THE EXPANSION OF AQUACULTURE AND ITS EFFECTS ON GLOBAL LAND USE AND SUSTAINABILITY

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Abstract

Being the fastest growing food producing sector, aquaculture has the potential to provide high quality protein sources and meet increasing future food demand. However, the raising concerns over competition for land - direct and through feed competition – and sustainability as well as restrictive regulations may limit the expansion of aquaculture. We provide a thorough literature review of the complex interlinkages across aquaculture, land use and sustainability. As these relationships have, to our knowledge, not systematically been analyzed before, the literature review is of an explorative character and touches and combines various topics in and around aquaculture (e.g. environmental sustainability, political regulation). However, it is always centered on global aquaculture and land use. In order to answer key questions as: (1) how aquaculture contributes to food security?, (2) how sustainable is aquaculture?, and (3) how aquaculture connects with agriculture?, we combine existing literature from various disciplines (e.g. aquaculture, agricultural economics, land use) for a thorough description of the relationships and give an overview of quantitative models for economic and environmental impact assessment. Additionally, this study provides a conceptual idea for the construction of a fisheries module in the CAPRI model (Britz, 2005) including a suitable classification of fish species for policy advice in the EU. Based on the understanding and concept developed in this paper, the fisheries module will be implemented and refined in the CAPRI model in a later step. It will be used for analyzing the impacts of the expansion of aquaculture on land use and simulating policies to enhance aquaculture sustainability.

Keywords

Aquaculture, Sustainability, Land use, Modelling, Aquafeed, CAPRI model

Introduction

Nearly all arable land is being utilized to feed the world; however, the global population is still growing. The global population is projected to reach 9.7 billion by 2050, and culture in the water, the fastest growing food sector, could make a significant contribution to meet the future food demand, particularly the need for protein. Wild fish stock has leveled off globally. The FAO (2010a) According to FAO (2010a), 53% of marine fish stocks were fully exploited in 2008 and 28.8% of marine fish stocks were estimated to have diminished to a biological unsustainable level. Therefore, hunting in the sea seems not anymore a solution to fulfill the increasing demand of seafood. Gatlin et al. (2007) state that nearly one third of fish consumption is provided for by fish farms and overall aquaculture production has doubled in the past decade and tripled since 1995. Aquaculture is considered to have the potential to provide high-quality aquatic products for the projected demand of 270.9 million tonnes by 2050 (Wijkstrom, 2003). Currently, the aquaculture production is dominated by Asia, accounting for 91% of total production in 2013, and China is the biggest supplier as well as exporter in the world. In terms of the most farmed species, finfish culture accounts for approximately 50% of world production, the rest are equally divided between aquatic plants and crustaceans/mollusks. Apart from its potential contribution to food and protein security, aquaculture has also been questioned as being another problem of sustainability rather than its solution. The main issues of concern are its significant impacts on the environment (e.g. mangrove deforestation, coastal damage, eutrophication and gene pollution) and its competition with agriculture for freshwater and land resources (Olsen, 2011). Thus, environmental and resource use sustainability should be considered in any new regulation on aquaculture.

Feedstock is a crucial factor determining the growth of aquaculture in the future. With technology innovation in feed production and high incentives for seeking cost-efficient alternatives for fish meal (FM) and fish oil (FO) from wild fish, soybean meal (SM) became the major component used for aquafeed. Soybean meal is now not only used for freshwater omnivorous species, but also for cultured carnivores. As a consequence of the resulting cost advantage, the demand for feed from crop production, particularly soybean is expected to grow dramatically. This way, however, aquaculture significantly contributes to the rapidly growing competition for land. The additional competition for land from aquaculture through fish feed production and direct use as well as more restrictive regulations may limit the expansion of aquaculture.

So far, only very few economic models for analysis and scenario simulation of the complex interrelationships between capture fishery, aquaculture and land use are in place. However, such models will be needed for the provision of sound policy advice on growing aquaculture and its effects on the agricultural sector and markets, globally and in Europe.

