for the fishers and their 35 000 dependents.

The SOLSTICE-WIO South African case study sought to discover the reasons for these fishery crashes. Results of this enormous international effort are published in a Deep-Sea Research Part II Special Issue which yields the causes for these fishery collapses. Models now pave the way for an early warning system to inform the fishery and Government of future collapses.

An international team of scientists led by Prof Mike Roberts brought together key information which helped forge hypotheses that guided the scientific investigation. From a backdrop of huge volumes of literature, including a combined mix of knowledge gaps in the dynamics of the Agulhas Bank, historically observed trends in the Agulhas Current and the adjacent shelf ecosystem, as well as a deep understanding of the chokka squid life cycle, four possible scenarios were created that could, potentially, explain these fishery crashes.

Roberts, M., et al., Dynamics of the Agulhas Bank ecosystem functioning, shifts and future trends in the South African squid fishery. Deep-Sea Res. Part II Top. Stud. Oceanogr. (In Review)

Image Credit: Jean Treston

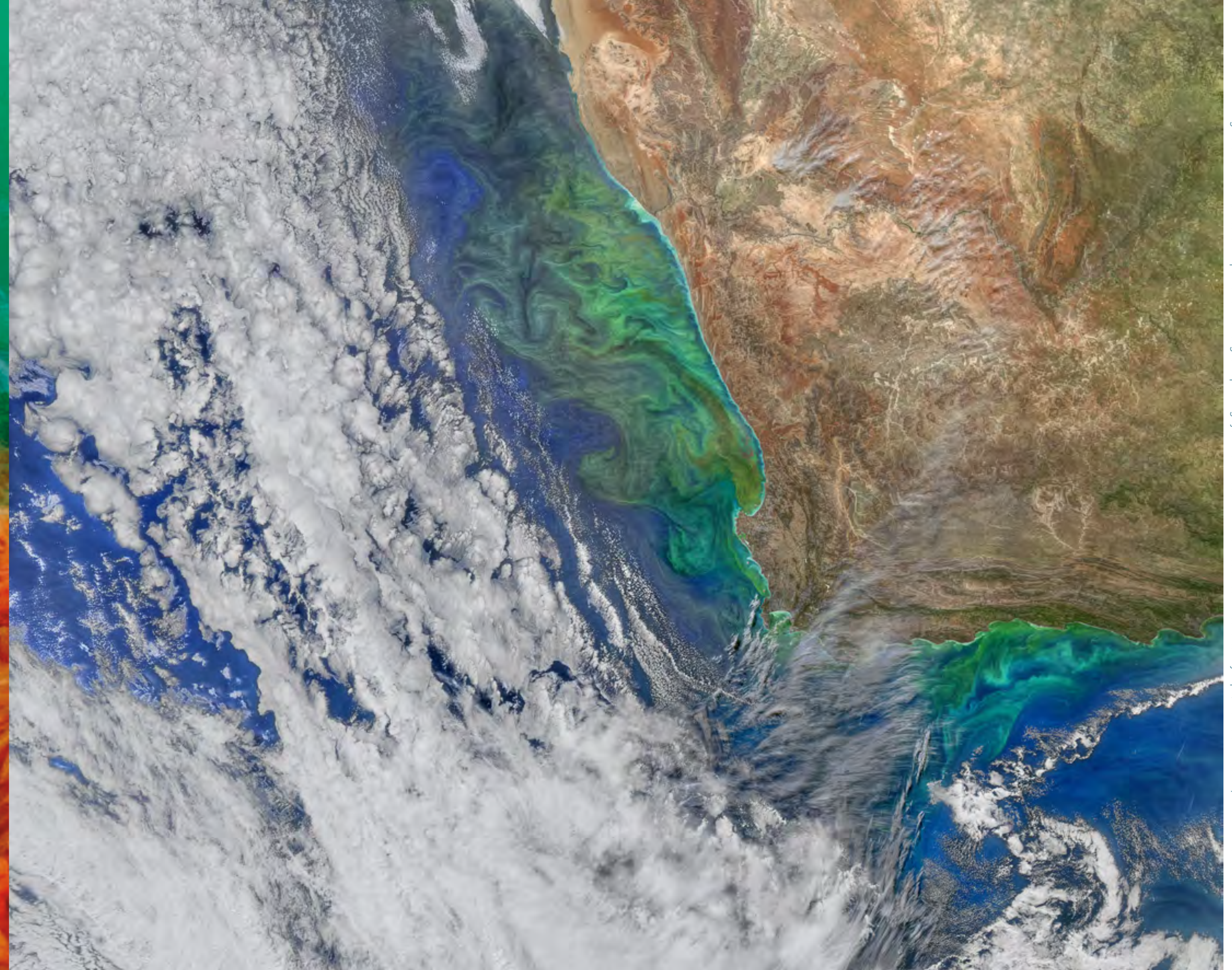


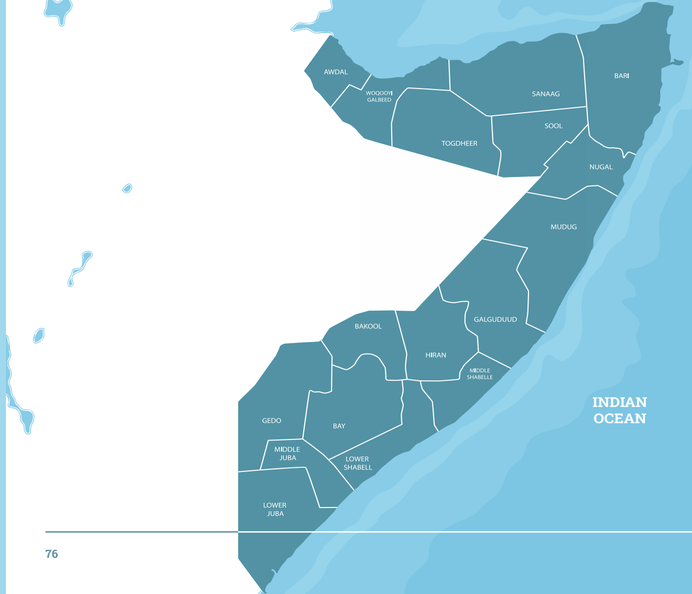
Image Credit: view of the southern portion of the Benguela upwelling system off of South Africa's west coast was collected by Aqua/MODIS on March 27, 2020. © NASA.

MACHINE LEARNING FOR MARINE ECOSYSTEMS
RESEARCH HIGHLIGHT

Most people are familiar with Machine Learning through applications like automated facial recognition, but it can also help us understand what is happening in our oceans. Increasingly large amounts of data from Earth observations and models can be difficult to examine and analyse by traditional methods. For example, it is challenging to look at the tens of thousands of satellite images of sea surface temperature (SST) which have been acquired over several decades to determine patterns of variation in space and time. Machine Learning can be applied to sift through the large amounts of data, learn from it and pull out the dominant patterns and how they may be changing over time.

NOC scientist Fatma Jebri has been developing Machine Learning approaches to analyse satellite derived SST, chlorophyll-a (and so phytoplankton biomass) and surface currents. The results have shown how the different flow patterns of the Agulhas Current off South Africa can affect phytoplankton availability (which lie at the base of the food chain and sustain rich and productive fisheries) on the Agulhas Bank. The approach has helped to understand which types of flow patterns correspond to productive regimes and which patterns are responsible for reduced levels of productivity.

Jebri, F., et al. Machine learning and Earth observation reveal the dynamics of productive upwelling regimes over the Agulhas Bank. Remote Sens. Environ. (In Review)



SOMALIA

THE WORLD'S STRONGEST SEASONAL UPWELLING

CLIMATE CHANGE IMPACTS

Off the coast of the Horn of Africa runs the fastest current in the global ocean – the seasonally reversing Somali Current. From June to September during the southwest monsoon (when winds blow towards the northeast) the world strongest seasonal upwelling occurs along the coastline of Somalia, bringing cool, nutrient-rich waters to the surface. This nutrient supply fuels marine primary production and drives productive local ecosystems and fisheries.

Little is known about this ocean region. Somalia's turbulent recent history, in particular its issues of maritime security, have resulted in limited ship-based research expeditions, meaning there are very few in-situ data available. However, modelling and remote sensing data provide us with powerful tools to begin unravelling the dynamics of this upwelling system and understanding its possible fate under the impacts of climate change.

MODELLING THE FUTURE FATE OF SOMALI UPWELLING

SOMALI WATERS IN A WARMER WORLD

Funded by the World Bank and in partnership with MacAlister Elliott & Partners (consultants in sustainable fisheries and aquaculture) SOLSTICE-WIO scientists, Dr Zoe Jacobs and Dr Fatma Jebri, analysed model projections of climate change impacts on the Somali Upwelling. Their analysis showed that under a high CO_2 emissions scenario, nutrient availability and primary production are expected to decline in this region. Despite this, the Somali Upwelling will remain active through the course of this century and continue its important role bringing deep, nutrient rich, cooler waters to the surface.

