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The future of fish supply-demand in Malawi and its implications for nutrition security and poverty reduction

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List of abbreviations

AAH	aquatic animal health (program)
AS	alternative scenario
CPUE	catch per unit effort
FAO	Food and Agriculture Organization
GDP	gross domestic product
WDI	World Development Indicator
SPAITS	Scaling Systems and Partnerships for Accelerating the Adoption of Improved Tilapia Strains by Small-Scale Fish Farmers

Executive summary

Fish plays an important dietary and economic role in Malawi, providing 28% of animal protein intake. Per capita fish consumption increased from 10.7 kg in 2016 to about 12.6 kg in 2018. The contribution of fish to Malawi's gross domestic product (GDP) is about 4%. In 2020, aquaculture supplied around 9400 t against almost 171,100 t from capture fisheries (FAO 2022). In response to the increase in domestic fish demand, Malawi imported more than 5000 t of fish in 2019 (FAO 2020a). Despite the high potential of capture fisheries and high level of aquaculture development and training, Malawi still lags behind other countries, such as Egypt, where 80% of fish production comes from aquaculture (FAO 2022). Malawi's aquaculture production remains relatively low, accounting only for 5.2% of total national fish production (FAO 2022).

Understanding the dynamics of fish production, consumption, trade, prices and their implications on food and nutrition security in Malawi is critical to supporting national policy and decision-making to ensure the growth of sustained fish production while minimizing unexpected socioeconomic and environmental impacts. The objective of this study was to provide a future outlook of the fish sector in Malawi by projecting the dynamics of fish supply and demand and drawing policy implications that can be of interest to policymakers in the country.

As part of the analysis, we first review past trends of fish supply and demand in Malawi using existing data and literature to help further develop a fish supply-demand model for the country. In the review section, we highlight factors influencing fish supply and demand in Malawi and the need for further research, investment and sustainable management of aquatic food systems in the country. Total fishery output in Malawi from its inland fishery resources has been trending upward since the early 2000s; even so, per capita fish consumption in the country remains low. As fish is a vital source of animal protein, supplying affordable, nutritious food to many Malawians, it is important to take careful consideration in the management of this resource.

The increase in Malawi's fish production has been seen in many inland capture fisheries in the region. It is possible that this reflects actual increases in both yields and the efficiency of catch data recording. However, although this trend might sound encouraging, it should be noted that almost all recent increases in production have been attributed to newly fished small pelagic species. In contrast, more traditionally fished species have remained mostly stable or have been decreasing. Malawi also has an aquaculture subsector that currently produces a small number of fish for consumption. Aquaculture has an increasingly vital role in the domestic provision of fish for the country, as Malawi has large amounts of suitable land for production.

Although fish production has been increasing in Malawi, there are still several issues that the industry faces. Climate change and post-harvest losses are the most predominant, affecting all fishery sectors. Climate change is also predicted to severely affect inland water bodies, including fishponds, because of their enclosed system and continental location. Regarding capture fish production, overfishing remains an alarming threat. The pattern of catching small pelagic fish to increase production because of the stagnation of larger more traditional species, such as tilapia, can be characterized as "fishing down the food chain" and can, in extreme circumstances, lead to the collapse of the fishery. In addition to the concerns that Malawi's capture fisheries face, three factors hinder the development of aquaculture in the country: (1) limited access to key inputs, including fingerlings and feed, (2) lack of affordable financing and (3) inefficient extension support services.

As demand for fish continues to grow in the foreseeable future, modeling certain scenarios is necessary to ensure Malawi's food security. We developed a fish supply-demand model for Malawi and carried out a scenario analysis to help understand the potential impacts of policies, including aquaculture subsidies or capture fish yield limits on key indicators, such as per capita fish consumption and trade. The scenarios modeled include the stagnation and decline of the country's production of capture fish, the growth of the aquaculture industry and the accelerated economic growth of the country. We find that while the stagnation of the nation's capture fishery production has detrimental effects on per capita fish consumption, as well as fish prices and trade, the sector's decline in production has profound consequences that could drastically affect food security. Both the economic growth and increasing aquaculture scenarios prove to be the most beneficial for the country, with fast aquaculture growth providing substantial positive outcomes.

The results of the modeling exercise provide insight into the consequences of five possible scenarios for Malawi's fishery sector. From these results, policy interventions can be implemented to maximize the probability of positive outcomes. In our model, stagnating and/or declining capture fishery yields both have detrimental effects on per capita consumption, trade and prices. Mitigating these outcomes should be a priority for future fishery policy. Policy steps that can achieve this goal include involving fishers in the design of future policy decisions, considering indirect threats to fish productivity and strengthening the enforcement of fishery regulations. Results from the aquaculture scenarios indicate substantial positive outcomes from increased growth of the sector. To see the benefits produced from these scenarios, Malawi must overcome the challenges in availability that the industry faces, namely of quality feed/seed and of viable species for farming. Implementing feed standards and certificates, incentivizing quality feed production domestically and reducing import taxes levied on foreign feed are some policy options that can help improve the availability and affordability of feed in the country, which would improve the economic viability of fish farming. Additionally, identifying a suitable, fast-growing species for use in aquaculture has the potential to improve public attitudes toward aquaculture and reduce the attrition rate of fish farmers.

More specifically, to stimulate the growth of the aquaculture industry, the government should consider the following recommendations:

1. Strengthen extension support services.
2. Create enabling conditions to attract domestic and foreign direct investment to expand investments across the value chain. Specific areas that require immediate attention are (i) production of high-quality aquafeeds and fingerlings, (ii) value addition and market links and (iii) affordable financing.
3. Strengthen the Aquatic Animal Health (AAH) program.
4. Enhance product quality assurance.

Introduction

Fish plays a vital role in the economic development and nutritional intake of the population in many countries. This is especially relevant for developing countries in Asia and Africa, where most fishers and fish farmers work and where fish protein accounts for about 29% of animal protein intake (FAO 2020b). The sector will continue to play an increasingly important role as population growth, economic development and changing consumer attitudes drive demand (Abdulai and Aubert 2004; Naylor et al. 2021). Increasing the consumption of fish can have positive effects on the health of individuals in developing nations by providing essential micronutrients to vulnerable populations (Thilstead et al. 2016; Golden et al. 2021; O'Meara et al. 2021). However, rising demand for fish in Africa against stagnating domestic supply has already created a dramatic rise in imported fish, leading to the share of imports in the consumption of fish being higher than other commodities (Naylor et al. 2021). If the necessary steps are not taken, this could lead to a decrease in per capita fish consumption and an overreliance on imported fish in the future (Obiero et al. 2019). This underlines the importance of efficient and equitable fisheries management to ensure food security well into the future.

Malawi is a growing country in southeastern Sub-Saharan Africa, with vast inland freshwater resources and a GDP of about USD 11.8 billion. The country currently has a population of about 19 million people and, like other Sub-Saharan countries, is growing substantially faster than developed nations, at approximately 2.7% per year. Economically, Malawi is going through a period of high uncertainty, as growth in real GDP per capita fluctuates considerably, with periods of negative growth (WB and OECD 2022). This is mostly a result of the pronounced inflation rates of the past 20 years, sometimes in the double digits. According to recent household surveys and governmental sources, fish is the preferred animal protein source in Malawian households, making up 70% of all animal protein consumed (Department of Economic Planning and Development 2019). In the likely occurrence that high preferences for fish remain, population growth and economic growth could contribute to the demand for fish. In addition to these effects, terrestrial meat may be increasingly substituted for fish because of changing attitudes and preferences for the health benefits of fish (Naylor et al. 2021), further increasing demand.

Approximately 20% of Malawi is covered by water, with the fisheries sector indirectly employing more than 500,000 people and contributing about 4% to GDP (DOF 2016). As a landlocked country in the African Great Lakes region, Malawi has exclusively freshwater fish production. The sector is largely artisanal in nature, with small-scale fishers and fish farmers supplying 90% of aquatic foods (DOF 2016; Armstrong Simmance et al. 2021). Capture fish production has been increasing steadily in recent years, from about 98,000 t in 2010 to over 171,000 t in 2020 valued at more than USD 270 million (Department of Economic Planning and Development 2019). Aquaculture production in Malawi is small compared to capture fisheries. As of 2020, aquaculture only accounted for about 5% of total fish production. However, its potential in Malawi is substantial, with 15%–25% of the total land area being suitable for aquaculture production (Brooks 1992). Malawi has large amounts of suitable aquacultural areas that could position the country to drastically increase fish production to meet supply, such as in Egypt and Nigeria (Adeleke et al. 2021).

To understand both the economic dynamics of the fish industry in Malawi and the consequences of likely future events, this study designs a multimarket model of the country's fish sector to examine several possible future scenarios. Building upon earlier work by WorldFish, we model the impacts of the stagnation and decline of capture fisheries production, the accelerated growth in the aquaculture industry and faster-than-predicted economic growth. These scenarios were chosen after a careful literature review and inputs taken from a national stakeholder workshop in Malawi, and they represent a set of likely occurrences moving forward. The results of the modeling effort can assist government officials and other stakeholders in developing policies and initiatives that could benefit the sector or help it confront existing challenges.

This study seeks to address the following questions:

1. How will capture fisheries and aquaculture production systems in Malawi respond to the increasing demand for fish in the future, considering complex interactions of domestic supply, demand, trade and imports?
2. What are the driving factors that will influence future fish supply, demand and trade (based on scenario analysis modeling)?

