The North Kenya Banks pelagic fishery in the context of climate change

By

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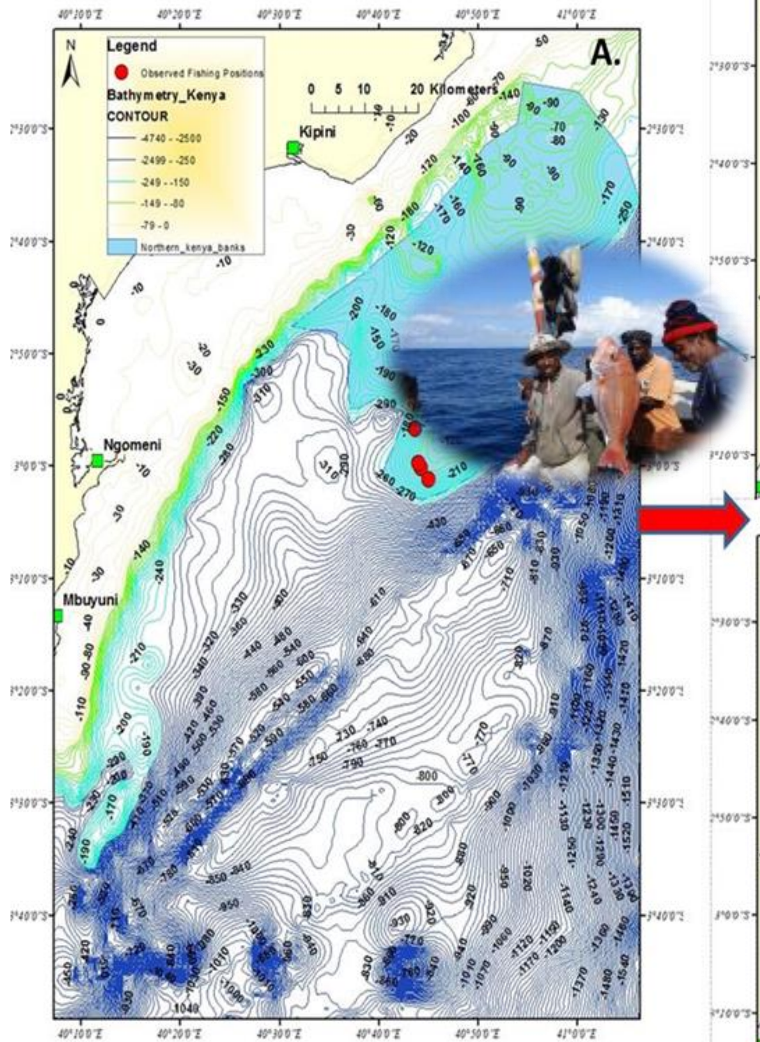
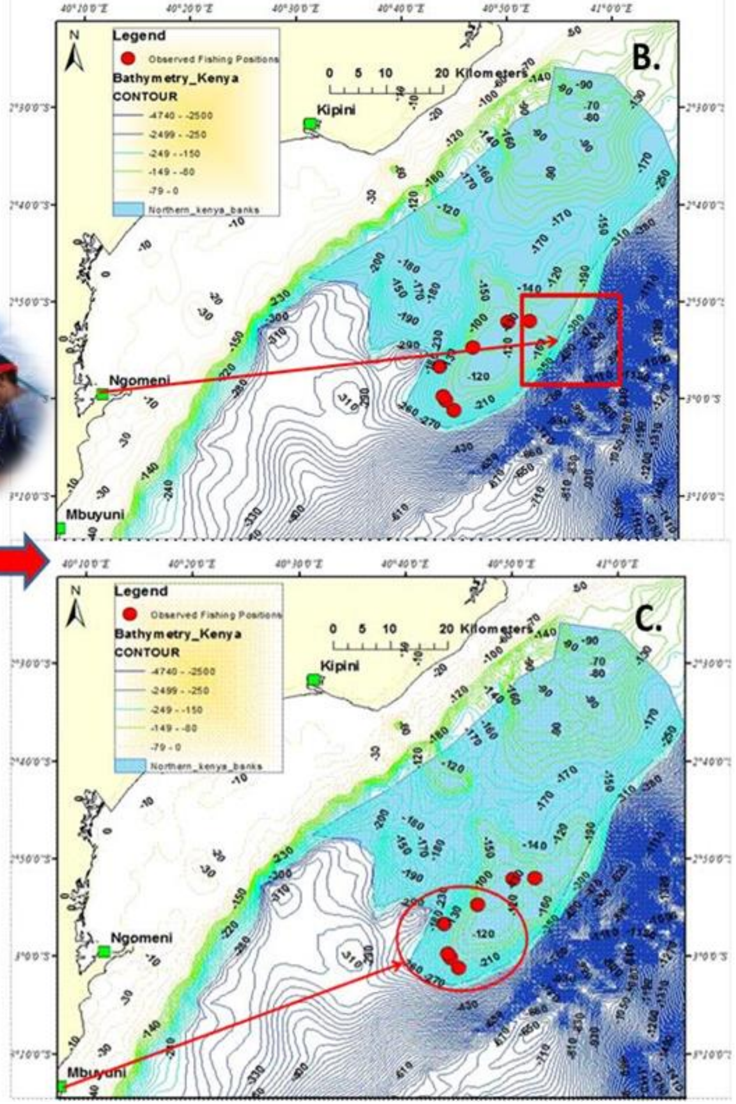
North Kenya Banks Artisanal Fishing grounds

The region between latitude 2°50" - 3°00" S ; and Longitude 40°45" - 40°57" E.

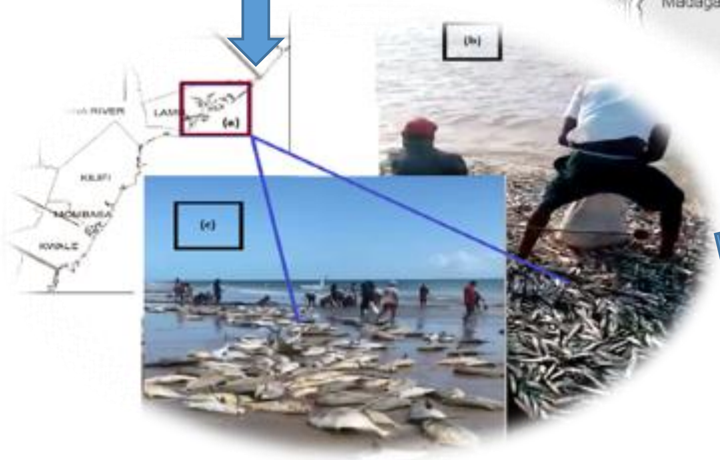




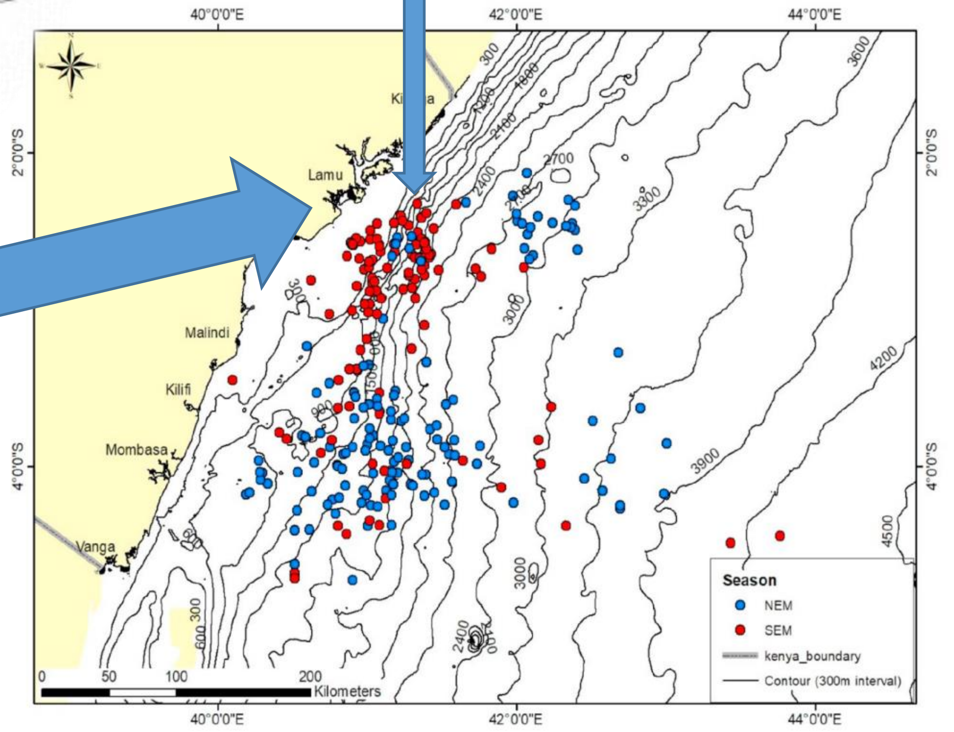
WIO region Tuna migration path; location indicated by month

July is the month when tuna fishery migrate to the Kenyan coast

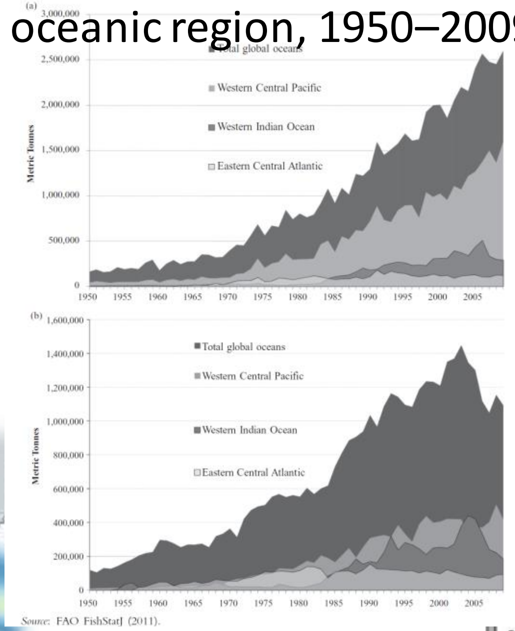
During the SEM fishing is concentrated at the North Kenya Banks driven by the fast flowing EACC and the topographic forcing on the NKBs

