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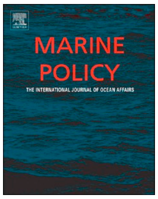

Fish supply and demand for food security in Sub-Saharan Africa: An analysis of the Zambian fish sector

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ABSTRACT

The demand for fish in Sub-Saharan Africa, as driven by the trend of diet-shift to fish, economic and demographic growth, outstrips supply. The resulting fish deficit is drawing attention of policy makers as it poses threats to economic stability as well as food security in the region. In this paper, a multi-species, multi-sector equilibrium model is developed and applied to Zambia as a case study to provide a tool for policy makers to examine the interaction between fish supply and demand. Projection results show that under business-as-usual scenario, the fish deficit in Zambia will increase and fish import will be a key contributor of fish for consumption in 2030. Increasing import tax will not solve the fish deficit due to a limited substitution between domestic and imported fish, while this tariff restriction may increase the fish price and affect poor people. The model results suggest that further investment in aquaculture could provide a solution if input markets for seed and feed are appropriately developed. Though calibrated to Zambia's fish sector, the model can be applied to analyze the outlook of fish sectors in other developing countries.

1. Introduction

Fish is a critical source of animal protein, mineral, and micronutrient supplies in Africa where more than 200 million people are reported to eat fish regularly [1]. There are about 20 African countries where fish accounts for more than 20% of animal protein supplies [2]. Similar to other continents, Africa has recently experienced a diet transformation toward increasing demand for animal source products such as meat and fish [3,4]. Growth in fish consumption was high (at 25–50%) between 2007 and 2015 in most countries in Sub-Saharan Africa (SSA) [5]. As observed in other regions, the trend of increasing demand for fish in Africa is driven by population and income growth, and increasing appreciation of health benefits of fish consumption [6]. Changes in lifestyles and consumer preferences associated with rapid urbanization and globalization are also reported to be positively correlated with increasing fish consumption.

Despite the increasing demand for fish, fish production growth in capture fisheries and aquaculture in Africa has been slow [7–9]. Capture fisheries, particularly inland capture fisheries represent the most important source of fish supply in many countries in SSA. Nonetheless overfishing, lack of effective fisheries management, and water and land-use change have caused many fisheries in Africa to decline or stagnate. Key drivers negatively affecting inland capture fisheries in Africa include hydropower developments, deforestation, mining, introduction of invasive species and environmentally damaging fishing gear [10–12]. At the same time, inland fisheries statistics are recognized as failing to capture the productivity and values of the sector [13], and require improvement. Besides capture fisheries, aquaculture has a long history in SSA. For many decades, however, government and donor interventions focused almost exclusively on the promotion of small-scale aquaculture for improving household food and nutrition security at household level. The success and sustainability of these interventions has remained marginal, due to heavy subsidies whilst disregarding the importance of enabling environments and infrastructure to improve access to inputs, extension services, and markets [14–17].

Current trends in fish production, consumption and trade suggest that fish is among the most traded food commodities and fish trade is playing an increasingly important role to improve the welfare of local and global

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Abbreviation: BAU, business-as-usual; SADC, Southern African Development Community; SSA, Sub-Saharan Africa; GDP, gross domestic product

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fish food systems for developed and developing countries [18]. The developing countries tend to export high –value seafood to developed markets, while retaining and importing lower-value seafood products to achieve food security goals [19]. In quantity terms, fish imports by African countries have surged sharply in recent years and if current production, consumption and trade trends continue, 50% of fish for human consumption in Africa is projected to be met by imported fish products by 2050 [7]. Africa has become China's second most important tilapia export market after the United States [20]. The increasing demand for fish in Africa has also created opportunities for re-inventing African aquaculture development. Recently, there is evidence that aquaculture growth in Africa has speeded up [8]. A number of countries in SSA such as in Ghana, Kenya, Nigeria, South Africa, Uganda, and Zambia have experienced rapid growth in commercial aquaculture as a market /demand response [21–23]. These emergent trends in aquaculture development have contributed largely to the seven-fold increase in aquaculture production in Sub-Saharan Africa during the last decade, with an average annual growth rate of 21% [24].

The ongoing transformations in fish supply, and its impacts on fish availability, ultimately affect the contribution of fish to food and nutrition security in SSA. Hence, much of the future development will depend on policy and decision makers to provide guidance on how to sustainably valorize existing and emergent opportunities in aquaculture and fisheries and thus to improve the supply of fish to a growing population. Under this development context, there are substantial policy questions that need to be addressed: 1) how do capture fisheries and aquaculture production systems in African countries respond to the increasing fish demand in the future, taking into account complex interactions of domestic supply, demand, and international seafood trade? 2) What are the potential impacts of new market driven aquaculture development on African food and nutrition security? 3) Under what circumstances can capture fisheries be sustained or declined? This understanding is critical to provide policy recommendations for sustaining future fish supply and for exploring sustainable aquaculture and fisheries development options in Africa.

