



Measurement and implications of marine food security in the Western Indian Ocean: an impending crisis?

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Abstract

Ten percent of the world's population depends on the ocean for a readily accessible source of protein and employment. Coastal ecosystems and the communities that rely upon them are facing extreme challenges of increases in ocean pollution, loss of habitat, ocean warming, and changes in ocean productivity. With the whole system under mounting pressure, governments need to scale down food security analyses to the coastal community level to avoid overseeing rising levels of food insecurity. This paper provides an alternative view and analysis of food security at both a national and community level taking into account these marginalised communities. The results propose a refined definition of marine food security and new quantitative methods to measuring direct and indirect reliance on fish within developing countries. Application of this concept and methods reveals that aggregated national statistics mask the extreme levels of dependence on fish for food security in coastal communities within Kenya and Madagascar. The Comoros, Mauritius, Mozambique, and Somalia appear to be the most vulnerable to increasing sea surface temperature, population, and fluctuation in total catch and will be severely affected by a changing Western Indian Ocean from a national, community, and individual perspective. Overall, the study highlights that governments need to disaggregate fisheries data and redefine measurements of food security to more accurately reveal the severity of the potential marine food insecurity crisis at hand.

Keywords Food security · Fish · Small-scale fisheries · Fisheries · Coastal communities · Ocean productivity

1 Introduction

The number of people worldwide suffering from hunger increased from around 804 million in 2016 to almost 821 million in 2017 (FAO 2018a). Climate variability and extremes are notably a key driver behind the rise in global hunger. Climate change, as one of the leading causes of severe food crises, negatively influences all aspects of food security including food availability, access, utilisation, and stability. Ten percent of the global population depends on the ocean

for an accessible source of protein and employment with the majority (95%) living in developing countries (FAO 2014). Climate change is effecting coastal and marine ecosystems and consequently influencing fisheries and communities reliant on these ecosystems. Simultaneously, demand for fish keeps growing at a rapid rate with per capita annual consumption of fish doubling since the 1960s (Blasiak et al. 2017). Coastal communities and fisheries in developing countries are at the frontier for climate change impacts, compounded by population growth and food demand, but are among the least resilient to the challenges of the future.

The case of the Western Indian Ocean (WIO) is becoming the quintessential scenario of coastal communities and developing economies experiencing the aftereffects of climate change influencing a major source of food and livelihoods – the ocean. Of particular interest are those Least Developed Countries and island states on the eastern side of Africa, namely the Comoros, Kenya, Madagascar, Mozambique, and Tanzania. Together with Mauritius and Seychelles (both upper middle income), this block is commonly referred to as the WIO countries (Fig. 1; oecd.org). They have a total

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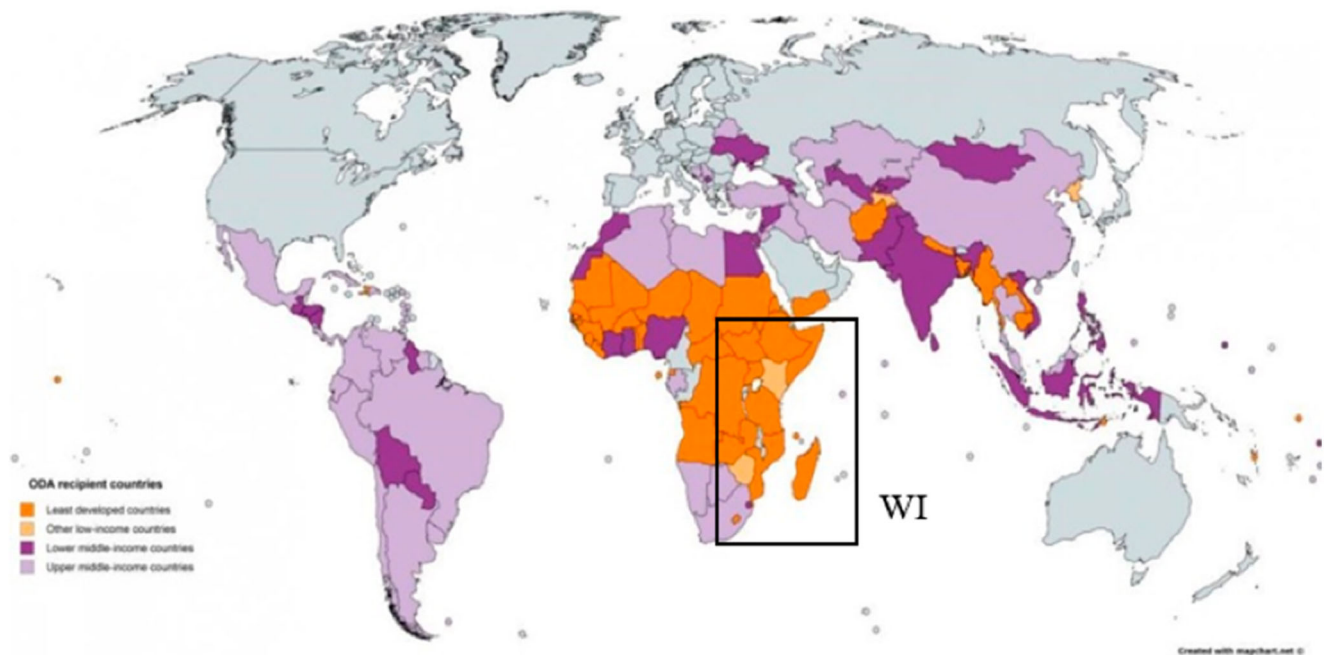


Fig. 1 Map showing ODA recipient countries and their level of development (source: oecd.org). The block box highlights the Western Indian Ocean countries

population of over 135 million with the proportion of population in the coastal zone varying in country but particularly high on the islands. Estimates suggest that 30–60 million people in the WIO coastal communities are dependent on the coastal environment for goods, services, livelihood and income (UNEP-Nairobi Convention and WIOMSA 2015). The only other similar situations of highly dense ocean-dependent coastal communities worldwide are the Bay of Bengal and the west coast of Africa. In all cases, subsistence and artisanal fisheries are paramount to their fishing industries and coastal communities by providing direct and indirect food security to the coastal population (Fig. 2).

The growing concern for the WIO is that observations and models show this region of the ocean to be undergoing some of the fastest changes seen globally. In 1990, the Intergovernmental Panel on Climate Change (IPCC) released its first scientific assessment of climate change research (Houghton et al. 1990) and concluded then that a warming

of about 0.38 °C had occurred over the last century in the Northern Hemisphere oceans, and about 0.38–0.58 °C in the Southern Hemisphere (Folland et al. 1990). This was not good news for the coastal and marine ecosystems of the WIO countries, as coral reefs are highly exposed to bleaching, mangroves are exposed to sedimentation and sea level rise, and coastal lands to flooding and erosion (UNEP-Nairobi Convention and WIOMSA 2015). Community livelihoods have the same vulnerability scale particularly coastal agriculture, fisheries, human health and industrial activities. Added to this was a study by Roxy et al. (2014) who suggested the WIO has not only been warming for more than a century, but at a rate faster than any other region of the tropical oceans, and appears to be the largest contributor to the overall trend in the global mean sea surface temperature (SST) (further detail given in Fig. 6). During the period 1901–2012, while the Indian Ocean warm pool went through an increase of 0.78 °C, the WIO experienced anomalous warming of 1.28 °C in summer

Fig. 2 Villagers in Zanzibar eagerly await their fishermen (source: Patrick Kimani)



SSTs. The warming of the generally cool WIO against the rest of the tropical warm pool region alters the zonal SST gradients, and has the potential to change the Asian monsoon circulation and rainfall, as well as alter marine food webs in this biologically productive region.

The WIO hosts one of the largest summer concentrations of marine phytoplankton blooms in the world's tropical oceans. Another study by Roxy et al. (2015) points out an alarming decrease of up to 20% in phytoplankton in this region over the past six decades. This is driven by enhanced ocean stratification due to rapid warming in the Indian Ocean, which suppresses nutrient mixing from subsurface layers. The authors concluded that future climate projections suggest that the Indian Ocean will continue to warm, driving this productive region into an ecological desert.

Evidence of global warming continues to grow as researchers from NOAA in 2017 (Huanga et al. 2017) updated their reconstructed observational global SST time series and concluded that the oceans have actually warmed 0.12 °C per decade since 2000 — nearly twice as fast as earlier estimates of 0.07 °C per decade, corroborating the IPCC Fifth Assessment Report (2013) which showed that leading climate change models predicted a much faster increase in ocean heat content over the last 30 years than observations. In a brand new article, Cheng et al. (2019) “How fast are the oceans warming?” demonstrates that ocean warming continues to accelerate.

Assuming a “business-as-usual” scenario in which no effort has been made to reduce greenhouse gas emissions, the Coupled Model Intercomparison Project 5 (CMIP5) models predict that the temperature of the top 2000 m of the world's oceans will rise 0.78 °C by the end of the century. The resulting thermal expansion will raise sea levels 30 cm on top of the already significant sea level rise caused by melting glaciers and ice sheets. Warmer oceans also contribute to stronger storms, hurricanes and extreme precipitation. For the WIO it is anticipated that precipitation will be less abundant during dry seasons and more intense during rainy seasons, and the average rainfall will be higher for the Comoros, Kenya, Seychelles, Tanzania, and reduced for Madagascar, Mozambique and Mauritius (Rakotobe 2012). The increased frequency of intense cyclones registered in recent years will continue.