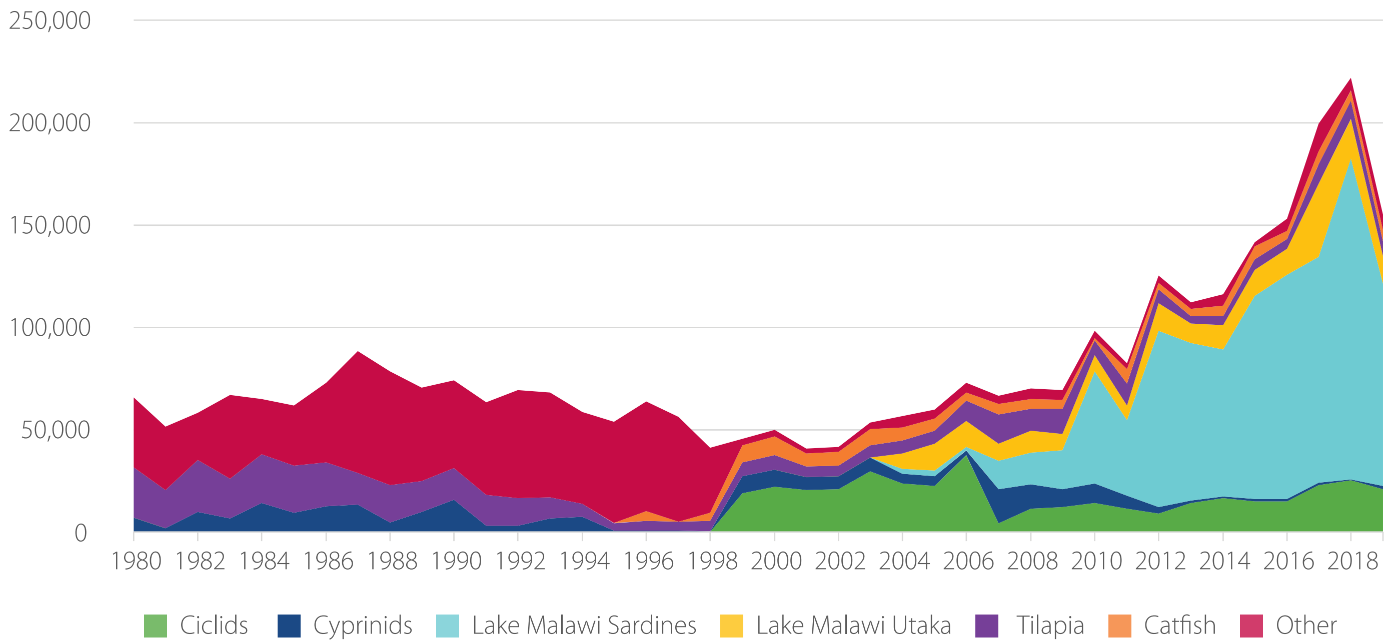
Figure 1. Malawi's location.

1. A review of fish supply-demand in Malawi

1.1. Capture fisheries

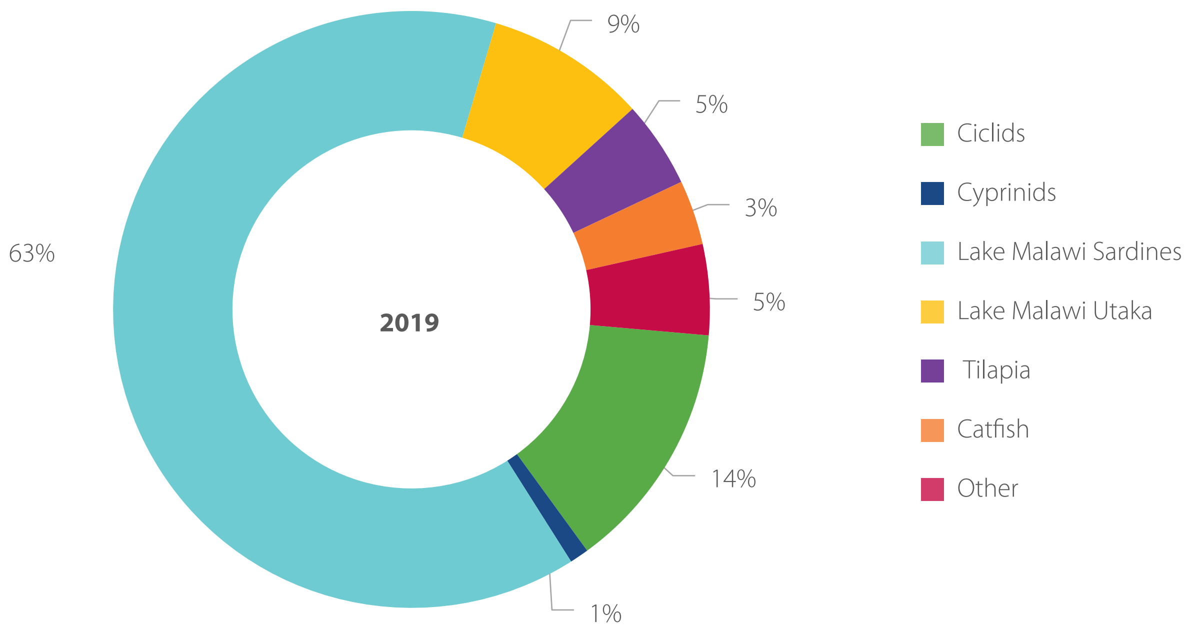
Malawi's fish sector is entirely made up of inland freshwater species. Lying within the African Great Lakes region, Malawi has several large lakes available for fishing, including Lake Malawi, Lake Chilwa, Lake Malombe and Lake Chiuta. Capture fisheries account for the vast majority of fish production in Malawi (95% in 2019), averaging 140,500 t per year from 2010 to 2019 (FAO 2021). Within the past 10 years, there has been a sharp increase in production and notable changes in target species in the country (Figure 2). It should be noted that recent increases in fish production in Malawi have not been steady, with sizable declines in 2013 and 2019, demonstrating the relative uncertainty of fish production. This can be attributed to the drastic increases in the exploitation of the small offshore species, such as Lake Malawi sardine and Lake Malawi utaka (Figure 2). Relatively unharvested by the commercial sector prior to the 21st century, Lake Malawi sardine yields have increased rapidly and represented more than 60% of the total fish catch in 2019 (FAO 2021) (Figure 3). It should be noted, however, that recent increases in inland fishery harvests could also be attributed to better data collection (Youn et al. 2014).

The freshwater resources of Malawi face several challenges. The largest is overexploitation, which was the main cause of collapse of the chambo fishery in the early 2000s (Hara 2006). Catch per unit of effort (CPUE) can be an indicator of the status of fishstock, with higher values indicating a larger stock and lower values a smaller stock. Studies that examined trends in CPUE in Malawi showed mixed results. A study by Kanyerere et al. (2018) found declining trends, while another (Innocent 2019), focused on usipa or Lake Malawi sardine, showed evidence to the contrary. Yet another study by Weyl et al. (2010) found that conclusions on CPUE trends were sensitive to the fishing method used. These results could indicate that while the stocks of species that have not been fished for long periods are healthy, including usipa and utaka, more traditionally fished species are overexploited, including tilapia and other species of cyprinids and cichlids. The changes in catch composition could also indicate



Source: FAO 2021.

Figure 2. Capture production species composition in Malawi since 1980.



Source: FAO 2021.

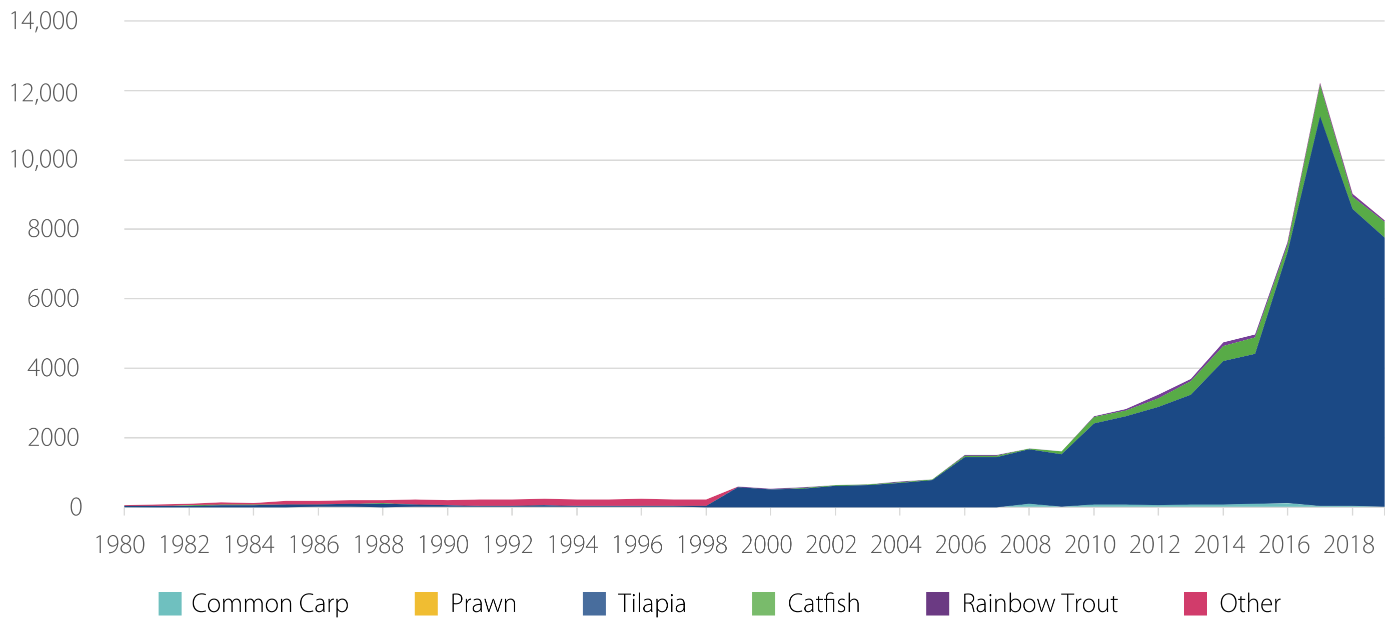
Figure 3. Capture fishery composition, 2019.

the "fishing down the food web" phenomenon, where increasing catches lead to stagnating or decreasing catches (Pauly et al. 1979; Msiska et al. 2017). Climatic fluctuations, including decreased/increased rainfall and increased surface temperature, are predicted to have negative impacts on inland fishery productivity (O'Meara et al. 2021). Additionally, climate change could affect inland water bodies more severely because of their continental location (Thilstead et al. 2016). Other threats to capture fishery performance include eutrophication from agricultural runoff/ development projects (Weyl et al. 2010), infrastructure deficiencies and post-harvest losses (Department of Economic Planning and Development 2019; Torell et al. 2020).

