

Prospects and challenges of fish for food security in Africa

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ARTICLE INFO

Keywords:

Africa
Aquaculture
Fisheries
Food security
Foresight modeling
Policy

ABSTRACT

Fish contribute to Africa's food and nutrition security, but future directions for the fish sector remain uncertain. Using a structural foresight modeling approach, this paper examines past, present, and future trends of fish supply and demand in Africa to highlight challenges and prospects of the fish sector's contribution to food security in the continent. If historical trends are maintained, growth of aquaculture and fisheries would be slow, resulting in declining per capita fish consumption. Alternative scenarios highlight the potential importance of African aquaculture development in addressing food security. Policies to promote sustainable aquaculture, reduce post-harvest losses, and facilitate fish trade are indispensable. Fish deserves more attention in food and nutrition policies due to its prominence in the African food basket.

1. Introduction

Through the Sustainable Development Goals (SDG) (UN, 2015), the world has committed to ending all forms of food and nutrition insecurity. Yet, food insecurity remains one of the most visible dimensions of poverty, particularly in Africa. One in every four people is estimated to be undernourished in Sub-Saharan Africa (FAO, 2015, 2017a). The prevalence of vitamin A deficiency in young children and iron deficiency in women in Sub-Saharan Africa are the highest across the globe (Kassebaum et al., 2014; Stevens et al., 2015).

Being an important part of the African agri-food system, fish has significant potential to contribute to the goal of reducing food and nutrition insecurity in Africa. Fish provides 19% of animal protein intake to Africans (Table 1) and plays a unique role in providing a range of micronutrients and essential fatty acids, especially long-chain polyunsaturated fatty acids, which cannot be easily substituted by other food commodities (Béné et al., 2015; Kassebaum et al., 2014; Kawarazuka and Béné, 2011; Tacon and Metian, 2013). In Africa, small indigenous fish, such as Dagaa from Lake Victoria and Kapenta in

southern Africa, are an important source of micronutrients in traditional diets (Grainger, 2016). Furthermore, fish is also an efficient converter of feed into high quality food (Béné et al., 2015).

In addition to food and nutrition security, fish is also an important contributor to other development goals in Africa. The fish sector contributes by promoting socioeconomic growth, alleviating poverty, and improving the livelihoods of marginalized communities. The sector supports the livelihoods of 12.3 million people of which more than one-fourth are female and who are often considered to be among the poorest and most marginalized group on the continent (de Graaf and Garibaldi, 2014). In 2014, the Joint Conference of African Ministers of Agriculture, Rural Development, Fisheries and Aquaculture highlighted the role of fisheries and aquaculture through its 6% share of annual agricultural growth and 1.3% share of total GDP and called for development of fisheries and aquaculture as an integral component of sustaining the Comprehensive African Agriculture Development Program (CAADP) results framework (African Union, 2014). In support of this policy implementation, the African Union-New Partnership for Africa's Development (AU-NEPAD) and African Union-Interafrican Bureau for

Abbreviations: AARTC, Africa Aquaculture Research and Training Center; AU-IBAR, African Union-Interafrican Bureau for Animal Resources; AU-NEPAD, African Union-New Partnership for Africa's Development; BAU, business-as-usual; CAADP, Comprehensive African Agriculture Development Program; CAPRI, Common Agricultural Policy Regionalised Impact; CGIAR, Consultative Group on International Agricultural Research; CRP, CGIAR Research Program; FAO, Food and Agriculture Organization; GDP, gross domestic product; GLOBIOM, Global Biosphere Management Model; HLPE, High Level Panel of Experts; IFPRI, International Food Policy Research Institute; IMPACT, International Model for Food Analysis of Agricultural Commodities and Trade; OECD, Organization of Economic Cooperation and Development; SDG, Sustainable Development Goals

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<https://doi.org/10.1016/j.gfs.2018.12.002>

Received 5 May 2018; Received in revised form 30 November 2018; Accepted 11 December 2018

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Table 1
Proportion of undernourished population, per capita fish consumption and fish, animal protein intake by region, 2013.

Countries	Population (million)	Undernourished (%)	Fish consumption (kg/person/ year)	Fish protein (g/person/day)	Animal protein (g/person/day)	Fish/animal protein (%)
Africa	995.4	19.8	10.8	3.1	16.1	19.3
Northern Africa	203.2	-	13.5	4.0	26.8	15.0
Western Africa	331.3	9.0	15.3	4.2	12.4	34.1
Eastern Africa	333.0	31.9	4.8	1.5	10.1	14.7
Central Africa	67.5	40.9	14.1	4.0	15.3	26.2
Southern Africa	60.4	5.3	6.1	1.8	34.2	5.2
Asia	4262.8	12.4	21.4	5.8	26.6	21.9
Eastern Asia	1620.8	10.1	35.9	9.2	40.1	23.0
Southeast Asia	613.4	10.0	33.0	10.0	24.4	40.9
Southern Asia	1748.3	15.9	6.4	1.9	13.9	13.7
Central Asia	64.4	7.3	2.3	0.7	36.5	1.8
Western Asia	216.0	8.5	8.0	2.2	31.9	6.8
Latin America and the Caribbean	611.3	5.7	9.9	2.6	36.9	7.0
North America	355.3	-	21.6	5.1	68.3	7.5
Europe	742.2	-	21.9	6.6	57.9	11.3
Oceania	30.4	14.0	26.9	6.8	66.2	10.2
World	6997.3	11.0	19.0	5.2	32.1	16.2

Animal Resources (AU-IBAR) have identified aquaculture development and intra-African trade as key priorities for investment.