In addition to the countries of the WIO experiencing changes in ocean productivity, there is growing concern in the Indian Ocean Tuna Commission (IOTC) of increased fishing capacity in high seas by distant fishing fleets impacting coastal states. At a time where future access to overfished key tropical species and access arrangements with distant water fishing nations, coastal states need to understand their dependence on fish for both local consumption and economic benefits from trade. Such issues may result in limited access to marine food resources for coastal states (Teh et al. 2016), as well as revenue generated from access arrangements potentially not

being directed back into maintaining impacted levels of food security in coastal communities. This pertinent issue highlights the need for disaggregated and scaled-down food security analyses. Revenue from access arrangements may be viewed as economic growth which is often assumed to benefit food security and access from a national perspective (Ravallion and Chen 1997; Roemer and Gugerty 1997). However, when addressing the impact of restricted access to marine resources from a coastal community perspective, the trade-off may not be worthwhile.

Given the high dependence of WIO coastal communities on the marine environment, particularly for their diet, and the rapid adverse changes occurring in the Indian Ocean and its ecosystems — there is a clear need to accurately assess the status of food security — particularly in the LCDs. From a food security perspective, key issues facing countries of the WIO are: (i) reduced ocean productivity influencing and changing marine productivity patterns in food-sensitive regions; (ii) a growing population increasing the demand for seafood; (iii) a high level of dependence on fisheries for fish as food and livelihoods; (iv) a high dependence of developing countries on small-scale fisheries for economic growth. Both (iii) and (iv) are of high importance as both issues are often masked and overseen within national food security analyses.

To address this in a definitive and quantitative manner, we need to know (1) how many people are really involved in the fisheries and live in the coastal communities of the WIO, (2) their spatial distribution, (3) the extent to which they are dependent on the ocean for food, and (4) anticipated changes in ocean productivity including non-linear “tipping points.”

This paper focuses around the pivotal point of (3) above. It first revisits the formal definitions of food security and recognises that coastal communities are often masked or overlooked in these aggregated global and national scales of food security. We suggest a new approach to food security, namely *marine* food security, which refines the concept to specifically assessing levels of dependence on the ocean for securing levels of food security. The definition of marine food security is based on the global definition of food security but utilises both a national and community based perspective of food security to create refined methods of quantifying the levels of dependence on marine assets for economic growth and as a food source.

Do national definitions and measurements of food security accurately reflect scaled-down scenarios such as the potential looming coastal community food insecurity? The gravity of the paper deals with this question by proposing a more granular measurement framework and testing it for the WIO region based on global and local datasets. The marine food security definition and framework developed (illustrated in Fig. 5) demonstrates the direct and indirect aspects of how developing countries are dependent on fish for national economic growth and as a food source on an individual and community level. We quantify the dependence of the developing

economies on small-scale fisheries and how dependent coastal communities are on fish. This case study on countries of the WIO aims to emphasise the urgency of disaggregating national fisheries data and concepts of food security to prevent assumptions of homogeneity masking potential impending food insecurity crises. A key question is how severe is the problem?

2 Methods

The methods used to address the key issues facing the WIO from a food security perspective involve: a qualitative analysis of the traditional concept of food security; an empirical analysis of traditional methods to measuring national food security; an analysis of national dependence on fish; and then finally we propose a refined concept – marine food security – as a means to better include marginalised marine-dependent coastal communities. New methods of quantifying marine food security are proposed and tested for countries of the WIO on both a national and community-based scale. The countries analysed are the Comoros, Kenya, Madagascar, Mauritius, Seychelles, Somalia, South Africa, and Tanzania.

It should be noted that subsistence fisheries are defined as a fishery where the fish caught are shared and consumed directly by the families and kin of the fishers rather than being bought by middle-(wo)men and sold at the next larger market (FAO 1999a). Artisanal fisheries are traditional fisheries involving fishing households using a relatively small amount of capital and energy, relatively small fishing vessels if any, making short fishing trips that are close to shore mainly for the purpose of local consumption (FAO 1999a). Artisanal fisheries can be subsistence or commercial fisheries providing for consumption or export.

Small-scale fisheries are a dynamic and evolving sub-sector of fisheries employing labour-intensive harvesting, processing, and distribution technologies to exploit fishery resources (FAO 2004). This sub-sector is not homogenous within countries as these fisheries operate at differing organisational levels ranging from self-employed single operators to informal sector businesses serving both local markets and international markets.

Coastal communities are defined within this paper as coastal settlements within a local authority area whose boundaries include the foreshore, including local authorities whose boundaries only include estuarine foreshore (Coastal Communities Alliance 2015).

3 Analysing the traditional concept of food security

The concept and relative studies on food security have developed from being mostly concerned with national and global

food supplies in the 1970s (FAO 1979; Guerrero 2010), to a more inclusive understanding incorporating households and individuals in the definition (FAO 1983; Brink 2001; Applanaidu et al. 2014). The Food and Agriculture Organisation (FAO) 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” (FAO 2011). This definition implies the Four Pillars Model, which addresses food availability, food access, the utilisation of food, and the stability of food sources (FAO 2008). By emphasising all people at all times the FAO definition depicts a global perspective of food security. Other definitions have attempted to more accurately address issues such as equality and equity such as Powledge (2012) including equal and consistent access to food by all people.

The level of food security addressed influences the practical application of the concept. Over the years food security policies and programmes have been based on global, national, regional, community, household, or individual scales. The most common food security assessments are done at the global or national scale. Although community perspectives of food security are highly relevant and important as they have the potential to change the way food security studies are done at all levels, they are the least common due to cost and specificity (Cochrane 2017). These smaller scale assessments effectively emphasise the specific dynamics of complex food systems, which allows a deeper understanding of how food security issues should be solved at this level.

The food security concept, and subsequent solutions, therefore should not assume homogeneity within multiple communities whereby food sources hold different social and cultural importance (Uraguchi et al. 2018). The importance of emphasising the distinct aspects and variables of different food economies will allow the study to not limit the understanding of food security to a problem only of supply. New problems such as resource exhaustion, climate change, and unsustainable development policies have added to a more holistic understanding of the food security problem and should be addressed (Funk et al. 2008; Garcia et al. 2010; Rice and Garcia 2011).

Although total capture production of all fisheries in the WIO supported a total catch of 4.9 million tons of fish in 2016 (FAO 2016a) with fisheries and aquaculture generating around US\$1.9billion annually (Obura et al. 2017), most fishers in the region are among the poorest in society and levels of hunger are still alarming. This paradox exemplifies how food security on a national scale does not necessarily imply that food security exists on an individual level (Broca 2002). Effectively breaking apart challenging case studies, like the case of food security in the WIO, should involve a mixed-methods approach such as Cochrane’s (2017) Stages of Food Security methodology employed to assess food security

in Ethiopia. These mixed-method approaches draw upon qualitative and quantitative processes to speak the ‘language’ of decision makers. What do countries experiencing potential food insecurity need to address and measure?

Complex food system and economy needs to be understood and measured at both a national and community level. A national perspective of food security focuses on domestic food self-sufficiency. Food self-sufficiency is achieved when a country can successfully produce enough food to meet domestic demand (Clapp 2017). Assessments of food security on a national scale often focus on measuring and analysing aggregate demands and availability. There is danger in only addressing this perspective as the aggregation can mask smaller scale food insecurity. The case of South Africa illustrates this as the country is food secure on a national level; however, a study done on food security in South Africa (De Cock et al. 2013) scaled down the problem and conducted 599 household assessments revealing that 53% of the sampled rural households in Limpopo were severely food insecure.

Understanding isolated groups such as small-scale fishing communities exposes the complexity of food systems and different levels of food security. The assumption that food *availability* guarantees *access* does not hold true in all communities. *Access* encompasses having physical, social, and economic access to food so to enable sufficient “entitlement to food” (Sen 1982). Subsistence fishers in isolated fishing communities that directly rely on fish as a source of food (Béné et al. 2007) may not have the geographic access to or the financial ability to access other food types. In theory they are financially excluded from domestic markets selling the food produce that has been imported to sustain a national level of food security. In a scenario where fish stocks are depleted what would this mean for these marginalised groups?

A critical aspect of food security to clarify is the difference between food as subsistence and food as a commodity contributing to food security as an economic activity (Béné 2006). Producing food through fishing activities can contribute *directly* to individual food security, referring to the subsistence element of the activity as fishers then have direct access to a supply of food (Thompson et al. 2002; Bell et al. 2009; Singh 2009). This may also contribute *indirectly* to the individual’s food security through incomes such as selling portions of catch or receiving an income from a formal fishery sector, allowing the individual to buy food (Allison 2005; Smith et al. 2005; Heck et al. 2007).

The price of food affects the status of food security in vulnerable countries and economies (Gustafson 2013; van Wyk and Dlamini 2018). In coastal communities fishers that have access to markets and are willing to participate in the markets sell and/or buy fish and other food types. The influence of food prices becomes evident in this scenario as food access and availability are linked by the price of food within these markets. Food availability represents the supply side of

the food security equation and access to food represents the effective demand. Food prices link the two sides of the equation (Timmer et al. 1983). It has been reported that by 2050, millions of people in developing countries might not be able to afford fish, which currently is relied on as a major source of food and protein (WWF 2016) thereby potentially disabling sufficient access to a critical food source.

The dimension of food stability is similarly important for coastal communities. A decrease in the productivity of the WIO will impact spawning and recruitment processes of fish stocks. The change in fish distributions may impact the stability of species that are relied on as one of the coastal communities’ major food sources or most valued species in domestic and international markets. Food stability implies that people must have access to adequate food at all times (FAO 2006). The case for vulnerable small-scale fisheries needs to be made because fishers directly dependent on catch for food security sometimes without alternatives, such as income to purchase food, will be hit the hardest by fluctuations in access to fish as food. Fishers in isolated areas may not have access to redistribution mechanisms emphasising the need to progress discourse around individual food entitlement (Béné 2006). The heart of food insecurity problems often lies at the misunderstanding that all individuals have equal access to the adequate food supply at a national-self sufficiency level.

