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The mass balance of production and consumption: Supporting policy-makers for aquatic food security

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ABSTRACT

This work addresses divergences between data on consumption and availability for wild-caught and farmed fish, and normalisation of reported production data, to support integrated fisheries and aquaculture management. The methodologies developed, centred on improved parameterisation and on mass balance closure, were tested in two case studies: (i) the cod fishery in Europe, with particular emphasis on Iceland and the United Kingdom; and (ii) the overall balance of aquatic products for Portugal, the ICES member with the most diverse range of landed marine species. Data for consumption, Illegal, Unreported, or Unregulated (IUU) catch, and official availability statistics were used to identify discrepancies between consumption and official availability data. The identification of discrepancies between supply and demand, when coupled with source-discriminated data, showed a pattern where products with no unmet demand tend to display a considerable IUU percentage—above 9% in three cases (hake, sardine, and horse mackerel).

By contrast with fished products with an over-met demand such as cod (144%) and sardine (124%), farmed species display low Optimal Consumption Level (OCL) satisfaction. Atlantic salmon, gilthead seabream, and European seabass register 45%, 58% and 44% respectively; this suggests a considerable unmet demand for these products and/or a high volume of undeclared fish reaching consumers, which may be due to the lack of landings control that exists for wild-caught fish.

Improvements to production estimates using live-weight coefficients illustrate the impacts of seafood processing. Different processing methods can generate variations in live-weight estimates, leading to errors in officially reported data, and expose the limitations of the current statistical methods. As an example, the corrected *per capita* consumption for Portugal for 2014 (the latest FAO data) increases from 57 to 66 kg ind^{-1} y^{-1}, which places the country as the second-greatest consumer in the world, well above both Malaysia and South Korea (each with 58 kg ind^{-1} y^{-1}). The corrected data show that Portugal had the highest consumption rate in the world until the mid-1970's, when it was overtaken by Iceland for reasons discussed herein.

The lack of detailed per-species consumption data, as well as the grouping of species by commodities, hinders a more detailed seafood consumption analysis, required by policy makers and stakeholders to effectively develop management measures to reduce illegal fishing or bycatch, and to correctly formulate strategic options for development of aquaculture and fisheries, necessary for ensuring food security over the next decades.

1. Introduction

Seafood production worldwide primarily originates from shelf and coastal areas, including bays and estuaries. Demand for finfish and other aquatic products generates employment and supports livelihoods in coastal regions and nations, but may also be a significant environmental stressor (FAO, 2016a; Newton et al., 2014; Robins et al., 2016; Wilson, 2002), for instance by perturbing ecosystem equilibria (Rocchi et al., 2016; Smith et al., 2011) or impacting benthic habitat (Aguado-Giménez et al., 2011; Grigorakis

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and Rigos, 2011; Puig et al., 2012; Roberts, 2006).

Global consumption of aquatic products has increased from 9.9 kg per *capita* in the 1960's to an all-time high of 20 kg *per capita* in 2014 (Carlucci et al., 2015; FAO, 2016a). The most significant planetary challenge for the next three decades will be the supply of safe and adequate nutrition to a population of nearly 10 billion by 2050 (Cressey, 2009; FAO, 2016a; Godfray et al., 2012); worldwide seafood consumption *per capita* is expected to reach 21.8 kg in 2025, generating an additional annual requirement of 31 million tonnes of aquatic products (FAO, 2016a).

Many wild fish stocks around the globe are currently over-exploited (Halpern et al., 2012; Jayasinghe et al., 2016) and capture fisheries will be unable to address this shortfall (Cressey, 2009; Naylor et al., 2000; Pauly et al., 2002). Since the late 1970's, the decline of world fisheries has been accompanied by strong growth in aquaculture. In 2014, farmed finfish and shellfish production reached 73.8 million tonnes, representing 44% of total seafood production (FAO, 2016a; Merino et al., 2012; Naylor et al., 2000), and in May 2013, world aquaculture production overtook capture fisheries for human consumption (Fig. 1).

This 'blue revolution' has been led by China, which accounts for 60% of global production, and countries in SE Asia. In the European Union, by contrast, farmed finfish and shellfish production has grown modestly at 1% per year, and the high demand for aquatic products, accompanied by recent stagnation and even decrease of autochthonous production (European Commission, 2014a, 2012, 2008), has increased dependency on external sources of seafood (Esteban and Crilly, 2012; Little et al., 2012). Over the coming decades, the increase in *per capita* GDP in China and SE Asia will drive up the price of seafood, as domestic consumption increases in Asian nations (Ferreira et al., 2014; Nunes et al., 2011). Total seafood consumption in India and China alone has increased by approximately 20 million tonnes in less than 10 years (FAO, 2014, 2008), and the expected additional consumption by 2025 should increase this number by a further 14 million tonnes (FAO, 2016a).