Despite the immense potential of its fisheries and aquaculture, Africa lags behind other regions in developing its share in global fish production, consumption, and trade (FAO, 2017b, 2018). Fisheries and aquaculture in Africa face enormous challenges, which are limiting the capabilities of local governments to ensure the sector's sustainability and profitability. Key constraints of stronger aquaculture growth in Africa include: a lack of improved fish breeds, feeds and technical training; weak research capacity; inadequate human and financial resources; poor market infrastructure and access; and weak governance and regulation (Brummett et al., 2008). Fish post-harvest losses and waste in Africa pose another serious challenge to African governments' efforts to reduce food insecurity. Slightly over a quarter of the fish harvest is lost post-harvest in Sub-Saharan Africa (Affognon et al., 2015), with underdeveloped cold chains being recognized as a key area of intervention to increase resource use efficiency and profits for value chain actors. Compared with aquaculture producing countries in Asia, the African aquaculture sector, particularly commercial aquaculture, is still in its infancy though Egypt and Nigeria are notable exceptions (FAO, 2018; Hishamunda, 2007). Depleted fish stocks, due in part to overfishing and overcapacity, are creating further stress on fishery resources, particularly in western Africa (NEPAD, 2016a). The OECD-FAO Agricultural Outlook (OECD/FAO, 2017) recently projected that per capita fish consumption will grow on all continents except Africa. From both food and nutrition security perspectives, declining African per capita fish consumption will affect millions of malnourished people as fish provides valuable micronutrients and protein.

Given the combination of promising prospects and compelling challenges faced by Africa's fish sector, there is a strong need for decision-makers to understand future trends of fish supply and demand, taking into account complex interactions across fish commodities, as well as among fish producing and consuming countries, in order to address food insecurity in Africa. To date, several comprehensive foresight modeling reports, including *Fish to 2020* (Delgado et al., 2003), *Fish to 2030* (World Bank, 2013), *Fish to 2050* in the ASEAN region (Chan et al., 2017), the OECD-FAO Agriculture Outlook (OECD/FAO, 2017), and the CGIAR Research Portfolio report (Rosegrant et al., 2017) have been released to provide a global and regional overview of future fish supply and demand.

Nonetheless, the High Level Panel of Experts (HLPE) on food security and nutrition report that fisheries and aquaculture are often arbitrarily separated from other parts of the food and agricultural systems in food security studies, debates, and policy-making (HLPE, 2014).

Particularly in Africa, the importance of fish in securing food and nutrition for the undernourished population has been frequently underestimated and overlooked in the international debate. This paper aims to examine the dynamic interaction of Africa's fish production and trade in response to potentially surging demand, with an emphasis on scenarios of strong capital investment in aquaculture development to address continent-wide food and nutrition insecurity issues. This study seeks to highlight prospects and challenges faced by Africa's fish sector and to inform dialogue about sector policies and investment priorities. The paper begins with a review of the past and current trends of fish demand and supply. In the following sections we apply a quantitative foresight modeling approach to project Africa's fish trends to 2030 and 2050.

2. Past and current trends of fish in Africa

Demand for fish has been increasing rapidly. This is driven chiefly by population and income growth, but has also been spurred on by an increasing appreciation for the health benefits of fish consumption (Thurstan and Roberts, 2014) as well as changes in lifestyles and preferences associated with rapid urbanization and globalization. However, seafood demand research, which often focuses on developed countries and commercially important fish species, has offered limited information on consumer preferences for fish in most African countries (Dey et al., 2011). Many past studies (Cai and Leung, 2017; Lem et al., 2014; World Bank, 2013; Ye, 1999) on the changes in consumer preferences and the future demand offer only limited details and parameterization, particularly for Africa. Few studies have integrated information on the combination of urbanization and increase in income to estimate accurate future demand for fish (Béné et al., 2015). Some studies assume constant consumption rates in the future (Barange et al., 2010) or fixed nutritional targets (Rice and Garcia, 2011). Others worked directly with projected fish consumption (Merino et al., 2010; OECD/FAO, 2017) by dividing the projected supply by the projected population. Meanwhile, the combination of fast population and income growth, as well as urbanization trends in Africa could transform some African countries (e.g. Nigeria, Egypt) into the world's largest consumers of fish and seafood by 2050.

Currently, however, Africans are in the paradoxical position of being highly dependent on fish for animal protein but ranking low in per capita fish consumption. Globally, Africans are second only to Asians in terms of relying on fish as a major share of the total animal protein intake in their diet (Table 1). Fish represent over 20% of animal protein intake in twenty African countries (FAO, 2017a). However,