4 Global and National Measurements of food security

4.1 Prevalence of food insecurity

The 2018 State of Food Security and Nutrition in the World report revealed increasing levels of global hunger with almost all sub-regions of Africa experiencing increasing undernourishment and severe food insecurity (FAO 2018a). The FAO report (2018a) measures food insecurity levels based on results of the Food Insecurity Experience Scale (FIES) survey module. This is the first method that has been used to measure food insecurity at the individual level globally (Wambogo et al. 2018). The method allows for results to be disaggregated, making it valuable in the process of identifying subpopulations mostly affected by food insecurity (FAO 2018a).

The FIES methodology is now a global measurement standard of food insecurity. This indicator defines food insecurity by limited *access* to food at the individual or household level. The eight-question FIES survey module is generally applied to nationally representative samples of around 1000 individuals in most countries.

A scale of food-insecurity is constructed using the Rasch model, which hypothesises that the probability of respondent *i* responding affirmatively to question *j* is a logistic function of

the distance, on an underlying scale of severity, between the position of the respondent, a_i , and that of the item, b_j .

$$Prob(X_{i,j} = Yes) = \frac{\exp(a_i - b_j)}{1 + \exp(a_i - b_j)} \quad (1)$$

Applying the Rasch model to the FIES data results in an estimate of the probability of being food insecure ($p_{i,L}$) at any given level of severity of food insecurity L , for each respondent i , with $0 < p_{i,L} < 1$.

The prevalence of food insecurity at a given level of severity (FI_L) in the population is calculated as the weighted sum of the probability of being severely food insecure for all respondents (i) in a sample:

$$FI_L = \sum p_{i,L} w_i \quad (2)$$

where w_i are post-stratification weights indicating the proportion of individuals or households in the national population represented by each record in the sample. Samples are only taken from the adult population, which is defined as aged 15 or older.

Regional and global aggregates of food insecurity at severe levels, $FI_{L,r}$, are calculated as:

$$FI_{L,r} = \frac{\sum_c FI_{L,c} \times N_c}{\sum_c N_c} \quad (3)$$

where r specifies the region, $FI_{L,c}$ is the value of FI at level L estimated for country c in the region and N_c is the corresponding population size.

4.2 Prevalence of undernourishment

The Prevalence of Undernourishment (PoU) is the FAO indicator used to assess and measure hunger at both global and national levels by addressing levels of undernourishment. The PoU estimates the percentage of individuals in the total population that are in the condition of undernourishment. The household surveys used to collect data for this indicator do not provide direct evidence on individual food consumption (FAO 2018a). The distribution of consumption is modeled for the population's representative individual, therefore limiting the results made on assumptions of the representatives in which the data were collected from.

4.3 National food self-sufficiency

National food self-sufficiency is defined by the FAO (1999b) as the extent to which a country can meet its food supply needs from domestic production. One of the traditional

measurements of food self-sufficiency is assessing the net food trade position of a country. National food self-sufficiency can be measured by determining if a country is a net exporter of basic foodstuffs rather than a net importer relying on a constant supply of food from another country. Based on this description, national food self-sufficiency (NFS) could be defined as:

$$NFS = E > I \quad (4)$$

where E is exports and I is imports. National food security is achieved when exports outweigh imports of foodstuffs.

Although most net food exporting countries are food self-sufficient, food self-sufficiency does not automatically assure food security within a country (Clapp 2017). The two concepts are related but the traditional concept of food security does not distinguish whether the available, accessible, nutritious, and stable food is in fact imported or produced locally (Clapp 2014). However, food self-sufficiency effectively concentrates on the aspect of food supply making it a plausible indicator of the food availability component of food security.

This is important as the FAO classification of low-income food-deficit countries (LIFDC) is based on two criteria; namely whether imports of basic foodstuffs outweighs exports and whether the per capita gross national income (GNI) falls below the level used by the World Bank to determine eligibility for IDA assistance (FAO 2016b). The self-exclusion criterion can be applied if countries meeting the above criteria choose to be excluded from the LIFDC category.

4.4 The global hunger index

The Global Hunger Index (Fig. 3) tracks the state of hunger worldwide and highlights areas of the world where action to address hunger is most urgently needed. Approximately 124 million people suffer acute hunger with climate change and poor governance being identified as some of the major drivers of global hunger (von Grebmer et al. 2018). The scores for countries are based on the three dimensions of the GHI: inadequate food supply measured by undernourishment, child mortality measured by under-five mortality rate, and child undernutrition measured by wasting and stunting.

As shown in Fig. 3, Eastern Africa is experiencing serious and alarming levels of hunger thereby emphasising the need for urgent attention to food security issues and policy.

5 National Dependence on fish

Coastal communities are usually heavily reliant on marine resources with fish being a major contributor. The WWF (2016) link fish dependence to country-specific situations of

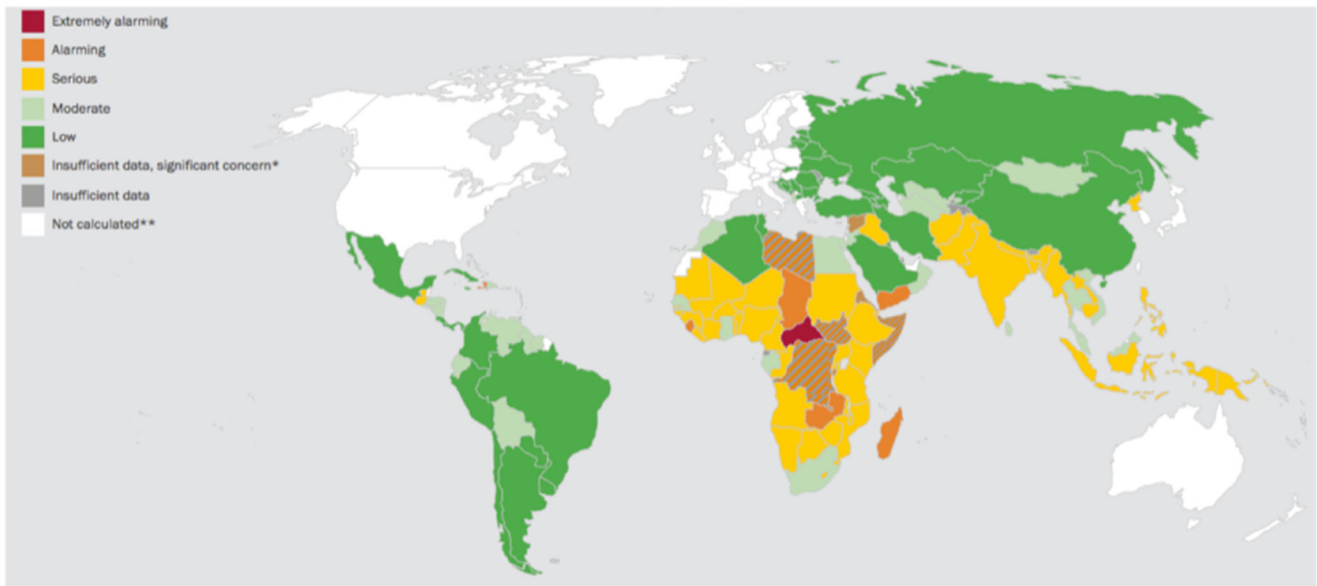


Fig. 3 2018 Global Hunger Index by Severity. Map in 2018 Global Hunger Index: Forced Migration and Hunger, by von Grebmer et al. (2018). Bonn and Dublin: Welthungerhilfe and Concern Worldwide

food security, fish consumption, capture production per capita, and the gross domestic product (GDP) per capita as a proxy for substitution capacity. Figure 4 taken from the WWF (2016) report shows the global result, which highlights Indonesia, Malaysia, Russia, China, Iceland, and most of Africa as heavily dependent on fish resources. The evaluation criterion includes measuring the amount of fish in a population’s diet therefore functioning as an effective preliminary national assessment of dependence of the WIO country’s on fish for food security.

The report also highlighted that fish production in the large marine ecosystems of the WIO countries are inadequately meeting current local demand, with catches of between 0.01–0.60 million tonnes only meeting between 0 and 80% of local demand (WWF 2016). The report concluded that poor countries with a large fishing sector run a very high risk of increased food insecurity if fish is lost as an income source.