The objective of this study was to provide a future picture of the fish sector in Zambia by projecting the dynamics of fish supply and demand, and draw policy implications that can be of interest for policy makers in Zambia and other countries in SSA at a comparable stage of development. Zambia has recently experienced a growing demand for fish, which is largely triggered by the growing population and an emergent urban middle class within Zambia and also neighboring countries. To satisfy the demand, a supply response in aquaculture has been observed whereby medium to large scale farms have started to upgrade operations and successfully managed to increase aquaculture output [22]. In 2014, Zambia has become the sixth largest producer of farmed fish (mainly breams – a local name for tilapia) in Africa and the largest in the in the Southern African Development Community (SADC). Whilst the small-scale aquaculture sector faced a 27% drop in production between 2011 (4060 t) and 2014 (2954 t), the commercial sector grew at an annual growth rate of 11.6% from 1500 t (1996) to 13,600 t (2014) and now accounts for the largest contribution (71%) to the overall estimated aquaculture production in the country. Aquaculture contribution to the total fish supply has increased from 5% in 1995 to 20% in 2014 [25].

By 2014, the main source of fish supply for Zambian consumption is inland capture fisheries (80,000 t and accounted for 50% of fish supply in 2014), but capture outputs are stagnant and started to show signs of severe overfishing [12]. A sudden and sharp increase in Zambian fish supply has been largely contributed by fish imports, which have grown 14-fold between 2004 and 2014 (55,200 t). In total, fish supply in 2014 accounted for approximately 158,000 t of fish. Hence Zambia's per capita fish supply was estimated at 11 kg per capita per year for 2014, compared to 6.8 kg in 2011. If without fish imports, the per capita supply would drop by 3.9 kg.

Although the per capita fish supply rates are relatively low compared to the global average of 20 kg per capita per year [26], fish accounts for over 20% of animal protein supplies particularly for low-income Zambian families [27] is a crucial source for vitamins and micronutrients [28]. According to Zambian government statistics, the prevalence of stunting among young is reported over 40% [29]. Securing fish supply and increasing fish consumption in Zambia is hence expected to stimulate positive health and development outcomes, particularly the marginalized and vulnerable population.

2. Material and methods

There are a number of models developed to produce fish supply and demand projections at the country level (e.g., AsiaFish model [30–32]) and the global level (e.g., IMPACT fish model [7,8,33]). Calibrating these models requires a large number of behavior parameters, including how outputs and inputs in each production category respond to output and input prices, and also how each component in the demand for each species varies with income and prices. Most of these parameters must be estimated from real-life data using econometric techniques [30] which is difficult in many developing countries, but particularly those in SSA. For instance, our literature review shows that data about the fish sector of Zambia (the country used for our empirical analysis) is often rough, of poor quality, or exhibits inconsistencies if verified from different sources. Information about basic behavioural parameters (e.g., how consumers and producers respond to changes in price) is scant or not available.

To overcome this challenge, our approach was to minimize the data and parameters required for calibration while maintaining the key objective of the model, i.e., being able to analyze the fish supply-demand interaction and evaluate policy impacts on the Zambian fish sector. To do so, the analysis was limited to main fish species groups and production types, collected the best reliable information, and then adjusted the modelling specification to fit with what is available. Collaboration with the Department of Fisheries, Ministry of Fisheries and Livestock of Zambia to collect and compare data from various sources to eliminate inconsistencies is essential. As a result, consistent data for year 2014 were obtained which covers five key fish species, each of which can possibly be produced with three types of aquaculture, or naturally caught in five fishing sites in Zambia. This data will be described later in this section. More disaggregated or longer data series was not available or unreliable.

Our empirical model in this paper is built to best fit with the reliable data in 2014, which is used as the base year, and other available information. Following the earlier frameworks of Dey et al. [30] and Rosegrant et al. [34], a multi-market equilibrium feature was formalized to reflect the interaction of supply and demand on all related markets. However, instead of using the dual modelling approach, our model uses the primal approach for production and consumption sectors which is less data and parameter demanding. In particular, the model derives the Marshallian demand function of a utility maximization problem, which does not rely on a long series of data to estimate the demand as required in the dual approach, though at a cost of reduced flexibility. Furthermore, the primal approach can help overcome the shortcoming of the dual approach which often uses a linearized estimate of the demand function, and so it may not be pertinent to non-linear and (long-horizon) dynamic models [35,36]. The production function was also specified for each fish species group with each production method to derive how fish producers respond to changes via optimising the input quantities. With this approach, the need for borrowing parameters from literature - where most of them were not estimated for Zambia - was minimized.

2.1. Data

The production data for year 2014 are presented in Table 1. They cover five fish groups which are referred to by their local names, i.e., breams (Tilapia; *Oreochromis* spp.), kapenta (*Limnothrissa miodon* and *Stolothrissa tanganicae*), catfish (*Clarias* spp.), buka (*Luciolates* spp.) and other fish. Throughout this paper, we use a five-element set to refer to

Table 1
Production data by production category, production types and species in 2014.

