ROMA TRE
UNIVERSITÀ DEGLI STUDI

Dottorato in Economia e Metodi Quantitativi
XXIX CICLO

Tesi di dottorato

IMPACT EVALUATION OF AQUACULTURE DEVELOPMENT ON FOOD SECURITY: A GLOBAL ASSESSMENT

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Abstract

This research deals with the impact of aquaculture development on food security. The added value of the analysis is to evaluate the impact of aquaculture development on the outcomes of food security instead of its determinants, and to perform a global assessment across developing countries. The results of this research show that the set of selected aquaculture indicators has an impact on an important outcome of food security, the prevalence of undernourishment. In developing countries, aquaculture, whether developed through or without government interventions, can be addressed as one of the phenomena that may have contributed to the improvement of food security.

JEL Codes: Q22, O11, C23

Keywords: aquaculture, food security, global assessment, impact evaluation, panel data

Introduction

«Food security exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life» (FAO, 2009). Food security is a multifaceted concept composed by four dimensions: availability, access, utilisation and stability. Since a standalone indicator is not suitable to capture the dimensional complexity of food security, the Food and Agriculture Organization of the United Nations (FAO), the International Fund for Agricultural Development (IFAD) and the World Food Programme (WFP) have formulated a set of indicators for this purpose (FAO, et al., 2013). The proposed indicators measure two different and consequential aspects of food security, its determinants and outcomes. Determinant indicators address all the structural conditions that may cause food insecurity, whereas outcome indicators identify and measure the results of food insecurity in terms of inadequate food intake, anthropometric failures, or poor health (Akinyoade, et al., 2014). Therefore, while the determinant indicators could be considered a guide to elaborate adequate policy interventions, the outcome indicators are more suitable for the evaluation and/or assessment of policies. In particular, among the latter, the prevalence of undernourishment (POU) is the traditional hunger indicator used by FAO. It was adopted by the United Nations (UN) as one of the official Millennium Development Goals (MDGs) indicators for monitoring the progress of MDG 1 "Eradicate extreme poverty and hunger" and, recently, as one of the indicators monitoring the second Sustainable Development Goal[1] (SDG) "End hunger, achieve food security and improved nutrition and promote sustainable agriculture" (United Nations, 2016). In developing countries, POU decreased from 23.3 per cent in the period 1990–1992 to 12.9 per cent in the period 2014–2016, which is less than one percentage point away from the MDG "hunger target" of halving, between 1990 and 2015, the proportion of people who suffer from hunger" (FAO, et al., 2015). However, Africa as a whole, and sub-Saharan Africa (SSA) in particular, have not met the hunger target. At country level, 22 out of 40 SSA countries, 10 out of 39 Asian countries, 10 out of 27 countries in Latin America and

[1] In September 2000, at United Nations Headquarters in New York (United States of America), world leaders adopted the United Nations Millennium Declaration, establishing a series of targets to be achieved by 2015, called MDGs. In September 2015, based on the achievements of the MDGs, world leaders of 193 Member States of the United Nations adopted the 2030 Agenda for Sustainable Development during the UN Sustainable Development Summit in New York, and convened as a high-level plenary meeting of the General Assembly; the 17 SDGs of the 2030 Agenda for Sustainable Development officially came into force on 1 January 2016. For more information: www.un.org/sustainabledevelopment.

the Caribbean (LAC) and 1 out of 5 countries in the Oceania region have not met the hunger target yet (FAO, et al., 2015). Despite these progresses, achieving the SDG[2] "zero hunger target" by 2030 remains a significant challenge, especially in Asia and SSA. Asia faces a higher hunger concentration, two thirds of total population. While SSA records the highest prevalence of hunger, with an undernourishment rate of almost 23 per cent in the period 2014–2016 (United Nations, 2017).

Aquaculture's contribution to food security is a prominent element in the international academic and political debate. The aquaculture sector is one of the fastest growing food production systems in the world (Tacon, 1997; FAO Fisheries Department, 1997; Asian Development Bank, 2005; Martinez-Porchas & Martinez-Cordova, 2012; FAO, 2014b) and developing countries have recorded the highest increase in aquaculture production (Beveridge, et al., 2010). In 2014, aquaculture reached an important milestone at global level by surpassing capture fisheries, for the first time, in terms of fish supply for human consumption (FAO, 2016l). According to projections, the growth in global fish demand along with a stagnant supply of capture fisheries will create a gap between supply and demand. The continued growth in aquaculture supply is expected to fill this gap (World Bank, 2013). The Abuja Declaration on Sustainable Fisheries and Aquaculture in Africa called for a range of actions in support of aquaculture, including «aquaculture to be adequately reflected in the national and regional economic policies, strategies, plans, and investment portfolios, including […] food security strategies» (NEPAD, 2005). During the eighth session of the FAO Sub-Committee on Aquaculture, the Members Countries «cognizant of the increasing contribution of the small-scale aquaculture sector to food security […] recommended FAO to make available guidance to systematically assess its contribution» (FAO Committee on Fisheries, 2015a).

FAO is one of the most influential international organizations on this topic; its first Strategic Objective (SO)[3] is to "Help eliminate hunger, food insecurity and malnutrition". Within the latter, the issue of food security is declined in the specific lines of its Departments, each of which deals with a particular sector, topic and/or commodity, including aquaculture. For this purpose, the UN agency, which «recognizes the fast-growing contribution aquaculture is making to food security» (FAO, 2017a), embraces normative as well as

[2] SDG 2 includes the Target 1 "By 2030, end hunger and ensure access by all people, in particular the poor and people in vulnerable situations, including infants, to safe, nutritious and sufficient food all year round" (United Nations, 2016).
[3] The five SOs represent the FAO priority areas of intervention. For more information: www.fao.org/about/what-we-do/en.

operational activities in terms of data collection and standards[4], knowledge sharing, policy dialogue, formulation and assessment.

Within this framework, this dissertation starts from a review of the evolution of the definition of food security and provides, first, an extensive description of the indicators and related data sources (Chapter 1). The second part of Chapter 1 shifts the focus to aquaculture and – after a brief overview of its origins – presents a complete descriptive analysis of the current trends and future developments of this sector from a food security perspective, mainly employing the datasets available from the FAO software for fishery statistical time series – FishStatJ[5]. This first chapter serves as a necessary conceptual framework for setting both the literature review (Chapter 2) and the empirical analysis (Chapter 3).

An extensive literature is available analysing aquaculture contribution to food security through both anecdotal and empirical evidences. However, as extensively documented in Chapter 2, the existing studies present several gaps. Indeed, many studies look at the contribution of all fishery activities instead of addressing aquaculture specifically; assess the impact on food security together with poverty alleviation; or do not consider all of the four food security dimensions (e.g., Allison, 2011; Merino, et al., 2012; AFSPAN, 2015; Béné, et al., 2016). Moreover, the existing literature mostly focuses on regional situations within a country and on limited time frames (e.g., Dey, et al., 2006; Jahan, et al., 2010; Belton, et al., 2011; Toufique & Belton, 2014; El Mahdi, et al., 2015). Finally, most studies consider only one dimension of food security, mostly the utilization dimension in terms of nutrient content, and look at the impact of aquaculture only on the determinants of food security rather than the outcomes. Few empirical analyses have been conducted to evaluate the evidence base for the actual contribution of the aquaculture sector itself to food security (Béné, et al., 2016). Therefore, there would appear to be incompleteness in evaluating the impact of aquaculture on the outcomes of food security at global level.

Starting from these findings, the comprehensive empirical analysis presented in Chapter 3 offers a twofold original contribution to the debate on the impact of aquaculture on food security.

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[4] As shown in Section 1.2, The FAO definition of fish farming is utilised by the Statistical Office of the European Communities (Eurostat) and international fishery bodies such as International Council for the Exploration of the Sea (ICES) and Southeast Asian Fisheries Development Center (SEAFDEC), amongst others (FAO Fisheries Department, 2005).

[5] The selected datasets are the following: aquaculture production from 1950 to 2014, capture fisheries production from 1950 to 2014, global fisheries production from 1950 to 2014 and fisheries commodities production and trade from 1961 to 2013.

First, the aim of this research is to evaluate whether aquaculture development had a positive impact on food security outcomes, rather than on its determinants. According to the suggestion of OECD (2006), the distinction between the causes or determinants of food security and the manifestations or outcomes is pivotal to properly assess how the sector being evaluated affects outcomes, whether these effects are intended or unintended. This approach is justified considering that for policy-makers in developing countries supporting aquaculture development is not a goal in itself but a means for achieving other outcomes, such as food security (NEPAD, 2005; ECOWAS, 2008; AUC-NEPAD, 2014).

For this purpose, I propose a logical framework to develop a suitable methodology for evaluating the impact of agricultural sector, in general, and aquaculture, specifically, on food security.

Second, I perform a panel rather than a cross-section analysis, in order to extend the assessment of the impact to the global level and over a long time horizon. In particular, the research evaluates whether the development of the aquaculture sector has improved food security in developing countries that experienced undernourishment issues.

To this end, I use three databases: the FAO suite of food security indicators, FAO FishstatJ and the FAO Corporate Statistical Database (FAOSTAT)[6], and apply a full set of estimation techniques. Specifically, pooled ordinary least squares (POLS), fixed effects (FER), random effects (RER) and panels corrected standard errors (PCSEs) regressions are employed to test the hypothesis of a positive impact of aquaculture on food security outcomes using the panel data. The panel data is composed by 104 developing countries over time, a total of 23 periods from 1990–92 to 2012–14. Food security outcome represents the endogenous variable, measured by the prevalence of undernourishment. The aquaculture development is the exogenous variable, measured by the share of aquaculture production on total fishery production. The other selected independent variables are the Gross Domestic Product (GDP) per capita, the apparent consumption per capita of fish and fishery product, the fish protein supply, the imports and exports of fish and fishery products.

[6] The FAO suite of food security indicators, whose last updated was released on 16 December 2016, provided the dataset on the prevalence of undernourishment at country level from 1990 to 2014 on a 3-year average only and the Gross domestic product per capita (in purchasing power equivalent) (constant 2011 international $) from 1990 to 2014. From FAO FishstatJ, the following four datasets were selected: aquaculture production and total fishery production at country level from 1950 to 2014, fish and fishery products imports and exports at country level from 1961 to 2013. FAOSTAT provided the datasets on food supply quantity and fish protein supply quantity at country level from 1961 to 2011. See Section 3.3 and Appendix 3 for a full description of the selected datasets, countries and timeframe.

To the best of my knowledge, this work is the first to assess the impact of aquaculture on food security using an outcome indicator of food security as endogenous variable, the aquaculture development as exogenous variable and the PCSEs estimator, which allows to control for both heteroskedasticity, cross-sectional correlation and first-order autocorrelation that affect the other mentioned estimators.

The empirical analysis provides the following results. All the explanatory variables, except for fish imports and exports, were statistically significant and showed a positive impact on food security[7]. The PCSEs estimates are consistent with the findings of the literature that underline the positive impact of aquaculture on food security (see Ahmed & Lorica (2002), Hishamunda et al. (2009b), Beveridge et al. (2013), among others). This suggests that the PCSEs estimator is the proper technique for assessing the impact of aquaculture on a specific food security outcome.

Summarizing, the thesis is structured in three chapters. Chapter 1 "Aquaculture and Food Security: a Snapshot" presents a complete overview of the key topics of this research, food security and aquaculture, analysing their definitions and trends, in order to clarify the context of this research and to highlight the complexity of the subject being discussed. Chapter 2 "Aquaculture Contribution to Food Security: a Literature Review" revised the literature investigating the contribution of aquaculture to food security by dimensions along with the methodologies applied to perform the empirical analyses. Since most of this literature has been already reviewed and synthesized by some scholars – e.g. AFSPAN (2012), Béné et al. (2016), Kawarazuka (2010) and HLPE (2014) – the purpose of the Chapter 2 is not to review all the studies addressing this topic but rather to cover the findings that are most relevant to this work along with the most recent advances. Having presented the conceptual framework for setting the original empirical analysis, Chapter 3 "Impact Evaluation of Aquaculture Development on Food Security" evaluated, through a panel data, the impact of aquaculture development on food security outcomes in developing countries. The most relevant aspects of the research are recalled and commented in the conclusions.

[7] The endogenous variable "Fish protein supply quantity" has been removed from the model because the variance inflation factors (VIF) detected Multicollinearity in "Fish protein supply quantity" and "Apparent per capita consumption of fish and fishery products".

1 Aquaculture and Food Security: a Snapshot

> «As world fish consumption continues to grow, aquaculture […] has emerged to meet demand. Already, just under half of all fish that people consume come from aquaculture, which is one of the world's fastest-growing animal food producing sectors. With the supply of wild-caught fish stagnating, any future increase in world fish consumption will need to be supplied by aquaculture» (Waite, et al., 2014).

This chapter presents a complete overview of the key topics of this research, food security and aquaculture, by analysing their definitions and trends, in order to clarify the context of this thesis and to highlight the complexity of the subject being discussed.

Within this framework, this chapter reviews the evolution of the definition of food security and provides first an extensive description of the indicators and related data sources. In the second part, the focus shifts to aquaculture and – after a brief overview of its origins – a complete descriptive analysis of the current trends and future developments of this sector are depicted from a food security perspective, by looking at the composition and trends of production, trade, consumption, price and employment.

For this purpose, I use the following datasets available from the FAO software for fishery statistical time series – FishStatJ: aquaculture production, capture fisheries production, global fisheries production, available from 1950 to 2014, and imports and exports of fish and fishery products, available from 1961 to 2013. Information on fish consumption, available from 1961 to 2011, was extrapolated from the Food Balance Sheet (FBS) dataset of the FAO Corporate Statistical Database (FAOSTAT). Unfortunately, data on aquaculture price and employment are scattered. Aquaculture prices, which are collected in the FAO Food Outlook Biannual Report on Global Food Markets[8] (FAO, 2016k), are available from 2006 and only at global level. While data on aquaculture employment, collected in the FAO State of World Fisheries and Aquaculture (FAO, 2014b), are available at regional level for scattered years only.

[8] Food Outlook is a FAO biannual publication focusing on developments affecting global food and feed markets.

1.1 Food Security

The concept of food security has evolved significantly in the last forty years. During the World Food Conference, which was held in Rome, Italy from 5 to 16 November 1974, food security was defined as the «availability at all times of adequate world food supplies of basic foodstuffs to sustain a steady expansion of food consumption and to offset fluctuations in production and prices» (FAO, 2003b). This supply-based definition of food security was affected by a historical period of grain stocks reduced by poor harvests, market shortages, rising food prices in many countries and decline in per capita availability of starchy staples (Committee on World Food Security, 2012; Pieters, et al., 2012; Benoit & Douillet, 2013; Pangaribowo, et al., 2013). Within this framework, the policy measure generally introduced was to increase agricultural productivity (Burchi & De Muro, 2016).

In the early 1980s, it was acknowledged that supply-based policies cannot provide a self-sustaining solution to end world hunger, but are only one aspect of a more complex issue. The ownership and exchange of entitlements' approach[9], developed by Sen (1981), shifted the level of food security analysis from country to individual level and allowed to move forward from a food security definition centred on supply-based issues only (Pieters, et al., 2012; Burchi & De Muro, 2016). The evidences of the supply-based policies and the theoretical debate led to a new definition of food security, produced by the UN Committee on World Food Security (CFS) in 1983. This definition encompassed three objectives, adequacy of food supplies, stability in food supplies and markets, and security of access to supplies, in which the final goal was «ensuring that all people at all times have both physical and economic access to the basic food that they need» (FAO, 2003b).

The World Bank (1986) enriched the concept of food security by differentiating between long- and short-terms (FAO, 2003b; Pieters, et al., 2012). Long-term or chronic food insecurity defines an inadequate diet on continuing basis caused by the inability to buy or produce food; while short-term or transitory food insecurity detects a temporary decline to access to enough food (World Bank, 1986). In addition, seasonal food security refers to the cyclical patterns in inadequate food availability and access due to seasonal variability climate, cropping patterns, labour demand and/or disease (FAO, 2008).

[9] «The entitlement approach concentrates on each person's entitlements to commodity bundles including food, and views starvation as resulting from a failure to be entitled to any bundle with enough food» (Sen, 1981). Entitlements refer to, for example, trade, production, labour, inheritance and transfer (Sen, 1981).

During the 1990s, the nutritional aspect of food security became an essential issue in the international debate. The topic encompasses macronutrient and micronutrient intakes and needs, coupled with access to adequate sanitation, health care and clean water (Pieters, et al., 2012). It is acknowledged that deficiencies in micronutrients, particularly iron, iodine, and vitamin A, are associated with specific health conditions, e.g. anaemia, goitre, cretinism and blindness (DeRose, et al., 1998). According to the definition adopted during the 1996 World Food Summit (WFS), which embraces more than 20 years of academic and political debate, «Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life» (FAO, 1996b).

The concept of food security is then refined in the State of Food Insecurity in the World (SOFI) of 2001 to include the social access to food. Food security is defined as «a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life» (FAO, 2001). This definition was formally reaffirmed in the 2009 Declaration of the World Summit on Food Security (WSFS), as follows: «Food security exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life. The four dimensions of food security are availability, access, utilization and stability» (FAO, 2009), along with the explicit reference to the nutritional dimension[10] (Committee on World Food Security, 2012) by considering the aspects of adequate caring practices, health and hygiene in addition to the dietary adequacy (FAO, et al., 2015).

According to the WSFS definition (FAO, 2009), food security encompasses by four dimensions: availability, access, stability and utilisation. Achieving food security implies the satisfaction, at once, of all the four dimensions (Pieters, et al., 2012). Availability addresses the supply side of food security and is determined by the level of food production, stock levels and net trade (FAO, 2008). Access refers to the three-fold ability to acquire adequate amounts of food: economic (i.e., the financial ability to acquire adequate food to meet the dietary requirements), physical (i.e., food is accessible at the location where people need it) and social (i.e., food is acquired and/or consumed in socially acceptable ways) (WFP, 2009). As pointed-out by Pinstrup-Andersen (2009), by holding constant the availability of food, the

[10] Nutrition security describes «a situation that exists when secure access to an appropriately nutritious diet is coupled with a sanitary environment, adequate health services and care, in order to ensure a healthy and active life for all household members» (FAO, IFAD & WFP, 2015).

food preferences that are socially and culturally acceptable and consistent with religious and ethical values could determine different food security scenarios. Utilization aims to individual efficiency in biologically converting nutrients in order to meet their specific nutritional and health needs (WFP as cited in FAO Statistics Division (2014). Stability addresses the ability to access to food on a regular basis; natural disasters, droughts, adverse weather conditions, political instability, civil conflicts or economic factors may affect it (FAO, 2006; FAO, 2008).

At international level, the objective of food security is pursued, among others, by the UN through the coordination of the activities of its agencies. The High Level Task Force on Global Food and Nutrition Security (HLTF), established by the UN Secretary-General Ban Ki-moon in 2008, «promote a comprehensive and unified response of the international community to the challenge of achieving global food and nutrition security» (United Nations, 2015a). FAO is one of the most influential international organizations on this topic. Its first Strategic Objective[11] (SO) is to "Help eliminate hunger, food insecurity and malnutrition". Within the latter, the issue of food security is declined in the specific lines of its Departments, each of which deals with a particular sector and commodity, including aquaculture. For this purpose, the UN agency, which «recognizes the fast-growing contribution aquaculture is making to food security» (FAO, 2017a), embraces normative[12] as well as operational activities in terms of data collection and standards[13], knowledge sharing, policy dialogue, formulation and assessment. Several indicators have been proposed by FAO to assess the contribution of aquaculture to food security for the food availability, access and stability dimensions, for which the data collection has not yet been implemented[14] (Bondad-Reantaso & Prein, 2009; Hishamunda, et al., 2009b; FAO, 2014a; FAO, 2016m). The FAO Sub-

[11] The SOs represent the FAO priority areas of intervention. FAO mandate through SO 1 is «to support members in their efforts to ensure that people have regular access to enough high-quality food» and «help by supporting policies and political commitments that promote food security and good nutrition and by making sure that up-to-date information about hunger and malnutrition challenges and solutions is available and accessible» (FAO, 2015a).

[12] Aquaculture development is regulated under the article 9 of the FAO Code of Conduct of Responsible Fisheries (CCRF). CCFR is a voluntary instrument adopted in October 1995 by over 170 Member Countries during the Twenty-eight Session of the FAO Conference, which provides principles and standards applicable for the conservation, management and development of all fisheries activities (FAO, 1995). The implementation of the CCFR led to the drafting of several FAO Technical Guidelines for Responsible Fisheries, which have no formal legal status.

[13] As shown in Section 1.2, The FAO definition of fish farming is widely utilised by the Statistical Office of the European Communities (Eurostat) and international fishery bodies such as International Council for the Exploration of the Sea (ICES) and Southeast Asian Fisheries Development Center (SEAFDEC), amongst others (FAO Fisheries Department, 2005).

[14] Appendix 7 shows the list of indicators proposed by from Bondad-Reantaso and Prein (2009), Hishamunda et al. (2009b) and FAO (2016m) for measuring aquaculture's contribution to food security.

Committee on Aquaculture provides a forum for consultation, discussion and advices in terms of aquaculture-related matters (FAO Fisheries and Aquaculture Department, 2005).

The literature review shows that through the 1990s and into the 2000s research on food security mostly focused on improving the terminology adopted and on defining the dimensions of food security and a general consensus seems to be reached in this regard (Maxwell & Smith, 1992; Riely, et al., 1999; Pieters, et al., 2012; Pangaribowo, et al., 2013).

From the 2000s, research has moved forward from a theoretical perspective keen to define accurately the concept to an applied dimension willing to measure the extent of food security and its relationship with poverty, education, climate change and, to a lesser extent, with the primary sector.

The High Level Panel of Experts on Food Security and Nutrition (HLPE), created in 2010 to provide the CFS with analysis to underpin policy debates on food security specific issues (HLPE, 2014), analysed the linkages between food security and, for example, price volatility, climate change, social protection, biofuels, sustainable forestry, fisheries and aquaculture. The International Food Policy Research Institute (IFPRI) focuses on food security in terms of cash transfers, agricultural technologies, resilience to shocks and trade-offs between nutrition benefits and environmental costs of production (International Food Policy Research Institute, 2017b). Its latest Global food policy report, which focused on food security in the urban areas of low- and middle-income countries, highlighted food security issues in both the access and stability dimensions (International Food Policy Research Institute, 2017a). According to the IFPRI's analysis, urban population faces increasing food security issues related to the economic access to food, e.g. 33 per cent of stunted children are living in urban areas. Moreover, given a budget allocation of 50 per cent on food items, the poorest households are likely to be extremely affected by employment instability, income and price volatility, e.g. during the global food price spikes, from 2008 to 2011, 14 African countries[15] faced food riots in their urban environment (Sneyd, et al., 2013; International Food Policy Research Institute, 2017b).

The many modifications undergone in food security definition challenged the statistics to provide new measurements and data in order to detect the several dimensions of an increasingly complex concept and to provide a systematic evidence of the extent and distinctive features of food security. Section 1.1.1 reviews the most recent indicators proposed

[15] The countries are Algeria, Cameroon, Côte d'Ivoire, Egypt, Guinea Conakry, Madagascar, Mauritania, Morocco, Mozambique, Senegal, Somalia, Tunisia and Uganda (Sneyd, et al., 2013).

by the empirical literature and specifically by FAO – broadly adopted by other research institutions and policy-makers – and presents the plethora of food security indicators. Section 1.1.2 focuses one of the FAO's indicators, specifically the Prevalence of Undernourishment (POU). In this work, POU is used to implement the empirical analysis in Chapter 3, together with the specific datasets on aquaculture described in Section 1.2.2.

1.1.1 Measuring Food Security: Methods, Indicators and Data

The empirical literature suggests different methods to quantify appropriately food security (Maxwell & Smith, 1992; Riely, et al., 1999; Kennedy, 2003; Pieters, et al., 2012; FAO, et al., 2013; Pangaribowo, et al., 2013; van Dijk, et al., 2016; von Grebmer, et al., 2016; Economist Intelligence Unit, 2017).

Recently, to capture the complexity and multidimensionality of this concept, a suite of indicators was presented in the 2013 State of Food Insecurity in the World[16] (SOFI) by FAO, IFAD and WFP (Table 1). The plethora of food security indicators complemented the traditional FAO hunger indicators, the number of people undernourished and the proportion of undernourished in total population (Section 1.1.2). In Table 1, each indicator is linked to one of the four food security dimensions as well as to the determinants and outcomes of food security.

Determinant indicators address all the structural conditions that may cause food insecurity in the absence of adequate policy interventions (Akinyoade, et al., 2014). The indicators suitable for measurement of the determinants of food security encompass all the four dimensions. Determinants of the availability component are levels of production, imports and exports, and stock excluding fish used for non-food purposes (FAO, 2008; Beveridge, et al., 2013). Food prices, employment, and income are examples of determinants in the access dimension (Gross, et al., 2000; FAO, 2008). The utilization dimension is affected by, for example, dietary habits, health care and conditions, access to clean water, adequate caring practices, especially for infants, young children, pregnant and lactating women (Hishamunda, et al.,

[16] Compared to 2013 SOFI (FAO, et al., 2013), in 2015 SOFI (FAO, et al., 2015), the following suite of "additional useful statistics were added": Total population; Number of people undernourished; Minimum Dietary Energy Requirement (MDER); Average Dietary Energy Requirement (ADER); Minimum Dietary Energy Requirement (MDER) - PAL=1.75; Coefficient of variation of habitual caloric consumption distribution; Skewness of habitual caloric consumption distribution; Incidence of caloric losses at retail distribution level; Dietary Energy Supply (DES); Average fat supply; and Prevalence of food over-acquisition.

2009b; Genschick, et al., 2015; Kawarazuka & Béné, 2011). Determinants of the utilization dimension, such as access to improved sanitation facilities and access to improved water sources, capture information on health and hygiene conditions, food quality and preparation. These measurements may determine how effectively the available food is consumed (FAO, et al., 2013). Natural disasters, droughts, adverse weather conditions, political instability, food price shocks in domestic or world markets (FAO, 2006; FAO, 2008; Hishamunda, et al., 2009b) are some of the causes of the stability dimension of food security. Outcome indicators identify and measure the results of food insecurity in terms of inadequate food intake, anthropometric failures, or poor health (FAO, et al., 2013; Pangaribowo, et al., 2013; Akinyoade, et al., 2014). In Table 1, outcomes indicators address the access and utilization dimensions of food security only (FAO, et al., 2013).

Therefore, while the determinant indicators could be considered a guide to elaborate adequate policy interventions, the outcome indicators are more suitable for the evaluation and/or assessment of policies. The quantitative analysis performed in Chapter 3 follows the suggestion of OECD (2006) according to which the distinction between the various causes or determinants of food security, and the manifestations or outcomes is pivotal to properly assess how the sector being evaluated affects outcomes, whether these effects are intended or unintended.

Table 1. Suite of food security indicators

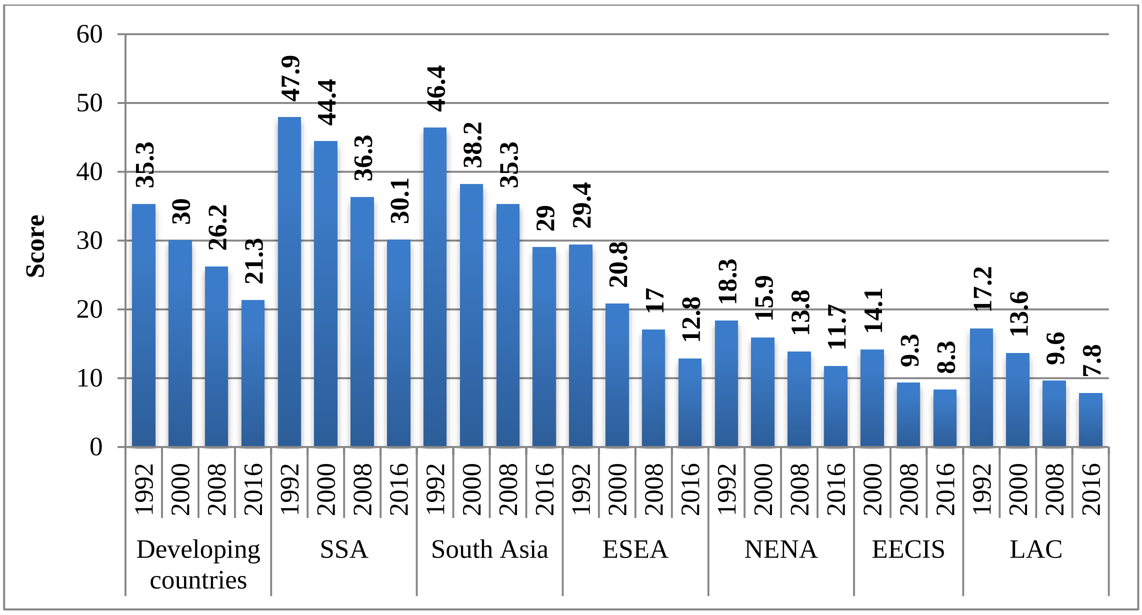
FOOD SECURITY INDICATORS	DIMENSION	
Average dietary energy supply adequacy Average value of food production Share of dietary energy supply derived from cereals, roots and tubers Average protein supply Average supply of protein of animal origin	AVAILABILITY	**STATIC AND DYNAMIC DETERMINANTS**
Percentage of paved roads over total roads Road density Rail lines density	PHYSICAL ACCESS	
Domestic food price index	ECONOMIC ACCESS	
Access to improved water sources Access to improved sanitation facilities	UTILIZATION	
Cereal import dependency ratio Percentage of arable land equipped for irrigation Value of food imports over total merchandise exports	VULNERABILITY	
Political stability and absence of violence/terrorism Domestic food price volatility Per capita food production variability Per capita food supply variability	SHOCKS	
Prevalence of undernourishment Share of food expenditure of the poor Depth of the food deficit Prevalence of food inadequacy	ACCESS	**OUTCOMES**
Percentage of children under 5 years of age affected by wasting Percentage of children under 5 years of age who are stunted Percentage of children under 5 years of age who are underweight Percentage of adults who are underweight Prevalence of anaemia among pregnant women Prevalence of anaemia among children under 5 years of age Prevalence of vitamin A deficiency Prevalence of iodine deficiency	UTILIZATION	

Source: FAO et al. (2013).

As opposed to the FAO's approach, other institutions proposed composite indexes to capture the several facets of food security (Kennedy, 2003; von Grebmer, et al., 2016; Economist Intelligence Unit, 2017).

IFPRI developed the Global Hunger Index (GHI) at global, regional and country levels. GHI combines four outcome indicators, namely the percentages of undernourished population, children under five who suffer from wasting (low weight-for-height), children under five who suffer from stunting (low height-for-age) and children who die before the age of five (child mortality). GHI, calculated for 118 countries and for scattered years (1992, 2000, 2008 and 2016), ranges between zero (no hunger) and 100 (greater hunger), where scores above 20 are classified as serious, greater than 35 are alarming and exceeding 50 are extremely alarming (von Grebmer, et al., 2016). According to the latest available data, in developing countries, GHI decreased from 30.0 in 2000 to 26.2 in 2008 to 21.6 in 2016. At regional level, in 2016, the highest scores are recorded in SSA (30.1) followed by South Asia (29.0), East and Southeast Asia (12.8), Near East and North Africa (11.7), Eastern Europe and Commonwealth of Independent States (8.3) and Latin America and Caribbean (7.8). In SSA and South Asia, the GHI scores detected serious levels of hunger compared to low or moderate levels in other developing regions (Figure 1). Moving to the analysis of the GHI's components, in South Asia, both child stunting and child wasting values are higher than in SSA, while SSA shows higher undernourishment and child mortality percentages (von Grebmer, et al., 2016).

Figure 1. Global Hunger Index scores in developing countries by regions



SSA = sub-Saharan Africa; ESEA = East and Southeast Asia; NENA = Near East and North Africa; EECIS = Eastern Europe and Commonwealth of Independent States; LAC = Latin America and Caribbean.
Source: von Grebmer et al. (2016).

The Economist Intelligence Unit[17] (EIU) has also developed a composite index, the Global Food Security Index (GFSI), for 113 countries, from 2012 to 2016. The index is constructed from 28 indicators across three dimensions: affordability, availability, quality and safety. Affordability refers to «the ability of consumers to purchase food, their vulnerability to price shocks and the presence of programmes and policies to support customers when shocks occur» (Economist Intelligence Unit, 2017). Availability measures «the sufficiency of the national food supply, the risk of supply disruption, national capacity to disseminate food and research efforts to expand agricultural output» (Economist Intelligence Unit, 2017). The quality and safety dimension detects «the variety and nutritional quality of average diets, as well as the safety of food» (Economist Intelligence Unit, 2017). The quality dimension is similar to the FAO's utilization dimension. Whereas the affordability dimension seems to focus only on the economic access in comparison with the FAO's access dimension. Moreover, the stability dimension of food security has been encompassed in both the availability and affordability dimensions.

In GFSI, the countries are then ranked into four categories: best performance, good performance, moderate performance and needs improvement (Economist Intelligence Unit, 2017). The ranges of each category are not clearly stated in the methodology.

Qualitative indicators have been adopted in the USA. First, data are collected through a food security module of 18 questions, which is part of the population survey, to capture households' anxiety about the food budget or supply, perceptions about food inadequacy in terms of either quantity or quality, and reduced food intake in adults and children. In order to measure the severity and the prevalence of food insecurity, the survey's results are then converted into a food security scale, through a non-linear factor analysis, ranging from zero to ten. Lastly, the population is divided into the following food security category: food security when the index is less than 2.32, food insecurity without hunger for values between 2.32 and 4.56, food insecurity with moderate hunger if the index is between 4.56 and 6.53 and food insecurity with severe hunger for values greater than 6.53 (Kennedy, 2003).

Although these indexes offer empirical evidence of some interesting features of food security, they are only available for scattered years or, do not distinguish between the various causes or determinants of food security or, have a limited geographical coverage. GHI, for

[17] EIU is the research and analysis division of The Economist Group. For more information: http://www.eiu.com/home.aspx.

example, focused on emerging economies, middle- and low- income countries, while GFSI addressed both developing and developed countries (Pangaribowo, et al., 2013).

In addition to that, the academic research developed different methods and procedures for assessing/evaluating food security; e.g., the research project FOODSECURE, funded by the Seventh Framework Programme for Research (FP7), proposed methodologies and framework for assessing food security (FOODSECURE, 2016). Among the FOODSECURE studies, van Dijk, et al. (2016) proposed to assess food security at global level through economic and biophysical models based on projections on exogenous variables such as population growth, urbanization, economic development and technological change. In these models, population growth in Africa had an impact on food security driven by food demand. In Laborde et al. (2013), land tenure, food wastes and losses are considered food security drivers on the food supply side. By addressing the stability dimension of food security, Pieters et al. (2012; 2013) focused on vulnerability, i.e. the probability of becoming food insecure, and the possible strategies to address this issue, such as risk prevention (e.g., migration), mitigation (e.g., insurance) and coping (e.g., sales of assets).

As recalled above (Section 1.1), in this work, I have adopted the FAO hunger indicator, the prevalence of undernourishment[18] (POU), which represents the main reference point in the current debate on food security (Section 1.1.2) and the benchmark for the empirical analysis presented in Chapter 3. In the next Section 1.1.2, I explore the reasons behind my choice.

1.1.2 The Prevalence of Undernourishment: Definition and Relevance

Among the indicators listed in Table 1, in this work special attention is paid to the Prevalence of Undernourishment (POU), an outcome indicator of food security and the traditional hunger indicator used by FAO. At the WFS, representatives of 182 governments pledged «… to eradicate hunger in all countries, with an immediate view of reducing the number of undernourishment people to half their present level no later than 2015» (FAO,

[18] The FAO suite of food security indicators, whose last updated was released on 16 December 2016, provided data on the prevalence of undernourishment. The database is provided free of charge and downloadable at: www.fao.org/economic/ess/ess-fs/ess-fadata/en.

1996a). POU[19] expresses the probability that a randomly selected individual from the population consumes an amount of calories that is insufficient to cover her/his energy requirement for an active and healthy life. This probability can be considered an estimate of the likely proportion of people that are undernourished in the population (FAO, et al., 2015). Its interpretation is intuitive and can be considered a good proxy of food insecurity.

Although food security can be measured through a plethora of indicators (Section 1.1.1), the relevance of POU within this suite is confirmed by the fact that it has been adopted as one of the official Millennium Development Goal[20] (MDG) indicators for monitoring the progress of MDG 1 “Eradicate extreme poverty and hunger”, Target 1c “Halve, between 1990 and 2015, the proportion of people who suffer from hunger”. More recently, POU is also one of the indicators of the second Sustainable Development Goal[21] (SDG) “End hunger, achieve food security and improved nutrition and promote sustainable agriculture”, Target 1 “By 2030, end hunger and ensure access by all people, in particular the poor and people in vulnerable situations, including infants, to safe, nutritious and sufficient food all year round” (United Nations, 2015b; United Nations, 2016). Hunger is still the main health threaten at the global level that kills more people every year than Acquired Immune Deficiency Syndrome (AIDS), malaria, and tuberculosis combined (Tacon & Metian, 2013).

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[19] POU, as show in the below formula, is computed by comparing *f(x)* – the probability density function of the *habitual levels of daily dietary energy consumption* in a population during a year – with a threshold level called the *minimum dietary energy requirement* (MDER). Both *f(x)* and MDER refer to an average individual in the reference population (FAO, et al., 2015).

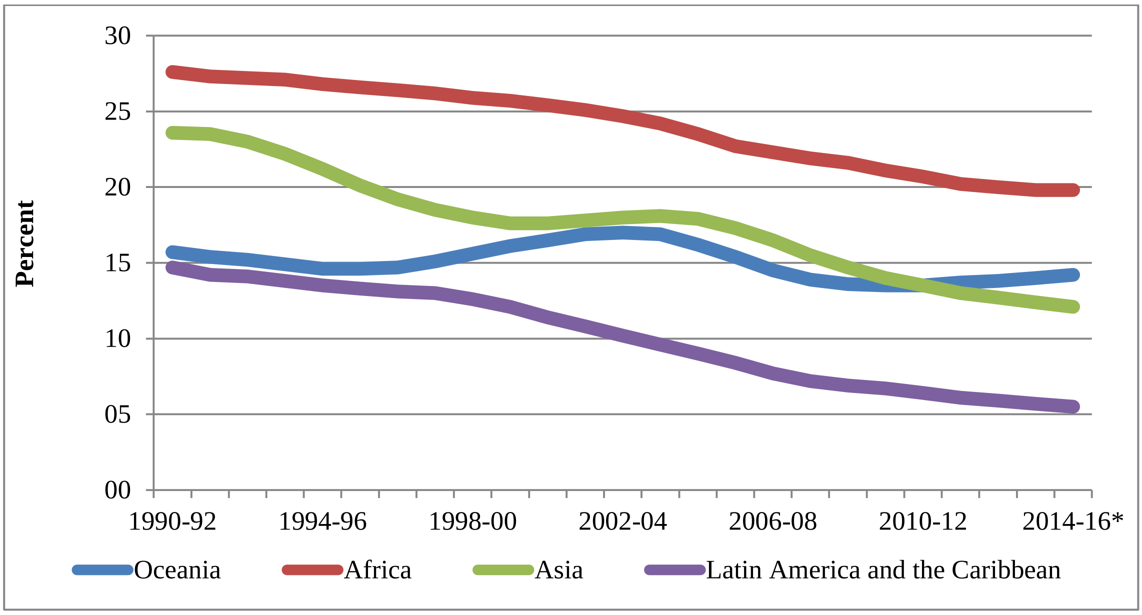
$$POU = \int_{x<MDER} f(x)dx$$

The parameters describing *f(x)* are: the mean level of per capita dietary energy consumption (DEC) in calories, MDER, the coefficient of variation (CV) which accounts for inequality in food consumption and the skewness (SK) accounting for asymmetry in the distribution (FAO, et al., 2015). DEC calculation is based on Food Balance Sheet (FBS). The food composition data in the FBS allows estimating the per capita dietary energy supply (DES) (FAO, et al., 2015). CV and SK parameters are derived from National Household Surveys (NHS), if available and reliable, otherwise, indirect estimates are used (FAO, et al., 2015). MDER is based on the normative energy requirement standards established during a joint FAO/WHO/United Nations University expert consultation in 2001. These standards take into account the basic metabolism needs (i.e., the energy expended by the human body in a state of rest) multiply by the physical activity level (PAL) index (i.e., the factor that takes into account the physical activity) (FAO, et al., 2015).