Using the measures described above, Table 1 summarises the traditional global and national measurements used to quantify levels of food security, hunger, and fish dependence

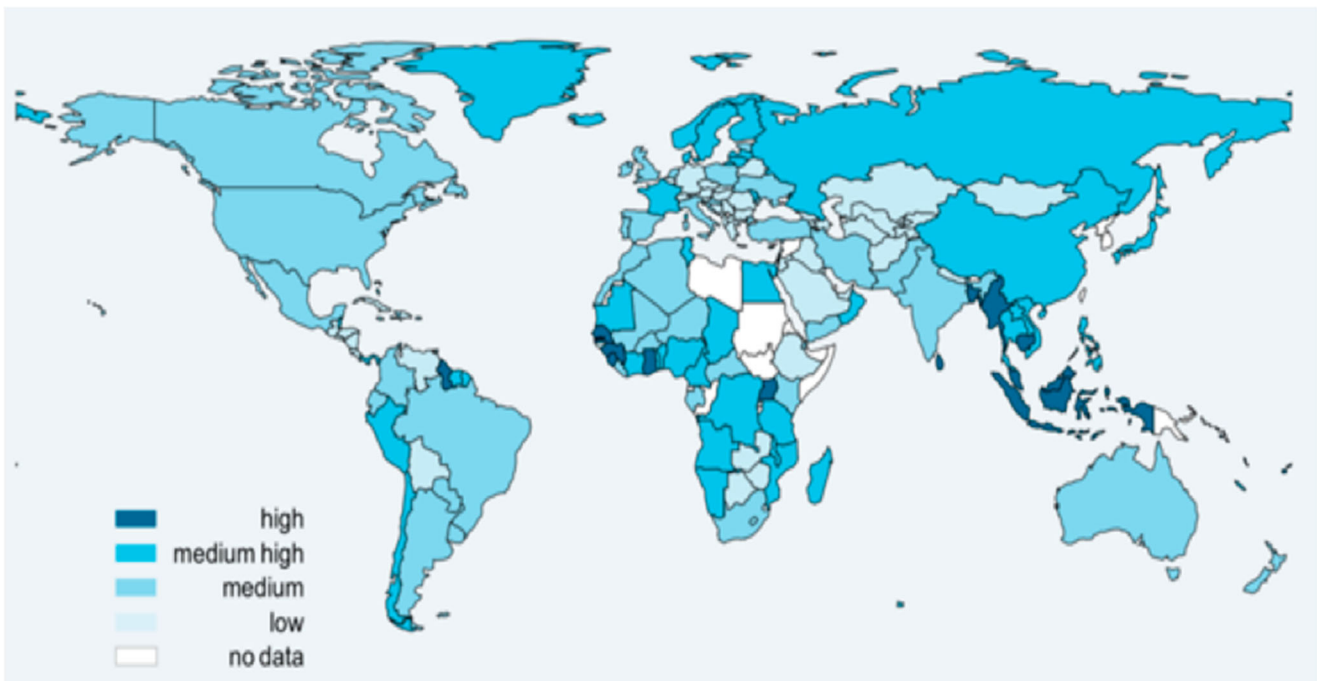


Fig. 4 WWF 2016 Overview of Global Fish Dependence. *Fishing for Proteins*. Note: includes freshwater fish

specifically for the WIO countries. The values highlight that serious levels of hunger, undernourishment, and food insecurity are prevalent as well as a clear dependence on fish for protein and livelihood stability. The cells highlighted emphasise where the country is experiencing alarming results of each of the measurements. Kenya is one of the most alarming as there is high prevalence of severe food insecurity, high prevalence of undernourishment, imports of food outweigh exports suggesting that Kenya is not food self-sufficient on a national level, highly ranked on the GHI, and there is above average dependence on fish for food and protein. This is a sufficient national overview but what does this mean for the marginalised and isolated coastal communities within these countries when reduced ocean productivity puts further pressure on the WIO?

6 “Marine” food security and the need to include coastal communities

Small-scale fisheries form part of complex livelihoods embedded in local fishery economies that are crucial anchors for the social, economic, and cultural structure of isolated communities. They are vital for food security and are highly vulnerable to threats such as natural disasters and competition for large-scale fishing (Allison and Ellis 2001; Jentoft and Eide 2011; World Bank et al. 2012). Fisheries are an integral part of ensuring food security worldwide with fish providing 6.7% of total protein consumed by humans (FAO 2016a). The fishery industry also provides direct and indirect employment for about 200 million people worldwide (McCord et al. 2011). Nine out of ten persons involved in capture fisheries are small-scale fishers, and are responsible for around half of the 60 million tonnes of marine fish caught for direct human consumption every year (UNEP 2005; Jaquet and Pauly 2008).

Small-scale fisheries therefore directly increase the availability of nourishing food for local, national, and international markets while also enabling people involved in the sector to receive a source of income (FAO 2015).

Even though small-scale fisheries prove to be economically and socially important, many small-scale fishing communities are still marginalised and their full potential and contribution to food security remains undervalued (Mills et al. 2011; Kolding et al. 2014). Food producing livelihoods, such as small-scale fisheries, have the potential to improve food security and levels of nourishment through *direct* consumption or *indirectly* through income (Fiorella et al. 2014). From a direct food security perspective, fish provides over 4.5 billion people with at least 15% of their average per capita intake of animal protein (Béné et al. 2015). Fish also contribute significantly to the income of over 10% of the world, therefore contributing *indirectly* to food security through livelihoods. Indirect food security may also include the economic benefits gained from exporting fish to international markets or the economic gains of fishing licenses purchased by international fleets operating in the EEZs of the WIO for example. In the case of countries of the WIO there is a need to further explore food security in coastal communities as small-scale fisheries provide a huge portion of the world with a supply of fish but are seemingly lacking adequate food security themselves (as shown in Table 1).

The role that fisheries, especially small-scale fisheries, play in ensuring food security in the WIO will be used as a proxy for the community scale of food security. Assessing the complex levels of dependency on fish in coastal communities will explore the food systems and potential levels of vulnerability to climate change induced food insecurity. The national scale of food security in the WIO will be assessed using adapted traditional methods of measurement such as national self-sufficiency on fish for food and the value fisheries add to WIO countries’ Gross Domestic Product (GDP). This will

Table 1 Overview of WIO countries’ level of food security, hunger, and fish dependence measurements

Country	PoSFI in Total Population (2015–2017)	PoU in Total Population (2015–2017)	LIFDC (2016)	GHI (2018)	WWF Dependence on Fish (2016)
	%				
Comoros	...	...	Yes	Serious	...
Kenya	35.6	24.2	Yes	Serious	Medium
Madagascar	...	43.1	Yes	Alarming	Medium high
Mauritius	5.9	5.8	No	Moderate	...
Mozambique	...	30.5	Yes	Serious	Medium high
Seychelles	2.4	...	No	...	...
Somalia	...	...	Yes	Lack of data, significant concern	No data
South Africa	...	6.1	No	Moderate	Medium
Tanzania	...	32.0	Yes	Serious	Medium high

help conceptualise the economic dependence on fish. We therefore propose here a new view of looking at *marine* food security. We refer to this as the Marine Food Security Framework, which is a basic framework proposed as a preliminary assessment of the relationship between food security, coastal communities, small-scale fisheries, and environmental change.

The Marine Food Security Framework is demonstrated in Fig. 5 to illustrate the new definition of food security defined in this paper. Figure 5 addresses both the *direct* and *indirect* food security elements of marine food security within the context of fisheries in developing countries. We concentrate on three fisheries namely subsistence, artisanal, and formal fisheries. The subsistence fisheries do not partake in market-related activities and therefore are only related to direct marine food security. Direct marine food security is quantified by dependence on fish caught for food (diet dependence) shown as B in Fig. 5. This relates to food security on a household and community level. Artisanal fisheries contribute to direct food security, as fishers consume catch, and indirect food security, as catch can be sold to markets. This sector therefore lies between the two channels of marine food security and relates to food security on a household, community, and national level. The more formal fisheries sell catch to both domestic and international markets thereby contributing to national economic growth. Indirect food security relates to food security on a national economic level and is quantified by the value fisheries add to GDP shown as A in Fig. 5. Fisheries are only a percentage of a country’s GDP, hence the fragmented illustration of GDP as a visual representation of economic growth. The three fishery sectors are not discrete as boats and fishers can operate in many sectors. However, the end product of the fishing activity in the sector is of importance to classify marine food security. The fisher catching fish to consume is direct marine food security while the fisher catching fish to sell to

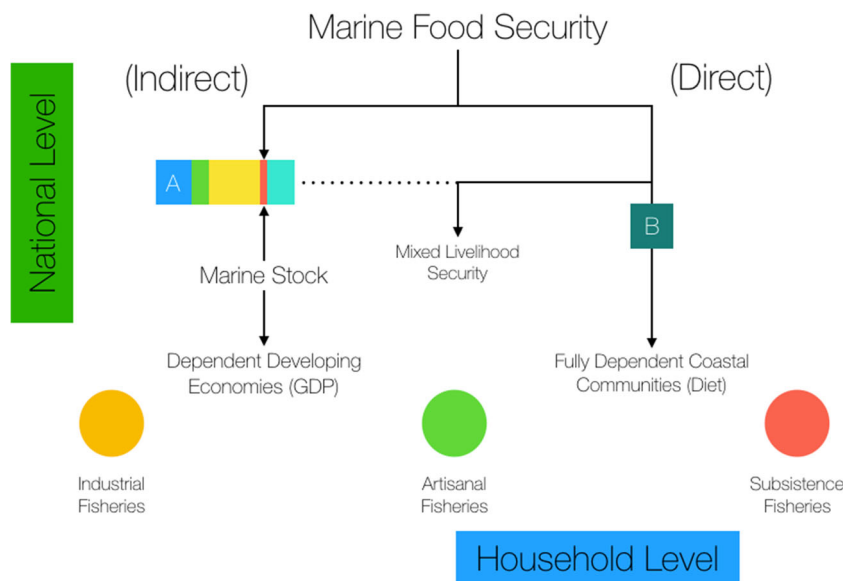
a domestic market for money is indirect marine food security as the sale has added to the economy and livelihood of the fisher.

With reference to Fig. 5, *indirect* marine food security relates to the importance of marine stock to national economies and livelihoods of the people involved in fisheries. This aspect of the model is important to analyse as the majority of people in the world have adequate access to food by having the necessary income to purchase food and not necessarily producing a sufficient diet entirely oneself (Staatz et al. 2009). Fisheries in this category of marine food security play a larger role in indirect food security as fishers participating in these formal fisheries, such as industrial large-scale fisheries, receive an income and don’t necessarily fully rely on catch for direct food consumption security.