Category	Production	Species	Output			Input				
			Quantity supplied (t)	Revenue (1000USD)	Price (USD/t)	Seed cost (1000USD)	Feed cost (1000USD)	Labor cost (1000USD)	Fuel cost (1000USD)	Capital (1000USD)
Aquaculture	Land-based	Breams	9840	24,600	2500	2353	3030	1004	1087	17,126
	Water-based	Breams	3807	9518	2500	585	968	13	421	7531
	Small-scale	Breams	2954	7385	2500	847	1092	362	392	4693
		Catfish	1697	5312	3130	588	758	251	282	3432
		Other fish	983	2794	2842	309	399	132	148	1805
Capture fisheries	Tanganyika	Breams	3336	8340	2500	–	–	493	4169	3678
		Kapenta	1991	5973	3000	–	–	353	2986	2634
		Catfish	289	905	3130	–	–	53	452	399
		Buka	8130	23,723	2918	–	–	1401	11,859	10,463
		Other fish	61	173	2842	–	–	10	87	76
	Bangweulu	Breams	10,433	26,083	2500	–	–	2089	8449	15,545
		Catfish	796	2491	3130	–	–	277	807	1408
		Other fish	4103	11,661	2842	–	–	2549	3777	5335
	Kariba	Breams	2791	6978	2500	–	–	1282	1032	4663
		Kapenta	6490	19,470	3000	–	–	3578	2881	13,011
		Catfish	167	523	3130	–	–	96	77	349
		Other fish	1143	3248	2842	–	–	597	481	2171
	Mweru-Luapula	Breams	4672	11,680	2500	–	–	1094	3783	6803
		Catfish	3544	11,093	3130	–	–	1441	3593	6059
		Other fish	7321	20,806	2842	–	–	5319	6740	8748
	Other locations	Breams	12,512	31,280	2500	–	–	1685	10,132	19,463
		Catfish	2298	7193	3130	–	–	265	2330	4598
		Other fish	10,751	30,554	2842	–	–	2250	9897	18,407

the fish groups, i.e., $S = \{Breams, Kapenta, Catfish, Buka, Other\ fish\}$.

There are two production techniques, namely aquaculture and (wild) catch. Aquaculture is further classified into three types, i.e., land-based commercial, water-based commercial, and small-scale production. Wild catch includes five fishing sites, namely Tanganyika, Bangweulu, Kariba, Mweru, and other locations. There are eight production categories in total, and we use an eight-element set to refer to the production categories, i.e., $PC = \{land, water, small, Tanganyika, Bangweulu, Kariba, Mwere, Other\ locations\}$. The first three elements are aquaculture types, and the last five elements are wild-catch.

There are 40 combinations of the categories and the fish species groups. Each of the 40 combinations is termed a *'sector'*. Not all sectors are active, or in other words, not all species groups are produced in all production categories. In fact, there are only 23 active sectors (Table 1 has 23 data rows). To distinguish active and non-active sectors, 40 binary variables $w(PC, S)$ were used, one for each sector, to indicate whether the sector is active (value 1) or inactive (value 0).

The production sectors may use different sets of inputs. For example, the aquaculture sectors use five types of inputs namely seed, feed, labor, fuel, and sector-specific inputs (e.g., investment in expertise or facility). Wild-catch sectors only use labor, fuel and sector-specific inputs. Thus, the data for seed and feed in the wild-catch sectors are zero.

Table 2 shows the fish consumption, export and import for year 2014, one row for each of the five species groups. Fish consumers can consume domestically produced or imported products. Domestic products can also be consumed locally or exported. Data in Tables 1 and 2 have been cross-checked to ensure consistencies, i.e., the sum of domestic production and import equals to the sum of consumption and export.

2.2. Model specification

2.2.1. Production and production inputs

As described in Section 2.1, there are 40 production sectors, but only 23 are active, and the 17 sectors are inactive. The outputs of inactive sectors are zero, and this is formalized in Eq. (1) where $q_t^P(PC, S)$ is the output of each species in each production category at time t.

$$q_t^P(PC, S) = 0 \text{ if } w(PC, S) = 0 \tag{1}$$

For declaring inputs, a four-element set $CI = \{Seed, Feed, Labor, Fuel\}$ was denoted for the inputs and $x_t^{CI}(PC, S, CI)$ for the quantity of each input used in each sector at time t. These quantities are zero if the inputs are not used, or if the sector is not active. The input demands of active sector are presented in Eq. (2). From here when a full description of set has been defined, the shortcut (.) for compactness was used, unless when purposely avoiding possible confusions.

$$x_t^{CI}(.) = q_t^P(.)A_t^{CI}(.) \tag{2}$$

where $A_t^{CI}(.) = A_{BaseYear}^{CI}\left(\frac{1}{1+g_{A^{CI}}(PC, S, CI)}\right)^t$ is the required quantities of each input to produce one unit of output (or equivalently, the inverse productivity coefficients of the inputs) at time t; $g_{A^{CI}}(.)$ represents the annual rate of technological progress, i.e., less inputs required to produce 1 unit of output. Please note that the specification in Eq. (2) allows

Table 2
Zambia fish consumption and international trade in 2014.

	Consumption of domestic fish		Import		Export	
	Quantity (ton)	Retail price (USD/t)	Quantity (t)	Import-tax-inclusive price (USD/t)	Quantity (t)	Tax-inclusive price (USD)
Breams	50,327	3250	40,000	4063	18	2250
Kapenta	8481	4500	0	5625	0	0
Catfish	8791	4069	5184	5086	0	0
Buka	8130	3793	0	4742	0	0
Other fish	24,244	3695	10,000	4618	118	0

different rates of technological progress across the inputs. Here calculating the input demands via the levels of inputs required to produce one unit of output assumes the inputs, e.g., seed, feed, and labor, are to be used in certain proportions [37]. This assumption is widely used in multi-market economic modelling such as the global GTAP model [38] and the national ORANI model [39] because it reflects a realistic fact that in highly specialized sectors input substitutability (e.g., between labor and seed or between fuel and feed) is not always possible.