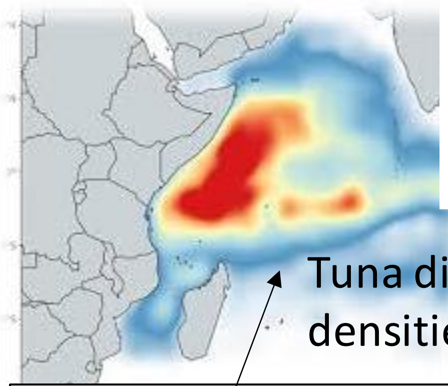


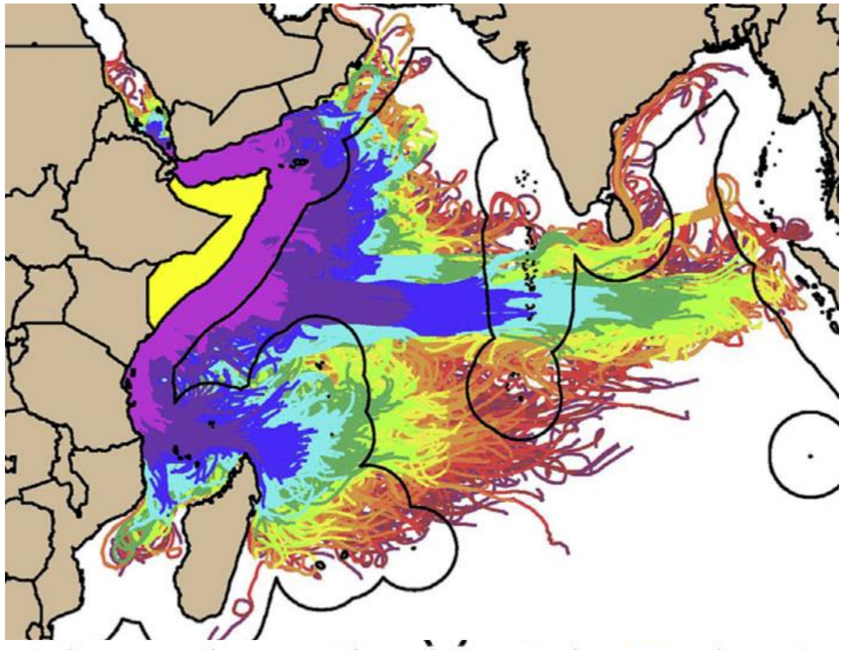
Sardine run observed in July at the North in Lamu



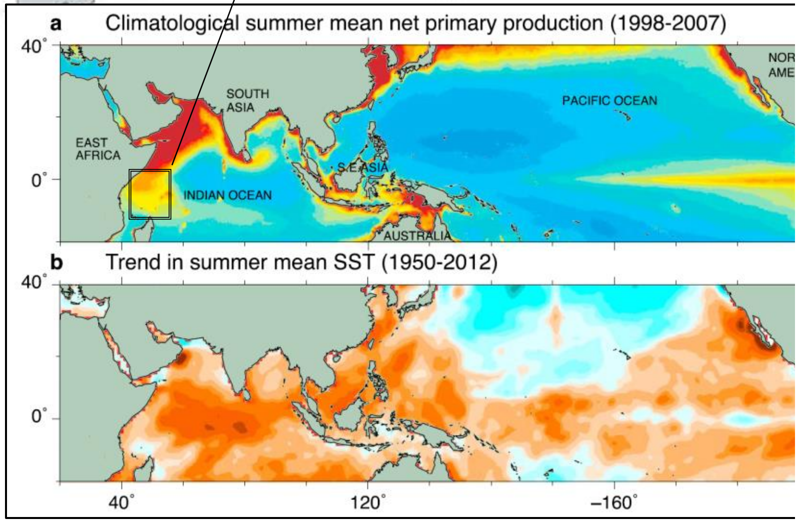
The global skipjack (a) and yellowfin (b) catch by all gear types and by major oceanic region, 1950–2009