It is important to note here that the economic importance of fisheries is often underreported and undervalued (Misund et al. 2002; Mills et al. 2011). It has recently been proven that data for most important fisheries are underreported, especially in less regulated fisheries such as small-scale fisheries (Pauly and Zeller 2016). This results in misconceptions being drawn and the real value of fisheries to developing economies being undervalued.

Direct marine food security encompasses the true subsistence form of food security. Fisheries in this category are informal and often completely overlooked due to a lack of data. True subsistence fishers directly consume and share the fish caught with families and next of kin, rather than being bought by middlemen and sold at a larger market (WIOFish 2019). This group of fisheries and the fishers involved are therefore the most vulnerable to the declining productivity of the WIO as there potentially is no alternative livelihood available to stabilise levels of food security in these isolate coastal communities.

Fig. 5 Marine Food Security Framework, where A is Economic Dependence on Marine Stock, and B is Diet Dependence



In addition to indirect and direct marine food security, it is important to note that there is an additional aspect namely *Mixed Livelihood Security*. This aspect of marine food security refers to fisheries, such as artisanal fisheries defined as fishing households using a relatively small amount of capital and energy with relatively small fishing vessels (if any) fishing close to shore mainly to sell catch to national domestic markets (WIOFish 2019). These fishers often eat a portion of their catch too, thereby substantiating the middle ground between direct and indirect food security. This access to food and an income for livelihood is why small-scale fisheries provide many communities with a source of food security and livelihoods (Béné et al. 2010; Jentoft and Eide 2011; FAO 2015). National data in many countries often only record primary occupation and may therefore misrepresent the nature of communities that rely on mixed livelihoods (Keskinen 2003).

The case of the WIO is highly relevant to use as a case study for assessing marine food security as the fisheries of the WIO vary from subsistence fisheries operating close to shore within EEZs right through to large industrial fleets fishing on high seas. For example, subsistence, artisanal, small-scale commercial, and semi-industrial fisheries operate within the purse seine fishery in Tanzania. Based on data collected from WIOFish (2019), this fishery provides direct food security as fishers are reported to eat a portion of their catch. The fishery operates in both territorial waters and the EEZ. The catch is also processed, whole frozen, and sold on in domestic markets thereby providing revenue and indirect marine food security to coastal communities. Similarly, the crab fishery in Kenya operates across all sectors providing direct food security to subsistence fishers and revenue to the artisanal and small-scale commercial sector selling catch in both domestic and export markets. There are also industrial sectors operating within EEZs, such as the tuna fishery in Comoros, which are foreign fleets that do not provide food security to the coastal communities and the catch is sold in foreign markets. Understanding the contribution to and impact on marine food security of these varying sectors will aid in understand the levels of dependence on marine resources for food security in the WIO.

7 Results

7.1 National Fish Food Systems (indirect marine food security)

The indirect marine food security (A in Fig. 5) status of the WIO dependent countries will now be assessed and quantified. The role of small-scale fisheries in developing economies is undeniable as 90 % of small-scale fisheries are situated in developing countries (Hamilton 2018). They account for 38% of the total oceanic fish catch and are the ocean's largest

employer, employing more than 90% of the world's capture fishers (FAO 2015). The issue lies in correctly quantifying the value of fisheries to a country's economic growth. Fisheries-related activities are typically reported at an aggregated level under "Agriculture, forestry, and fishing," therefore making it difficult to understand and quantify the economic value of fishing activities in isolation (de Graaf and Garibaldi 2014).

When disaggregated data are available, fisheries-related activities are commonly reported and grouped with aquaculture therefore still making fisheries GDP values not as informative as they could be to help policy makers and stakeholders realise the true value of fisheries to an economy. Small-scale fisheries are even more commonly overlooked and undervalued due to a lack of complete data and the complexity of the less regulated sectors (Mills et al. 2011).

FAO Food Balance Sheets are used to analyse a country's food system through three components namely domestic food supply, domestic food utilisation, and per capita values for the supply of the commodities. A food balance sheet primarily assessing fish and fishery products provides a comprehensive overview of the pattern of a country's fish supply. A food balance sheet of fish and fisheries has been constructed (Table 2) for the countries of the WIO, adapted from the FAO food balance sheets (2013) (FAO 2018c). The estimated coastal population has been added as an indicator of the size of the portion of population this paper is analysing. The WIO countries classified as LIFDCs are marked with asterisks.

The data from the fish food balance sheets are used to evaluate fish food trade and therefore levels of deficit or surplus. Assessing levels of food self-sufficiency gives indications to the trade and food security status of countries (Clapp 2017). Although food self-sufficiency does not automatically guarantee food security it will be used as a preliminary assessment tool to analyse fish food supply and trade. It should be noted that assessing trends of imports and exports of fish as food alongside levels of dependence on fish for protein might be an important indicator of changing oceans and fish distributions affecting food supply and therefore security more than defining an actual level of food security.

The measurement of the net food trade position of a country will be used as a proxy for the level of national fish food self-sufficiency (NFFS). Applying Eq. 4 to the marine food security framework, measuring national fish food self-sufficiency of a country can be calculated by assessing if exports of fish (E_F) outweigh imports of fish (I_F).

$$NFFS = E_F > I_F$$

Analysing the LIFDCs, the results of the national fish food self sufficiency correlate with the national food self-sufficiency results in the case of Comoros, Mozambique, and Somalia as these countries import fish (and food in

Table 2 Food balance sheets of WIO Countries. Adapted from FAO Fishery and Aquaculture Statistics 2016 (published 2018)

Country	Production	Non-food uses	Imports	Exports	Total Fish as Food Supply	Population (thousands)	Coastal Population (2010) (% of tot pop)	Per Capita Supply (kgs)	Fish Proteins (grams per capita per day)	Animal Proteins	Total Proteins	Fish/Animal Proteins (%)	Fish/Total Proteins (%)
World	162,762,181	21,371,744	45,054,148	45,220,253	142,126,714	7,162,118	4.97	19.8	5.4	32.1	80.0	16.9	6.7
Africa	9,605,152	504,027	4,012,841	2,303,825	11,225,497	1,110,636	...	10.1	2.9	16.0	66.6	18.4	4.4
*Comoros	10,400	0	936	0	11,336	735	0.72	15.4	5.1	12.8	54.4	39.8	9.3
*Kenya	186,716	279	17,901	23,111	181,227	44,345	0.41	4.1	1.2	15.8	61.8	7.3	1.9
*Madagascar	112,771	10,860	19,169	25,466	95,614	22,925	1.66	4.2	1.2	9.8	46.5	12.5	2.6
Mauritius	7794	7361	192,313	163,438	29,308	1244	1.41	23.6	7.4	39.8	88.4	18.7	8.4
*Mozambique	222,822	0	53,235	15,664	260,393	25,834	5.25	10.1	2.9	7.0	46.3	42.0	6.3
Seychelles	74,128	18,750	56,475	106,588	5265	93	16.64	56.6	17.5	35.3	75.9	49.7	23.1
*Somalia	30,000	0	3424	1285	32,139	10,496	2.5	3.1	0.9	27.9	54.8	3.2	1.6
South Africa	416,520	136,387	210,532	160,480	330,185	52,776	0.17	6.3	1.8	36.4	85.3	5.0	2.1
*Tanzania	415,709	2202	10,520	71,723	352,304	49,253	0.71	7.2	2.3	10.4	58.0	22.5	4.0

general) more than they export it. Interestingly Kenya, Madagascar, and Tanzania were found to be fish food self-sufficient and would therefore not be classified as food deficit countries in terms of fish and seafood.

South Africa and Mozambique prove to not be fish food self-sufficient even though on a general national scale they are classified as food self-sufficient. Seychelles is fish food self-sufficient, which correlates with the national food self-sufficiency status. This measurement could function as a primary overview of national marine food self-sufficiency as it exposes countries that are, on a national scale, unable to produce enough fish as food to meet all their demand if they are net importers.

The FAO food balance sheets measures per capita fish as food supply (PCFS) by calculating the total fish as food supply divided by the total population (PCFS). This is a reflection of how adequately countries are supplying the population with fish as a food source.

$$PCFS = \frac{\text{total fish}}{\text{total population}}$$

Kenya, Madagascar, Somalia, South Africa, and Tanzania have alarmingly low results that would suggest, based on this analysis and data, that these countries are possibly marine food insecure as their populations do not have sufficient access to adequate fish food supplies. In the case of Kenya this finding correlates with the results in Table 1 showing Kenya to be experiencing high levels of food insecurity, high prevalence of undernourishment, and serious levels of overall hunger. Madagascar and Tanzania are not adequately supplying their populations with fish which also correlates with Table 1 results showing alarming levels of undernourishment and hunger. South Africa appears to be at low risk of food insecurity on a national scale from results in Table 1. However, South Africa does not have sufficient access to adequate fish food supplies yet the country is quite dependent on fish according to the WWF results in Table 1.

As a preliminary assessment of individual dependence on fish for protein (DoF), the percentage of animal protein consumed by populations dependent on fish could be an indicator of direct marine food security on a national scale.

$$DoF = \left(\frac{\text{protein from fish}}{\text{total animal protein}} \right) \times 100$$

The DoF results found Seychelles and Mozambique to be the most reliant WIO countries on marine food security within this indicator analysis. The Comoros, Mauritius, and Tanzania are all highly dependent too as they ranked above the world average. These results correlate with the WWF results in Table 1 in the case of Mozambique and Tanzania.

7.1.1 Disaggregating fisheries data

Fisheries data collected by the FAO suggest that global marine fisheries catch increased to 86 million tonnes in 1996 and then marginally declined. Pauly and Zeller (2016), using a decade long catch reconstruction project, identified noticeably different catch trajectories than those submitted to the FAO. The results suggested that catch peaked at 130 million tonnes, and has since been declining at a more rapid rate than previously assumed. This study proved a need to improve monitoring of all fisheries including the often-neglected small-scale fisheries.