1.2. Aquaculture

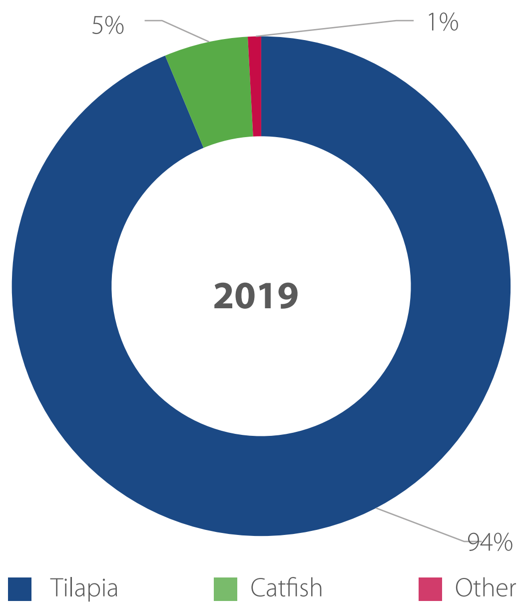
Aquaculture was introduced in Malawi in the early 1900s with rainbow trout for angling, and later in 1956 with native tilapia species for food (Department of Economic Planning and Development 2019). In 2018, the sector employed about 15,000 fish farmers, using predominantly pond construction, with a few large-scale operations (DOF 2016; Department of Economic Planning and Development 2019). In recent years, yields from aquaculture have increased from 500 t in 2000 to about 10,000 t in 2019 (FAO 2021). The sector still contributes relatively little to the overall fish supply (5%), but there is much potential for growth, given the large amount of suitable area in Malawi, estimated at over 11,000 km^2 (Brooks 1992). In 2019, a variety of local tilapia species were the main species farmed in the country, making up about 94% of production, with another 5% being catfish and 1% carp and trout. Common carp has been farmed in small amounts despite policy restrictions prohibiting further implementation of the species. The common carp was introduced in the mid-1980s to increase the viability of aquaculture because of the low growth rates of the local species that were cultivated (Kassam and Mtethiwa 2017). However, common carp was eventually banned because of the environmental concerns stemming from the effect of the fish on the natural biodiversity of the country's lakes, specifically Lake Malawi, which is one of the most diverse freshwater ecosystems in the world (Weyl 2010). The ban was not well received by fish farmers, who were enjoying substantially increased profits from carp production and caused the exodus of many Malawian fish farmers from the industry (Kassam and Mtethiwa 2017).

The aquaculture sector is a fragile system easily affected by climatic variance such as rainfall patterns. These were to blame for the decrease in yields from 2017 to 2018 and will be a future concern as the effects of climate change increase (Department of Planning



Source: FAO 2022.

Figure 4. Aquaculture species composition in Malawi since 1980.



Source: FAO 2022.

Figure 5. Aquaculture composition, 2019.

> *"Aquaculture has the potential to contribute to food security and poverty reduction goals by supplementing capture fisheries that are being exploited at over their maximum sustainable yields."*
>
> ***– Department of Fisheries, Malawi***

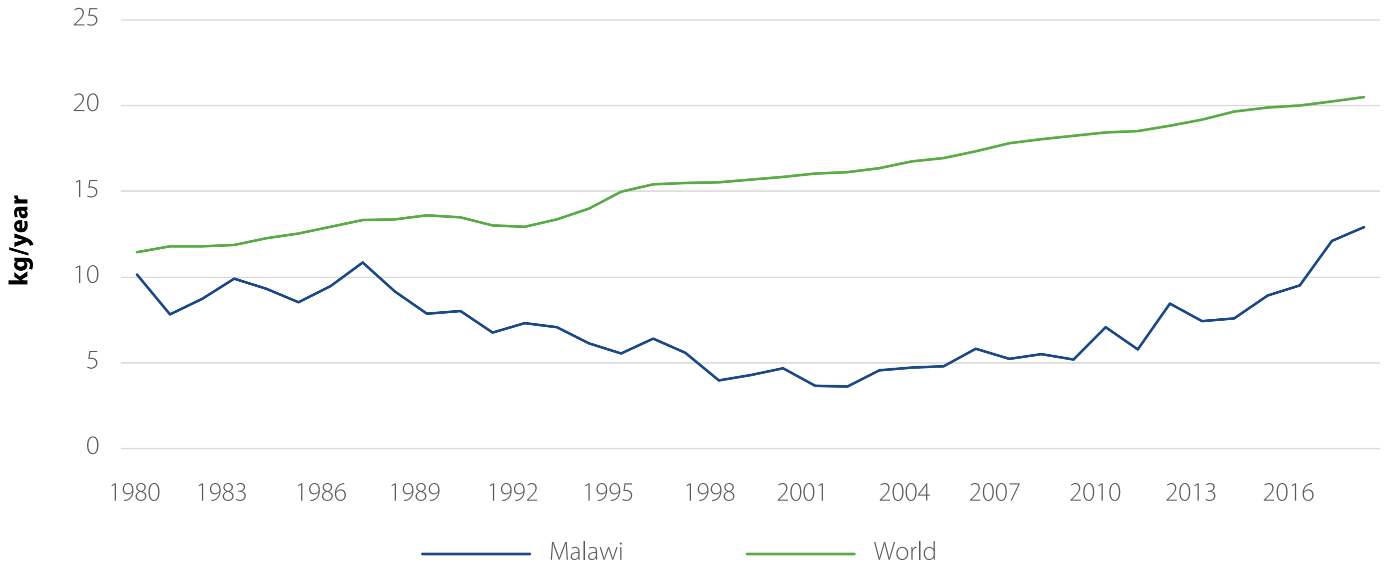
and Economic Development 2019). Another concern is the availability of key inputs, including fingerlings and feed in Malawi. Although there are producers in the country that make sinking fish feed, there is limited production of the more efficient floating fish feed (Department of Planning and Economic Development 2019; Mwema et al. 2021). Furthermore, high taxes levied on imported feed to mitigate the country's reliance on external inputs are causing imported feed to be prohibitively expensive (Mwema et al. 2021). Additionally, a more suitable and efficient indigenous species for aquaculture has not yet been identified. Fish farmers have been requesting a replacement for the common carp since the ban on the species, which would increase profits and so incentivize the viability of aquaculture in the country (Kassam and Mtethiwa 2017). Finally, similarly to the capture fishery sector, infrastructure issues affect post-harvest processes, including fish processing, storage, marketing and transportation, which lead to high post-harvest losses (Department of Economic Planning and Development 2019; Torell et al. 2020).

1.3. Fish demand

Sub-Saharan Africa is the only region of the world where per capita fish consumption remains well below international levels despite large gains in production (Béné et al. 2010: FAO 2020b). In Malawi, per capita consumption of fish has not kept pace with international trends. From 1980 to

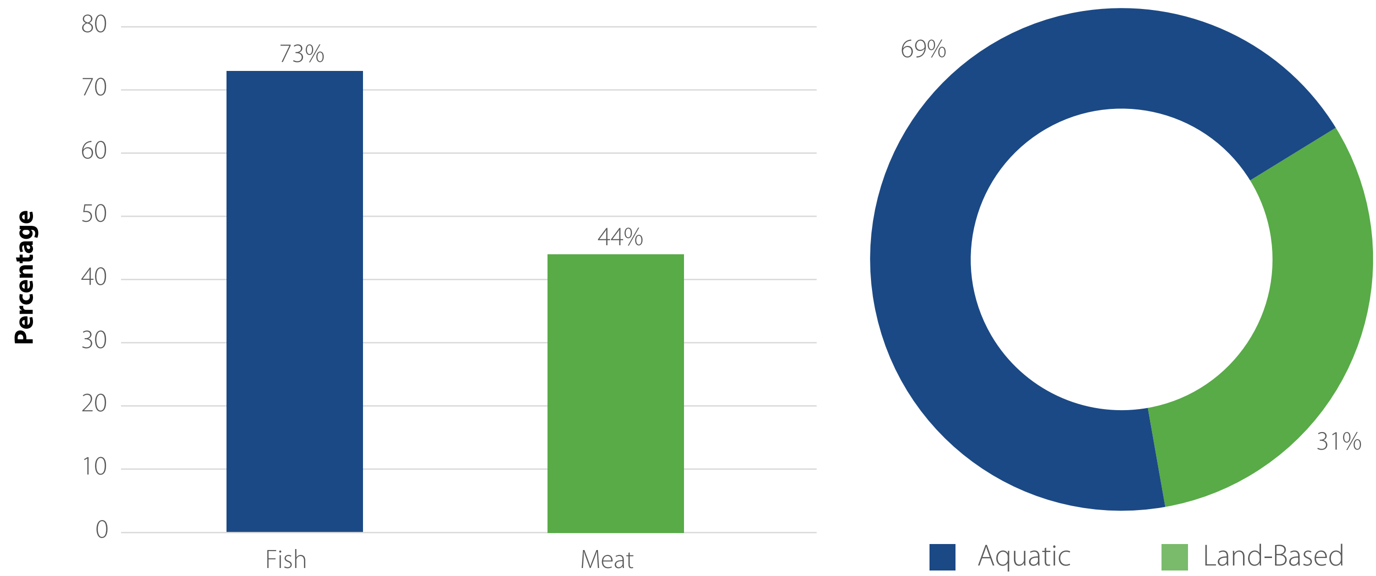
2016, average global fish consumption increased from about 11 kg per person to over 20 kg. In Malawi, however, there was a sharp decline in this statistic until the early 2000s (Figure 6), at which point it started to increase (FAO 2021). The decline was partially the result of a collapse in the chambo fishery of southern Lake Malawi and Lake Malombe, which caused capture fishery yields to decrease until about 2004 (Hara 2006), after which small pelagic fish, including the Lake Malawi sardine and utaka, started contributing large amounts to overall capture fishery yields. In 2019, annual per capita fish consumption in Malawi was 8.75 kg.

Despite low levels of consumption relative to other parts of the world, fish is a staple food item in Malawi, providing the majority of animal-based protein (Department of Planning and Economic Development 2019). Data from the Fifth Integrated Household Survey conducted by the National Statistical Office of Malawi (2020) indicates that more than 70% of households consume fish weekly (Figure 7), compared to less than 50% for land-based meat. Additionally, the households surveyed spent approximately 69% of their weekly expenditure for animal-based meat on aquatic foods.



Source: FAO 2020c

Figure 6. Per capita fish consumption, Malawi versus the world.



Source: NSO 2021.