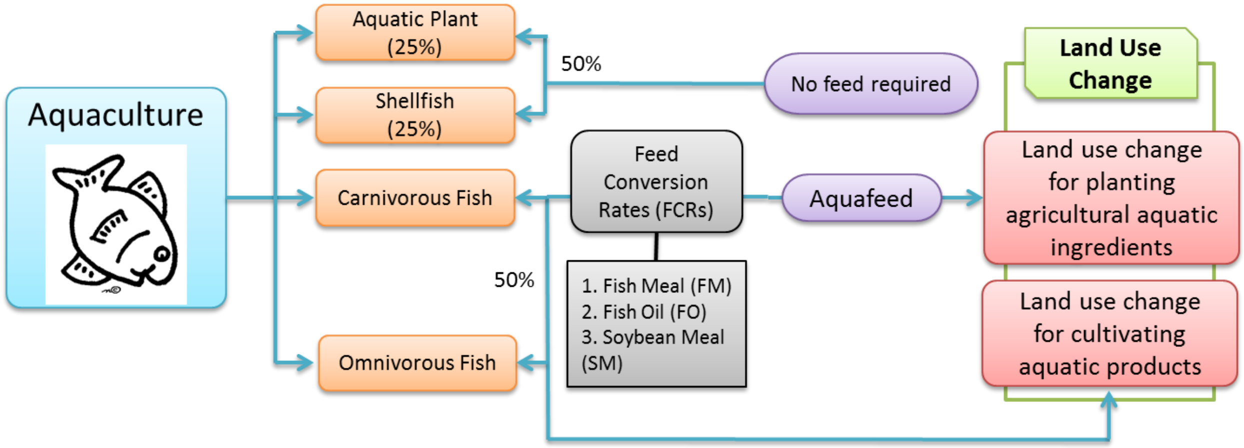
The aim of this paper is to assess the interdependencies between a growing aquaculture sector and its demand for land and explore aquaculture sustainability. First, this study provides evidence of the connection between aquaculture and land use and sketches the main mechanisms of this interaction. Second, we explore the main concerns about aquaculture sustainability. Third, we discuss models used to monitor and analyze aquaculture activities environmentally and economically and provide a first possible classification of fish species to be considered for policy advice in the EU.

Land use and its connection to aquafeed

"Different land uses will be competing for the available land" (Lambin and Meyfroidt, 2011). For aquaculture, we distinguish between direct land use (land used directly for aquaculture ponds), rice-cum-fish paddies or integrated agriculture-aquaculture system (IAA) systems, and indirect land use resulting from land used for aquafeed production.

Figure 1 indicates how aquaculture is interlinked with land use change. Cultured aquatic plant and shellfish farming are not directly relevant for land use change even though they account for half of the aquaculture production (25% each). However, the other half, marine carnivores and omnivorous species are relevant for land use change. Both marine carnivores and omnivorous species are linked to land use since a high percentage of fish feed is based on plant ingredients from agriculture. Additionally, many omnivorous species such as shrimps, carps, tilapias are farmed in ponds or IAA systems which are directly related to land use.

Figure 1: Linkage between aquaculture and land use change



Source: Author

Direct land use

Several aquaculture activities demand land as one of the most important inputs for production, such as pond rearing and coastal rafts, ropes and stakes' systems. Zhao et al., (2004), for example, stress that land use for aquaculture ponds in Dongtan, Chonming Island, China amounted to more than 6%, 36% and 39% in 1990, 1997 and 2000, respectively. Also, shrimp aquaculture has a considerable impact on land cover change. In Sinaloa, Mexico, for example, the landscape has changed by 3190 ha between 1984 and 1999 (Alonso-Pérez et al., 2003). Another example is Damarpota in Southwestern Bangladesh where 79% (274 ha) of the rice fields of the village were transformed to shrimp ponds between 1985 and 2003 (Ali, 2006). The conversion not only happens between agricultural land and aquaculture but also natural mangrove forests are affected (Delgado et al., 2003). In Vietnam, for example, shrimp farming caused wetland deterioration, where 440 ha (approximately 60%) of mangrove area disappeared between 1986 and 1992 (Béland et al., 2006). Direct competition for land resource between agriculture and aquaculture or the damage to forest land caused by aquaculture has been an issue to pay attention.