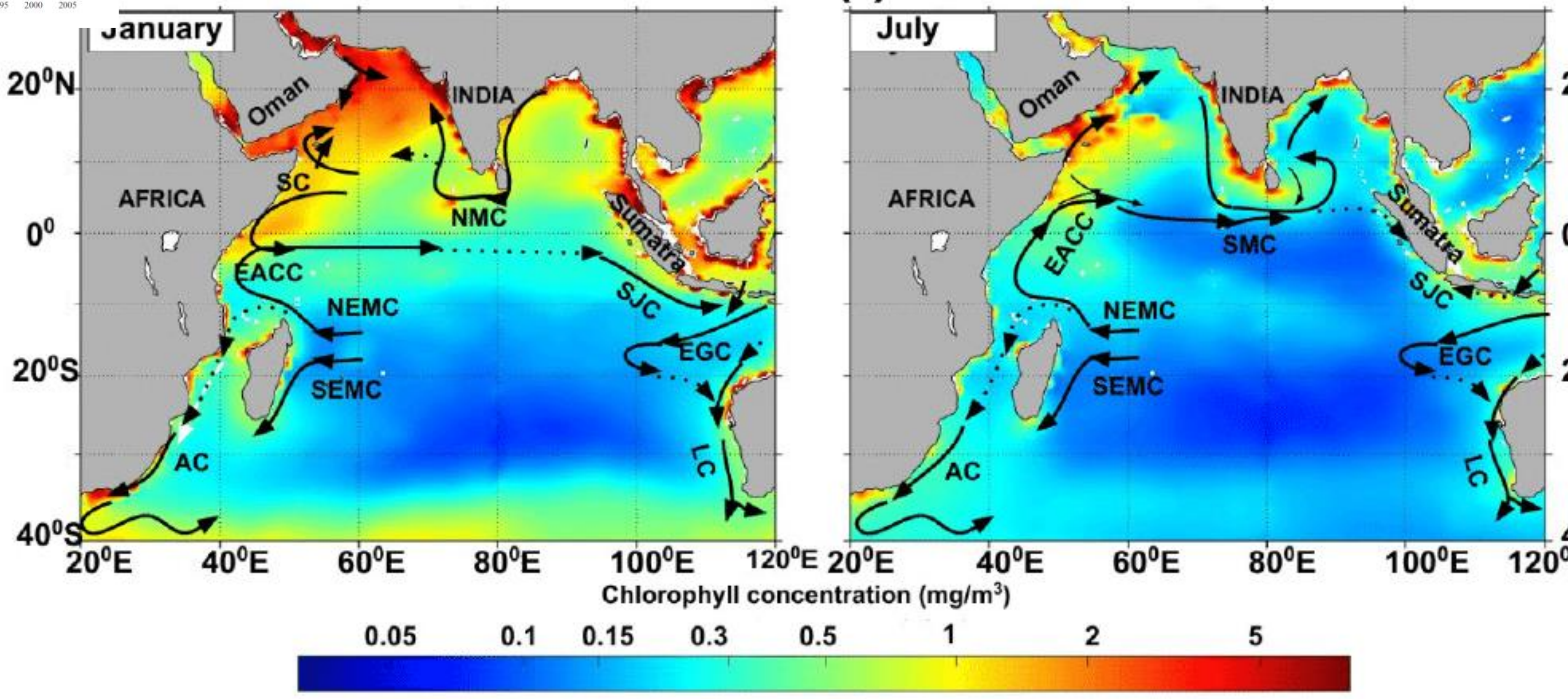




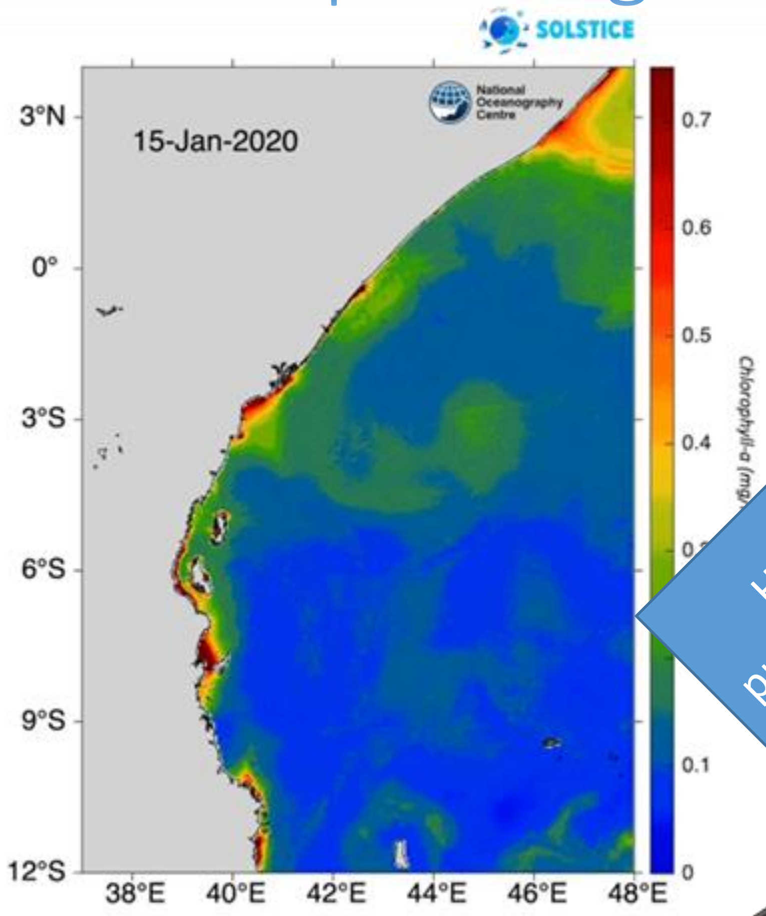


Tuna distribution densities

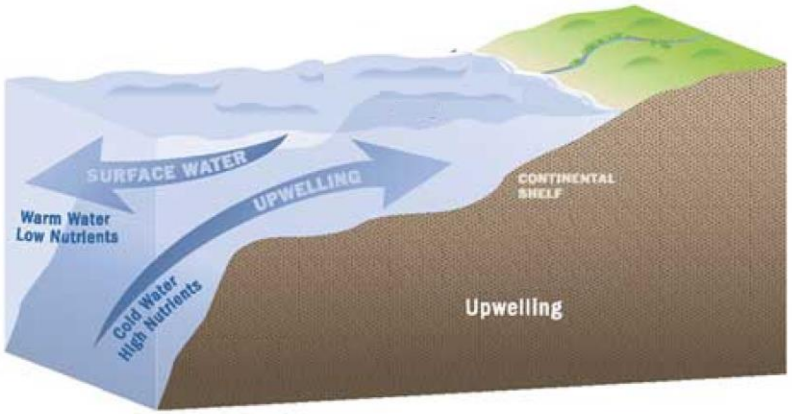




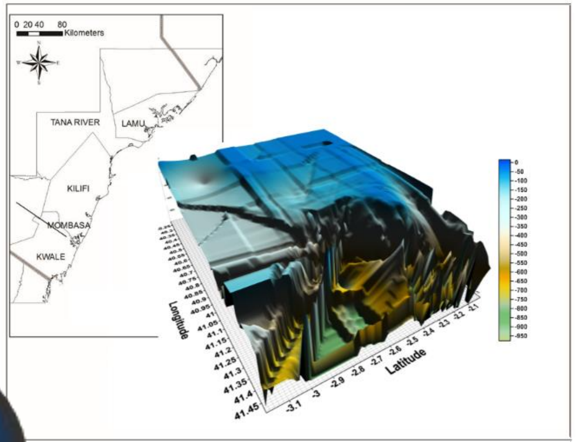
Upwelling occurrence along the Kenyan Coast



Upwelling enhance productivity



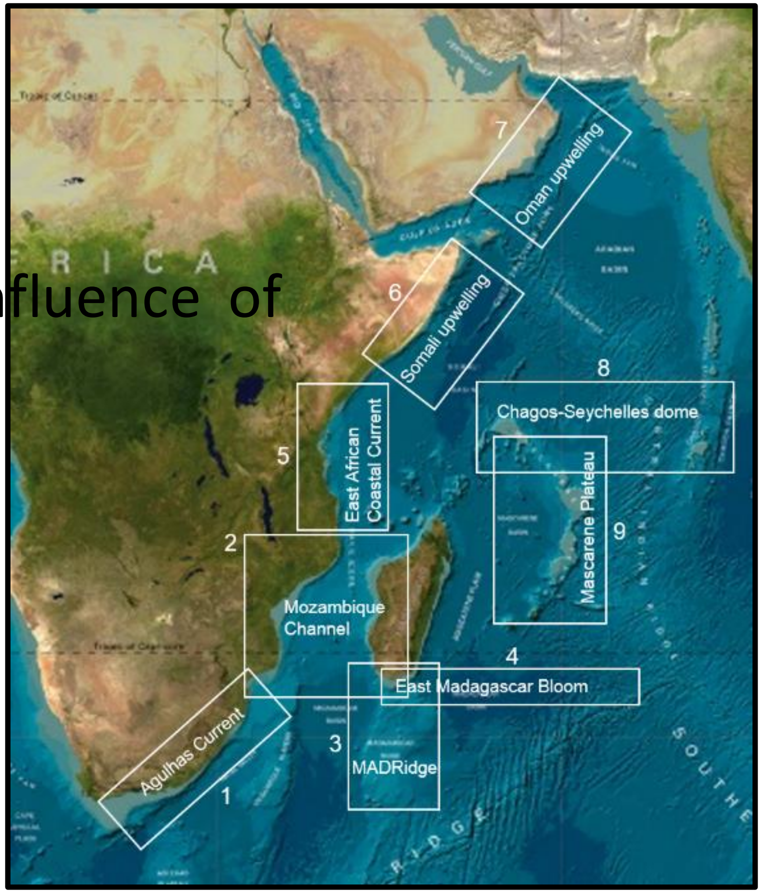
High productivity support fishery



Upwelling systems supporting the Western Indian Ocean Tuna Fishery

The varying upwelling systems in the WIO can be grouped into 9 systems

1. Upwelling in the Mozambique Channel
2. Madagascar Ridge and seamounts upwelling
3. Southeast Madagascar shelf and (SICC) chlorophyll bloom
4. Upwelling in the East African Coastal Current (EACC) and influence of major islands (Mafia, Zanzibar, Pemba)
5. Upwelling Somalia Current system
6. Oman/Arabian Sea upwelling system
7. Chagos-Seychelles upwelling dome (SCTR) and Chagos Ridge
8. Mascarene Plateau induced upwelling

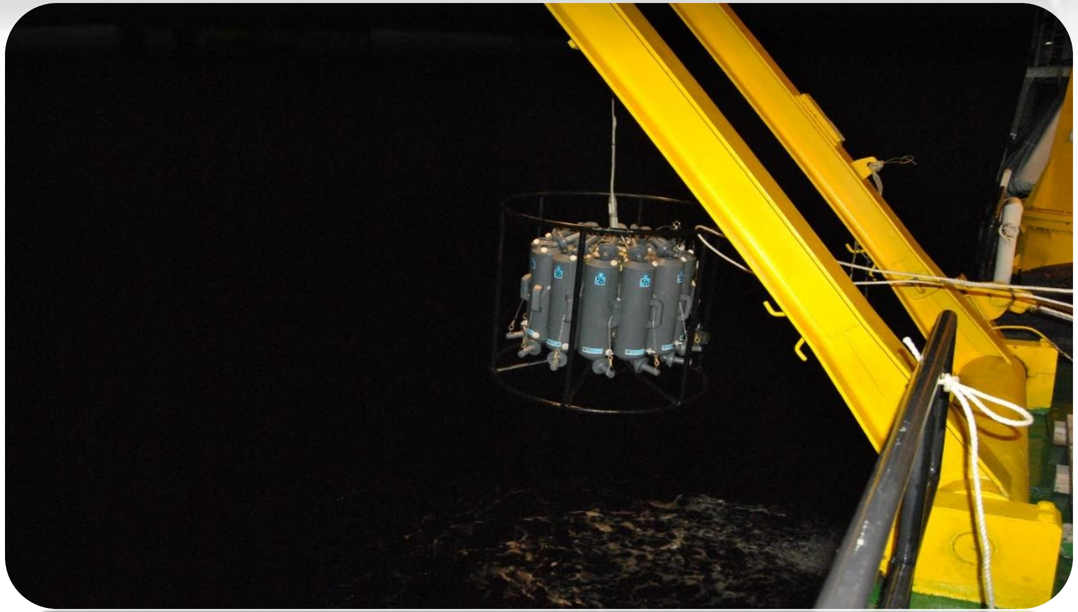


OCEAN DATA SOURCES

Ocean modelling

RV. Mtafiti

Remote sensing

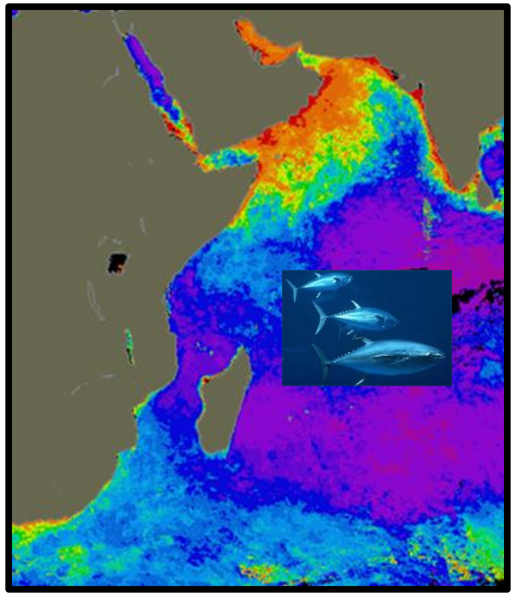


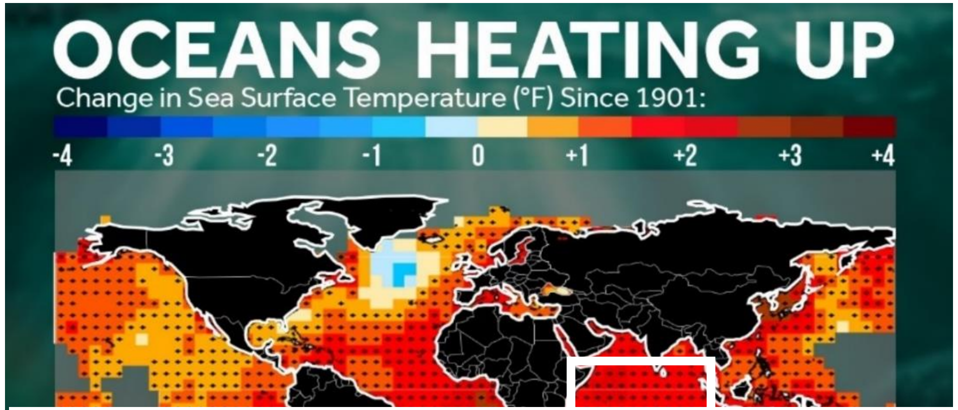
Insitu Sampling

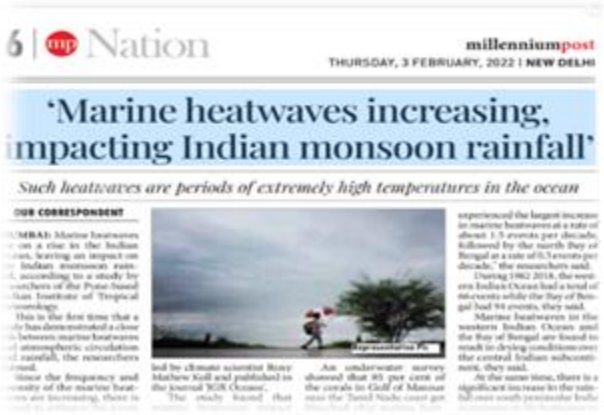
Current and projected scenario

- Studies have shown that the whole Indian Ocean has been warming throughout the past half century.
- During 1901-2012, the western Indian Ocean experienced anomalous warming of 1.2°C
- However in comparison with the rest of the Indian Ocean, the western Indian Ocean generally has cooler mean SSTs in summer, owing to the strong monsoon winds and the resultant upwelling over the western Indian Ocean (Rao et al. 2012; Swapna et al. 2013).
- The western Indian Ocean is also one of the most biologically productive regions during the summer due to the intense upwelling (Ryther and Menzel 1965). Hence a significant change in the SSTs of this region can also alter marine food webs (Behrenfeld et 42 al. 2006).
- The migration of several coastal and oceanic pelagic fishes is also known to follow changes in ocean circulation pathways
- Large projected reductions in marine fish biomass for Kenya and Tanzania in the absence of climate mitigation
- Studies have implied local ocean-atmosphere coupled mechanisms for the continuous warming over the region, in addition to anthropogenic forcing.