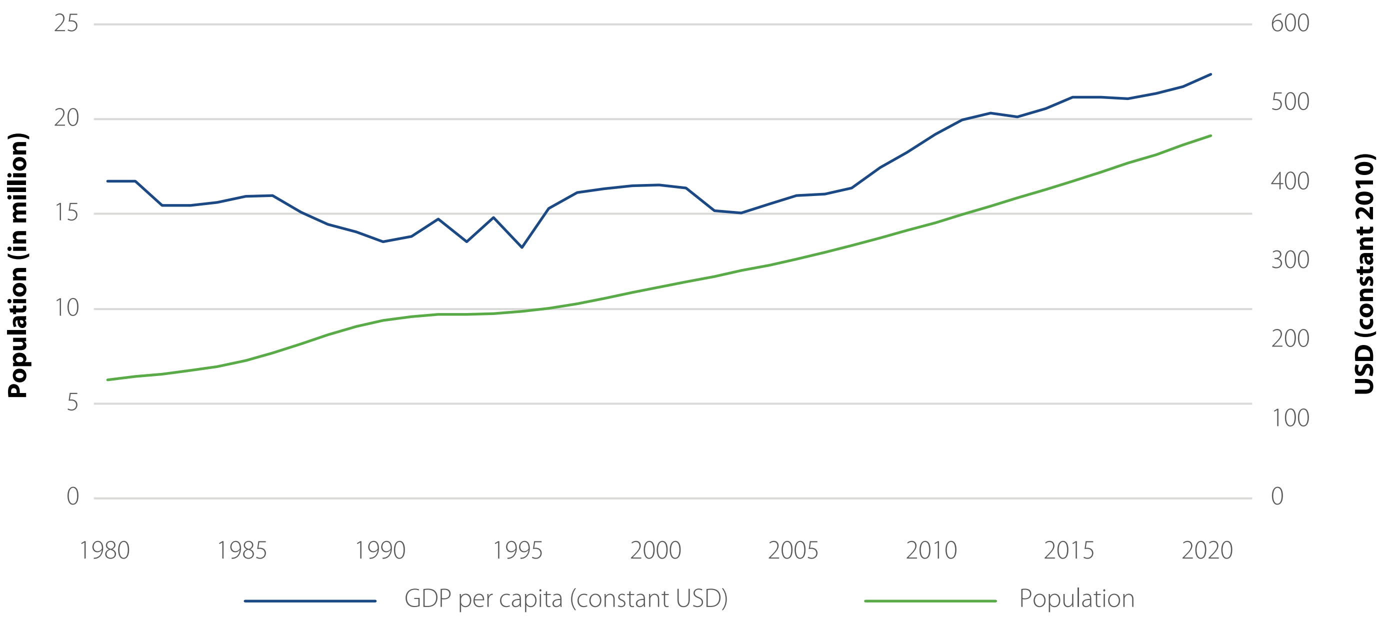
Figure 7. Percentage of households in Malawi who consume fish and meat weekly (left); percentage of animal-based meat expenditures (right).

Demand for fish at the national level is primarily fueled by population growth, economic growth, evolving consumer preferences, and relative prices (Naylor et al. 2021). The population has grown in Malawi at about 2.8% per year for the past 40 years, with no signs of slowing down (Figure 8). It is safe to assume that the absolute number of fish consumed will increase somewhat linearly with the population, possibly representing a 78% increase by 2040. Similarly, economic growth has the potential to drastically increase the consumption of fish. Nankwenya et al. (2016) estimate the expenditure elasticities for all types of fish (dried, fresh, smoked and tinned) to be positive, ranging from 1.11 for dried fish to 1.9 for smoked. Although Malawi has not yet experienced the rapid economic growth exhibited by other nations in Sub-Saharan Africa, the potential is there and must be accounted for to effectively plan for the future.

1.4. Fish trade

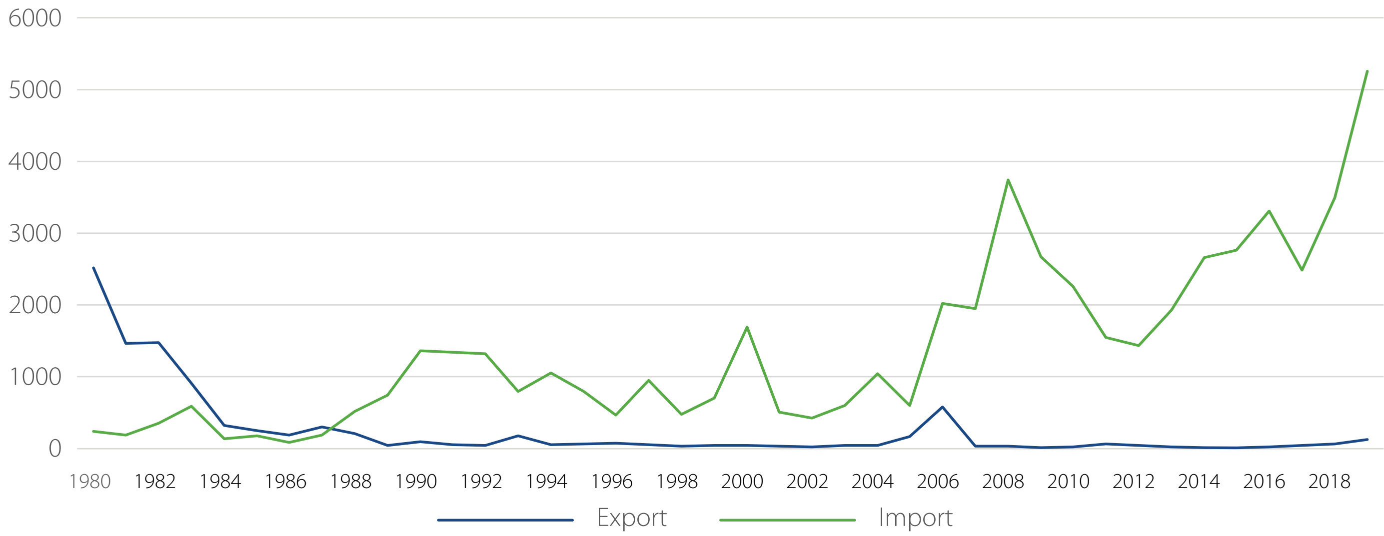
The fish trade in Malawi has followed the trend seen in many Eastern African nations characterized by increasing imports against stagnating exports (Obiero 2019) (Figure 9). To meet domestic demand for fish, imports in Malawi have increased steadily, from about 500 t in 1999 to over 5000 t in 2019. These imports are largely made up of tilapia and mackerel, and predominantly come from other African nations, notably Tanzania (FAO 2021). These statistics do not consider any informal trade being conducted between nations, which has been estimated to be substantial (Mussa et al. 2017). With regards to exports, Malawi sends primarily ornamental fish species to Asian and European countries, such as Hong Kong, China and Germany (Department of Planning and Economic Development 2019). While arguments are being made that fish exports can harm the food security of developing nations (Béné et al. 2010), this does not seem to be the case in Malawi as most fish exports tend to be non-food related.

The value of traded fish in Malawi also differs significantly between imported and exported fish, as in most developing nations (Obiero 2019). The country imports relatively inexpensive species of fish and exports more lucrative species, mostly ornamental. As indicated in Figure 10, the value of imports remains steady at about USD 1500 per metric ton, while exports vary from USD 16,000 in previous years to approximately USD 4000 per metric ton in 2019. The importation of cheaper fish reflects Malawi's need to provide increased access to affordable sources of protein, while the high value of exports provides necessary economic stimulation. Although imported fish are a vital component of fish supply in Malawi, foreign fish tend to be more expensive (Nankwenya et al. 2016). As such, an increasing share of imported fish could increase fish prices.



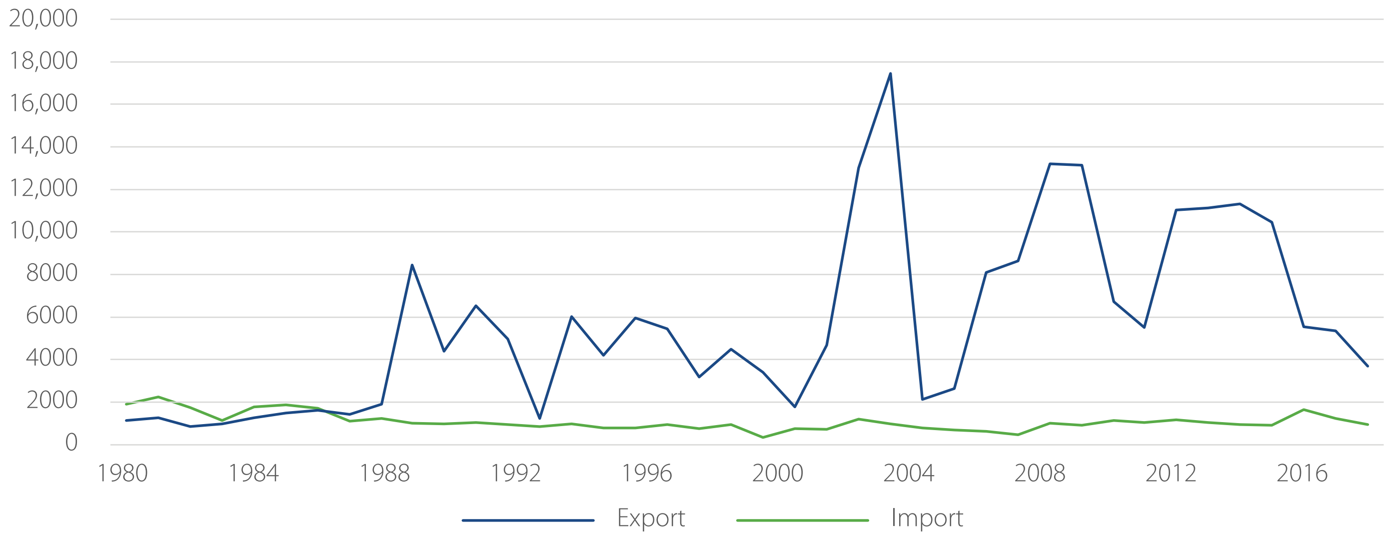
Source: WB and OECD 2022.

Figure 8. Malawi's population and GDP per capita growth.



Source: FAO 2020a.

Figure 9. Fish import and export quantities (metric tons) in Malawi since 1980.



Source: FAO 2020a.

Figure 10. Fish import and export value (USD/metric ton) in Malawi since 1980.

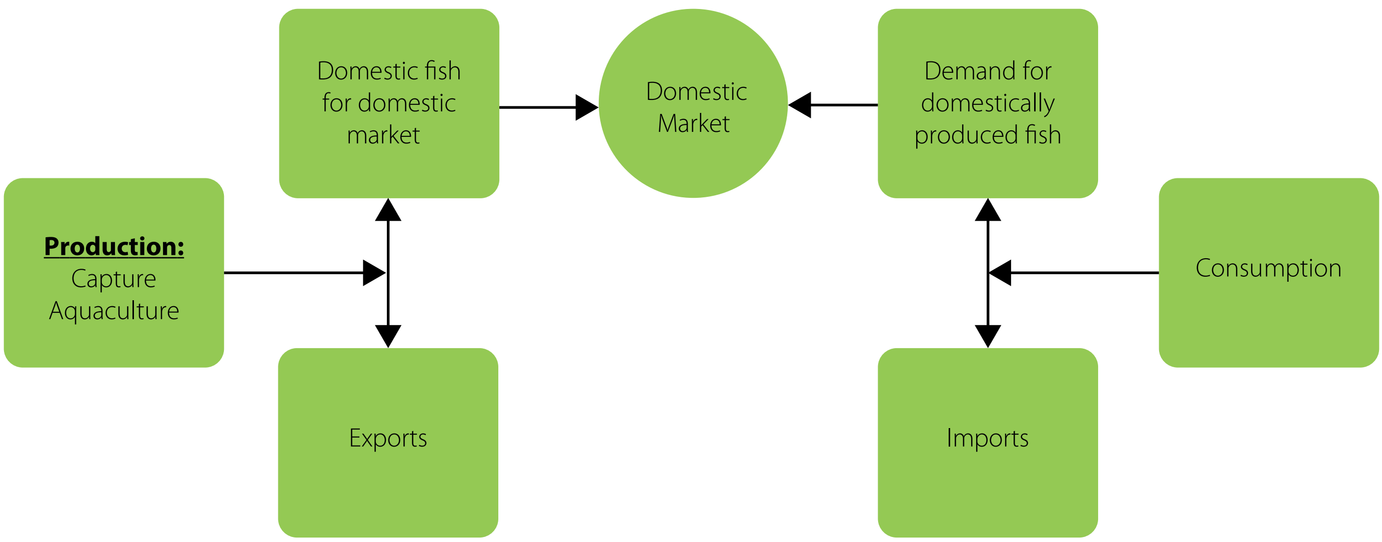


Figure 11. Schematic diagram for all fish groups in the model.