Rice-cum-fish paddies and integrated agriculture-aquaculture (IAA) systems

Rice-cum-fish paddies and IAA systems are ancient fish rearing practices in China. Prein 2002) defines them as "an integrated farming on the basis of diversification of agriculture towards linkage between subsystems". They also compose a special agro-landscape in other Asian countries and are usually taken into account as a part of an integrated ecosystem (Lu and Li, 2006) positively contributing to the environment, for example, by nutrient recycling. They are usually extensive production systems in terms of low input demand and low yields in many Southeast Asian countries and China that rely on the their own subsystems and serve as important protein source to local households (FAO et al., 2001). Phong et al., (2011) compare the environmental impact of several IAA systems in the Mekong Delta of Vietnam using Life Cycle Assessment (LCA) and conclude that one kilogram of fish produced in orchard-based and low input fish systems has 28% higher land use than rice-based and high input fish systems and rice-based and medium input fish systems.

Indirect land use and its linkage with aquafeed

Indirect land use refers to the need of agricultural land derived from the demand for other products. The rapid growth of aquaculture is associated with land use for fish feed production (Henriksson et al., 2011). The expected expansion of aquaculture is considered to lead to an increasing demand for crops in the future.

Aquafeed plays an especially vital role in the expansion of aquaculture as it accounts for roughly 50 percent of the total rearing cost (FAO, 2009). Moreover, it plays a significant role in the most important issues linking aquaculture with agriculture, i.e. land use and sustainability. Aquafeed is composed of the main elements: Fish meal (FM), fish oil (FO) and plant ingredients such as soybean, peas/lupins, wheat, canola, corn and cottonseed. Those plants are processed as protein concentrated ingredients and fat sources in aquatic feed to replace FM and FO. Soybean meal (SM) is currently the predominant additive in world aquaculture. FM and FO are often used in all kinds of animal feed. However, their use for fish feed has significantly grown: In 1995, only 27% of FM is used to produce aquafeed; however, in 2010, the proportion had increased to 73%. Similarly, 34% of FO was used to produce aquafeed in 1995, and the percentage rose to 81% in 2010 (once even reached 90% in 2005) (Table 1). Not least because of a dramatic increase in FM and FO prices in 2006 and 2007 (the world price of FM rose from 744 USD to 1074 USD per ton in 2006, and the world price of FO rose from 812 USD to 1002 USD per ton in 2007 (OECD.Stat), plant alternatives are increasingly used in compound fish feed as to seek for cost-efficient protein and oil sources (Hardy, 2010).