[20] In September 2000, at United Nations Headquarters in New York (United States of America), world leaders adopted the United Nations Millennium Declaration, establishing a series of goals and targets to be achieved by 2015, called MDGs. For more information: www.un.org/sustainabledevelopment.

[21] In September 2015, based on the achievements of the MDGs, world leaders of 193 Member States of the United Nations adopted the 2030 Agenda for Sustainable Development during the UN Sustainable Development Summit in New York, and convened as a high-level plenary meeting of the General Assembly; the 17 SDGs of the 2030 Agenda for Sustainable Development officially came into force on 1 January 2016. For more information: www.un.org/sustainabledevelopment.

Figure 2. Prevalence of undernourishment in developing countries by regions



Source: author's elaboration on (2016e). *Data for 2014–16 refer to provisional estimates.

The dataset on the prevalence of undernourishment is available at country level from 1990 to 2014 on a 3-year average only[22]. According to the latest available statistics, the number of people undernourished decreased by 21.4 per cent from the period 1990–1992 to the period 2014–2016 (FAO, et al., 2015). In developing countries, POU has decreased from 23.3 per cent in the period 1990–1992 to 12.9 per cent in the period 2014–2016, which is less than one percentage point away from that required to reach the MDG target by 2015 (FAO, et al., 2015).

At the regional level, during the same period, POU has decreased from 27.6 per cent to 19.8 per cent in Africa, from 23.6 per cent to 12.1 per cent in Asia, from 14.7 per cent to 5.5 per cent in Latin America and the Caribbean (LAC), and from 15.7 per cent to 14.2 per cent in Oceania (Figure 2). However, Africa as a whole, and SSA in particular, have not met the MDG 1 "hunger target"; while Northern Africa has reached the target. Both LAC, and Asia and Oceania have achieved the hunger target. Nationally, 22 out of 40 SSA countries, 10 out of 39 Asian countries, 10 out of 27 LAC countries and 1 out of 5 countries in the Oceania region have not met the hunger target (FAO, et al., 2015). Despite these progresses, with reference to SDG 2, achieving the "zero hunger target" by 2030 remains a significant

[22] POU is calculated in three-year averages to reduce the impact of possible errors in estimated DES, due to the difficulties in properly accounting of stock variations in major food (Food Security Information and Knowledge Sharing System, 2016).

challenge, especially in Asia and SSA. Asia faces a higher hunger concentration, two thirds of total population, almost 512 millions of people undernourished in 2014–2016. While SSA records the highest prevalence of hunger, with an undernourishment rate of almost 23 per cent in 2014–2016 (FAO, 2016e; United Nations, 2017).

FAO has also collected also food security indicators from household surveys but only for a limited number of countries[23], e.g. dietary energy consumption, total food consumption in monetary value and share of food consumption in total income. A total of 43 household surveys are available for 36 countries for selected years[24]. However, the data are not disaggregated by food item and the database reported only the mean, the median and the standard deviation values, and the number of observations for each of the food security statistics.

The suite of food security indicators (Table 1) includes other outcome indicators, i.e., the anthropometric indicators. The anthropometric indicators use human body measurements to obtain information about nutritional status. The rationale behind these indicators is the measurement of the nutritional imbalance and malnutrition[25] resulting in undernutrition assessed by underweight, stunting and wasting. Undernutrition represents the outcome of undernourishment, and/or poor absorption and/or poor biological use of nutrients consumed resulting from repeated infectious disease. While undernourishment is defined as the inability, for at least one year, to acquire enough food, defined as the level of food intake insufficient to meet dietary energy requirements (FAO, et al., 2015).

[23] The following indicators are available: Dietary energy consumption; Total food consumption in monetary value; Total consumption in monetary value; Average Carbohydrates consumption; Average Fat consumption; Average Protein consumption; Dietary energy unit value (LCU/1000 kcals); Share of DEC from total carbohydrates and alcohol (per cent); Share of dietary energy consumption from fat (per cent); Share of dietary energy consumption from protein (per cent); Share of food consumption in total income (per cent); Share of own produced food in total food consumption (per cent) (in dietary energy); Share of purchased food in total food consumption (per cent) (in dietary energy); Share of food consumed away from home in total food consumption (per cent) (in dietary energy); Share of food from other sources in total food consumption (per cent) (in dietary energy). For more information: http://www.fao.org/faostat/en/#data/HS.

[24] The following household surveys are available: Albania (2005); Azerbaijan (2006); Bangladesh (2000–2001; 2005); Bolivia (2003–2004); Cambodia (2004; 2009); Chad (2009); Côte d'Ivoire (2002); Egypt (1997); Ghana (1998–1999); Guatemala (2006); Haiti (1999–2000); Hungary (2004); Iraq (2007); Kenya (2005–2006); Lao People's Democratic Republic (2008); Lithuania (2002); Malawi (2004–2005); Mali (2001) ; Mexico (2004; 2006; 2008); Mozambique (2002–2003); Nepal (1995–1996); Niger (2007–2008); Pakistan (2005–2006); Panama (2008); Papua New Guinea (1996); Paraguay (1997–1998); Philippines (2003); Republic of Moldova (2006); Sri Lanka (1999–2000); Sudan (former) (2009); Tajikistan (2007); Timor-Leste (2001); Togo (2006); Uganda (2002–2003; 2005–2006); Venezuela (2004–2005); Viet-Nam (1992–1993; 2006); Zambia (2002–2003). For more information: http://www.fao.org/faostat/en/#data/HS.

[25] The concept of malnutrition includes undernutrition, overnutrition and micronutrient deficiencies (FAO, et al., 2015).

The anthropometric indicators include, among the others, the following: wasting prevalence, stunting prevalence, underweight prevalence and the percentage of adults who are underweight.

Wasting prevalence measures the proportion of children under five whose weight for height is more than two standard deviations below the median for the international reference, based on the World Health Organization (WHO) Child Growth Standards (FAO, 2016e). Wasting may detect short-term weight loss as caused by negative health conditions or acute food shortage (Pieters, et al., 2012). Stunting prevalence, an indicator for chronic malnutrition, is the proportion of children under five whose height for age is more than two standard deviations below the median for the international reference, based on the WHO Child Growth Standards (FAO, 2016e). Underweight prevalence, which results from short-term weight loss coupled with long-term growth problems (Pieters, et al., 2012), is the proportion of children under five whose weight for age is more than two standard deviations below the median for the international reference, based on the WHO Child Growth Standards (FAO, 2016e). Underweight prevalence in adults is defined by a Body Mass Index (BMI) below the international reference standard of 18.5. The BMI is weight (kg) divided by squared height (m) (FAO, 2016e).

In developing countries, in 2014, wasting prevalence ranged from 0.3 per cent in Chile to 16.3 per cent in Sudan. The highest prevalence (27.8 per cent) was recorded in Mali in 1996, which decreased to 15.3 per cent in 2006 (the latest available data) (FAO, 2016e). This improvement could have been generated by the adoption of several strategic documents by the Government of Mali in order to eradicate hunger and food and nutrition insecurity at national and household levels; such as the National Food Security Strategy in 2002, the National Programme for Food Security in 2005, covering the period 2006–2015, and National Food and Nutrition Security Policy (FAO, 2017c).

Stunting prevalence ranged from 1.8 per cent in Chile to 42.2 per cent in Malawi in 2014. The highest prevalence (76.6 per cent) was recorded in Bangladesh in 1991; while the indicator decreased to 36.1 per cent in 2014 (FAO, 2016e), thanks also to the adoption of the National Food Policy (NFP) in 2006 and the related plan of action covering the period 2008–2015 (FAO, et al., 2015). The NFP goal was «to ensure a dependable food security system for all people of the country at all times». In details, NFP encompassed three food security objectives, namely: “Ensure adequate and stable supply of safe and nutritious food”, “Enhance purchasing power of the people for increased food accessibility” and “Ensure adequate nutrition for all, especially women and children" (Ministry of Food and Disaster Management of Bangladesh, 2006).

Underweight prevalence ranged from 0.5 per cent in Chile to 33.0 per cent in Sudan in 2014. As for stunting, the highest prevalence (64.3 per cent) was recorded in Bangladesh in 1991, the indicator decreased to 32.6 per cent in 2014 (FAO, 2016e). Data on adults' underweight prevalence are collected from 1990 to 2007 for only 29 developing countries. In 2007, data were available for only two countries, i.e. Turkey (3.5 per cent) and Republic of Korea (4.7 per cent) (FAO, 2016e).

Although the anthropometric indicators are able to capture the outcomes of food security in terms of food utilization, the data available are scattered, not available for all the countries or for all the years. However, POU is open for criticism too. As undernourishment represents one of the causes of undernutrition, POU has been criticised for being a poor predictor of nutritional development, mortality and productivity (Pangaribowo, et al., 2013).

Nonetheless, compared to similar datasets, the POU dataset has a number of distinguishing features, which brought me to adopt this data source to implement my analysis. Primarily, the POU dataset offers a higher level of harmonization of statistical data across countries. Moreover, the POU dataset provides a high level of data quality because it is based on official and publicly available data provided by statistical institutes, which are subject to a more reliable checking and validation procedure than data generated for specific research purposes (e.g., surveys). In addition, the POU dataset provides a long time-series that can be used to trace development over time whereas other data indicators have been compiled only for particular benchmark years (e.g., anthropometric indicators, GDFI and GHI). In particular, the POU dataset cover the period 1990–2014 and it is regularly updated on annual basis. Finally, the POU dataset not only offers high quality data, but extends the number of covered countries to all countries in the world compared with other indicators (e.g., anthropometric indicators) and survey data (e.g., USA's food security module), which cover only a limited number of countries. For all these reasons, among the several indicators reviewed in Sections 1.1.1 and 1.1.2 to capture food security, I decided to focus the attention to POU and to use it as a proxy for food security in the empirical analysis of the impact of aquaculture on food security outcome presented in Chapter 3. In addition, given the lack of data, it was not possible to properly test the model on other outcome indicators of food security, such as the anthropometric indicators.

1.2 Aquaculture

FAO defines aquaculture as «the farming of aquatic organisms including fish, molluscs, crustaceans and aquatic plants. Farming implies some sort of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators, etc. Farming also implies individual or corporate ownership of the stock being cultivated. For statistical purposes, aquatic organisms which are harvested by an individual or corporate body which has owned them throughout their rearing period contribute to aquaculture while aquatic organisms which are exploitable by the public as a common property resource, with or without appropriate licences, are the harvest of fisheries» (FAO Fisheries Department, 1997). This clear and complete definition is widely utilised by the Statistical Office of the European Communities (Eurostat) and international fishery bodies such as International Council for the Exploration of the Sea (ICES) and Southeast Asian Fisheries Development Center (SEAFDEC), amongst others (FAO Fisheries Department, 2005) and I consider it as a reference point for this work[26].

This general definition includes several types of aquaculture practices, which primarily differ in terms of environment, area, farming systems, level of intensification, farmed species and stages of the growing cycles.

Aquaculture is practised in different environment: freshwater, brackish water, and marine. The environments are defined by the nature of the waters. Freshwater, such as that from reservoirs, rivers, lakes, canals and groundwater, has a consistently negligible salinity, i.e. not normally exceeding 0.5‰. In brackish water, such as estuaries, coves, bays, lagoons and fjords, salinity is appreciable but not at a constantly high level, i.e. salinity may lie or generally fluctuate between 0.5‰ and full strength seawater. Brackish water is usually characterized by regular daily and seasonal fluctuations in salinity due to the influxes of freshwater and full strength marine water. Enclosed coastal and inland water bodies in which the salinity is greater than freshwater but less than marine water are also regarded as brackish. In marine coastal and offshore waters, such as fjords, inland seas, inshore and open waters,

[26] Among the less influent definitions, it is worth mentioning the definition adopted by the National Marine Fisheries Service of the United States of America (NMFS), which refers to aquaculture as «the breeding, rearing, and harvesting of plants and animals in all types of water environments including ponds, rivers, lakes, and the ocean. Researchers and aquaculture producers are "farming" all kinds of freshwater and marine species of fish, shellfish, and plants. Aquaculture produces food fish, sport fish, bait fish, ornamental fish, crustaceans, molluscs, algae, sea vegetables, and fish eggs» (NOAA Fisheries, 2016). Differently from FAO, the NMFS definition does not refer to the issue of the ownership of the stock.

the salinity is maximal (around 35 parts per thousand [ppt]), generally exceeds 20‰, and is not subject to significant daily and seasonal variation (Statistics and Information Branch of the Fisheries and Aquaculture Department, 2014; FAO, 2016c).

In particular, it is possible to identify two different areas, inland and marine aquaculture. Marine aquaculture, or mariculture, refers to the farming of all aquatic organisms in coastal and offshore areas; while inland aquaculture takes place in freshwater (FAO, 2016f).

Aquatic organisms are grown in different farming systems: water-based, e.g. cages and pens, land-based, e.g. ponds, tanks and raceways, recycling, e.g. recirculating aquaculture systems (RAS), and integrated, e.g. agriculture and fish (Funge-Smith & Phillips, 2001). The life cycle of farmed fish species encompasses different phases, e.g. spawning, incubation, sex-reversal, nursery and grow out (FAO, 2005).

According to the level of intensification, production inputs include seed, e.g. juvenile and fingerlings[27], manure, lime, feed, electricity, water, oxygen, paid labour, amongst others (Kumar, 1999). In extensive or traditional farming techniques, the nutritional requirements rely on natural sources, often add nutrient-rich materials, use little or no fishmeal or fish oil[28], and human intervention is limited. In semi-extensive systems, fertilizers and/or supplemental feeds are used to enhance the carrying capacity[29]; whereas, in intensive farming, all nutritional requirements rely on external sources (FAO, 1984; Naylor, et al., 2001; FAO, 2017b).

Overall, the environment, the level of intensification, the farmed species, the farming systems, and the stages of growing cycles create a rich assortment of systems and technologies, which at present characterize aquaculture (Funge-Smith & Phillips, 2001).

1.2.1 Past Trends in Aquaculture Development

In order to understand the geographical localization and specialization of modern aquaculture, it is useful to briefly present an overview of its historical origin.

[27] Juvenile and fingerling indicate to different stages of the fish life cycle. Juvenile refers to the fish «between the post-larval stages up to the time they first become sexually mature» (FAO, 2016f). Fingerling indicates the fish «from advanced fry to the age of one year from date of hatching» (FAO, 2016f).

[28] Fishmeal and fish oil are both ingredients in the aquaculture feed. Fishmeal refers to the feed for aquaculture species and may include flours, meals and pellets from fish, crustaceans, molluscs or other aquatic invertebrates (FAO, 2016f). Fish oil, which is produced by pressing cooked fish, «represents the richest available source of long-chain highly unsaturated fatty acid» (FAO, 2016f).

[29] In aquaculture, the carrying capacity is defined as «the maximum quantity of fish that any particular body of water can support over a long period without negative effects to the fish and to the environment» (FAO, 2016f).

Aquaculture probably originated in Egypt and Assyria around the twenty-fifth century BC and only around the fifth century BC in China. In Egypt, evidences of aquaculture activities come from an engraving on a tomb dated around the twenty-fifth century BC; the engraving showed the harvesting of tilapia from an artificial pond. However, neither records nor detailed descriptions were available aside from narrative descriptions. According to the first known Chinese monograph, "the Classic of Fish Culture" by Fan-Li, inland aquaculture has raised interest by the Chinese around the fifth century BC. It represented the first record describing the structure of ponds, the method of propagation of the common carp and the growth of fry, i.e. fish at the post-larval stage (UNDP/FAO/ARAC, 1987; Rabanal, 1988; Jolly & Clonts, 1993). The ancient Romans were instead the first known marine aquaculturists; they designed ponds supplied with seawater. Roman fish farming reached its peak between the first century BC and the first century AD with the development of a highly specialized architectural element: the *piscinae*, or artificial fishpond (Jolly & Clonts, 1993; Higginbotham, 1997).

As described in Rabanal (1988), during the golden age of common carp, from 500 BC to 500 AD, aquaculture continued to develop in China and in the neighbouring countries. Furthermore, Rabanal (1988) reported that during the Tang Dynasty in China, from 618 to 906, aquaculture and the activities connected with common carp were prohibited by an imperial decree because the family name of Tang emperor was Li, the name of the common carp. Given the importance of aquaculture as a source of food and livelihood, the prohibition did not prevent aquaculture development but allowed for the flourishing of other farmed fish species (e.g., silver carp, big-head carp, grass carp and mud carp) and farming systems, such as polyculture[30], leading to a maximization of the productivity. During the Sung Dynasty, from 906 to 1120, the systematic collection of fry and dispersal in natural waters were highly developed (Rabanal, 1988).

Around 1400, brackish water aquaculture was established in Java, Indonesia. This evidence is suggested by the penal laws of the country (*Kutara Menawa*) which prohibited stealing fish from ponds. Brackish water aquaculture spread to the neighbouring areas including the Philippines, Malaysia, Thailand and Taiwan (Rabanal, 1988). Approximately during the same period, the common carp, *Cyprinus carpio,* reached Europe from Asia (The new Encyclopedia Britannica, 1998). From the Ming Dynasty (1368–1644) to the end of the Qing Dynasty, in 1911, China introduced and improved production technologies such as rearing density, polyculture, stocking rotation and seasonality, ponds structure, fertilizer, disease control and

[30] Polyculture is «the rearing of two or more non-competitive species in the same culture unit» (FAO, 2016f).

further specialized on fry production (Rabanal, 1988). These origins are reflected in the current prominent role of Asia in aquaculture production and export.

1.2.2 Current Status and Trends in Aquaculture Development

Having clarified the reference definitions and the origins of aquaculture, a comprehensive descriptive analysis of the composition and current trends of the sector from a food security perspective is presented, focusing on production, trade, price, consumption and employment. This descriptive analysis provides a useful background for setting the analyses to be performed in the next chapters, anticipating some of the main findings of the literature on the aquaculture contribution to food security, developed in detail in Chapter 2 and in the empirical analysis in Chapter 3.

For this purpose, I use the following datasets available from the FAO software for fishery statistical time series – FishStatJ[31]: aquaculture production, capture fisheries production, global fisheries production and fisheries commodities production and trade. Information on fish consumption was extrapolated from the Food Balance Sheet (FBS) dataset of the FAO Corporate Statistical Database[32] (FAOSTAT). FishStatJ and FAOSTAT are the only databases that provide an international coverage of fisheries data, both geographically and across time (Béné, et al., 2010) . Unfortunately, data on aquaculture price and employment are scattered. Aquaculture prices, which are collected in the FAO Food Outlook Biannual Report on Global Food Markets (FAO, 2016k), are available from 2006 and only at global level. While aquaculture employment data, collected in the FAO State of World Fisheries and Aquaculture (FAO, 2014b), are available at regional level for scattered years only.

Moreover, in my analysis, aquaculture and capture fisheries statistics refer to "food fish", which includes finfishes, crustaceans, molluscs, amphibians, freshwater turtles and other aquatic animals (such as sea cucumbers, sea, urchins, sea squirts and edible jellyfish) produced for, or intended for, human consumption. In order to obtain the same aggregates presented in the summary tables of the FAO yearbooks of fishery and aquaculture statistics, which are the main reference for policy-makers and research institutions, all the production figures in this document exclude marine mammals, crocodiles, corals, pearls, mother-of-pearl,

[31] The FishStatJ software is provided free of charge and downloadable at: http://www.fao.org/fishery/statistics/software/fishstatj/en.
[32] FAOSTAT database is provided free of charge and downloadable at: http://faostat3.fao.org.

sponges and aquatic plants[33]. Following the FAO's statistics collection methodology, farmed aquatic plants are not included in food fish because much of overall aquatic plant production is used for non-food purposes[34] (FAO, 2014b).

As extensively documented in the literature, aquaculture is one of the fastest growing food production systems in the world (Tacon, 1997; FAO Fisheries Department, 1997; Asian Development Bank, 2005; FAO, 2014b; Martinez-Porchas & Martinez-Cordova, 2012; FAO, 2017a). «The global trend of aquaculture development gaining importance in [terms of] total fish supply has remained uninterrupted» (FAO, 2014b). In particular, from 1950 to 2014, world aquaculture production increased from just over 600 thousand tonnes to almost 74 million tonnes (Figure 3). During the same time interval, fish farming contribution to total fish production increased from 3 to 44 per cent, significantly reducing the gap between capture fisheries[35] and aquaculture production (Figure 4).

In recent decades, in general, «world aquaculture production continues to grow, albeit at a slowing rate» (FAO, 2014b) but this rate is still higher than that of capture fisheries production. The last three decades showed that aquaculture production increased at higher annual rates compared to capture fisheries production. For example, from 1984 to 1994, aquaculture increased by an annual rate of 11.6 per cent while capture increased by 1.9 per cent. From 1994 to 2004, aquaculture increased by 7.2 per cent while capture increased by 0.1 per cent. From 2004 to 2014, aquaculture increased by 5.8 per cent while capture increased by 0.1 per cent[36] (author's elaboration based on FAO (2016i).

According to the most recent literature (World Bank, 2013; Troell, et al., 2014; Waite, et al., 2014; OECD/FAO, 2015a), the slowing growth rate of aquaculture production could be due,

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[33] In order to obtain the same aggregates presented in the summary tables of the FAO yearbooks of fishery and aquaculture statistics, the datasets, downloaded from FishStatJ, were filtered using the custom group <Fish, crustaceans, molluscs, etc>.

[34] The culture of microalgae, including *Spirulina spp.* for human consumption and feed use, *Haematococcus pluvialis* for pharmaceutical, nutraceutical and feed use, and microalgae biofuel production are poorly reported in terms of production statistics (FAO, 2014b).

[35] Capture fisheries is defined as «the sum (or range) of all activities to harvest a given fish resource. It may refer to the location (e.g. Morocco, Gearges Bank), the target resource (e.g. hake), the technology used (e.g. trawl or beach seine), the social characteristics (e.g. artisanal, industrial), the purpose (e.g. (commercial, subsistence, or recreational) as well as the season (e.g. winter)» (FAO, 2016f).

[36] The annual percentage rate (APR) refers to the traditional average annual (compound) growth rate adopted in FAO publications, such as the State of World Fisheries and Aquaculture (SOFIA). APR is calculated as:

$$APR = \left(\left(\left(\frac{Q_{t_1}}{Q_{t_o}}\right)^{\frac{1}{(t_1-t_0)}}\right) - 1\right) \times 100$$

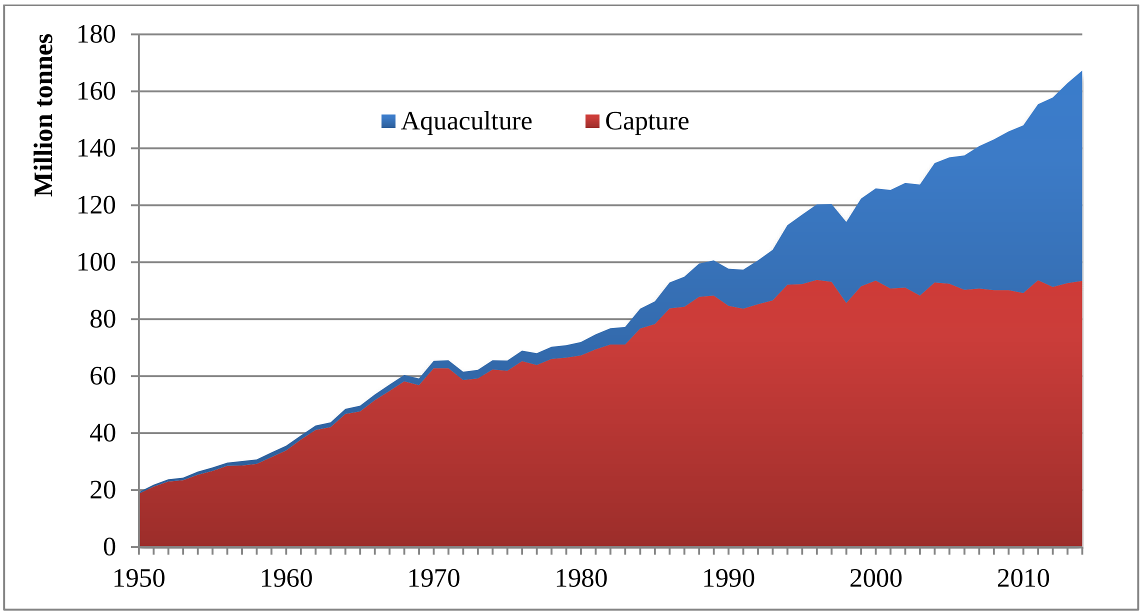
where, Q_{t_1} and Q_{t_o} are, respectively, the ending and beginning values of aquaculture production.

among the others, to competition over land and water uses and, to a minor extent, since they substantially declined, to the costs of fishmeal, fish oil and other feeds.

Nevertheless, the growth in aquaculture production remains relatively strong due to the increasing demand for food fish among most producing countries and elsewhere (FAO, 2014b). In 2014, aquaculture reached an important milestone at global level by surpassing capture fisheries, for the first time, in terms of supply of fish for human consumption (FAO, 2016l). Unfortunately, statistics on fish consumption at country level refers only to total fishery supply. The world average per capita apparent fish consumption increased from 9.0 kg in 1961 to 19.1 kg in 2011 (Figure 5). According to FAO (2014b), this growth has been driven by a combination of population growth, rising incomes and urbanization, and was facilitated by the fish increase in production and more efficient distribution channels. Moreover, because of the high rates of increase in farmed fish production and very low rates of capture fisheries production, it can be inferred that aquaculture facilitated more the growth in per capita apparent fish consumption than capture fisheries.

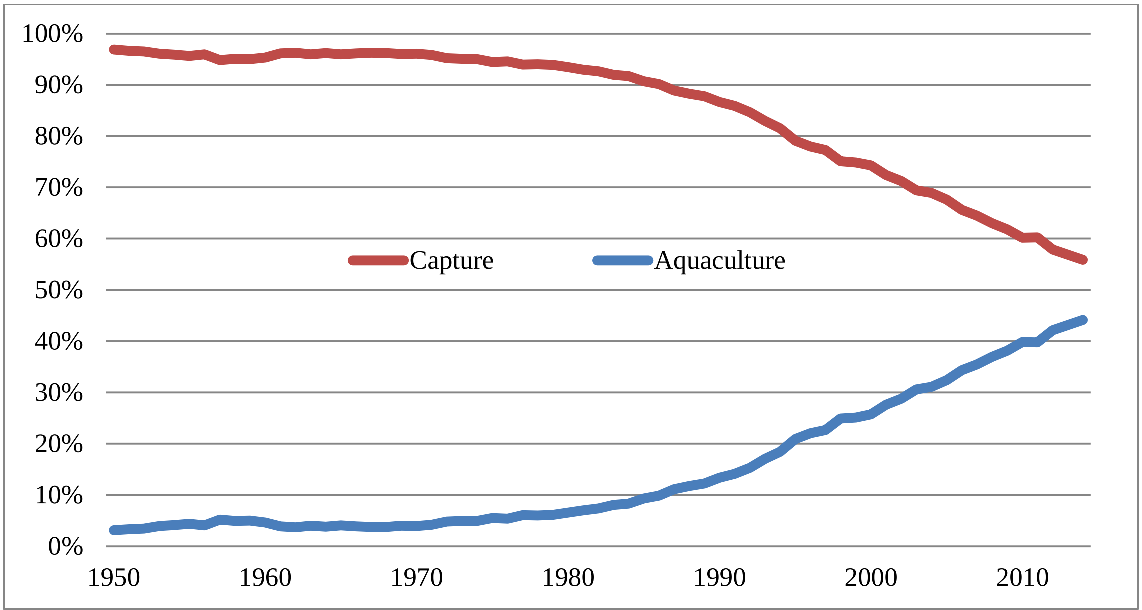
The explanation of the low growth demonstrated by the capture fisheries production lies in the state of marine fish stocks, which have been broadly exploited by human activities. According to the State of World Fisheries and Aquaculture (SOFIA) report (FAO, 2014b), the marine fish stocks at biologically sustainable levels declined from 90 per cent in 1974 to 71.2 per cent in 2011. Of this percentage, 61.3 per cent were fully fished with no expected room for further expansion. Close to 29 per cent (28.8 per cent) of fish stocks had reached a biologically unsustainable level of fishing and, therefore, overfishing.

Figure 3. World capture and aquaculture production



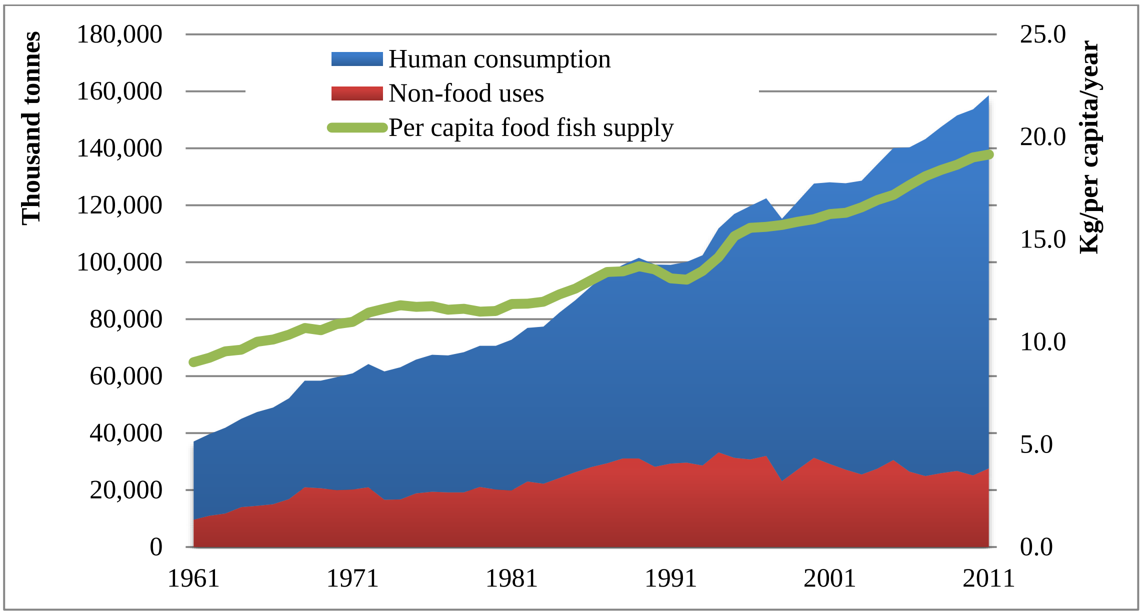
Source: author's elaboration on FAO (2016i).

Figure 4. World capture and aquaculture contribution to total fish production



Source: author's elaboration on FAO (2016i).

Figure 5. World fish utilization and supply

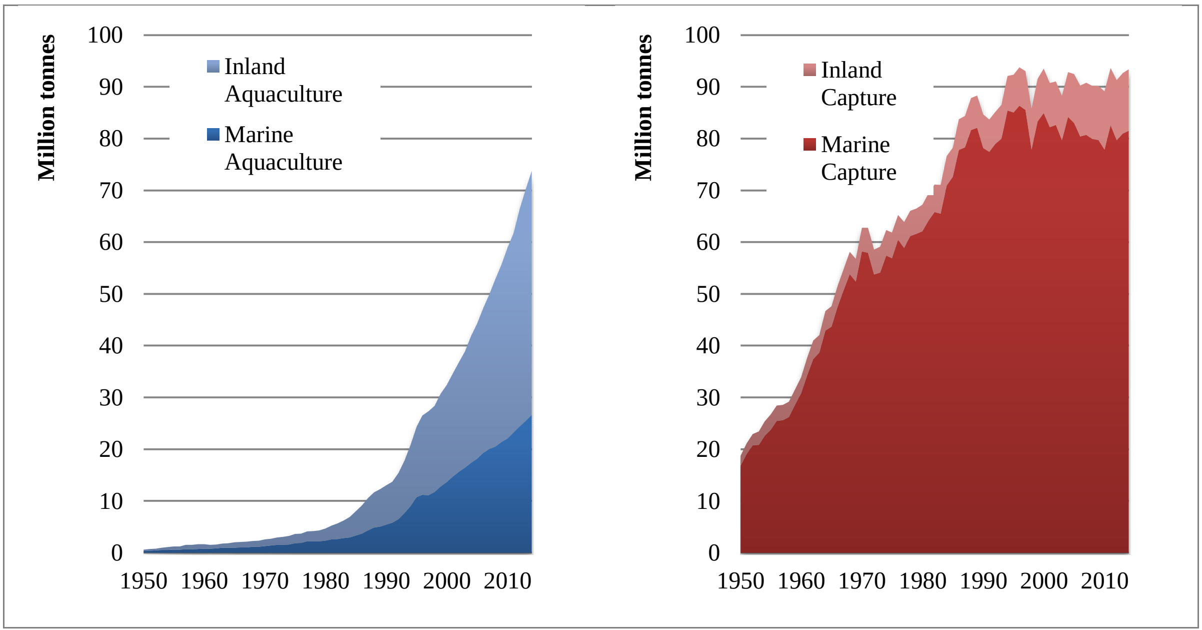


Source: author's elaboration on FAO (2016h).

If the analysis is disaggregated – i.e., by area, regions, environment and fish species – these remarks on the state of marine fish stocks could be extended at the analysis of the aquaculture production trend by area. Figure 6 shows that global inland and marine aquaculture production were at the same level up to 1980. Thereafter, inland aquaculture took over, and in 2014, for example, 64 per cent of the world aquaculture production came from inland areas. Conversely, the majority of capture fisheries (87 per cent) continues to come from marine waters.

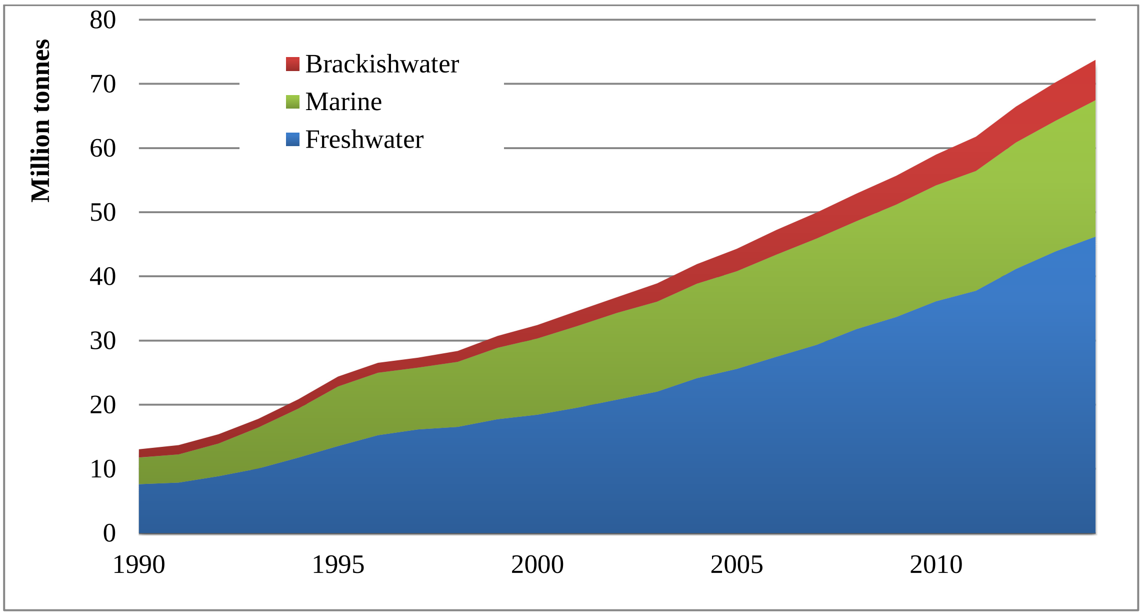
As introduced in Section 1.2, aquaculture occurs in different environments: freshwater, brackish water and marine environments. As shown in Figure 7, world aquaculture takes mostly place in freshwater environment. In 2014, roughly 63 per cent of farmed fish came from fresh water, followed by marine (29 per cent) and brackish water (6 per cent).

Figure 6. World capture and aquaculture production by area



Source: author's elaboration on FAO (2016i).

Figure 7. World aquaculture production by environment



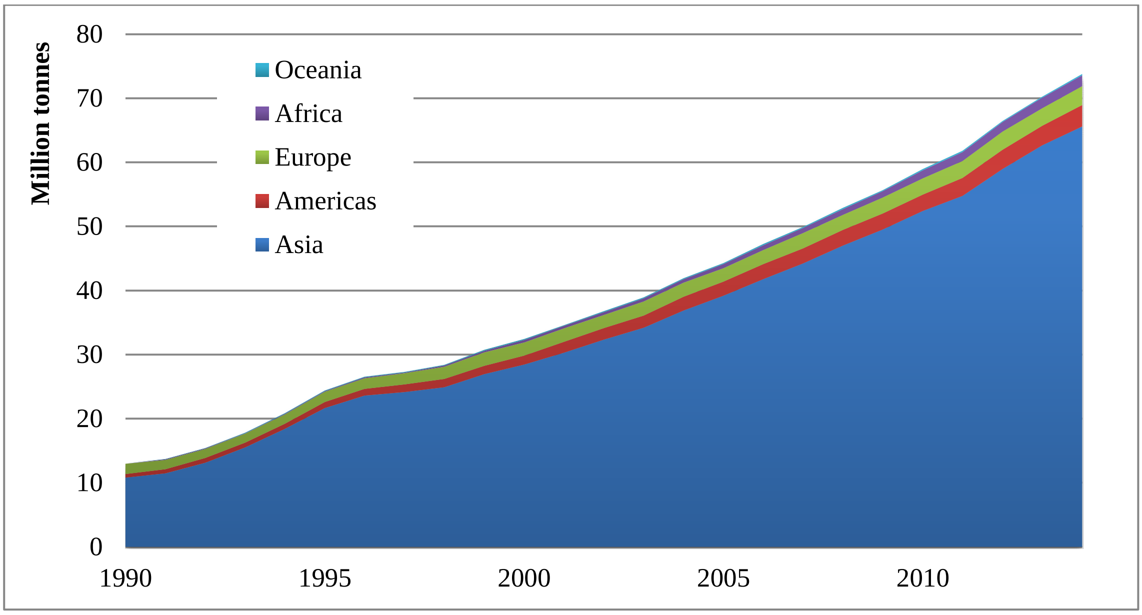
Source: author's elaboration on FAO (2016b).