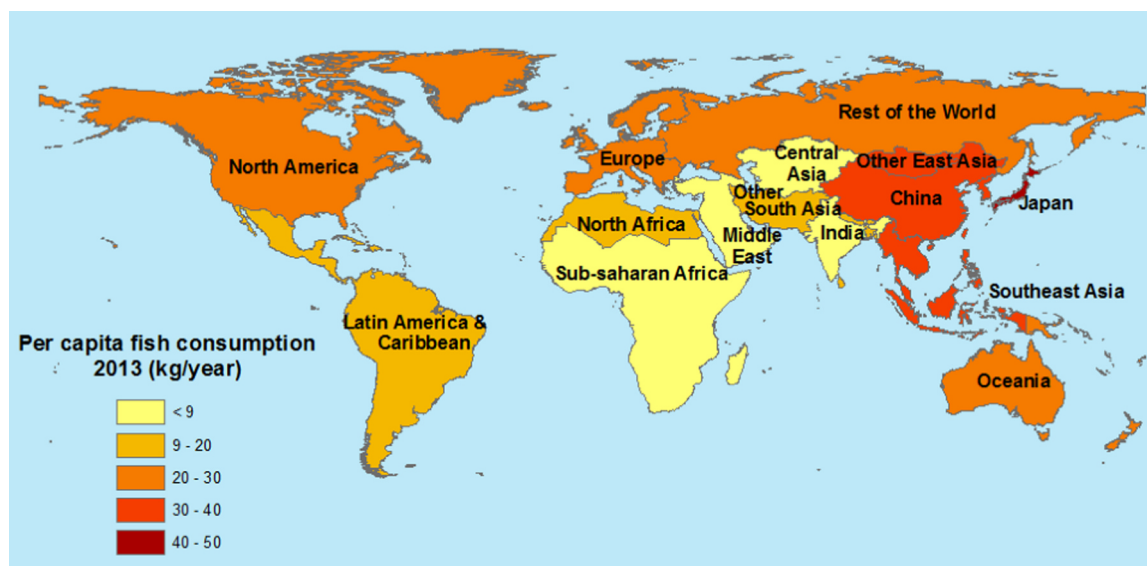


Fig. 1. Per capita fish consumption by region, 2013.
Sources: Data from FAO food balance sheet (FAO, 2017b)

animal protein intake is low in this continent and fish consumption patterns are not homogeneous across the region (Table 1). This heterogeneity reflects the disparities in affordability, accessibility, availability, cultural food preferences, and social behavior in different countries. Despite the high dependence on fish as a source of animal protein compared to other developed and developing regions, Africa, particularly Sub-Saharan Africa, has the lowest levels of per capita fish consumption (Fig. 1). Africans consume only approximately half of the global and Asian per capita averages (Table 1).

On the supply side, most of the growth in global fish production has come from aquaculture as global wild catches have leveled off since 1990 (FAO, 2018). Although production from African fisheries mirrors the global trend, growth of aquaculture in Africa has not significantly contributed to the global share (Brummett et al., 2008; FAO, 2018; Nadarajah and Flaaten, 2017). African aquaculture production only accounted for 2.5% of the global aquaculture share in 2016, of which Egypt accounted for about two-thirds and Nigeria for one-sixth. With this extremely uneven distribution, the rest of the African countries make only small contributions to the continental share (Fig. 2). Compared to Asia, which represented 89% of global aquaculture share (FAO, 2018), aquaculture development in Africa has lagged far behind. Nevertheless, African aquaculture output has doubled in the past 7 years and has experienced accelerated growth at 10.1% annually in the past decade (2006–2016) (FAO, 2018).

Africa's domestic fish supply is still dominated by capture fisheries owing to the continent's endowment of vast fish resources in marine and inland waters. Morocco, Nigeria, and South Africa are the top three fisheries producers in the continent (Fig. 2) (FAO, 2018). Small-scale fisheries play a fundamental role in African economies, providing livelihoods for millions of people, especially in remote rural areas, and have been strengthened significantly through the role fish plays in both food security and income generation (Béné et al., 2009). Africa currently produces about 10.2% of the global fish catches (FAO, 2018). Like much of the world, most African fisheries resources are at their limit. Recent studies suggest almost half of the African fish stocks are overexploited or fully exploited (NEPAD, 2016b). Hence, despite the dominance of capture fisheries in total fish production in the continent, the promise of aquaculture as the new frontier for development holds strong. About one-sixth of total production of food fish in Africa in 2016 comes from aquaculture (FAO, 2018). The fish supply deficit in most African countries presents significant prospects for aquaculture development.

The latest population estimates project that over half of the growth in global population to 2050 is likely to occur in Africa (UN, 2017). To meet the rising demand and in the face of domestic fish supply deficits, fish imports in Africa have increased substantially in the last decade (Fig. 3) (FAO, 2017b). While developing countries on the whole continue to be net fish exporters, Africa is a net fish importer by quantity. Paradoxically, it has been a net exporter of fish by value, suggesting the lower unit value of imports (Fig. 3) (Béné et al., 2010; FAO, 2017b). African fish imports are dominated by low-value small pelagic fish species, mostly mackerel, which are relatively rich in nutrient value (FAO, 2017b; Isaacs, 2016). This implies that most African countries, as lower income countries, are exporting higher value seafood in part to achieve the broader goal of ending poverty, while achieving the food security goal by retaining and importing lower-value nutritional fish (Watson et al., 2017).

3. Fish foresight modeling

In recent years, fish and seafood have become more integrated into foresight models of the agriculture and land-use sectors. To date, results that include fish commodities have been published based on several of this type of partial-equilibrium economic models, such as the International Model for Policy Analysis of Agriculture Commodities and Trade (IMPACT) and the AgLINK-COSIMO model (Lem et al., 2014; OECD/FAO, 2017). A few other modeling teams are also currently working on incorporating a fish component into their modeling systems, including the Common Agricultural Policy Regionalised Impact (CAPRI) model, and the Global Biosphere Management Model (GLOBIOM) (Chang et al., 2018; Latka et al., 2018). These comprehensive models focus on medium- or long-term projections at the global and regional level. Historical data in conjunction with stakeholder consultation inputs are used to generate projections which mirror historical trends while giving direction to future projections. Recently, an econometric model (Cai and Leung, 2017) focused on short-term projections up to the early 2020s was developed to assess the future fish demand-supply gaps at the country, regional, and global levels and to estimate aquaculture growth needed to fill the gaps.