2. Malawi fish supply-demand model

2.1. Model overview

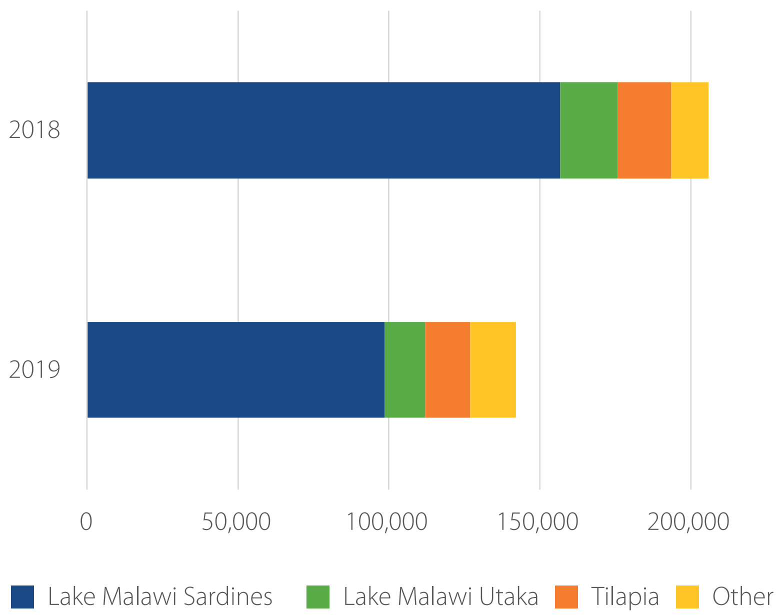
The use of models in scenario building exercises is neither new nor limited to the fisheries sector. In the case of fisheries, WorldFish has constructed and applied a multimarket fish model known as AsiaFish to various countries in Asia and beyond since the early 2000s (Dey et al. 2005; Dey 2008; Gordon and Pulis 2011; Weeratunge et al. 2011; Brooks and Phillips 2012; Henriksson et al. 2017; Tran et al. 2017; Rodriguez et al. 2018; Rodriguez et al. 2019). It also recently developed a similar but simpler model for Zambia (Trans et al. 2019). The Malawi fish model borrows key features from both tools to account for challenges in the availability of data and parameter estimates in the country.

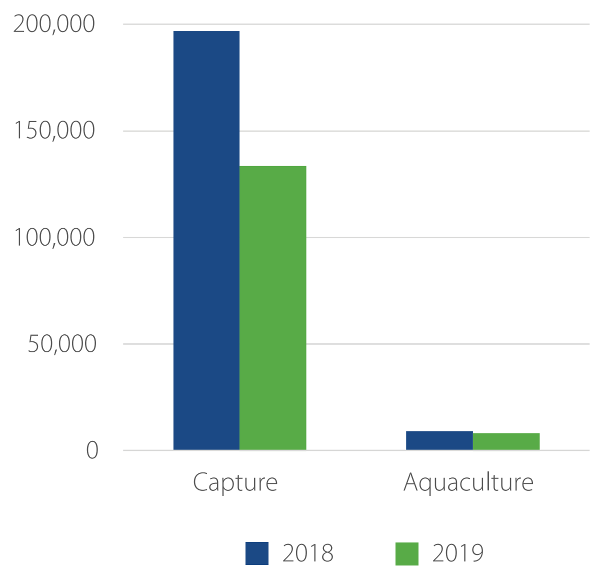
This paper seeks to contribute to the planning process with the development of a multimarket fish model for Malawi. Combining elements of supply and demand, the model can illustrate the impacts of an event or shock within the sector on different species or groups of fish and on the industry. The tool is also able to evaluate how changes outside of fishing affect the sector. The model presented in this paper generates aggregated and disaggregated results for the quantities and prices of fish production, consumption, imports and exports. Solving the model forward in time under various assumptions also facilitates the development of alternative future scenarios for the country.

2.2. Model structure

The model is composed of different fish groups. These could be a species of fish or a collection of species. Domestic production of a fish group could be destined for domestic and foreign (exports) markets. Household consumption, which may be sourced from local or foreign (imports) producers of fish, represents demand. Figure 11 summarizes the sources and uses of a fish group in the model. An important assumption in the model is the treatment of Malawi as a small open economy. This means that the country has no influence on the world prices of commodities. Applied to the model, this assumes that import and export prices of fish are taken as given.

The model is divided into four blocks: production, consumption, trade and equilibrium. The production block recognizes that the domestic production of a fish group could come from multiple environments or sources. Each environment or source could also use its own set





Source: FAO 2021, 2022.

Figure 12. Fish production by species (left) and by source (right), 2018 and 2019.

of production inputs and technology. For example, tilapia may be caught in the wild (capture fisheries) or raised in farms (aquaculture). In addition, the inputs used in raising tilapia on farms are not necessarily the same as those used to capture wild fish. The Malawi fish model, like AsiaFish, incorporates this assumption by allowing multiple equations for production for a specific fish group.

The production side of the model specifies that the domestic price and the prices of inputs determine the output/harvest of fish from environment *k*. Output is assumed to be non-negatively related to its price and non-positively related to input prices. Following Briones (2010), the Malawi fish model adopts a fixed elasticity specification to relate the prices to fish output.[1] The sum of production over its different environments determines the total production of fish group *f*. Equations 1 to 3 of Appendix 1 describe the production block.

Fish consumption is treated as a multistage process. Stage 1 determines per capita fish expenditures. It specifies a fixed elasticity formulation where per capita expenditures for all fish are non-positively related to average fish prices and non-negatively to income. While inspired by the specification of the AsiaFish model, the specification of the Malawi fish model is simpler because of constraints on data and available parameters.[2] Stage 2 identifies the per capita expenditures for specific fish groups. It follows Tran et al. (2019), who specify that per capita expenditures on fish group *f* are influenced by the consumer price of fish group *f*, average consumer prices of all fish and per capita expenditures on all fish. National expenditures of fish group *f* are determined by taking the product of the population and per capita fish consumption in stage 2. The ratio of national expenditures on fish group *f* and the consumer price of fish group *f* provides an estimate of the quantity of fish group *f* that is consumed by all households in the country. Equations 4 to 8 of Appendix 1 describe the consumption block.

Following the practice in the AsiaFish model and in many computable general equilibrium models, consumption of local and foreign (imports) variants of fish are determined through an optimization processes. To be more specific, it supposes that domestic agents try to find the combination of domestically produced and imported fish that minimizes the cost of acquiring the quantity of fish that is determined in the consumption block. The process also assumes that the consumption of fish group *f* is a constant elasticity of substitution composite of its local and foreign (imports) variants. The optimization process generates demand equations for domestic and foreign (imports) variants of fish group *f*. It states that the domestic demand for the domestic variant of fish group *f* is a function of its price, the average price of domestic and foreign variants, and the consumption of fish group *f*. In contrast, domestic demand for the imported variant of fish group *f* depends on the import price of fish group *f*, the average price of domestic and foreign variants, and the consumption of fish group *f*. Along with formulations for the calculation of average prices and situations where a fish group is not imported, equations 9 to 11 in Appendix 1 describe the relationships discussed.

Domestic production of fish could be destined for local and foreign (export) markets. Borrowing an optimization process implemented for the AsiaFish model (Dey et al. 2005; Dey 2008) equations 12 and 13 in Appendix 1 describe the following: for each fish group, the ratio of fish destined for foreign (export) and domestic markets is influenced by the ratio of prices of the fish group in foreign and domestic markets; a higher relative price in foreign markets raises the ratio of exports to fish sold in domestic markets. The other equation in this block describes the calculation of average prices.

The final block of the model determines the equilibrium price of the domestically produced fish in local markets. Equation 14 in Appendix 1 implements this by equating the quantity of fish production and imports to the sum of fish consumption and exports.

2.3. Data, parameters and solving the model

The model requires data for its endogenous variables, exogenous variables and equation coefficients. In the case of fish, the model needs disaggregated information on the quantities and prices for consumption, production, exports and imports. Data requirements also include prices for inputs used in fish production, income, exchange rate and population.

Item	Sardinesa	Utaka	Tilapia	Other fish	Total
Quantity (t)					
Production: Capture	156,717	19,136	9058	11,840	196,751
Production: Aquaculture	0	0	8544	470	9014
Imports	117	0	403	2971	3491
Exports	0	0	0	60	60
Consumption	156,834	19,136	18,005	15,221	209,196
Value (USD 1000)					
Production: Capture	203,598	24,860	39,515	44,312	312,285
Production: Aquaculture	0	0	37,272	1759	39,031
Imports	152	0	830	3341	4323
Exports	0	0	0	183	183
Consumption	203,750	24,860	77,617	49,229	355,456
Value (MWK)					
Production: Capture	149,101	18,206	28,938	32,451	228,696
Production: Aquaculture	0	0	27,296	1288	28,584
Imports	111	0	608	2447	3166
Exports	0	0	0	134	134
Consumption	149,212	18,206	56,841	36,052	260,311

Source: FAO 2020a, 2020c, 2021 and 2022; WB and OECD 2022.