With reference to the main producing countries, the growing trend in aquaculture production was almost unaltered between regions in terms of contribution to total fishery production, with a prominent role of Asia mainly due to its long tradition (Section 1.2.1), but more recently also as a response to national and international demand (Hishamunda &

Subasinghe, 2003; Hishamunda, et al., 2009a). Aquaculture development has been driven by profit opportunities of the private sector and government involvement; e.g. in China, through the egalitarian model under the Centralised State and the Open Market Economy Regime (Hishamunda & Subasinghe, 2003). Specifically, in 2014, Asia accounted for about 88.9 per cent of the world aquaculture production by volume, followed by the Americas (4.5 per cent) including Latin America and the Caribbean (LAC) and Northern America, Europe (4.0 per cent), Africa (2.3 per cent) and Oceania (0.3 per cent) (Figure 8).

It is noteworthy that between 2004 and 2014, annual aquaculture production growth was fastest in Africa (11.8 per cent) and LAC (7.2 per cent). In 2014, the majority of Africa's production of farmed fish comes from Northern Africa (67 per cent); while SSA accounts for 33 per cent (author's elaboration based on FAO (2016i).

Figure 8. World aquaculture production by region



Source: author's elaboration on FAO (2016i).

In 2014, the top ten countries produced almost 89 per cent of the total world aquaculture production. They include China with 62.1 per cent of this production, followed by India (6.6 per cent), Indonesia (5.8 per cent), Viet Nam (4.6 per cent), Bangladesh (2.7 per cent), Norway (1.8 per cent), Chile (1.6 per cent), Egypt (1.5 per cent), Myanmar (1.3 per cent) and Thailand (1.3 per cent). The top ten producers are all developing countries, with the exception of Norway that mainly produces Atlantic salmon (94 per cent of its domestic aquaculture production). Furthermore, seven out of the top ten were Asian countries; Chile was the only Latin American country (seventh place) and Egypt was the only African country (eighth position). Nigeria, the first country from SSA was the world's 19th aquaculture producer country in volume terms (author's elaboration based on FAO (2016i). Given the geographical specialization of aquaculture development, I decided to include the regional component in the empirical analysis in Chapter 3.

Moving on to the analysis of the main fish species that are produced by aquaculture (Figure 9), the freshwater fish species proves to be the most relevant production group[37]. Given the definition of aquaculture environments (Section 1.2), the conclusions might be quite straightforward. However, it is worth mentioning that several fish species can be farmed in different environments, regardless of their nature. A further complication is that the life cycle of farmed fish species encompasses different stages, e.g. spawning, incubation, sex-reversal, nursery and grow out. In order to be associated to a specific environment, the end product has to be raised in that particular waters (e.g., grow out), while earlier stages of the life cycle of fish farmed species may have been spent in different environments (e.g., in a nursery).

Nuances aside, Figure 9 shows that in aquaculture, fish species are mostly freshwater fishes[38] (58 per cent) and molluscs[39] (22 per cent), followed by crustaceans[40] (9 per cent), diadromous

[37] In Figure 9, fish species groups refer to the FAO International Standard Statistical Classification of Aquatic Animals and Plants (ISSCAAP), which is used for the collection of capture and aquaculture fisheries statistics. ISSCAAP is a nomenclature developed by FAO to classify commercial species into 50 groups and 9 divisions based on their taxonomic, ecological and economic characteristics. The division are the following: Freshwater fishes, Diadromous fishes, Marine fishes, Crustaceans, Molluscs, Whales, seals and other aquatic mammals, Miscellaneous aquatic animals, Miscellaneous aquatic animal products, Aquatic plants. (Garibaldi & Busilacchi, 2002).
Since production figures exclude marine mammals, crocodiles, corals, pearls, mother-of-pearl, sponges, and aquatic plants, the following divisions are not displayed: whales, seals and other aquatic mammals (division 6), miscellaneous aquatic animal products (division 8) and aquatic plants (division 9). For the same rationale, several group species under division 7 (Miscellaneous aquatic animals) are excluded.

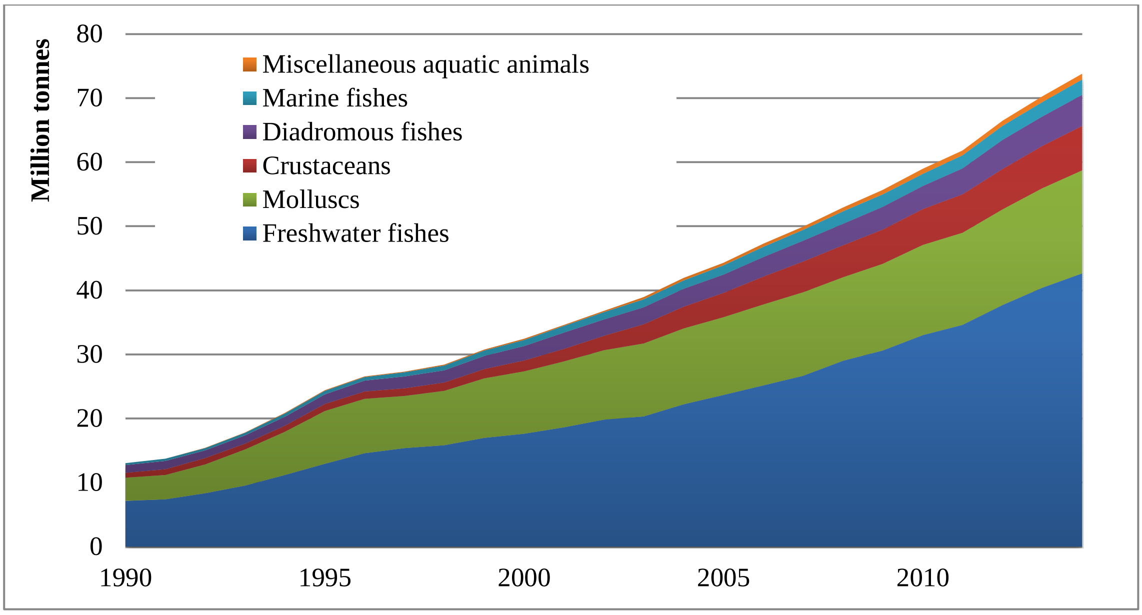
[38] Freshwater fish refers to any aquatic species that spends all or part of its life cycle in freshwater (FAO, 2016f). The groups of freshwater fishes include: carps, barbels and other cyprinids, tilapias and other cichlids, Miscellaneous freshwater fishes.

[39] Molluscs are invertebrate animals belonging to the *phylum Mollusca* with a soft unsegmented body and covered by a calcium carbonate shell, of 1 to 8 parts or sections. In some species, the shell is lacking or reduced. The surface is coated with mucus and cilia. Major cultured molluscs are mussels, oysters, scallops, cockles, clams (bivalves) and abalone (gastropod) (FAO, 2016f).

[40] Crustaceans refer to the aquatic animals belonging to the *phylum Arthropoda*, a major group of invertebrate organisms characterized by their chitinous exoskeleton and jointed appendages, occurring in marine and freshwaters and on land, e.g. crabs, lobsters, crayfish, shrimps, prawns, etc. Microcrustaceans include cladocerans and copepods (FAO, 2016f).

fishes[41] (7 per cent), marine fishes[42] (3 per cent) and miscellaneous aquatic animals (one per cent).

Figure 9. World aquaculture production by fish species divisions



Source: author's elaboration on FAO (2016i).

Specifically, as of 2014, there were 398 farmed fish species. Ten species represented more than half of the world aquaculture production (53.1 per cent) in terms of quantity produced. The fish species are Grass carp (White amur), Silver carp, Cupped oysters not elsewhere included (nei), Common carp, Japanese carpet shell, Nile tilapia, Whiteleg shrimp, Bighead carp, Catla and Carassius species (spp). The specialization of aquaculture production on a limited number of farmed fish species can be attributed to the combination of both biological and economic factors in the selection process. Biological factors include, among the others, feed efficiency, growth efficiency, mortality, grow-out period, tolerance to environmental conditions, disease resistance; while economic factors encompass, for example, feed and seed costs and availability (FAO, 1978; Wu, 1989; FAO, 2017b).

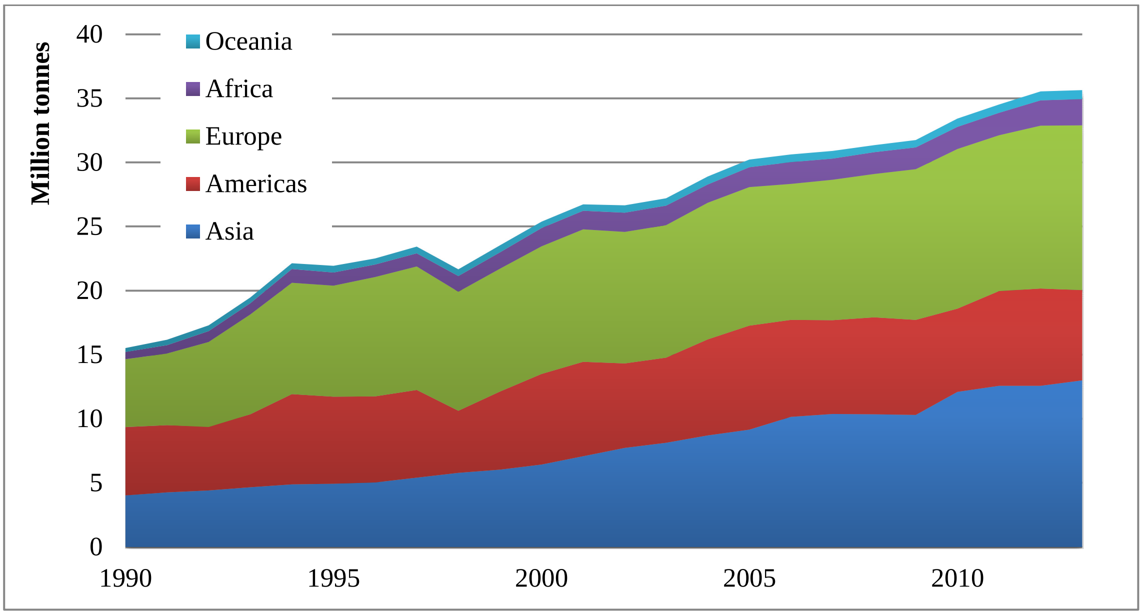
[41] Diadromous is a comprehensive term used for fish, which migrate freely between the sea and freshwater (FAO, 2016f). The groups of diadromous fishes include: sturgeons, paddlefishes, river eels, salmons, trouts, smelts, shads and miscellaneous diadromous fishes.
[42] Marine fishes include any aquatic species that spends all or part of its life cycle in seawater (FAO, 2016f). The groups of marine fishes include: flounders, halibuts, soles, cods, hakes, haddocks, miscellaneous coastal fishes, miscellaneous demersal fishes, herrings, sardines, anchovies, tunas, bonitos, billfishes, miscellaneous pelagic fishes, sharks, rays, chimaeras, and marine fishes not identified.

Some of the mentioned fish species were cultured in more than one environment. The Whiteleg shrimp, for example, is farmed in brackish water (75 per cent), freshwater (20 per cent) and marine (5 per cent). However, the majority have been farmed in freshwater environments (64 per cent), followed by marine (25 per cent) and brackish water (11 per cent) environments. Most of the top ten fish species are farmed in China, which alone accounts for about 73 per cent of their production, followed by India with nine per cent of aquaculture production (author's elaboration based on FAO (2016i).

Like production, trade influences the availability of fish and fishery products, and, therefore, their level of consumption, also considering that «fish is among the most traded food commodities worldwide. Fishery trade has expanded considerably in recent decades» (FAO, 2014b). Unfortunately, statistics on fish and fishery products trade refers only to total fishery production. As is the case for fish consumption, there is no disaggregation between wild fish or fish products in FAO's fishery trade statistics; the classification used internationally to record trade statistics for fish does not distinguish between products of wild and farmed origin (FAO, 2014b).

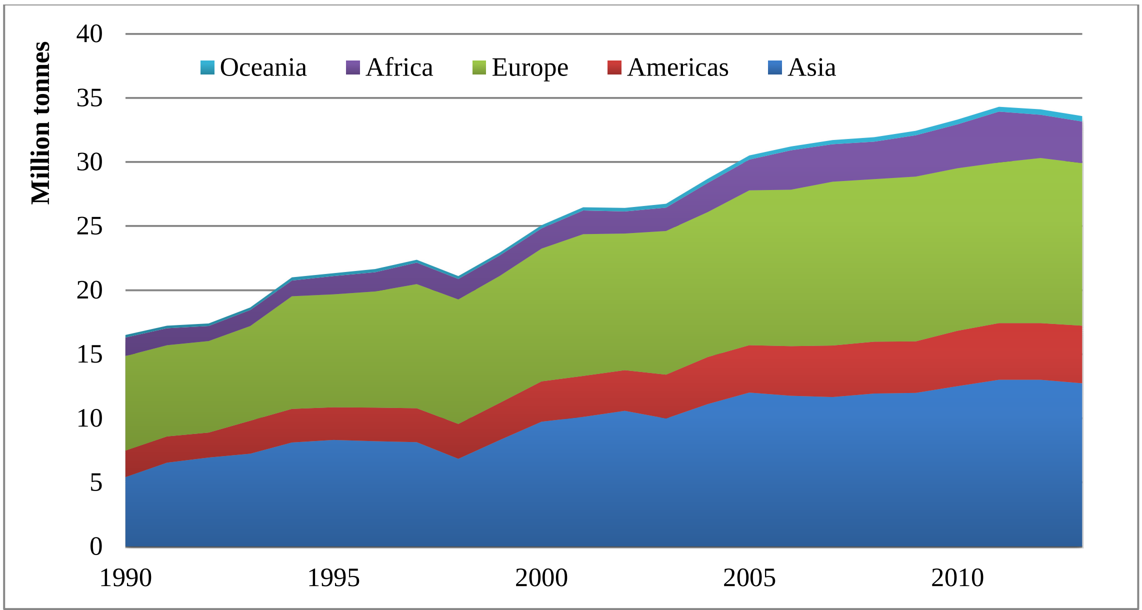
From 1990 to 2013, the contribution of developing countries to fishery trade, both exports and imports, has increased. The share of developing countries on fish and fishery products exports increased from 43 per cent in 1990 to 54 per cent in 2013; while imports increased from 28 per cent to 45 per cent during the same period. From 2003 to 2013, fish and fishery products exports annual growth was fastest in Asia (4.8 per cent), followed by Africa (2.9 per cent); China is, by far, the largest exporter of fish and fishery products (author's elaboration based on FAO (2016j). According to FAO (2014b), many species registering the highest export growth rates in recent years are produced by aquaculture. In the last two decades, there has been a substantial increase in aquaculture trade, for both high-value species (from an economic perspective) such as salmon, seabass, seabream, shrimp and prawns, bivalves and other molluscs and low-value species such as tilapia, catfish (including pangasius) and carps. Moving to the import side, from 2003 to 2013, imports annual growth was fastest in Africa (5.9 per cent), followed by Oceania (3.3 per cent) (author's elaboration based on FAO (2016j).

Figure 10. Fish and fishery products exports by region



Source: author's elaboration on FAO (2016j).

Figure 11. Fish and fishery products imports by region



Source: author's elaboration on FAO (2016j).

As documented extensively in both theoretical and empirical literature (Beveridge, et al., 2013; Belton & Thilsted, 2014; Troell, et al., 2014; AFSPAN, 2015; El Mahdi, et al., 2015), food price is an important determinant of access to food. However, it is unlikely to find a univocal answer to the question of whether lower price increase access to food or vice versa[43]. The Fish Price Index[44] (FPI), increased markedly from 94 in 2002 to 146 in 2016, although with strong oscillations within-year. In October 2013, FPI recorded a pick of 160, mainly due to a rise in prices for farmed species, particularly shrimp, and for some wild-caught species such as cod and certain pelagic species (FAO, 2014b). According to the FAO Food Outlook Biannual Report on Global Food Markets (FAO, 2016k), the supply of fish and fishery products was unable to meet the strong growth in global demand, thereby affecting the upward price trend. A growth in global demand was caused by, among the others, an income growth in many developing regions and a robust demand in the United States of America (USA) and the European Union (EU).

FPI showed divergence in price trends for capture and aquaculture products, which could be attributed to the peculiar cost structures of each system: aquaculture increased from 114 in 2006 to 137 in 2015 while capture fisheries increased from 119 to 146 (Figure 12). Aquaculture prices, which are generally lower than those of capture fisheries are, experienced cost reductions through productivity gains and economies of scale; the recent increase has been affected by higher costs, in particular for feeds. Fish culture also responds to price changes with a time lag compared to capture fisheries, given by the length of the growing cycle (FAO, 2014b); for example, the average growing cycle of Nile Tilapia between the stocking of fingerlings and the complete harvest of fish is approximately eight months.

[43] The role of fish price in the access dimension has been addressed in Section 2.1.2.

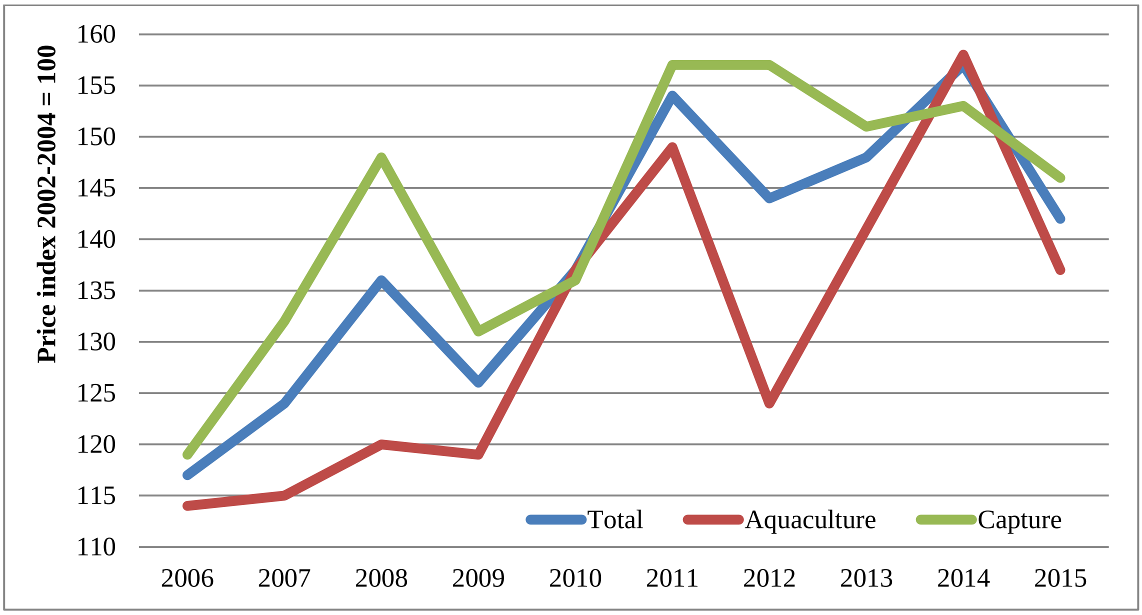
[44] FPI is being developed by FAO in cooperation with the University of Stavanger and with data support from the Norwegian Seafood Council. It has a base of 2002–2004 average set to 100. It is measured by the Fisher index (I_t^F), which is the geometric mean of Laspeyres (I_t^L) and Paasche (I_t^P) (Tveteras, et al., 2012):

$$I_t^F = \sqrt{I_t^L / I_t^P} = \sqrt{\left(\sum_i p_{it} * q_{i0} / \sum_i p_{i0} * q_{i0}\right) / \left(\sum_i p_{it} * q_{it} / \sum_i p_{i0} * q_{it}\right)}$$

FPI is based on nominal import values expressed in CIF (Cost, Insurance and Freight) in three major import markets: Japan, USA and EU. According to Tveteras, et al. (2012), the choice of Japan, USA and EU is reasonable because they account for a large fraction of total seafood imports globally and produce reliable and regularly updated data.

FPI data are available for aquaculture, capture fisheries, and major fish species, e.g. fresh and frozen white fish, salmon, crustaceans, pelagic fish excluding tuna, tuna, and a broad category of other fish species (FAO, 2016k).

Figure 12. FAO Fish Price Index by year



Source: author's elaboration on FAO (2016k).

By providing wages or incomes, employment enhances consumers' purchasing power and their access to food, including to fish (Hishamunda, et al., 2009b; Allison, 2011; Béné, et al., 2015). Employment in the fisheries sector, including both capture and aquaculture, has grown faster than the world's population and employment in the traditional agriculture sector (FAO, 2014b). Globally, since 1990 the number of people engaged in aquaculture has increased at higher annual rates than the number of those engaged in capture fisheries. The relative proportion of those engaged in aquaculture to total fisheries increased from 17 in 1990 to 32 per cent in 2012 (FAO, 2014b). Small-scale fish farmers represent around 70–80 per cent of the aquaculture sector (Bondad-Reantaso & Subasinghe, 2013).

Employment rates in aquaculture are highest in Asia, followed by Africa, Latin American and the Caribbean countries (Table 2). From 2000 to 2012, annual growth in aquaculture employment was fastest in Africa (10.4 per cent), followed by Asia and North America (3.4 per cent) (author's elaboration based on FAO (2014b). Although these figures refer only to fish farmers rather than total employees, they can be considered a good proxy of aquaculture employment. In fact, according to a study conducted by FAO (2016m), fish farmers represented around 73 per cent (8.3 million) of total people employed in aquaculture value chains (11.4 million)[45], while around 3.1 million were employed as inputs suppliers, in feed mill operations, in hatcheries and nurseries, processing plants and distribution.

Between 1990–95 and 2005–10, Africa and Asia, with higher population growth and growing economically active populations in the agriculture sector, have shown increases in the number of people employed in aquaculture also related to the increases in aquaculture production. Latin America and Caribbean recorded instead a decreasing population growth and economically active population in the agriculture sector but increased aquaculture production and employment. Therefore, in the latter, the production and employment trends seem to respond to other determinants rather than the demographic dynamics. In particular, according to FAO (2014b), it seems that aquaculture responds positively to technological developments through production boost, and hence, employment growth.

Table 2. Fish farmers by region (thousands)

Regions	**1995**	**2000**	**2005**	**2010**	**2011**	**2012**	**APR 2000–2012**
	(thousands)						*(percentage)*
Africa	65	91	140	231	257	298	10.4
Asia	7 762	12 211	14 630	17 915	18 373	18 175	3.4
Europe	56	103	91	102	103	103	0.0
Latin America and the Caribbean	155	214	239	248	265	269	1.9
North America	6	6	10	9	9	9	3.4
Oceania	4	5	5	5	6	6	1.5
World	**8 049**	**12 632**	**15 115**	**18 512**	**19 015**	**18 861**	**3.4**

Source: author's elaboration on FAO (2014b).

1.2.3 Projections on Aquaculture Development

There are two main studies currently generating projections on aquaculture development; namely, the OECD-FAO agricultural outlook 2015–2024 (OECD/FAO, 2015a)

[45] The FAO study (2016m) was conducted in nine countries in Africa, Asia and Latin America, which accounted for about 16 per cent of global aquaculture.

and the World Bank's Fish to 2030 (World Bank, 2013)[46]. With different time horizons, both projections depicted aquaculture as the main driver in total fishery production.

The OECD-FAO agricultural outlook is based on a partial equilibrium model that utilises the AGLINK-COSIMO modelling system. The OECD AGLINK model is an economic model of world agriculture for OECD countries as well as Argentina, Brazil, China and Russia; while the FAO agricultural model COSIMO represents the agricultural sectors in a large number of developing countries (OECD, 2016).

Compared to the World Bank's Fish to 2030, the OECD/FAO developed only one scenario, which runs from the baseline period 2012–2014 to 2024. The OECD-FAO projections are built on macroeconomic and policy assumptions. OECD/FAO (2015a) specified that macroeconomic assumptions are based on the OECD Economic Outlook (OECD, 2014) and the International Monetary Fund's World Economic Outlook[47] (International Monetary Fund, 2014) of 2014. In addition to fisheries, other commodities are included in the projections, e.g. cereals, oilseeds, sugar, meat, dairy, cotton and biofuels.

According to OECD/FAO (2015a), aquaculture will remain one of the fastest growing food production systems in the world. At global level, the increase of total fishery production will be mainly driven by aquaculture, which will expand by 38 per cent between the baseline period (2012–2014) and 2024, and will surpass capture fisheries in 2023 (Figure 13). In 2024, 94 per cent of all aquaculture production is expected to originate from developing countries. World aquaculture will contribute to 50.4 per cent of total fishery production; this contribution will be higher in developing countries (56.1 per cent).

Globally, per capita apparent fish food consumption is projected to reach 21.5 kg in live weight equivalent[48] in 2024, up from 19.7 kg in the base period (Figure 14). In line with the production trends, the majority of future fish consumption is expected to depend on aquaculture. Per capita fish consumption will remain higher in more developed economies, even if it is expected to grow more rapidly in developing countries. For the first time[49], a

[46] There are also a series of peer-reviewed articles relying on various types of modelling and projection tools, which have been analysed in Béné et al. (2015).

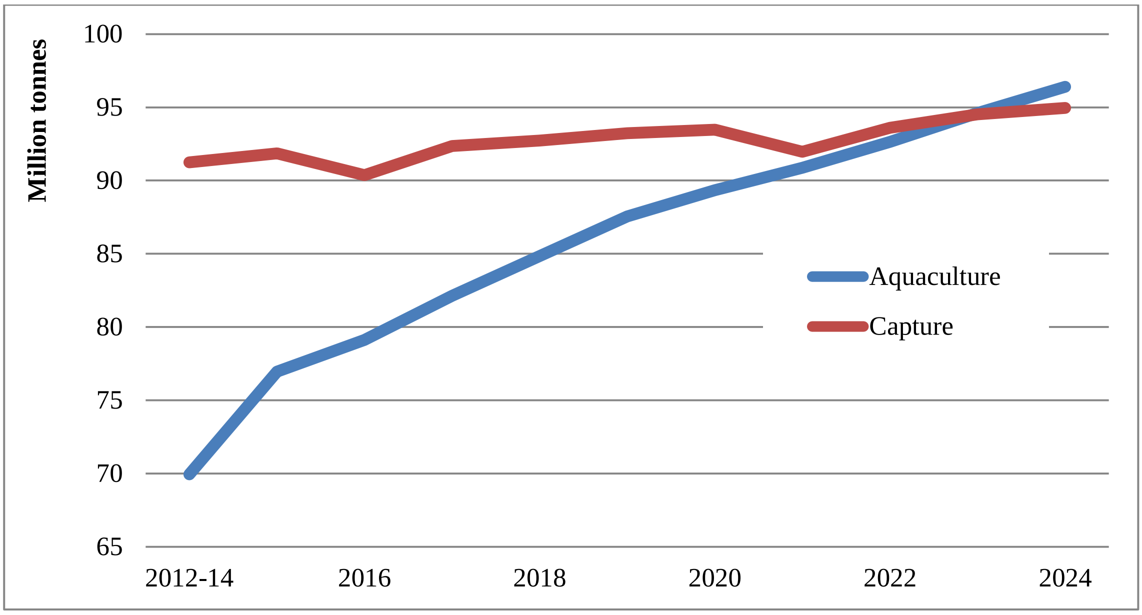
[47] OECD (2014) addressed the following topics: real GDP, the GDP deflator, the private consumption expenditure (PCE) deflator, the Brent crude oil price (in US dollars per barrel) and exchange rates expressed as the local currency value of USD 1 in OECD countries, Brazil, Argentina, China and Russian Federation. For the other countries, the information where obtained from IMF (2014) (OECD/FAO, 2015a).

[48] The live weight equivalent is the weight of finfish and shellfish at the time of their capture or harvest. It is calculated on the basis of conversion factors from landed to nominal weight and on rates prevailing among national industries for each type of processing (Laurenti, 2014).

[49] The OECD-FAO agricultural outlook was first published in 1999; however, fish commodity analysis was introduction only in 2011.

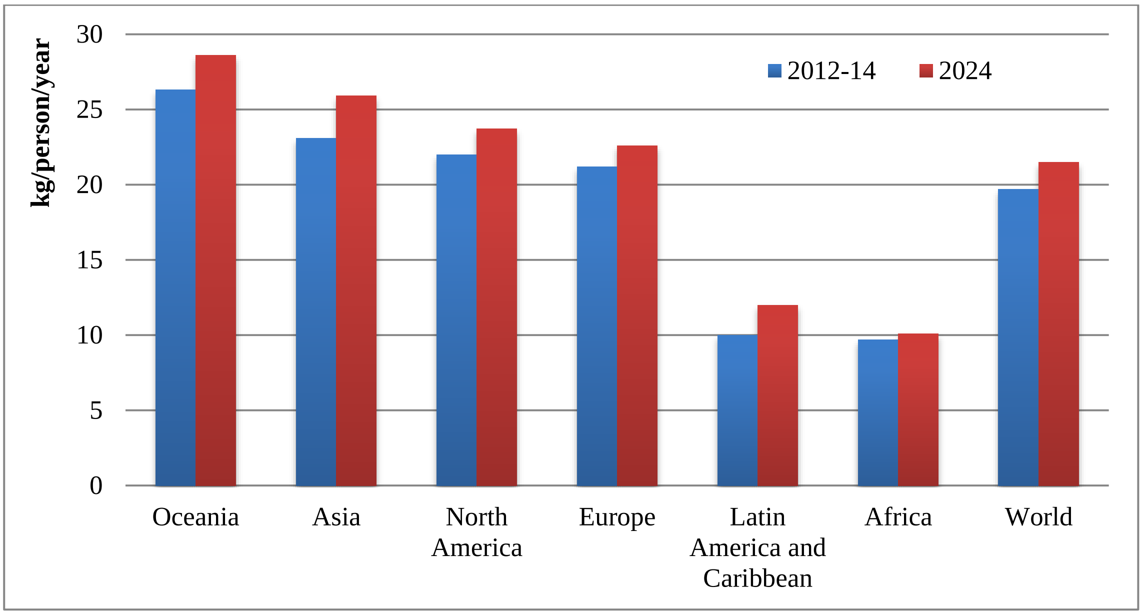
slight increase in per capita fish consumption is projected for Africa, from 9.7 kg in the base period to 10.1 kg in 2024 (OECD/FAO, 2015a).

Figure 13. OECD-FAO agricultural outlook: aquaculture and capture production projections



Source: adapted from OECD/FAO (2015b).

Figure 14. OECD-FAO agricultural outlook: apparent per capita fish consumption projections



Source: OECD/FAO (2015b).

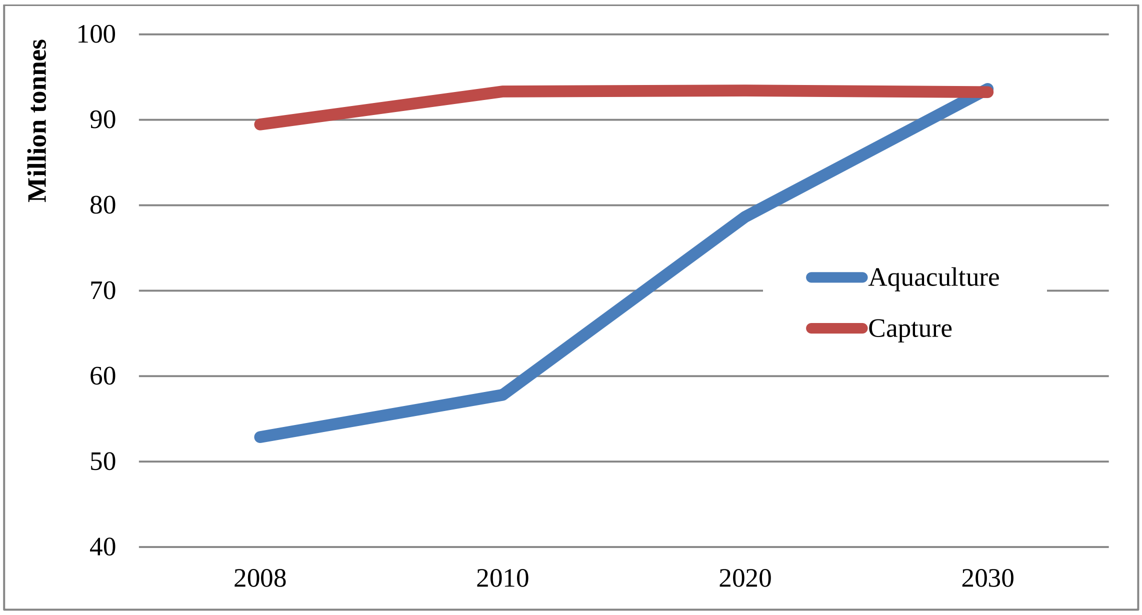
The World Bank's Fish to 2030 employs the IFPRI's International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) model to generate projections of global fish supply and demand. IMPACT is a global, multimarket, partial equilibrium economic model that covers a number of agricultural products, e.g. cereals, oilseeds, roots and tubers, pulses, livestock products, and fish products (World Bank, 2013). The model generates projections on supply, demand and trade, from 2000–2008 to 2030 for 115 countries/regions and for 18 fish and fishery products as well as other agricultural commodities (Kobayashi, et al., 2015).

Fish to 2030 included seven scenarios: baseline, faster growth of aquaculture, waste in fishmeal and fish oil production, disease outbreak in shrimp aquaculture, increase of consumers demand in China, capture growth and climate change. According to Kobayashi et al. (2015), the "baseline scenario", which is based on the current trends of supply and demand, seems the "most plausible", while the other scenarios show the impact on production or consumption due to hypothetical shocks, like disease outbreak in aquaculture (Kobayashi, et al., 2015).

In the baseline scenario projections, Fish to 2030 (World Bank, 2013) predicted that the total fishery production will increase from 151 million tonnes in 2010 to 186 million tonnes in 2030, with a major role of aquaculture compared to a stagnant capture fisheries supply (Figure 15). By 2030, aquaculture (50.2 per cent) and capture fisheries (49.8 per cent) will almost equally contribute to total fish supply. China will continue to be the largest aquaculture producer. While all regions are expected to expand their aquaculture production, the largest expansion will take place in Southeast Asia and India.

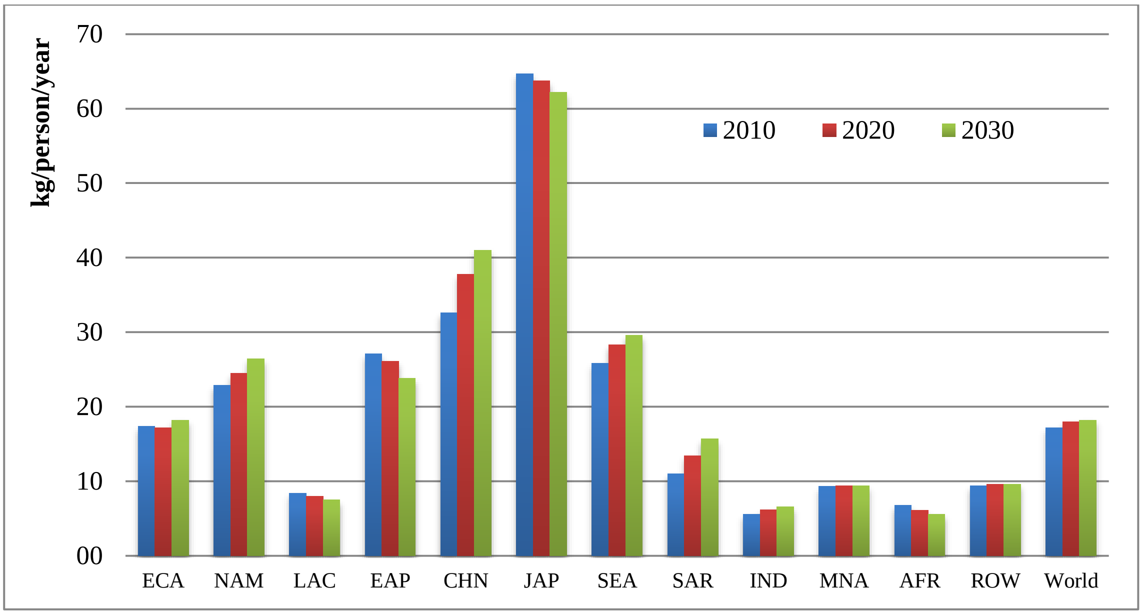
As for fish consumption, the model predicts that 62 per cent of food fish will be produced by aquaculture by 2030. The growth in global fish demand along with a stagnant supply of capture fisheries will create a gap between fish supply and demand. The continued growth in aquaculture supply, notably in Asia (Figure 16) will fill this gap. Aquaculture will likely confirm its role in total fish supply also beyond 2030 (Kobayashi, et al., 2015).

Figure 15. Fish to 2030: aquaculture and capture production projections



Source: adapted from World Bank (2013).

Figure 16. Fish to 2030: apparent per capita fish consumption projections



Note: ECA = Europe and Central Asia; NAM = North America; LAC = Latin America and Caribbean; CHN = China; JAP = Japan; EAP = other East Asia and the Pacifi c; SEA = Southeast Asia; IND = India; SAR = other South Asia; MNA = Middle East and North Africa; AFR = Sub-Saharan Africa; ROW = rest of the world.

Source: adapted from World Bank (2013).

2 Aquaculture Contribution to Food Security: a Literature Review

> «Aquaculture addresses […] food insecurity through a variety of routes and at various scales. It offers a means for smallholder farmers to diversify production, thereby providing nutritious food for their own families, and sometimes those of their neighbours, while also generating surpluses for sale. Aquaculture enterprises from micro to large scale, providing fish exclusively for sale, create farm income and employment opportunities throughout the value chain and provide affordable, highly nutritious food in response to market demand» (Beveridge, et al., 2010).

In the last decades, an extensive research literature has sought to study the contribution of the increasing development of aquaculture to food security, stimulating a lively academic and political debate. Indeed, this is a topic of growing relevance for both the countries that have implemented actions to support the sector, like in Southeast Asia (Hishamunda & Subasinghe, 2003; Hishamunda, et al., 2009a), and the countries and/or regional bodies that are planning policy measures to enable the development of the sector, such as in SSA (FAO, 2016m). Overall, these studies suggest that aquaculture had a positive impact on food security (e.g., HLPE, 2014; Béné, et al., 2015; Béné, et al., 2016), among the others). However, their results are hardly comparable since they use very different datasets, in terms of temporal and geographic coverage, and diverse analysis techniques, and, most importantly, they address different elements of food security.

This chapter has a threefold purpose. First, it reviews the literature addressing the impact of aquaculture development on each food security dimension. I am aware that food security dimensions need in-depth theoretical work to properly explain the overall impact on food security, but this theoretical research goes beyond the scope of this work. For this purpose, I here adopt the term “food fish”- availability, access, utilization and stability to specifically highlight the focus on aquaculture. As mentioned in Section 1.2.2, “food fish” refers to finfishes, crustaceans, molluscs, amphibians, freshwater turtles and other aquatic animals produced for the intended use as food for human consumption (FAO, 2014b).

Second, the chapter explores if, in the reviewed literature, the impact of aquaculture development refers to the determinants and/or on the outcomes of food security. As introduced in Section 1.1.1, food security determinants address all the structural conditions that may cause food insecurity, whereas outcome identify the results of food insecurity in terms of inadequate food intake, anthropometric failures, or poor health (Akinyoade, et al., 2014).

Third, the chapter attempts to identify the shortcomings of these studies and the gaps of the literature that I attempt to overcome in the empirical analysis performed in Chapter 3.