Global aquaculture production excluding aquatic plants is projected to reach 78.6 and 93.6 million tonnes by 2020 and 2030, respectively (World Bank, 2013). Therefore, also an increasing demand for aquafeed is expected. The total estimated aquafeed production in 2006 was 25.4 million tonnes and the total estimated feed used in 2005, 2010, 2015 and 2020 are 23.8, 34.6, 48.8 and 66.6 million tonnes, respectively (Tacon and Metian, 2008). With the technology advance in feed production, particularly in making plant protein digestible for carnivorous fish, the feed conversion ratio (FCR), which equals to consumption of fry matter from feed over weight gain (Refstie et al., 1998), and the reduction of consumption of FM and FO for rearing species could be decreased. Thus, the overall FM use in fish feed has been successfully reduced from 25% in 1995 to 9% in 2010. The use of FO in fish feed could be reduced from 6% to 2% in the same time period. The share of FM and FO in fish feed are expected to fall to 4% and 1% by 2020, respectively. Since FM, FO and plant ingredients are the major components in aquafeed, the proportion of plant meal use increases with reduced FM and FO use. Please note that apart from FM, FO and plant ingredients also other minor additives are used for fish feed. Since their share is not high and they do not constitute significant agricultural land use, the additives are not considered in this study. Table 1 shows that the percentage of plant ingredients in fish feed are projected to rise from 69% in 1995 to 95% in 2020. Thus, cost-efficient and sustainable feed ingredients extracted from plants will dominate the expansion of aquaculture in the future. Paul and Keith (2002) state that 54 out of 358 cultured species were fed with soybean meal (SM) at the time their article was published. Usually, SM is made from soybean cake by processing through crush and oil extraction and has soy oil as a co-product (Dalgaard et al., 2007). However, some carnivorous species in aquaculture are still very sensitive to handle soy. Some species can digest feed up to a maximum share of SM of 15% only. Salmonids (e.g. salmon and trout) can digest feed with a maximum share of SM between 25% and 30%. Some authors believe that with technical progress, species like the hybrid striped bass will likely be able to handle up to 40% or even 50% once the important essential amino acids (EAA) requirements of target rearing species are evaluated because so far the feed formulations are normally on a crude protein basis (Paul and Keith, 2002). For freshwater omnivorous species, Delbert stress that up to 60% of SM could be contained in the feed. Leave aside the technical nutrition or digestion problems, SM is not only more sustainable but also a cheaper protein alternative compared to FM and FO. Although the price of SM has fluctuated between 250 USD/ton and 500 USD/ton since 2007 (with an exception of 550 USD per ton in 2012), SM is still much cheaper than FM (more than 1500 USD/ton after 2010). Until 2005, demand for SM for farmed fish has risen from almost 0 to about 5 million tonnes in China since a program funded by the United Soybean Board (USB) was implemented in 1995 (Gatlin et al., 2007). Consequently, land use change due to the expansion of aquaculture and the rising demand for plant meal became an important issue. Expanding aquaculture coming along with maximum profit chasing behavior and technology progress of aquafeed will result in increasing demand for plants for protein and oil that leads to the competition for land between soybean for fish feed and other agricultural products.

Table 1: World production and price of Aquaculture, fish meal (FM) and fish oil (FO)

Unit: Production: thousand tonnes; Price: USD

		1995	2000	2005	2010	2015*	2020*
Aquaculture	Production (1)	24,382	32,417	44,308	58,987	76,944	89,352
	World Price	1,603	1,472	1,464	1,972	2,183	2,041
Fish meal	Production (2)	6,874	6,970	6,436	4,492	4,701	5,009
	World Price	521	452	744	1,687	1,574	1,387
Fish oil	Production (3)	1,381	1,327	934	947	1,021	1,065
	World Price	457	262	719	1,122	1,731	1,639
FM used in aquafeed (4)**		1,882	2,922	4,300	3,291	3,111	2,385
FO used in aquafeed (5)**		474	631	843	770	756	712
FM used in aquaculture (4)/(2)		27%	42%	67%	73%	66%	48%
FO used in aquaculture (5)/(3)		34%	48%	90%	81%	74%	67%
Aquafeed used (6) **		7484	14782	23812	34647	48874	66636
FM used in aquafeed		25%	20%	18%	9%	6%	4%
FO used in aquafeed		6%	4%	4%	2%	2%	1%
Plant ingredients used in aquafeed ***		69%	76%	78%	88%	92%	95%

1. The aquaculture production excludes aquatic plants
* By estimation (OECD.STAT)
** Tacon and Metian, (2008)
*** Estimated by author, Plant ingredients used in aquafeed = Aquafeed use - FM - FO
Source: OECD.STAT, Tacon and Metian, (2008), authors‘ calculation

Sustainability

According to the definitions of aquaculture and sustainability by (FAO, 1998), we summarize sustainable aquaculture as "the management and conservation, and the orientation of technological and institutional change in farmed aquatic organisms to ensure the satisfaction of human need for present and future generations in a way of environmental, economic and social development." Few studies also discuss including animal welfare (Valenti et al., 2011) and consumer behavior (Verbeke et al., 2007) to the definition of sustainability, though measurement of both is very complex.