IMPACT was first used by Delgado et al. (2003) to produce projections of global food fish production, consumption, and trade for the 1997–2020 period. Approximately 10 years after the *Fish to 2020* publication by International Food Policy Research Institute (IFPRI) and WorldFish (Delgado et al., 2003), a follow-up study was commissioned

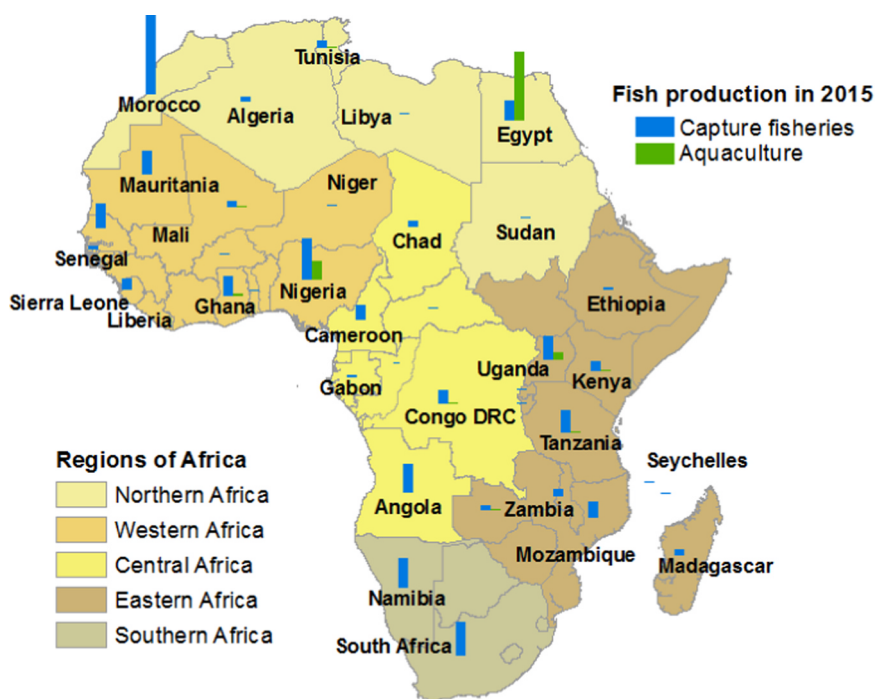


Fig. 2. Africa distribution of aquaculture and capture fisheries production, 2015. Sources: Data from FAO (FAO, 2018)

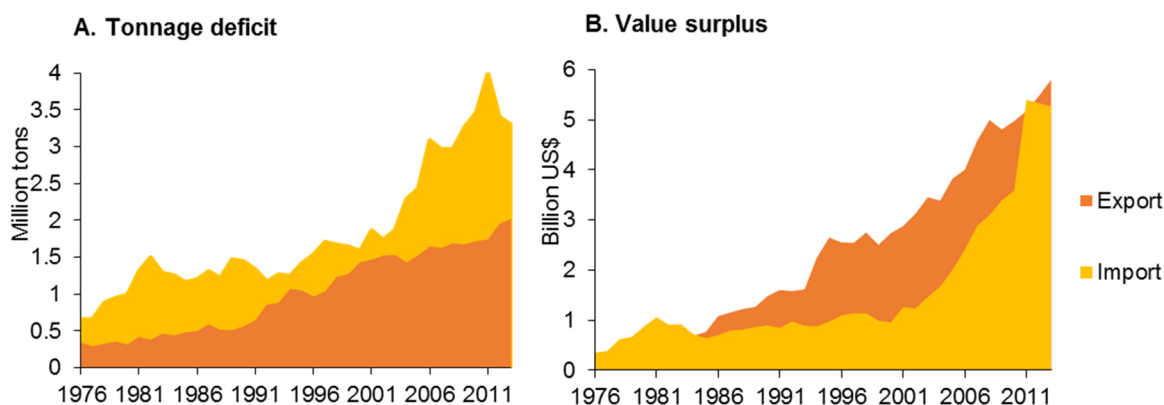


Fig. 3. Africa net trade of fish deficit in tonnage (A) and surplus in value (B), 1976–2013.

by the World Bank in collaboration with the IMPACT modeling team at IFPRI, the Fisheries and Aquaculture Department of the FAO, and the University of Arkansas at Pine Bluff. Incorporating the lessons learned from *Fish to 2020*, a new fish module of the IMPACT model was developed and used to generate the *Fish to 2030* report (World Bank, 2013) covering a period from 2000 to 2030. *Fish to 2030* also incorporated new developments in the global seafood markets and aquaculture sector. Whereas *Fish to 2020* used a fish species aggregation based on market characteristics from the consumer perspective, the new model used an aggregation based on production systems, feeding regimes, and fish diets. The disaggregation is aimed at better reflecting the rising role of aquaculture and the closer linkages between the fish and agricultural markets. These linkages operate through feed markets, where the livestock and aquaculture sectors compete for fishmeal and fish oil ingredients that are also used in livestock feed. At the same time, the livestock and aquaculture sectors compete for agriculturally produced plant-based feeds, which are now major inputs in aquaculture production. The increasingly important linkages between the agricultural and fish sectors, and the increasing role of aquaculture versus capture fisheries, provide justification for conducting analysis of

seafood markets using the IMPACT model. In 2017, WorldFish and IFPRI published the *Fish to 2050* in the ASEAN region report (Chan et al., 2017), with significant model updates to closely replicate the latest FAO historical trends and to calibrate future trends in the ASEAN region to 2050, taking into account industry-specific biophysical and socioeconomic factors, such as fisheries management and ecosystem carrying capacity plus fish production targets defined by national governments. The details of the model structure and model update are described in previous papers (Chan et al., 2017; Kobayashi et al., 2015; World Bank, 2013).