To this end, I do not provide a comprehensive review of this extensive literature, but I rather focus on the most recent contributions (the last 15 years). In addition, in line with the description presented in Section 1.1, I have adopted a specific criterion of analysis, showing how this literature has addressed the impact of aquaculture development on each of the four food security dimensions: availability (Section 2.1.1), access (Section 2.1.2), utilization (Section 2.1.3) and stability (Section 2.1.4). The approach has been to address, whether available in the selected literature, the contribution of the aquaculture sector on each element defining the food security dimension, e.g. production in the availability dimension. The elements of each food security dimension have been introduced in Section 1.1 and recalled in Section 2.1. A separate section, which serves as a support to the development of the empirical analysis in Chapter 3, analyses the methodologies applied in the studies reviewed (Section 2.2).

2.1 An Overview

Aquaculture’s potential contribution to food and nutrition security is extensively addressed in the academic and political debate (Béné, et al., 2015).

The Abuja Declaration on Sustainable Fisheries and Aquaculture in Africa, which was adopted in 2005 by the Heads of States during the Fish for All Summit of the New Partnership for Africa's Development (NEPAD), called for a range of actions in support of aquaculture. In particular, the declaration called for «aquaculture to be adequately reflected in the national and regional economic policies, strategies, plans, and investment portfolios, including […] food security strategies» (NEPAD, 2005).

In 2005, The Economic Community of West African States[50] (ECOWAS) adopted the Regional Agricultural Policy for West Africa (ECOWAP). The related regional action plan for its implementation included, among its priority areas, the development of the fish farming supply chain. In this context, programmes have been formulated for promoting food security through fish farming (ECOWAS, 2008).

Following the 2010 Banjul Conference of African Ministers for Fisheries and Aquaculture (CAMFA I), the African Union (AU) developed a Policy Framework and Reform Strategy for Fisheries and Aquaculture (PFRS) in Africa (AU, 2015). One of the PFRS objectives is to assist AU Member States, Regional Economic Communities (RECs) and Regional Fisheries Bodies (RFBs) «to develop realistic fisheries and aquaculture policies by suggesting standards and best practices to the sector's benefits to AU member states, in terms of food security, employment and income» (AUC-NEPAD, 2014).

During the eighth session of the FAO Sub-Committee on Aquaculture[51], held in Brasilia, Brazil, from 5 to 9 October 2015, the Members Countries «cognizant of the increasing contribution of the small-scale aquaculture sector to food security […] recommended FAO to make available guidance to systematically assess its contribution» (FAO Committee on Fisheries, 2015a). Nevertheless, little or no hard statistical information exists concerning the performance of the aquaculture sector, in general, and the impact of aquaculture on food security, in detail (Tacon, 2001; AFSPAN, 2014a; FAO, 2014b). In addition, surveys of methodologies for assessing this contribution are poorly documented (Cunningham, 2005).

From a chronological perspective, in the earlier studies, from mid-1990s and mid-2000s, aquaculture impact on food security was mainly analysed in terms of employment, foreign exchange generation or food supply[52]. However, positive impacts were mostly assumed and rarely based on in-depth analysis (Agüero & González, 1997).

This chapter reviews the most recent literature addressing the contribution of aquaculture to food security. The search was mostly performed electronically in Google and Google Scholar[53] using the following keywords: aquaculture, food security, availability, access,

[50] ECOWAS is composed by Benin, Burkina Faso, Cape-Verde, Côte d'Ivoire, the Gambia, Ghana, Guinea, Guinea Bissau, Liberia, Mali, Niger, Nigeria, Sierra Leone, Senegal and Togo.

[51] Established in 2001, the FAO Sub-Committee on Aquaculture provides, in terms of aquaculture-related matters, a forum for consultation and discussion and advices to Committee on Fisheries (COFI) and FAO (FAO Fisheries and Aquaculture Department, 2005).

[52] A comprehensive literature review has been conducted by Ahmed & Lorica (2002).

[53] In addition, some studies were suggested by one of the referees.

utilization and stability. The main aim was to select the literature relevant to the goal of this research, i.e. studies that seek to evaluate the impact of aquaculture on food security and/or could bring out this impact in at least one dimension of food security. The search covered only international literature for the last fifteen years, from 2001 to 2016. This topic is addressed, in particular, by FAO, through the SO 1 "Help eliminate hunger, food insecurity and malnutrition", WorldFish[54], an international research organization, and the Network of Aquaculture Centres in Asia-Pacific (NACA), an intergovernmental organisation[55].

The literature review identified 54 papers in line with the goal set. They addressed the utilization dimension (28 of which 17 were utilization only), access (28, of which nine were about access only), availability (24, of which six availability only), and stability (seven) (Figure 18). The impact on the stability dimension of food security is the most neglected among the reviewed studies. The results have been mapped according to the following criteria: focus (i.e., aquaculture only, or both aquaculture and capture fisheries), type of impact (food security only, or both food security and poverty), impact on food security by dimension (i.e., availability, access, utilization and stability), method of analysis (literature review only, quantitative analysis only, or both), and the level of analysis of the quantitative literature (macro or micro level). The mapping exercise is detailed in Appendix 1.

The reviewed literature mostly addresses the contribution of total fishery instead of addressing aquaculture specifically (31 documents); investigates, in most cases, the impact on food security's determinants only (51 studies); does not assess all four food security dimensions (only four studies addressed all the four dimensions) nor assesses the impact on food security together with poverty (11 papers) (Figure 18).

Amongst the screened studies, 24 rely on the review of existing literature only whereas 22 perform a quantitative analysis only (Figure 18). In general, among the quantitative papers, those focusing on micro-level studies provide more detailed information from a methodological perspective, compared to the studies addressing the topic at macro level. Different methodologies have been applied, such as descriptive analyses (e.g., Banda Nyirenda, et al., 2010; Belton & Thilsted, 2014; Toufique & Belton, 2014; El Mahdi, et al., 2015; Ben, et al., 2015) and regression models (e.g., Dey, et al., 2005; Béné, et al., 2010; Ahmed & Garnett, 2011). The applied methodologies are reviewed in Section 2.2.

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[54] WorldFish is a member of the Consultative Group on International Agricultural Research (CGIAR). For more information: https://www.worldfishcenter.org.

[55] The Member Countries of NACA are Australia, Bangladesh, Cambodia, China, Hong Kong SAR, India, Indonesia, I.R. Iran, Korea (DPR), Lao PDR, Malaysia, Maldives, Myanmar, Nepal, Pakistan, Philippines, Sri Lanka, Thailand and Viet Nam. For more information: https://enaca.org.

Figure 17. Literature review: impact on food security by dimension

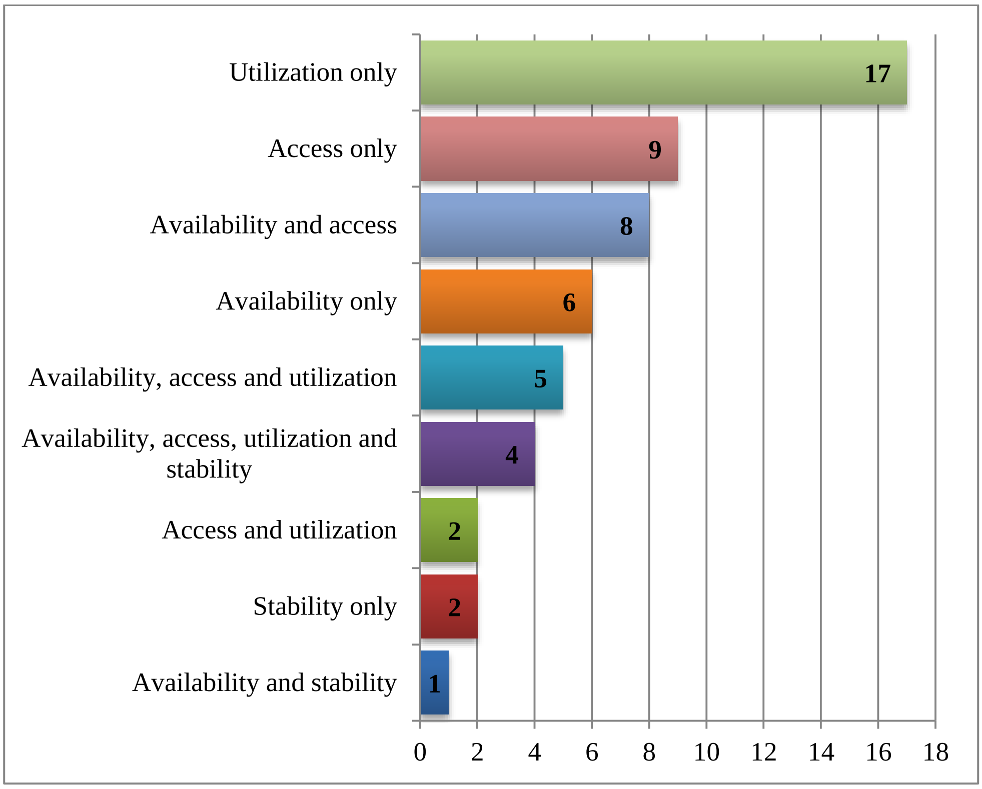
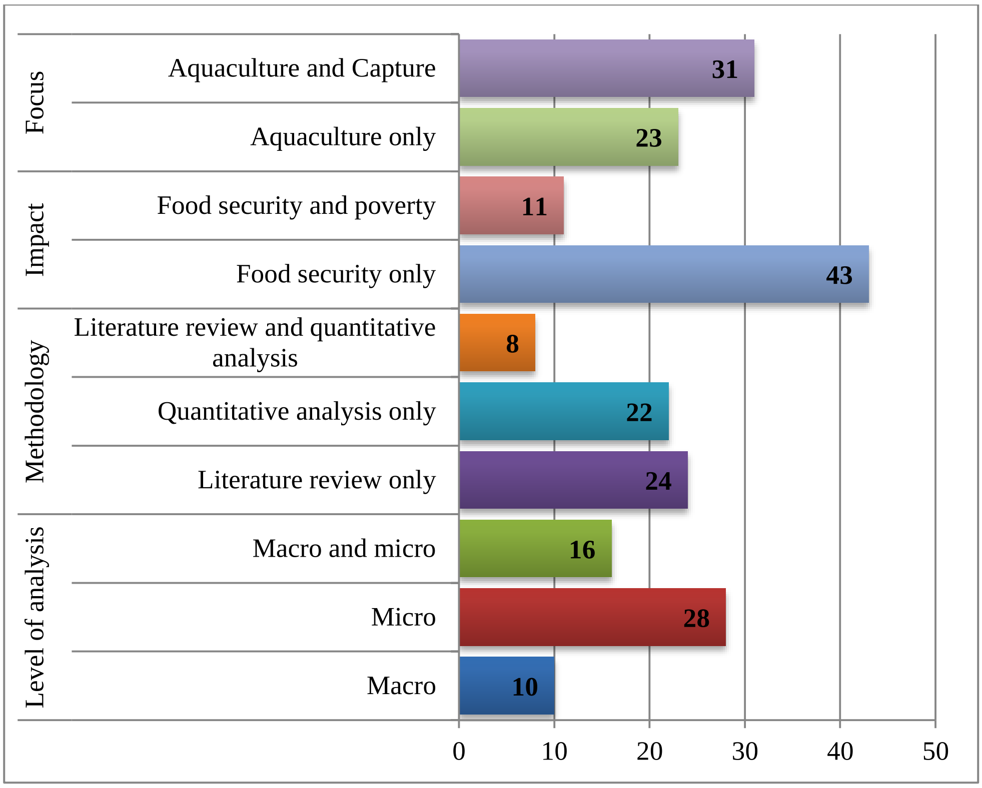


Figure 18. Literature review: focus, impact, methodology and level of analysis



Some studies set their scope only as a review of the existing literature (e.g. AFSPAN, 2012; Béné, et al., 2016; Kawarazuka, 2010). In 2012, CFS requested the HLPE to explore the role of sustainable capture fisheries and aquaculture on food security and nutrition (HLPE, 2014). The Aquaculture for Food Security, Poverty Alleviation and Nutrition (AFSPAN) project, under FP7, performed a literature review of the contribution of fishery as a whole, i.e. capture fisheries and aquaculture, on both food and nutrition security and poverty in Low Income and Food Deficient Countries (LIFDCs) (AFSPAN, 2012). The study addresses three out of the four food security dimensions, namely availability, access and utilization in the selected 65 documents (peer-reviewed articles, project reports, international agencies' reports)[56]. Similarly, Béné et al. (2016) evaluated both capture fisheries and aquaculture's contribution to both food security and poverty in developing and emerging economy countries by screening 202 documents (journal articles, books and book chapters, government and international institution studies, reports, working papers, and other grey literature sources) published between 2003 and 2014[57].

Since most of this literature has been already ably reviewed and synthesized by prominent scholars (Ahmed & Lorica, 2002; Kawarazuka, 2010; AFSPAN, 2012; HLPE, 2014; Béné, et al., 2016), the purpose of this section is not to review all the studies on this topic but rather to cover the most relevant findings for this dissertation. Moreover, compared to the above-mentioned studies, the literature review completed here focused, whenever feasible, on the contribution of aquaculture to food security only, without considering the contribution of capture fisheries and the impact on poverty, even if the selected studies included in the literature review addressed these aspects. Starting from the definition of food security and the elements that characterize each of its dimensions (Section 1.1), the main effort of this review was to make a clear connection between the results of the selected literature and each dimension of food security in order to highlight the impact of aquaculture on the availability, access, utilization and stability dimensions. From this review, it became apparent that the majority of the selected studies had focused on one or more specific elements of each food security component; for example, the fish trade as related to the availability component or nutritional intake as a proxy for the utilization component.

[56] The studies were grouped and classified according to the following features: study type, methodologies, and data sources.
[57] The scope was to assess the scientific quality and consistency of the literature, and, where it exists, the reasons for inconsistencies.

It is worth mentioning that in the selected literature, the linkages between aquaculture and sectors other than capture fisheries are mostly addressed in terms of integration, rather than in terms of competition, over the use of resources, such as land and water. Aquaculture affects the demand for land, directly for aquaculture production in land-based farming systems, e.g. in ponds and integrated systems, and indirectly for feed production (Chiao-Ya, et al., 2015). At the global level, in 2010, aquaculture occupied around one per cent of agricultural land. Land availability for direct aquaculture purposes is a key constraint for the growth of the sector (Waite, et al., 2014). Competition for inshore sites coupled with increased production costs, in some regions, led to the development of aquaculture on agricultural land and to the intensification of production. In other regions, competition over both agricultural land and inshore sites led to the development of offshore aquaculture in open seawater[58] (Troell, et al., 2014). Some studies address the contribution of integrated aquaculture and agriculture farming systems in enhancing food security, particularly with regard to food availability, through the shared use of land and water resources, and coexisting production activities (Dey, et al., 2006; Ahmed & Garnett, 2011). While recognizing the importance of the linkages between aquaculture and agriculture in terms of competitions over the resources' utilization, these topics have not been explored because they do not relate to the purpose of this research project.

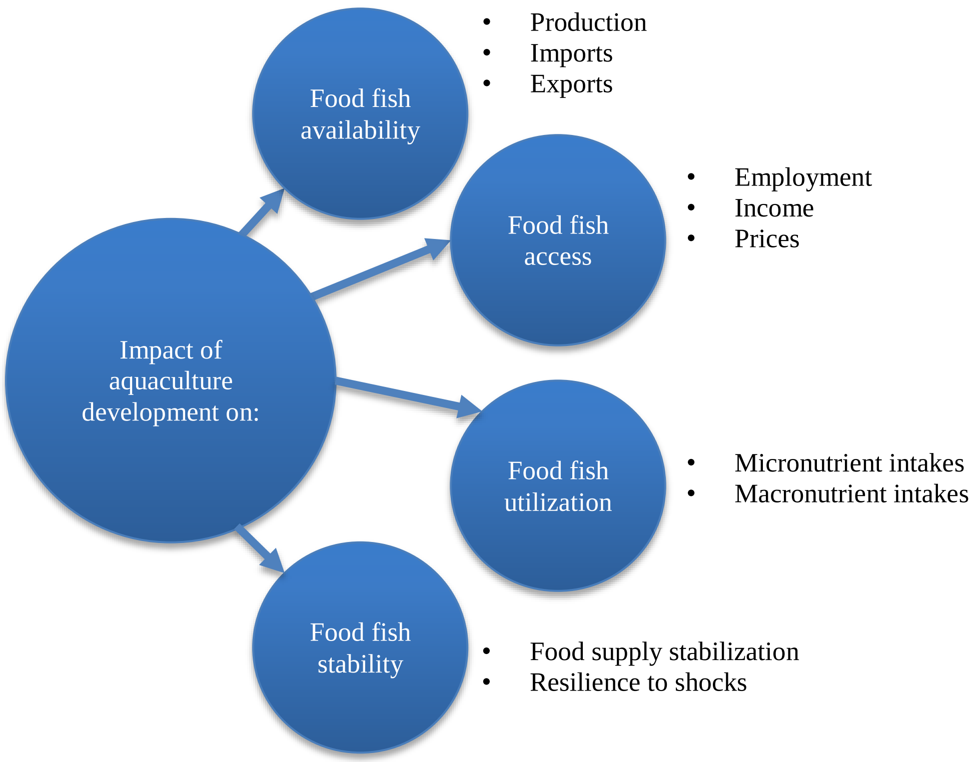
Since the purpose of the literature review is to address specifically the impact of aquaculture development on each food security dimension, the terms "food fish"- availability, access, utilization and stability have been adopted here to highlight the focus of this review. As mentioned in section 1.2.2 of this analysis, "food fish" includes finfishes, crustaceans, molluscs, amphibians, freshwater turtles and other aquatic animals produced for the intended use as food for human consumption (FAO, 2014b). For this purpose, I have developed a conceptual framework that underlines the main elements that influence food security through the aquaculture sector in the reviewed literature (Figure 19). It also serves as a useful background for setting the empirical analysis performed in Chapter 3. Moreover, the next sections explore if, in the reviewed literature, the impact of aquaculture development refers to the determinants and/or on the outcomes of food security, according to the definition provided in Section 1.1.1.

[58] Offshore aquaculture, which is run in open seawaters, is exposed to wind and wave actions and required equipment and vessels to operate, eventually, in severe sea condition (Drumm as cited in Kapetsky et al. (2013).

I am aware that food security dimensions need in-depth theoretical work to properly explain the overall impact on food security, but this theoretical research goes beyond the scope of this work. To offer a comprehensive interpretation of the analysis presented in next sections, it could be useful to combine the literature addressing the impact on food security of aquaculture development with the studies on the impact of the agriculture sector as a whole and/or of specific commodities (see Achterbosch et al. (2014), Bertelli and Macours (2014) and Mango et al. (2017), among the others).

Finally, although the fragmented nature of the literature, in terms of both datasets and econometric techniques, makes it difficult to accomplish systematic comparisons, some scholars have performed meta-analyses (Zheng, et al., 2012; Zhao, et al., 2015). However, these studies focused on total fisheries impact on only the utilization dimension, showing that fish consumption was associated with a reduced risk of mortality. Nevertheless, this type of analysis goes beyond the scope of my work but it could be part of my future research projects.

Figure 19. Literature review: conceptual framework



2.1.1 The Availability Dimension

The food fish availability dimension is composed by the following elements: levels of production, imports and exports, and stock excluding fish used for non-food purposes[59] (FAO, 2008; Beveridge, et al., 2013). The aquaculture contribution to this dimension depends on the characteristics of the farmed fish species, for example nutrition content, suitability to local taste and storability (Hishamunda, et al., 2009b). The aim of this section, as introduced in Section 2.1, is not to provide a comprehensive review of the literature addressing food security from a food availability perspective, but rather to analyse how aquaculture development has been addressed in the different theoretical frameworks and, in particular, in the studies that have linked the sector development to the availability dimension. Within the food fish availability dimension, the impact of aquaculture is here analysed in terms of production, imports and exports level.

When dealing with the availability dimension in terms of **production levels**, the literature has referred mainly to the existing statistics in order to highlight the uninterrupted increase in aquaculture production, especially in developing countries, and the rising importance over capture fisheries in terms of total fishery production. As shown in Section 1.2.2, from 1950 to 2014, aquaculture increased from just over 600 thousand to almost 74 million tonnes. Its contribution to total fish production increased from 3 to 44 per cent, narrowing the gap from capture fishery production. In 2014, the top ten producers, making up almost 89 per cent of world aquaculture production, are all in developing countries with the exception of Norway (author's elaboration based on FAO (2016i). Even considering the feeding practices for carnivorous fish species, aquaculture still represents a net contributor to the global fish supply, mainly through herbivorous species (Naylor, et al., 2001). The diet of carnivorous fish such as salmonids, seabass, seabream and eels, is composed by high levels of proteins derived from animal sources. Fishmeal, which is composed of flours, meals and pellets from fish, crustaceans, molluscs or other aquatic invertebrates, represents between 20 and 40 per cent of their diets (Huntington & Hasan, 2009). It is worth mentioning that fish processing waste, around 15 per cent, is also used in global fishmeal supply and it is expected to increase according to World Bank's Fish to 2030 projection (World Bank, 2013).

[59] This element "fish stock" is not been addressed in this review because information on changes in stocks occurring between the production and the retail levels, or in levels of inventories, is very incomplete. Fish used for non-food purposes includes utilization of aquatic products for reduction to meal and oil as aquaculture feed, for ornamental purposes and any other non-food use (e.g., fertilizers and medical uses) (Laurenti, 2014).

The aquaculture contribution to the availability dimension in terms of production levels is a key element also in studies generating projections on aquaculture development (OECD/FAO, 2015a; World Bank, 2013; Merino, et al., 2012). According to OECD/FAO (2015a), the rise in total fishery production will be mainly driven by aquaculture, which will expand by 38 per cent between the baseline period (2012–2014) and 2024, and will surpass capture fisheries in 2023. In 2024, almost all aquaculture production is expected to originate from developing countries (94 per cent). At global level, aquaculture will contribute to 50.4 per cent of total fishery production; this contribution will be higher in developing countries (56.1 per cent) (OECD/FAO, 2015a). At the global level, it is believed that aquaculture supply should be able to meet food demand (Martinez-Porchas & Martinez-Cordova, 2012) by coping with a growing fish demand driven by population increase, economic development and urbanisation (Brummett & Williams, 2000; Merino, et al., 2012). However, this scenario would require improving the efficiency at which farmed fish converts a weight-equivalent unit of wild fish into a unit of farmed fish[60]. It could also mean to increase the proportion of the global fishmeal supply from aquaculture (Merino, et al., 2012).

As mentioned in Section 1.2, aquaculture includes a rich assortment of farming systems and technologies (Funge-Smith & Phillips, 2001). Some studies address the impact of specific aquaculture farming systems, i.e. integrated farming system[61] and polyculture[62], on the availability component in terms of production levels (Ahmed & Garnett, 2011; Dey, et al., 2006; Genschick, et al., 2015). In Ahmed & Garnett (2011), factors that hampered the ability to meet food demand in Bangladesh, such as population growth and reduction of farming land, were overcome through integrated rice-fish farming. Compared to rice monoculture and alternate farming (i.e., rice and fish grown rotationally), the integrated farming system provided for increased food production and higher rice productivity. In detail, rice production was higher in the integrated farming system. The integrated farming reported the highest average annual productivity of rice per hectare (10 178 kg), followed by rice monoculture (9 691 kg) and alternate farming (4 986 kg). Fish production did not increase to the same extent as the alternate farming. The study suggested that higher yields could be achieved by increasing the inputs in the integrated farming system. In Dey et al. (2006), small-scale

[60] This "fish conversion ratio" is measured by the Fish In-Fish Out (FIFO) ratios.
[61] Integrated aquaculture systems refer to the production, shared management and use of aquaculture, agriculture and/or livestock (FAO/ICLARM/IIRR, 2001).
[62] In polyculture systems, several fish species are farmed in the same water body, e.g. North African catfish and tilapia in freshwater in Africa, milkfish and shrimp in brackish water in the Philippines and Indonesia, amongst the others (UNDP/FAO/ARAC, 1987).

farmers practicing integrated agriculture-fish farming grew more high-value crops, e.g. vegetables, around their fishponds. Moreover, integrated farming recorded higher productivity levels, by 11 per cent, compared to non-integrated farmers.

In Bangladesh, polyculture of small- and large-sized fish species, most commonly native carps, led to an increase in total production without affecting the performance of the individual fish species. Since small-sized fish species required a shorter growing cycle compared to large-sized fish species, multiple harvests of small-size fishes have been achieved. This allowed households to increase food availability during seasons of food shortage, thereby improving the availability, utilization and stability dimensions of food security, and increase their income, therefore enhancing the access component of food security (Genschick, et al., 2015).

Concerning the effect of **imports and exports levels** on the availability dimension of food security, it is worth noting that, at the global level, aquaculture data are available only on production. It is equally noteworthy that statistics on imports and exports are collected as a total fishery aggregate without distinguishing between capture fisheries and aquaculture. Fish trade contribution to food security is poorly assessed and lack of solid evidence in both narratives through and versus fish trade (HLPE, 2014; Béné, et al., 2016). Béné et al. (2010) stress that supporters of fish trade contribution to food security tend to rely on country level data in value unit, which refer to foreign exchange earnings and/or revenues from fish trade. According to the authors, these statistics do not show the effects on people's livelihoods; on the other side, fish trade opponents seem to found their narrative on case studies, which restrain the generalizability of their findings and, probably, the acceptance within the scientific community (Béné, et al., 2010).

An analysis conducted by AFSPAN[63] (2015) found that international fish trade did not affect domestic fish availability. The seafood trade flow from developing countries[64] to developed countries, and from developed countries to developing countries, was similar in quantity. The main difference was in quality terms, since developing countries exported high-value seafood and imported low-value seafood. However, these outcomes were not supported by quantitative results. Aquaculture development in Bangladesh and Myanmar driven by private investments along the value chain, resulted in production mostly destined for domestic

[63] ASPAN developed a framework to quantify aquaculture's contribution to reducing poverty and hunger in eleven LIFDCs (Kenya, Uganda, Zambia, for Africa, Bangladesh, China, India, Philippines, Viet Nam, for Asia, and Brazil, Chile, Nicaragua, in Latin America) (AFSPAN, 2014a).

[64] The countries in the AFSPAN's study (2015) were Kenya, Uganda, Zambia, for Africa, Bangladesh, China, India, Philippines, Viet Nam, for Asia, and Brazil, Chile, Nicaragua, in Latin America.

consumption (Belton, et al., in press; Hernandez, et al., in press). Kurien (2005) points out that fish production growth coupled with increases in international fish food imports and exports, seems to improve domestic fish availability in selected LIFDCs[65]. While Béné et al (2010) detect neither negative nor positive impacts of fish trade between sub-Saharan Africa (SSA) and developed countries on food security. Intraregional trade between African countries, which, according to the authors, could affect the growing demand for low-value fish species, was not addressed in the study.

2.1.2 The Access Dimension

Food fish access dimension is primarily affected by fish prices and consumers income. Households' ability to effectively utilize their physical and financial resources to access food is also influenced by the surrounding physical, social and policy environment (Riely, et al., 1999).. The purpose of this section is not to review all the studies on the impact on overall food access but just cover the findings that are most relevant to this dissertation, in particular in terms of food security outcomes. In the reviewed literature, aquaculture's contribution to food fish access has been mainly addressed in terms of employment, income and prices levels.

According to the conceptual framework developed by Ahmed and Lorica (2002), aquaculture has the potential to affect the access dimension of food security in at least three ways. It is by affecting **income and purchasing power** (through positive income elasticity of fish and other non-staple food demand, and income effect from aquaculture production and sale), **employment** (through the ability to earn wage or income, to consume nutrient-rich fish, and to increase labour productivity) and **consumption** (through in-house consumption and price effect).

In terms of **employment and income generation**, the literature stresses that aquaculture, in particular commercial aquaculture[66], can contribute to the access to fish and other food items by generating income, wages and salaries, especially in low income and

[65] The countries in the Kurien's study (2005) were Brazil, Chile, Fiji, Ghana, Kenya, Namibia, Nicaragua, Senegal, Sri Lanka, the Philippines and Thailand.

[66] The features defining commercial aquaculture are the presence of a business orientation and the adopted method of remuneration of the production factors, i.e. commercial farms tend to hire labour instead of relying primarily on family labour. Commercial fish farmers participate actively in the markets by purchasing their inputs and ensuring the sale of their outputs (Percy & Hishamunda, 2001; Ridler & Hishamunda, 2001; Manning & Hishamunda, 2002).

emergent countries (Hishamunda, et al., 2009b; Allison, 2011; Béné, et al., 2015). Commercial aquaculture is defined as an aquaculture operation whose goal is to maximize profit regardless of the size of the farm and the farming system (Ridler & Hishamunda, 2001).
Employment in the fisheries sector, both capture and aquaculture sectors, has grown faster than the world's population and the employment in the traditional agriculture sector (FAO, 2014b). Ahmed and Lorica (2002) have reported that aquaculture development in a number of countries, i.e. Bangladesh, China, India, Indonesia, Thailand and Vietnam, created additional employment and income. Moreover, along the value chain, aquaculture generated backward, e.g. seed and feed deliveries, and forward, e.g. harvesting, processing and marketing, opportunities. From a gender perspective, according to Kawarazuka and Béné (2010), the involvement of women in aquaculture related activities, such as processing and trading, can positively impact the allocation of household income to food commodities and, therefore, the household energy intake.

Aquaculture affects the access component also through local multiplier and spillover effects in fishery-dependent regions. Aquaculture is able to generate employment multiplier effects in hatcheries, feeding mills, processing industries, distribution, retail and service sectors (Ridler & Hishamunda, 2001; Hishamunda, et al., 2009b; Allison, 2011). Salmon farming in Chile created one indirect job for every two employed directly in the sector. Shrimp culture in Sri Lanka created one indirect job for each direct job. The employment multiplier effect of shrimp farming in Madagascar was estimated at 1.4 (Ridler & Hishamunda, 2001).

Aquaculture represents the main source of **income** in most households and, therefore, the main livelihood component to guarantee access to food. Revenues are also generated from exports, taxation, license fees and from foreign investments in aquaculture (Hishamunda, et al., 2009b; Allison, 2011; Béné, et al., 2015).

In AFSPAN (2015), aquaculture incomes, wages and salaries were found to be at the same level or higher than the average per capita income of the bottom 40 per cent recorded at country level[67]. Moreover, the sector produced an income multiplier effect, for every dollar generated by aquaculture activities, an additional US$ 1.3 was created at the local level. The share of aquaculture in household income for the poorest household, at the first poverty quartile, was 0.97. In Bangladesh, for example, the fish farm income of the poorest

[67] The analysis is conducted in the following 11 countries: Kenya, Uganda, Zambia, for Africa, Bangladesh, China, India, Philippines, Viet Nam, for Asia, and Brazil, Chile, Nicaragua, in Latin America (AFSPAN, 2014a).

households (at the first poverty quartile) was US$ 270 and represented the 97 per cent of the total household income (AFSPAN, 2015).

Some studies addressed the impact of specific aquaculture farming systems, i.e. integrated farming system, on the access component in terms of income generation (Ahmed & Garnett, 2011; Dey, et al., 2006). For example, Ahmed and Garnett (2011) have found that integrated rice-fish farmers consume more food and recorded higher incomes than farmers engaged in rice monoculture or alternate fish/rice farming. The households of integrated farmers consumed 40 per cent of their fish production while alternate farmers consumed only 15 per cent. The average annual net income was estimated at US$ 633 for a farmer in integrated farming, US$ 508 in rice monoculture and US$ 368 in alternate farming.

In Dey et al. (2006), integrated agriculture-fish small-scale farmers showed higher levels in terms of profit, employment, and animal protein consumption compared to non-integrated farmers. Farm income were higher for integrated farmers (US$ 185) and contributed to 80 per cent of total household income, compared to non-integrated farmers (US$ 254), whose farm income of US $115 contributed to 66 per cent of total household income (US$ 174). Integrated farming households consumed fresh fish and other animal protein foods more frequently than non-integrated farming households did. As shown in these studies, aquaculture has the potential to contribute to food security by increasing the purchasing power of the households through the sales of aquaculture products (Beveridge, et al., 2013) and by affecting consumption through **in-house consumption** (Ahmed & Lorica, 2002; Beveridge, et al., 2013).

In-house consumption is not restrained to non-commercial/subsistence aquaculture. In Bangladesh, for example, small-scale commercial fish farms showed higher in-house fish consumption compared to subsistence fish farmers (Belton, et al., 2014a). According to AFSPAN (2015), households practicing aquaculture recorded fish consumption generally higher than the national level. However, these findings are based on anecdotal evidence not supported by data.

There is some value in taking into consideration that Dey et al. (2005) and Belton et al. (2011) focus on the **food security outcomes** by measuring the share of food expenditure of the poor. As mentioned in Table 1, this food security indicator addresses one manifestation of the access component[68]. In the study conducted by Dey et al. (2005) in Asian countries[69], consistent with Engel's law, the income proportion devoted to food commodities, 60–90 per cent of total expenditure, was higher in low-income groups, and a substantial share was spent on fish. The share of food expenditure that poorer households spent on fish was 72.4 per cent in Southern Viet Nam, 53.6 per cent in the Philippines, 31.2 per cent in China, 26.1 per cent in Bangladesh, 14.1 per cent in Thailand, 13.7 per cent in India, 12.5 per cent in Northern Viet Nam and 9.2 per cent in Indonesia. Fish represented an important source of animal protein in poorer households and was mostly consumed in rural areas compared to the consumption of urban dwellers. Moreover, fish producers consumed more fish than non-producers in rural areas did. In the Philippines, for example, the total annual per capita fish consumption was 72.6 kg for producers in the rural areas, 39.7 kg for non-producers in the rural areas and 33.9 in the urban areas. Except in China and Thailand, consumers tended to allocate a higher proportion of their food budget to fish.

By contrast, in Belton et al. (2011), in Bangladesh, the expenditure on fish ranged from 9 per cent of the total food expenditures in low income groups (i.e., household with a monthly income of less than 750 Bangladeshi Taka [Tk]) to 14 to 15 per cent in the wealthiest categories (i.e., monthly income higher than Tk 20 000). Low-value fish species and farmed carps were consumed mostly in rural areas, while high-value capture fish species were preferred by urban dwellers. Poorer households paid a lower average price, Tk 46 per kilogram, compared to better-off households (Tk 109), which indicates that low-income groups consumed cheaper, small-sized, or poorer quality fish species.

In an effort to understand the access dimension in terms of **fish price levels**, the survey conducted by El Mahdi et al. (2015) in Egypt points out that price is an important factor affecting fish consumption. A higher supply of fish from aquaculture compared to capture fisheries results in lower prices of farmed fish, thereby in increased food access in Beveridge et al. (2013) and Hernandez et al. (in press).

According to Troell et al. (2014), the lower volatility of aquaculture prices compared to other food commodities has contributed to a more stable food supply. This had a higher impact on

[68] According to FAO et al. (2013), the share of food expenditure of the poor is an outcome indicator of food security. It measures the «proportion of food consumption over total consumption (food and non-food) for the lowest income quintile of the population. […] this indicator captures the monetary value of food obtained from all the possible food sources (purchases, own-production, gift, in-kind payment, etc.), rather than just the monetary value of purchased food. Total consumption expenditures include both food and non-food expenditures, and exclude non-consumption expenditures such as taxes, insurances, etc.» (FAO, 2016e).

[69] The study is conducted in the following Asian countries: Bangladesh, China, India, Indonesia, the Philippines, Thailand, and Viet Nam.

lower income groups, which are likely to allocate a greater proportion of their budget to food commodities. At the international level, aquaculture prices have also contributed to keep aggregated fish prices, including both farmed and wild-caught fish, lower compared to a scenario without aquaculture. This could have also contributed to reduce the level of exploitation of wild-caught fish stocks (Belton & Thilsted, 2014; AFSPAN, 2015). Troell et al. (2014) calculate a correlation of 0.97 between aquaculture and capture fisheries price index. However, the literature review by Bjørnal and Guillen (2016) on market integration between farmed and wild-caught fish reveals that some species and markets are more likely to be affected than others. In Asia, lower aquaculture prices also affected seafood prices thereby generating a less marked increase in fish prices compared to other regions (Tveteras, et al., 2012). One explanation is that fish farming has been able to ensure a more stable and continuous supply compared to capture fisheries, given that the latter is affected by seasonality. This high production control has contributed to reduce price volatility in both sectors (Tveteras, et al., 2012).

By applying the above-mentioned conceptual framework developed by Ahmed and Lorica (2002), some studies (Jahan, et al., 2010; Toufique & Belton, 2014) take into account **all the elements of the access dimension**. The analysis conducted by Jahan et al. (2010) shows a positive impact of aquaculture development on employment, income and consumption in selected project sites in Bangladesh[70]. In the surveyed households, total labour, including family and hired employees, increased by 10.2 per cent, while the gross income increased by 8.1 per cent. Moreover, the annual per capita fish consumption increased by 6.6 per cent. In addition, consumption of the cereals staple foods such as cereals increased at a rate of 0.6 per cent. In Toufique and Belton (2014), commercial aquaculture lowered fish prices, resulting in increased fish consumption by poor consumers and those in rural areas of Bangladesh. On average, per capita fish consumption increased by 28.6 per cent at the national level.

[70] Jahan et al. (2010) referred to the Development of Sustainable Aquaculture Project (DSAP), funded by the United States Agency for International Development (USAID) and implemented by the WorldFish Center in Bangladesh between 2001 and 2005, whose objective was to improve resource use efficiency and increasing productivity at the farm by the diffusion of low-cost aquaculture technologies.

2.1.3 The Utilization Dimension

The food fish utilization dimension of food security looks at aspects like nutrition, food preparation and sanitation knowledge, dietary habits, health care and conditions, access to clean water, adequate caring practices, especially for infants, young children, pregnant and lactating women (Hishamunda, et al., 2009b; Genschick, et al., 2015; Kawarazuka & Béné, 2011). Rather than addressing the overall impact on food security from a food utilization perspective, this section seeks to analyse how aquaculture has been addressed in the studies that have linked the sector development to the utilization dimension and, whenever feasible, in terms of food security outcomes. Within the food fish utilization dimension, the selected literature addressed the impact of aquaculture in terms of micronutrient and macronutrient intakes.

When dealing with the utilization dimension in terms of **nutrients**, most of the selected literature focused on macronutrients intakes that provide energy and protein, and the micronutrients, i.e. mineral and vitamins, without distinction between aquaculture and capture fisheries products. Fish is considered an important domestic source of animal protein and other essential nutrients (omega-3 polyunsaturated fatty acids (PUFAs), fat-soluble vitamins (A, D and E), water-soluble vitamins (B complex), and minerals like calcium, phosphorus, iron, iodine and selenium (Tacon, 2001; FAO/WHO, 2011; Béné, et al., 2015; Genschick, et al., 2015).

The role of fish consumption in improving **micronutrient** deficiencies in developing countries has been widely analysed in the literature. Small-sized fish species, e.g. mola (*Amblypharyngodon mola*), darkina (*Esomus danricus*), sardines and pilchards, anchovy, seabass and tilapia, consumed whole provide for minerals such as iodine, selenium, iron, calcium, phosphorus, potassium, and vitamins such as A, D and B, as most micronutrients are concentrated in bones, head and viscera (Roos, et al., 2007b; Kawarazuka & Béné, 2011; Thilsted, 2012; Béné, et al., 2015; FAO, 2016l; Thilsted, et al., 2016).
High levels of vitamin A, Fe and Zn exist in some small fish species in developing countries. Small-size fish are more accessible to the poor, being relatively less expensive than large-size fish and other animal-source foods and vegetables, help improve micronutrient deficiencies and provide complementary food for undernourished children (Kawarazuka & Béné, 2011). The high level of iodine in some fish, for example, can help prevent iodine deficiency, which can cause stunted growth and impaired cognitive development (Béné, et al., 2015).