Referring to sustainability, aquaculture is considered as a sustainable solution of compensating the leveled-off marine resources to meet the increasing future demand of aquatic products (Kutty, 2010; Olsen, 2011). Since 1980s, capture fishery stays stagnant. On the contrary, aquaculture has grown more than 30% until now making a significant contribution to the world economy as well as creating numerous working opportunities in the society. Environmentally, approximately 30% of the aquaculture production, shellfish, is non-fed species (FAO). Shumway et al., (2003) define shellfish farming as a 'green industry' as well as an optimal environmentally sustainable form of aquaculture. Naylor et al. (2000) also point out that the production of some herbivorous species such as carp do have positive effects on fish supplies. However, aquaculture might also cause a severe reduction of marine fish stocks (Naylor et al., 2000). Marine carnivorous finfish and shrimp farming are raising concerns over their exploitation of marine fish stocks resulting from the high fish-in fish-out (FIFO) ratios. For example, in 1997, on average 1 kg of fish that fed with formulated feed required 1.9 kg wild fish. Among the formulated feeds, salmon feed comprises 45% of FM and 25% of FO and trout feed 35% and 20%, respectively. That is, 1 kg weight gain of salmon and trout require 3.16 kg and 2.46 kg of wild fish, respectively (Naylor et al., 2000). This indicates that carnivores in aquaculture consume much more wild fish than they gain weight themselves, which is not sustainable in terms of not further exploiting wild fish stocks. Even though the FIFO ratios declined to 4.9, 3.4, 3.5, 2.2, and 1.4 for farmed salmon, trout, eel, marine fish and shrimp by 2006 (Tacon and Metian, 2008), the cultured species still are net consumers of scarce ocean fish resources. Using captured small pelagic stocks as fish feed raises concerns not only about the negative environmental and ecological impacts on other predators in the food chain but also about social problems such as direct human consumption, which refers to the fact that the low value small pelagic fish is used to produce FM instead of being consumed as a protein source by the low income households locally. Additionally, some farming types and species have raised concerns about their negative impacts on the environment. The large scale offshore nets or cage farming of carnivores, e.g. salmon farming in Chile (Holmer, 2010) or shrimp farming in Thailand, might potentially destroy ocean and coastal resources through habitat destruction, waste disposal, exotic species, pathogen invasions and using captured fish meat and oil as aquaculture feed (Naylor et al., 2000). In addition, the replacement of the fish diet components by artificial ingredients in order to fatten the reared species at higher growth rates as well as the genetic engineering technique applied to farmed fish resulted in various unexpected concerns. For instance, the compound fish feed on the plant ingredient basis may contain insufficient EAA and fatty acids, and therefore the farmed fish flesh offers less essential nutrients (Hunter and Roberts, 2000). Moreover, the safety of gene modified aquatic products has not been confirmed yet. Debates also evolved on whether the farmed aquatic products are still healthy and provide suitable nutrients for daily intake. Other concerns refer to water pollution by feed sedimentation, deforestation of mangroves, coast damage for expanding shrimp farms, genetic pollution resulting from the escapees, disease dispersion to natural species, the overuse of antibiotics to reduce rearing mortality etc. (Pauly et al., 2002). For some of these issues, using plant alternatives in fish feed production is considered to enhance sustainability.

Recent research uses a multitude of indicators to evaluate the sustainability of aquaculture. Valenti et al., (2011) assess aquaculture sustainability in three parts: economically, environmentally and socially through computing indicators. Other assessments, for example of ecological and carbon footprint and energy use offer critical information and precise calculation to evaluate the impact of aquaculture on sustainability issues. Beyond that, several models and monitoring systems have been developed to monitor aquaculture activities, access the influence of fish farming on the environment and simulate different scenarios to minimize environmental costs. Additionally, the use of antibiotics in aquaculture has been a controversial topic especially in developing countries. Emphasis here is not only on its negative influence on ecological and biological systems, but also on its harmful effects on human health through the food chain.

Research on sustainability in aquaculture encompasses also animal welfare and consumer behavior with respect to sustainability issues in fish production (e.g. Ashley, 2007; Valenti et al., 2011; Grunert, 2011; Verbeke et al., 2007). However, they are beyond the scope of this paper since they have no direct connection to the agricultural sector and are not further considered here.