Indian Ocean is Changing!






6 | mp Nation
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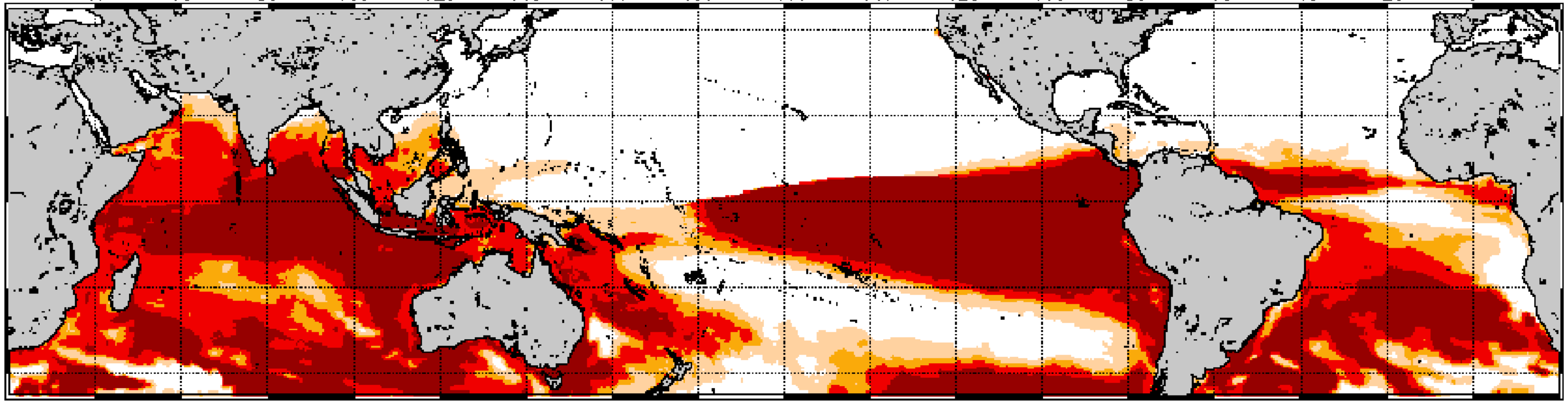
'Marine heatwaves increasing, impacting Indian monsoon rainfall'

Such heatwaves are periods of extremely high temperatures in the ocean

OUR CORRESPONDENT

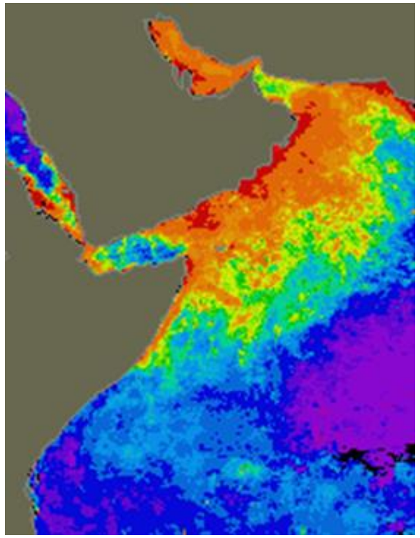
2015 Oct 6 NOAA Coral Reef Watch 60% Probability Coral Bleaching Thermal Stress for Feb-May 2016



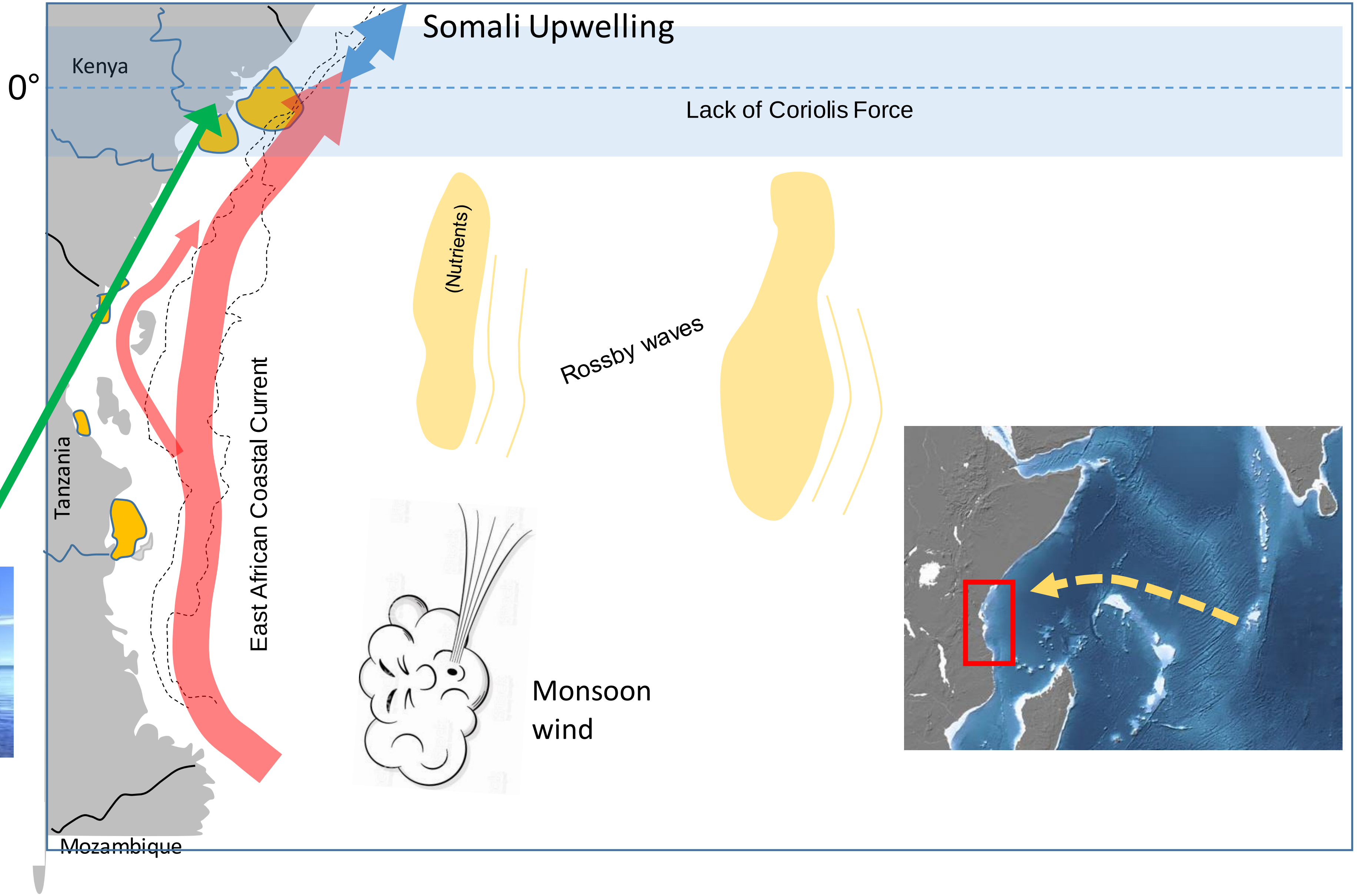
Potential Stress Level: Watch Warning Alert Level 1 Alert Level 2