[a] Lake Malawi sardines or usipa

Table 1. Fish balance sheet, 2018.[a]

Given the available information, a dataset for the model was assembled for 2018 (Table 1). The dataset also identifies four fish groups: Lake Malawi sardines (usipa), utaka, tilapia and other fish. The explicit treatment of the first three fish groups was motivated by their relative importance in total fish production. For example, Table 1 suggests that sardines account for 79.6% of total fish production. Utaka and tilapia have shares of 9.7% and 4.6%, respectively. Combined, these three fish groups accounted for 93.9% of total fish production in 2018. Three points about the dataset are worth noting. The first is that tilapia combines the production/harvest of Mozambique tilapia, redbreast tilapia, and other subspecies that were not explicitly specified in FAO FishStat. Second, the fish group called "other fish" is a collection of species that are produced, exported, imported or consumed in Malawi that are not classified as sardines, utaka or tilapia. Its values are calculated to ensure that the sum of the four fish groups matches the total for the country. Fourth, the totals in Table 1 deviate from those that the Food and Agriculture Organization (FAO) provided because seaweeds and ornamental fish were excluded.

The quantities of fish production, exports and imports were obtained from FishStatJ (FAO 2022). Except for production from capture fisheries, prices were determined by dividing the values obtained from FishStatJ with the corresponding quantities. The resulting prices were then converted into domestic currency using exchange rates provided by the World Development Indicators (WDIs) of the World Bank (WB and OECD 2022).

In the absence of data from FAO, domestic prices of capture fisheries were generated as follows. For tilapia and other fish, prices in aquaculture were used as proxies for their counterparts in capture fisheries. As Lake Malawi sardines, or utaka and usipa, are not reported to be produced in aquaculture and are not exported, their prices were assumed to be the same as imported sardines. The sources of other model information are as follows: the WDIs provided data on income (represented by per capita GDP) and population, while prices of labor, fish feeds and fuel were obtained from local sources in Malawi.

In an ideal world, detailed data would be collected and used to estimate the parameters of the model. However, as this was not possible in the current modeling effort, elasticities and other parameters were borrowed from related studies in Malawi or other countries. Appendix 2 lists the key parameter assumptions of the model.

As with AsiaFish and other models, several coefficients were calibrated to replicate the 2018 dataset. This involves adjusting the scale and intercept parameters so that the solution of the model in 2018 is equivalent to the information provided in Table 1. As 2019 production data is also available, model parameters were also calibrated so that model solutions for 2019 are as close as possible to the actual data. The calibration process and all model solutions were implemented using the General Algebraic Modeling System (GAMS) software.

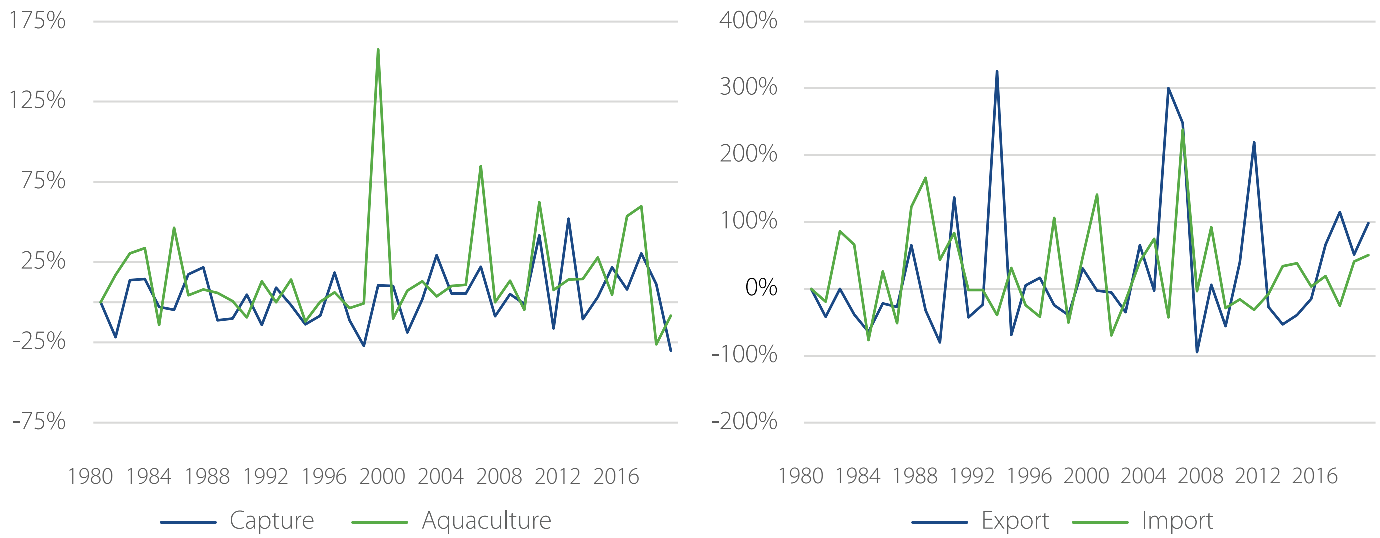
It is important to note that fish production in 2019 contracted sharply. Data from FishStatJ (FAO 2022) (Figure 12) suggests that the output of capture fisheries was 32% and aquaculture 8.3%, lower in 2019 compared to 2018. This led to a fall in total fish production from 205,765 t in 2018 to 142,127 t in 2019. Within capture fisheries, large declines were observed for the distinct model fish groups: sardines (37%), utaka (29.5%) and tilapia (19.7%). In aquaculture, tilapia production fell 9.4%. Fish species outside of the three distinct fish groups in the model collectively experienced an increase in output between 2018 and 2019. However, these increases were not sufficient to overcome the declines of sadines, utake and tilapia.

2.4. Baseline and alternative scenario analysis

Baseline scenario: Business as usual (BAU)
As noted in section 4.1, the model will be used to examine future scenarios for Malawi's fish sector. Developing future scenarios requires specifying a trajectory for the values of exogenous variables and parameters and then solving the model forward in time. Assumptions may be based on historical trends or educated guesses on the future values of these variables and parameters.

An integral part of scenario building exercises is developing a baseline that can serve as a point of comparison for all other alternative settings. This task was challenging because Malawi's fish sector exhibited substantial variability over the past two decades. This is shown in Figure 13 by the growth rates of selected variables in the fish sector. The variability is not limited to the sector. Data from the World Bank also shows significant fluctuations in the macroeconomy from 2001 to 2020.

Given the observed variabilities, key exogenous variables were assumed to grow at the same rates as in 2019 to 2020 (Table 2). Export and import prices of fish and the prices of inputs in production were assumed to grow at the same rate as the consumer price index. The growth rate of per capita GDP in nominal terms implies a 0.6% average annual growth of its counterpart in real terms.



Source: FAO 2020a, 2021, 2022.

Figure 13. Growth rates of key variables in the fish sector (%).

Productivity parameters were also adjusted so that the outputs of capture fisheries and aquaculture in the baseline scenario grow at average annual rates of 3% and 13%, respectively, from 2020 to 2040. This trajectory roughly captures production patterns over the past 30 years. These projections are also conservative compared to trends in the past 10 and 20 years, where the average annual growth was at least 5% for capture fisheries and 14% for aquaculture.[3] In most of the scenarios, the model's productivity parameters were adjusted to simulate the intended outcomes. The only exception is AS3, where it was the growth of real per capita GDP that was adjusted.

AS1: Stagnation of capture fisheries
In this alternative scenario (AS1), the aggregate outputs of capture fisheries from 2023 to 2040 remain at their 2022 level. It is designed to mirror the current trends in fisheries worldwide, which have remained relatively constant since the 1990s (FAO 2020b).The limited growth in capture fishery output has been attributed to the status of global fishstocks being predominantly maximally sustainably fished (FAO 2020b). Although this trend has not yet been seen in Malawi, as capture fish production has been steadily increasing since the early 2000s, it is likely that capture fish yields will soon level off in the country. The reason for this is that although total yields have been increasing, these increases can be almost entirely attributed to small pelagic species, which are more recently fished species (FAO 2021). Yields of more traditionally fished species such as tilapia declined until the early 2000s, after which they remained relatively constant. Fishing smaller, low trophic level fish is termed "fishing down the food web" and could contribute to stagnation or even decline in capture fish production in the future (Pauly et al. 1979).

AS2: Decline of capture fisheries
This scenario is similar to AS1, but the impacts are more severe. Rather than output remaining at its 2022 levels, the total harvest from capture fisheries will decline from 2023 onward. To be more specific, this setting assumes that capture fisheries production contracts at an average of 1% per year from 2020 to 2040. This is a possibility given overexploitation of many fish species and the fishing down the food web phenomenon described in the previous section. In addition to these effects, environmental threats from climate change and anthropogenic threats such as eutrophication could exacerbate any damage to the fisheries and lead to declining yields.

AS3: Faster economic growth
This scenario assumes that real per capita GDP will grow one percentage point faster than the baseline from 2023 to 2040. Designed to simulate faster growth of incomes, this can be the outcome of successful policies and/or favorable events that stimulate economic activity in the Malawi economy.

AS4: Faster growth of aquaculture
This setting assumes that aquaculture production grows faster than the baseline from 2023 onward. More specifically, it assumes that fish production from the sector (Makwinja et al. 2021) grows at an average of 15% per year from 2020 to 2040. This is two percentage points faster than its growth rate in the baseline. It represents favorable outcomes of improved policies and practices and/or higher investments in the sector.

AS5: Rapid growth of aquaculture.
This alternative scenario is similar to AS4. However, it assumes that the adjustments are far more successful and cause aquaculture output to grow 18% per year from 2020 to 2040.

Variable	Annual growth rate (%)
Population	2.7%
Nominal GDP per capita	9.4%
Real GDP per capita	0.6%
Prices of imported fish, fish exports and inputs to fish production	9.0%

Source: WB and OECD 2022.

Table 2. Assumed annual growth rates of variables in the baseline scenario.

3. Projection results

3.1. Baseline scenario projection

Table 3 summarizes selected results for the baseline scenario of the model. It suggests the following patterns for the fish sector of Malawi to the year 2040. First, total fish production is expected to grow at close to 4.6% annually from 2020 to 2040. This growth rate suggests that fish production in 2040 is expected to be 378,263.1 t, or about 1.8 times its level in 2018. Second, per capita fish consumption is projected to rise about 1.9% per year between 2020 and 2040. By 2040, an individual in Malawi is expected to be consuming an average of 12 kg of fish per year. Third, while rising at relatively high rates over the projection period, international trade in fish will continue to play a small role in the country. On the one hand, exports of fish in 2040 (266.8 t) are still expected to be less than 1% of total production for the same year. On the other hand, fish imports in 2040 (11,904 t) are projected to be about 3.1% of fish consumption.