What this means for local fisheries, however, is a big unknown. Being so close to the Equator, sea surface temperatures in Somali waters by the end of the century are likely to be higher than those currently observed anywhere in the tropical ocean. How marine species will adapt to this change is unclear, as it will be compounded by other important factors including reduced ecosystem productivity and increasing ocean acidification. However, as the region will remain an upwelling system, its immediate vicinity will continue to be cooler and more productive than the surrounding ocean and it could become a refuge for marine species forced out of warmer adjacent waters.

> *"To have been able to accurately map the Somali upwelling system and subsequently model its fate to the end of the century is an extremely important piece of information for the Somali fisheries sector. Given the strong ecological connections between Somali fisheries and the upwelling system also evidenced by this research, it is now more important than ever for Somalia to benefit from its unique situation and protect its fisheries."*
>
> FRANCES JAMES, MACALISTER ELLIOTT & PARTNERS

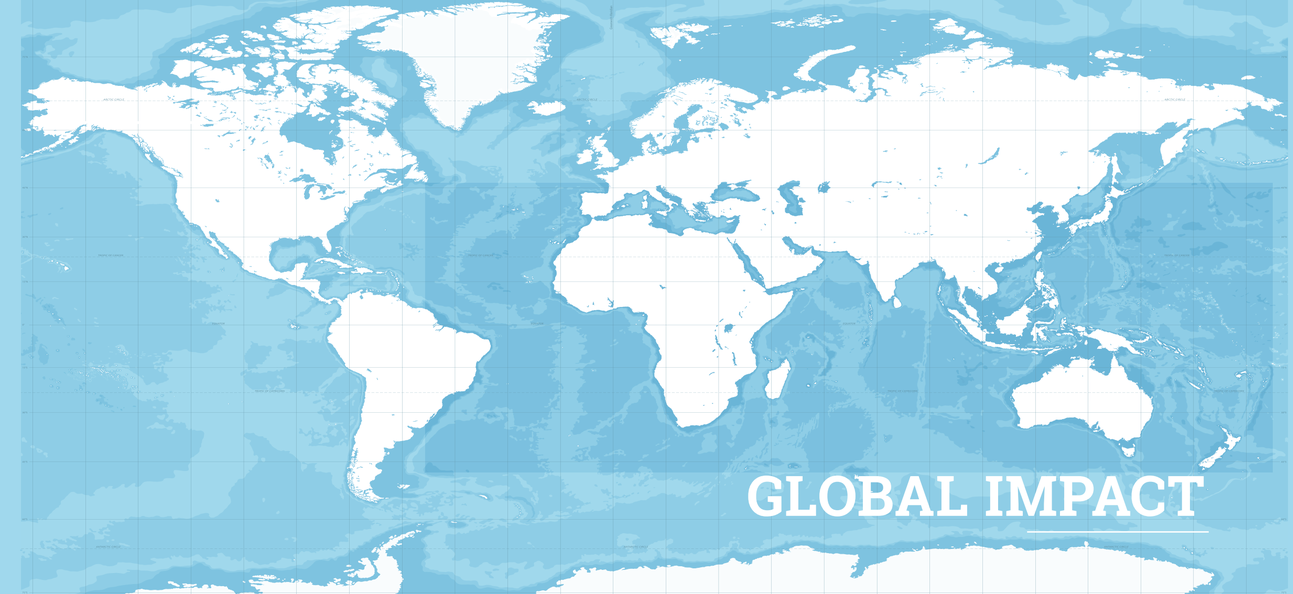
SOMALIA FISHERIES

PRODUCTIVE UPWELLING ECOSYSTEM

At 3,300 km, Somalia has the longest coastline in continental Africa. Its extensive Exclusive Economic Zone (EEZ) includes one of the largest seasonal upwelling systems in the world, the Somali Upwelling. Ongoing political instability has limited data collection on many aspects of the fisheries sector, however, between 10 to 20 thousand fishers are estimated to be active, supporting a further 30 to 60 thousand people in trading, processing and boat building.

Between June and September, the upwelling system in Somali waters is most productive, and tuna pass through to feed on this abundance of food. However, at the same time, wind and current conditions are also at their strongest and most fishing boats (particularly small local boats) must wait until weather conditions are calmer between October and April to fish.

At present, growth of the fisheries sector is restricted by a lack of co-ordinated governance, a lack of suitable fisheries infrastructure and coastal geography. However, Somalia's fisheries could support a thriving fisheries sector if they are well managed, well-monitored and generate sufficient value for Somali fishers.

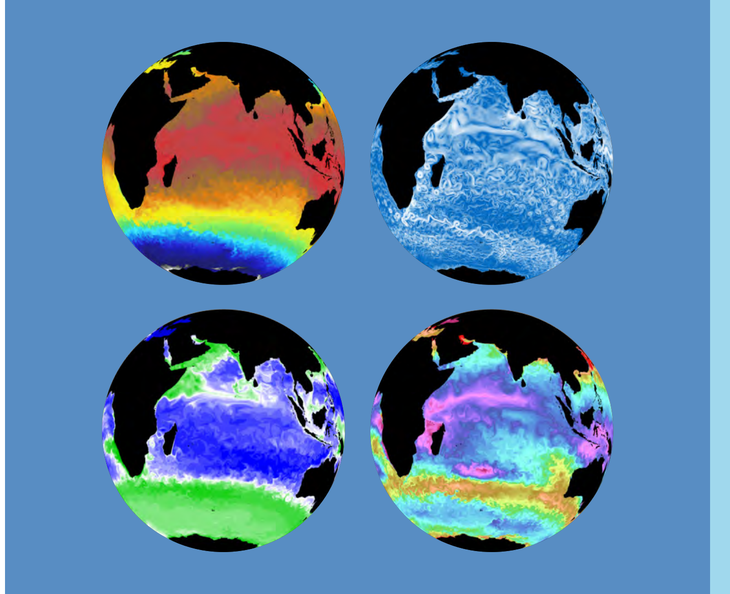


GLOBAL IMPACT

CONNECTING OCEAN PROCESSES WITH ECONOMIES AND SOCIETIES

BEYOND THE SOLSTICE-WIO CASE STUDIES

With increasing computing power, it is now possible to simulate ocean circulation, ecosystem dynamics and the distribution and productivity of key marine species with remarkable detail and realism. Such global ocean models now underpin the development of Blue Economies and sustainable resource management around the world, allowing marine scientists to address issues such as adverse impacts of climate change and marine pollution, or carry out resource characterisation and deliver information relevant to food security. Using numerical models in SOLSTICE-WIO case studies, the project developed many tools and approaches which are now being applied to problems at global scale.



SO FAR, YET SO CLOSE

ECOLOGICAL CONNECTIVITY BETWEEN THE HIGH SEAS AND TERRITORIAL WATERS

An international team of scientists led by SOLSTICE-WIO Director Dr Ekaterina Popova and Dr Essam Yassin Mohammed, head of blue economy at the International Institute for Environment and Development (IIED) demonstrated that coastal communities in Least Developed Countries (LDCs) are highly dependent on key areas of the 'high seas', those areas beyond any national jurisdiction (ABNJ). These areas are critical to the overall livelihoods of coastal LDCs for employment, food supply and income opportunities. They are also crucial to the life cycles of fish stocks, their development and migration as well as for carbon sequestration, which is a key process for mitigating climate change and sea level rise. Many areas of the high seas are already being impacted by pollution, particularly from plastic contamination and shipping, overfishing, mining and geoengineering experiments.

"When the High Seas are viewed from a coastal perspective, they are often considered as remote and inconsequential for the coastal communities whose lives are dependent on living marine resources. However, nothing can be further from the truth.

Growing scientific evidence points towards strong ecological connectivity between the High Seas and the coastal zones.

Thus, when marine protected areas are proposed in the High Seas, their locations must be chosen not only to protect biodiversity within these areas, but also to safeguard interests of poor coastal communities in their downstream zone of influence.

We are proud to note that the latest draft of the text of the treaty on the conservation and sustainable use of marine biological diversity in ABNJ was updated to recognise that the it must protect the many millions of people who depend on the high seas via downstream connectivity."

DR EKATERINA POPOVA

The results of the study were published in the Journal of Marine Policy, an associated policy brief for the LDCs participating in the UN Convention on the Law of the Sea (UNCLOS) negotiations and WIO country connectivity profiles. The study was presented at a dedicated side event during UNCLOS negotiations in New York, in March 2019.

Popova, E., et al. (2019) Ecological connectivity between the areas beyond national jurisdiction and coastal waters: Safeguarding interests of coastal communities in developing countries. Mar Policy, doi:10.1016/j.marpol.2019.02.050
Popova, E., et al. (2019) So far, yet so close: ecological connectivity between ABNJ and territorial waters. IIED Briefing Paper (17500).