Productivity Influencing systems

Somali upwelling

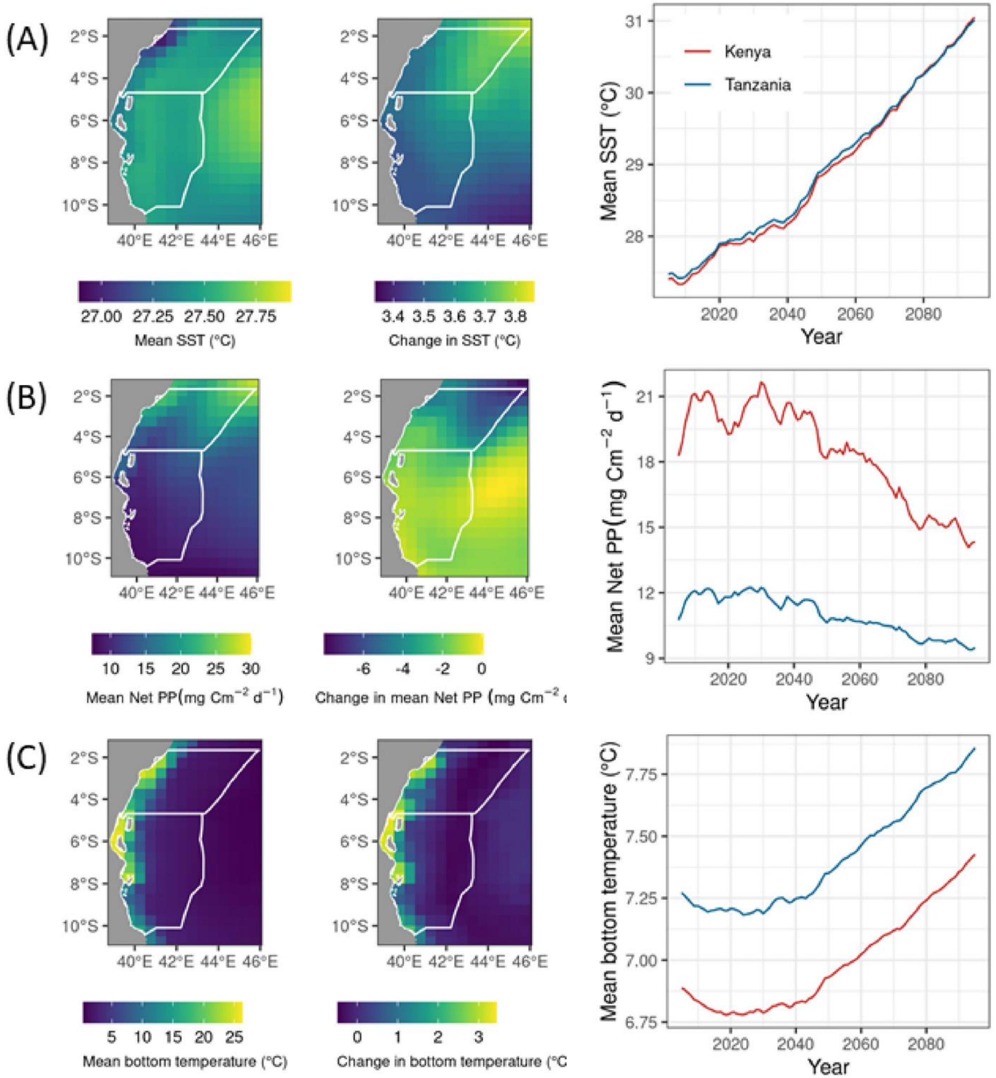


Mangroves & Rivers

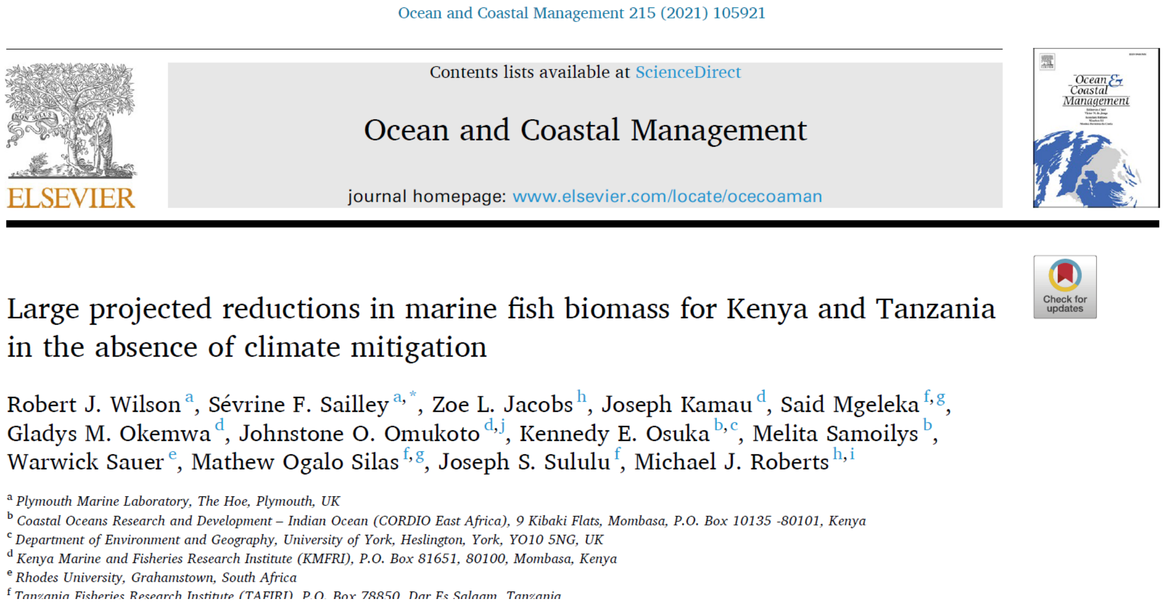


Ecosystem shift

- A multi-species fish model (Size Spectrum Dynamic Bio-climate Envelope Model; SS-DBEM) for 43 species of commercial and artisanal importance was run, to investigate the effects of climate change.
- Future changes in fish biomass have been projected for the EEZs of Kenya and Tanzania
- Forty-three fish species that are representative of exploited fish species were modelled, and the species choice aims to represent both commercial and sustenance types of species.
- Changes in key physical and biogeochemical properties such as temperature, salinity, pH, chlorophyll and velocities were taken from version 2.0 of the NEMO-MEDUSA model
- The model was forced at the surface using air temperature projections from the HadGEM2-ES Earth System Model (Collins et al., 2011).
- The outputs from NEMO-MEDUSA were used to drive a dynamic bioclimate envelope model (DBEM), which projects changes in fish species distribution and biomass while explicitly considering known mechanisms of population dynamics and dispersal (both larval and adult), as well as eco-physiological changes caused by changing ocean conditions (Cheung et al., 2011).



A) annual mean sea surface temperature (SST), B) water column integrated net primary productivity (Net NPP), and C) sea bottom temperature. Column 1 shows climatological mean values (2000–09),



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Large projected reductions in marine fish biomass for Kenya and Tanzania in the absence of climate mitigation

Robert J. Wilson[a], Sévrine F. Sailley[a,*], Zoe L. Jacobs[h], Joseph Kamau[d], Said Mgeleka[f,g], Gladys M. Okemwa[d], Johnstone O. Omukoto[d,j], Kennedy E. Osuka[b,c], Melita Samoilys[b], Warwick Sauer[e], Mathew Ogalo Silas[f,g], Joseph S. Sululu[f], Michael J. Roberts[h,i]

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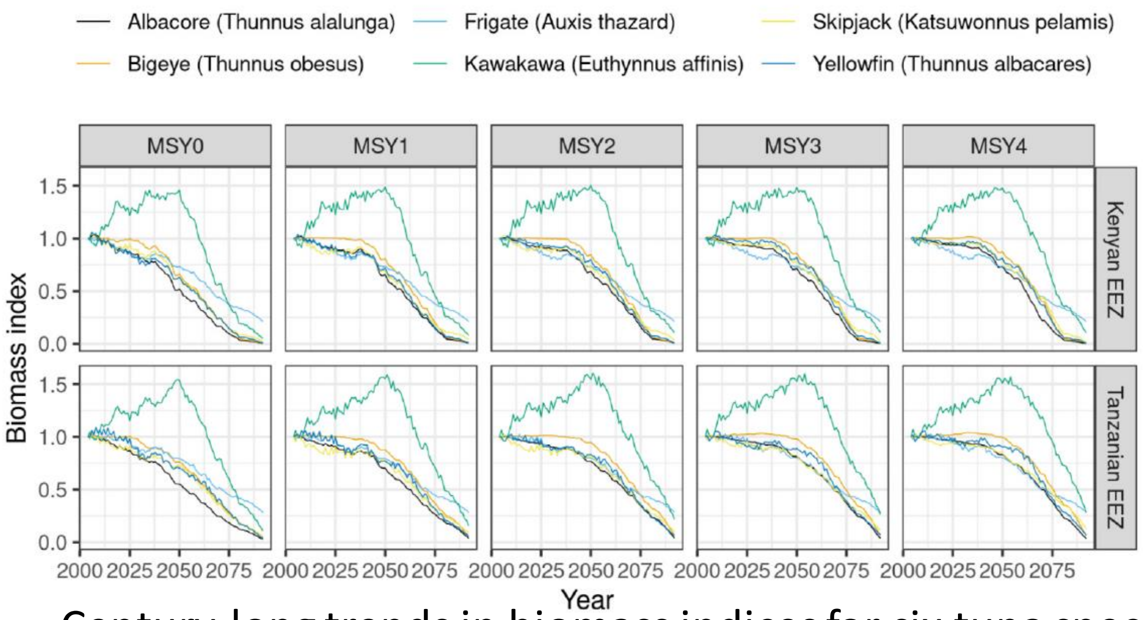
[b] Coastal Oceans Research and Development – Indian Ocean (CORDIO East Africa), 9 Kibaki Flats, Mombasa, P.O. Box 10135 -80101, Kenya
[c] Department of Environment and Geography, University of York, Heslington, York, YO10 5NG, UK
[d] Kenya Marine and Fisheries Research Institute (KMFRI), P.O. Box 81651, 80100, Mombasa, Kenya
[e] Rhodes University, Grahamstown, South Africa
[f] Tanzania Fisheries Research Institute (TAFIRI), P.O. Box 78850, Dar Es Salaam, Tanzania



Century-long trends in biomass indices for six tuna species (subset of 41 species) in the Kenyan and Tanzanian EEZs for varying catch scenarios.

Confluence shift

- We define the Confluence Zone (CZ) as the latitude where the northward flowing EACC meets the southward flowing SC.

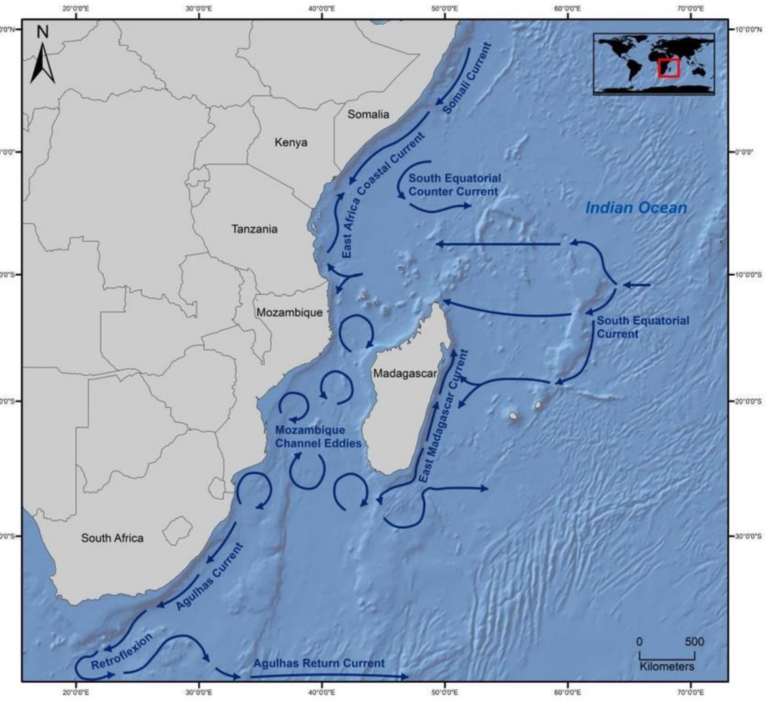
- Model analyses presents evidence that the position of the confluence zone is highly variable

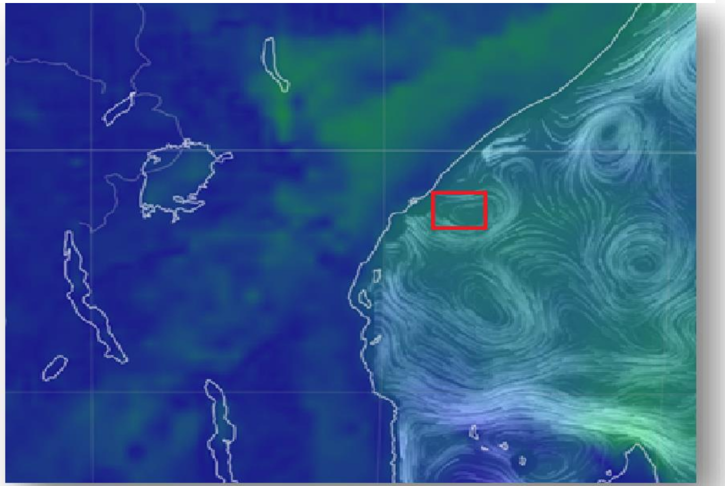
- The departure of the SC and EACC from the coast induce upwelling at the shelf-edge, observed in both model and remotely sensed SST and chlorophyll.