Disaggregated projections suggest significant changes in future fish production (Table 4). Designed to grow at slightly over 13% per year, aquaculture production is projected to reach 121,617 t in 2040 or over 13 times its level in 2018. Despite this, capture fisheries will continue to be the main source of fish. However, its share in total production is expected to shrink from 95.6% in 2018 to 67.8% by 2040. Shifts in the sources of fish are also reflected in the production of the different fish

	2018	2025	2030	2040	Change (%/year)
Production	205,765	172,517	210,891	378,263	4.6
Imports (t)	3491	4535	5499	11,904	5.2
Consumption (t)	209,196	176,635	215,328	389,900	4.6
Exports (t)	60	417.8	1061	266	6.6
Annual per capita fish consumption (kg)	11.5	8.1	8.6	12	1.9

Table 3. Baseline projections for key fish aggregates.

Variable	2018	2025	2030	2040	Change (%/year)
By source:					
Capture	196,751	155,545	179,307	256,646	3%
Aquaculture	9014	16,973	31,584	121,617	13%
By fish group:					
Sardines	156,717	118,194	137,978	190,837	3%
Tilapia	17,602	24,818	40,367	130,318	10%
Utaka	19,136	16,153	18,803	25,728	3%
Other	12,310	13,352	13,744	31,380	3%

Table 4. Baseline production by fish group and production source.

groups. The production of Lake Malawi sardines is expected to be about 190,836.6 t by 2040. Growing at about 3.1% per year from 2020 to 2040, this is only about a third of the growth rate for tilapia over the same period. As a result, the share of Lake Malawi sardines is expected to contract from about three-quarters of total production in 2018 to only about half of the total in 2040. In contrast, tilapia is projected to become a more important fish group. Accounting for less than a tenth of total fish output in 2018, tilapia's contribution is projected to reach about a third of the total by 2040.[4]

3.2. Alternative scenario projections

Table 5 provides comparative results for the alternative scenarios in the year 2040. With its output remaining at 2022 levels, the production of capture fisheries in 2040 in AS1 is expected to be about 43.9% lower than its baseline value in the same year. Combined with a relatively small decline in aquaculture output (1.8%), this leads to a total fish production in 2040 that is 30.4% lower than its baseline estimates of 378,263 t. The stagnation of capture fisheries is an adverse supply shock that leads to consumer prices of fish in 2040 that are, on the average, 12% higher than the baseline. This is detrimental to stakeholders in two other ways. First, higher prices make fish produced in Malawi less competitive in world markets. Along with the sharp decline in production, this explains the lower exports (54.3%) compared to the baseline. Second, higher fish prices also make the commodity more expensive for the average local consumer. This is the main culprit for the lower per capita fish consumption in AS1. This decline is sharper than it appears. The 30.1% in 2040 is equivalent to an annual per capita fish consumption of 8.4 kg in AS1. Appealing to earlier results in Table 3, this is in the range of solutions for fish consumption in the baseline from 2025 to 2030. In other words, not only is fish consumption in AS2 lower than the baseline in 2040, but it is also lower than baseline fish consumption of 10 to 15 years earlier. Compared to the baseline, fish imports in 2040 are 21.3% lower in AS1. As higher domestic fish prices make fish from other countries more attractive to local consumers, this result underscores the strength of the relatively significant decline in domestic fish consumption.

The decline in capture fisheries (AS2) represents a more serious impact of the factors that caused the stagnation of the sector (AS1). This explains why the impacts for AS2 in Table 5 are, in absolute terms, larger than in AS1. However, a result worthy of note is that the decline in capture fisheries in AS2 is strong enough that this ceases to be the main source of fish in 2040. Compared to the baseline, the output of capture fisheries in 2040 is expected to be 58.2% lower with AS2. This translates to about 107,305 t, which is lower than the estimated 118,596 t from aquaculture in this scenario for 2040.

The higher growth of per capita GDP (AS3) is expected to stimulate the demand for fish. In Table 5, this is reflected in per capita fish consumption in 2040 being about 2.2% higher than the baseline scenario. Higher demand tends to raise fish prices, making total fish production in 2040 about 3.4% higher than the baseline. The impacts on output are more substantial in aquaculture because of the assumption that production in this sector is more price-sensitive than capture fisheries. Higher consumer prices of fish (3.4%) explain why exports in AS3 are lower than the baseline. In contrast, higher per capita fish consumption is the reason for higher fish imports.

Faster growth of aquaculture in AS4 causes production from the sector in 2040 to be about 47.1% higher than the baseline. Given the relatively small impacts on capture fisheries, total fish production is also expected to be higher. The increase in fish supply explains the decline in the consumer price of fish. Combined with higher production, lower domestic fish prices favor exports. Higher fish consumption, arising from lower fish prices, also explains the expansion of fish imports. As AS5 provides a more favorable outlook than AS4, the impacts in this scenario shown in Table 5 are stronger in absolute value. However, it is worth noting that the output of aquaculture in this scenario is 315,190 t (159.2% higher than the baseline value of 121,617 t). This impact makes farmed fish overtake capture fish as the main source of the commodity in 2040.

Variable		Percentage deviation from baseline				
	Baseline[a]	AS1	AS2	AS3	AS4	AS5
Domestic production						
Capture	256,646	-43.9	-58.2	1.8	0.1	0.7
Sardines[b]	190,837	-43.6	-57.4	1.8	0.8	2.5
Utaka	25,728	-43.7	-57.4	1.8	0.8	2.5
Tilapia	12,858	-49.7	-64.1	1.7	-6.9	-15.9
Other	27,224	-43.6	-61.7	2.4	-1.5	-5.5
Aquaculture	121,617	-1.8	-2.5	2.7	47.1	159.2
Tilapia	117,461	-2.5	-3.6	2.7	46	154.1
Other	4156	17.1	29.4	3.8	78.8	302.4
Total	378,263	-30.4	-40.3	2.1	15.2	51.7
Trade						
Exports	267	-54.3	-71.2	-5.5	15.1	64.8
Imports	11,904	-21.3	-30	6.6	9	30.4
Consumption per capita	12	-30.1	-39.9	2.2	15	51
Consumer price	2166	12	17.1	3.4	-3.3	-10.2

[a] *The levels of production, exports and imports are in metric tons. Per capita fish consumption is in kilograms while consumer prices are in MWK per kilogram.*

[b] *Lake Malawi sardines or usipa.*

Table 5. Results of alternative scenarios, 2040.

4. Conclusion and recommendations

4.1. Policy recommendations

It is clear from the study that the production of capture fisheries has almost plateaued at 200,000 t annually and is unlikely to go up given various challenges the fisheries face. To meet the fish supply demand, the country will therefore depend mainly on aquaculture and fish imports. Aquaculture is preferred to fish imports, as it aligns with the country's Vision 2063 for, among other things, creating jobs, diversifying the economy and strengthening commodity value chains. Fish imports, on the other hand, will be exporting jobs to countries exporting fish to Malawi. In fact, if well developed, aquaculture could allow Malawi to export excess fish and earn revenues in foreign currency.

To minimize the likelihood of a decline in capture fishery production, extensive fishery management addressing factors inhibiting the sector's sustainability and performance is needed. Particular attention should be paid to policies aiming to limit fishing down the food web, which has the potential to drastically decrease capture fishery yields (Pauly et al. 1979; Makwinja et al. 2021). Policy interventions should not only be limited to regulating gear targeting smaller species or setting closed seasons but should also address the socioeconomic factors causing fishers to continually overexploit the resource to maintain their livelihoods (Makwinja et al. 2021). While current fish sector policies implement direct fishing regulations, such as protected areas, gear limitations and size limits, a more holistic fishery policy incorporating indirect threats to productivity from industrialization, climate change and population growth is recommended (Jamu et al. 2011). In addition, the involvement of fishers in the design of fishery regulations and increased enforcement of said regulations could decrease instances of non-compliance, which threaten the sustainability of Malawi's freshwater resources (Jamu et al. 2011).

The scenarios modeling the impacts of increased growth in the aquaculture sector provide more favorable results in all indicators than the BAU scenario. Aquaculture has the potential to increase per capita fish consumption, decrease prices and increase exports, all while reducing the reliance on wild-caught fish. Aside from post-harvest losses, infrastructure limitations and improper species for aquaculture, three main constraints inhibit growth in Malawi's aquaculture sector: (1) limited quality feed/seed, (2) lack of affordable financing and (3) inefficient extension support services. To expand aquaculture in Malawi, these problems need to be addressed. Policy interventions that could be effective at increasing the availability of feed/seed include decreasing the import tax on imported feed levied by the government and incentivizing feed producers in Malawi to produce the more efficient floating feed. Other interventions include establishing fish feed standards and/or certifications to limit the persistence of low-quality feed in the market (Mwema et al. 2021) and exploring alternative feed materials, such as insect meal (Mulumpwa 2018). More specifically, the government of Malawi could take the following steps to stimulate aquaculture growth:

1. Strengthen extension support services

To enhance the production and productivity of aquaculture, there is a need to improve the deployment of extension services in the subsector, especially among smallholder farmers. Continued dependence on the public sector for extension services will continue to exacerbate the situation because of resource constraints that public agencies continue to face. A mix of delivery approaches facilitated by (among others) the private sector, research-based organizations, civil society organizations and farmer-to-farmer support services will help bridge the gap in delivering these critical services. However, the government, through the Department of Fisheries, should coordinate the deployment of these services to create a uniformed approach and quality control on technologies disseminated to farmers. The objectives of the extension services should focus on, among others, the following: facilitating technology transfer, linking farmers to input and output markets, providing access to finance and other support services, building entrepreneurial capacity, and strengthening the AAH program and biosecurity.

2. Create enabling conditions to attract additional investment in the subsector

To further improve the productivity and production of the subsector, additional investment is required. To achieve this, the government should create appropriate incentives that will facilitate the mobilization of domestic investments and attract foreign direct investments in the subsector. Innovative financing will be key to growing the aquaculture industry. In the domestic market, there is a need to increase awareness of the industry among local financing institutions to stimulate their interest to provide tailormade financial products for the industry. We argue that investment should be directed to the missing link—small to medium entrepreneurs (SMEs)—to stimulate growth of the subsector, as SMEs are critical to strengthening market links and the deployment of extension services. Experience elsewhere has shown that to grow SMEs, the government, working with its partners, should create business incubation platforms. Investments are urgently required in the production of high-quality aquafeeds and fingerlings.

3. Strengthen its Aquatic Animal Health program

The recent outbreaks of epizootic ulcerative syndrome place fisheries and aquaculture under renewed risk of aquatic animal diseases, which can limit aquaculture production. Additionally, the AAH program will enhance the promotion of food safety and facilitate the international trade of fish and fish-based products. It is therefore important to strengthen the country's AAH program to protect the sustainability of the aquaculture industry. Specific attention should be given to enhancing the monitoring and surveillance of aquatic animal diseases as an early warning system for disease response preparedness. To achieve this, the government should invest in training veterinarians and other animal health professionals in the AAH program and the development of key infrastructure for the program.