2.2.2. *Fish consumption sector*

To model the consumption sector, i.e., demand for fish, a double-layer structure for a representative consumer was used in this study. The double-layer structure has been used intensively to model consumer demands which can be met by domestic and imported supplies. Here consumers decide the quantity of each good in order to maximize the utility with a certain budget, e.g., how much to spend on each species and then within each species how much to spend on domestic and imported products [30]. Both layers can be modelled using the Armington preference [40] which allows for a certain level of substitutability, e.g., when a product becomes more expensive, the consumer will substitute it with similar products. The two-layer optimization for the consumer decision is presented in Eqs. (3) and (4).

$$\max_{e_t^{Com}(S)} \left[\sum_S A^{Com}(S) e_t^{Com}(S)^{1-\frac{1}{\sigma^{Com}}} \right]^{\frac{\sigma^{Com}}{1-\sigma^{Com}}} \quad \text{s.t.} \ \sum_S e_t^{Com}(.) = y_t \tag{3}$$

where $e_t^{Com}(.)$ is a 5-element vector of the spending on each species (both domestic and imported if any) at time t; $y_t = y_{BaseYear}(1 + g_y)^t$ is the total spending on fish of each population unit at time t, which grows at an annual rate g_y; σ^{Com} is a scalar constant-elasticity-of-substitution (CES); $A^{Com}(.)$ is the vector of coefficients which can, without the loss of generality, be normalized such that $\sum_S A^{Com}(.) = 1$.

$$\max_{Q_t^{Dom}(S), Q_t^{\mathrm{Im}}(S)} = \begin{bmatrix} A^{Dom}(S) Q_t^{Dom}(S)^{1-\frac{1}{\sigma(S)}} \\ + A^{Im}(S) Q_t^{\mathrm{Im}}(S)^{1-\frac{1}{\sigma(S)}} \end{bmatrix}^{\frac{\sigma(S)}{1-\sigma(S)}} \quad \text{s.t.} \ p_t^{Dom}(.) Q_t^{Dom}(.) + p_t^{\mathrm{Im}}(.) Q_t^{\mathrm{Im}}(.) = e^{Com}(.) \tag{4}$$

where $Q_t^{Dom}(.)$ and $Q_t^{\mathrm{Im}}(.)$ are the consumption quantities of domestic and imported fish by a representative consumer respectively; $\sigma(.)$ is a vector of 5 CES coefficients, one for each species group; $A^{Dom}(.)$ and $A^{Im}(.)$ are vectors of coefficients which can, without the loss of generality, be normalized such that $A^{Dom}(.) + A^{Im}(.) = 1$.

Solving the optimization in Eqs. (3) and (4) is a straightforward calculus exercise though a little lengthy. The quantity demanded for domestically produced and imported fish by a representative consumer can be derived as in Eqs. (5) and (6):

$$Q_t^{Dom}(.) = \frac{e^{Com}(.) \left(\frac{A^{Dom}(.)}{p_t^{Dom}(.)} \right)^{\sigma(.)}}{p_t^{Dom}(.) \left(\frac{A^{Dom}(.)}{p_t^{Dom}(.)} \right)^{\sigma(.)} + p_t^{\mathrm{Im}}(.) \left(\frac{A^{\mathrm{Im}}(.)}{p_t^{\mathrm{Im}}(.)} \right)^{\sigma(.)}} \tag{5}$$

$$Q_t^{\mathrm{Im}}(.) = \frac{e^{Com}(.) \left(\frac{A^{\mathrm{Im}}(.)}{p_t^{\mathrm{Im}}(.)} \right)^{\sigma(.)}}{p_t^{Dom}(.) \left(\frac{A^{Dom}(.)}{p_t^{Dom}(.)} \right)^{\sigma(.)} + p_t^{\mathrm{Im}}(.) \left(\frac{A^{\mathrm{Im}}(.)}{p_t^{\mathrm{Im}}(.)} \right)^{\sigma(.)}} \tag{6}$$

where $e_t^{Com}(S) = y_t \dfrac{p_t^{Com}(S) \left(\frac{A^{Com}(S)}{p_t^{Com}(S)} \right)^{\sigma^{Com}}}{\sum_S p_t^{Com}(S) \left(\frac{A^{Com}(S)}{p_t^{Com}(S)} \right)^{\sigma^{Com}}}$ with

$$p_t^{Com}(S) = \begin{bmatrix} p_t^{Dom}(.) \left(\frac{A^{Dom}(.)}{p_t^{Dom}(.)} \right)^{\sigma(.)} \\ + p_t^{\mathrm{Im}}(.) \left(\frac{A^{\mathrm{Im}}(.)}{p_t^{\mathrm{Im}}(.)} \right)^{\sigma(.)} \end{bmatrix}^{\frac{1}{1-\sigma(.)}}$$

The market demand for the domestic and imported fish, $q_t^{Dom}(S)$ and $q_t^{\mathrm{Im}}(S)$, can be formalized as in Eqs. (7) and (8).

$$q_t^{Dom}(.) = N_t Q_t^{Dom}(.) \tag{7}$$

$$q_t^{\mathrm{Im}}(.) = N_t Q_t^{\mathrm{Im}}(.) \tag{8}$$

where $N_t = N_{BaseYear}(1 + g_n)^t$ is the population at time t which grows at an annual rate of g_n.