Some studies focus on the impact of specific aquaculture farming systems, i.e. integrated farming system and polyculture, on the utilization component in terms of **nutrient content** (Ahmed & Garnett, 2011; Kawarazuka, 2010). Integrated farming systems between aquaculture and agriculture can contribute to improve dietary intakes (Kawarazuka, 2010). In Ahmed & Garnett (2011), integrated rice-fish farming allowed access to a more balanced diet compared to rice monoculture and alternate farming. Polyculture of small-sized indigenous fish species with large-size fish species, e.g. carps and prawns, has the potential to improve micronutrient deficiencies and their adverse health consequences (Kawarazuka, 2010).

In terms of **macronutrient intakes**, fish provides for the long-chain omega-3 fatty acids docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA), which are important for optimal neurodevelopment in children and for improving cardiovascular health (FAO, 2016l). The levels of PUFA in large freshwater fish species, such as carp and tilapia, is relatively low while small pelagic forage fish, including anchovies and sardines, which are more affordable and traded in developing countries, are richer in PUFA (Kawarazuka & Béné, 2011). This is a significant finding since around 25 per cent of all disability-adjusted life years lost [71] (DALY) due to ischemic heart disease and one per cent of all DALY are caused by low omega-3 fatty acids intake (Genschick, et al., 2015).

At the global level, indicators of the relevance of fish in the human dietary needs are given by the contribution of fish to protein and animal protein intakes. According to Kawarazuka and Béné (2011), fish consumption may improve the plant-based diets in LIFD countries for two main reasons. First, the digestibility of fish proteins is 5–15 per cent higher than that of plant proteins. Second, fish proteins, having a balanced concentration of all essential amino acids, and lysine in particular, help the absorption of plant proteins.

In 2013, about 16.8 per cent of intake of animal proteins and 6.8 per cent of all proteins consumed derived from fish at global level. At regional level, Asia recorded the highest share of fish proteins in terms of animal proteins (22.9 per cent), followed by Africa (18.1 per cent). Asia showed also the highest share of fish proteins in terms of total proteins (7.9 per cent), followed by Oceania (6.8 per cent) (FAO, 2016n). Fish contributes to, or exceeds, 50 per cent of animal protein intake in some countries, such as Bangladesh, Cambodia, Ghana, Indonesia, Sierra Leone, and Sri Lanka (Dey, et al., 2005; Tidwell & Allan, 2011; FAO, 2016l).

[71] DALY quantifies the burden of disease from mortality and morbidity. One DALY measure one lost year of healthy life (WHO, 2016).

Developing countries and LIFDCs record the higher share of fish protein in their diet (FAO, 2016l).

Compared to other terrestrial livestock systems, aquaculture is more efficient in converting feed into consumable protein (Hasan & Halwart, 2009; Hall, et al., 2011). Aquaculture has, on average, a feed conversion ratio[72] (FCR) of 30 per cent compared to 18 per cent for poultry, 13 per cent for pigs, and 2 per cent for sheep (Hasan & Halwart, 2009). The production of one kilogram of farmed finfish protein requires less than 13.5 kilograms of grain compared to 61.1 kg of grain for one kilogram of beef protein and 38 kg grain for one kilogram of pork protein (Hall, et al., 2011).

Farmed species compared to wild-caught species have similar protein quality and amino acid profile. However, since aquaculture species are often richer in lipids than capture fisheries species, the protein quantity may be lower (HLPE, 2014). The difference in lipid content between farmed and wild-caught of the same fish species arises from feeding practices in terms of quantity and composition, and animal activity (Beveridge, et al., 2013). A study conducted by Tacon and Metian (2013) revealed that even if farmed salmonids fish species showed a higher fat content compared to wild-caught salmonids fish species, the levels of EPA/DHA in the edible part were similar. The same study showed that the EPA/DHA levels in farmed channel catfish were considerably lower compared to the wild-caught channel catfish (Tacon & Metian, 2013).

Aquaculture contributes to the utilization component through the nutritional benefits from fish consumption by allowing for a more balanced diet (Ahmed & Lorica, 2002; Allison, 2011). Households engaged in aquaculture activities, practicing subsistence or commercial aquaculture, are able to improve their nutritional intakes by consuming their own fish production. Moreover, household involved in business-oriented aquaculture are able to diversify their diet, by increasing their purchasing power through the sale of fish (Kawarazuka & Béné, 2010; Kawarazuka, 2010). The survey conducted by Banda Nyirenda et al. (2010) among people living with HIV/AIDS in selected provinces in Zambia highlighted the importance of having a steady source of livelihoods and food accessibility for survival, with fish being the most preferred source of protein. Intra-household distribution of food on nutrient intakes from fish has been addressed by Longley et al. (2014). The study points out

[72] FCR, an efficiency measure of the aquaculture production system, is the« ratio between the dry weight of feed fed and the weight of yield gain. Measure of the efficiency of conversion of feed to fish» (FAO, 2016f).

the importance for both mother and, then, the child to get the right nutrients in adequate amounts during the first 1 000 days, i.e. from conception until a child is two years old.

None of the studies reviewed here addresses the topic of either micronutrient absorption or food security outcomes as undernutrition. As pointed out by Pangaribowo et al. (2013), micronutrient intakes are not a proxy for micronutrient absorption. The latter can be hampered by, among the others, poor health care and conditions, lack of access to clean water and adequate caring practices.

2.1.4 The Stability Dimension

The food fish stability component of food security is hampered by occasional shocks such as natural disasters, droughts, adverse weather conditions, political instability, civil conflicts or food price shocks in domestic or world markets (FAO, 2006; FAO, 2008; Hishamunda, et al., 2009b). This section does not review all the studies on the impact of aquaculture on overall food stability but only those whose findings are most relevant to this dissertation. In the reviewed literature, aquaculture's contribution to stability has been addressed mainly as **resilience capacity to stabilize food supply** and **to overcome shocks**.

In developing countries, the whole agriculture sector, including crops, livestock, fisheries and forestry, absorbs 22 per cent of total damage, e.g. damages in aquaculture equipment or hatcheries, and losses, e.g. decline in aquaculture production and increased costs of farm inputs, caused by natural hazards[73] (FAO, 2015b). These processes or phenomena have a direct impact on food security. FAO (2015b) estimates that, after each disaster, the losses in food commodities are equivalent to 7 per cent of national per capita dietary energy supply (DES), and to 2.6 per cent of national agricultural value-added growth.

Aquaculture can positively impact the stability dimension by providing more **stable food supply** compared to capture fisheries, where supplies are often affected by catch limits, quotas, amongst the others, or alternative types of farming (Tveteras, et al., 2012; Troell, et al., 2014; Cunningham, 2005) and thereby increasing the resilience to transitional shocks through food availability[74]. Stability in aquaculture supply also affects food access by

[73] Natural hazards are defined as the «natural process or phenomenon that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage» (UNISDR as cited in (FAO, 2015b).

[74] The impact of aquaculture on fish price stability has been addressed in Section 2.1.2.

securing income and employment and, therefore, resilience to transitional shocks for households (Hishamunda, et al., 2009b).

Hishamunda et al. (2009b) measured the volatility of the actual production value of commercial aquaculture from an estimated trend (28 per cent) in a number of SSA[75] countries in order to assess the potential contribution of stable aquaculture production to transitory food security[76], i.e. short-term and temporary food security. The Democratic Republic of the Congo, Madagascar, and Zimbabwe recorded lower volatility, less than 6 per cent, compared to the other SSA countries. Volatility in Central African Republic, Kenya, Rwanda, and Zambia were higher than 44 per cent. Stability has been also assessed by calculating the correlations between aquaculture protein supply and the total supply of fish protein (0.14 on average) and animal protein (0.11 on average). Low values in volatility and in the correlations above show a general stabilizing role for commercial aquaculture households (Hishamunda, et al., 2009b).

In terms of **resilience capacity to overcome shocks,** the reviewed literature mostly focused on environmental conditions rather than political or economic factors. Bell et al. (2011) assess the vulnerability of aquaculture to the effects of climate change in the Tropical Pacific. The study predicts both the direct effects of various features of climate change including on reproduction, growth and survival of the organisms, and the indirect effects due to habitat alteration including on aquaculture infrastructure. Results indicate that existing and planned aquaculture production of tilapia, carp, and milkfish in freshwater ponds for food security are likely to benefit from the anticipated changes in surface climate. They also show that aquaculture enterprises producing commodities for livelihoods in coastal waters (e.g., shrimp, freshwater prawns and seaweeds) are likely to encounter production problems due to projected changes in the tropical Pacific Ocean. As for freshwater fish species, the benefits in terms increased production are projected to accrue by 2015 and to stabilize within 2100, under the hypotheses that surface temperatures will increase by 2.5–3.0°C and rainfall by 10–20 per cent.

From an opposite perspective, in terms of **aquaculture impacts on the environment**, Waite et al. (2014) assess the possible environmental impact of increasing aquaculture

[75] The analysis was conducted on 12 SSA countries: Cameroon, Central African Republic, the Democratic Republic of the Congo, Congo, Côte d’Ivoire, Kenya, Madagascar, Nigeria, Rwanda, United Rep. of Tanzania, Zambia and Zimbabwe (Hishamunda, et al., 2009b) .

[76] See Section 1.1. Transitory food security may result from «short-term shocks and fluctuations in food availability and food access, including year-to-year variations in domestic food production, food prices and household incomes» (FAO, 2008).

production from 67 million tonnes (Mt) in 2012 to roughly 140 Mt in order to meet global animal protein demand in 2050. First, Waite et al. (2014) have assessed the current aquaculture's environmental performance in 2010. In the current scenario, the impacts varied greatly depending on the species farmed (e.g., carp, molluscs, shrimp, tilapia, catfish, salmon), natural resources exploited, greenhouse gas production, wild fish-based feeding practices and level of production intensity. The majority of species groups studied (i.e., carp, molluscs, tilapia, and catfish), which represented 74 per cent of global production by quantity, consumed low level of wild fish-based feeds. For these species, the Fish In-Fish Out (FIFO) ratios were lower than 0.7, compared to a 1.9 ratio for salmonids species. On the other hand, freshwater fish species, such as carps and catfish, required more land and freshwater per unit of protein produced compared to salmonids species (indirectly for the production of plant-based feeds). For example, the ratio "land use in terms of hectare (ha) to edible tonnes of fish produced" was 12.0 for carps, 9.5 for catfish and 2.4 for salmonids.

Compared to other sources of animal protein, Hall et al. (2011) found that products from aquaculture generally generated less nitrogen and phosphorus emissions per unit weight than pork and beef. According to Martinez-Porchas and Martinez-Cordova (2012), sustainable aquaculture is achievable through the implementation of the strategies proposed during the last decade and the formulation and improvement of dedicated aquaculture laws and regulation. Possible strategies include Integrated Coastal Zone Management (ICZM), reliance on foreign investment, and nucleus farming. Measures that may be appropriate include stakeholder participation, subsidiarity and community-driven decentralization (Hishamunda, et al., 2014).

2.2 Existing Applied Methodologies

The existing methods used to evaluate the impact of aquaculture development on food security, as found in the literature reviewed, albeit being a good starting point, do not provide a meaningful tool to address the issue at hand in this dissertation, which is to evaluate the impact of aquaculture development to food security outcome at global level.

This is because almost all the reviewed studies assess the impact of aquaculture development on the determinants of food security only. Few analyses address also the outcome component of food security (Dey, et al., 2005; Béné, et al., 2010; Belton, et al., 2011). Moreover, most of them focus on few countries and on limited time frames (e.g., Naylor, et al., 2001; Dey, et al., 2006; Gomna & Rana, 2007; Roos, et al., 2007a; Roos, et al., 2007b; Banda Nyirenda, et al., 2010; Jahan, et al., 2010; Ahmed & Garnett, 2011; Belton, et al., 2011; Belton, et al., 2014a; Cleasby, et al., 2014; Kassam, 2014; Toufique & Belton, 2014; El Mahdi, et al., 2015; Ben, et al., 2015).

Since a broad range of methods have been applied, including descriptive analyses (e.g., Banda Nyirenda, et al., 2010; Belton & Thilsted, 2014; Toufique & Belton, 2014; El Mahdi, et al., 2015; Ben, et al., 2015) and regression models (e.g., Dey, et al., 2005; Béné, et al., 2010; Ahmed & Garnett, 2011), it was not possible to identify mainstream methodologies.

Most of the reviewed quantitative methods (20) address the access dimension of food security, 14 address the availability dimension, 10 study the utilization dimension and 5 address the stability dimension. The applied methods, along with the areas addressed and the period of analysis, are mapped in Appendix 2.

The rest of this section describes the methodologies applied in selected studies where the methodology information is sufficiently detailed (and whose results have been already discussed from Section 2.1.1 to 2.1.4).

Among the reviewed literature, as recalled above, only three studies address the outcomes of food security (Dey, et al., 2005; Béné, et al., 2010; Belton, et al., 2011). In detail, Dey et al. (2005) and Belton et al. (2011) focus on the share of food expenditure of the poor, an outcome indicator of the food access dimension, while Béné et al. (2010) look at the underweight prevalence, an outcome indicator of the food utilization dimension.

Dey et al. (2005) first use a regression analysis to show the impact of freshwater fish production on per capita fish consumption, and then perform a pair wise comparison using Duncan’s Multiple Range Test (DMRT) to show differences in average per capita fish consumption between different income quartile groups. The primary data were collected through a year-round survey of 5 931 households in both rural and urban areas in Bangladesh, China, India, Indonesia, the Philippines, Thailand and Vietnam. The FAO database and other published materials were also used to analyse trends in fish consumption. In the latter database, fish consumption encompasses both aquaculture and capture fisheries, while micro level data focus on selected aquaculture species. As mentioned in Section 2.1.2, the study shows that the low-income quartile groups allocated higher food budget to fish.

In order to analyse the current state of knowledge on the aquaculture sector and fish consumption in Bangladesh, Belton et al. (2011) perform a descriptive data analysis by coupling official statistics from numerous sources, including the Household Income and Expenditure Survey 2005, with secondary sources (including unpublished data) and experts' consultations.

Béné et al. (2010) analyse the effects of fish export on economic and human development, by regressing four human development indicators[77] (endogenous variables), including malnutrition prevalence as the outcome of food security, against five fish trade indicators[78] (exogenous variables), in combination with 15 additional sets of socioeconomic indicators reflecting the macro-economic, infrastructure, governance and trade policy environments of 47 SSA countries. OLS and two-stage least squares (2SLS) regressions were calculated. The results show that none of the fish trade indicators was significant on the development indicators, what the authors address as the "lack of evidence".

Ahmed and Garnett (2011) and Merino et al. (2012) mostly address the determinants of food security in the availability dimension.

Merino et al. (2012) evaluate the feasibility of increasing aquaculture production to meet fish consumption rates in 2050. They simulate the physical-ecosystem model for the 30 Large Marine Ecosystems (LMEs) considered coastal oceans through the POLCOMS hydrodynamic model[79] coupled to the ERSEM ecosystem model[80]. The aggregate fish catches of 69 Exclusive Economic Zones (EEZs) are predicted through a marine ecosystem model using the output from the POLCOMS-ERSEM simulations (daily mean temperature and daily mean phytoplankton, microzooplankton and detritus biomass density). A global bio-economic network model assesses how aquaculture development affects wild-caught fish species used to produce fishmeal. The model considered the 12 most important fishmeal-producing countries[81], and the 15 largest fishmeal and 6 fish oil consumers to estimate the export pathways in terms of quantity and price of the commodities.

Ahmed and Garnett (2011) use a Cobb-Douglas production function model to assess the production efficiency of rice-fish farming systems in Mymensingh district of north-central

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[77] In Béné et al. (2010), human development indicators were: mortality rate, malnutrition prevalence, mean monthly per capita income, and per capita Gross Domestic Product (GDP).

[78] In Béné et al. (2010), fish trade indicators were the following: percentage of fish production exported, per capita fish export value, fish export as a percentage of the total agriculture export value, per capita fish production, Per capita fish production, presence of fishery agreements with the European Union (EU).

[79] The Proudman Oceanographic Laboratory Coastal Ocean Modelling System (POLCOMS) is designed for the study of shelf sea processes and ocean-shelf interaction (Holt, 2008).

[80] The European Regional Seas Ecosystem Model (ERSEM) is a pelagic marine ecosystem simulation model (Blackford, et al., 2004).

[81] In Merino et al. (2012), the following fishmeal producing countries were included in the analysis: China, Japan, Taiwan, Chile, Peru, United Kingdom, Norway, USA, Denmark, Indonesia, South Africa, Canada, Iceland, Morocco and Viet Nam.

Bangladesh, considering rice seed, fish stocking, fish seed, fertilizer and labour as explanatory variables. An ordinary least square (OLS) regression analysis is used to determine the effect on the total food production, composed by rice and fish, of the above-mentioned explanatory variables, in integrated and alternated fish/rice farming. The coefficient of multiple determinations (R^2) has increased from 0.71 in integrated farming to 0.84 in alternate farming. In both farming systems, all five explanatory variables are statistically significant at 0.01 level and have positive effects on food production.

Most of the reviewed literature focus on the determinants of food security in the food access dimension (Dey, et al., 2006; Banda Nyirenda, et al., 2010; Jahan, et al., 2010; Toufique & Belton, 2014; El Mahdi, et al., 2015).

In Dey et al. (2006), the impact assessment is performed through the RESTORE approach (Research Tools for Natural Resource Management, Monitoring and Evaluation), a combination of farmer-participatory field procedures and an analytical database. In 2004, a survey was conducted to collect data of farmers adopting and non-adopting integrated aquaculture-agriculture (IAA) in six sites in Malawi. Additional data sources used included the monitoring data from a small sample of farmers participating to the project of WorldFish testing IAA technologies and a household health survey of 545 respondents including IAA and non-IAA farms. RESTORE is a software tool developed by the International Center for Living Aquatic Resources (ICLARM) for assessing natural resources accessed and used by the farms. The outcomes include financial budgets and sustainability indicators, e.g. diversity indicators such as number of enterprises and approximating stocks (Prein, 2007). The results showed increased profits, employment and animal protein consumption in integrated agriculture-fish small-scale farmers compared to non-integrated farmers (Section 2.1.2).

Banda Nyirenda et al. (2010) conducted a survey in selected rural and peri-urban sites in Lusaka and Central Provinces, Zambia. The purpose was to establish a baseline of the food security and fish consumption levels of people affected by HIV/AIDS in order to perform the statistical analysis of frequencies and cross tabulations of information.

The study of Jahan et al. (2010) relies on a ‘before-and-after’, ‘with-and-without’ experimental design. A one-way analysis of variance (ANOVA) is applied to detect variation over the years among the project and control (non-project) farmers[82]. T-tests were conducted to compare the differences between control and project farmers in a specific year. Data were

[82] The study of Jahan et al. (2010) refers to the Development of Sustainable Aquaculture Project (DSAP). See Section 2.1.2.

collected from 225 farmers from 2001 to 2005 in four districts in Bangladesh. In project households, total labour increased by 10.2 per cent, the gross income increased by 8.1 per cent and annual per capita fish consumption increased by 6.6 per cent (Section 2.1.2).

The aim of Toufique and Belton (2014) was to assess, through a descriptive analysis, if the increased farmed fish consumption have reduced poverty in Bangladesh. The Bangladesh Bureau of Statistics (BBS) collected fish consumption data in its Household Income and Expenditure Survey (HIES) in 2000, 2005, and 2010. Households were categorized as extreme-poor, moderate-poor or non-poor, according to the BBS procedures. The main indicators used in the study included: annual per capita fish consumption and growth, composition of fish supply by source, composition of fish consumption by source and poverty group, changes in annual fish consumption per capita, changes in fish consumption per capita by poverty group and source, frequency of fish consumption, average fish prices by source, percentage change in real fish prices by source, and change in nominal fish and coarse rice prices.

El Mahdi et al. (2015) conducted 1 400 household surveys and 32 in-depth interviews in 5 governorates in Egypt. The purpose was to detect the factors determining food preferences and consumption, in a focus on intra-household dynamics. The sample included villages close to fish farms, villages far from fish farms, and urban districts. Descriptive statistics about surveyed households included household expenditures and animal-source food preferences and consumption.

The determinants of food security in the food utilization dimension have been mostly addressed through descriptive analyses. Belton and Thilsted (2014) performed a descriptive data analysis in terms of capture fisheries and aquaculture’s contribution to total fish production and average fish consumption per capita, from 1980 to 2009, at the global level and for selected countries (China, Bangladesh, Egypt, India, Indonesia, Myanmar, Nigeria, Philippines, Thailand and Viet Nam). The analysis also encompassed micronutrient and omega 3 PUFA contents of selected wild-caught and farmed fish species.

Hishamunda et al. (2009b) propose a number of indicators for quantifying the contribution of commercial aquaculture to national economies, poverty alleviation and three dimensions of food security, i.e. availability, access and stability (Appendix 2). The stability dimension is addressed in terms of resilience capacity of aquaculture to stabilize food supply. In detail, the volatility of production value and protein supply of commercial aquaculture was measured to assess aquaculture’s contribution to the stability of fish supply, and hence, food stability in twelve SSA countries. They did so by calculating the average deviation of aquaculture fish supply from trends of aquaculture production value and protein supply, and the correlations between aquaculture protein supply and both total fish protein and animal proteins. According to Hishamunda et al. (2009b), the transitory shocks are measured by the differences between actual and expected supply. The expected supply resulted from the linear trend, which, in turn, was calculated through OLS regression over the sample periods, from 1990 to 2000.

In terms of resilience capacity of aquaculture to overcome shocks, Bell et al. (2011) assess the vulnerability of aquaculture to the effects of climate change in the Pacific Island Countries and Territories (PICTs). Explanatory variables included the character, magnitude and rate of climate variation to which natural and social systems are exposed, their sensitivity and adaptive capacity in different scenarios, based on the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios storylines B1 (low emissions) and A2 (high emissions) for 2035 and 2100[83]. The vulnerability framework takes into account six phases describing, in the first phases, the observed and projected changes to surface climate in both terrestrial and in the water environments. Then the framework includes the assessment of the impact of projected changes on ecosystems that support fisheries resources, the impact assessment of the direct and indirect projected changes on wild-caught and farmed fish species in terms of quantity and distribution. The last phases have identified the economic and social implications and the adapting policies to climate changes.

[83] The main results have been discussed in section 2.1.4.

3 Impact Evaluation of Aquaculture Development on Food Security

> «Given the continuous growth of the aquaculture sector in the economy of an increasing number of developing or emergent countries, there is an urgent need to develop a rigorous and multi-country assessment, which would allow us not only to quantify but also to compare the performance of aquaculture in relation to […] food security» (AFSPAN, 2014a).

As extensively illustrated in Chapter 2 and shown in Appendix 2, it is not possible to identify mainstream methodologies for estimating the impact of aquaculture on food security. The reviewed empirical studies have a limited temporal and geographic coverage. Moreover, few applied researches address the impact of aquaculture development on the outcomes on food security and no robust empirical evidence is available.

Drawing on these findings on the existing gap in the literature, the empirical analysis presented in this chapter offers three original contributions to evaluate the impact of aquaculture development on food security. First, it evaluates the impact of aquaculture on food security outcomes, and specifically on POU, rather than on its determinants. According to the suggestion of OECD (2006), the distinction between the causes or determinants of food security and the manifestations or outcomes is deemed to be pivotal to properly assess how the sector being evaluated affects outcomes, whether these effects are intended or unintended. This analysis is justified considering that for policy-makers in developing countries supporting aquaculture development is not a goal in itself but a means for achieving other outcomes, as food security (NEPAD, 2005; ECOWAS, 2008; AUC-NEPAD, 2014). Second, it performs a global assessment across developing countries, rather than focusing on single countries. Third, it looks at the contribution of aquaculture on food security over a long time horizon (1990–2014) rather than across more limited periods. I perform a panel rather than a cross-section analysis, in order to extend the assessment of the impact to the global level and over a long time horizon. In particular, this research tested whether the development of the aquaculture sector has improved food security in developing countries that experienced undernourishment issues.

In view of that, the research question can be stated as follows: which is the impact of aquaculture development on the outcome of food security in developing countries for the period 1990–2014?

The structure of the chapter is the following. Section 3.1 proposes an original logical framework to perform the global assessment across developing countries. Section 3.2 addresses the empirical methodology. Section 3.3 contains a description of the variables together with a presentation of the data source. Section 3.4 shows the empirical outcomes of the analysis. Section 3.5 discusses the likely policy implications and future research arising from these results.

3.1 Logical Framework

According to the literature review presented in Chapter 2, aquaculture development is found to contribute to each food security dimensions. However, as mentioned in Section 2.2, the empirical studies address few countries with limited time horizons, and mostly focus on the determinants of food security. Kawarazuka (2010) highlighted that many aquaculture studies do not employ indicators such as the anthropometric indicators to examine the nutritional outcomes. The more detailed analysis of the frameworks and methodologies applied for the evaluation of the impact of aquaculture development on food security (Chapter 2), confirms the need to fill a gap and assess the impact on the outcomes of food security at global level and over a long time horizon.

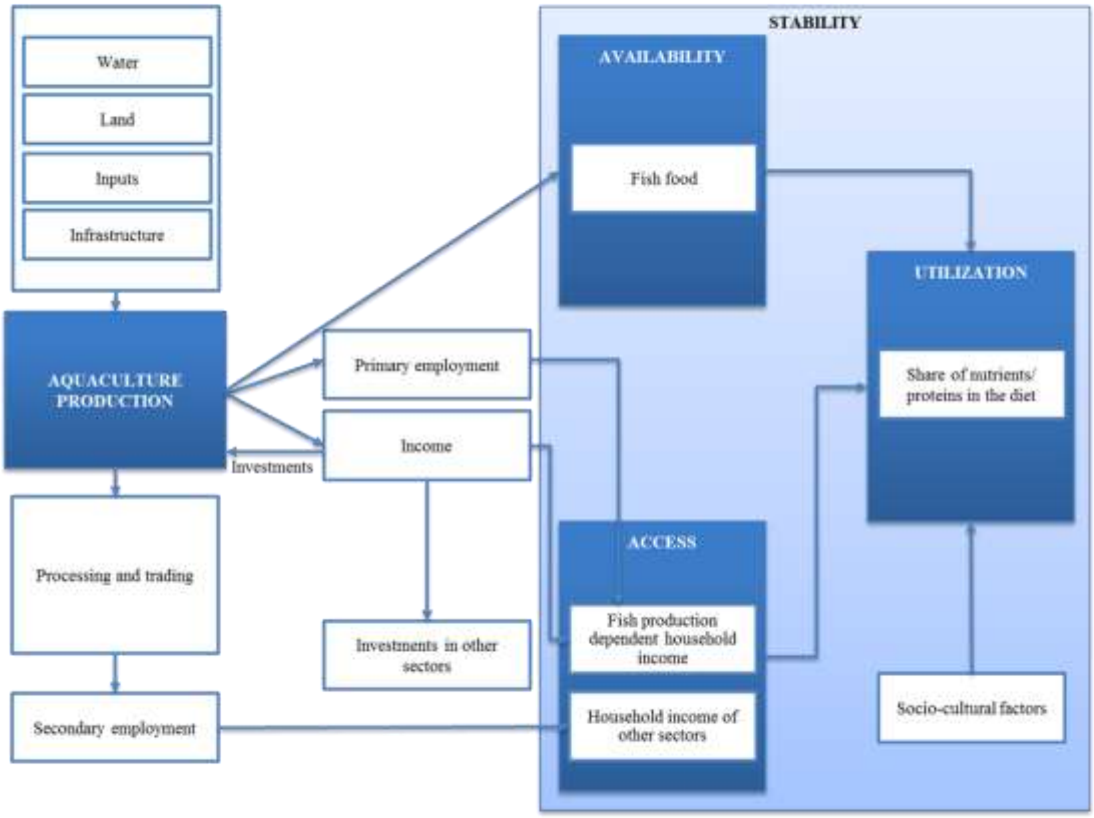
Conceptual frameworks addressing the determinants and outcomes of food security have been developed in the literature (UNICEF, 1998; WFP, 2009; Ecker & Breisinger, 2012; Pieters, et al., 2013; Pangaribowo, et al., 2013; Burchi & De Muro, 2016).

UNICEF (1998) produced a conceptual framework linking the determinants and outcomes of malnutrition. The determinants are grouped at individual, household, and societal levels. At societal level, determinants look at the factors that may limit the utilization of potential resources (e.g. political, cultural, religious, economic, and social factors). At household level, the causes of malnutrition include insufficient access to food, inadequate maternal and childcare practices, poor water and sanitation, and inadequate health services. Inadequate dietary intakes and disease are the determinants at individual level. Along with child malnutrition, the outcomes include also death and disability.

Burchi and De Muro (2016) propose to analyse food security in three phases, by analysing first the food entitlements (e.g., employment status, type of employment and savings), then the basic capabilities for food security (e.g., calorie intakes, school enrolment, access to drinkable water and sanitation) and finally the capability to be food secure (e.g., diet diversification and nutrition knowledge).

HLPE (2014) has conceptualized the different pathways through which aquaculture contributes to food security (Figure 20). According to this conceptual framework (2014), aquaculture can contribute to the availability dimension through the production of fish food at the household, local and national market levels. Aquaculture supply, processing and trading, can generate employment and income thereby improving access to food, including fish and other food commodities. Consumption of fish and other food commodities can contribute to the utilization dimension in terms of dietary intakes improvement. Stability, which is proposed as a combination of availability, access and utilization, results from aquaculture capacity to stabilize food supply and to overcome shocks.

Figure 20. Conceptual framework of the contribution of aquaculture to food security



Source: adapted from HLPE (2014).

For the purpose of this analysis, I propose a logical framework to evaluate the impact of aquaculture development on food security (Figure 21). The logical framework (logframe), which was first developed in 1969 by the United States Agency for International Development (USAID) for project design and evaluation purposes (Practical Concepts Incorporated, 1979), represents a reference tool throughout the project management cycle (World Bank, 2005). The logframe ranges the objectives into different levels and identifies indicators to measure the achievements within each level.

Given the scope and structure of the logframe, I have envisaged a similar approach to develop a suitable methodology for evaluating the impact of the agricultural sector, in general, and aquaculture, specifically, on food security[84].

In the logical framework pictured in Figure 21, the objectives are first divided into two levels, micro and macro levels; and the latter is in turn divided into two sub-levels, i.e. global and/or regional and country levels. The indicators to measure the achievements within each level are the determinant and the outcome indicators of food security.

When the objective of the analysis is to evaluate the impact of aquaculture development on food security at macro level, i.e. at global and/or regional level, without distinction among countries, the empirical analysis adopt the outcome indicators of food security to measure the magnitude of the impact. The rationale is that the outcome indicators of food security are based on internationally applied standards and, therefore, comparable among countries. The wasting prevalence, for example, measures the proportion of children under five whose weight for height is more than two standard deviations below the median for the international reference population ages 0–59 (FAO, 2016e). The percentage of adults who are underweight are defined as those with a Body Mass Index (BMI) below the international reference standard of 18.5 (FAO, 2016e).

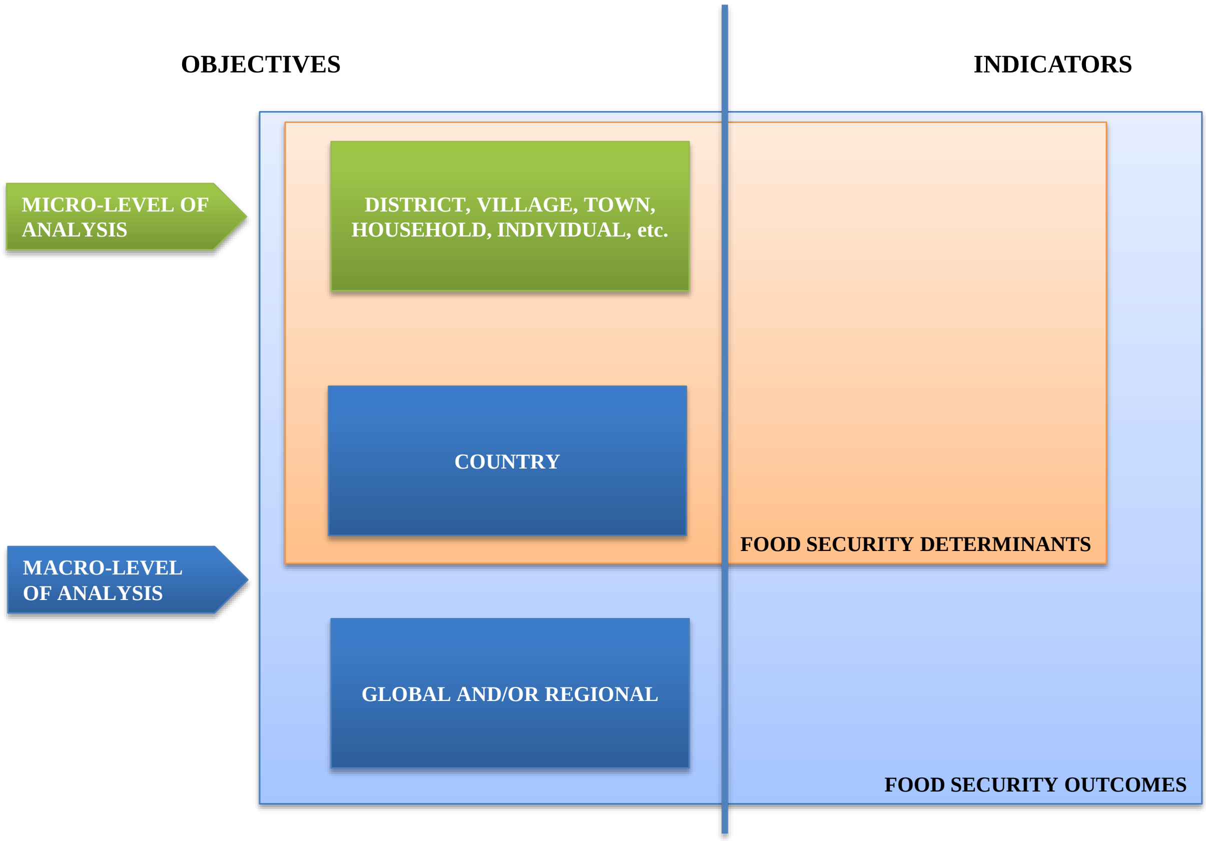
When the objective is to evaluate the impact of aquaculture development on food security at country level and/or micro level (e.g., individual, households), the empirical analysis focuses on both the outcomes and/or the determinants of food security. The rationale is that the determinants of food security are highly different, therefore, hardly comparable among countries and less suitable to perform the impact evaluation at global level. Determinants of food insecurity can include, for example, insufficient production, low consumption due to

[84] Although distant from the current focus, it is not altogether irrelevant to highlight that a conceptual framework refers to «the system of concepts, assumptions, expectations, beliefs, and theories that supports and informs» on the research (Maxwell, 2013). I proposed a conceptual framework in Chapter 2 to develop the literature review on the specific contribution of aquaculture to food security.

lack of income, inadequate means of transportation, lack of access to clean water or sanitation facilities, political instability and/or occasional shocks such as natural disasters. An increase per se of determinants of food security at global level (e.g. fish production or consumption), does not necessarily imply that food security is improved.

I am aware that this logical framework does not propose a methodology to evaluate the links between the different levels of analysis but this type of analysis goes beyond the scope of my work.

Figure 21. Logical framework to evaluate the impact of aquaculture development on food security



Both at macro- and micro-level, the analysis on the outcomes of food security is often neglected (Chapter 2). Since the existing literature mostly address the contribution of aquaculture development to food security determinants, this research seeks to assess whether the development of aquaculture has contributed to food security outcomes at global level following the suggested logical framework (Figure 21). This can be accomplished by selecting as outcome indicators, for example, the anthropometric measurements and/or the undernourishment index (Section 1.1.2). Relying on the logical framework suggested above (Figure 21), the quantitative analysis performed in Section 3.4 analyses the available data (Section 3.3.1) to confirm the hypothesis that the development of the aquaculture sector has improved food security in developing countries that experienced undernourishment issues.

3.2 Model and Econometric Approach

Impact evaluation represents the assessment of how the sector being evaluated affects the outcomes, whether these effects are intended or unintended (OECD, 2006). As stressed by the Asian Development Bank (2006), the impact evaluation addresses the effects of the intervention on the final outcomes, whether at individual, household or community level. In this research, the definition of impact evaluation is utilized in an extensive way since the intervention being assessed is the development of a sector. According to Allison (2011), «deeper analysis is needed before causal linkages can be inferred and […] food security benefits for aquaculture can be claimed». The existence of a reliable exogenous variation represents one of the main difficulties in establishing a causal linkage between an intervention and the food security outcomes (Bertelli & Macours, 2014).

As pointed out by Ravallion (2008), there is no dominant statistical methodology for evaluating the impact of any policy, programme or project. The empirical studies on aquaculture contribution to food security address few countries with a limited time horizon, and they mostly focus on determinants of food security. No robust empirical evidence exists on the impact of aquaculture on food security outcomes (Section 2.2). By analysing the share of food expenditure of the poor, Dey et al. (2005) and Belton et al. (2011) draw conflicting conclusions (Section 2.1.2). Whereas Béné et al. (2010) do not detect either negative or positive impacts of fish trade between SSA and developed countries on food security. The authors have used OLS and 2SLS regression to analyse the effect of fish export on economic and human development; the only outcome indicator employed is the underweight prevalence (Section 2.1.1).

Other studies have applied regression's methods to evaluate the impact of sectors, others than aquaculture, or specific topics to food security at macro and micro levels. De Muro and Burchi (2007), using household-level data from Demographic and Health Surveys (DHS) for 48 low-income countries, have analysed through OLS regression the connections between education and the outcomes of food insecurity in rural areas. A composite index of food insecurity based on data on infant and child mortality, female malnutrition[85], stunting, wasting and underweight measurements, was used as endogenous variable. The exogenous variables were: the school attendance of children ages from 6 to 10, the lack of access to toilet facilities, as a proxy for lack of sanitation, and the lack of ownership of non-productive assets, as a proxy for an asset based measure of absolute poverty (De Muro & Burchi, 2007). Wang (2010) has analysed the impact of climate change on the determinants of food security[86] using a dynamic panel data analysis from a sample of 27 provinces in China from 1985 to 2007. The study uses pooled ordinary least squares (POLS), fixed effects, difference generalized method of moments (DIF-GMM) and system generalized method of moments (SYS-GMM) to estimate the relationship among all the variables. Agboola (2014) has analysed the long-run impact of food security[87] on economic growth through a reduced-form growth regression within 124 countries, with a five-year average data from 1970–74 to 2000–09.

In order to estimate the impact of aquaculture on food security outcome at global level, this work applies an empirical strategy in multiple steps, showing the results of a wide variety of empirical/estimation techniques. Following the approach of Salmoral and Garrido[88] (2015), I employ, in the first step, traditional pooled ordinary least squares (POLS), fixed effects (FER) and random effects (RER) regressions. In the second step, I implement a panels corrected standard errors (PCSEs) regression.

In implementing POLS, this study is similar to Béné et al. (2010) but different from it in several ways. First, it focuses on undernourishment rather than on undernutrition. Second, a panel and not a cross-section analysis is performed. Third, it shows regional estimates in addition to the aggregated ones.

[85] Female malnutrition is measured as percentage of rural women whose BMI is less than 18.5 (De Muro & Burchi, 2007).