As a secondary assessment of the value of fisheries in the WIO countries, data from the “Sea Around Us”¹ was used to assess reconstructed catch and value of their fisheries (Table 3). The Sea Around Us assesses the impact of fisheries on the marine ecosystems of the world, offering comprehensive fisheries data through expert peer reviewed algorithms to reconstruct more accurate total catches as a solution to data poor countries and underreported data in fisheries. Thus, providing an estimation of unreported catch which is the portion of total catch in countries that is unregulated and not accurately reported for reasons such as a lack of capacity or regulation in smaller fisheries. The traditional aggregated measurement of the value added by agriculture, forestry, and fishing as a percentage of GDP is examined alongside disaggregated fisheries data of the specific fisheries sectors. By doing so, a more thorough analysis of the small-scale fisheries within each of the countries could be conducted to emphasise the often-underreported value and importance of small-scale fisheries to developing economies. All of the data is based on 2013 to maintain the same time frame as Table 2. Data on GDP and the value added totals of agriculture, forestry, and fishing industries were collected from the World Bank.

Total reconstructed catch and total reconstructed catch values were calculated using the equation:

$$TotCatch_s = \sum_s (Reported + Unreported)$$

where s is the fishery sector. For total reconstructed catch and catch values all fishery sectors were included in the sum. The subsistence, artisanal, and industrial sectors are separately evaluated as these fisheries form part of the marine food security framework and need to be analysed. Recreational fisheries were not included in this analysis as they fall outside of the marine food security framework. This formula was applied for total catch in tonnes and total catch value in real US\$ 2010 value.

¹ FAO acknowledged that catch reconstructions such as those done by the “Sea Around Us” help fill the gaps in national fisheries data and demonstrate how catches have really changed over time (FAO 2018b).

Table 3 Total Catch and Value Reconstructed for WIO Countries in 2013. Data on GDP and Agriculture, forestry, and fishing, value added from World Bank; data on catch and value from Sea Around Us

Country	GDP (constant 2010 US\$)	Agriculture, forestry, and fishing, value added	(% of GDP)	Catch (tonnes × 1000)			Real 2010 value (million US\$)			Catch (tonnes × 1000)			Real 2010 value (million US\$)			
				Total reported catch	Total reconstructed catch	Total reconstructed catch value	Total reported catch value	Total reconstructed Catch Value	Total subsistence sector catch	Total artisanal sector catch	Total industrial sector catch	Total subsistence sector catch value	Total artisanal sector catch value	Total industrial sector catch value	Total subsistence sector catch value	Total artisanal sector catch value
*Comoros	580,236,282	35.9	14.44	23.67	24.89	37.69	7.84	10.7	5.13	8.45	7.84	10.7	5.13	8.45	17.38	11.86
*Kenya	46,989,153,289	26.44	10.36	17.36	28.46	46.23	3.87	9.21	2.97	7.93	3.87	9.21	2.97	7.93	29.84	6.07
*Madagascar	9,330,835,549	24.29	114.92	160.87	251.75	346.22	35.15	68.46	57.26	68.1	35.15	68.46	57.26	68.1	158.31	119.81
Mauritius	11,137,678,209	3.38	14.18	19.9	41.93	55.17	1.49	3.32	13.91	2.77	1.49	3.32	13.91	2.77	6.79	42.95
*Mozambique	12,492,636,703	24.08	143.94	158.36	189.4	213.03	68.36	60.58	29.43	53.47	68.36	60.58	29.43	53.47	99.18	60.39
Seychelles	1,123,401,382	2.67	45.79	51.43	62.0	68.6	...	5.39	45.86	...	...	5.39	45.86	...	7.24	61.11
*Somalia	...	...	30.86	142.61	37.39	267.99	8.12	40.11	94.39	8.99	8.12	40.11	94.39	8.99	35.68	223.33
South Africa	406,049,405,943	2.1	422.1	466.89	458.64	592.27	4.14	34.87	421.83	15.33	4.14	34.87	421.83	15.33	129.62	431.99
*Tanzania	38,220,903,729	31.19	99.37	139.68	189.68	254.1	17.2	116.26	6.22	24.99	17.2	116.26	6.22	24.99	214.6	14.51

GDP is an important measurement of the size of an economy and can be used as a proxy for substitution capacity as in the WWF (2016) analysis of dependence on fish. Of the WIO countries South Africa has the largest GDP and Comoros has the smallest. Assessing the value fisheries add to the economic wealth of the WIO countries in Table 3 proved that the sector does not appear to contribute significantly to the GDP at the national scale except in the Comoros, which correlates with the results from McClanahan and Cinner's study on the region (McClanahan and Cinner 2012). However, in analysing South Africa it was interesting to note how underreported the values of fisheries were, by an estimated 133.63million US\$, which could attribute to the supposed low value fisheries add to the GDP. The results of disaggregating fisheries data also proved the value of small-scale fisheries outweigh the value of industrial sector in the Comoros, Kenya, Madagascar, Mozambique, and Tanzania.

South Africa has the largest total reconstructed catch therefore correlating with Table 2 proving South Africa to have produced the highest amount of fish. Somalia had the largest discrepancy between total reported catch and total reconstructed catch, with reported catch potentially underreporting the value of estimated actual total catch by 230.6million US\$. Kenya is the least underreported with a difference of 7000 t and catch value potentially being underreported by 17.77million US\$.

Disaggregating data on sectors helps identify the value of specific sectors to countries. The most important sectors to a country can be measured by looking at the sector with the largest catch and highest value of catch. In Mozambique this is the subsistence sector, Tanzania the artisanal sector, and South Africa's most important sector is the industrial sector.

An important result of Table 3 is to note that for the Comoros, Kenya, Madagascar, Mozambique, and Tanzania the value of the small-scale fisheries outweighs the value of the industrial sector. This proves the importance of disaggregating fisheries data in the pursuit of understanding the value of small-scale fisheries to economies.

7.2 Coastal community food systems (direct marine food security)

The direct marine food security (B in Fig. 5) status of the WIO dependent countries will now be assessed and quantified. Countries of the WIO have been identified as being dependent on fish for protein (direct marine food security) and as being dependent on fisheries economically (indirect marine food security). Specifically looking at the example of the Comoros and Mozambique where the population greatly depends on fish for protein and small-scale fisheries for economic stability and growth, an analysis of the marginalised coastal communities needs to be conducted to better understand the most vulnerable groups within the countries of the WIO. The

data on the socio-economic side of the fisheries for the direct marine food security analysis are taken from "WIOFish"² so to provide a more precise understanding and more reliable measurement on the habitual consumption of fish dependent coastal communities.

The importance of small-scale fisheries ensuring levels food security is further proven when analysing the severe reliance of fishers on fish for food. Table 4 illustrates the levels of marine food security from national dependence scaling down to the percentage of fisheries that contribute to food security on an individual and household level. A total of 266 fisheries in eight countries were analysed.

The criteria for the percentage of fisheries providing food security was whether the fishers are dependent on catch for food (even if it is just a portion of the catch). This satisfies the definition of direct marine food security as the fishers have access to fish as food. The criterion for the percentage of true subsistence dependence was the amount of subsistence fisheries within the fisheries defined as providing food security. This measurement emphasises the amount of truly dependent fishers who would be the most vulnerable to marine food insecurity, as they do not generate any income or derive livelihood from fishing activities.

Methodology and results from the dependency table pose possible measurements of direct marine food security (MFS) and direct true subsistence marine food security (TS). Using the percentage of fisheries providing food security as a proxy for marine food security in coastal communities and the percentage of subsistence fisheries as a proxy for direct marine food security the following calculations were developed:

$$MFS = \left(\frac{FS \text{ fisheries}}{\text{total fisheries}} \right) \times 100$$

$$TS = \left(\frac{\text{subsistence fisheries}}{\text{food security fisheries}} \right) \times 100$$

Where MFS is marine food security represented as the percentage of fisheries that provide fishers with food security. These fisheries are classified as *FS (food security) fisheries* if fishers within the fishery report that they eat all or a portion of their catch. Direct marine food security is measured as True Subsistence (TS), which represents the percentage of true subsistence fishers that rely on catch only for food. The fishers do not sell a portion of their catch, which makes their level of dependence on a healthy ocean the highest as they do not generate money from this activity, which would enable the fishers to purchase substitutes for fish if fish stocks were to decline.

² WIOFish is a collaborative programme originating out of identifying the dire need for more detailed information and understanding of small-scale fisheries that are extremely common in the WIO region. The data collected on the countries of the WIO (excluding Somalia) provides a better understanding of biological and socio-economic aspects of fisheries in the region.

Table 4 Direct Marine Food Security Dependency Table. Data on seafood consumed and fish as a percentage of protein intake from World Bank, data on food security in fisheries from WIOFish

Country	Seafood consumed per capita per year (kg)	Percentage fish accounts for in total animal protein intake (%)	Percentage of fisheries providing food security (%)	Percentage of true subsistence dependence within food security fisheries (%)
Comoros	15.4	39.8	46%	73%
Kenya	4.1	7.3	77%	58%
Madagascar	4.2	12.5	46%	80%
Mauritius	23.6	18.7	81%	12%
Mozambique	10.1	42.0	70%	14%
Seychelles	56.6	49.7	81%	17%
South Africa	6.3	5.0	53%	42%
Tanzania	7.2	22.5	79%	89%

Assessing the data collected from WIOFish most fishers in the WIO countries rely on a portion of their catch for their own food security. Out of the eight countries assessed in Table 4 only two, the Comoros and Madagascar, have a less than 50 % share of fisheries providing food security. The significantly high percentages of fisheries providing food security to fishers and their families within the WIO region proves the high level of dependence on fish for food for these fishers and coastal communities.