2.2.3. *Fish export*

The demand for fish export is specified with a constant elasticity function as in Eq. (9):

$$q_t^{Exp}(S) = Z_t^{Exp}(S) \times p_t^{Exp}(S)^{\varepsilon^{Exp}(S)} \tag{9}$$

where $q_t^{Exp}(.)$ is the export quantity of the species (if any) at time t; $\varepsilon^{Exp}(.) \leq 0$ is the elasticity coefficients for export demand showing how export quantity respond to price; and $Z_t^{Exp}(.)$ is price-shift coefficients.

2.2.4. *Fish price formation*

Products (of any species) from all operative sectors are assumed to be homogeneous, so they have the same price. Denote $p_t^P(S)$ as the farm-gate prices at time t, $p_t^{CI}(PC, S, CI)$ as the prices of the common inputs, $\Pi_t(PC, S)$ is the surplus (or profit) of each active sector, the price formation equation can be determined in Eq. (10).

$$p_t^P(.) = \Pi_t(PC, S) + \sum_{CI} p_t^{CI}(.) x_t^{CI}(.) \quad \text{for all element in } PC \text{ whenever } w(PC, S) = 1 \tag{10}$$

The consumer price of domestic fish equals the farm gate price plus retail margin and sales tax (if any) as presented in Eq. (11).

$$p_t^{Dom}(S) = p_t^P(S)(1 + M_t^{Dom}(S))(1 + T_t^{Dom}(S)) \tag{11}$$

where $p_t^{Dom}(.)$ is the market price of the domestic fish; $M_t^{Dom}(.)$ and $T_t^{Dom}(.)$ are the domestic margin and sale-tax rates.

The consumer price of imported fish equals the CIF imported price plus import tax (if any) as presented in Eq. (12).

$$p_t^{Im}(.) = p_t^{CIF}(S)(1 + T_t^{Im}(S)) \tag{12}$$

where $p_t^{Im}(.)$ is the market price of imported fish; $p_t^{CIF}(.)$ is the CIF price; and $T_t^{Im}(.)$ is the rate of import tax.

The export price of fish equals the farm gate price plus export margin and export tax (if any) as presented in Eq. (13).

$$p_t^{Exp}(.) = p_t^P(.)((1 + M_t^{Exp}(S))(1 + T_t^{Exp}(S)) \tag{13}$$

where $M_t^{Exp}(S)$ and $T_t^{Exp}(S)$ are the export margin and export-tax rates.

2.2.5. Equilibrium conditions

Fish market equilibrium conditions require the total (domestic) supply from all production categories be equal to the consumption demand for domestic fish plus export as in Eq. (14).

$$\sum_{PC} q_t^P(PC, S) = q_t^{Dom}(S) + q_t^{Exp}(S) \tag{14}$$

where $q_t^P(.) = q_{BaseYear}^P(.) \prod_{i=1}^t (1 + g_i^Q(.))$ with $q_{BaseYear}^P(.)$ being the supply quantity at the base year, and $g_t^Q(.)$ being the growth rate of the supply at year *i*. Please note that the specification of Eq. (14) allows the annual growth rate of input supply (i.e. annual expansion rate of a production sector) to vary inter-annually. This flexibility helps control for the situation that the Zambian government might use the expansion growth rate for fishery sectors as a time-varying policy parameter to intervene the equilibrium fish market.

2.3. Model calibration

The calibration of our multi-market equilibrium follows the process described by Dawkins et al. [41]. Specifically, the productivity coefficients in Eq. (1) and the two-layer preference structure in Eqs. (4) and (5) are calibrated by combining the data in Tables 1 and 2 with modeler-specified behavioural parameters. The number of the behavior parameters has been reduced due to the specific functional forms, and there are only five types of parameters that need to be specified. They are the elasticity of export demand (ε^{Exp}), the elasticity-of-substitution for layer 1 and layer 2 in the consumption preference (σ^{Com} and σ), and the elasticity of supply for the common and sector-specific inputs (ε^{CI} and ε^{SI}).

The export elasticity was specified to be $\varepsilon^{Exp}(.) = -0.6$, which implies that if the price increases by 1%, the export quantity will reduce by 0.6% [42]. It is also specified that $\sigma = 1.5$ for the CES coefficient for layer 1 (substitutability between domestic and imported products), which similar to the estimate for agricultural products in South Africa, including fish, by Gibson [43] and comparable to the estimate of other countries, e.g. the Philippines [44]. Tune for the CES coefficient for layer $\sigma^{Com} = 2.224$, based on a specific estimate of price elasticity of kapenta in Zambia [45]. The elasticity of labor supply is set to be infinity, implying that the real wage is exogenous, consistent with the high unemployment rate in Zambia – always above 10% [46] and the fact with the fish sector accounts for only 1% in Zambia's GDP [27]. The elasticity of fuel supply is also set to be infinity given the fact Zambia is a small economy and must be a price taker in the world energy market. The elasticity of feed, seed and sector-specific inputs will vary across scenarios and will be described in the analysis.