[86] Wang (2010) considered the below dynamic panel data model.

$$lny_{it} = \delta lny_{it-1} + X'_{it}\beta + \alpha_i + \varepsilon_{it}$$

The rural per capita food consumption represented the endogenous variable (lny) and the exogenous variables included the rural per capita food consumption, food retail price index, income of rural residents, agricultural disaster area, sown area and saving of urban and rural residents.

[87] In Agboola (2014), the exogenous variables included indicators of human capital (life expectancy, primary school enrolment, and secondary school enrolment), of physical capital (investment), population growth rate, initial gross domestic growth rate, inflation rate, and food availability a proxy for food security in the study (endogenous variable).

[88] Salmoral and Garrido (2015) evaluated the impact of the Common Agricultural Policy (CAP) on the concentrations of nitrates and suspended solids in Spain from 1999 to 2009.

The pooled OLS model is specified as follow (Equation 1):

$$POU_{it} = \alpha_0 + \beta_1 AD_{it} + \beta_2 FC_{it} + \beta_3 GDP_{it} + \beta_4 FI_{it} + \beta_5 FE_{it} + \beta_6 FP_{it} + \delta_1 SR1_{it} + \cdots + \delta_{16} SR16_{it} + \varepsilon_{it} \quad (1)$$

In this model $i = 1, \ldots, 104$ is the number of developing countries and $t = 1, \ldots, 23$ is the number of 3-year periods, from 1990−92 to 2012–14, in the panel i. The chosen variables are shown in Table 3, where subregions (SR) are the dummy variables and ε_{it} is a normally distributed error term.

More specifically, POU denotes the prevalence of undernourishment, in year t, which is a measure of food security outcome. AD is the share of aquaculture production on total fishery production, which is here considered as a proxy of aquaculture development. Thus, the coefficient of main interest is β_1 that represents the impact of aquaculture development on the outcome of food security. GDP denotes the Gross Domestic Product per capita in purchasing power parity (PPP). FC is the apparent per capita consumption of fish and fishery products. FE and FI represent the quantities of fish and fishery products exports and imports, respectively. FP is the fish protein supply.

The SRs represent the dummy variables for the regional component, for a total of 16 dummy variables; e.g., SR_{1t} assumes the value 1 to indicate the presence of the Eastern Africa region at the time t and 0 otherwise, SR_{2t} assumes the value 1 to indicate the presence of the Caribbean region at the time t and 0 otherwise, and so on up to SR_{16t}, which assumes the value 1 to indicate the presence of the Western Asia region at the time t and 0 otherwise. SRs have been introduced in the model given the importance of the regional component in both food security and aquaculture development, as extensively discussed in Chapter 1.

Table 3. Models' variables

Symbol	Variable
POU	Food security outcome: Prevalence of Undernourishment
AD	Aquaculture development: Aquaculture production (tonnes)/Total fishery production (tonnes)
GDP	GDP per capita (PPP)
FC	Apparent per capita consumption of fish and fishery products (kg/per capita/year)
FE	Quantities of fish and fishery products exports (tonnes)
FI	Quantities of fish and fishery products imports (tonnes)
FP	Fish protein supply (g/capita/day)
SR_1	Dummy variable Eastern Africa
SR_2	Dummy variable Caribbean
SR_3	Dummy variable Caucasus and Central Asia
SR_4	Dummy variable Central America
SR_5	Dummy variable Eastern Asia
SR_6	Dummy variable Melanesia
SR_7	Dummy variable Micronesia
SR_8	Dummy variable Middle Africa
SR_9	Dummy variable Northern Africa
SR_{10}	Dummy variable Polynesia
SR_{11}	Dummy variable South America
SR_{12}	Dummy variable South-Eastern Asia
SR_{13}	Dummy variable Southern Africa
SR_{14}	Dummy variable Southern Asia
SR_{15}	Dummy variable Western Africa
SR_{16}	Dummy variable Western Asia

FC has been removed from the model because the variance inflation factors (VIF) detected multicollinearity between the two variables FC and FP. The results of the multicollinearity test are shown in Appendix 6.

As Greene (2002) pointed out, in presence of heteroskedasticity and autocorrelation, the POLS estimator is inefficient. For this purpose, the Breusch-Pagan/Cook-Weisberg test for heteroskedasticity and the Wooldridge test for autocorrelation in panel data (Woolridge, 2002) have been performed.

The Breusch-Pagan/Cook-Weisberg test indicated the presence of heteroskedasticity[89] (Table 6). The Wooldridge test revealed significant first-order autocorrelation in the panel data; the test on the variables POU, AD, FC, GDP, FE and FI rejected the null hypothesis of no first-order autocorrelation AR(1)[90].

Therefore, following Salmoral and Garrido (2015) and Antonie et al. (2010), being POLS estimator inefficient, I have tested both FER and RER regressions. The FER model is specified as follow (Equation 2):

$$POU_{it} = \alpha_i + \beta_1 AD_{it} + \beta_2 FC_{it} + \beta_3 GDP_{it} + \beta_4 FI_{it} + \beta_5 FE_{it} + \varepsilon_{it} \qquad \textbf{(2)}$$

In the FER model α_i is a group-specific constant term (Greene, 2002). The FER estimator has been tested for heteroskedasticity and cross-sectional correlation (Table 6) given the fact that ignoring cross-sectional correlation in panel models can lead to severely biased estimates (Hoechle, 2007).

The Modified Wald test for groupwise heteroskedasticity indicated the presence of heteroskedasticity[91] in FER regression. The Pesaran's test (Pesaran, 2004)[92] indicated the presence of cross-sectional dependence (CD).

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[89] The Breusch-Pagan/Cook-Weisberg test rejected the null hypothesis of constant variance in the POLS regression with the following results:

$$\chi^2(1) = 74.65$$
$$Prob > \chi^2 = 0.0000$$

[90] The Wooldridge test on the variables POU, AD, FC, GDP, FE and FI rejected the null hypothesis of no first-order autocorrelation AR(1) in panel data, with the following results:

$$F(1, 103) = 90.80$$
$$Prob > F = 0.0000$$

[91] The Modified Wald test rejected the null hypothesis of homoskedasticity in FER regression with the following results:

$$\chi^2(104) = 2.00E + 06$$
$$Prob > \chi^2 = 0.0000$$

[92] The Pesaran's test is designed to test for cross-sectional dependence in panels with large number of units (i.e., developing countries) and small time periods (De Hoyos & Sarafidis, 2006). The CD test rejected the null hypothesis of cross-sectional independence in FER regression, according to the following results:

$$CD\ test = 22.84$$
$$Prob = 0.0000$$

The RER model is specified as follow (Equation 3):

$$POU_{it} = \alpha_0 + \beta_1 AD_{it} + \beta_2 FC_{it} + \beta_3 GDP_{it} + \beta_4 FI_{it} + \beta_5 FE_{it} + \delta_1 SR1_{it} + \cdots + \delta_{16} SR16_{it} + u_i + \varepsilon_{it} \quad (3)$$

The RER estimator has a compound disturbance given by u_i, the group specific random element (Greene, 2002). Pesaran's test revealed the presence of cross-sectional correlation in RER[93] (Table 6).

Since none of the models tested have proven to be efficient, in a first instance, I considered to test the Parks' feasible generalized least squares (FGLS) regression (Parks, 1967), which uses generalized least squares (GLS) coefficients, to control for heteroskedastic, correlated error structure and first-order autocorrelation within the panel. However, the FGLS is not feasible for panels having a cross-sectional dimension greater than the time dimension (Hoechle, 2007; Reed & Ye, 2011), which is the case of panel here tested. Moreover, according to Beck and Katz (1995), FGLS is prone to estimate unacceptably small standard errors (Hoechle, 2007) and they proposed the panels corrected standard errors (PCSEs) regression. Applications of the PCSEs estimator in impact evaluation studies have been found in Bitzer and Stephan[94] (2007), Mosca[95] (2007), Ghani[96] (2011), Salmoral and Garrido (2015), Kumar et al.[97] (2016) and Muratori and Fricke[98] (2017).

The PCSEs model here adopted estimates parameters through Prais–Winsten regression. In PCSEs, the disturbances are heteroskedastic and contemporaneously correlated across panels. Being disturbances heteroskedastic, the variance of the error term is constant

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[93] The CD test rejected the null hypothesis of cross-sectional independence in RER regression as specified below:

$$CD\ test = 21.59$$
$$Prob = 0.0000$$

[94] Bitzer and Stephan (2007) evaluated the impact of R&D capital stocks on the output of the industries in nine OECD countries.

[95] Mosca (2007) explored the impact of decentralization on the health care expenditure of 20 OECD countries from 1990 to 2000.

[96] Ghani (2011) analysed the tax performance in 104 from 1996 to 2005, by adopting the foreign aid as endogenous variable.

[97] Kumar et al. (2016) assessed the climate change impacts on land productivity of major food and non-food grain crops in India.

[98] Muratori and Fricke (2017) evaluated the impact of price insulating policy on spatial transmission of maize rice and wheat in Cameroon, Kenya and Tanzania from 2005 to 2015.

within a cluster (Equation 4), but it varies across clusters (Equation 5). Disturbances are correlated across the balanced panels (Equation 6) (Beck & Katz, 1995).

Through Monte Carlo simulations, Beck and Katz (1995) have shown the accuracy of PCSEs in the presence of both panel heteroskedastic and contemporaneously correlation (Menard, 2008).

$$E\left({e^2}_{it}\right) = E\left({e^2}_{is}\right) = {\sigma^2}_i \tag{4}$$

$$E\left({e^2}_{it}\right) \neq E\left({e^2}_{jt}\right) \tag{5}$$

$$E\left(e_{is}e_{js}\right) = E\left(e_{it}e_{jt}\right) = \sigma_{ij} \neq 0 \tag{6}$$

The Prais–Winsten regression uses the GLS method to estimate the parameters in a linear regression model in which the errors are serially correlated. Specifically, within panels, there is first-order autocorrelation and coefficient of the AR(1) process is specific to each panel (Equation 7).

$$E\left(e_{is}e_{jt}\right) \neq 0 \tag{7}$$

According to the test performed above, the PCSEs' features have proven to be suitable for my panel data. Heteroskedasticity has been detected in POLS residuals with Breusch-Pagan/Cook-Weisberg test and in the FER residuals with the modified Wald statistic for groupwise heteroskedasticity. The cross-sectional correlation has been detected through the Pesaran test after running the FER and RER models (Table 6). The autocorrelation has been tested through Wooldridge test. For these reasons, and in accordance with the approach followed by Salmoral and Garrido (2015), the PCSEs regression has revealed to be the most suitable model to evaluate the impact of aquaculture development on food security outcome in developing countries. The PCSEs model[99] is specified in Equation 8, and the characteristics of the error term ε_{it} in Equations 4–7.

$$POU_{it} = \alpha_0 + \beta_1 AD_{it} + \beta_2 FC_{it} + \beta_3 GDP_{it} + \beta_4 FI_{it} + \beta_5 FE_{it} + \delta_1 SR1_{it} + \cdots + \delta_{16} SR16_{it} + \varepsilon_{it} \quad (8)$$

3.3 Data Description and Sources

In order to perform the empirical analysis, I use the following databases: the FAO suite of food security indicators, FAO FishstatJ and FAOSTAT for the years 1990–2014 for 104 developing countries. This span in terms of countries and years is the reference used to construct the panel data[100] for the analysis. The following subsections contain the variables description and data sources (Section 3.3.1 and related subsections) and the timeframe (Section 3.3.2) that have been selected to perform the global evaluation of aquaculture development impact on food security.

The countries selected in this analysis are developing countries as classified by FAO in the suite of food security indicators (FAO, 2016e). It is worth mentioning that there is no established convention for the designation of developed and developing countries or areas in the UN system. In common practice, Japan, Canada and the United States, Australia and New Zealand, and Europe are considered developed regions or areas (United Nations Statistics, 2013; United Nations, 2012). Looking at the FAO food security indicators, all developed countries have a percentage prevalence of undernourishment below 5 per cent. The full list of countries is shown in Appendix 3.

The final panel data contains repeated measures of the same variables (Table 4), taken from the same 104 developing countries from 1990−92 to 2012–14, for a total of 23 periods. Periods of three years have been considered because POU, the food security variable selected in this analysis, is available only in three-year averages (Section 1.1.2). Compared to cross-sectional data or time series dataset, panel data offers a twofold advantage. First, having a

[99] The PCSEs model specification appears to be similar to the POLS model. However, the PCSEs estimator takes into account for heteroskedasticity, cross-sectional correlation and serial correlation.

[100] The panel data, also called longitudinal data or cross-sectional time-series data, has «observations on the same units in several different time periods» (Kennedy, 2008).

higher number of observations, a panel data may produce more accurate estimates. Second, a panel allows controlling cross-section effects (Wang, 2010).

3.3.1 Variables

Focusing on aquaculture in developing countries implies that, in most of the cases, information and knowledge (especially quantitative indicators) are absent (FAO, 2014b; AFSPAN, 2014a; FAO Committee on Fisheries, 2015b). This could be due to the fact that the sector, as well as the systematic data to be collected, have been often neglected by planners and policy-makers in the past. Moreover, whenever available, data are rarely disaggregated to differentiate between aquaculture and capture fisheries (AFSPAN, 2014a),

Based on the descriptive analysis (Chapter 1) and literature review (Chapter 2), a set of variables has been selected (Table 4). The pursued approach has prioritised the variables for which data are available at global level, for both the selected countries (Appendix 3) and the timeframe (Section 3.3.2) considered in this research.

As introduced in Section 3.2, in the empirical analysis here performed, food security (FS) represents the endogenous variable *(Y)* measured by POU at country level, expressed in percentage. The aquaculture development (AD) is the exogenous variable *(X)* measured by the percentage of aquaculture production of the total fishery production, expressed in percentage. The other selected independent variables are GDP per capita (GDP), apparent consumption per capita of fish and fishery product (FC), fish protein supply (FP), quantities of fishery commodities imports (FI) and exports (FE). All the exogenous variables have been calculated in three-year average (Simple Moving Average [SMA]), from 1990−92 to 2012–14 to be comparable with POU.

The lack of disaggregation between farmed and wild products for fish consumption, protein supply, imports and exports statistics, represents the main limitation to the quantitative analysis. At country level, these datasets refer only to total fishery production (Section 1.2.2). Moreover, it was not possible to include aquaculture employment among the explanatory variables of the econometric model since data are available only at regional level and for scattered years (Table 2).

Summary statistics of the panel data set are reported in Table 5. The overall mean (19.1) and standard deviation (14.6) of POU are ordinary statistics based on 2 392 observations. POU varies between 5.0 and 80.8 per cent. Table 5 shows also the "between" standard deviation (13.0), calculated on the basis of summary statistics of 104 developing countries (entities) regardless of time period, and the "within" standard deviation (5.8) by summary statistics of 23 time periods regardless of developing countries. The variation across countries is more than double to that observed within a country over time. The average POU for each developing country varies between 5.0 and 56.7 per cent. The average POU "within" varies between -7.2 and 77.3 per cent. The exogenous variables AD, FC, GDP and FP record a higher between standard deviation compared to the within variation, while the within variation is higher for FI and FE. The within values refer to the deviation from each country's average. There are no time-invariant variables and no entity-invariant variables. Figures by subregion are shown in Appendix 5.

3.3.1.1 Food Security

A major challenge in identifying the impact of specific sectors on food security outcomes is given by the plethora of existing indicators and definitions of food security (Bertelli & Macours, 2014). The endogenous variable here selected to measure the food security outcome is the prevalence of undernourishment (POU), the traditional FAO hunger indicator. POU represents an outcome indicator of food access dimensions (FAO, et al., 2013). The dataset was downloaded from the suite of FAO food security indicators released on 16 December 2016 (FAO, 2016e).

The reasons behind this choice, along with the analysis of alternative indicators, have been discussed in Sections 1.1.1 and 1.1.2.

3.3.1.2 Aquaculture Development

The exogenous variable aquaculture development (AD) has been calculated as the share of **aquaculture production** (AP) **on total fishery production** (TFP), expressed in percentage (Equation 9).

$$AD = \left(\frac{\text{AP}}{TFP}\right) \times 100 \qquad \textbf{(9)}$$

To calculate AD[101], the datasets "global aquaculture production" for AP data[102] and the "global production by production source" for TFP have been used[103].

Both datasets, released in March 2016, were downloaded from FAO FishStatJ. The data are available from 1950 to 2014 and the measurement unit is tonnes (FAO, 2016i). Data expressed in value (US$) are collected only for aquaculture production; therefore, the choice of quantity was straightforward. These datasets contain data on AP and TFP at a global level for all the countries and years considered in this research.

AD captures two major trends of aquaculture development. On one side, the continuing growth in aquaculture production, given the stagnant capture fisheries supply. On the other side, the increasing importance of aquaculture development for total fish supply (FAO, 2014b), which was predicted to surpass capture fisheries according to OECD/FAO projections (2015a). Moreover, AD was selected as a suitable indicator of aquaculture development based on the fact that growth in aquaculture has been linked to immanent development rather than interventionist development (Little, et al., 2016). In immanent systems, aquaculture development is demand-driven, while in interventionist systems, external agencies support the promotion of non-commercial, subsistence aquaculture (Béné, et al., 2016)

It is worth noting that the production of fish, crustaceans and molluscs is expressed in live weight, i.e. the nominal weight of the aquatic organisms at the time of capture. This could result in an overestimate of aquatic food supply depending upon species and dietary preferences, given by the inclusion of inedible components (e.g., the heads, skin, and gastro-intestinal tract of fish) (Tacon & Metian, 2013).

[101] All the data reported in the datasets as less than 5.0 per cent (<5.0) were rounded to 5.0 per cent.

[102] The annual series on AP includes «aquatic organisms which are harvested by an individual or corporate body which has owned them throughout their rearing period contribute to aquaculture while aquatic organisms which are exploitable by the public as a common property resource, with or without appropriate licences, are the harvest of fisheries» (FAO Fisheries Department, 1997).

[103] The annual series of TFP relates to nominal catch of fish, crustaceans and molluscs, the production of other aquatic animals, residues and plants and catches of aquatic mammals, taken for commercial, industrial, recreational and subsistence purposes from inland, brackish and marine waters. The harvest from mariculture, aquaculture and other kinds of aquaculture is also included (FAO, 2016i).

Table 4. List of selected variables

Endogenous and exogenous variables	Datasets	Symbol	Unit	Time unit	Timeframe	Type	Unit of analysis	Database
Food security outcome	Prevalence of undernourishment	POU	Percentage	3-year average	1990–2014	Endogenous variable	Country	FAO food security indicators
Aquaculture development	Aquaculture production (tonnes)/Total fishery production (tonnes)	AD	Percentage	3-year average	1990–2014	Exogenous variable	Country	FAO FishstatJ
Apparent per capita consumption of fish and fishery products	Food supply quantity	FC	Kg per capita	3-year average	1990–2013	Exogenous variable	Country	FAOSTAT
GDP per capita	GDP per capita (PPP)	GDP	Constant 2011 international $	3-year average	1990–2014	Exogenous variable	Country	FAO food security indicators
Quantities of fish and fishery products imports	Fish and fishery products imports	FI	Tonnes	3-year average	1990–2013	Exogenous variable	Country	FAO FishstatJ
Quantities of fish and fishery products exports	Fish and fishery products exports	FE	Tonnes	3-year average	1990–2013	Exogenous variable	Country	FAO FishstatJ
Fish protein supply quantity	Fish protein supply quantity	FP	g/capita/day	3-year average	1990–2013	Exogenous variable	Country	FAOSTAT

Table 5. Panel summary statistics

Variables	Unit		Mean	Std. Dev.	Min	Max	Observations
POU [a]	%	overall	19.11	14.16	5.00	80.80	N=2392
		between		12.97	5.00	56.71	n=104
		within		5.81	-7.23	77.32	T=23
AD [b]	%	overall	13.25	19.71	0.00	92.95	N=2392
		between		17.93	0.00	67.22	n=104
		within		8.37	-26.29	63.35	T=23
FC [c]	kg/capita	overall	13.53	13.81	0.00	79.03	N=2392
		between		13.50	0.08	72.10	n=104
		within		3.20	-5.59	31.34	T=23
GDP [a]	International $	overall	9 118.17	14 723.83	257.93	11 0325.70	N=2392
		between		14 547.99	613.87	9 1574.14	n=104
		within		2 663.59	-24100.20	27869.73	T=23
FI [d]	Tonnes	overall	1 089.64	668.62	1.00	2 252.00	N=2392
		between		284.29	153.87	2 020.61	n=104
		within		605.78	-536.89	2 837.07	T=23
FE [d]	Tonnes	overall	935.28	621.23	1.00	2 024.00	N=2392
		between		343.26	1.00	1 865.61	n=104
		within		518.83	-504.20	2 520.71	T=23
FP [e]	g/capita/day	overall	3.95	4.05	0.00	22.86	N=2392
		between		3.96	0.02	21.98	n=104
		within		0.94	-1.37	8.83	T=23

[a] Source: FAO (2016e); [b] Source: FAO (2016i); [c] Source: FAO (2016h); [d] Source: FAO (2016j); [e] Source: FAO (2016a).

3.3.1.3 Gross Domestic Product

The Gross domestic product per capita in purchasing power equivalent (constant 2011 international $)[104] (GDP) has been selected as exogenous variable. The dataset was downloaded from the suite of FAO food security indicators released on 16 December 2016 (FAO, 2016e). In the reviewed literature, the economic growth represents one of the drivers of the food demand increase (Merino, et al., 2012; Béné, et al., 2015; Brummett & Williams, 2000). GDP is included in the empirical analysis as a basic measure of economic performance. According to FAO, et al. (2012), the annual increase of 2 per cent in GDP per

[104] GDP in purchasing power parity (PPP) is converted to international dollars using purchasing power parity rates, where an international dollar has the same purchasing power on GDP as US$ in the USA (FAO, 2016e).

capita from 1990 to 2010 contributed to an increased dietary energy supplies[105] (DES) of 8 per cent or 210 kcal/person/day at global level, and of 275 kcal/person/day in developing countries.

The choice of this variable represents a second-best because the availability of data on the contribution of aquaculture, or in general of total fisheries to GDP is limited in terms of both countries and years. Béné et al. (2016) highlight that, in the literature, the evidence of aquaculture contribution to national economic growth is not strong due to problems in the datasets used and to the aggregation of different types of aquaculture. According to Little et al. (2016), at global level, aquaculture contributes to less than two per cent of GDP, with the exception of Bangladesh and Viet Nam where contribution is higher than five per cent (Little & Bostock, 2015). Hishamunda et al. (2009b) have estimated the annual share of commercial aquaculture value-added in the GDP of 14 SSA countries from 1984 to 2001; on average the valued-added increased from 0.01 to 0.06 per cent. De Graaf and Garibaldi (2014) have estimated the value added of the fisheries sector as a whole in 2011 in 23 African countries at 1.26 per cent of the GDP, and aquaculture at 0.15 per cent of GDP. In AFSPAN (2015), on average, the aquaculture sector contributed to 1.24 per cent of GDP ranging from 0.06 per cent in Brazil to 5.86 per cent in Bangladesh. While aquaculture contribution to agricultural GDP varied from 1.06 per cent in Brazil to 31.51 per cent in Bangladesh.

3.3.1.4 Fish and Fishery Products Consumption

The "apparent consumption per capita of fish and fishery product" (FC), expressed in kg/per capita/year, has been selected as exogenous variable. The contribution of aquaculture to food security through consumption was addressed through the literature review on the access dimension (Section 2.1.2) and the descriptive analysis in Section 1.2.2.

FC has been calculated by summing up the datasets on food supply quantity (kg/per capita/year) of the aggregated item "fish, seafood" and the item "aquatic animals, others". In

[105] Dietary energy supply (DES) identifies the «food available for human consumption, expressed in kilocalories per person per day (kcal/person/day)» (FAO, et al., 2012).

detail, the groups of species are divided into nine broad groups of species[106] (Laurenti, 2014). The selected datasets have been downloaded from the FAOSTAT database on food supply for livestock and fish primary equivalent (FAO, 2016a).

FC encompasses both aquaculture and capture fisheries. However, as introduced in Section 1.2.2, in 2014, aquaculture surpassed capture fisheries in terms of supply of fish for human consumption at global level (FAO, 2016l). Moreover, because of the high rates of increase in aquaculture fish production and very low rates of capture fisheries production, it can be inferred that aquaculture facilitated more the growth in per capita apparent fish consumption than capture fisheries.

In fish consumption, the term "fish" indicates fish, crustaceans, molluscs and other aquatic invertebrates, but excludes aquatic mammals and aquatic plants (FAO, 2014b). In this analysis, even if FC was calculated by summing up the groups' species mentioned above, it is worth to mention that total fish available for apparent human consumption (TFC) is derived by the FAO Food Balance Sheet (FBS) of fish and fishery products in live weight tonnes using the Equation 10 (Laurenti, 2014).

$$TFC = TFP - NFU + fi - (fe + fre) \pm fs \qquad \textbf{(10)}$$

Per capita fish available for apparent human consumption (FC) is estimated by dividing total fish available for apparent human consumption by population total (P) (Equation 11).

$$FC = TFC/P \qquad \textbf{(11)}$$

Non-food uses (NFU) refer to the «utilization of aquatic products for reduction to meal and oil, for feed and bait, for ornamental purposes, withdrawals from markets and any other non-food use of fish production (e.g., fertilizers, medical uses)» (Laurenti, 2014). According to the General trade system, general imports (*fi*) include «all imports into a country, including

[106] The groups' species include: *(1)* Freshwater (carps, barbels, tilapias, etc.); *(2)* Diadromous fish (sturgeons, eels, salmons, trouts, shads, etc.); *(3)* Demersal fish (flatfishes, cods, hakes, haddocks, redfishes, sharks, coastal demersal fish, etc.); *(4)* Pelagic fish (anchovies, herrings, sardines, tunas, mackerels, etc.); *(5)* Marine fish, other (unidentified marine fish); *(6)* Crustaceans (crabs, lobsters, shrimps, krill, etc.); *(7)* Molluscs, excluding Cephalopods (abalones, oysters, mussels, scallops, clams, etc); *(8)* Cephalopods (cuttlefishes, octopuses, etc.); *(9)* Aquatic animals, others (frogs, turtles, sea cucumbers, sea-urchins, etc.) (Laurenti, 2014).

goods for domestic consumption and imports into bonded warehouses or free zones» (FAO, 2016j). General Exports combine exports (*fe*) and re-exports (*fre*), which consist of the «outward movement of nationalized goods plus goods which, after importation, move outward from bonded warehouses or free zones without having been transformed» (FAO, 2016j). Fish stock (*fs*) refers to the «changes in stocks occurring between the production and the retail levels, or in levels of inventories» (Laurenti, 2014). Since very limited data on FS is available, the data specified in FBS mostly refers to the minimum requirement to avoid a negative balance in FBS (Laurenti, 2014).

Dey et al. (2005) highlight that the estimates on per capita fish consumption based on the total availability of fish, often do not include many small and non-commercial fish species obtained from subsistence aquaculture, implying that the actual per capita fish consumption in many developing countries could be higher.

3.3.1.5 Fish Protein Supply

The “protein supply quantity of fish, seafood, aquatic animals and others” (FP), expressed in g/capita/day, has been selected as exogenous variable. In the reviewed literature, the contribution of aquaculture to food security in terms of macronutrient intakes is generally addressed through the lens of the utilization dimension (Section 2.1.3).

The selected dataset was downloaded from the FAOSTAT database on food supply for livestock and fish primary equivalent (FAO, 2016a), which encompasses both aquaculture and capture fisheries.

3.3.1.6 Fish and Fishery Products Imports and Exports

Quantity of fish and fishery products imports (FI) and quantity of fish and fishery products exports (FE) have been selected as exogenous variables.

The datasets “fishery commodities imports” (fi), “fishery commodities exports” (fe) and “fishery commodities re-exports” (fre) have been used. All datasets, released in March 2016, were downloaded from FAO FishStatJ. The measurement unit is tonnes and refers to the net weight of the commodities (FAO, 2016j) .

As introduced in Section 3.3.1.4, in accordance with the FAO yearbooks of fishery and aquaculture statistics, fish and fishery products imports and exports are aggregated according to the General trade system by summing up national *fe* and *fre*.

The data includes the «quantities of preserved and processed fishery commodities produced from nominal catches of all aquatic animals (except the catches of all aquatic mammals and the production of all aquatic plants) taken for commercial, industrial and subsistence purposes, by all types of fishing units operating in freshwater and marine areas, aquaculture production and imported raw materials» (FAO, 2016j). However, as mentioned in Section 1.2.2, many species recording the highest export growth rates in recent years are produced by aquaculture (FAO, 2014b).

The contribution of aquaculture to food security through fish trade was addressed through the literature review on the availability dimension (Section 2.1.1) and the descriptive analysis in Section 1.2.2. Fish is among the most traded food commodities worldwide, with a net flow from low- to high- income countries (FAO, 2014b; Smith et al. as cited in Thilsted et al. (2016). However, fish trade contribution to food security is poorly assessed and lack of solid evidence in both narratives on food security through and versus fish trade (HLPE, 2014; Béné, et al., 2016). According to Béné et al. (2010), linking fish exports to fish per capita supply may be misleading about the effects of fish trade on food security, as the latter is an outcome of the former. The authors also stress that fish trade supporters tend to base their view on statistics in value unit, usually positive, instead of quantity unit, generally negative.

3.3.2 Timeframe

The timeframe covers the periods from 1990−1992 to 2012–2014 and the indicators are calculated on three-year average. The choice was driven by the fact that POU, the selected food security indicator, is only available from the period 1990–92 and calculated on three-year average. It would be preferable to start the analysis from 1984 to better capture the impact of aquaculture development since, as mentioned in the Section 1.2.2, the last three decades showed that aquaculture production increased at higher annual rates compared to capture fisheries production.

Unbalanced panel data could entail some computation and estimation issues. Many missing values are likely to lower the quality of the panel data. A list-wise deletion, i.e., a procedure that excludes from the analysis all observation units with missing values, tends to reduce the number of observations used in a model and thus weaken the statistical power of a test (Park, 2011; Weber & Denk, 2011). It is common practice to reconstruct missing values rather than losing information about entire countries or subregions[107].

To perform the analysis on a balanced panel data, i.e. having all entities measurements in all time periods (Park, 2011), linear regression predictions have been taken into account to perform deterministic imputation by using the least squares method to calculate the line of best fit for the above mentioned time series. However, deterministic imputation has been adopted to replace missing values by values that are specified ad-hoc to fill in an incomplete response (Sande, 1982); each missing value may be treated differently in a manual procedure, or a few rules may be formulated (Weber & Denk, 2011). In this analysis, different imputation techniques have been adopted according to the type of data.

For FC, GDP, FI, FE and FP, datasets are not updated to 2014 but available for analysis only up to 2013 or before. This type of missing values have been calculated through the average annual (compound) growth rate on the last four years available (Equation 12) because more accurate in fitting known data. FC, GDP, FI, FE and FP have been handled as univariate time series, i.e. estimated for each country, separately. Appendix 4 keeps record of all estimations performed to fill in the missing values, specifying the years and the countries.

$$y_{t_{i+4}} = y_{t_{i+3}} \times \left[1 + \left(\left(\frac{y_{t_{i+3}}}{y_{t_i}}\right)^{\left(\frac{1}{t_{i+3}-t_i}\right)} - 1\right)\right] \qquad (12)$$

FAO collects fishery data through a system of standard format questionnaires, which use harmonized concepts, definitions, and codes. The national statistical authorities are requested to complete a single questionnaire, providing copies to all interested agencies. This procedure also largely reduces the possibility of discrepancies between different databases (FAO, 2016d). In general, there could be several reasons why some data were missing, e.g. data were not available, unobtainable or were not separately available but included in another category. They could have been available from the year they were initiated, some countries

[107] I attempted to perform the empirical analysis by selecting as endogenous variables also the wasting, stunting and underweight measurements, which are outcome indicators of the food utilization dimension. However, given their limitations in terms of missing data (Section 1.1.2), it was not possible to reconstruct the datasets through the different imputation techniques here adopted.

may not have regularly reported data due to conflict, lack of statistical capacity, or other reasons and some countries did not have data for earlier years simply because they did not exist (World Bank, 2016b).

The selected datasets include also missing data, which have been handled through donor-based imputation (DBI) using hot deck methods. Donor-based imputation is a method for handling missing data in which each missing value is replaced with an observed response from a "similar" unit. It involves replacing missing values of one or more variables for the so-called recipient with observed values from a donor, the "nearest neighbour". The donor is a complete observation with similar characteristics as the incomplete observation (the recipient). Hot deck methods select donors from the same dataset (the one with missing values) (Andridge & Little, 2010; Weber & Denk, 2011). DBI has been applied to the datasets for GDP per capita, apparent per capita consumption of fish and fishery products and fish protein supply quantity[108].

3.4 Results and Evaluation of the Aquaculture Impact on Food Security

Several panel data estimations have been carried out in order to identify the most robust model. The selected variables, i.e. POU, AD, GDP, FI and FE, have been tested through POLS, RER, FER and PCSEs regressions. FP has been removed because the variance inflation factors (VIF) detected multicollinearity between the two variables FC and FP[109]. The results of the multicollinearity test are shown in Appendix 6.

The most suitable regression model is found to be the PCSEs model (Section 3.2).

Table 6 reports the results for the selected models for the suite of designated variables and the related tests that conducted to the choice of the model. As detailed in Section 3.2, given the features of the panel data of heteroskedasticity, first-order autocorrelation and cross-sectional correlation, the PCSEs regression was found to be the most suitable model.

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[108] For GDP per capita, DBI was applied in Afghanistan (from 1990 to 2001), Burkina Faso (from 1990 to 1992), Haiti (from 1990 to 1997), Kuwait (from 1990 to 1994) and Timor-Leste (from 1990 to 1998). For both apparent per capita consumption of fish and fishery products and fish protein supply quantity, in Armenia, Azerbaijan, Georgia, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan, the DBI technique was applied for the years 1990 and 1991; in Ethiopia, DBI was used in the years 1990, 1991 and 1992.

[109] I decided to keep FC in the model because FC results more informative compared to FP, being able to capture both consumption dimension and more elements of the utilization dimension compared to FP. In fact, FP measures the macronutrients intakes related to proteins only. While FC could be inferred to be a proxy of both macronutrients and micronutrients intakes. This topic has been addressed in Section 2.1.3.

In addition, Table 7 shows the detailed empirical results of the PCSEs model only, which tested all the selected variables (PCSEs_1). Almost all the explanatory variables are statistically significant at the 0.001 significance level, except for the binary variables Caucasus and Central Asia (SR_3) and Southern Africa (SR_{13}) (at the 0.01 level). Whereas fish imports and exports are not statistically significant. This is in line with the results of Béné et al. (2010), whose empirical analysis did not detect either negative or positive impacts of fish trade on food security.

Therefore, the PCSEs model (PCSEs_2) has been retested to include only the statistically significant variables, thereby omitting the exogenous variables FI and FE. Table 8 shows the estimates' results for PCSEs_2, the final selected model.

The analysis shows that in developing countries the prevalence of undernourishment (POU) can be correlated to a linear combination of three macro level variables: the share of aquaculture production on total fishery production (AD), the apparent per capita fish consumption (FC) and the GDP per capita (GDP). The model has a relatively satisfactory goodness-of-fit (R^2) value of 0.57, given the number of statistically significant variables.

In PCSEs_2, all the explanatory variables are statistically significant at the .001 significance level, with the exception of SR_3 (at the 0.01 level) and SR_{13} (at the 0.05 level). All the statistically significant variables show a positive impact on food security, with the exception of the binary variable Middle Africa[110] (SR_8).

According to the proposed analysis, the development of the aquaculture sector can decrease the prevalence of undernourishment in developing countries. For one unit increase in aquaculture development, the total prevalence of undernourishment is expected to decrease by 0.0699 units, holding all other variables constant. It is important to emphasize that, being the first attempt of its kind, this result cannot be compared with other empirical analysis. However, it seems to be in line with the general findings of the literature that underline a positive impact of aquaculture on food security (Ahmed & Lorica, 2002; Hishamunda, et al., 2009b; Beveridge, et al., 2013; HLPE, 2014; Béné, et al., 2015; Béné, et al., 2016).

The magnitude of the effect of fish consumption reported is higher than the aquaculture development. The PCSEs model found that increasing FC by one unit improves POU by 0.2687 units. The effect of FC could be stronger than AD because it encompasses both farmed and wild caught fish consumption.

[110] SR_8 is composed by Angola, Cameroon, Central African Republic, Chad, Congo and Gabon (Table 11).

On the contrary, the effect of GDP per capita is negligible compared to both FC and AD. For one unit increase in GDP, POU is expected to decrease by 0.0002 units, holding all other variables constant. This result seems to confirm that economic growth is necessary but not sufficient to reduce hunger (Wik, et al., 2008; FAO, et al., 2012). Economic growth should be complemented with the implementation of pro-poor policies and improvement of aquaculture governance (FAO, et al., 2012; Hishamunda, et al., 2014).

The additive dummy variables SR show the difference in the constants (α_0) of the PCSEs model. The positive effect of the regional component ranks from 28.5949 in the Northern African region (SR_9) to 6.4933 in South-Eastern Asia (SR_{12}), with the exception of the negative effect of 7.8024 in SR_8. Studies addressing the status of aquaculture development in Middle Africa are almost inexistent. According to FAO (2016m), the recent growth of aquaculture driven by small and medium-sized enterprise (SMEs) in Middle African countries, such as Angola, Cameroon and Ghana, and their contribution to aquaculture production in SSA, have been neglected by both African governments and international donors. Therefore, one tentative explanation of this result could be that SMEs aquaculture is not properly accounted for in aquaculture statistics[111]. However, this topic has to be further investigated in order to propose a feasible and more comprehensive explanation about the negative impact of SR_8 on POU.

In order to address potential endogeneity of aquaculture development caused by reverse causality[112], I follow the approach proposed by Ghani (2011) and Hu, et al. (in press) by creating a lagged variable of AD. According to the logical framework proposed in Section 3.1, I do not consider the reverse causality between AD and POU, since food security represents by definition an outcome of aquaculture development. However, testing for endogeneity has provided a robustness check of both the logical framework and the PCSEs model.

PCSEs model does not consider the edogeneity issues. Following Ghani's approach (2011), as first step, I have created a one-year lagged variable of AD (lagAD). Then, I have tested again the PCSEs model (PCSEs_3) by employing lagAD. The PCSEs model with lagged values of AD (PCSEs_3) and the PCSEs model with contemporaneous values (PCSEs_2) produced very similar estimates in terms of both significance level and magnitude of the effect of each

[111] Aquaculture statistics are compiled by FAO from national aquaculture statistics submitted by FAO Members (FAO, 2016m).

[112] The reverse causality refers to the possibility that the exogenous variable has an impact on the endogenous variable and, at the same time, the endogenous variable has an impact on the exogenous variable (Verbeek, 2008).

variable (Table 9). Therefore, in agreement with the conclusions of Ghani (2011), since PCSEs_3 and PCSEs_2 do not show marked differences, the endogeneity does not represent an issue.

This work responds to the need to evaluate empirically the positive impact of aquaculture on food security at global level, previously claimed by anecdotal evidence (Agüero & González, 1997; Tacon, 2001; Allison, 2011; AFSPAN, 2014a; FAO, 2014b).