SCALING-UP UPWELLING RESEARCH
AT THE FRONTIER OF CLIMATE CHANGE IMPACTS

Using remote sensing and modelling datasets, SOLSTICE-WIO has characterised four WIO seasonal upwelling systems – Somali, North Kenya Banks, Tanzanian and Agulhas Bank – and demonstrated both their significance for local economies and their vulnerability to climate change impacts. The relocatable tools and expertise developed while conducting this research, including machine learning approaches and advanced high-resolution models, are now ready to be applied across global shelves.

Seasonal upwelling systems are at the forefront of climate change impacts, being both hotspots for the early onset of acidification and deoxygenation and, at the same time, places where water temperatures will remain cooler for longer. Essentially, they may both experience climate change impacts first, while potentially acting as refugia from it. Engaging with the UN Ocean Decade programme, CoastPredict, the coastal seasonal upwelling theme employs the cutting-edge future projections of the ocean and its ecosystems. Further, it links to another Ocean Decade programme, the Digital Twins of the Ocean (DITTO), with its ambition of connecting ocean information with people. Characterising and predicting seasonal upwelling systems, as well as the impacts of their changes on economies and societies, are of critical importance to priority applications of the Digital Twins programme. These include fisheries and mariculture, marine protected areas, ocean-based tourism, ecological forecasting and nature-based solutions.

Digital Twins of the Oceans

GOOS | CoastPredict
with The Global Ocean Observing System

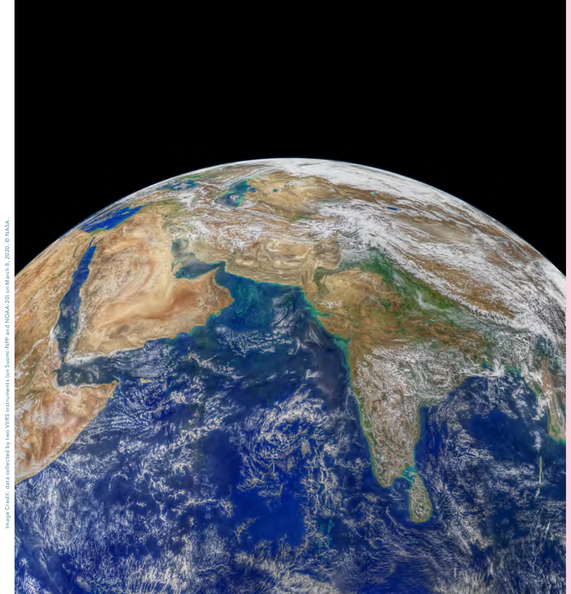


Image Credit: data collected by two VIIRS instruments on Suomi NPP via NOAA/JPL on May 14, 2012, © NASA.

COMMUNICATING OUR RESEARCH

Communicating our research is essential to all stages of the project, in engaging stakeholders and local communities, in capacity building and in achieving impact for our findings within economies and society. Throughout SOLSTICE-WIO, the project team have worked to engage a very broad range of audiences, from local to global scales, through a variety of communication platforms.

Our communication approaches have ranged from holding engagement events for regional and local government and fisheries managers, to publications in peer-reviewed journals, to presenting at United Nations Convention on the Law of the Sea (UNCLOS) negotiations. We have created printed information in local languages, developed a Massive Open Online Course, with a global reach, and provided information through a website and social media presence. Through these platforms we have reached audiences from UN negotiators, to scientists, students, local decision makers and managers and fishers in coastal communities.

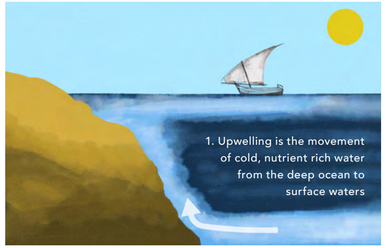
Communication materials, such as open access research papers, information leaflets, policy briefs and the Massive Open Online Course, form part of the project legacy, in that they remain available and in use after the project has ended. Our communication efforts have contributed to the United Nations Decade of Ocean Science for Sustainable Development outcome of "An inspiring and engaging ocean where society understands and values the ocean in relation to human wellbeing and sustainable development".

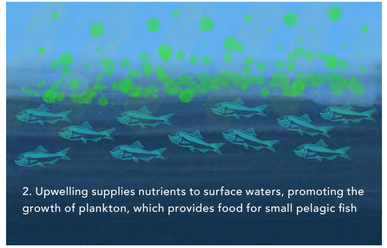
COMMUNICATING OUR FINDINGS TO COASTAL COMMUNITIES

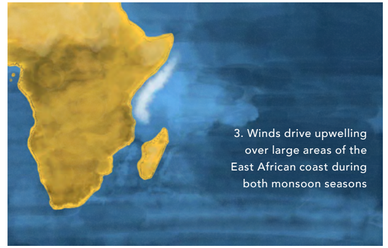
SHARING KNOWLEDGE OF UPWELLING AND ENVIRONMENTAL CHANGE

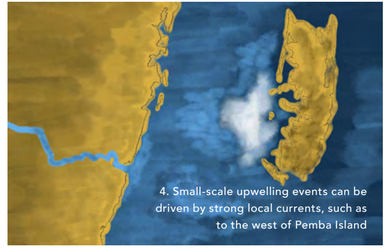
Coastal community stakeholders in Tanzania and Kenya represent a key demographic for whom our results have direct relevance. It was thus essential that towards the end of the project our results were communicated to these communities. Due to COVID-19 however we were not able to travel for in person discussions and to report back on our work. Instead we developed two leaflets "Upwelling, ecosystems and coastal communities" and "Marine ecosystems and climate change" to communicate our most significant results. These leaflets were translated into Swahili with the help of our partners in Tanzania and Kenya, who also distributed the printed copies and described the key findings.