To calibrate the dynamics of the fish demand over the projection period until 2030, the annual dynamics of population and of per-capita income as well as the elasticity of fish consumption to income are incorporated into the model. It is assumed that Zambia population will increase by 2.81% a year ($g_n = 0.0281$), the average demographic growth rate over 2000–2014 period [46]. Meanwhile, the average GDP growth rate of Zambia was 6.76% implying per-capita income growth of 3.95% a year, so we use this number to calibrate the growth of per-capital income in our model. The elasticity of fish consumption to income is specified to be 0.834 [45] implying that when the income increases by 1%, fish consumption will increase by 0.834% ceteris paribus. This number is comparable to the estimate for Africa [47], and that gives $g_y = 0.0395 + 0.01 = 0.0495$

3. Scenarios

Based on data and information collected from various sources, published literature and stakeholder consultations, 2014 was chosen as the base year, and the model generates annual projections to 2030. The business-as-usual scenario (BAU) was defined such that all aquaculture outputs grow at 6.76% per year which is the same as the gross domestic product (GDP) growth rate; the output capture fisheries output was set as stagnant with zero growth rate over the projection period. On the demand side, the income and population growth rates were assumed at 6.76% and 2.81% to 2030, respectively.

Alternative scenarios to be assessed with the model were selected via a stakeholder consultation process combined with an expert information approach [48]. Two participatory workshops were conducted in Lusaka in 2016 to explore future fish supply and demand scenarios in Zambia. These alternative scenarios are summarized as below.

The first scenario, optimistic GDP growth (*HiGDP*) assumes gross domestic product (GDP) grows at 9.76% per year, 3% higher than that in the BAU scenario, *ceteris paribus*. The objective of this scenario is to understand how fish consumption, trade and prices respond to increasing domestic income, and what the implications are for consumers.

The second scenario, slower GDP growth *(LowGDP)* hypothesizes that GDP grows at only 3.76% per year to 2030 and population growth and supply targets remain the same as those in the BAU scenario. This scenario simulates impacts of weaker macro-economic performance on fish demand, imports and prices.

The third scenario, named as stronger fish import regulation (HiTAX), is to evaluate the impact of import tariffs. Tariff is a first-line instrument to control trade deficit which has been used widely in trade policies, and it is also available for the Zambian government to apply this instrument toward the objective of curbing the fish deficit. This scenario assumes that the Zambian government increases fish import tariffs by 50% to regulate fish imports, whilst the other assumptions remain the same as those assumed in the BAU scenario.

The fourth scenario, faster commercial aquaculture growth (*HiAQUA*) postulates that commercial private sectors increase their investments in the aquaculture sector so that land based and water based commercial aquaculture grows at 15% per year. Other assumptions remain as those in the BAU scenario.

The fifth scenario, capture fisheries output growth at 1.5% (*HiCAP*) involves successful capture fisheries enhancement implemented by the government as well as fisheries development and conservation communities so that capture fisheries output can increase 1.5% per year to 2030. Other assumptions remain as those hypothesized in the BAU scenario. This scenario is motivated by the fact that capture fisheries play an essential role in food security in Zambia and SSA and that fisheries development interventions can led to improvements in fisheries outputs and related ecological, social and economic performance indicators [49].

4. Results

4.1. Business-as-usual (BAU)

Findings of the Zambian fish supply and demand modelling projections show that under the BAU scenario, fish demand in Zambia is

Table 3
Projected growth rate for different scenarios between 2014 and 2030 in Zambia.

Average annual growth rate (%)	BAU	HiGDP	LowGDP	HiTAX	HiAQUA	HiCAP
Total fish	1.9	1.9	1.9	1.9	5.2	2.9
Capture fisheries	0.0	0.0	0.0	0.0	0.0	1.5
Aquaculture	6.8	6.8	6.8	6.8	13.4	6.8
Per capita fish consumption	1.6	3.4	0.0	0.8	3.0	1.9
Fish imports	7.4	10.6	4.2	5.9	6.9	7.2
Fish exports	− 1.9	− 2.8	− 1.0	− 2.0	− 1.4	− 1.5
Retail price						
Breams	3.0	5.0	0.9	3.2	− 0.4	2.3
Kapenta	3.8	5.5	2.1	4.2	3.2	2.9
Catfish	3.5	5.5	1.4	3.7	2.7	2.7
Buka	3.8	5.5	2.1	4.2	3.2	2.9
Other fish	4.1	6.1	2.1	4.4	3.4	3.1

Table 4
Fish production, consumption, trade and prices in 2014 and 2030 in Zambia.