- The major monsoonal variability of the surface circulation is apparent during the NEM with reduced velocities visible in the Northeast Madagascar Current (NEMC) and EACC, specifically a reduction of more than 0.5 ms^{-1} in AVISO

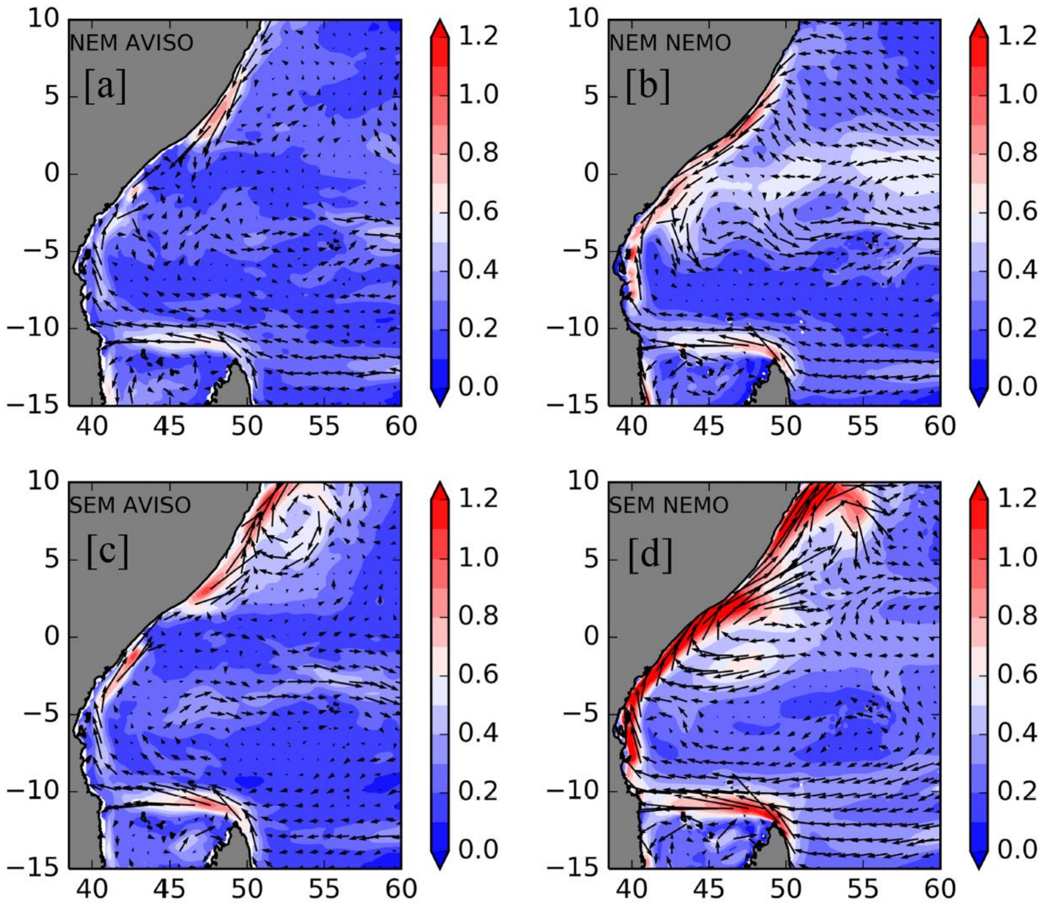
- The model circulation shows a fast (>1.25 ms^{-1}) SC meeting a weak EACC, likely pushing the confluence south wards away from the productivity region of the North Kenya Banks.

The NKBs are located in a very complex region where a multitude of factors may be causing, or influencing the strength of, the shelf-edge upwelling over this topographic feature.





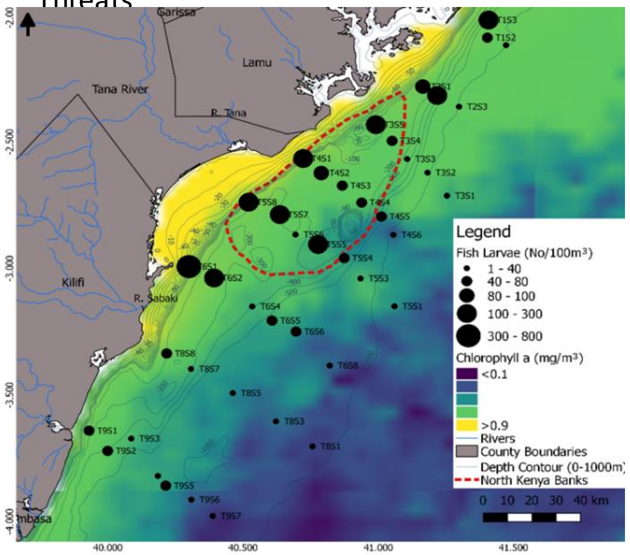
Currents circulation regme during the SEM notice the obstraction and deflection at the NKBs (red box)

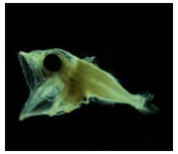


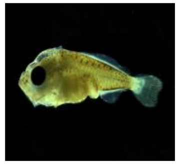
Decadal average of surface currents (ms−1) during the NEM (DJF) and the SEM (MJJAS) (a and c) from altimetry and (b and d) from the model over the period 2001–2010. Model vectors are plotted every 3 grid points to appear consistent with AVISO

Recruitment areas of NKB prevalent with fish larvae (Tunas, Snappers and Jacks 4.0-5.0 mm)

- Threats







- ➢ Recent scientific research demonstrates that the NKB region contains important breeding and nursery grounds for migratory fish including tuna and tuna-like species.

- ➢ The NKB region is therefore predicted to play a crucial role in the management of commercially important migratory species in the future and requires development of a tuna and tuna-like species monitoring strategy.

Threats to this fishery associated to Climate change:

- ➢ Climate change is already altering marine ecosystems; changes in the intensity and timing of coastal upwelling will impact fish migration patterns, recruitment, growth, distribution, abundance and predator and prey relationship.

Ocean and Coastal Management

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Assemblage structure and distribution of fish larvae on the North Kenya Banks during the Southeast Monsoon season