Further analysing the fisheries providing food security in WIO region, the percentage of true subsistence fishers within those fisheries is significantly high in Tanzania, Madagascar, and the Comoros. Looking at Tanzania, the subsistence sector accounts for 89% of the fisheries that provide food security. Subsistence sectors in Madagascar and Comoros account for 80% and 73% respectively.

Countries with the lowest per capita seafood consumption interestingly prove to have a high reliance on fish and catch for food in their fisheries, such as Kenya, South Africa, and Tanzania. Cinner and Bodin's (2010) study also found a high community level of dependence on fish in contrast to national-level statistics for Kenya and Tanzania. This proves the importance of disaggregating data as on a national level it may appear that countries don't rely heavily on fish, but a high dependence is found when assessing coastal communities and fisheries. This shows the complexity of marine food security and why understanding local food systems will help address potential food insecurity in the future.

Seychelles proves to have the highest per capita consumption of seafood with one of the lowest percentages of fish as food dependent subsistence fisheries. This highlights the complexity of food systems and fish value chains in coastal communities as 81% of fisheries depend on fish for food but are mostly artisanal and industrial fisheries that will also sell portions of catch in domestic markets or receive an income from

fishing activities too. Tanzania appears to have a low per capita consumption of seafood but a relatively high 22% dependence of protein on fish alongside a high 79% of fisheries providing food security. Results in Table 3 proved that Tanzania's most highly valued sector is the artisanal sector.

8 Implications: So what does this mean for food security in the WIO?

Our results of national and community-based scales of dependence are summarised in Table 5. This final table serves as an overview of national and community-based food security measurements used in this study to address the question of whether there is a potential food insecurity crisis. The shaded rows emphasise the most vulnerable countries. Comoros, Mauritius, Mozambique, and Somalia are the most vulnerable to food insecurity as they rank as the most alarming in each column of the food security measurements. Comoros, Mauritius, and Mozambique are reliant on fish imports, highly to extremely dependent on fish for protein at a national level and coastal community level, and highly to extremely dependent on fish for food within fisheries. These vulnerable countries are not fully aware of the real economic dependence on fisheries, as the values of their fisheries are all underreported. The case of Somalia highlights the danger of a lack of complete and accurate data. The value of their fisheries is underreported by an estimated 86.1%, which triggers warnings of misunderstanding both the economic and social importance of fisheries within the country.

The levels of national dependence on fish for protein were ranked according to the world average (based on Table 2). Levels below the world average were ranked as low dependence, levels just above the world average were ranked as highly dependent, and levels that were prominently higher than the world average were ranked as extremely dependent.

The percentage of fisheries providing all or a portion of catch for direct consumption by fishers is used as a proxy for direct marine food security. The data used, from Table 4, classifies a fishery as providing food security if fishers eat all or a portion of their catch. Therefore, the percentage of fisheries providing food security was used to rank the level of dependence on fish for food. Percentages around 50% were ranked as highly dependent and percentages above 70% were ranked as extremely dependent.

The results show a discrepancy between food security analyses at the national aggregated level using national statistics compared to more community based analyses using disaggregated fisheries data. In order for countries to fully understand how vulnerable they are to climate change affecting fish stock supply and food security, a

Table 5 National and community scales of marine food security in the WIO

Country	National fish food self-sufficiency	Percentage of underreporting the value of fisheries	National dependence on fish for protein	Fisheries' Dependence on fish for food
	$NFFS = E_F > I_F$	Real 2010 value	$DoF = \left(\frac{\text{protein from fish}}{\text{total animal protein}} \right)$	Percentage of fisheries providing fish as food to fishers
Comoros	Reliant on Imports	33.9%	Extremely Dependent	Highly Dependent
Kenya	Self-Sufficient	38.4%	Low Dependence	Extremely Dependent
Madagascar	Self-Sufficient	27.3%	Low Dependence	Highly Dependent
Mauritius	Reliant on Imports	24%	Highly Dependent	Extremely Dependent
Mozambique	Reliant on Imports	11.1%	Extremely Dependent	Extremely Dependent
Seychelles	Self-Sufficient	9.6%	Extremely Dependent	Extremely Dependent
Somalia	Reliant on Imports	86.1%	Low Dependence	...
South Africa	Reliant on Imports	22.6%	Low Dependence	Highly Dependent
Tanzania	Self-Sufficient	25.4%	Highly Dependent	Extremely Dependent

more granular approach such as the one used in this paper needs to be applied to understand the potential increase in food insecurity in the WIO.

With negotiations such as the IOTC allocating fishing opportunities for IOTC species, analysing both national and scaled-down food security assessments would be beneficial to more accurately understand the country's levels of dependence on the marine resources in question. This scenario shows the potential benefit of governments using national and disaggregated data to assess how a country would be impacted on both a national and community level when access to certain marine resources is limited locally or increased for distant water fishing nations. There may appear to be low dependence nationally on a marine resource thereby justifying access agreements with distant water fishing nations. However, smaller-scale fisheries and coastal communities may in fact rely heavily on that marine resource for food and livelihoods. Understanding the different levels of dependence and collecting both national and community level statistics would benefit ocean governance by countries being able to understand the trade-offs within such scenarios. The ESCAP and UN Environment led Ocean Accounts Platform is an example of a platform where all levels of data can be integrated to provide a more comprehensive view. The platform provides guidance on electing, prioritising, and standardising data of national, regional, and global importance (UN ESCAP 2018).

9 Worrying trends?

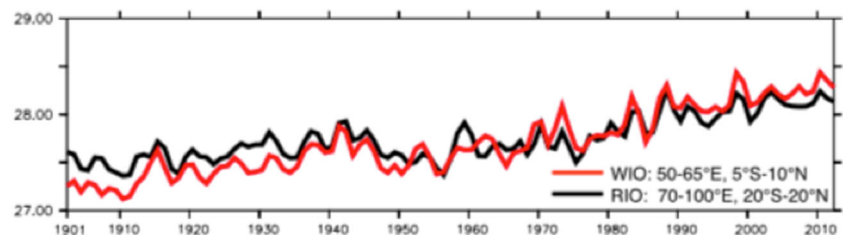
What of the future? If the indirect and direct dependence on a productive WIO continues what pressure will expanding populations, increasing SSTs, and fluctuating total catch place on marine food security?

Small-scale fishers are the oceans largest employer and, although often undervalued or realised, their contribution to food security and nutrition plays a large role in coastal communities (Allison and Ellis 2001). Global hunger is increasing, coastal populations are expanding, and increasing sea surface temperatures are affecting the productivity of ecosystems that many coastal communities in developing countries rely on. These important parameters are assessed to contextualise the potential impending food security crisis.

In the case of fisheries food security becomes a complex issue to solve as maintaining food security on a global level by supplying the increasing demand for seafood may lead to a decline in individual food security as small-scale fishers are fished out trying to compete with industrial fisheries. An ever-increasing catch rate and habitat destruction above a sustainable threshold will result in increasing food insecurity for the small-scale fishers and the coastal communities that rely on their catch for food (CRS 2006).

Coastal areas are vulnerable as they are exposed to hazards such as sea-level rise and increasing SSTs (Fig. 6) that affect the already exposed small-scale fisheries. They are often more

Fig. 6 Time series of annual mean SST (degrees Celsius) over the Western Indian Ocean (WIO in red) and the Rest of the Indian Ocean (RIO in black). Source: Roxy et al. (2014)



densely populated than inland areas and exhibit high rates of population growth and urbanisation (Neumann et al. 2015). Figure 7 illustrates the exponential increase in population size from 1993 to 2017 in the countries of the WIO.

Expanding populations increase demand for food (Boserup 2017). Global fish production is already approaching its sustainability threshold with approximately 90% of the world's stocks being fully or overfished (FAO 2016a). Overexploitation of fish stock has more than tripled since the 1970s and looking forward an estimated further a 17% increase in production by 2025 is anticipated (FAO 2016a).

The ongoing exhaustion of the world's marine fisheries is a worrying trend when considering the dependence on fish for direct and indirect marine food security in coastal communities. Overfishing proves to result in a loss of jobs, an increase in fish prices, and a reduction in income for coastal, regional, and national economies (Kellher and Webber Kelleher and Weber 2006). These impacts are particularly detrimental to developing countries where dependence levels on fish and levels of vulnerability are especially high such as the countries in the WIO.

Total catches and catch-per-unit-effort of fishing have radically declined over the past decades in many artisanal fisheries (Zeller et al. 2007; Bender et al. 2014; Muallil et al. 2014). Total catch is an important parameter as fishers and economies of the WIO rely directly on fish for food or indirectly through

livelihoods, income, and economic growth. Figure 8 illustrates the total catch (in tonnes) of the countries of the WIO from 1950 to 2014. The graphs are indicative of the portions of total catch accountable to the different sectors (subsistence, industrial, and artisanal) in the WIO countries. The black line on each of the graphs indicates reported catch over the years to show the difference between reported and the total reconstructed catch (Sea Around Us 2019).

A common trend is a noticeable peak in catch in the early 2000s in the Comoros, Mauritius, Seychelles, Somalia, and South Africa followed by a substantial steady decrease in catch since. Total catch in Tanzania also peaked in the early 2000s followed by a sharp decline that started recovering from 2008 onwards. There was, however, a decrease in catch between 2013 and 2014 and although catch seemed to be increasing it did not reach the peak catch of 154,210 t in 2004. It is evident that small-scale fisheries are incredibly significant in Tanzania, as the artisanal sector accounts for majority of the total catch. In 2014 the artisanal sector accounted for 82% of the total catch.