3.1. IMPACT fish model update and scenarios

Similar to agriculture commodity data, species-specific fish production, consumption, and trade data are compiled by FAO (FAO, 2017b, 2018). In this study, we update additional historical production data to 2015 for all Africa countries with incorporated expert opinions collected via stakeholder consultation workshop shaping the projection to 2050. The latest population estimates (UN, 2017) are incorporated as part of the model updates. This study examines four scenarios,

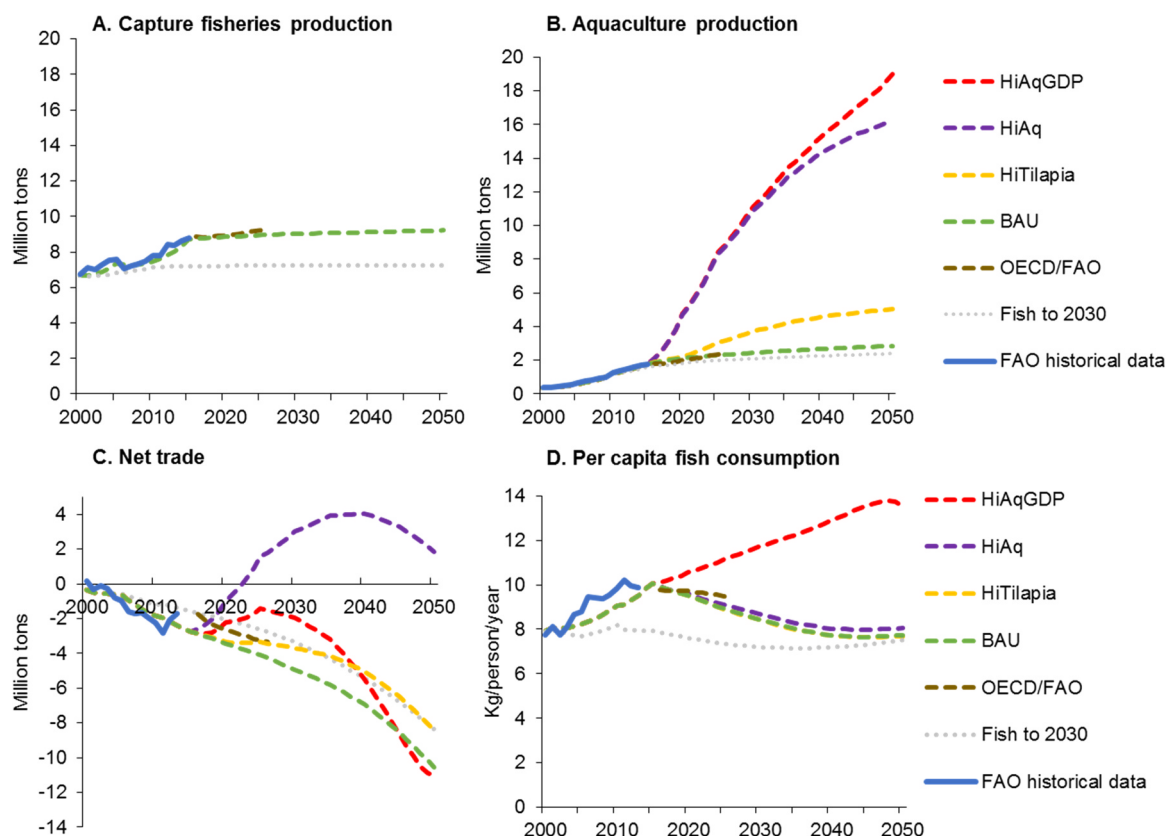


Fig. 4. Evolution and projected Africa fish trend (2000–2050) in A) capture fisheries production; B) aquaculture production; C) net trade; and D) per capita consumption for BAU and alternative scenarios*. *Note: The HiTilapia scenario trend line in Fig. D parallels that of BAU and is hidden by it.

including business-as-usual (BAU) and three alternative scenarios, in terms of key outcomes: fish production, per capita consumption, and net trade (exports minus imports) in Africa. The BAU scenario is characterized by a set of model parameters to reflect a continuation of past trends into the future with adjustments to align projections with regional capacities and endowments. These trends take into account knowledge from published sources, regional experts, and feedback from stakeholder consultation.

Alternative scenarios were developed during a stakeholder consultation workshop conducted to investigate the key challenges and prospects of the fish sector's future potential deviations from the BAU. At the workshop held in Africa Aquaculture Research and Training Center (AARTC), Abassa, Egypt in October 2017, 15 participants, representing key fish producing countries in Africa (Egypt, Nigeria, South Africa, Zambia, Tanzania, Ghana, and Kenya), were invited to provide data, share expert opinions for developing alternative scenario for analysis, and to validate preliminary projection results. The BAU projection from *Fish to 2030* report (World Bank, 2013) was revised and updated taking into account the inputs and comments from the stakeholder consultation for representing countries as well as national government targets and a country-level understanding of maximum carrying capacities for fish production.

