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Review

Aquaculture: Relevance, distribution, impacts and spatial assessments – A review

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ABSTRACT

Aquaculture is the fastest-growing animal food production sector worldwide and is becoming the main source of aquatic animal food in human consumption. Depletion of wild fishery stocks, rising global populations, continuing demand for food fish, and international trade has driven aquaculture's tremendous expansion during the last decades – in terms of production volume and value. Farmed aquatic products are among the most widely traded commodities in the world food economy. Aquaculture has mainly been developed in valuable fertile coastal environments and caused large-scale land use changes, destruction and loss of coastal wetlands and pollution of waters and soils. This article presents an overview of the relevance, current status and distribution of aquaculture in global and regional scales and depicts its key environmental impacts. Quantitative assessment of the spatial extent, distribution, and dynamics of aquaculture is of utmost importance for a sustainable management of our planet's land and water resources ensuring human and environmental health. The article points to the potential of remote sensing to detect, map and monitor large-scale aquaculture areas and gives a complementary review of satellite remote sensing studies addressing the observation of aquaculture including site selection, site detection and monitoring of related impacts on the environment.

1. Introduction

Fish is one of the most traded food commodities worldwide (Allison, 2011) and the main source of valuable animal protein in many regions of the world (Béné et al., 2015; Toufique and Belton, 2014). With stagnating global capture fisheries production, growing human population, and continuing demand for food fish, the production of safe and quality aquatic food will be a great concern for global food security in the next years (FAO, 2011; Natale et al., 2012; OECD/FAO, 2013; Toufique and Belton, 2014; UN, 2011). Over the last 30 years, global production of cultivated aquatic food increased rapidly and has driven aquaculture to be one of the fastest-growing animal-food-producing sectors (Allison, 2011; UN, 2011). Today aquaculture accounts for almost half of the fish consumed worldwide (FAO, 2014; Troell et al., 2013). Forecasts on food security indicate that aquaculture has great potential to produce more fish in the future and compensate stagnating supplies from capture fisheries (Natale et al., 2012). The Food and Agriculture Organization of the United Nations (FAO) Director-General José Graziano da Silva declared that the human health and future food security highly depends on how we treat the "blue world" (UN, 2014). Roughly 39 percent of all fishery production being exported are used for human consumption (FAO, 2012). As the fishery sector operates in an increasingly globalized environment (FAO, 2014) it is expected that the share will further expand up to 25 percent in the period 2012–2021 (FAO, 2012). On a global scale, the average per capita apparent fish consumption almost doubled from an average of 9.9 kg in the 1960s to 18.9 kg in 2010 (FAO, 2014) and fish accounts for 17 percent of animal-derived and 6.5 percent of total protein consumption (Troell et al., 2014b). From a human health point of view, future development of aquaculture will be of utmost importance in terms of global protein supply, economic trade, and food security (Beveridge et al., 2013). Statistics from the most updated global capture and aquaculture database from the FAO Fisheries and Aquaculture Department (1950–2013) prove a global trend of rapid aquaculture development. In the period from 1983 to 2013, capture fisheries production increased from 71.1 to 92.6 million tonnes. Aquaculture production meanwhile expanded from 6.2 to 70.2 million tonnes (FAO, 2015, 2012;

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The World Bank, 2013) at an average rate of 8.6 percent per year (FAO, 2014), which exceeded even the rates of poultry (4.6%), pork (2.2%) and beef (1.0%) over the same period (Troell et al., 2014b). From 1980 to 1990, average annual expansion rate was highest at 10.8 percent and slowed down slightly to 9.5 percent in the period from 1990 to 2000 and 6.1 percent for 2000–2013.

More than 600 different animal species (Troell et al., 2014b) are produced in aquaculture systems comprising finfish (e.g. catfish, trout, carp, tilapia, salmon), crustaceans (shrimp, prawn, crabs, freshwater crayfish), and molluscs (e.g. mussels, oysters and clams) (FAO, 2014). Aquatic photosynthetic organisms are also being recorded in the FAO global database on aquaculture production statistics, but mostly listed separately in the global reports. Aquatic photosynthetic organisms are not included in the statistics shown in this paper since the focus is on livestock species only.