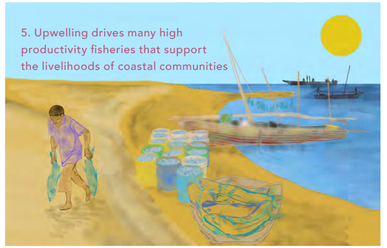
UPWELLING, ECOSYSTEMS AND COASTAL COMMUNITIES

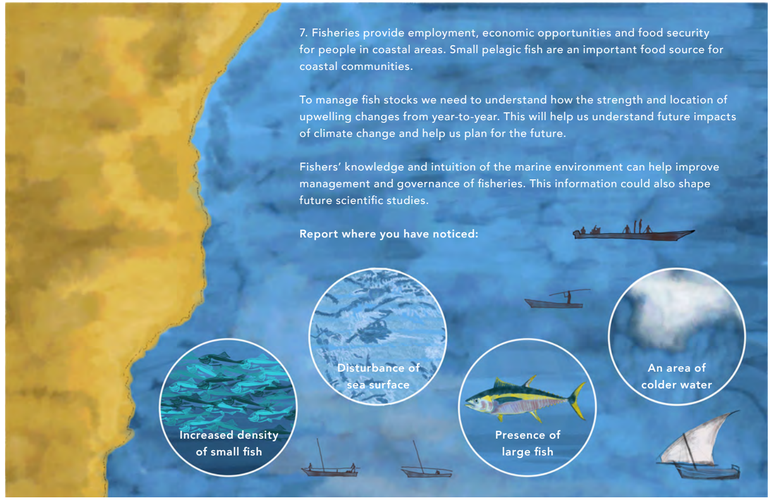




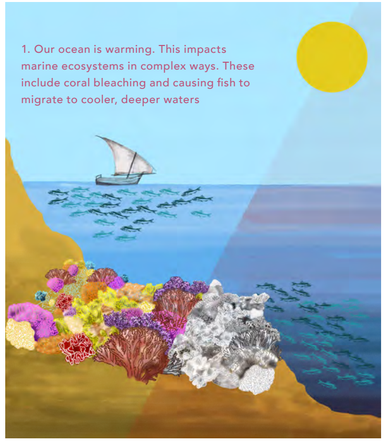


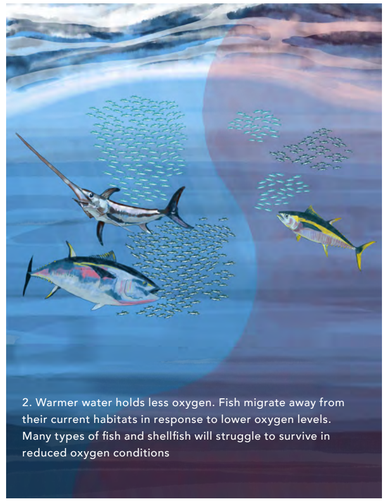


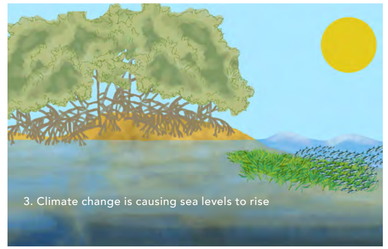


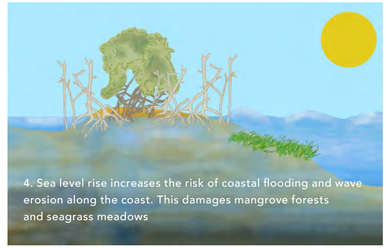


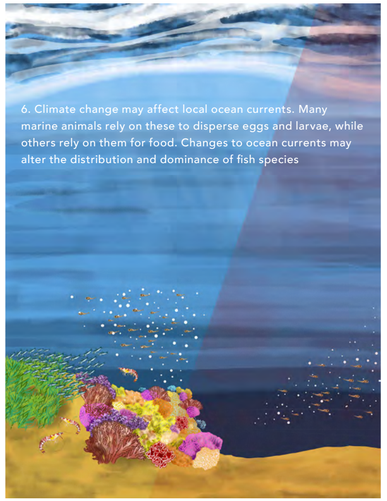
MARINE ECOSYSTEMS AND CLIMATE CHANGE

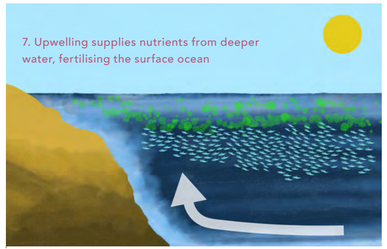


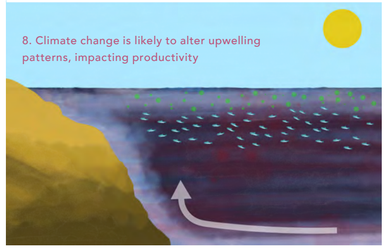


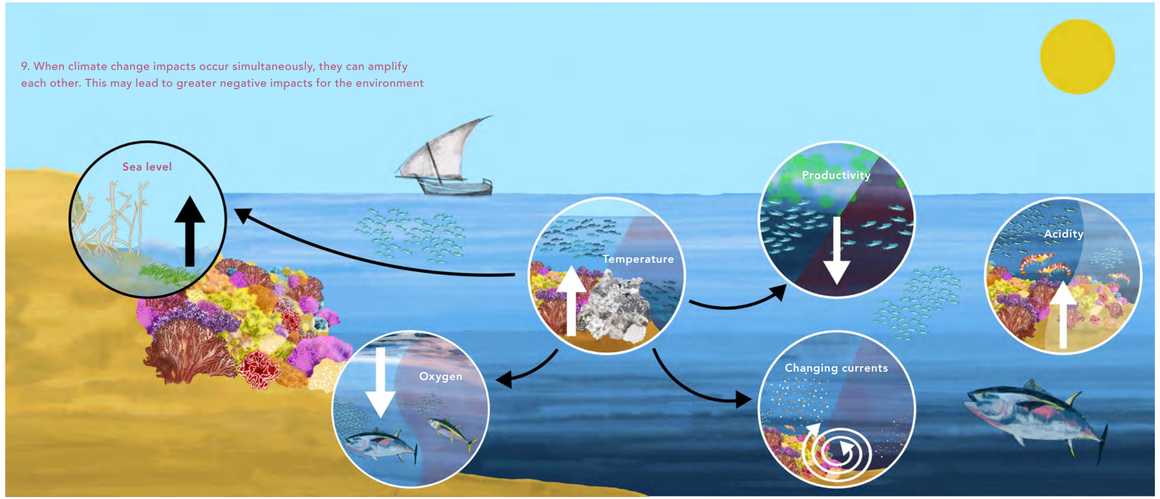


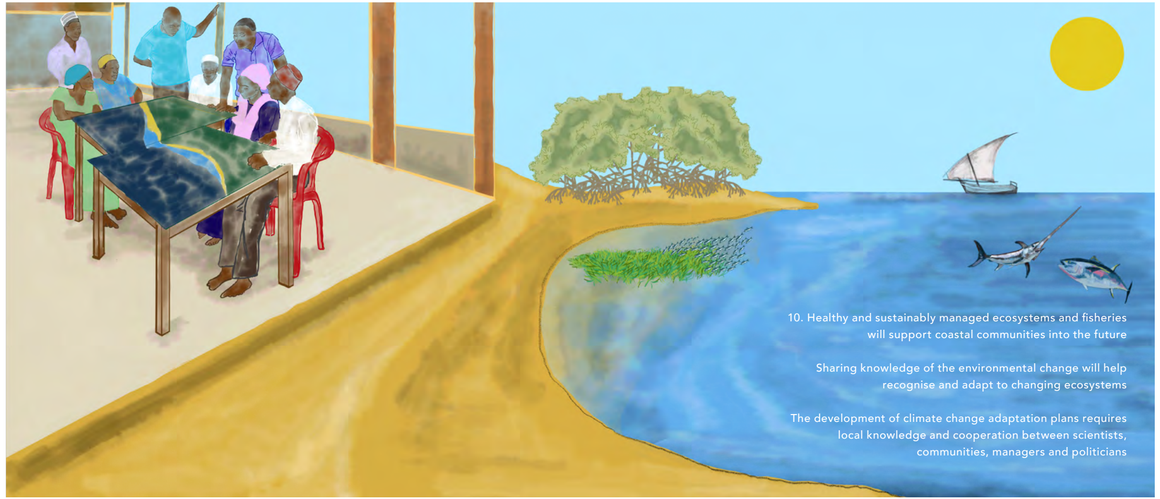









9. When climate change impacts occur simultaneously, they can amplify each other. This may lead to greater negative impacts for the environment
Sea level
Temperature
Productivity
Acidity
Oxygen
Changing currents


10. Healthy and sustainably managed ecosystems and fisheries will support coastal communities into the future
Sharing knowledge of the environmental change will help recognise and adapt to changing ecosystems
The development of climate change adaptation plans requires local knowledge and cooperation between scientists, communities, managers and politicians

CONTINUING THROUGHOUT A GLOBAL CRISIS

THE IMPACTS OF THE COVID-19 PANDEMIC

SOLSTICE-WIO was not immune to the impacts of COVID-19. Nearly half of the total project duration was spent under some form of restriction, limiting our communication and shared activities to online meetings. The COVID-19 pandemic meant we had to be flexible, but the science and collaboration did not stop and we found new ways to work. The challenges facing the ocean have not gone away and the coming decade is critical to protecting the health of the ocean upon which our lives and wellbeing depend.

The most obvious consequence of the pandemic for the project was the suspension of all project synthesis and science-into-policy in-person meetings and, inevitably, the final high-level project events at leading WIO institutions. However, hard work by the dedicated teams in all partner countries minimised the risks to the programme deliverables. The partnership has adapted to a new way of working and has been inventive in the new world of online communication. Our MOOC has become one of the success stories of the project, sharing our ideas and communicating them to a broad audience. Restrictions on international travel helped us find new ways of working and our success in delivering the programme made us realise that international partnerships can be green and work successfully whilst minimizing our travel carbon footprint.

CHANGING THE PUBLICATION MAP OF THE WORLD

LEADING ROLE OF SOLSTICE-WIO AFRICAN PARTNERS IN PUBLICATIONS IN INTERNATIONAL PEER-REVIEWED JOURNALS

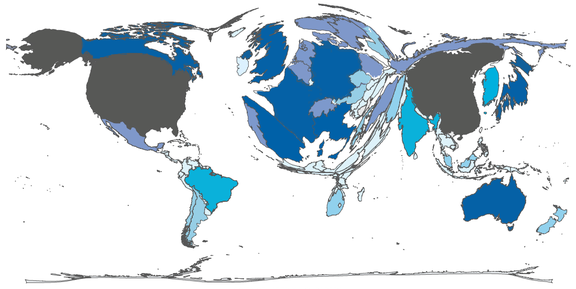
Beyond the geographical, there are many ways of representing the world on a map. One of them is to display the size of countries in proportion to some key indicator such as population, environment or economy. Predictably, the world map of Gross Domestic Product (GDP) is dominated by North America and Europe while Africa almost disappears. The world map of fish and aquaculture production is almost unrecognisable, dominated by South East Asia.

But what would a world map look like if the scale of countries is instead proportional to ocean science publications?

Such a map shows that major disparities exist in the capacity around the world to undertake marine scientific research. While some countries benefit from sophisticated, cutting-edge scientific infrastructure, technology, and human capacity for science and innovation, many countries risk being left behind. Our ability to observe the global coastal and shelf environment will not improve if modern marine technologies continue to be concentrated in a few centres of excellence. Scientific capacity development is one of the core objectives of the UN Decade of Ocean Science for Sustainable Development 2030, especially for the Small Island Developing States and the Least Developed Countries.

SOLSTICE-WIO is proud to have made a substantial contribution to changing the weight of African countries on this map. With 95% all of SOLSTICE-WIO publications co-authored by African scientists, and seventeen papers led by African researchers in 2020-21, SOLSTICE-WIO collaboration and capacity development activities have contributed to realising the Vision of the Decade 2030 to develop scientific knowledge and foster partnerships for a sustainable and healthy ocean.