The three alternative scenarios address the key challenges observed in Africa's fish sector: 1) fish supply deficit; 2) low per capita fish consumption; and 3) low contribution of aquaculture to total fish output produced in Sub-Saharan Africa. These scenarios represent modifications of the HIGH (high increase in research and development investment across the CGIAR portfolio) and HIGH+NARS scenarios (high increase in research and development investment across the CGIAR portfolio plus complementary National Agriculture Research System investments) analyzed by Rosegrant et al. (2017). These investment scenarios were modified in order to reflect a greater impact of

increased aquaculture output throughout the projection period incorporating feedback from the stakeholder consultation workshop.

The first scenario focuses on the possibility of substantially increased investment in the aquaculture industry continent-wide. This scenario, called *high aquaculture growth (HiAq)* exogenously assumes high growth rates of aquaculture production, which translate into an overall output growth in African aquaculture of 12.7% from 2015 to 2030 (a relative improvement on the 10.6% output growth of the past decade from 2005 to 2015). This is achieved by adjusting the BAU exogenous growth rates from 2015 to 2050 in the top five aquaculture producing countries in Africa (Egypt, Nigeria, Uganda, Ghana and Zambia) for selected key species (tilapia, mullet, and *Pangasius* and other catfish).

To investigate the low per capita fish consumption in Africa, the second scenario, *high aquaculture and GDP growth (HiAqGDP)*, assumes an increase in per capita incomes on top of the HiAq scenario. In the BAU scenario, African economies are assumed to grow at a 2.9% annual rate from 2015 to 2050, which is increased to 4.8% per year under HiAqGDP. (This scenario uses the medium-scale optimistic GDP growth employed in "I2base" from the IMPACT model (Rosegrant and Team, 2012)).

The third scenario, *high Tilapia aquaculture growth (HiTilapia)*, focuses on a specific scaling up of a successful approach to aquaculture development identified by regional experts. Specifically, Egypt, the leading tilapia producer in Africa is assumed to serve as a role model. Promising Egyptian technologies and management practices are assumed to spill-over to tilapia producers in the rest of Africa. This scenario assumes that all African countries currently engaged in tilapia aquaculture will achieve the productivity of Egypt. These countries therefore take the same exogenous growth rate of tilapia production in Egypt from 2000 to 2035 in BAU to their future growth from 2015 to 2050.

Table 2
IMPACT model BAU projected growth of fish production, net trade and per capita consumption for Africa, 2015–2050.

Item	Year								Average annual growth	
	2015	2020	2025	2030	2035	2040	2045	2050	(2015–2030, %)	(2030–2050, %)
Million tons										
Aquaculture production	1.82	2.11	2.31	2.44	2.57	2.68	2.77	2.86	2.0	0.8
Tilapia	1.08	1.30	1.45	1.53	1.61	1.68	1.73	1.78	2.4	0.7
Pangasius and other catfish	0.31	0.33	0.34	0.36	0.37	0.38	0.40	0.41	0.9	0.7
Mullet	0.12	0.13	0.14	0.14	0.15	0.15	0.15	0.16	1.1	0.4
Carp	0.12	0.12	0.13	0.13	0.14	0.14	0.15	0.15	0.7	0.7
Others	0.19	0.22	0.25	0.27	0.30	0.32	0.35	0.37	2.6	1.5
Capture fisheries production	8.71	8.85	8.95	9.03	9.07	9.12	9.16	9.21	0.2	0.1
Pelagics	3.54	3.54	3.54	3.54	3.54	3.54	3.54	3.54	0.0	0.0
Freshwater and diadromous	2.15	2.17	2.19	2.20	2.20	2.21	2.22	2.22	0.1	0.1
Major demersals	1.09	1.16	1.20	1.24	1.26	1.28	1.31	1.33	0.9	0.3
Others	1.93	1.98	2.01	2.05	2.06	2.08	2.10	2.12	0.4	0.2
Net Trade	– 2.75	– 3.46	– 4.11	– 4.96	– 5.80	– 6.95	– 8.54	– 10.59	4.0	3.9
Total availability	13.28	14.43	15.37	16.43	17.44	18.74	20.48	22.66	1.4	1.6
Billion										
Africa population	1.2	1.3	1.5	1.7	1.9	2.1	2.4	2.6	2.3	2.2
kg/person/year										
Per capita consumption	10.0	9.5	8.9	8.5	8.0	7.7	7.7	7.7	– 1.1	– 0.5

4. Future trends of fish in Africa

4.1. Business-as-usual projection

The previous *Fish to 2030* BAU scenario used historical data up through 2009 (World Bank, 2013). The projection from that model underestimated the 2010–2015 historical trend of aquaculture and fisheries production. Adding the recently available data from 2010 to 2015 along with other adjustments based on expert feedback on regional potentials, our new BAU follows the historical trend closely throughout the 2000–2015 period (Fig. 4A and B). For comparison, we plot the OECD/FAO fish model (AgLINK-COSIMO) (OECD/FAO, 2017) results in Fig. 4; the medium-term projection closely parallels the projection trend with the updated BAU for aquaculture and capture fisheries production from 2016 to 2026. The projection using the IMPACT model in the previous study (Chan et al., 2017) reveals that, under the BAU scenario, world aquaculture is likely to overtake capture fisheries production before 2030. In contrast, our projection for Africa shows that even though capture fisheries production remains almost constant, aquaculture production remains well below capture production through 2050 (Fig. 4A and B). Reflecting the different growth trajectories, Table 2 shows aquaculture's share of total African fisheries production is likely to increase gradually from 17% in 2015 to 24% in 2050, with a 2% average annual growth rate between 2015 and 2030. With sluggish growth of capture fisheries and relatively slow growth of aquaculture, and even assuming per capita fish consumption gradually declines from 10.0 kg in 2015 to 8.5 kg in 2030, then 7.7 kg in 2050, more imported fish will be needed to sustain the domestic consumption. Under the BAU scenario, despite a projected production of 11.5 million tons by 2030 and 12.1 million tons by 2050, Africa has a trade deficit of 5.0 million tons by 2030 and 10.6 million tons by 2050 (Table 2). The expected rapid population growth weighs heavily on the future of per capita consumption. Even with declining in per capita fish consumption, Africa will need an additional 10.6 million tons from aquaculture by 2050 simply to reduce its dependence on fish imports.