Models and methods implemented in aquaculture

Considering aquaculture and its potential impact on land use and sustainability is of great importance also for the agricultural sector and agricultural market analysis. Therefore, several models have been developed for further research. However, aquaculture is often absent from most of the economic agricultural models. Currently, most existing aquaculture models focus on analyzing the environmental impacts of aquaculture, such as Life Cycle Assessments (LCA) (Klöpffer, 2005), the Farm Aquaculture Resource Management (FARM) model (Ferreira et al., 2009) or the Offshore Mari culture Escapes Genetics Assessment (OMEGA) (NOAA and ICF, 2012), the Modelling–Ongrowing fish farm-Monitoring System (MOM) (Maroni, 2000), Depositional Modeling (DEPOMOD) (Cromey et al., 2002) and the Integrated Valuation of Environmental Services and Tradeoffs (InVEST) model (http://www.naturalcapitalproject.org/invest/). Those models are used to analyse different sorts of situations including monitoring environmental indicators and simulating possible fish farming scenarios. Among the ten AgMIP global economic models (Lampe et al., 2014), the IMPACT model (International Model for Policy Analysis of Agricultural Commodities and Trade hosted at IFPRI, http://www.ifpri.org/program/impact-model) is the only one also considering aquatic products. Apart from the IMPACT model, also AgLink-CoSiMo (FAO-OECD) features a relatively completely structured fisheries sector (http://www.agri-outlook.org/abouttheoutlook/). In addition, a regional economic model, Taiwan’s Fisheries Sector Equilibrium Model (Sun et al., 1999), was developed for economic analyses of capture fishery and aquaculture at a country level. Below, the fish modules in the IMPACT and AgLink-CoSiMo model frameworks are briefly introduced.

IMPACT has been developed at IFPRI and is a global, multimarket, partial equilibrium economic model. The World Bank (2013) implemented the IMPACT model for projecting global fish supply and demand and simulating 6 scenarios until 2030 in one of the first integrated aquaculture-agriculture reports called “Fish to 2030 – Prospects for Fisheries and Aquaculture” (World Bank, 2013). The IMPACT fish module includes 17 fish products, aggregated non-fish commodities for reducing the size of the model and 115 world regions. IMPACT can handle multiple fish species, fish feed and the linkage with the agricultural sector. IMPACT is thus the first large-scale economic model that includes a comprehensive and comparably detailed fish module. Disadvantages of the model mentions in the report refer to the simplified model structure, a rather unrealistic market-clearing price, homogeneity assumptions and a lack of bilateral trade flows. Particular attention is given to the link between aquaculture and land use through the consideration of aquafeed from plant-based ingredients. IMPACT therefore features a strong linkage between aquaculture and agriculture.

The fish module of the AgLink-CoSiMo Framework (FAO-OECD) was conceptually introduced by the FAO in 2010. AgLink-CoSiMo is a partial equilibrium model to simulate midterm projections for international agriculture and food markets. The fish model is a standalone model that can be linked to AgLink-CoSiMo through feed use. The goal of the combination of both models is to analyze the interaction between fisheries and agriculture.

Table 2: Aquaculture modelling

Environmental Model	Institute	Objective
Life Cycle Assessment	(Klöpffer, 2005)	Evaluate the environmental impacts
Farm Aquaculture Resource Management (FARM)	(Ferreira et al., 2009)	1. Location/species selection 2. Ecological/economic optimization 3. Eutrophication effects
Offshore Mariculture Escapes Genetics Assessment (OMEGA)	NOAA	Evaluate the possible genetic and ecological effects of escaped fish on wild fish of the same species.
Modelling–Ongrowing fish farm–Monitoring system (MOM)	(Maroni, 2000)	Evaluate the local environmental impact through estimating the holding capacity of sites focusing on organic enrichment
Depositional Modeling (DEPOMOD) and MERAMOD	(Cromey et al., 2002)	Predict the impact of those huge marine cages on the benthos and improves to regulate the decision making process
InVEST Marine Fish Aquaculture model	Natural Capital Project	Evaluate how human activities and climate change affects production and value
Global Economic Model	**Institute**	**Issue**
IMPACT model	IFPRI	Analyze the interaction between fisheries and agriculture, simulate scenarios and projection
AgLink-CoSiMo Framework (FAO-OECD Model)	FAO OECD	Analyze the interaction between fisheries and agriculture
Regional Economic Model	**Institute**	**Issue**
Taiwanese Fishery Sector	(Sun et	Evaluate the impact of policy scenarios on fisheries in