PUBLICATION MAP OF THE WORLD WHERE THE AREA OF EACH COUNTRY IS SCALED AND RESIZED ACCORDING TO THE NUMBER OF OCEAN SCIENCE PUBLICATIONS



SCIENCE-METRIX NO. PAPERS

NO INFO	1 - 2,500	2,500 - 5,000	5,000 - 10,000	10,000 - 15,000	15,000 - 30,000	20,000 - 100,000

Source: Global Ocean Science Report, IOC/UNESCO, 2017

A MAJOR CONTRIBUTION TO THE INTERNATIONAL INDIAN OCEAN EXPEDITION

EXPLORATION OF AN OVERLOOKED OCEAN BASIN

The second International Indian Ocean Expedition (IIOE-2) is a major global scientific programme, which engages the international scientific community in collaborative oceanographic and atmospheric research from coastal environments to the deep sea. It is revealing new information on the Indian Ocean, fundamental for future sustainable development and expansion of the Indian Ocean's blue economy.

Focused research on the Indian Ocean has benefits for all nations. The Indian Ocean is highly complex and drives the region's climate, including extreme events (e.g. cyclones, droughts, severe rains, waves and storm surges). It is the source of important socio-economic resources (e.g. fisheries, oil and gas exploration/extraction, eco-tourism, and food and energy security) and is the background and focus of the region's human populations around its margins.

With its wide range of research activities, especially in some of the most understudied areas of the Indian Ocean, SOLSTICE-WIO provided a major contribution to IIOE-2.

FUTURE LEADERS

A COHORT OF EARLY CAREER RESEARCHERS WITH A UNIQUE COMBINATION OF SKILLS

SOLSTICE-WIO early career researchers played a key role in the project delivery. They brought talent and originality, and are at the core of the legacy of the project. These are a new generation of interdisciplinary scientists who work in the true spirit of the UN Decade of the Ocean Science 2030, dedicating their careers to the oceans of the future, and transforming ocean science for a better world, both for all of us and for the natural biological communities we share the planet with. SOLSTICE-WIO early career researchers have already moved into teaching and research roles in Universities and research centres where their experiences working on SOLSTICE-WIO will shape how they educate and inform students and develop research programmes of their own.

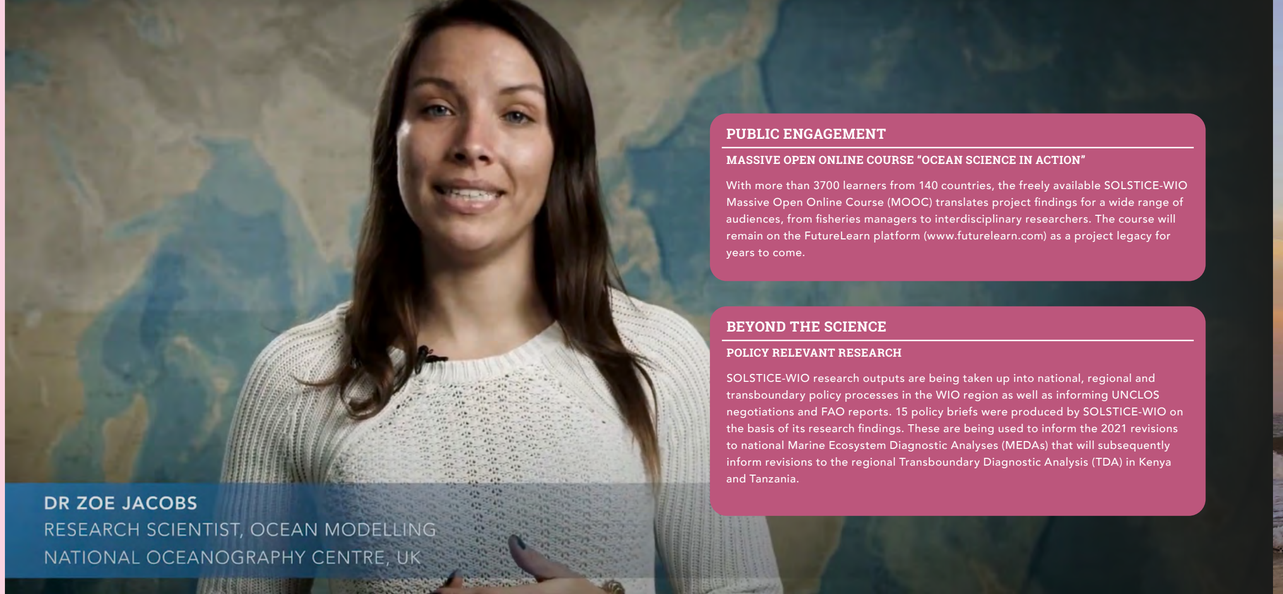
LASTING LEGACY

LOOKING BEYOND THE END OF THE PROJECT

The Legacy of research projects is often talked about, required by various funders, and expected in the impact statements attached to funding proposals. But is it really understood in the same way by all parties involved? And more than that, can a common definition ever be found, and can legacy ever really be planned for?

In the simplest definition 'Legacy' represents the impact one leaves behind. This can be either positive or negative, tangible or intangible, deliberate or unintentional, permanent or temporary, real or perceived, visible in a physical product, such as a pool of equipment, or in an emotion produced, such as the feeling of pride for the success of a complex international and interdisciplinary field campaign.

As SOLSTICE-WIO draws to a close, we can begin to reflect on all that has been achieved through the collective effort of our multi-cultural teams and the many fantastically talented individuals involved. Here are some of the project achievements with impact beyond the life of the project.



PUBLIC ENGAGEMENT

MASSIVE OPEN ONLINE COURSE "OCEAN SCIENCE IN ACTION"

With more than 3700 learners from 140 countries, the freely available SOLSTICE-WIO Massive Open Online Course (MOOC) translates project findings for a wide range of audiences, from fisheries managers to interdisciplinary researchers. The course will remain on the FutureLearn platform (www.futurelearn.com) as a project legacy for years to come.

BEYOND THE SCIENCE

POLICY RELEVANT RESEARCH

SOLSTICE-WIO research outputs are being taken up into national, regional and transboundary policy processes in the WIO region as well as informing UNCLOS negotiations and FAO reports. 15 policy briefs were produced by SOLSTICE-WIO on the basis of its research findings. These are being used to inform the 2021 revisions to national Marine Ecosystem Diagnostic Analyses (MEDAs) that will subsequently inform revisions to the regional Transboundary Diagnostic Analysis (TDA) in Kenya and Tanzania.

LONG-TERM IMPACTS

PEER-REVIEWED PUBLICATIONS ADDRESSING SUSTAINABILITY OF LIVING MARINE RESOURCES AND FOOD SECURITY OF COASTAL COMMUNITIES

SOLSTICE-WIO datasets, models and methods will be explored by the international research communities for years to come. However, two Special Issues and more than forty research papers have already been published, with more than three hundred and fifty citations.

SUSTAINABILITY

SELF-SUSTAINED INTERDISCIPLINARY NETWORK SUPPORTED BY ADDITIONAL FUNDING

From the beginning of the project, leveraging additional funds was always very prominently on the agenda. We believe that the project will achieve a long-lasting legacy if the network created can be self-sustaining, with the ability to secure additional funding from a wide variety of sources. We have generated in excess of £1.5M of additional funding, with a number of further grant applications under review. This allows many partners to carry on working together, building on the ideas developed in SOLSTICE-WIO.

NEW RESEARCH OPPORTUNITIES FOR SUSTAINABLE MARINE ECOSYSTEMS

ADVANCES IN APPROACHES AND TECHNOLOGIES FOR FOLLOW ON PROJECTS

SOLSTICE-WIO used pioneering approaches throughout its marine research activities: from building partnerships to sharing information and methods, exploiting the power of marine technologies, and developing the capacity of research scientists in the UK and WIO region to work together to achieve common goals. In the five years since the project was designed, there have been several significant advances in marine technologies and in global community recognition that the Ocean holds the keys to an equitable and sustainable planet.