The main limitations of this model resulted from the lack of both indicators and data. First, the available data on fish consumption, imports and exports statistics are not disaggregated between farmed and wild products. At country level, these datasets refer only to total fishery production. Second, as for the per capita GDP, there are no indicators, at global level, on the valued added either of the total fishery sector or disaggregated between aquaculture and capture fisheries. Third, it was not possible to include the labour component among the explanatory variables of the econometric model since data are available only at regional level and for scattered years. Fourth, given the lack of data, it was not possible to test the PCSEs model with different outcome indicators of food security.

Despite the restrictions mentioned above, overall this work presents a methodology that brings together the limited data available and produces a solid analysis from it.

Table 6. Results of the estimation based on OLS, FER, RER and PCSEs by testing all selected variables

Exogenous variables	Endogenous variable = POU							
	POLS		FER		RER		PCSEs_1	
AD	-0.1211	***	-0.1461	***	-0.1420	***	-0.0734	***
	0.0128		*0.0143*		*0.0137*		*0.0186*	
FC	-0.4485	***	-0.3038	***	-0.3213	***	-0.2624	***
	0.0242		*0.0371*		*0.0352*		*0.0273*	
GDP	-0.0002	***	-0.0002	***	-0.0002	***	-0.0002	***
	0.0000		*0.0000*		*0.0000*		*0.0000*	
FI	0.0000		0.0000		0.0000		0.0000	
	0.0003		*0.0002*		*0.0002*		*0.0001*	
FE	-0.0014	***	-0.0002		-0.0003		-0.0001	
	0.0003		*0.0002*		*0.0002*		*0.0001*	
SR								
2	-9.0049	***			-10.1100	*	-17.9838	***
	1.1005				*4.7308*		*1.2797*	
3	-18.0857	***			-16.7671	***	-15.1757	**
	1.0505				*4.3375*		*5.0376*	
4	-17.2430	***			-16.9400	***	-16.2363	***
	1.0063				*4.3236*		*1.1464*	
5	-2.9220				-6.5415		-9.8793	***
	1.8733				*7.2345*		*1.8649*	
6	-14.1698	***			-17.7145	**	-12.9155	***
	1.5083				*6.1205*		*1.9322*	
7	-0.9512				-9.7808		-13.5997	***
	2.7109				*9.9723*		*2.0540*	
8	2.2559	*			0.9985		7.8024	***
	1.0937				*4.7275*		*2.1107*	
9	-26.1477	***			-26.2703	***	-28.5949	***
	1.2393				*5.4264*		*1.1866*	
10	-9.6861	***			-14.8267		-17.4198	***
	2.3959				*9.7998*		*1.5230*	
11	-17.5127	***			-18.2772	***	-14.2499	***
	0.8988				*3.8899*		*1.4423*	
12	-1.9875				-3.8600		-6.4933	***
	1.0892				*4.2365*		*1.3622*	
13	-15.2532	***			-14.5724	**	-14.7727	**
	1.2522				*5.4279*		*4.5361*	
14	-9.6333	***			-9.2700	*	-11.8675	***
	1.0639				*4.5009*		*2.1709*	
15	-11.4033	***			-12.5743	***	-11.1483	***
	0.8803				*3.8133*		*2.5723*	
16	-14.4196	***			-14.6894	***	-12.6660	***
	1.1062				*4.3379*		*1.6716*	
Constant	40.8794	***	27.4013	***	39.1638	***	38.2993	***
	0.7844		*0.6292*		*2.8201*		*1.1084*	

Statistic summary	POLS	FER	RER	PCSEs_1
N	2392	2392	2392	2392
R^2	0.4987	0.1134		0.5961
R^2 adj	0.4945	0.0715		
R^2 w		0.1134	0.1133	
R^2 b		0.2699	0.5652	
R^2 o		0.2430	0.4890	
rmse	10.0678	5.5998	5.5997	1.7430
Wald test of the null hypothesis				
χ^2			405.11	7291.87
Prob> χ^2			0.0000	0.0000
F	117.95	58.40		
Prob> F	0.0000	0.0000		
Breusch-Pagan / Cook-Weisberg test for heteroskedasticity				
χ^2 (1)	74.65			
Prob> χ^2	0.0000			
Modified Wald test for groupwise heteroskedasticity				
χ^2 (104)		2000000		
Prob> χ^2		0.0000		
Pesaran's test of cross sectional independence				
CD test		22.84	21.98	
Prob		0.0000	0.0000	
Breusch and Pagan Lagrangian multiplier test for random effects				
χbar^2 (1)			12242.67	
Prob> χ^2			0.0000	
Hausman test				
χ^2 (5)			4.98	
Prob> χ^2			0.4189	

Legend: * p<0.05; ** p<0.01; *** p<0.001; Standard Errors in *italics*; N = number of observations; rmse = root mean squared error; R^2 adj = R-squared adjusted; R^2 w = R-squared within; R^2 b = R-squared between; R^2 o = R-squared overall.

Table 7. PCSEs_1 detailed results of the estimation by testing all selected variables

Group variable: country				Number of observations =			2392
Time variable: period				Number of groups =			104
Panels: correlated (balanced)				Observations per group: min =			23
Autocorrelation: panel-specific AR(1)				average =			23
				max =			23
Estimated covariance = 5460				R^2 =			0.5961
Estimated autocorrelations = 104				Wald χ^2 (20) =			7291.9
Estimated coefficients = 21				Prob > χ^2 =			0.0000

POU	PCSEs_1						
	Coef.	**Std. err.**	**z**	**P>|z|**		**95% Conf. Interval**	
AD	-0.0734	0.0186	-3.9600	0.0000	***	-0.1098	-0.0370
FC	-0.2624	0.0273	-9.6000	0.0000	***	-0.3160	-0.2088
GDP	-0.0002	0.0000	-7.4500	0.0000	***	-0.0002	-0.0001
FI	0.0000	0.0001	0.0100	0.9910		-0.0001	0.0001
FE	-0.0001	0.0001	-0.7000	0.4850		-0.0002	0.0001
SR							
2	-17.9838	1.2797	-14.0500	0.0000	***	-20.4919	-15.4758
3	-15.1757	5.0376	-3.0100	0.0030	**	-25.0491	-5.3022
4	-16.2363	1.1464	-14.1600	0.0000	***	-18.4832	-13.9893
5	-9.8793	1.8649	-5.3000	0.0000	***	-13.5344	-6.2242
6	-12.9155	1.9322	-6.6800	0.0000	***	-16.7025	-9.1285
7	-13.5997	2.0540	-6.6200	0.0000	***	-17.6255	-9.5738
8	7.8024	2.1107	3.7000	0.0000	***	3.6655	11.9393
9	-28.5949	1.1866	-24.1000	0.0000	***	-30.9206	-26.2692
10	-17.4198	1.5230	-11.4400	0.0000	***	-20.4048	-14.4349
11	-14.2499	1.4423	-9.8800	0.0000	***	-17.0767	-11.4232
12	-6.4933	1.3622	-4.7700	0.0000	***	-9.1632	-3.8233
13	-14.7727	4.5361	-3.2600	0.0010	**	-23.6634	-5.8820
14	-11.8675	2.1709	-5.4700	0.0000	***	-16.1224	-7.6126
15	-11.1483	2.5723	-4.3300	0.0000	***	-16.1900	-6.1066
16	-12.6660	1.6716	-7.5800	0.0000	***	-15.9423	-9.3897
Constant	38.2994	1.1084	34.5500	0.0000	***	36.1269	40.4718
ρ	0.9787	1.0000	0.9545	0.9908		0.8754	0.9748

Legend: * p<0.05; ** p<0.01; *** p<0.001

Table 8. PCSEs_2 detailed results of the estimation by testing all statistically significant variables

Group variable: country			Number of observations =			2392
Time variable: period			Number of groups =			104
Panels: correlated (balanced)			Observations per group: min =			23
Autocorrelation: panel-specific AR(1)			average =			23
			max =			23
Estimated covariance = 5460			R^2 =			0.5704
Estimated autocorrelations = 104			Wald χ^2 (18) =			5678.5
Estimated coefficients = 19			Prob > χ^2 =			0.0000

POU	PCSEs_2						
	Coef.	**Std. err.**	**z**	**P>|z|**		**95% Conf. Interval**	
AD	-0.0699	0.0184	-3.8100	0.0000	***	-0.1059	-0.0340
FC	-0.2687	0.0299	-8.9800	0.0000	***	-0.3274	-0.2100
GDP	-0.0002	0.0000	-4.9900	0.0000	***	-0.0002	-0.0001
SR							
2	-17.4816	1.4767	-11.8400	0.0000	***	-20.3759	-14.5873
3	-14.7420	5.1363	-2.8700	0.0040	**	-24.8089	-4.6751
4	-15.8982	1.1765	-13.5100	0.0000	***	-18.2041	-13.5923
5	-10.6999	1.8511	-5.7800	0.0000	***	-14.3280	-7.0718
6	-12.2346	2.1897	-5.5900	0.0000	***	-16.5263	-7.9428
7	-13.3076	2.1893	-6.0800	0.0000	***	-17.5985	-9.0168
8	7.7557	2.1220	3.6500	0.0000	***	3.5966	11.9149
9	-28.6810	1.3285	-21.5900	0.0000	***	-31.2848	-26.0772
10	-17.2085	1.4993	-11.4800	0.0000	***	-20.1470	-14.2700
11	-13.4538	1.5433	-8.7200	0.0000	***	-16.4787	-10.4289
12	-6.8165	1.4895	-4.5800	0.0000	***	-9.7357	-3.8972
13	-16.2879	6.7506	-2.4100	0.0160	*	-29.5188	-3.0570
14	-11.0110	2.4322	-4.5300	0.0000	***	-15.7780	-6.2441
15	-10.5841	3.1742	-3.3300	0.0010	***	-16.8053	-4.3628
16	-12.7177	1.8560	-6.8500	0.0000	***	-16.3554	-9.0799
Constant	38.2724	1.2351	30.9900	0.0000	***	35.8517	40.6931
ρ	0.9819	1.0000	0.9518	0.9954		0.8751	0.9779

Legend: * p<0.05; ** p<0.01; *** p<0.001

Table 9. PCSEs_3 results of the estimation with lagged AD

Exogenous variables	Endogenous variable = POU			
	PCSEs_2		PCSEs_3	
AD	-0.0699	***		
	0.0184			
lagAD			-0.0804	***
			0.0195	
FC	-0.2687	***	-0.2665	***
	0.0299		*0.0332*	
GDP	-0.0002	***	-0.0002	***
	0.0000		*0.0000*	
SR				
2	-17.4816	***	-17.7475	***
	1.4767		1.8595	
3	-14.7420	**	-13.6652	**
	5.1363		4.7171	
4	-15.8982	***	-15.6250	***
	1.1765		1.1966	
5	-10.6999	***	-11.9620	***
	1.8511		2.1189	
6	-12.2346	***	-13.8468	***
	2.1897		1.8898	
7	-13.3076	***	-13.8944	***
	2.1893		2.3161	
8	7.7557	***	6.6003	**
	2.1220		2.0589	
9	-28.6810	***	-29.1317	***
	1.3285		1.2397	
10	-17.2085	***	-17.6447	***
	1.4993		1.6834	
11	-13.4538	***	-14.8333	***
	1.5433		1.3855	
12	-6.8165	***	-8.7513	***
	1.4895		1.5037	
13	-16.2879	*	-17.2670	*
	6.7506		7.5972	
14	-11.0110	***	-9.9494	***
	2.4322		2.3182	
15	-10.5840	***	-11.9408	***
	3.1742		2.5083	
16	-12.7177	***	-12.2186	***
	1.8560		2.0380	
Constant	38.2724	***	38.7717	***
	1.2351		*1.1533*	
Statistic summary	**PCSEs_2**		**PCSEs_3**	
N	2392		2288	
R^2	0.5704		0.5981	
R^2 adj				
rmse	1.7323		1.7662	
Wald test of the null hypothesis				
χ^2	5678.50		5082.71	
Prob> χ^2	*0.0000*		*0.0000*	

Legend: * p<0.05; ** p<0.01; *** p<0.001; Standard Errors in italics; N = number of observations; R^2 adj = R-squared adjusted; rmse = root mean squared error

3.5 Policy Implications and Future Research

Based on the main results of the descriptive (Chapter 1), theoretical (Chapter 2) and the empirical analyses (Section 3.4) performed, this section discusses possible policy recommendations along with future research topics.

A transversal policy in support of aquaculture development relates to the evaluation of the sector development's impact on food security. Evaluation of the impact of aquaculture development on food security requires both suitable indicators and reliable data to quantity them.

The international political and academic debate is quite lively on this subject. Several aquaculture indicators have been proposed to monitor, assess and/or evaluate aquaculture contribution to food security, for which the data collection has not yet been implemented (Appendix 7). Simple techniques are required to construct most of the proposed indicators, for example, calculation of the share of aquaculture's protein supply in total protein supply and in total animal protein supply.

The main issue is that the available data on fish and fish products are not only limited (FAO, 2016m), but also rarely disaggregated by aquaculture and capture fisheries origin. In addition, a large amount of data, available at both national and regional levels, is not employed since the data collection agencies lack the mandate and/or the institutional capacities[113] (FAO, 2014a).

The «lack of data and related low visibility of the sector may affect policy decisions» (FAO, 2016l). Given the current and foreseen future importance of aquaculture development within the food security framework, adequate and disaggregated data have to be collected and made publicly available if monitoring, assessment and evaluation of the sector performance and its impact on food security are to be achieved. Such data and analyses are needed to better support all stakeholders involved in aquaculture planning and policy formulation and implementation (Brugère, et al., 2010; FAO, 2016m). Collecting such data should be a shared responsibility, which both aquaculture producers and consumers countries should adopt as a part of their policy package.

[113] Academics, technical professionals and sector experts discussed the methodologies and techniques for assessing and monitoring the performance of the aquaculture sector during the FAO Expert Workshop on Assessment and Monitoring of Aquaculture Sector Performance, which was held in Gaeta, Italy, from 5 to 7 November 2012 (FAO, 2014a).

The empirical analysis has shown that aquaculture development brought positive effects on food security outcome in developing countries. This is a topic of growing global relevance for both the countries that have implemented actions to support the sector, like in Southeast Asia (Hishamunda & Subasinghe, 2003; Hishamunda, et al., 2009a), and the ones that are in the process of doing so, be it through planning or implementing policy measures to enable the sector development, as is the case in SSA (FAO, 2016m).

Being the first attempt of this kind, and according to the logical framework (Section 3.1), further research is needed to investigate the impact on food security outcome at country, household and/or individual level. Additional research addressing other outcome indicators of food security should also be performed, subject to the accomplishment of the recommendations proposed above.

Moreover, with reference to the monitoring and evaluation activities for policies implementation, the methodology here proposed could also be tested to evaluate the impact of applied aquaculture policies, strategies, plans, programmes and/or projects on food security outcomes. The feasibility of this analysis depends on the availability of baseline data and indicators (Brugère, et al., 2010).

Conclusions

At the 1996 World Food Summit (WFS), representatives of 182 governments pledged «… to eradicate hunger in all countries, with an immediate view of reducing the number of undernourishment people to half their present level no later than 2015» (FAO, 1996a). In 2015, almost 20 years after the WFS, during the United Nations Sustainable Development Summit, world leaders from 193 Member States adopted a set of 17 SDGs as part of the new 2030 Agenda for Sustainable Development. The second SDG set a challenging target "by 2030, end hunger and ensure access by all people, in particular the poor and people in vulnerable situations, including infants, to safe, nutritious and sufficient food all year round" (United Nations, 2015b; United Nations, 2016). In this framework, aquaculture's contribution to food security is a prominent element in the international debate and this dissertation has considered this issue in a three-fold approach including a conceptual, a theoretical and an empirical perspectives.

Chapter 1 has provided the comprehensive conceptual framework of the research, highlighting, first, how food security is a multifaceted concept composed by four dimensions: availability, access, stability, and utilisation. Chapter 1 also provided an extensive description of the indicators which have been formulated to capture the dimensional complexity of food security, in particular of those suggested by FAO et al. (2013) due to their relevance in the international debate. The latter differ from all the others indicators because they allow to measure two different and consequential aspects of food security, its determinants and outcomes. Among these indicators, the prevalence of undernourishment (POU) can be considered a good proxy of food security.

The focus has then shifted to aquaculture, presenting and updating a complete descriptive analysis of the current trends and future developments of this sector, from a food security perspective. This analysis has confirmed that aquaculture is, and will remain, one of the fastest growing food production systems in the world. Aquaculture development is gaining importance in terms of total fish production and consumption against the low growth demonstrated by capture fisheries production and the increasing demand for food fish.

In Chapter 2, an extensive overview of the literature analysing aquaculture's contribution to food security, through both anecdotal and empirical evidences, has been presented, in order also to identify the shortcomings of these studies and the gaps in the literature. In particular, as summarized by HLPE (2014), aquaculture may contribute to the availability component of food security through the production of fish food at the household, local and national market levels. Aquaculture supply, processing and trading, may generate employment and income thereby improving access to food, including fish and other food commodities. Consumption of fish and other food commodities may contribute to the utilization component in terms of dietary intakes improvement. Stability results from aquaculture capacity to stabilize food supply and to overcome shocks.

However, the overview has shown that many of the empirical studies focus merely on one dimension of food security, mostly the utilization dimension in terms of nutrient content, and look at the impact of aquaculture on only the determinants of food security, once again the utilization dimension in terms of nutrient. Moreover, the literature mostly analyses regional situations within a country and focuses on limited periods.

Therefore, the empirical analysis presented in Chapter 3 joined the debate on the aquaculture contribution to food security by providing three original contributions. First, it investigated the contribution of aquaculture on food security outcomes rather than determinants and, specifically on POU. Second, it performed the analysis at a global level rather than focusing on single countries. Third, it looked at the contribution of the aquaculture sector on food security over a long time horizon (1990–2014) rather than across limited periods.

For this purpose, I have proposed a logical framework to develop a suitable methodology for evaluating the impact of agricultural sector, in general, and of aquaculture, specifically, on food security. Following this framework, the empirical analysis focused on the outcomes of food security to assess the impact of aquaculture development at global and regional level across developing countries.

Then, the empirical analysis tested whether the development of the aquaculture sector has improved food security in developing countries that experienced undernourishment issues using a panel data composed by 104 developing countries and 23 periods from 1990–92 to 2012–14. Among different estimated models, the PCSEs regression was found to be the most adequate test of the hypothesis, since it allowed for the production of efficient estimates in the presence of heteroskedasticity, contemporaneously correlation disturbances and serial correlation.

To conclude, the results seem to confirm that, in line with the existing literature, the development of the aquaculture sector has improved food security in developing countries and specifically that for one unit increase in aquaculture development indicator, i.e. the share of aquaculture production on the total fishery production, food security, measured by the total prevalence of undernourishment, is expected to decrease by 0.0699 units, holding all other variables constant.

However, focusing on aquaculture in developing countries means that, in most cases, information and knowledge (especially quantitative indicators) are absent (FAO, 2014b; AFSPAN, 2014a; FAO Committee on Fisheries, 2015b). Moreover, whether available, data are rarely disaggregated to differentiate between aquaculture and capture fisheries (AFSPAN, 2014a). Therefore, the main shortcomings of the quantitative analysis have resulted, first, from the lack of disaggregation between farmed and wild products for fish consumption, imports and exports statistics. Moreover, it was not possible to include the labour component among the explanatory variables of the econometric model since data are available only at regional level and for scattered years. In addition, given the lack of data, it was not possible to test the model on other outcome indicators of food security, such as the anthropometric indicators. Through human body measurements, the anthropometric indicators are able to detect the undernutrition status of individuals.

Therefore, the assessment of the aquaculture contribution to food security within a more comprehensive (and complex) framework requires further advances, first in collecting high quality data for a large number of countries. Such data and analyses are needed to better support all stakeholders involved in aquaculture planning and policy formulation and implementation (Brugère, et al., 2010; FAO, 2016m).

This work responds to the need to evaluate empirically the positive impact of aquaculture on food security. The methodology brings together the limited data available and produces a solid analysis from it. The empirical analysis does not pretend to be exhaustive in evaluating the impact of aquaculture on food security. Nonetheless, it still represents a first innovative attempt to assess, at global level, the contribution of the sector on one of the outcomes of food security and this fascinating field of study will certainly continue to be part of my research agenda.

Appendixes

Appendix 1. Literature Review: Mapping of the Main Elements

IDL	Focus		Impact on food security				Impact on poverty	Methodology		Level of analysis		Source
	Aquaculture	Capture	Availability	Access	Utilization	Stability		Literature	Quantitative analysis	Macro	Micro	
1	✓	✓	✓	✓	✓		✓	✓		✓	✓	(AFSPAN, 2012)
2	✓	✓	✓	✓	✓		✓	✓		✓	✓	(Béné, et al., 2016)
3	✓	✓	✓			✓	✓		✓	✓		(Merino, et al., 2012)
4	✓		✓	✓	✓	✓			✓		✓	(Ahmed & Garnett, 2011)
5	✓	✓	✓						✓	✓		(Béné, et al., 2010)
6	✓		✓	✓	✓	✓	✓	✓	✓	✓		(Hishamunda, et al., 2009b)
7	✓	✓	✓	✓					✓		✓	(Dey, et al., 2005)
8	✓	✓	✓	✓	✓	✓		✓		✓	✓	(Beveridge, et al., 2013)
9	✓	✓			✓			✓			✓	(Kawarazuka & Béné, 2010)
10	✓		✓	✓	✓	✓		✓		✓	✓	(Ahmed & Lorica, 2002)
11	✓			✓					✓		✓	(Jahan, et al., 2010)

IDL	Focus		Impact on food security				Impact on poverty	Methodology		Level of analysis		Source
	Aquaculture	Capture	Availability	Access	Utilization	Stability		Literature	Quantitative analysis	Macro	Micro	
12	✓		✓	✓					✓		✓	(Dey, et al., 2006)
13	✓			✓			✓		✓		✓	(Toufique & Belton, 2014)
14	✓	✓		✓					✓		✓	(Tveteras, et al., 2012)
15	✓	✓	✓	✓	✓		✓		✓	✓	✓	(AFSPAN, 2015)
16	✓			✓					✓		✓	(Belton, et al., 2011)
17	✓			✓					✓		✓	(Hortle, 2007)
18	✓				✓		✓	✓		✓	✓	(Tacon, 2001)
19	✓	✓			✓			✓		✓	✓	(Genschick, et al., 2015)
20	✓	✓			✓			✓		✓	✓	(Béné, et al., 2015)
21	✓	✓			✓			✓		✓	✓	(HLPE, 2014)
22	✓	✓			✓			✓	✓	✓		(Belton & Thilsted, 2014)

IDL	Focus		Impact on food security				Impact on poverty	Methodology		Level of analysis		Source
	Aquaculture	Capture	Availability	Access	Utilization	Stability		Literature	Quantitative analysis	Macro	Micro	
23	✓	✓			✓			✓			✓	(Kawarazuka & Béné, 2011)
24	✓	✓			✓			✓		✓	✓	(Kawarazuka, 2010)
25	✓					✓			✓		✓	(Bell, et al., 2011)
26	✓					✓			✓		✓	(Waite, et al., 2014)
27	✓	✓	✓	✓	✓		✓		✓	✓	✓	(AFSPAN, 2014a)
28	✓	✓		✓			✓	✓		✓	✓	(Allison, 2011)
29	✓		✓	✓				✓		✓		(Hishamunda & Ridler, 2006)
30	✓	✓	✓					✓		✓		(AFSPAN, 2014b)
31	✓			✓					✓		✓	(Cleasby, et al., 2014)
32	✓		✓	✓			✓		✓		✓	(Belton, et al., 2014a)
33	✓	✓		✓	✓				✓		✓	(Gomna & Rana, 2007)

IDL	Focus		Impact on food security				Impact on poverty	Methodology		Level of analysis		Source
	Aquaculture	Capture	Availability	Access	Utilization	Stability		Literature	Quantitative analysis	Macro	Micro	
34	✓		✓					✓	✓	✓		(Naylor, et al., 2001)
35	✓		✓					✓		✓		(Martinez-Porchas & Martinez-Cordova, 2012)
36	✓		✓	✓				✓		✓		(Troell, et al., 2014)
37	✓	✓			✓				✓		✓	(Belton, et al., 2014b)
38	✓	✓			✓			✓			✓	(Tacon & Metian, 2013)
39	✓	✓			✓				✓		✓	
40	✓	✓			✓				✓		✓	(Roos, et al., 2007b)
41	✓	✓	✓					✓	✓	✓	✓	(Kurien, 2005)
42	✓	✓	✓					✓		✓		(FAO, 2003a)
43	✓	✓			✓			✓			✓	(Powell, et al., 2015)
44	✓	✓		✓	✓				✓		✓	(Banda Nyirenda, et al., 2010)

IDL	Focus		Impact on food security				Impact on poverty	Methodology		Level of analysis		Source
	Aquaculture	Capture	Availability	Access	Utilization	Stability		Literature	Quantitative analysis	Macro	Micro	
45	✓			✓					✓		✓	(El Mahdi, et al., 2015)
46	✓		✓	✓	✓			✓		✓	✓	(Tidwell & Allan, 2011)
47	✓			✓			✓	✓	✓		✓	(Kassam, 2014)
48	✓	✓			✓			✓		✓	✓	(FAO/WHO, 2011)
49	✓				✓			✓			✓	(Thilsted, 2012)
50	✓		✓	✓				✓	✓		✓	(Belton, et al., 2015)
51	✓	✓			✓			✓			✓	(Longley, et al., 2014)
52	✓	✓			✓			✓		✓	✓	(Thilsted, et al., 2016)
53	✓		✓	✓				✓	✓		✓	(Hernandez, et al., in press)
54	✓		✓	✓				✓	✓		✓	(Belton, et al., in press)

Note: IDL = Internal Identifier of the Literature

Appendix 2. Literature Review: Mapping of the Quantitative Methods

IDL	Quantitative methods	Time frame	Area	Source
3	POLCOMS hydrodynamic model, ERSEM ecosystem model , Bio-economic network model	1992–2050	30 LME, 69 EEZs, 33 countries	(Merino, et al., 2012)
4	OLS, Cobb-Douglas production function model	2007–2008	1district in Bangladesh	(Ahmed & Garnett, 2011)
5	OLS, 2SLS	1990–2001	47 SSA countries	(Béné, et al., 2010)
6	Set of indicators: CA's protein (or other nutrients) supply; Share of CA's protein supply in total protein supply; Share of CA's protein supply in total animal protein supply; CA's direct protein supply; CA's indirect food supply; CA's direct contribution to labour income; CA's total contribution to labour income; CA's average wage rate; Wage level comparison between CA and agriculture; CA's employment composition; Female share in CA's employment; Magnitude deviation of production (protein supply) from trend; Percentage deviation of production from trend; Magnitude deviation of price from trend; Percentage deviation of price from trend ; Covariance between CA's total protein supply and total protein supply for the entire economy; Correlation between CA's total protein supply and total protein supply for the entire economy	1990–2000	12 SSA countries	(Hishamunda, et al., 2009b)
7	Inverse semi-log regression model, DMRT	1995–1996, 1998–1999	5 Asian countries	(Dey, et al., 2005)
11	ANOVA	2001–2005	4 districts in Bangladesh	(Jahan, et al., 2010)
12	RESTORE	2004	4 sites in Malawi	(Dey, et al., 2006)
13	Descriptive analysis	2000, 2005, 2010	Bangladesh	(Toufique & Belton, 2014)
14	FPI	1990–2011	Global	(Tveteras, et al., 2012)

IDL	Quantitative methods	Time frame	Area	Source
15	Animal-source food replacement approach Causality between wild-caught and farmed fish prices Proportion of aquaculture in-house consumption Proportion of aquaculture income	2010	11 countries	(AFSPAN, 2015)
16	Descriptive analysis	2005	Bangladesh	(Belton, et al., 2011)
22	Descriptive analysis	1980–2009	Global, 10 countries	(Belton & Thilsted, 2014)
25	Vulnerability framework	2035–2100	PICTs	(Bell, et al., 2011)
26	LCA	2010–2050	Global	(Waite, et al., 2014)
27	Animal-source food replacement approach Causality between wild-caught and farmed fish prices Proportion of aquaculture in-house consumption Proportion of aquaculture income	2010	11 countries	(AFSPAN, 2014a)
31	Mann Whitney rank sum test ANOVA Rank correlation	2010	Peri-urban area (Solomon Islands)	(Cleasby, et al., 2014)
32	Descriptive analysis	2012	Bangladesh	(Belton, et al., 2014a)
33	Pearson correlation OLS	2003	2 States in Nigeria	(Gomna & Rana, 2007)
34	Descriptive analysis	1997	Global	(Naylor, et al., 2001)
37	Descriptive analysis	1996–1997, 2006–2007	Bangladesh	(Belton, et al., 2014b)

IDL	Quantitative methods	Time frame	Area	Source
39	Fish species sampling and screening	2001	Cambodia	(Roos, et al., 2007a)
40	Descriptive analysis	1991–1992, 1995, 1996–1997, 1997–1998	Bangladesh, Cambodia	(Roos, et al., 2007b)
41	Descriptive analysis	1998–2001	11 countries	(Kurien, 2005)
44	Descriptive analysis	2010	Zambia	(Banda Nyirenda, et al., 2010)
45	Descriptive analysis	2014	5 governorates (Egypt)	(El Mahdi, et al., 2015)
47	Descriptive analysis	2013	Ghana	(Kassam, 2014)
50	Descriptive analysis	1990–2014	Myanmar	(Belton, et al., 2015)
53	Descriptive analysis, stacked value chain surveys	2004, 2009, 2014	20 districts (Bangladesh)	(Hernandez, et al., in press)
54	Descriptive analysis, mapping using satellite imagery, interviews, surveys	2014	4 sites, 49 villages (Myanmar)	(Belton, et al., in press)

Note: IDL = Internal Identifier of the Literature; CA = Commercial Aquaculture

Appendix 3. Unit of Analysis

The unit of analysis is the country. The countries' taxonomy is not uniform among the datasets selected in this research to perform the global assessment (section 3.3.1). Therefore, it was decided to name the countries after the taxonomy applied in the FAO food security indicators (FAO, 2016e), which is slightly different from other selected datasets for this empirical analysis (e.g., FAO FishstatJ and FAOSTAT).

According to the FAO food security indicators' taxonomy, China included China mainland, Hong Kong Special Administrative region (SAR), Macao SAR and Taiwan Province of China. In order to be comparable with the FAO food security indicators' taxonomy, the country China (Internal Identifier [ID] code 351) has been created by adding China, mainland (ID 41), China, Hong Kong SAR (ID 96), Taiwan, Province of China (ID 214) and China, Macao SAR (ID 128). Even if there is no aquaculture production in Macao SAR, it was considered because there are data on total fishery production and to be consistent with FAO food security indicators' taxonomy.

The following countries have been removed from the quantitative analysis since they had not data in one or more of the selected datasets: Bonaire, Sint Eustatius and Saba (BES) (ID 283), Netherlands Antilles[114] (ID 151), Channel Islands[115] (ID 259), Falkland Islands (Malvinas) (ID 65), Marshall Islands[116] (ID 127), Zanzibar[117] (ID 276), The People's

[114] BES (ID 283), which gained independency from Netherlands Antilles (ID 151) in 2010, is not included in the list of countries of the selected FAO food security datasets (i.e., prevalence of undernourishment (POU), per capita GDP and total population both sexes datasets), the FishStatJ dataset on trade of fishery commodities, the FAOSTAT datasets on food supply quantity and protein supply quantity. For BES, the data are available only in the FishStatJ datasets on aquaculture production and global production by source. Netherlands Antilles is included in the list of countries of the FAO food security indicators but data are not available in the datasets here selected (i.e., POU, per capita GDP and total population both sexes datasets). For Netherlands Antilles, data are available in the FishStatJ datasets on aquaculture production and global production by source, fishery commodities trade, and the FAOSTAT datasets on food supply quantity and protein supply quantity.

[115] Channel Islands (ID 259) are not included in the list of countries of the FAO food security indicators. They are included in the FishStatJ datasets on aquaculture production and global production by source. In the food balance sheets of fish and fishery products in live weight and fish contribution to protein supply, data for England and Wales, Scotland, Northern Ireland, Isle of Man and Channel Islands have been combined (Statistics and Information Branch of the Fisheries and Aquaculture Department, 2014). The data on fish consumption and fish proteins have been first downloaded from FAO Statistic Division website, alias FAOSTAT and, whenever not available, from the FAO fishery and aquaculture statistics yearbook.

[116] Both Falkland Islands (Malvinas) (ID 65) and Marshall Islands (ID 127) are not included in the list of countries of the FAO food security indicators. They are included in the FishStatJ datasets on aquaculture production, global production by source and fishery commodities trade, and the FAOSTAT datasets on food supply quantity and protein supply quantity.

Democratic Republic of Ethiopia[118] (ID 62) and the Union of the Soviet Socialist Republics[119] (ID 228). A set of 40 countries have been excluded from this analysis because data on prevalence of undernourishment were not available[120].

The developing countries selected for this analysis are 104: 38 from Africa, 35 from Asia, 26 from LAC and 5 from Oceania. The list of countries is included in Table 11.

The subregions (SR) have been selected as dummy variable in the quantitative analysis (Section 3.2). As shown in Table 10, African countries are mostly for sub-Saharan Africa (34) and the rest from Northern Africa (4). In sub-Saharan Africa, developing countries are mostly concentrated in Western Africa (13) and Eastern Africa (11), followed by Middle Africa (6) and Southern Africa (4). Asia countries are from the following regions: South-

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[117] Only the FishStatJ datasets on aquaculture production and global production by source collected data on both United Republic of Tanzania (ID 215) and Zanzibar (ID 276). As reported in study on the value of African fisheries (de Graaf & Garibaldi, 2014), the FAO capture and aquaculture databases include separate statistics for Tanzania mainland and Zanzibar, since they are submitted by two different offices. It could be hypothesized that the ID 215 of United Republic of Tanzania address only Tanzania mainland in both datasets on global aquaculture and global production by source. In this analysis, data on aquaculture production and total fishery production exclude production figures for marine mammals, crocodiles, corals, pearls, mother-of-pearl, sponges and aquatic plants (section 3.2.1.1). In this regards, Zanzibar data on aquaculture production are negligible since they refer mostly to aquatic plants. Therefore, even if the ID 215 of Tanzania in the datasets on global aquaculture and global production by source should refer only to Tanzania mainland, the exclusion of Zanzibar should have a minor impact for the purposes of this research. The FAO food security indicators referred to Tanzania and identified the country with the same ID (215) of the above-mentioned datasets. Therefore, it can be assumed that food security indicators referred only to Tanzania without Zanzibar. For these rationales, Zanzibar was not considered in the quantitative analysis.

[118] The People's Democratic Republic of Ethiopia (ID 62) is not included in the list of countries of the FAO food security indicators, and the FishStatJ datasets on aquaculture production and global production by source. It is included in the FishStatJ dataset on fishery commodities trade, and the FAOSTAT datasets on food supply quantity and protein supply quantity. In the food balance sheets (Statistics and Information Branch of the Fisheries and Aquaculture Department, 2014), data from 1990 to 1992 referred to the area that was formerly the People's Democratic Republic of Ethiopia. The new independent republics are Ethiopia (ID 238) and Eritrea (ID 178), for which data are shown separately. Since the People's Democratic Republic of Ethiopia is not included in this analysis, the data from 1990 to 1992 for Ethiopia and Eritrea are considered not available for the above-mentioned datasets.

[119] The Union of the Soviet Socialist Republics (ID 228) is not included in the list of countries of the FAO food security indicators. It is included in the FishStatJ datasets on aquaculture production, global production by source and fishery commodities trade, and the FAOSTAT datasets on food supply quantity and protein supply quantity. Starting with 1992 information for each independent republic is shown separately. Data from 1992 refers to Armenia, Azerbaijan, Belarus, Estonia, Georgia, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Republic of Moldova, Russian Federation, Tajikistan, Turkmenistan, Ukraine, Uzbekistan. Since the Union of the Soviet Socialist Republics is not included in this analysis, the data from 1990 to 1991 for each independent republic are considered not available for the above-mentioned datasets.

[120] American Samoa (ID 5), Aruba (ID 22), Bahamas (ID 12), Bahrain (ID 13), Bhutan (ID 18), Burundi (ID 29), Cook Islands (ID 47), Democratic Republic of the Congo (ID 250), Dominica (ID 55), Equatorial Guinea (ID 61), Eritrea (ID 178), French Guiana (ID 69), French Polynesia (ID 70), Grenada (ID 86), Guadeloupe (ID 87), Guam (ID 88), Libya (ID 124), Martinique (ID 135), Mayotte (ID 270), Micronesia (Federated States of) (ID 145), Nauru (ID 148), New Caledonia (ID 153), Northern Mariana Islands (ID 163), Palau (ID 180), Papua New Guinea (ID 168), Puerto Rico (ID 177), Qatar (ID 179), Réunion (ID 182), Saint Kitts and Nevis (ID 188), Saint Lucia (ID 189), Seychelles (ID 196), Singapore (ID 200), South Sudan (ID 277), Sudan (ID 276), Sudan (former) (ID 206), Syrian Arab Republic (ID 212), Tonga (ID 219), Turks and Caicos Islands (ID 224), Tuvalu (ID 227), United States Virgin Islands (ID 240), West Bank and Gaza Strip (ID 299).

Eastern Asia (9), Western Asia (9), Caucasus and Central Asia (8), Southern Asia (7) and Eastern Asia (2). As for LAC (26), majority of developing countries are concentrated in Latin America (20). In Latin America, 12 countries are from South America and the rest from Central America (8). In Oceania, three countries are in the Melanesia region, followed by Micronesia (1) and Polynesia (1).