Item	2014	2030					
		BAU	HiGDP	LowGDP	HiTAX	HiAQUA	HiCAP
Total fish (t)	100,109	135,740	135,740	135,740	135,740	224,577	157,481
Capture fisheries (t)	80,828	80,828	80,828	80,828	80,828	80,828	102,570
Aquaculture (t)	19,281	54,912	54,912	54,912	54,912	143,749	54,912
Per capita fish consumption (kg/person/year)	10.4	13.3	17.7	10.4	11.8	16.5	13.9
Fish imports (t)	55,184	173,900	277,288	106,901	138,855	160,740	167,067
Fish exports (t)	136	100	86	117	98	109	107
Retail prices (USD/t)							
Breams	3250	5181	7096	3733	5342	3066	4679
Kapenta	4500	8202	10,590	6257	8689	7405	7109
Catfish	4069	7012	9528	5093	7258	6210	6208
Buka	3793	6914	8927	5274	7324	6242	5993
Other fish	3695	7054	9497	5171	7332	6270	6053

projected to be strong to 2030. With aquaculture production growth rate following GDP growth rate at 6.76% per year (Table 3), aquaculture production is projected to increase from 19,300 t in 2014–54,900 t in 2030 (Table 4); breams fish price will rise at 3.0% per year and fish imports will also continue to increase from 55,200 t to 173,900 t in 2030 (projected to increase at 7.4% per year on average). As presented in Table 4, per capita fish consumption is projected to rise from 10.4 kg in 2014 to 13.3 kg in 2030 (projected increase at 1.6% per year on average). Under the BAU scenario, fish imports are projected to be the main contributor of fish for consumption in Zambia by 2030.

4.2. Optimistic GDP growth (HiGDP)

Under optimistic GDP growth scenario (HiGDP), where GDP growth rate was assumed at 9.76% and other assumptions remained as in the BAU scenario, per capita fish consumption is projected to grow at 3.40% per year (Table 3), increasing from 10.4 kg per capita per year in 2014 to 17.7 kg per capita in 2030 (Table 4). Fish prices (e.g., breams) are projected to increase at 5% per year to 2030. Stronger fish demand in the HiGDP scenario compared to the BAU scenario will trigger higher import demand for fish, which is projected to grow at 10.6% per year (projected imports increase from 55,200 t in 2014 to 277,300 t in 2030).

4.3. Slower GDP growth (LowGDP)

Under the slower GDP growth (*LowGDP)* scenario, per capita fish consumption is projected to remain the same from 2014 to 2030, at 10.4 kg. Due to lower fish demand, fish prices are projected to grow at 0.9% per year, which is lower than that in the BAU. Fish imports are projected to increase at 4.2% per year so that projected import volume increases from 55,200 t to 106,900 t. Under this scenario, domestic fish production from capture fisheries and aquaculture (137,500 t) is projected to remain the main contributor to fish consumption in the country by 2030.

4.4. Stronger fish import regulation (HiTAX)

With stronger fish import tax (assumed 50% increase in import tax), per capita fish consumption is projected to increase at a lower rate compared to that of the BAU scenario, at of 0.8% per year from 2014 to 2030. Consequently per capita fish consumption increases from 10.4 kg in 2014 to 11.8 kg in 2030. With higher import tax, fish import is projected to increase at a slower rate (5.9% per year to 2030) compared to the BAU scenario (7.4%). Fish import volume is projected to increase from 55,200 t in 2014 to 138,900 t in 2030. Fish prices are projected to increase higher than those projected in the BAU scenario (Table 3). With other assumptions remaining as in the BAU scenario, imposing higher fish import tax triggers higher consumer fish prices and a slowdown in the per capita fish consumption growth rate compared to the BAU scenario.

4.5. Faster commercial aquaculture growth (HiAQUA)

With assumptions of stronger growth rate of 15% per year for land based and cage based commercial aquaculture sectors, aquaculture output is projected to increase from 19,300 t in 2014 to 143,700 t in 2030 (Table 4). Per capita fish consumption is projected to grow at 3% per year, increasing from 10.4 kg in 2014 to 16.5 kg in 2030. Fish imports are projected to grow at a slower rate of 6.9% compared to that in the BAU scenario (7.4%). Consumer price of breams (tilapia) is projected to decline at 0.4% per year and prices of other fish groups are also projected to grow at slower rates compared to those in the BAU scenario over the projection period (Table 3). Under this scenario, consumers enjoy lower fish prices. However, producers will be forced to improve production efficiency (e.g., technological innovations in seed production, feed production and aquaculture management practices and value chain alignment) in order to be competitive in domestic markets.

4.6. Capture fisheries output growth at 1.5% (HiCAP)

The last scenario is a case where capture fisheries output is assumed to grow at 1.5% per year due to improved capture fisheries management. Capture fisheries is projected to grow from 80,800 t in 2014 to 102,600 t in 2030. Aquaculture production remain as assumed in the BAU scenario which grow from 19,200 t in 2014 to 54,900 t in 2030. Under this scenario, per capita fish consumption is projected to increase at 1.86% per year (increase from 10.4 kg in 2014 to 13.3 kg in 2030) which is higher than that projected in the BAU scenario. Fish import is projected to increase from 55,200 t in 2014 to 167,100 t in 2030, growing at a slower rate compared to that projected in the BAU scenario (7.17% versus 7.44). Domestic fish prices are projected to increase at slower rates compared to those projected in the BAU scenario. Results from the HiCAP scenario highlight that in addition to supporting sustainable aquaculture development, sustaining capture fisheries is also important for nutrition and food security of the Zambian people.

5. Discussion

Modelling fish supply, demand and trade at the country level is instrumental in understanding of structural changes such as technology innovation and policy reform in fisheries and aquaculture sectors as well as the implications of development interventions and shocks on fish food and nutrition security. The Zambia fish sector model that developed is an analytical tool for exploring how future fish supply and demand trends in Zambia might unfold, and how these trends might influence fish consumption, trade and prices as well as the implications on the poor and vulnerable consumers. Such analysis is important for developing interventional options for sustaining fish supply in Zambia (capture fisheries, aquaculture and fish import) and other countries in SSA. Our model is a complimentary approach to the fish sector model (AsiaFish) developed by Dey et al. [30,31].