New follow-on projects will be designed and delivered under the umbrella of the UN Decade of Ocean Science for Sustainable Development. Some of the advances which the new generation of researchers can now confidently build into future projects and partnerships to address the challenges of marine food security and climate change are:

CROSS DISCIPLINARY COLLABORATIONS
involving environmental and social scientists to address societal impacts of changes in the natural environment

AUTONOMOUS VEHICLES
cheaper, more reliable and more versatile platforms available for use in routine monitoring of the coastal and shelf zones

GLOBAL OCEAN MODELS
of increased resolution and regional realism readily available for analysis by regional scientists

AUTONOMOUS SENSORS
to measure an increasing number of parameters with increased resolution and frequency replacing labour intensive sampling and analysis

IMPROVED CLIMATE PROJECTIONS
with increased regional realism at the decision-scale, including novel impact metrics streamlining their use for policy and management decisions

REAL TIME MONITORING AND PREDICTION SYSTEMS
enhancing our ability to anticipate and respond to fluctuations in the marine environment (such as upwelling systems) impacting fisheries and aquaculture

MARINE FOOD SECURITY
recognised as one of the key challenges of this century with a broader scope of dedicated interdisciplinary research activities from fundamental understanding to solution-oriented research

CAPACITY DEVELOPMENT
in accessing, processing and analysing vast amounts of information available from global remote sensing and modelling data sets

NORTH-SOUTH PARTNERSHIPS
sharing information, methods, skills and publication efforts in addressing research challenges relevant to society

THANK YOU

SOLSTICE-WIO ADVISORY PANEL

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PROFESSOR KEVIN HORSBURGH

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SOLSTICE-WIO PUBLICATIONS
PUBLISHED UP TO END MARCH 2022

PEER REVIEWED PUBLICATIONS

Asdar, S.; Jacobs, Z.; Popova, E.; Noyon, M.; Sauer, W.H.H.; Roberts, M. (2022) Projected climate change impacts on the ecosystems of the Agulhas Bank, South Africa, Deep-Sea Research Part II: Topical Studies in Oceanography (In Review)

Bruggeman, J.; Jacobs, Z.; Popova, E.; Sauer, W.H.H.; Gornall, J.M.; Brewin, R.J.W.; Roberts, M. (2022) The paralarval stage as key to predicting squid catch: hints from a process-based model, Deep-Sea Research Part II: Topical Studies in Oceanography (In Review)

Demarcq, H.; Noyon, M.; Roberts, M.J. (2020) Satellite observations of phytoplankton enrichments around seamounts in the South West Indian Ocean with a special focus on the Walters Shoal. Deep-Sea Research Part II: Topical Studies in Oceanography, 176. 104800, https://doi.org/10.1016/j.dsr2.2020.104800

Gates, A.R.; Durden, J.M.; Richmond, M.D.; Muhando, C.A.; Khamis, Z.A.; Jones, D.O.B. (2021) Ecological considerations for marine spatial management in deep-water Tanzania, Ocean & Coastal Management, Volume 210, 105703, https://doi.org/10.1016/j.ocecoaman.2021.105703

Giering, S.; Noyon, M.; Godfrey, B.; Poulton, A.J.; Briggs, N.; Roberts, M. (2022) Optical particle measurements indicate resuspension as dominant mechanisms behind the formation of benthic nepheloid layers on the Agulhas Bank, Deep-Sea Research Part II: Topical Studies in Oceanography (In Review)

Harris, S.A.; Noyon, M.; Marsac, F.; Vianello, P.; Roberts, M.J. (2020) Ichthyoplankton assemblages at three shallow seamounts in the South West Indian Ocean. Deep-Sea Research Part II: Topical Studies in Oceanography, 176, 104809, https://doi.org/10.1016/j.dsr2.2020.104809

Jacobs, Z.L.; Jebri, F.; Raitsos, D.E.; Popova, E.; Srokosz, M.; Painter, S.C.; Nencioli, F.; Roberts, M.; Kamau, J.; Palmer, M.; Wihsgott, J. (2020) Shelf-break upwelling and productivity over the North Kenya Banks: The importance of large-scale ocean dynamics. Journal of Geophysical Research: Oceans, 125 (1), https://doi.org/10.1029/2019JC015519

Jacobs, Z.; Jebri, F.; Srokosz, M.; Raitsos, D.E.; Painter, S.C.; Nencioli, F.; Osuka, K.; Samoilys, M.; Sauer, W.; Roberts, M.; Taylor, S.F.W.; Scott, L.; Kizenga, H.; Popova, E. (2020) A major ecosystem shift in coastal East African waters during the 1997/98 Super El Niño as detected using remote sensing data. Remote Sensing, 12 (19), 3127, https://doi.org/10.3390/rs12193127

Jacobs, Z.L.; Yool, A.; Jebri, F.; Srokosz, M.; van Gennip, S.; Kelly, S.J.; Roberts, M.; Sauer, W.; Queirós, A.M.; Osuka, K.E.; Samoilys, M.; Becker, A.E.; Popova E. (2021) Key climate change stressors of marine ecosystems along the path of the East African coastal current, Ocean & Coastal Management, Volume 208, 105627, https://doi.org/10.1016/j.ocecoaman.2021.105627

Jacobs, Z.; Roberts, M.; Jebri, J.; Srokosz, M.; Kelly, S.; Sauer, W.H.H.; Bruggeman, J.; Popova, E. (2022) Drivers of productivity on the Agulhas Bank and the importance for marine ecosystems, Deep-Sea Research Part II: Topical Studies in Oceanography (In Review)

Jacobs, Z.L.; Kelly, S.; Jebri, F.; Roberts, M.; Srokosz, M.; Sauer, W.H.H.; Gornall, J.; Hancke, L.; Popova, E. (2022) Retention properties of the Agulhas Bank and their relevance to the chokka squid life cycle. Deep-Sea Research Part II Topical Studies in Oceanography (In Review)

Jebri, F.; Jacobs, Z.L.; Raitsos, D.E.; Srokosz, M.; Painter, S.C.; Kelly, S.; Roberts, M.J.; Scott, L.; Taylor, S.F.W.; Palmer, M.; Kizenga, H.; Shaghude, Y.; Wihsgott, J.; Popova, E. (2020) Interannual monsoon wind variability as a key driver of East African small pelagic fisheries. Scientific Reports, 10 (1), 13247, https://doi.org/10.1016/j.dsr2.2020.104813

Jebri, F.; Raitsos, D.E.; Gittings, J.A.; Jacobs, Z.; Srokosz, M.; Gornall, J.; Sauer, W.H.H.; Roberts, M.; Popova, E. (2022) Unravelling links between squid catch variations and biophysical mechanisms in South African waters, Deep-Sea Research Part II: Topical Studies in Oceanography , 105028, https://doi.org/10.1016/j.dsr2.2022.105028

Jebri, F.; Srokosz, M.; Jacobs, Z.L.; Nencioli, F.; Popova, E. (2022) Machine learning and Earth observation reveal the dynamics of productive upwelling regimes over the Agulhas Bank, Remote Sensing of Environment. (In Review)

Kamau, J.N.; Jacobs, Z.L.; Jebri, F.; Kelly, S.; Kimani, E.; Makori, A.; Mwaluma, J.; Mueni, E.; Ong'anda, H.; Palmer, M.R.; Popova, E.; Roberts, M.J.; Taylor, S.F.W.; Wihsgott, J.U.; Painter S.C. (2021) Managing emerging fisheries of the North Kenya Banks in the context of environmental change, Ocean & Coastal Management, Volume 209, 105671, https://doi.org/10.1016/j.ocecoaman.2021.105671

Kizenga, H.J.; Jebri, F.; Shaghude, Y.; Raitsos, D.E.; Srokosz, M.; Jacobs, Z.L.; Nencioli, F.; Shalli, M.; Kyewayanga, M.S.; Popova, E. (2021) Variability of mackerel fish catch and remotely-sensed biophysical controls in the eastern Pemba Channel, Ocean & Coastal Management, Volume 207, 105593, https://doi.org/10.1016/j.ocecoaman.2021.105593

Lamont, T.; Barlow, R.G.; Brewin, R.J.W. (2018). Variations in remotely-sensed phytoplankton size structure of a cyclonic eddy in the southwest Indian Ocean. Remote Sensing, 10(7):1143, https://doi.org/10.3390/rs10071143

Lamont, T.; Brewin, R.G.; Barlow, R.J.W. (2018). Seasonal variation in remotely-sensed phytoplankton size structure around southern Africa. Remote Sensing of Environment, 204, 617-631, https://doi.org/10.1016/j.rse.2017.09.038

Malauene, B.S.; Moloney, C.L.; Lett, C.; Roberts, M.J.; Marsac, F.; Penven, P. (2018) Impact of offshore eddies on shelf circulation and river plumes of the Sofala Bank, Mozambique Channel. Journal of Marine Systems, 185, 1-12, https://doi.org/10.1016/j.jmarsys.2018.05.001

Malauene, B.S.; Lett, C.; Marsac, F.; Roberts, M.J.; Brito, A.; Abdula, S.; Moloney, C.L. (2021) Spawning areas of two shallow-water penaeid shrimps (Penaeus indicus and Metapenaeus monoceros) on the Sofala Bank, Mozambique. Estuarine, Coastal and Shelf Science, 253, 107268, https://doi.org/10.1016/j.ecss.2021.107268

Marsac, F.; Galletti, F.; Ternon, J-F.; Romanov, E.V.; Demarcq, H.; Corbari, L.; Bouchet, P.; Roest, W.R.; Jorry, S.J.; Olu, K.; Loncke, L.; Roberts, M.J.; Ménard, F. (2020) Seamounts, plateaus and governance issues in the southwestern Indian Ocean, with emphasis on fisheries management and marine conservation, using the Walters Shoal as a case study for implementing a protection framework. Deep-Sea Research Part II: Topical Studies in Oceanography, 176, 104715, https://doi.org/10.1016/j.dsr2.2019.104715