Table 10. Selected developing countries by geographical taxonomy

Region/Subregion	Subregion	Region
Africa		38
Sub Saharan Africa		34
Western Africa	13	
Eastern Africa	11	
Middle Africa	6	
Southern Africa	4	
Northern Africa	4	
Asia		35
South-Eastern Asia	9	
Western Asia	9	
Caucasus and Central Asia	8	
Southern Asia	7	
Eastern Asia	2	
Latin America and the Caribbean		26
Latin America		20
South America	12	
Central America	8	
Caribbean	6	
Oceania		5
Melanesia	3	
Micronesia	1	
Polynesia	1	

Table 11. List of selected developing countries

FAO code	Country	Region	Subregion	Sub-subregion
2	Afghanistan	Asia	Southern Asia	na
4	Algeria	Africa	Northern Africa	na
7	Angola	Africa	Sub-Saharan Africa	Middle Africa
9	Argentina	LAC	Latin America	South America
1	Armenia	Asia	Caucasus and Central Asia	na
52	Azerbaijan	Asia	Caucasus and Central Asia	na
16	Bangladesh	Asia	Southern Asia	na
14	Barbados	LAC	Caribbean	na
23	Belize	LAC	Latin America	Central America
53	Benin	Africa	Sub-Saharan Africa	Western Africa
19	Bolivia (Plurinational State of)	LAC	Latin America	South America
21	Brazil	LAC	Latin America	South America
26	Brunei Darussalam	Asia	South-Eastern Asia	na
233	Burkina Faso	Africa	Sub-Saharan Africa	Western Africa
115	Cambodia	Asia	South-Eastern Asia	na
32	Cameroon	Africa	Sub-Saharan Africa	Middle Africa
37	Central African Republic	Africa	Sub-Saharan Africa	Middle Africa
39	Chad	Africa	Sub-Saharan Africa	Middle Africa
40	Chile	LAC	Latin America	South America
351	China	Asia	Eastern Asia	na
44	Colombia	LAC	Latin America	South America
46	Congo	Africa	Sub-Saharan Africa	Middle Africa
48	Costa Rica	LAC	Latin America	Central America
107	Côte d'Ivoire	Africa	Sub-Saharan Africa	Western Africa
49	Cuba	LAC	Caribbean	na
56	Dominican Republic	LAC	Caribbean	na
58	Ecuador	LAC	Latin America	South America
59	Egypt	Africa	Northern Africa	na
60	El Salvador	LAC	Latin America	Central America
238	Ethiopia	Africa	Sub-Saharan Africa	Eastern Africa
66	Fiji	Oceania	Melanesia	na
74	Gabon	Africa	Sub-Saharan Africa	Middle Africa
75	Gambia	Africa	Sub-Saharan Africa	Western Africa
73	Georgia	Asia	Caucasus and Central Asia	na
81	Ghana	Africa	Sub-Saharan Africa	Western Africa
89	Guatemala	LAC	Latin America	Central America
90	Guinea	Africa	Sub-Saharan Africa	Western Africa
91	Guyana	LAC	Latin America	South America
93	Haiti	LAC	Caribbean	na
95	Honduras	LAC	Latin America	Central America
100	India	Asia	Southern Asia	na
101	Indonesia	Asia	South-Eastern Asia	na
102	Iran (Islamic Republic of)	Asia	Southern Asia	na
103	Iraq	Asia	Western Asia	na

FAO code	Country	Region	Subregion	Sub-subregion
109	Jamaica	LAC	Caribbean	na
112	Jordan	Asia	Western Asia	na
108	Kazakhstan	Asia	Caucasus and Central Asia	na
114	Kenya	Africa	Sub-Saharan Africa	Eastern Africa
83	Kiribati	Oceania	Micronesia	na
118	Kuwait	Asia	Western Asia	na
113	Kyrgyzstan	Asia	Caucasus and Central Asia	na
120	Lao People's Democratic Republic	Asia	South-Eastern Asia	na
121	Lebanon	Asia	Western Asia	na
122	Lesotho	Africa	Sub-Saharan Africa	Southern Africa
123	Liberia	Africa	Sub-Saharan Africa	Western Africa
129	Madagascar	Africa	Sub-Saharan Africa	Eastern Africa
130	Malawi	Africa	Sub-Saharan Africa	Eastern Africa
131	Malaysia	Asia	South-Eastern Asia	na
133	Mali	Africa	Sub-Saharan Africa	Western Africa
137	Mauritius	Africa	Sub-Saharan Africa	Eastern Africa
138	Mexico	LAC	Latin America	Central America
143	Morocco	Africa	Northern Africa	na
144	Mozambique	Africa	Sub-Saharan Africa	Eastern Africa
147	Namibia	Africa	Sub-Saharan Africa	Southern Africa
149	Nepal	Asia	Southern Asia	na
157	Nicaragua	LAC	Latin America	Central America
158	Niger	Africa	Sub-Saharan Africa	Western Africa
159	Nigeria	Africa	Sub-Saharan Africa	Western Africa
221	Oman	Asia	Western Asia	na
165	Pakistan	Asia	Southern Asia	na
166	Panama	LAC	Latin America	Central America
169	Paraguay	LAC	Latin America	South America
170	Peru	LAC	Latin America	South America
171	Philippines	Asia	South-Eastern Asia	na
117	Republic of Korea	Asia	Eastern Asia	na
184	Rwanda	Africa	Sub-Saharan Africa	Eastern Africa
244	Samoa	Oceania	Polynesia	na
194	Saudi Arabia	Asia	Western Asia	na
195	Senegal	Africa	Sub-Saharan Africa	Western Africa
197	Sierra Leone	Africa	Sub-Saharan Africa	Western Africa
25	Solomon Islands	Oceania	Melanesia	na
202	South Africa	Africa	Sub-Saharan Africa	Southern Africa
38	Sri Lanka	Asia	Southern Asia	na
207	Suriname	LAC	Latin America	South America
209	Swaziland	Africa	Sub-Saharan Africa	Southern Africa
208	Tajikistan	Asia	Caucasus and Central Asia	na
216	Thailand	Asia	South-Eastern Asia	na
176	Timor-Leste	Asia	South-Eastern Asia	na
217	Togo	Africa	Sub-Saharan Africa	Western Africa

FAO code	Country	Region	Subregion	Sub-subregion
220	Trinidad and Tobago	LAC	Caribbean	na
222	Tunisia	Africa	Northern Africa	na
223	Turkey	Asia	Western Asia	na
213	Turkmenistan	Asia	Caucasus and Central Asia	na
226	Uganda	Africa	Sub-Saharan Africa	Eastern Africa
225	United Arab Emirates	Asia	Western Asia	na
215	United Republic of Tanzania	Africa	Sub-Saharan Africa	Eastern Africa
234	Uruguay	LAC	Latin America	South America
235	Uzbekistan	Asia	Caucasus and Central Asia	na
155	Vanuatu	Oceania	Melanesia	na
236	Venezuela (Bolivarian Republic of)	LAC	Latin America	South America
237	Viet Nam	Asia	South-Eastern Asia	na
249	Yemen	Asia	Western Asia	na
251	Zambia	Africa	Sub-Saharan Africa	Eastern Africa
181	Zimbabwe	Africa	Sub-Saharan Africa	Eastern Africa

Source: Adapted from FAO (2016e)
Note: na = not applicable; LAC = Latin America and the Caribbean.

Appendix 4. Predictions Estimated by Year and Country

Variable	Years	Countries
FC	2014	Afghanistan, Algeria, Angola, Bangladesh, Belize, Brazil, Burkina Faso, Chad, China, Colombia, Côte d'Ivoire, Dominican Republic, Ethiopia, Guatemala, Haiti, India, Indonesia, Jamaica, Kenya, Madagascar, Mexico, Mozambique, Nepal, Nigeria, Oman, Pakistan, Panama, Paraguay, Peru, Philippines, Sri Lanka, Thailand, United Republic of Tanzania, Viet Nam, Yemen, Zambia, Zimbabwe
	2012, 2013, 2014	Argentina, Armenia, Azerbaijan, Barbados, Benin, Bolivia (Plurinational State of), Brunei Darussalam, Cambodia, Cameroon, Central African Republic, Chile, Congo, Costa Rica, Cuba, Ecuador, Egypt, El Salvador, Fiji, Gabon, Gambia, Georgia, Ghana, Guinea, Guyana, Honduras, Iran (Islamic Republic of), Iraq, Jordan, Kazakhstan, Kiribati, Kuwait, Kyrgyzstan, Lao People's Democratic Republic, Lebanon, Lesotho, Liberia, Malawi, Malaysia, Mali, Mauritius, Morocco, Namibia, Nicaragua, Niger, Republic of Korea, Rwanda, Samoa, Saudi Arabia, Senegal, Sierra Leone, Solomon Islands, South Africa, Suriname, Swaziland, Tajikistan, Timor-Leste, Togo, Trinidad and Tobago, Tunisia, Turkey, Turkmenistan, Uganda, United Arab Emirates, Uruguay, Uzbekistan, Vanuatu, Venezuela (Bolivarian Republic of)
FP	2014	Afghanistan, Algeria, Angola, Bangladesh, Belize, Brazil, Burkina Faso, Chad, China, Colombia, Côte d'Ivoire, Dominican Republic, Ethiopia, Guatemala, Haiti, India, Indonesia, Jamaica, Kenya, Madagascar, Mexico, Mozambique, Nepal, Nigeria, Oman, Pakistan, Panama, Paraguay, Peru, Philippines, Sri Lanka, Thailand, United Republic of Tanzania, Viet Nam, Yemen, Zambia, Zimbabwe
	2012, 2013, 2014	Argentina, Armenia, Azerbaijan, Barbados, Benin, Bolivia (Plurinational State of), Brunei Darussalam, Cambodia, Cameroon, Central African Republic, Chile, Congo, Costa Rica, Cuba, Ecuador, Egypt, El Salvador, Fiji, Gabon, Gambia, Georgia, Ghana, Guinea, Guyana, Honduras, Iran (Islamic Republic of), Iraq, Jordan, Kazakhstan, Kiribati, Kuwait, Kyrgyzstan, Lao People's Democratic Republic, Lebanon, Lesotho, Liberia, Malawi, Malaysia, Mali, Mauritius, Morocco, Namibia, Nicaragua, Niger, Republic of Korea, Rwanda, Samoa, Saudi Arabia, Senegal, Sierra Leone, Solomon Islands, South Africa, Suriname, Swaziland, Tajikistan, Timor-Leste, Togo, Trinidad and Tobago, Tunisia, Turkey, Turkmenistan, Uganda, United Arab Emirates, Uruguay, Uzbekistan, Vanuatu, Venezuela (Bolivarian Republic of)
FI	2014	all
FE	2014	all
GDP	2014	Cuba, Yemen

Appendix 5. Two-Way Scatter Plots by Subregion

Figure 22. Two-way scatter plot: POU and AD by subregion

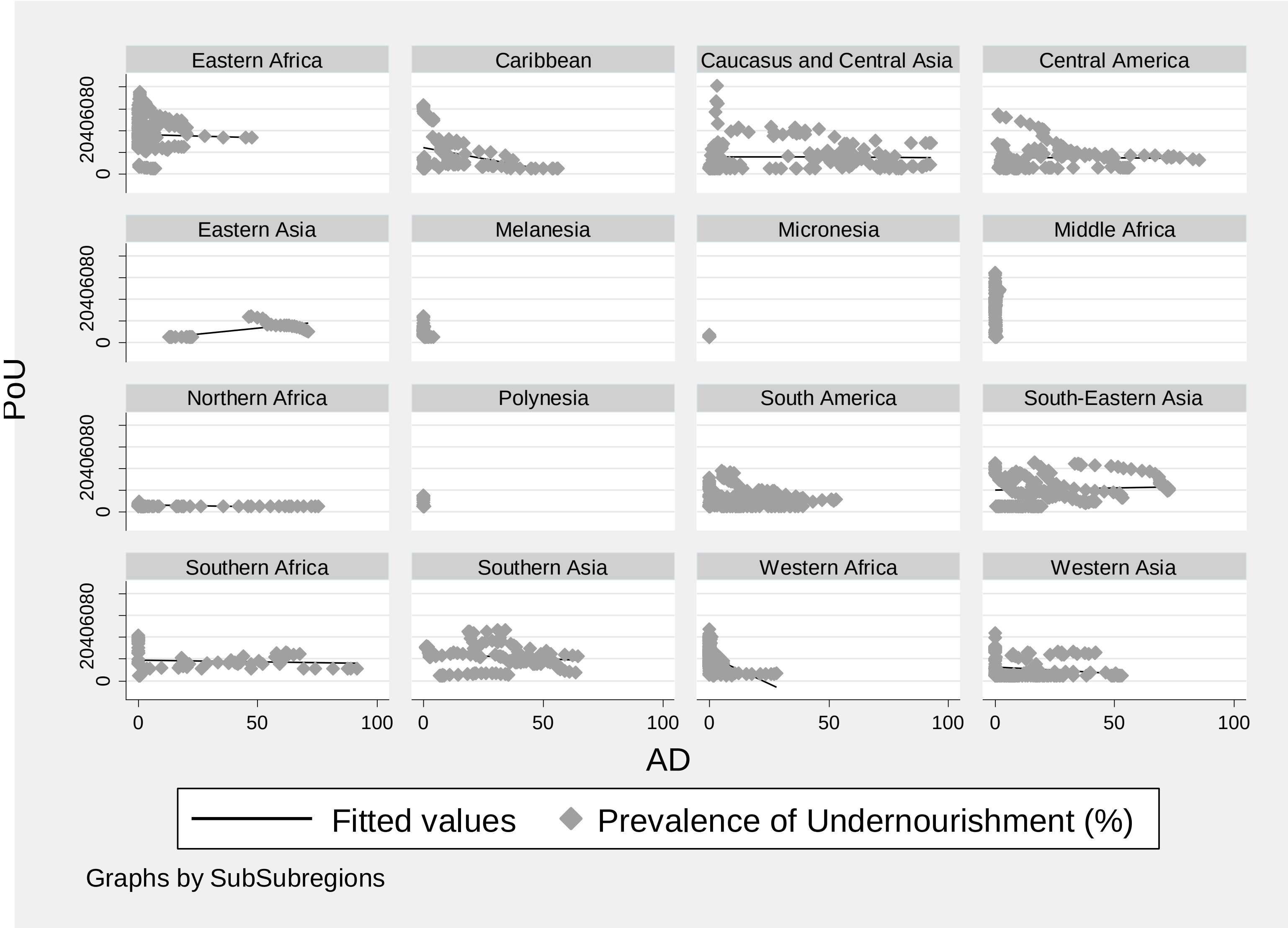


Figure 23. Two-way scatter plot: POU and FC by subregion

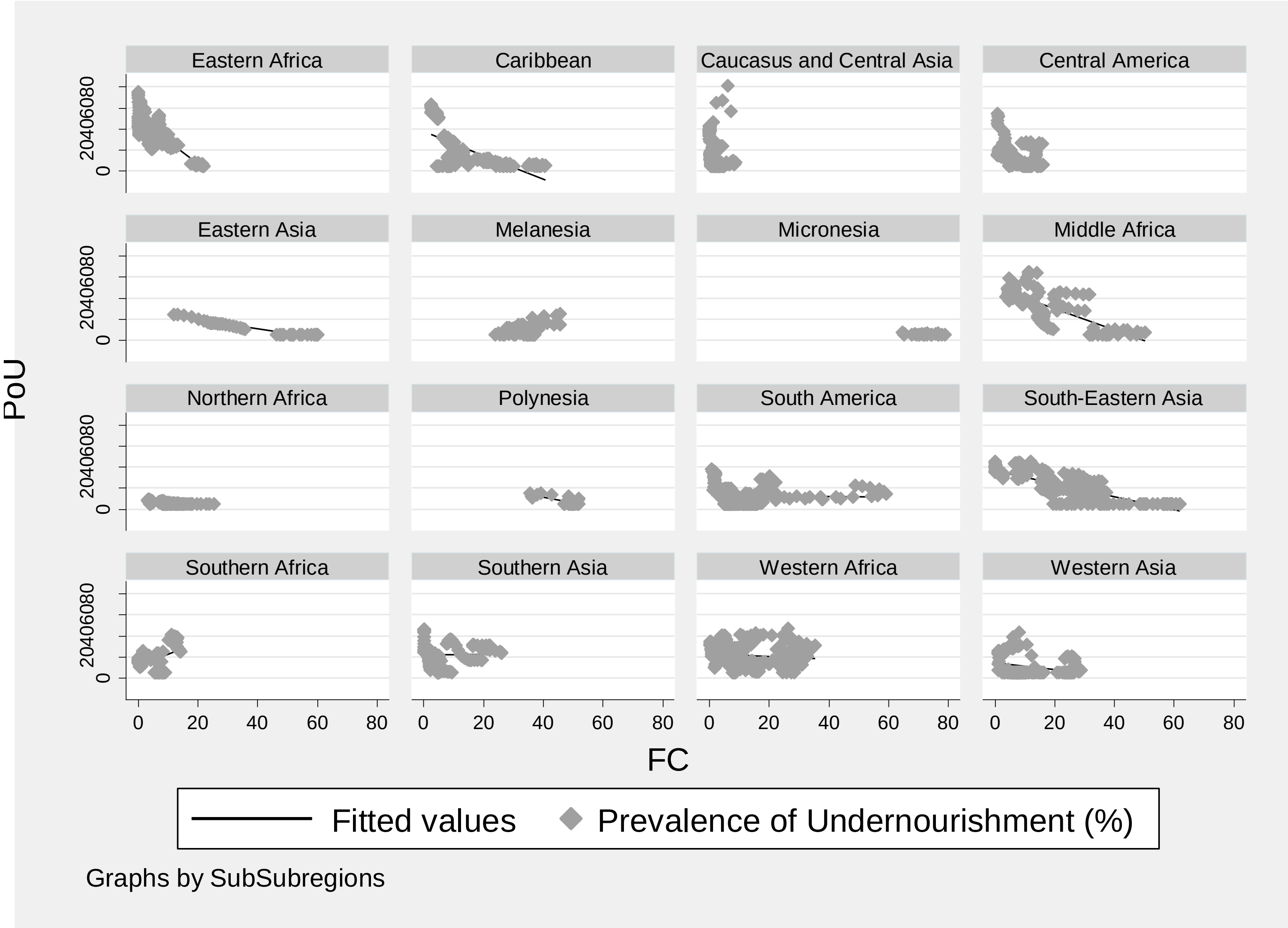


Figure 24. Two-way scatter plot: POU and GDP by subregion

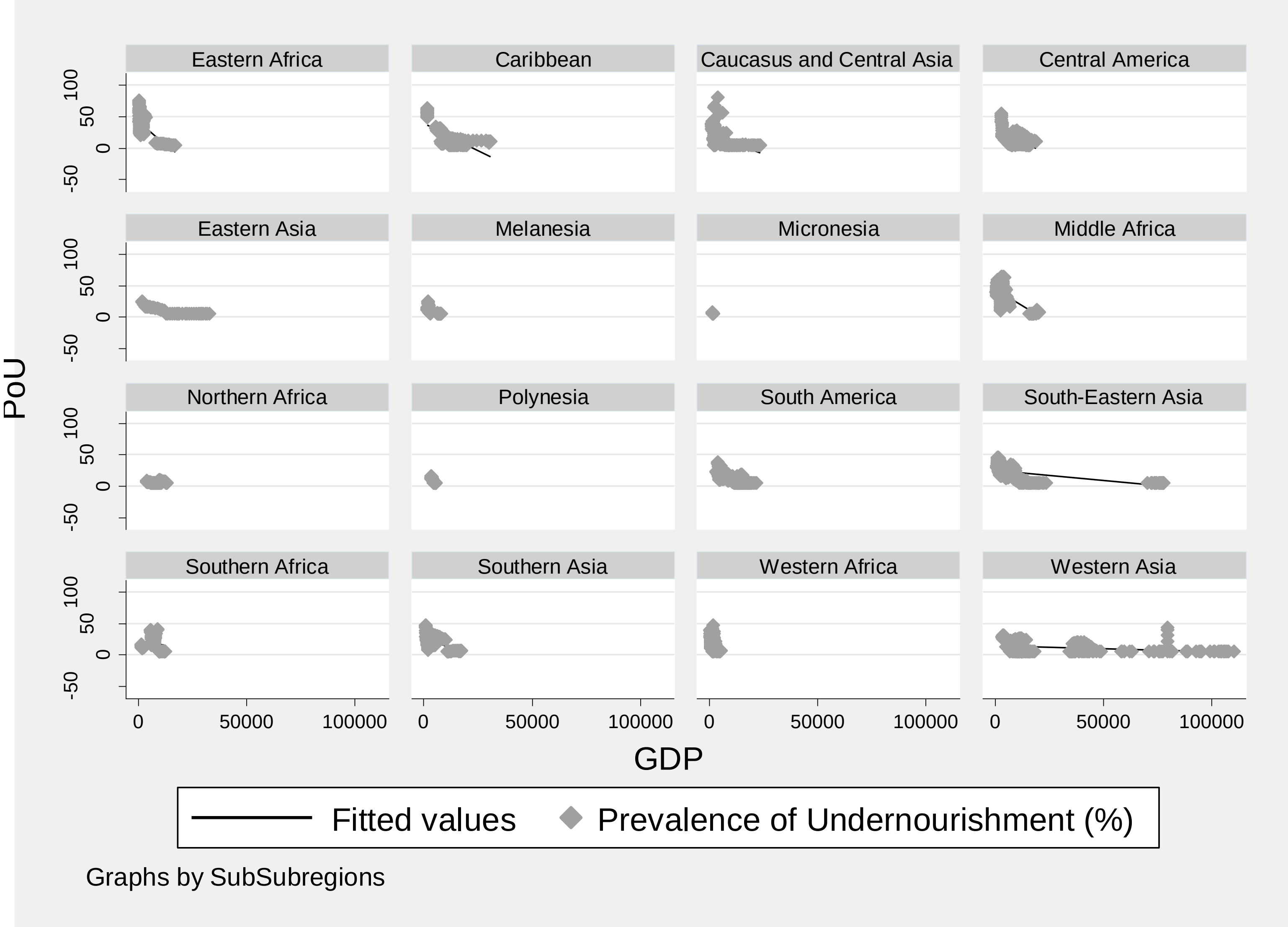


Figure 25. Two-way scatter plot: POU and FE by subregion

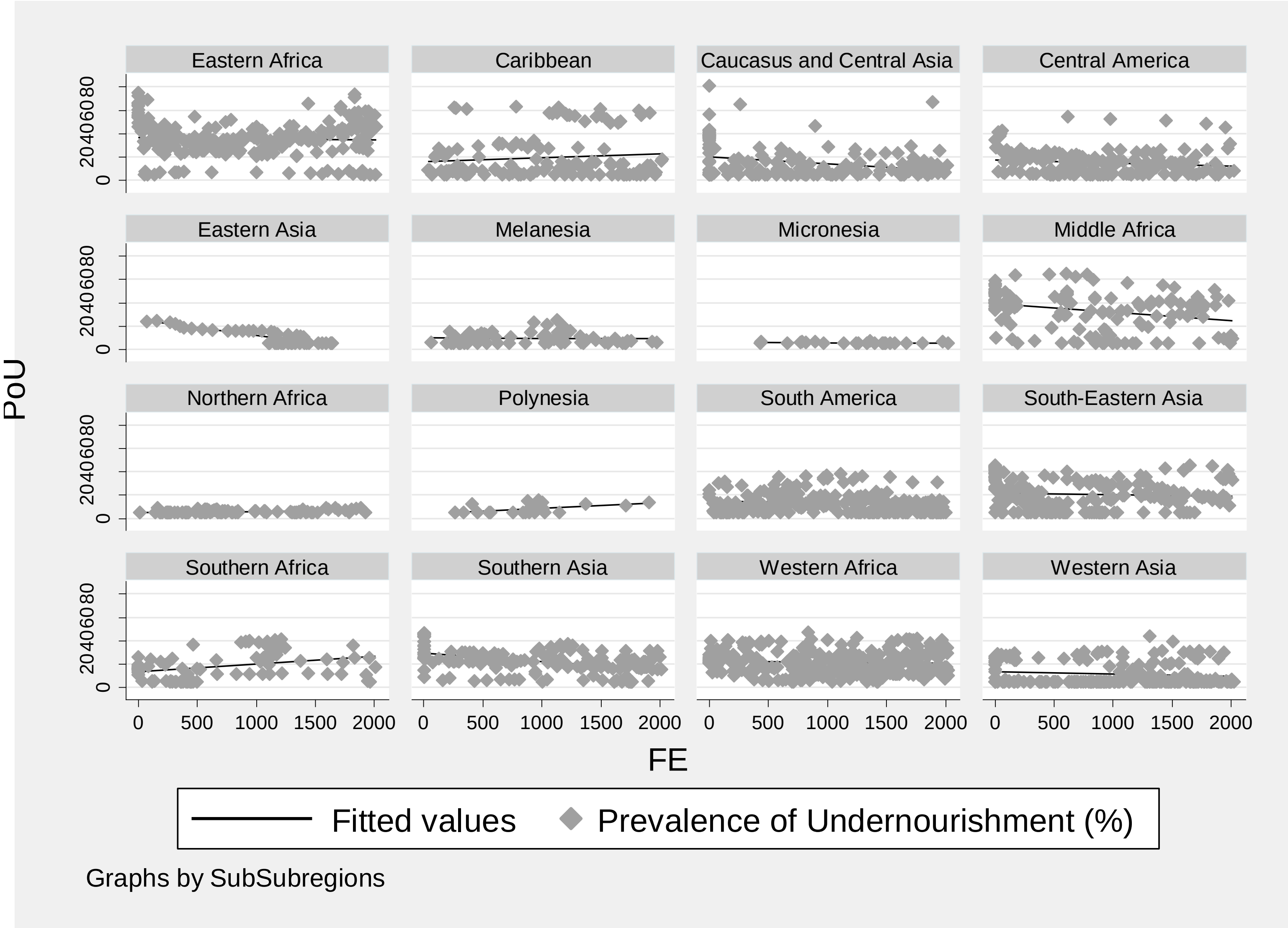


Figure 26. Two-way scatter plot: POU and FI by subregion

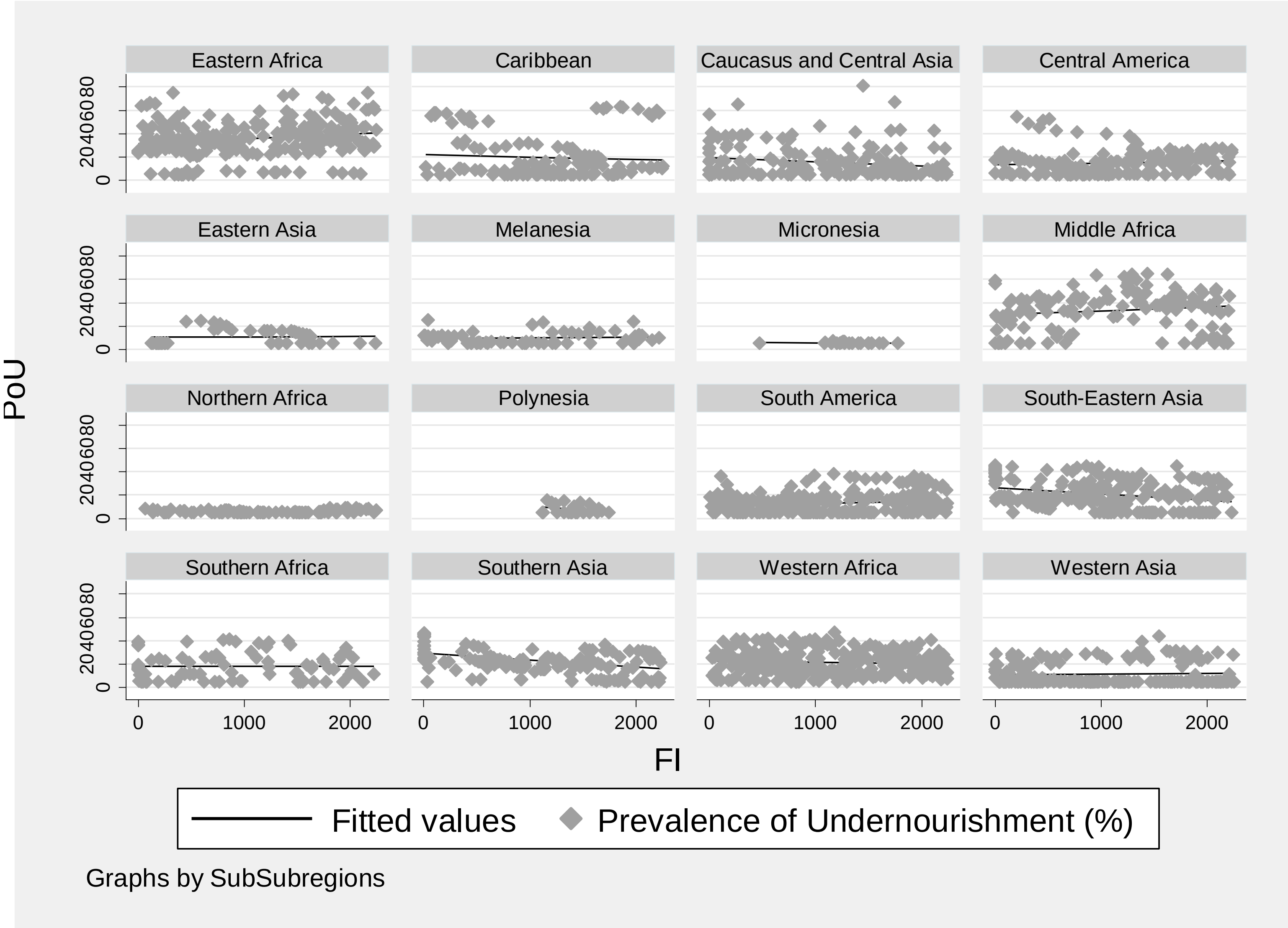
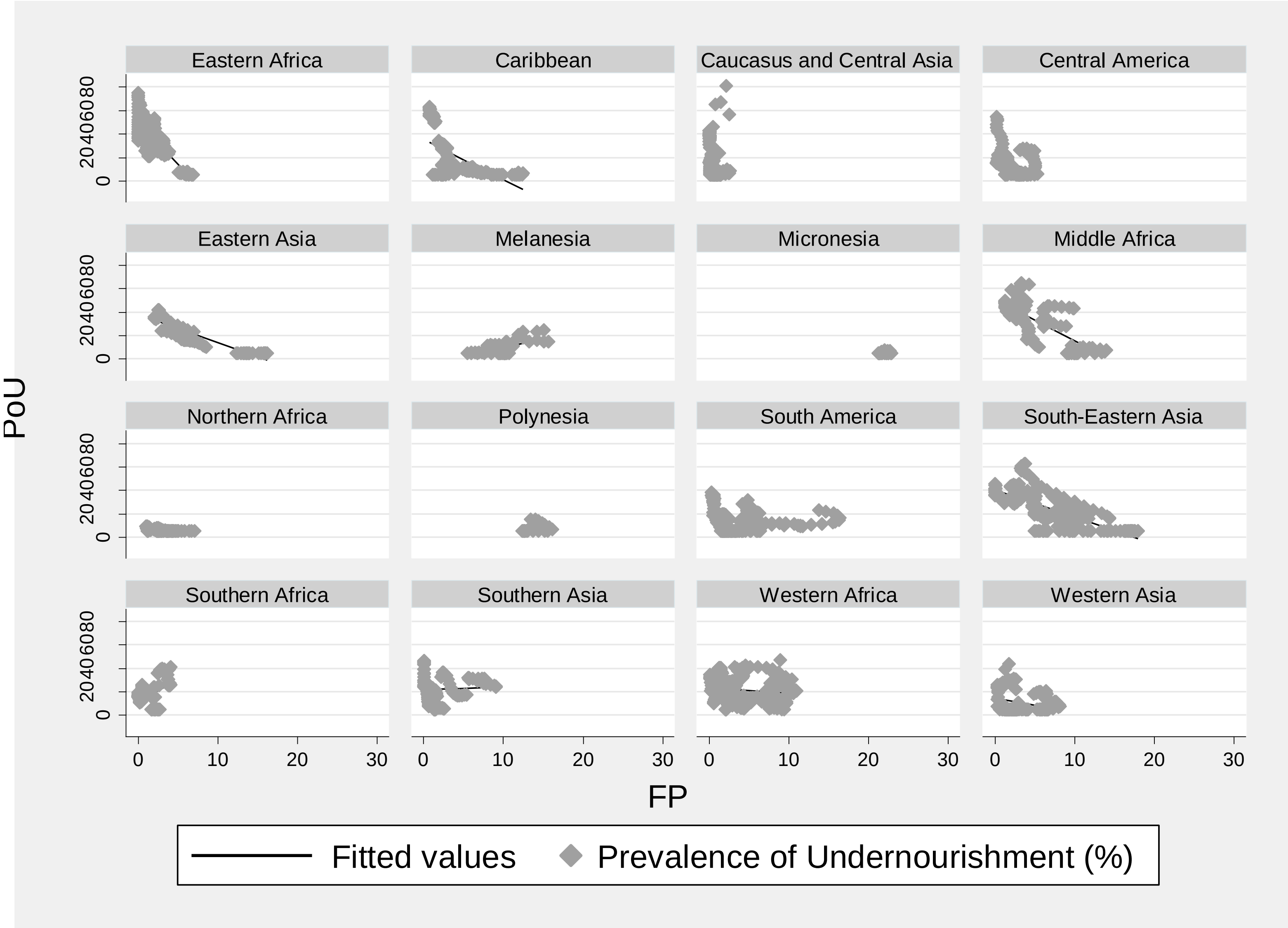


Figure 27. Two-way scatter plot: POU and FP by subregion



Appendix 6. Multicollinearity Test

Table 12. VIF on AD, FC, GDP, FI, FE, FP and SR

Variables	VIF	1/VIF
AD	1.52	0.66
FC	78.55	0.01
GDP	1.87	0.54
FI	1.03	0.97
FE	1.06	0.94
FP	76.61	0.01
SR		
2	1.56	0.64
3	1.85	0.54
4	1.70	0.59
5	1.70	0.59
6	1.51	0.66
7	1.68	0.59
8	1.53	0.65
9	1.34	0.75
10	1.29	0.77
11	1.95	0.51
12	2.22	0.45
13	1.37	0.73
14	1.69	0.59
15	2.00	0.50
16	2.28	0.44
Mean VIF	8.87	

Table 13. VIF on AD, FC, GDP, FI, FE and SR

Variable	VIF	1/VIF
AD	1.50	0.67
FC	2.63	0.38
GDP	1.74	0.57
FI	1.03	0.97
FE	1.06	0.94
SR		
2	1.55	0.64
3	1.85	0.54
4	1.70	0.59
5	1.56	0.64
6	1.50	0.66
7	1.65	0.61
8	1.53	0.65
9	1.34	0.75
10	1.29	0.78
11	1.95	0.51
12	2.21	0.45
13	1.37	0.73
14	1.68	0.60
15	2.00	0.50
16	2.28	0.44
Mean VIF	1.67	

Appendix 7. Indicators for Measuring Aquaculture's Contribution to Food Security

Indicators	Dimension
Aquaculture's protein (or other nutrients) supply Share of aquaculture's protein supply in total protein supply Share of aquaculture's protein supply in total animal protein supply Aquaculture's direct protein supply (aquaculture production minus aquaculture exports) Aquaculture's indirect food supply (aquaculture production minus aquaculture exports) Ratio of aquaculture's net foreign exchange earnings to total value of food imports (indirect contribution to food availability)	Availability
Aquaculture's direct contribution to labour income Aquaculture value chain's contribution to labour income Aquaculture's total contribution to labour income Aquaculture's average wage rate Wage level comparison between aquaculture and agriculture Aquaculture's employment composition Total employment in aquaculture value chains Share of female employment in aquaculture Share of female employment in total aquaculture value chain employment Per capita annual in-house consumption of fish in small-scale aquaculture household	Access
Magnitude deviation of production (protein supply) from trend Percentage deviation of production from trend Magnitude deviation of price from trend Percentage deviation of price from trend Covariance between aquaculture's total protein supply and total protein supply for the entire economy Correlation between aquaculture's total protein supply and total protein supply for the entire economy	Stability

Source: adapted from Bondad-Reantaso and Prein (2009), Hishamunda et al. (2009b) and FAO (2016m).

Acronyms

2SLS	Two-stage least squares
AD	Aquaculture development
AFSPAN	Aquaculture for Food Security, Poverty Alleviation and Nutrition
AIDS	Acquired Immune Deficiency Syndrome
ANOVA	One-way analysis of variance
AP	Protein supply quantity of animal products
ASF	Animal Source Foods
ASFIS	Aquatic Sciences and Fisheries Information System
AU	African Union
AUC	African Union Commission
BBS	Bangladesh Bureau of Statistics
BES	Bonaire, Sint Eustatius and Saba
BMI	Body Mass Index
CA	Commercial Aquaculture
CAMFA I	Conference of African Ministers for Fisheries
CCRF	Code of Conduct of Responsible Fisheries
CFS	Committee on World Food Security
CGIAR	Consultative Group on International Agricultural Research
CIF	Cost, Insurance and Freight
CO2e	Carbon dioxide equivalent
COFI	Committee on Fisheries
CU5	Prevalence of underweight children under five years of age
CV	Coefficient of variation
DALY	disability-adjusted life years lost
DBI	donor-based imputation
DEC	Dietary energy consumption
DES	Dietary energy supply
DHA	Docosahexaenoic acid
DHS	Demographic and Health Surveys
DIF-GMM	Difference generalized method of moments

DMRT	Duncan's Multiple Range Test
ECOWAP	Regional Agricultural Policy for West Africa
ECOWAS	Economic Community of West African States
EIU	Economist Intelligence Unit
EPA	Eicosapentaenoic acid
ERSEM	European Regional Seas Ecosystem Model
FAO	Food and Agriculture Organization of the United Nations
FAPDA	Food and Agriculture Policy Decision Analysis
FBS	Food Balance Sheet
FCR	Feed conversion ratio
FE	Fish and fishery products exports
fe	Fish and fishery products exports dataset
FER	Fixed effects
FGLS	Feasible generalized least squares
FI	Fish and fishery products imports
fi	Fish and fishery products imports dataset
FIFO	Fish In-Fish Out
FP	Protein supply quantity of "fish, seafood, aquatic animals and others"
FP7	Seventh Framework Programme for Research
fre	Fish re-exports dataset
fs	Fish stock
FS	Food security
GDP	Gross Domestic Product
GFSI	Global Food Security Index
GLS	Generalized Least Squares
HA	Hectare
HIES	Household Income and Expenditure Survey
HLPE	High Level Panel of Experts on Food Security and Nutrition
ICES	International Council for the Exploration of the Sea
ICLARM	International Center for Living Aquatic Resources
ICZM	Integrated Coastal Zone Management
ID	Internal Identifier
IDL	Internal Identifier of the Literature

IFAD	International Fund for Agricultural Development
IFPRI	International Food Policy Research Institute
IMF	International Monetary Fund
IMPACT	International Model for Policy Analysis of Agricultural Commodities and Trade
IPCC	Intergovernmental Panel on Climate Change
ISSCAAP	International Standard Statistical Classification of Aquatic Animals and Plants
LAC	Latin America and the Caribbean
LIFDC	Low-Income Food-Deficit Countries
LIFDCs	Low Income and Food Deficient Countries
LM	Lagrangian Multiplier
LME	Large Marine Ecosystems
MDER	Minimum dietary energy requirement
MDG	Millennium Development Goal
MERs	Market exchange rates
mt	Million tonnes
N	Number of observations
NACA	Network of Aquaculture Centres in Asia-Pacific
nei	not elsewhere included
NEPAD	New Partnership for Africa's Development
NFP	National Food Policy
NHS	National Household Surveys
NMFS	National Marine Fisheries Service of the United States of America
OLS	Ordinary least squares
PAL	physical activity level
PCSEs	Panels Corrected Standard Errors
PFRS	Policy Framework and Reform Strategy for Fisheries and Aquaculture
PICTs	Pacific Island Countries and Territories
POLCOMS	Proudman Oceanographic Laboratory Coastal Ocean Modelling System
POLS	Pooled ordinary least squares
POU	Prevalence of Undernourishment
PPP	Purchasing power parity
ppt	parts per thousand

PUFA	Polyunsaturated fatty acids
RAS	Recirculating aquaculture systems
REC	Regional Economic Community
RER	Random effects
RESTORE	Research Tools for Natural Resource Management, Monitoring and Evaluation
RFB	Regional Fisheries Bodies
rmse	Root mean squared error
SAR	Special Administrative region
SDG	Sustainable Development Goal
SEAFDEC	Southeast Asian Fisheries Development Center
SK	Skewness
SMA	Simple Moving Average
SME	Small and medium-sized enterprise
SO	Strategic Objective
SOFI	State of Food Insecurity in the World
SOFIA	State of World Fisheries and Aquaculture
spp	species
SR	Subregion
SSA	sub-Saharan Africa
SYS-GMM	System generalized method of moments
Tk	Bangladeshi Taka
TPP	Total protein supply quantity
UN	United Nations
UNICEF	United Nations Children’s Fund
US$	United States Dollar
VIF	Variance Inflation Factors
WFP	World Food Programme
WFS	World Food Summit
WHO	World Health Organization
WLS	Weighted least squares
WSFS	World Summit on Food Security
X	Exogenous variable
Y	Endogenous variable

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