Equilibrium Mathematic Programming model	al., 1999)	Taiwan

Source: Author

Other global economic models have started working on including fish modules in their models to account for the increasing importance of aquaculture for land use and environmental impacts. The World Bank (2013) states that compared to the IMPACT model, some general and partial equilibrium models such as CGE models developed under the framework of the GTAP modeling consortium, the World Bank's Linkage model, the Global Biosphere Management model or the CAPRI model could deal better with some of the shortcomings of the IMPACT model. However, the World Bank (2013) report also points out that, so far, the main problems for implementing aquaculture into the aforementioned models is to find a suitable aggregation of fish species and to identify how to handle aquafeed and its linkage with the agricultural sector.

Compared to IMPACT, the European-focused partial equilibrium model CAPRI has the potential to handle more complex structures and project medium term market developments (World Bank, 2013). However, currently, the fish sector in CAPRI is only divided into three categories: (1) freshwater fish (FFIS), (2) saltwater fish (SFIS) and (3) other aquatic animals (QAQU) and a connection to the agricultural sector has not been established yet. The first step for improving the fish sector in CAPRI would be to develop a more detailed classification of fish species tailored to EU policy advice. The main challenge here is how to aggregate hundreds of fish species represented, for example, in FAOSTAT and FISHSTAT (also maintained by the FAO). For simplicity and to warrant easy exchange with other models, we decided to adopt the IMPACT classification, which could in further developing the module be disaggregated into more fish species as needed. Table 3 shows a first sketch of the IMPACT classification adapted to the CAPRI model. Based on the species classification, our next step would be to build up the database in the market module of CAPRI, and third, set up the baseline. The final step of the fish module development would be scenario simulations and results analysis focusing on global land use.

The most important intermediate information, the FCR, is calculated from aquaculture production and demand and partly also taken from the literature. Also in the first step, we will focus on the three most important elements of fish feed, i.e. fish meal (FM), fish oil (FO) and soybean meal (SM), where the latter is used to link the module to the agricultural sector. AgLink-CoSiMo uses also cereals as component of fish feed, but mentions problems of its aggregation in compound fish feed (http://www.agri-outlook.org/abouttheoutlook/).

Table 3: Aggregation of aquatic products in CAPRI

FAO description	CAPRI code	FAO description	CAPRI code
Freshwater Fish	FFIS	Aquatic Animals, Others	OFIS
Demersal Fish	DFIS		
Pelagic Fish	PFIS	Fish body oil	FISO
Marine Fish, Other	OFIS	Fish liver oil	FISO
Crustaceans	CRUS	Fish meal	FISM

Cephalopods	MOLS	Aquatic products, other	OFIS
Molluscs, Other	MOLS		

Source: Author

Conclusions

The “Blue Revolution”, farming from land to ocean, is taking place to meet the increasing demand of food and protein resulting from population expansion. However, the rapidly growing carnivores aquaculture not only competes for land with other food and feed production, but also exploits ocean resources by consuming wild fish as well as FM and FO produced from wild fish, which raised concerns over its sustainability. In 1995, the percentage of plant ingredients used in the formulated fish feed has reached 80 - 90% for freshwater omnivorous species and around 30 - 40% for marine carnivorous species. Together with seeking cost-efficient and sustainable fish feed ingredients and the progress of turning carnivores into vegetarians, the proportion of plant source has increased to 60 - 70% in the feed for cultured carnivores in 2010. By 2020, fish meal (FM) and fish oil (FO) are expected to be almost replaced by plant protein and plant oil for both freshwater omnivores and carnivores. The impact these developments will have on global land use, food production and environment will be assessed in future research for which this paper lays the foundations in terms of identifying (1) the complex relationships between aquaculture and land use, (2) the main sustainability concerns, and (3) suitable model frameworks and applications. After having adopted a first classification of the most important fish species, the basic framework of the fish module in the CAPRI model is currently being set up. With proper parameter settings and scenario design, the fish module in CAPRI model could be used for the analysis of the impacts of future aquaculture expansion on land use and related questions.

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