4. Enhance product quality assurance

As the country endeavors to grow its aquaculture industry, there is a need to invest in product quality assurance at two levels. First is the quality assurance and certification of fingerling and aquafeed production through the Hatchery Quality Assurance and Aqua Feed Producers Certification Program. This will enhance the sustainable production and supply of high-quality fingerlings and aquafeeds. Second is a quality certification program for commercial processors of fish and fish-based products. Product certification will enhance product credibility in trade, especially international trade, of fish and fish-based-products. Since fish is a perishable product, continuous reassurance of the market of the safety of the products is therefore necessary.

4.2. Concluding remarks

This paper explored alternative scenarios for fish supply and demand in Malawi to the year 2040. The tool used was a multimarket model that is in the same vein, though much simpler, as the AsiaFish model. Following historical trends, this paper depicts a baseline scenario where capture fisheries grow at a substantially slower pace than aquaculture. However, fish from the wild is expected to remain the main source of fish for the country in the future. The increases in production are expected to generate rather conservative increases in per capita fish consumption over the simulation period. International trade in fish is projected to grow faster than production and consumption in the baseline. However, local consumption will still come mostly from fish produced or harvested in the country.

This paper explored five alternative scenarios. The first two dealt with the possible negative impacts on the output of capture fisheries of poor fishing practices and management of fishing resources, as well as other events such as climate change. The simulation results showed that, apart from the expected decline in fish production, such events are likely to raise domestic fish prices. This, among others, contributes to the negative impacts on consumption and international trade in fish. The third scenario focused on the impact of faster growth of per capita real GDP. The results highlight the favorable implications of successful macroeconomic policies and management on the fishing industry. More specifically, the simulation results suggest that such events lead to higher fish consumption and production. The last pair of alternative scenarios focus on the possible favorable outcomes of sustainable and successful policies and practices, and/or higher investments in aquaculture. The simulation results show that apart from the expected increase in aquaculture and total production, such events also tend to make fish more affordable to the population. The natural outcome is an increase in per capita fish consumption.

The modeling exercise was very challenging. Reliable detailed data on some crucial variables was unavailable. This was especially the case for prices of fish captured in the wild and variables critical to incorporating processed fish. Perhaps influenced by the dearth of data is the lack of studies that can provide demand, supply and trade elasticities that are useful to the model. The multimarket model development for Malawi's fish sector is clearly in its infancy. However, while hampered by severe data limitations, the current effort at least helps identify important variables that must be consistently collected with an acceptable level of precision in order to improve inputs to model building and quantitative analysis in particular, and policy and decision-making in the sector in general.

Breeding program in Zomba, Malawi.

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Notes

[1] The multimarket model of Briones (2010) was developed for the analysis of Philippine agriculture. It uses the fixed elasticity formulation for non-crops, including fisheries.

[2] Fish expenditures are actually determined in the second stage of the AsiaFish model. It specifies that fish expenditures are a function of average fish prices, average prices of non-fish food products and food expenditures. Food expenditures are determined in the first stage and are influenced by income, food prices and non-food prices. The current formulation integrates the two stages into one and effectively drops the influence of non-fish food prices and non-food prices.

[3] Data from FAO indicates that capture fisheries output rose from 70,554 t in 1989 to 154,992 t in 2019. In the case of aquaculture, the rise was from 217 t in 1989 to 8262 t in 2019.

[4] While it may be asserted that other fish will also become more important in 2040, it must be remembered that this is a collection of many fish species that are not classified as tilapia, usipa or Lake Malawi sardines.

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Appendix 1. Model equations

Sets

Set name	Definition	Relations
F	Fish groups/species	$F = FM \cup FMN$ $F = FX \cup FXN$
FM	Fish groups, imported	$FM \subset F$
FMN	Fish groups, not imported	$FMN \subset F$
FX	Fish groups, exported	$FX \subset F$
FXN	Fish groups, not exported	$FXN \subset F$
G	Fish inputs	
K	Fish production categories or environments	

Equations

Production block

(1) Production of fish group f from source k

$$QA_{fk} = \lambda_{fk} \cdot \prod_j PFG_j^{\phi_{1,jfk}} \prod_g pi_g^{\phi_{2,gfk}}$$

$$f, j \in F; \; k \in K; \; g \in G$$

(2) Production of fish group f from all sources

$$QS_f = \sum_k QA_{fk}$$

$$f \in F; \; k \in K$$

(3) Farmgate price of fish group f

$$PH_f = (1 + mard_f) \cdot PFG_f$$

$$f \in F$$

Consumption block

(4) Per capita expenditures on all fish (Stage 1)

$$ET = \Omega \cdot y^{\zeta_1} \cdot PF^{\zeta_2}$$

(5) Per capita expenditures on fish group f (Stage 2)

$$E_f = \eta_f^{\sigma} \cdot PC_f^{1-\sigma} \cdot \left(\frac{ET}{PF}\right)$$

$$f \in F$$

(6) Per capita consumption of fish group *f*

$$QCP_f = \frac{E_f}{PC_f}$$

$f \in F$

(7) Total consumption of fish group *f*

$$QC_f = pop \cdot QCP_f$$

$f \in F$

(8) Average price of fish

$$PF = \frac{\sum_f PC_f \cdot QC_f}{\sum_f QC_f}$$

$f \in F$

International trade in fish

(9) Domestic demand for domestically produced fish (Stage 3)

$$F \in FM: \quad QH_f = \delta_{1m,f} \cdot \left(\frac{PH_f}{PC_f}\right)^{-\sigma_{m,f}} \cdot QC_f$$

or

$$F \in FMN: \quad QH_f = QC_f$$

(10) Domestic demand for imported fish (Stage 3)

$$F \in FM: \quad QM_f = \delta_{2m,f} \cdot \left(\frac{PM_f}{PC_f}\right)^{-\sigma_{m,f}} \cdot QC_f$$

or

$$F \in FMN: \quad QM_f = 0$$

(11) Composite price of fish group *f*

$$PC_f = \frac{PH_f \cdot QH_f + PM_f \cdot QM_f}{QC_f}$$

$f \in F$

(12) Domestically produced fish destined for foreign markets

$$F \in FX: \quad \frac{QX_f}{QH_f} = \delta x_f \cdot \left(\frac{PX_f}{PH_f}\right)^{\sigma x_1}$$

or

$$F \in FXN: \quad QX_f = 0$$

(13) Composite price of the export-domestic aggregate

$$PARX_f = \frac{PH_f \cdot QH_f + PX_f \cdot QX_f}{QS_f}$$

$f \in F$

Equilibrium condition

(14) Total supply of fish equals total demand for fish

$$QS_f + QM_f = QC_f + QX_f$$

$$f \in F$$

Endogenous variables

Symbol	Description
QA_{fk}	Production of fish group *f* in source *k*
QS_f	Production of fish group *f* from all sources
PFG_f	Farmgate price of fish group *f*
ET	Per capita expenditures on all fish
E_f	Per capita expenditures on fish group *f*
QCP_f	Per capita consumption of fish group *f*
QC_f	National consumption of fish group *f*
QH_f	Domestically produced fish destined for the domestic market
QM_f	Imports of fish group *f*
PF	Average price of fish
PC_f	Consumer price of fish group *f*
QX_f	Exports of fish group *f*
$PARX$	Price of domestic-export composite for fish group *f*
PH_f	Price of domestically produced fish that is sold in the domestic market.

EXOGENOUS VARIABLES

Symbol	Description
pi_g	Price of input *g*
$mard_f$	Price margin for fish group *f*
y	Per capita income
pop	Population of the country
PM_f	Price of imports of fish group *f*
PX_f	Export price of fish group *f*

Coefficients

Symbol	Description
$\delta_{1m,f}$	Shifter in the demand for domestically sourced fish for fish group *f*
$\delta_{2m,f}$	Shifter in the demand for imported fish for fish group *f*
$\delta_{x,f}$	Shifter in the domestic supply of fish group *f* that is destined for export markets
η_f	Share parameter of fish group *f* in the CES function
$\phi_{1,jfk}$	Elasticity of the output of fish group *f* in category/source *k* with respect to the price of fish group *j*
$\phi_{2,gfk}$	Elasticity of the output of fish group *f* in category or source *k* with respect to changes in the price of input *g*
λ_{fk}	Shifter in the production of fish group *f* in category or source *k*
Ω	Shifter in the per capita consumption of fish
σ	Elasticity of substitution among expenditures on different fish groups
$\sigma_{m,f}$	Elasticity of substitution between domestically and imported variants of fish group *f*
$\sigma_{x,f}$	Elasticity of transformation between the supply of fish group *f* that is destined for domestic and foreign markets
ζ_1	Elasticity of fish expenditures to changes in income
ζ_2	Elasticity of fish expenditures to changes in the average price of fish

Appendix 2. Parameter assumptions

Symbol [a]	Value(s)	Remarks
$\phi_{1,jfk}$	0.5 and 0.8	Aquaculture = 0.8; Capture = 0.5 Based on estimates used in the AsiaFish model for Bangladesh (Rodriguez 2016) and Ghana (Gordon and Pulis 2011)
$\phi_{2,gfk}$	-0.05	Based on estimates used in the AsiaFish model for Bangladesh (Rodriguez 2016)
σ	2.224	Based on estimates used by Tran et al. (2019) for Zambia
$\sigma_{m,f}$	1.10	Based on the elasticity for fish in a CGE model of Malawi that was used by Lofgren et al. (2001)
$\sigma_{x,f}$	1.50	Based on the elasticity for fish in a CGE model of Malawi that was used by Lofgren et al. (2001)
ζ_1	0.83	Based on estimates used by Tran et al. (2019) for Zambia
ζ_2	-0.25	Based on estimates used in the AsiaFish model for Ghana by Gordon and Pulis (2011)

[a] Appendix 1 provides definitions of the coefficients.

WorldFish CGIAR

About WorldFish

WorldFish is an international, not-for-profit research organization that works to reduce hunger and poverty by improving aquatic food systems, including fisheries and aquaculture. It collaborates with numerous international, regional and national partners to deliver transformational impacts to millions of people who depend on fish for food, nutrition and income in the developing world.

The WorldFish headquarters is in Penang, Malaysia, with regional offices across Africa, Asia and the Pacific. The organization is a member of CGIAR, the world's largest research partnership for a food secure future dedicated to reducing poverty, enhancing food and nutrition security and improving natural resources.

For more information, please visit www.worldfishcenter.org