4.2. Alternative scenarios

4.2.1. High aquaculture growth (HiAq)

Under the HiAq scenario, a drastic increase in fish output is seen with a projection of 10.9 million tons and 16.2 million tons to be produced from aquaculture in 2030 and 2050, respectively (Fig. 4B). With the total amount of fish produced reaching 25.5 million tons in

2050, an increase of 13.4 million tons over the total BAU fish production, which pushes this scenario to a trade surplus by mid-term. (Fig. 4C). However, despite such a huge leap in aquaculture production, the assumption of unchanged population and income growth leads to a slim increase in per capita fish consumption compared to BAU to 8.0 kg in 2050 (Fig. 4D).

4.2.2. High aquaculture and GDP growth (HiAqGDP)

The HiAqGDP scenario projects the highest increase in aquaculture production, with African aquaculture production reaching 11.1 million tons in 2030 and 19.0 million tons in 2050 (Fig. 4B). However, high GDP growth drives up per capita consumption, which creates an exceptionally large net trade deficit, with a steep plunge from 2.7 million tons to 11.0 million tons of net imports from 2015 to 2050 (Fig. 4C). Compared to BAU, this scenario shows per capita fish consumption increasing 75% by 2050 (Fig. 4D). Increases in overall fish consumption in the HiAqGDP scenario are mainly attributable to the optimistic income growth throughout the continent. Income elasticities of demand for fish are generally high (Msangi and Batka, 2015), indicating that a higher purchasing power leads to relatively higher spending on fish in one's diet. The projection for per capita fish consumption follows a steady, nearly linear climb from 10.0 kg in 2015 to 11.7 kg in 2030 and 13.5 kg in 2050 (Fig. 4D), reflecting the increased purchasing power of what is predicted to be a majority-urban continent in 2050 (UN, 2017). Despite being the scenario with the highest overall fish production, the increased per capita consumption results in a sizable domestic production deficit and large volumes of fish would need to be imported to meet domestic demand.

4.2.3. High tilapia aquaculture growth (HiTilapia)

Under the HiTilapia scenario, Africa is projected to reach 3.1 and 5.0 million tons of aquaculture production by 2030 and 2050, respectively (Fig. 4B). Although not as large as the HiAq scenario, it is a 76% increase compared to the BAU aquaculture output in 2050 (Fig. 4B). This scenario assumes a subset of African countries that already produce tilapia achieve the higher growth rate of Egypt. The combination of a reduced country set with a restriction to just tilapia reduces the possible production contribution. Net trade decreases steadily until it reaches 8.4 million tons of net imports in 2050, a slight improvement from the BAU scenario due to the slow decline of per capita fish consumption throughout the projection period (as in the BAU).

5. Discussion

Our model projections highlight the prospects and challenges of future fish production, consumption, and trade in Africa under various scenarios. The BAU results show that Africa will remain a net importer of fish for the foreseeable future. By 2030, 5 million tons of fish for African consumption is likely to be met by imports and, by 2050, fish imports are likely to account for almost half of the fish for African consumption. This trade dependence persists in the HiAq and HiTilapia scenarios where aquaculture production is assumed to grow rapidly. The trade deficit is the largest under the HiAqGDP scenario where higher GDP growth triggers higher per capita demand for fish in Africa compared to other scenarios. This brings potential business opportunities for various actors involved in fish production, distribution, and trade systems in Africa to expand and establish themselves as significant players in Africa's future fish sector.

The increasing fish trade deficit to 2030 and through 2050 highlights the importance of international fish trade analysis for informing policy-making for the fisheries and aquaculture sectors to respond to growing fish demands in Africa. Given the current limitations of domestic fish production, international fish trade, particularly fish imports by African countries is critical to fill in the supply-demand gap. A recent study (Tran et al., 2019), for example, illustrates the prominence of fish imports to Zambia in moderating the effects of fish price increases and thus access for poor and vulnerable consumers in the country. Nonetheless, international fish trade between Africa and other continents should be investigated thoroughly to support developing sound fisheries and aquaculture development policies. As several studies (Béné, 2008; Béné et al., 2010) have pointed out, there is mixed evidence for the development benefits of fish trade between Africa and other countries. Fish exports from Africa to developed markets, in particular, might create negative impacts on local populations' food security and livelihoods.

Intra-African and regional fish trade can be an effective alternative to address the fish trade deficit problem and meet the growing demand for fish in Africa. Previous studies (Béné et al., 2010; Heck et al., 2007) show that many low-income households depend upon fish production and trade systems in Africa. Supporting this system can help reduce the fish supply-demand gap and contribute to poverty alleviation and improving food security in Africa. Policy-makers have recognized the need for intra-Africa fish trade improvements and have begun a series of reforms and infrastructure investments to facilitate easier movement of better quality fish across borders within the continent (NEPAD, 2016a). Intra-regional fish trade in Africa comprises both formal and informal trade. Removing tariffs and promoting regional free trade agreements can promote increased intra-regional trade through more formal and better regulated channels. At the same time however, trade facilitation can make key improvements to cross-border trade governance that can enhance informal exchanges, which is dominated by small scale traders (Hara et al., 2017).