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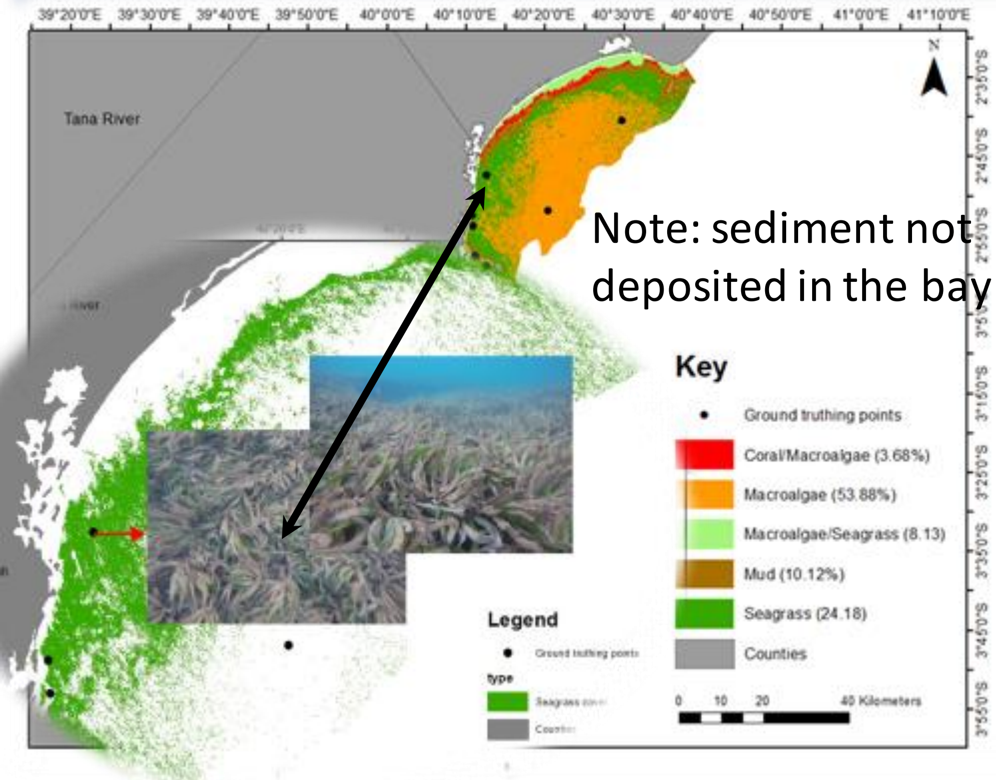
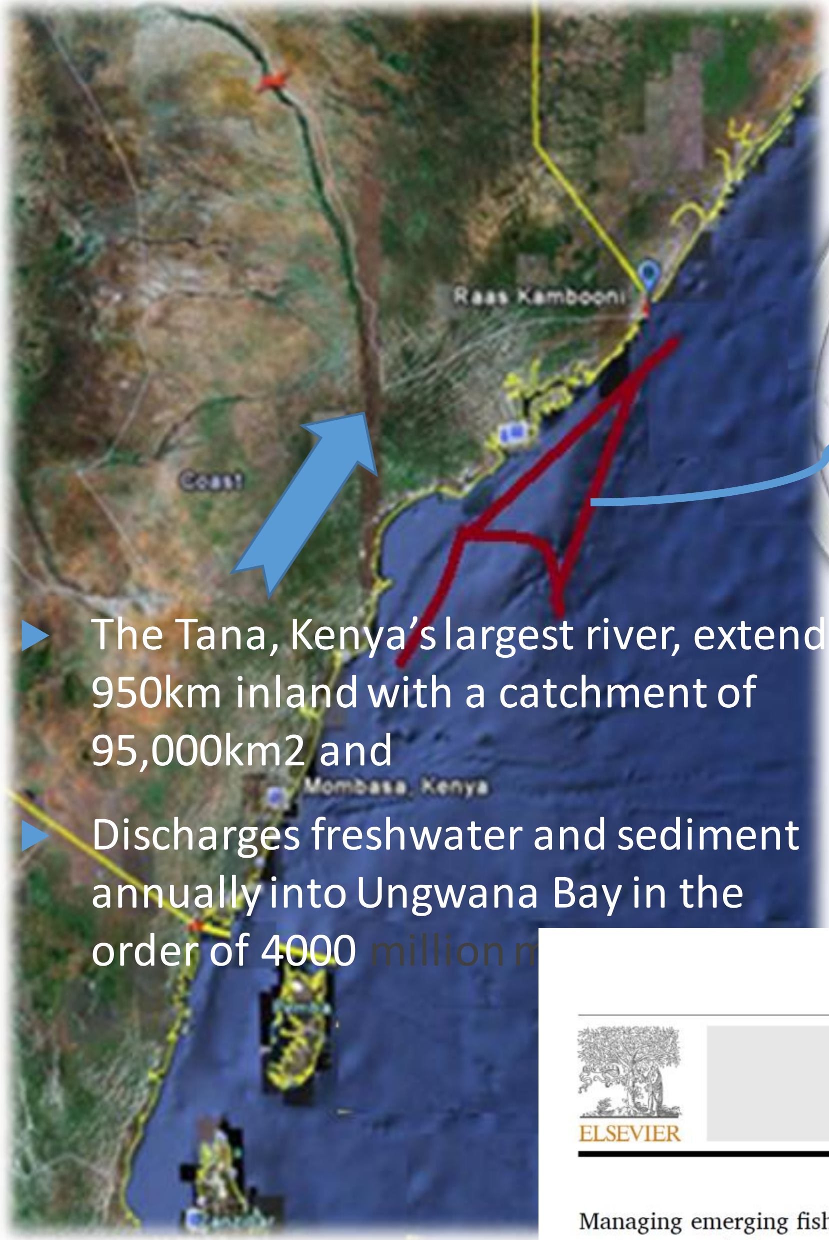
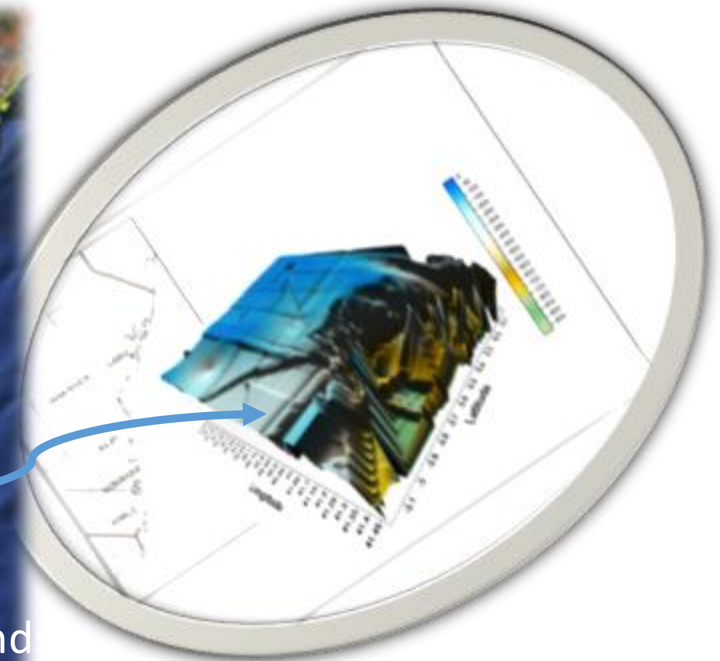
ARTICLE INFO

ABSTRACT





- The Tana, Kenya's largest river, extend 950km inland with a catchment of 95,000km2 and
- Discharges freshwater and sediment annually into Ungwana Bay in the order of 4000 million m



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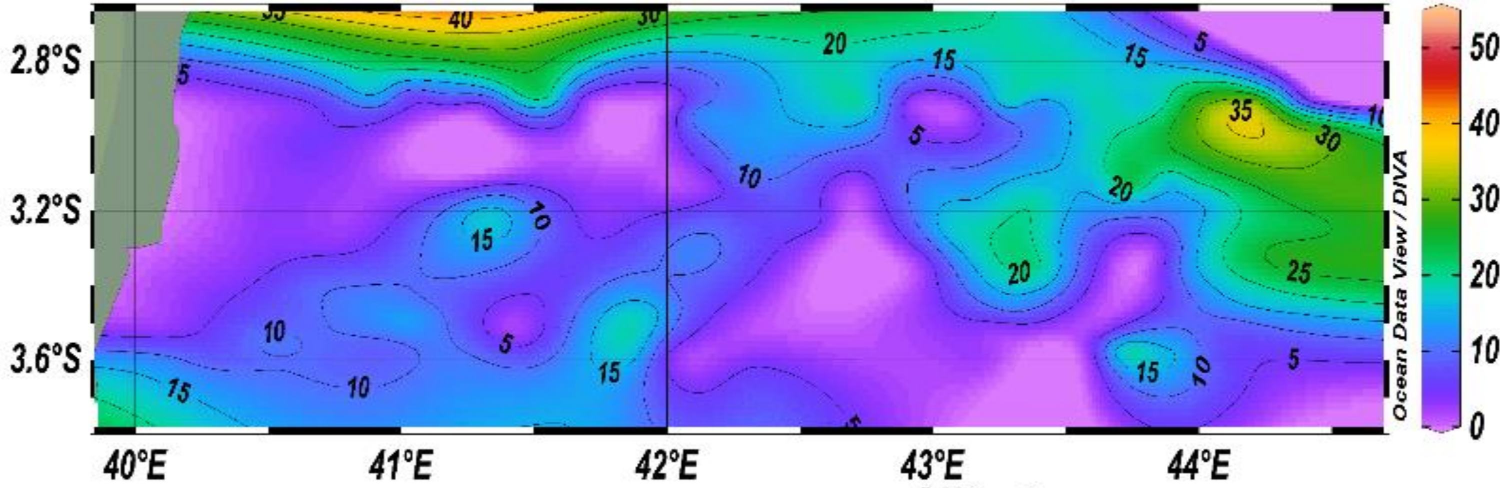
Joseph N. Kamau [a], Zoe L. Jacobs [b], Fatma Jebri [b], Stephen Kelly [b], Edward Kimani [a], Amina Makori [a], James Mwaluma [a], Elizabeth Mueni [c], Harrison Ong'anda [a], Matthew R. Palmer [b], Ekaterina Popova [b], Michael J. Roberts [b,d], Sarah F.W. Taylor [b], Juliane U. Wihsgott [b], Stuart C. Painter [b,*]

[a] Kenya Marine Fisheries Research Institute, Kenya
[b] National Oceanography Centre, United Kingdom
[c] Kenya Fisheries Service, Kenya

Pelagic fish densities



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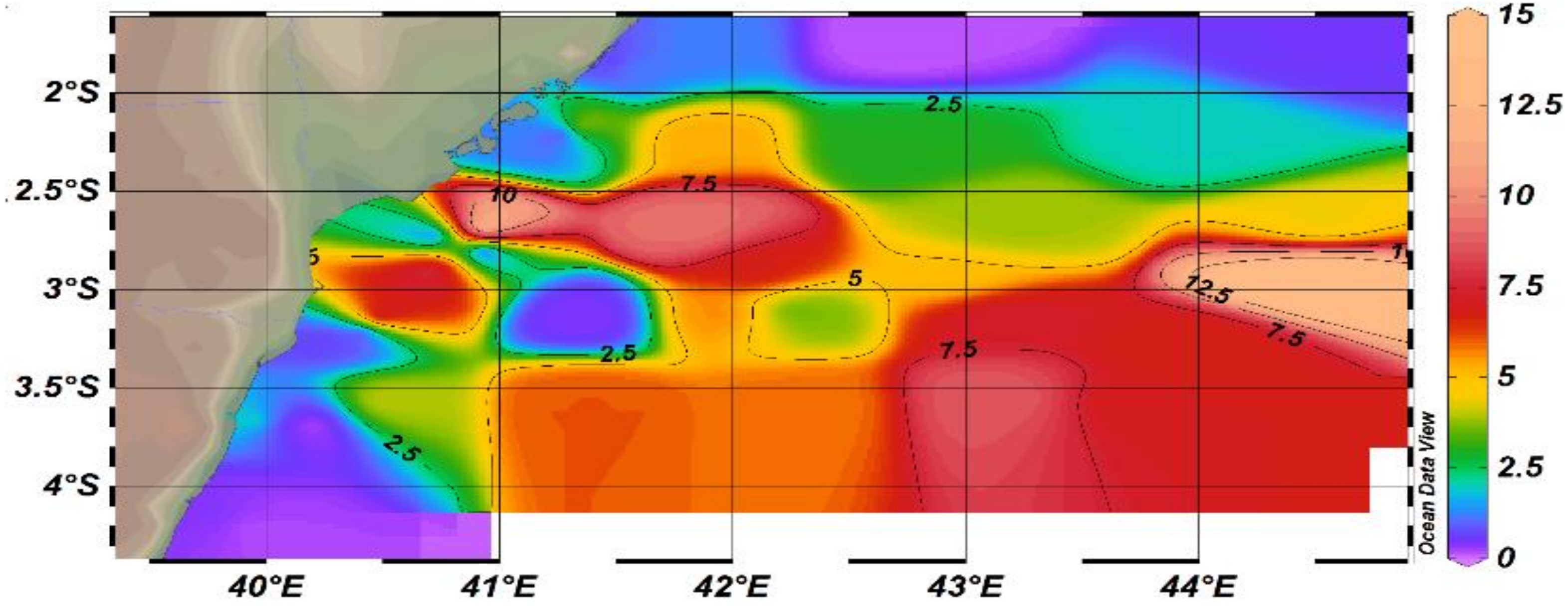