Mazwane, S.L.; Poulton, A.J.; Hickman, A.; Jebri, F.; Jacobs Z.; Roberts, M.; Noyon, M. (2022) Seasonal and long-term stability of Net Primary Production on the Agulhas Bank, 1998 - 2018, Deep-Sea Research Part II: Topical Studies in Oceanography (In Review)

Morris, T.; Hermes, J.; Beal, L.; du Pliessis, M.; Duncombe Rae, C.; Gulekana, M.; Lamont, T.; Speich, S.; Roberts, M.; Ansorge, I.J. (2017) The importance of monitoring the Greater Agulhas Current and its inter-ocean exchanges using large mooring arrays. South African Journal of Science, 113 (7/8), https://doi.

org/10.17159/sajs.2017/20160330

Mutia, D.; Carpenter, S.; Jacobs, Z.; Jebri, F.; Kamau, J.; Kelly, S.J.; Kimeli, A.; Langat, P.K.; Makori, A.; Nencioli, F.; Painter, S.C.; Popova, E.; Raitsos, D.; Roberts, M. (2021) Productivity driven by Tana River discharge is spatially limited in Kenyan coastal waters, Ocean & Coastal Management, Volume 211, 105713, https://doi.org/10.1016/j.ocecoaman.2021.105713

Mwaluma, J.; Ngisiang'e, N.; Osore, M; Kamau, J.; Ong'anda, H.; Kilonzi, J.; Roberts, M.; Popova, E.; Painter S.C. (2021) Assemblage structure and distribution of fish larvae on the North Kenya Banks during the Southeast Monsoon season, Ocean & Coastal Management, Volume 212, 105800, https://doi.org/10.1016/j.ocecoaman.2021.105800

Noyon, M.; Poulton, A.J.; Asdar, S.; Weitz, R.; Giering, S. L.C. (2022) Mesozooplankton community distribution on the Agulhas Bank in Autumn: size structure and production, Deep-Sea Research Part II: Topical Studies in Oceanography, Volume 195, 105015, https://doi.org/10.1016/j.dsr2.2021.105015

Noyon, M.; Rasoloarijao, Z.; Huggett, J.; Ternon, J.-F.; Roberts, M. (2020) Comparison of mesozooplankton communities at three shallow seamounts in the South West Indian Ocean. Deep-Sea Research Part II: Topical Studies in Oceanography, 176, 104759, https://doi.org/10.1016/j.dsr2.2020.104759

Osuka, K.E.; McClean, C.; Stewart, B.D.; Bett, B.J.; Le Bas, T.; Howe, J.; Abernerthy, C.; Yahya, S.; Obura, D.; Samoilys, M. (2021) Characteristics of shallow and mesophotic environments of the Pemba Channel, Tanzania: Implications for management and conservation, Ocean & Coastal Management, Volume 200,105463, https://doi.org/10.1016/j.ocecoaman.2020.105463

Osuka, K.E.; Stewart, B.D.; Samoilys, M.A.; Roche, R.C.; Turner, J.; McClean, C. (2021) Protection outcomes for fish trophic groups across a range of management regimes, Marine Pollution Bulletin, Volume 173, Part A, https://doi.org/10.1016/j.marpolbul.2021.113010

Painter, S. (2020). The biogeochemistry and oceanography of the East African Coastal Current. Progress in Oceanography, 102374, https://doi.org/10.1016/j.pocean.2020.102374

Painter, S.C.; Sekadende, B.; Michael, A.; Noyon, M.; Shayo, S.; Godfrey, B.; Mwadini, M.; Kyewalyanga, M. (2021) Evidence of localised upwelling in Pemba Channel (Tanzania) during the southeast monsoon, Ocean & Coastal Management, Volume 200, 105462, https://doi.org/10.1016/j.ocecoaman.2020.105462

Painter, S.C.; Popova, E.; Roberts, M.J. (2022) An introduction to East African Coastal Current ecosystems: At the frontier of climate change and food security, Ocean & Coastal Management, Volume 216, 105977, https://doi.org/10.1016/j.ocecoaman.2021.105977

Palmer, M.R.; Shagude, Y.W.; Roberts, M.J.; Popova, E.; Wihsgott, J.U.; Aswani, S.; Coupland, J.; Howe, J.A.; Bett, B.J.; Osuka, K.E.; Abernethy, C.; Alexiou, S.; Painter, S.C.; Kamau, J.N.; Nyandwi, N.; Sekadende, B. (2021) Marine robots for coastal ocean research in the Western Indian Ocean, Ocean & Coastal Management, Volume 212, 105805, https://doi.org/10.1016/j.ocecoaman.2021.105805

Popova, E.; Vousden, D.; Sauer, W.H.H.; Mohammed, E.Y.; Allain, V.; Downey-Breedt, N.; Fletcher, R.; Gjerde, K.M.; Halpin, P.N.; Kelly, S.; Obura, D.; Pecl, G.; Roberts, M.; Raitsos, D.E.; Rogers, A.; Samoilys, M.; Sumaila, U.R.; Tracey, S.; Yool, A. (2019). Ecological connectivity between the areas beyond national jurisdiction and coastal waters: Safeguarding interests of coastal communities in developing countries. Marine Policy, 104, 90-102, https://doi.org/10.1016/j.marpol.2019.02.050

Poulton, A.J.; Mazwane, S.L.; Godfrey, B.; Carvalho, A.; Mawji, E.; Wihsgott, J.U.; Noyon, M. (2022) Primary production dynamics on the Agulhas Bank in autumn (March 2019), Deep-Sea Research Part II: Topical Studies in Oceanography (In Review)

Queirós, A.M.; Talbot, E.; Beaumont, N.J.; Somerfield, P.J.; Kay, S.; Pascoe, C.; Dedman, S.; Fernandes, J.; Jueterbock, A.; Miller, P.I.; Sailley, S.F.; Sará, G.; Carr, L.M.; Austen, M.C.; Widdicombe, S.; Rilov, G.; Levin, L.A.; Hull, S.C.; Walmsley, S.F.; Nic Aonghusa, C. (2021). Bright spots as climate-smart marine spatial planning tools for conservation and blue growth. Global Change Biology, 27, 5514– 5531, https://doi.org/10.1111/gcb.15827

Roberts, M.J.; Ternon, J-F. (2020) The MADRidge project a major contribution to IIOE2-WIOURI focussing on three shallow seamounts and their pelagic ecosystems in the vicinity of the Madagascar Ridge, Deep-Sea Research Part II: Topical Studies in Oceanography, Volume 176, https://doi.org/10.1016/j.dsr2.2020.104817

Roberts, M.J.; Ternon, J-F.; Marsac, F.; Noyon, M.; Payne, A.I.L. (2020) The MADRidge project: Bio-physical coupling around three shallow seamounts in the South West Indian Ocean, Deep-Sea Research Part II: Topical Studies in Oceanography, Volume 176, https://doi.org/10.1016/j.dsr2.2020.104813

Roberts, M.; Popova, E.; Sauer, W.H.H.; Carter, L. (2022) Dynamics of the Agulhas Bank ecosystem functioning, shifts and future trends in the South African squid fishery, Deep-Sea Research Part II: Topical Studies in Oceanography (In Review)

Rocke, E.; Noyon, M.; Roberts, M. (2020) Picoplankton and nanoplankton composition on and around a seamount, affected by an eddy dipole south of Madagascar. Deep-Sea Research Part II: Topical Studies in Oceanography, 176, 104744, https://doi.org/10.1016/j.dsr2.2020.104744

Sekadende, B.; Scott, L.; Anderson, J.; Aswani, S.; Francis, J.; Jacobs, Z.; Jebri, F.; Jiddawi, N.; Kamukuru, A.T.; Kelly, S.; Kizenga, H.; Kuguru, B.; Kyewalyanga, M.; Noyon,M.; Nyandwi, N.; Painter, S.C.; Palmer, M.; Raitsos, D.E.; Roberts, M.; Sailley, S.F.; Samoilys, M.; Sauer, W.H.H.; Shayo, S.; Shaghude, Y.; Taylor, S.F.W.; Wihsgott, J.; Popova E. (2020) The small pelagic fishery of the Pemba Channel, Tanzania: What we know and what we need to know for management under climate change, Ocean & Coastal Management, Volume 197, 105322, https://doi.org/10.1016/j.ocecoaman.2020.105322

Sekadende, B.C.; Michael, A.; Painter, S.C.; Shayo, S.; Noyon, M.; Kyewalyanga, M.S. (2021) Spatial variation in the phytoplankton community of the Pemba Channel, Tanzania, during the south-east monsoon, Ocean & Coastal Management, Volume 212, 105799, https://doi.org/10.1016/j.ocecoaman.2021.105799