In addition to addressing international and intra-regional fish trade issues, an important option for Africa would be to invest in increasing the continent's fish production through aquaculture as shown in the high aquaculture scenarios. To date, despite extensive research and investment initiated by governments and donors in the past five decades, aquaculture development in Africa has had only limited success and is still struggling to realize its high potential (Brummett et al., 2008). Most donor- and government-driven programs have focused on promoting small-scale aquaculture production through an interventionist approach for boosting household consumption for food and nutrition security (Brummett et al., 2008). However, evidence shows that this intervention approach resulted in unsustainable outcomes due to limited capital, low quality input regimes, and poor infrastructure systems in rural regions in Africa (Kaminski et al., 2018). Recent investments have sought new models for business-oriented farming that seek to support small- and medium-scale enterprises in national and

international markets (Hishamunda, 2007; Kaminski et al., 2018). There are several complementary options for this approach, including: 1) promoting sustainable commercial aquaculture; 2) developing domestic private feed and seed industries; 3) diversifying culture environments and cultured fish species; 4) developing private hatcheries, especially those targeting high commercial value species and those with high demand from consumers; and 5) developing appropriate economic and regulatory policies that create favorable environments for commercial aquaculture development. However, there is an important caution for this alternative approach as the better established commercial aquaculture market chains are designed mostly to move food from the rural to urban markets given the relatively higher price of aquaculture products. Under these circumstances, poorer consumers may not benefit from an increased fish supply. While the large-scale commercial sector keeps growing, it will be important for producers and input suppliers to increase their market share and devise products that are more accessible and affordable for lower-income consumers also (Genschick et al., 2017).

With two thirds of African aquaculture supply and above-global average per capita fish consumption (FAO, 2017b, 2018), Egypt is generally regarded as a success model for aquaculture sector development in Africa. Capitalizing on some of the already developed tilapia farming technologies (e.g. genetically improved strains and better management practices) from Egypt, tilapia farmers across the Africa could increase aquaculture production substantially, as illustrated in the high tilapia aquaculture growth scenario. This intervention may be more practical and efficient given that the innovative technology and accessible inputs are already available on the continent.

Given the current extent of aquaculture in Africa, even an optimistic aquaculture growth scenario falls short of the trend for increasing demand for fish. GDP growth above the global average in African countries is plausible during the projection period (African Development Bank, 2011), which makes the HiAqGDP scenario (high aquaculture growth plus GDP growth) important to consider. This scenario is the only one among those considered that achieves increased per capita fish consumption. Recent projections (UN, 2017) have increased expected population growth, particularly in Africa. While this situation creates the burden of more mouths to feed, it also creates opportunities for attracting investments in the African aquaculture sector.

The potential upsurge in fish demand creates bright prospects for Africa to expand a vibrant fisheries and aquaculture sector. To realize this, policies and technologies to reduce post-harvest losses in existing fish value chains deserve attention. The continent experiences substantial losses in post-harvest management. As urbanization accelerates the fish supply chain will lengthen, especially for aquaculture producers, which could present even greater challenges for post-harvest losses. Investments in fish cold chain development can preserve more of the fish caught and improve the quality of fish on offer.

Fish foresight modeling in Africa generates an evidence-base to build continent and regional wide policy interventions. The availability of reliable data is one of the key prerequisites for informed decision making in fisheries and aquaculture. Currently, limited and inconsistent fish data hamper the Africa modeling efforts. Lack of trade data at desirable species classifications leads to the inability to analyze bilateral trade flows and makes analysis of specific Africa trade policy options difficult without complementary work. Also, data on the availability of high quality inputs is one of the significant limitations being faced by aquaculture sector. An integral component of the future development of the African fish sector will be to develop a pan-African strategy which prioritizes the improvement of fisheries and aquaculture data collection, analysis, and dissemination. Further refinement of foresight modeling tools for fisheries and aquaculture will greatly improve their accuracy and relevance for policy-making. Future modeling efforts should address the role of fish for food and nutrition security in Africa, changing demand patterns for fish products, constraints on productivity and trade, domestic self-sufficiency, and environmental

trade-offs.

6. Conclusions

Fisheries and aquaculture make a critical contribution to food security and livelihoods in Africa and could do more to meet development goals with well-designed policies and investments. Continued rapid population growth combined with robust income growth will fuel strong increases in demand for fish through the projection period analyzed in this research. Given a limited potential for growth in African capture fisheries, rapid expansion of aquaculture will be needed to meet this increased fish demand. As model results indicate, Africa will continue to be a net fish-importing continent, but this represents important opportunities for fish sector entrepreneurs. Policies to promote sustainable aquaculture growth, facilitate international and intra-African trade, and to reduce post-harvest losses while working to better distribute the benefits of increased fish availability are recommended.

Acknowledgements

This work was undertaken as part of the CGIAR Research Program on Policies, Institutions, and Markets (PIM) led by the International Food Policy Research Institute (IFPRI) and the CGIAR Research Program on Fish Agri-Food Systems led by WorldFish. Funding support for this study was provided by CGIAR Funders and the German Federal Ministry for Economic Cooperation and Development (BMZ) through the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ). The authors also highly acknowledge the partnership and contributions of a wide range of public, private, community and civil society members and organizations in Africa to the research.

Declaration of interest

None.

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