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[d] Nelson Mandela University, Port Elisabeth, South Africa

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edge upwelling occurs over the Kenya Banks (NKB) during rtheast Monsoon, leading to productivity
events can occur and exhibit erable interannual variability nsity, position, and spatial
omali-Zanzibar Confluence exerts an important control on welling, which is enhanced it is positioned further south

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L., Jebri, F., Raitsos, D. E., Popova, E., Srokosz, M., Painter, S. C., et al. (2020). Shelf-break upwelling and productivity over the North Kenya Banks: The importance of large-scale ocean dynamics. *Journal of Geophysical Research: Oceans, 125*, e2019JC015519. https://doi.org/10.1029/2019JC015519

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Shelf-Break Upwelling and Productivity Over the North Kenya Banks: The Importance of Large-Scale Ocean Dynamics

Z. L. Jacobs[1], F. Jebri[1], D. E. Raitsos[2,3], E. Popova[1], M. Srokosz[1], S. C. Painter[1], F. Nencioli[2], M. Roberts[1,4], J. Kamau[5], M. Palmer[1], and J. Wihsgott[1]

[1]National Oceanography Centre, Southampton, UK, [2]Plymouth Marine Laboratory, Plymouth, UK, [3]National and Kapodistrian University of Athens, Athens, Greece, [4]Nelson Mandela University, Ocean Sciences Campus, Port Elizabet South Africa, [5]Kenya Marine and Fisheries Institute, Mombasa, Kenya

Abstract The North Kenya Banks (NKBs) have recently emerged as a new frontier for food security an could become an economically important fishery for Kenya with improved resources providing better accessibility. Little research has been done on the mechanisms supporting high fish productivity over the NKBs with information on annual and interannual environmental variability lacking. Here we use a high-resolution, global, biogeochemical ocean model with remote sensing observations to demonstrate tha the ocean circulation exerts an important control on the productivity over the NKBs. During the Northea Monsoon, which occurs from December to February, upwelling occurs along the Kenyan coast, which is topographically enhanced over the NKBs. Additionally, enhanced upwelling events, associated with widespread cool temperatures, elevated chlorophyll, nutrients, primary production, and phytoplankton biomass, can occur over this region. Eight such modeled events, characterized by primary production exceeding 1.3 g C/m^{-2}/day, were found to occur during January or February from 1993–2015. Even thoug the upwelling is always rooted to the NKBs, the position, spatial extent, and intensity of the upwelling exhibit considerable interannual variability. The confluence zone between the Somali Current and East African Coastal Current (referred to as the Somali-Zanzibar Confluence Zone) forms during the Northea Monsoon and is highly variable. We present evidence that when the Somali-Zanzibar Confluence Zone is positioned further south, it acts to enhance shelf-edge upwelling and productivity over the NKBs. These findings provide the first indication of the environmental controls that need to be considered when developing plans for the sustainable exploitation of the NKB fishery.

Plain Language Summary The North Kenya Banks (NKBs) have recently emerged as a regio capable of sustaining a rich fishery, which would boost Kenya's economy. Little research has been conducted on the environmental controls that affect these fisheries and whether there is annual variabili

Enhance productivity in the Somali Upwelling

- Somali upwelling system, is a Western Boundary Upwelling System located near the Equator the upwelling affects the moisture responsible for monsoon rainfall
- Regardless of global or regional circulation models and the greenhouse warming scenario a significant upwelling increase ranging from 0.05 to 0.07m2 s−1dec−1 was projected for the whole Somali upwelling ecosystem along the twenty first century.
- Projected land-sea air temperature and air pressure differences along the twenty first century show a clear intensification as a consequence of the global warming. This intensification has a strong influence on coastal upwelling strengthening
- The most direct implication of a coastal upwelling strengthening is a projected nearshore SST warming less intense than at the adjacent ocean

SCIENTIFIC REPORTS

OPEN

How will Somali coastal upwelling evolve under future warming scenarios?

Received: 22 October 2015
Accepted: 28 June 2016
Published: 21 July 2016

M. deCastro[1], M. C. Sousa[2], F. Santos[1,2], J. M. Dias[2] & M. Gómez-Gesteira[1]

Somali upwelling system, the fifth in the world, presents some unique features compared with the other major upwelling systems: 1) it is a Western Boundary Upwelling System located near the Equator and 2) upwelling affects the moisture responsible for monsoon rainfall. The intensity of Somali coastal upwelling during summer was projected for the twenty first century by means of an ensemble of Global Climate Models and Regional Climate Models within the framework of CMIP5 and CORDEX projects, respectively. Regardless global or regional circulation models and the chosen greenhouse warming scenario, the strengthening of Somali coastal upwelling, which increases with latitude, is even higher than observed for the Eastern Boundary Upwelling System. In addition, coastal upwelling strengthening is mainly due to Ekman transport since Ekman pumping shows no clear trend for most of the latitudes. Projected land-sea air temperature and pressure show a clear intensification of land-sea thermal and pressure gradient as a consequence of the global warming, which is likely to affect the strengthening of Somali upwelling verifying the hypothesis of Bakun. As a consequence, projected sea surface temperature warming is less intense nearshore than at oceanic locations, especially at latitudes where upwelling strengthening is more intense.

The ecological and socio-economic impact of coastal upwelling along Eastern Boundary Upwelling Systems (EBUS) has been extensively documented in the past, mainly related to the productivity of fisheries[1] or to the distribution of marine biodiversity[2]. In 1990 Bakun[3] hypothesized the strengthening of upwelling intensity along the major upwelling ecosystems due to the increase in ocean-land thermal gradient induced by global warming. Since the hypothesis of Bakun, different studies[4–9] dealing with coastal upwelling intensification show contradictory results highly dependent on the area, the season and the database. In this sense, wind intensification has been analyzed within the framework of global warming for the four major EBUS[4]: Benguela, California, Humboldt and Canary. Sydeman *et al.*[4] shows that the first three upwelling ecosystems have suffered wind intensification, which was found stronger at higher latitudes consistently with the warming pattern associated to climate change. Other authors[5] also found upwelling strengthening in coastal areas of Benguela, Peru, Canary and northern California using reanalysis data over the period 1982–2010. These trends were significant only in the last two systems. In contrast, they found significant upwelling weakening along Chile, southern and central California coasts.

Somalia can be considered the fifth most important upwelling system[10] worldwide in terms of the volume of

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RESEARCH ARTICLE

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Shelf-Break Upwelling and Productivity Over the North Kenya Banks: The Importance of Large-Scale Ocean Dynamics

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Key Points:

- Shelf-edge upwelling occurs over the North Kenya Banks (NKB) during the Northeast Monsoon, leading to higher productivity
- Strong events can occur and exhibit considerable interannual variability in intensity, position, and spatial extent
- The Somali-Zanzibar Confluence Zone exerts an important control on the upwelling, which is enhanced when it is positioned further south

Supporting Information:

- Supporting Information S1

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Abstract The North Kenya Banks (NKBs) have recently emerged as a new frontier for food security and could become an economically important fishery for Kenya with improved resources providing better accessibility. Little research has been done on the mechanisms supporting high fish productivity over the NKBs with information on annual and interannual environmental variability lacking. Here we use a high-resolution, global, biogeochemical ocean model with remote sensing observations to demonstrate that the ocean circulation exerts an important control on the productivity over the NKBs. During the Northeast Monsoon, which occurs from December to February, upwelling occurs along the Kenyan coast, which is topographically enhanced over the NKBs. Additionally, enhanced upwelling events, associated with widespread cool temperatures, elevated chlorophyll, nutrients, primary production, and phytoplankton biomass, can occur over this region. Eight such modeled events, characterized by primary production exceeding 1.3 g C/m^{-2}/day, were found to occur during January or February from 1993–2015. Even though

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Productivity driven by Tana river discharge is spatially limited in Kenyan coastal waters

Damaris Mutia [a], Stephen Carpenter [b], Zoe Jacobs [b], Fatma Jebri [b], Joseph Kamau [a], Stephen J. Kelly [b,*], Amon Kimeli [a,c], Philip Kibet Langat [d], Amina Makori [a], Francesco Nencioli [e,f], Stuart C. Painter [b], Ekaterina Popova [b], Dionysios Raitsos [e,g], Michael Roberts [b,h]

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Large projected reductions in marine fish biomass for Kenya and Tanzania in the absence of climate mitigation

Robert J. Wilson [a], Sévrine F. Sailley [a,*], Zoe L. Jacobs [h], Joseph Kamau [d], Said Mgeleka [f,g], Gladys M. Okemwa [d], Johnstone O. Omukoto [d,j], Kennedy E. Osuka [b,c], Melita Samoilys [b], Warwick Sauer [e], Mathew Ogalo Silas [f,g], Joseph S. Sululu [f], Michael J. Roberts [h,i]

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How will Somali coastal upwelling evolve under future warming scenarios?

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M. deCastro[1], M. C. Sousa[2], F. Santos[1,2], J. M. Dias[2] & M. Gómez-Gesteira[1]

Somali upwelling system, the fifth in the world, presents some unique features compared with the other major upwelling systems: 1) it is a Western Boundary Upwelling System located near the Equator

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