Regarding the total amounts of yearly output volumes, world aquaculture production more than doubled from 32.4 million tonnes in 2000 to 70.2 million tonnes in 2013 (FAO, 2014). Aquaculture also contributes an increasing share to the total global fishery production output (Bondad-Reantaso and Subasinghe, 2008). Its share was only 13.4 percent in 1990 but expanded to 25.7 percent in 2000 and received a record of 43.1 percent share of the total 162.8 million tonnes of fish produced worldwide in 2013 (FAO, 2014). Projections by the World Bank for the year 2030 indicate a rise of global fish supply up to 187 million tons with aquaculture equaling global capture production (The World Bank, 2013). The FAO and Organization for Economic Co-operation and Development (OECD) state that capture fisheries output will rise at lower rates with a projected 5 percent growth by 2022 while the output from aquaculture will increase by 35 percent. Thus, it can be foreseen that aquaculture will be the main source of fish for human consumption in the next years (OECD/FAO, 2013; Toufique and Belton, 2014). However, further growth of global aquaculture production will pose a challenge to the sustainable management of our planet's resources and human development. This is a global issue and particularly true for people in rural coastal areas in developing countries (Beveridge et al., 2013; Hossain et al., 2013) where aquaculture provides high nutrition supply potential and is the main income source for poor people (Ahmed and Lorica, 2002).

In the light of a projected increase of world population to 9.6 billion in 2050 (UN, 2013), fish production from aquaculture can make an important contribution to global food security needs and provide human population with valuable protein (Béné et al., 2015; Natale et al., 2012; Naylor et al., 2000). Aquaculture can balance the stagnating production volumes from capture fisheries but also reduce the pressure on the earth's marine resources (Lee and Yoo, 2014). A drawback of aquaculture is its dependence on terrestrial crop and wild fish for feeds (Troell et al., 2014b). As a consequence, growing production output from aquaculture farming has also resulted in a net increase in total demand for fish resources (mainly small trash fish from capture fisheries) being used in aquaculture. Fishmeal and fish oil (mainly produced from small pelagic fish and bycatch) are such sources and widely applied as valuable, complementary or complete nutritional feed. Tacon and Metian (2008a) estimated that 68 percent of global fishmeal and 90 percent of fish oil were utilized by the aquaculture sector.

1.1. Inventory of aquaculture areas

For more than 65 years, the FAO has collected national data on catch and other fishery statistics which are generally submitted by national ministries and institutions. However, the first aquaculture production yearbook was published in the year 2000 and it has only been since 2003 that the FAO carried out a backward revision to provide the first separated capture and aquaculture datasets for the period 1950–2001 (Garibaldi, 2012). Statistical data on aquaculture production is made available by the FAO Fishstat software (FAO, 2015), a global database which allows for the analysis of trends at global, regional and national scales (see Fig. 1). Although there are other attempts to provide valuable database information on fisheries and aquaculture (e.g. the project www.seaaroundus.org), these databases also use previous FAO data as a starting point. Global aquaculture statistic databases should be evaluated with care as there are indications that some data submitted by the FAO member countries are of questionable quality. There are manifold reasons for this, such as over-reporting of production volumes from some countries (Pauly and Froese, 2012), underestimation of aquaculture volume due to large amounts produced by small-scale farmers in Asia and other regions entering domestic and regional markets which are poorly presented in production and trade statistics (Allison, 2011). Inventory and monitoring of aquaculture on a global scale is a challenging task and requires time, effort and significant costs (Marini et al., 2013). Therefore, the question arises which methods and data would be capable to assist or improve present available global statistics on aquaculture production? How can the status and dynamics of aquaculture be observed over large areas around the globe? Since aquaculture has been developed widely around the globe there is an urgent need not only to have global statistics on production volumes and values but more importantly to identify and assess the spatial distribution of aquaculture at local, regional and global scales. Such information is valuable to analyze the increasing pressure on ecosystems and its related environmental impacts.

1.2. Purpose of this paper

This paper starts with a brief background on the diversity of global aquaculture systems status, dynamics and aquaculture at different spatial scales. We discuss the most relevant environmental changes and impacts which can be directly or indirectly associated to aquaculture farming. We then introduce studies that used satellite data and methodologies to detect, monitor and analyze aquaculture areas in different regions around the globe. Through our paper we illuminate the relevance of aquaculture in terms of environmental and human health and the needs to assess spatial information of this fast growing food sector. The purpose of this paper is to:

- give an insight of the main farming environments, practices and main species in global aquaculture
- highlight the current status and dynamics of aquaculture in global and regional scales and its economic relevance in the global food trade system
- summarize the major direct and indirect environmental impacts associated with aquaculture activities
- elucidate the potentials and opportunities of Earth Observation for the application in aquaculture
- provide a comprehensive overview of recent studies which use remote sensing technologies to map or monitor aquaculture areas

2. Global aquaculture systems: environments, practices and main species

The FAO defines aquaculture as the farming of aquatic organisms such as fish, crustaceans, molluscs and aquatic photosynthetic organisms. Aquaculture farming implies individual or corporate ownership of the stock being cultivated and typically involves the enclosure of a species in a secure system (Naylor et al., 2000; Troell et al., 2013). The farming methods are very diverse and generally