Madagascar reached a peak catch of 187,110 t in 2009, with the artisanal sector accounting for largest portion of total catch. Total catch subsequently declined rapidly by 28% in 2014. In developing countries one of the main forces behind exploitation and declines in catch within small-scale fisheries is open access to fisheries, which results in over-capacity of fishing effort and fish stocks (Pomeroy 2011). Kenya and Mozambique seem to be the only countries experiencing an increase in catch, but in both cases have not recuperated levels back to their relative earlier peaks in catch.

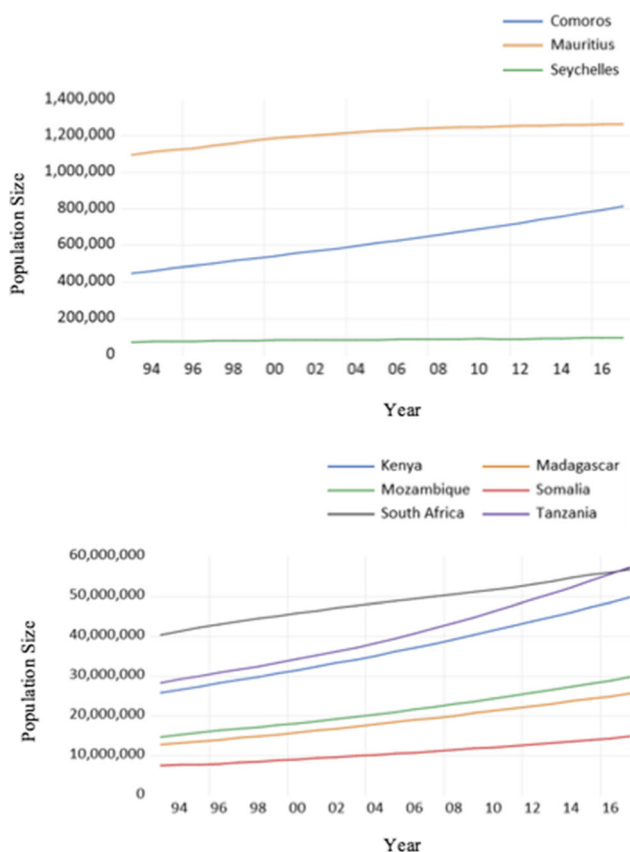


Fig. 7 Graphs of Expanding Populations. Data from World Bank

10 Conclusions

The Marine Food Security Framework (Fig. 3) proposed in this paper is an attempt to illustrate the relationship between food security, coastal communities, and small-scale fisheries to contextualise the possible effects of a decrease in ocean productivity on highly dependent coastal communities. While the new methods we created to measure marine food security include traditional methods of quantifying levels of food security, we scaled the problem down to the coastal community level. Using small-scale fisheries providing fish for food as a proxy for food security, the countries of the WIO were found to be significantly reliant on fish for preventing food insecurity.

There are two weaknesses of this study that should be considered. The scale of the problem is based on the *estimation* that between 30 and 60 million people rely on the WIO coastal environment for goods, services, livelihood and income (UNEP-Nairobi Convention and WIOMSA 2015). We therefore do not have a completely accurate number to scale this problem on. The national measurements of food security (Food Balance Sheets) are a snapshot of the issue at a specific time period. Time series trends were not analysed to view the

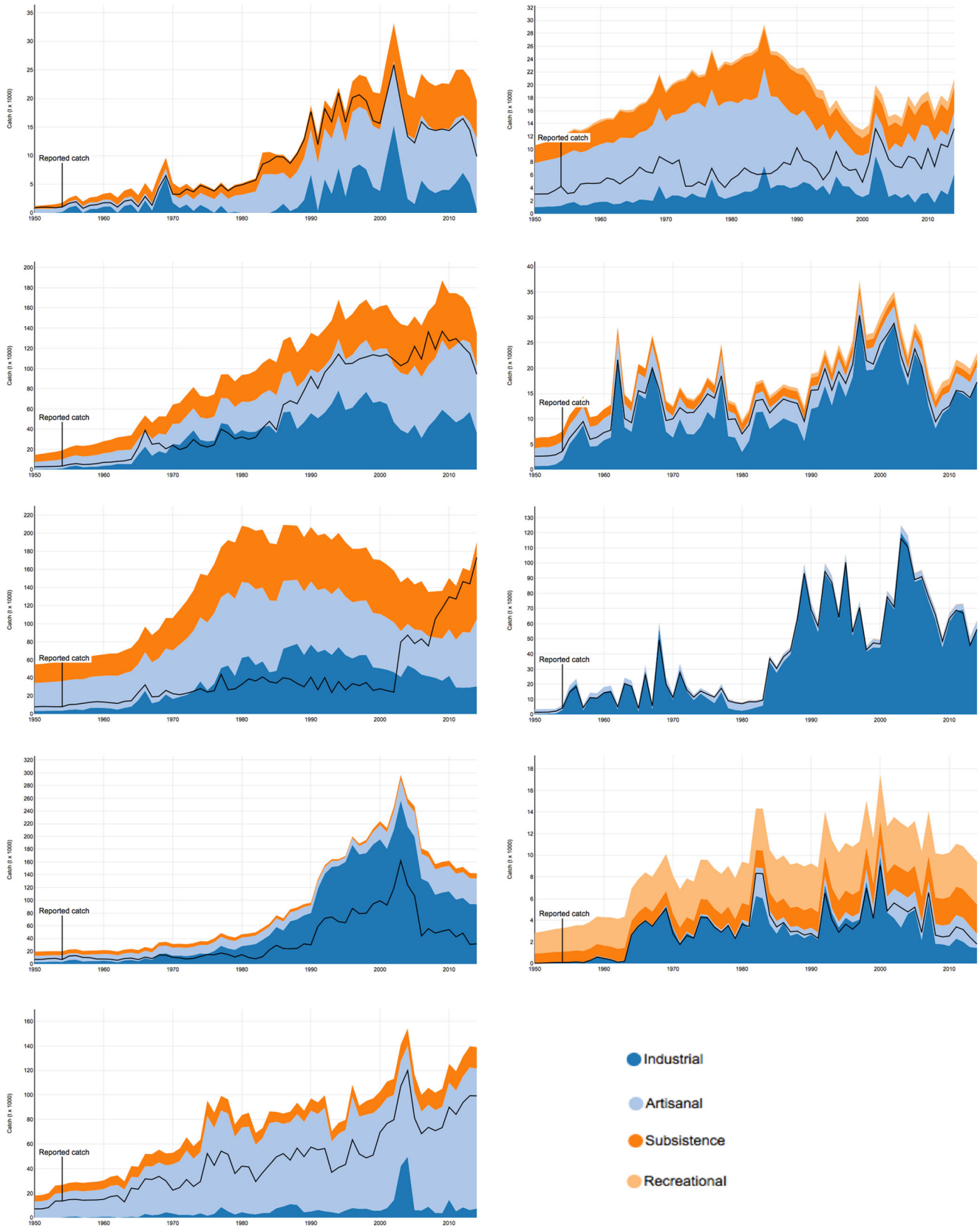


Fig. 8 Graphs of Catch by Sectors. Data and graphs generated from Sea Around Us (2018)
 a) Comoros b) Kenya c) Madagascar d) Mauritius e) Mozambique f) Seychelles g) Somalia h) South Africa i) Tanzania

overall trends due to the large sample size and qualitative nature of the paper.

The pivotal point of the food security issue in the WIO region is the misunderstanding that all individuals have equal access to adequate food supply when it appears that a country is food secure at a national level. The indirect marine food security analysis of national food security shows most countries as having sufficient supply of fish to be able to meet local demand and still export. This national overview does not, however, reflect the trends of food supply in coastal communities. The dependence of coastal communities on fish for food is larger than it seems, as subsistence fishers are not the only ones vulnerable to fluctuations in fish supply. The data shows that artisanal and industrial fishers also rely on fish for food and therefore direct food security, which makes the vulnerability of coastal communities larger than previously assumed.

An important lesson from this study is that food security analyses need to adopt similar scaled-down approaches to expose the weaknesses of single perspective food security studies. From the national perspective it appears that Kenya and Madagascar are marine food secure as they are self-sufficient and the national dependence on fish for protein appears to be low. Measuring marine food security on the community level challenges these national measurements, as fishers are extremely dependent on fish for food thereby relying on fish for household and individual food security. Relying solely on aggregated national data masks the looming potential food insecurity crisis in the WIO as worrying trends continue to add pressure on complex scenario.

We return to the key question of how big is the food security potential crisis? With an estimated 60 million people living within 100 km of the WIO shoreline the results illustrating significant household and national dependence on fish for food and economic health is worrying when acknowledging the increasing SSTs decreasing ocean productivity, expanding population pressurising food demand, and fluctuating total catch trends creating instability within small-scale fisheries. The Comoros, Mauritius, Mozambique, and Somalia appear to be the most vulnerable and will be extremely affected from both an indirect and direct food security perspective.

The overall message of this study is that WIO governments with highly populated coastal communities that are extremely reliant on the ocean for food and livelihoods need to relook at their national food security measurements and analyses. Marine food insecurity is looming in the face of a changing WIO all while aggregated data seemingly masks the severity of the problem at hand. Countries should consider applying this more granular approach to measuring food security. This study emphasises the need for countries to build structured datasets to enable more accurate calculation and monitoring of marine assets. By doing so governments will be able to better understand the severity of the potential marine food insecurity crisis in the WIO.

Compliance with ethical standards

Conflict of interest The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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