Semba, M.; Lumpkin, R.; Kimirei, I.; Shaghude, Y.; Nyandwi, N. (2019) Seasonal and spatial variation of surface current in the Pemba Channel, Tanzania. PLoS ONE 14(1): e0210303, https://doi.org/10.1371/journal.pone.0210303

Taylor, S.F.W.; Roberts, M.J.; Milligan, B.; Ncwadi, R. (2019) Measurement and implications of marine food security in the Western Indian Ocean: an impending crisis?. Food Security, 11, 1395–1415, https://doi.org/10.1007/s12571-019-00971-6

Taylor, S.F.W.; Aswani, S.; Jiddawi, N.; Coupland, J.; James, P.A.S.; Kelly, S.; Kizenga, H.; Roberts, M.; Popova, E. (2021) The complex relationship between asset wealth, adaptation, and diversification in tropical fisheries, Ocean & Coastal Management, Volume 212, 105808, https://doi.org/10.1016/j.ocecoaman.2021.105808

Vianello, P.; Ternon, J-F.; Demarcq, H.; Herbette, S.; Roberts, M.J. (2020) Ocean currents and gradients

of surface layer properties in the vicinity of the Madagascar Ridge (including seamounts) in the South West Indian Ocean. Deep-Sea Research Part II: Topical Studies in Oceanography, 176, 104816, https://doi.org/10.1016/j.dsr2.2020.104816

Vianello, P.; Herbette, S.; Ternon, J-F.; Demarcq, H.; Roberts, M.J. (2020) Observation of a mesoscale eddy dipole on the northern Madagascar Ridge: Consequences for the circulation and hydrography in the vicinity of a seamount. Deep-Sea Research Part II: Topical Studies in Oceanography, 176, 104815, https://doi.org/10.1016/j.dsr2.2020.104815

Vinayachandran, P.N.M.; Masumoto, Y.; Roberts, M.J.; Huggett, J.A.; Halo, I.; Chatterjee, A.; Amol, P.; Gupta, G.V.M.; Singh, A.; Mukherjee, A.; Prakash, S.; Beckley, L.E.; Raes, E.J.; Hood, R. (2021) Reviews and syntheses: Physical and biogeochemical processes associated with upwelling in the Indian Ocean, Biogeosciences, 18, 5967–6029, https://doi.org/10.5194/bg-18-5967-2021

Wilson, R.J.; Sailley, S.F.; Jacobs, Z.L.; Kamau, J.; Mgeleka, S.; Okemwa, G.M.; Omukoto, J.O.; Osuka, K.E.; Samoilys, M.; Sauer, W.; Silas, M.O.; Sululu, J.S.; Roberts, M.J. (2021) Large projected reductions in marine fish biomass for Kenya and Tanzania in the absence of climate mitigation, Volume 215, 105921, https://doi.org/10.1016/j.ocecoaman.2021.105921

POLICY BRIEFS

Anderson, J. (2021) Livelihoods from the Ocean: How science and technology can contribute to their sustainability in Tanzania. Science into policy review, October 2021. Available from: https://solstice-wio.org/sites/default/files/documents/outputs/Science_into_Policy_Review_TANZANIA.pdf

Popova, E.; Bladon, A.J.; Mohammed, E.Y.; Vousden, D.; Sauer, W. (2019) So far, yet so close: ecological connectivity between ABNJ and territorial waters, IIED Briefing Paper (17500), https://pubs.iied.org/17500iied

Accelerating climate change impacts on Kenya's marine ecosystems – what to be prepared for? Summary of policy relevant information. SOLSTICE-WIO Partnership. July 2021. Available from: https://solstice-wio.org/sites/default/files/documents/outputs/Accelerating%20climate%20change%20impacts%20on%20Kenya%E2%80%99s%20marine%20ecosystems.pdf

Connectivity between Areas Beyond National Jurisdiction and the coastal zones: Country Profile (The Federal Republic of Somalia). Policy and Practice Briefing. SOLSTICE-WIO Partnership. March 2020. Available from: https://solstice-wio.org/sites/default/files/documents/outputs/Connectivity%20between%20Areas%20Beyond%20National%20Jurisdiction%20and%20the%20coastal%20zones-%20SOMALIA.pdf

Connectivity between Areas Beyond National Jurisdiction and the coastal zones: Country Profile (Comoros). Policy and Practice Briefing. SOLSTICE-WIO Partnership. March 2020. Available from: https://solstice-wio.org/sites/default/files/documents/outputs/Connectivity%20between%20Areas%20Beyond%20National%20Jurisdiction%20and%20the%20coastal%20zones-%20COMOROS.pdf

Connectivity between Areas Beyond National Jurisdiction and the coastal zones: Country Profile (The Republic of Kenya). Policy and Practice Briefing. SOLSTICE-WIO Partnership. March 2020. Available from: https://solstice-wio.org/sites/default/files/documents/outputs/Connectivity%20between%20Areas%20Beyond%20National%20Jurisdiction%20and%20the%20coastal%20zones-%20KENYA.pdf

Connectivity between Areas Beyond National Jurisdiction and the coastal zones: Country Profile (The Republic of Madagascar). Policy and Practice Briefing. SOLSTICE-WIO Partnership. March 2020. Available from: https://solstice-wio.org/sites/default/files/documents/outputs/Connectivity%20between%20Areas%20Beyond%20National%20Jurisdiction%20and%20the%20coastal%20zones-%20MADAGASCAR.pdf

Connectivity between Areas Beyond National Jurisdiction and the coastal zones: Country Profile (The Republic of Mozambique). Policy and Practice Briefing. SOLSTICE-WIO Partnership. March 2020. Available from: https://solstice-wio.org/sites/default/files/documents/outputs/Connectivity%20between%20Areas%20Beyond%20National%20Jurisdiction%20and%20the%20coastal%20zones-%20MOZAMBIQUE.pdf

Connectivity between Areas Beyond National Jurisdiction and the coastal zones: Country Profile (The United Republic of Tanzania). Policy and Practice Briefing. SOLSTICE-WIO Partnership. March 2020. Available from: https://solstice-wio.org/sites/default/files/documents/outputs/Connectivity%20between%20Areas%20Beyond%20National%20Jurisdiction%20and%20the%20coastal%20zones-%20TANZANIA.pdf

Data management for ocean governance: Tanzania. SOLSTICE-WIO Partnership. July 2021. Available from: https://solstice-wio.org/sites/default/files/documents/outputs/Data%20management%20for%20ocean%20governance.pdf

Importance of ocean upwelling at the North Kenya Banks for the migratory fish species of the WIO region. SOLSTICE-WIO Partnership. July 2021. Available from: https://solstice-wio.org/sites/default/files/documents/outputs/Importance%20of%20ocean%20upwelling%20at%20the%20NKB%20for%20the%20migratory%20fish%20species%20of%20the%20WIO%20region.pdf

The key features of the North Kenya Banks upwelling and a need for a risk-based approach to fisheries management. SOLSTICE-WIO Partnership. July 2021. Available from: https://solstice-wio.org/sites/default/files/documents/outputs/The%20key%20features%20of%20the%20NKB%20upwelling%20and%20a%20need%20for%20a%20risk-based%20approach%20to%20fisheries%20management.pdf

Towards a joint management of the living resources in the Pemba Channel: Part 1 Oceanographic underpinning. SOLSTICE-WIO Partnership. July 2021. Available from: https://solstice-wio.org/sites/default/files/documents/outputs/Part%201_Towards%20a%20joint%20management%20of%20the%20living%20resources%20in%20the%20Pemba%20Channel.pdf

Towards a joint management of the living resources in the Pemba Channel: Part 2 Accelerating Climate Change impacts on marine ecosystems in Tanzania – what to be prepared for? SOLSTICE-WIO Partnership. July 2021. Available from: https://solstice-wio.org/sites/default/files/documents/outputs/Part%202_Towards%20a%20joint%20management%20of%20the%20living%20resources%20in%20the%20Pemba%20Channel.pdf

Towards a joint management of the living resources in the Pemba Channel: Part 3 Joint Management of the small pelagics in the Pemba and Zanzibar Channels. SOLSTICE-WIO Partnership. July 2021. Available from: https://solstice-wio.org/sites/default/files/documents/outputs/Part%203_Towards%20a%20joint%20management%20of%20the%20living%20resources%20in%20the%20Pemba%20Channel.pdf

KEEPING IN TOUCH

Although the project has ended, the research, capacity development and communication activities using SOLSTICE-WIO data sets, approaches and tools will carry on for years to come. You can find updates on our project website;

solstice-wio.org

You can find more about SOLSTICE-WIO results and activities through our Massive Open Online Course; Ocean Science in Action: Addressing Marine Ecosystems and Food Security, available on FutureLearn;

futurelearn.com/courses/ocean-science-in-action-addressing-marine-ecosystems-and-food-security-in-the-western-indian-ocean

If you would like to discuss the project further, please direct your enquiries to;

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The National Oceanography Centre is the lead organisation of the SOLSTICE-WIO project and the UK's centre of excellence for research and technology development in marine science. You can find out more at;

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