The rapid increase in worldwide seafood demand, fuelled by the twin factors of increased population and *per capita* GDP, poses a major challenge for food security and makes it compelling to better understand demand, the key driver for this sector (Carlucci et al., 2015). Consumption is estimated based on a mass balance (Eq. (1))

$$C = P + I - E \quad (1)$$

where C is apparent consumption; P is production; I is imports and E: is exports.

Although this approach is useful for dealing with large time periods, and multi-country data that require normalization, the output represents availability and not real consumption, despite being expressed in mass *per capita* (Almeida et al., 2015; FAO, 2007; Girard et al., 1998). These highly aggregated data are subject to the following potential limitations: (i) presentation as grouped commodities; (ii) application of normalization factors; (iii) unaccounted differences between net and live weight; and (iv) lack of illegal, unregulated, unreported (IUU) and subsistence fishing volumes. These factors condition seafood consumption estimates and are absent from official statistics (Fabinyi et al., 2016; FAO, 2007; Leitão et al., 2014; Pauly et al., 2002; Pramod et al., 2014; Rodgers et al., 2008). The importance of IUU data transcends fisheries, since aquaculture growth is considered to be partially driven by wild fisheries, either through bycatch or trash fish (Cao et al., 2015; Nunoo et al., 2009; Pauly et al., 2002), and due to the lack of a landings control on fish farms similar to what exists for wild fisheries. In addition to production factors, consumers are demanding better information and greater traceability of seafood (Pieniak et al., 2013), which begs a more detailed analysis of seafood sectors, from fishers to consumers.

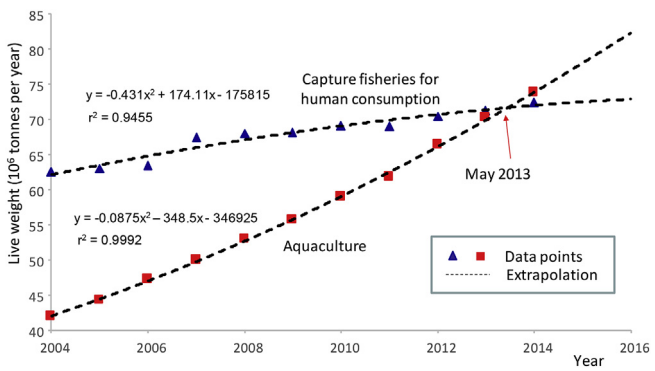

Fig. 1. Worldwide production of capture fisheries for direct human use and of aquaculture over the period 2004–2014.

In the context of the worldwide seafood market, the dried and processed aquatic goods trade has considerable importance in both value and volume. Cod is considered to be one of the key products in the dried goods industry; its importance in southern European countries, as well as in South America, is considerable, and cod trade plays an important role in determining prices both in vessels in Norway and in retailers in Portugal (Gudjónsdóttir et al., 2011; Lorentzen et al., 2016; Martínez-Alvarez and Gómez-Guillén, 2013; Pettersen and Myrland, 2016). Atlantic cod—the most commonly targeted and traded of the cod species—has in the past been used as an example of failed stock management, particularly the Newfoundland cod stock (Rose and Rowe, 2015; Schrank, 2007, 2005). This species has also been at the centre of fishing rights disputes among European countries, particularly the UK, Iceland, and Norway, since the XVth century (Thorsteinsson, 1976); the most recent disputes, from a documented series of ten so-called 'cod wars' or *þorskastríð* (Thorsteinsson, 1976), occurred between the mid-1950s and 1970s (Lescrauwaet et al., 2013; Stewart, 2016; The National Archives, 2016).

This study develops a methodology based on the compilation of both official statistics (imports, exports, aquaculture, and catch), and non-official reports (IUU and consumption surveys), in order to address seafood consumption and availability. This approach allowed a comparison between estimated consumption and total availability weights. To address availability estimates, the differences between net and live weight of a processed aquatic product were illustrated by means of a case study. The key objectives of this work are to:

1. Address the discrepancy between net and live weight of processed seafood products, and its impact on reported data;
2. Estimate seafood consumption at species level, discriminating among internal/external origin, and between regulated/unregulated fisheries and aquaculture sources;
3. Analyse the mass balance of availability calculated through a supply-side approach, and consumption estimated through demand. The null hypothesis is that this mass balance can be adequately closed for individual species and in aggregate;
4. Apply the results to improve decision-support for planning the sustainable development of aquaculture and fisheries in coastal and shelf seas.

2. Methodology

Two approaches were developed to test the hypothesis that the mass balance of supply and demand can be successfully closed. The