Our modelling analysis confirms that demand for fish in Zambia will continue to increase, driven by population growth, income growth and diet transformation towards consuming more animal based protein. Given that capture fisheries is considered more or less stagnant, aquaculture is projected to remain the main source of domestic fish supply growth in Zambia. Over the projection period from 2014 to 2030, aquaculture production can reach 55,000 t in 2030 under the BAU scenario (with an annual projected growth rate of 6.76%). Given that aquaculture starts from a low base (20,000 t in 2014), domestic fish supply in Zambia continues to depend on capture fisheries which causes a substantial fish deficit that is projected to be fulfilled by increasing fish imports. By 2030, fish import is projected to reach 173,900 t (Table 4) and become the main source of fish for consumption in Zambia if capture fisheries remains stagnant and aquaculture experiences a moderate growth rate of 6–7%. Future of fish demand in Zambia is strongly connected to population and domestic economic growth, and also developments in international seafood trade markets. In a pessimistic economic growth scenario, it is projected that there is modest increase in per capita fish consumption over the projection period, with Zambia remaining significantly below global norms for fish consumption.

Our hypothetical scenarios show the importance of sustaining fish supply for food and nutrition security within the Zambian population. This can be realized via interventions to enhance capture fisheries, facilitate fish imports and notably promote sustainable aquaculture development in Zambia. Given that wild capture fisheries remain the dominant supplier of fish for consumption in Zambia, a small increase in wild catch output as we demonstrated in the HiCAP scenario (wild capture fish increases 1.5% per year) will have positive impacts on per capita fish consumption and moderate the effect of fish price increases. As capture fisheries provides direct food to poor and vulnerable populations in the country and with an estimate of 25,000 artisanal fishers and 30,000 others participate in fish processing and trading in Zambia [50], interventions to improve fisheries management and governance will help address food security and rural poverty in Zambia.

Increasing fish imports have raised concerns and debates on fish trade policy in Zambia, nonetheless our analysis shows the importance of fish imports to the country, especially the price of fish, and thus access to poor and vulnerable consumers. An increase in fish import tax is projected to reduce fish imports and induce an increase in consumer fish prices, and consequently slowdown the growth of per capita fish consumption. Reviewing historical trends, Kaminski et al. [22] show that over the period 2004–2014, Zambia fish imports have grown 14 times (with an average increase of 30.5% per year) and played an important role in increasing fish supply and moderating the effects of fish price increases.

Rapidly increasing demand for fish products in Zambia creates diverse opportunities for investments in aquaculture value chains that can help producers and traders become more competitive and also improve consumer welfare by enjoying higher fish supply for consumption [23]. Our analysis shows that rapid aquaculture growth can moderate the effects of increasing fish price on consumers due to income and population growth, similar to other studies [51]. This effect might impose downward price pressure on domestic fish producers in Zambia for improving production efficiency to stay in business. Combining with the effects of increasing fish imports, domestic fish producers particularly, small scale aquaculture farmers will face higher competition. Under this production environment, commercial large-scale producers can produce cheaper (output increases, the cost of producing each unit goes down) and tolerate risks associated with declining prices). Increasing efficiency and productivity to lower costs per production unit is a must. Slumping small scale aquaculture development in the past suggests that sustained investments by the private sector is critical to enable innovation, productivity growth and reduced production costs. Public interventions in the form of stimulating public and private partnerships are essential to create a sound enable environment for domestic producers particularly small holders while addressing food security and undernutrition issues prioritized by the government [28].

The multi-market, multi-species, dynamic model developed in this study can be applied to other developing countries where fish supply-demand data are lacking, particularly those in SSA where fish supply and demand projections are urgently needed to inform fisheries and aquaculture planning and priority setting. The proposed primal modelling approach requires a minimal amount of data by specifying the production technology and consumer preference. The dual approach which relies on estimating parameters from data is more flexible, but it will be difficult if time-series data are not available or not enough for estimating behavioural parameters [52]. In many developing countries, data availability and reliability pose an obstacle to economic modelling efforts; so, when modellers do not want to borrow too many parameters from other countries because their applicability is much more limited outside of the specific context where they are estimated, the model developed for the Zambian fish sector analysis could be a feasible approach.

6. Conclusion

Fish supply and demand scenario analysis presented in this paper suggests that demand for fish in Zambia is likely to increase steadily, signalled by projected increase in fish prices to 2030. While wild capture fisheries presently remain the dominant supplier, aquaculture and fish import are projected to play more important roles in sustaining fish supply to meet increasing demand to 2030. Increasing import tax to stimulate domestic aquaculture investment cannot solve fish deficit but can cause inflation (increasing fish prices). Depending on wild-catch will result the fish consumers vulnerable to fish supply. Investing in aquaculture development and improving capture fisheries management could be solutions for improving food and nutrition security in Zambia. The fish sector model developed for the Zambia presented in this study could be a feasible approach for analysing fish supply and demand scenarios for drawing fish food and nutrition security implications in developing countries particularly those in SSA.

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Conflict of interest

None.

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