Environmental Research Letters

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OPEN ACCESS
IOP Publishing
Environmental Research Letters
Environ. Res. Lett. 9 (2014) 109001 (4pp)
doi:10.1088/1748-9326/9/10/109001

Comment

Comment on 'Water footprint of marine protein consumption—aquaculture's link to agriculture'

Max Troell[1,2], Marc Metian[2], Malcolm Beveridge[3], Marc Verdegem[4] and Lisa Deutsch[2]

[1] Beijer Institute of Ecological Economics, Royal Swedish Academy of Sciences, SE-104 05 Stockholm, Sweden
[2] Stockholm Resilience Centre, Stockholm University, SE-106 91 Stockholm, Sweden
[3] WorldFish, Jalan Batu Maung, Batu Maung, 11960 Bayan Lepas, Penang, Malaysia
[4] Department of Animal Sciences, Wageningen University, PO Box 338, 6700AH Wageningen, The Netherlands

E-mail: max@beijer.kva.se

Received 22 April 2014, revised 15 September 2014
Accepted for publication 16 September 2014
Published 3 October 2014

Abstract

In their article 'Freshwater savings from marine protein consumption' (2014 *Environ. Res. Lett.* **9** 014005), Gephart and her colleagues analyzed how consumption of marine animal protein rather than terrestrial animal protein leads to reduced freshwater allocation. They concluded that future water savings from increased marine fish consumption would be possible. We find the approach interesting and, if they only considered marine capture fisheries, their analysis would be quite straightforward and show savings of freshwater. However, both capture fisheries and aquaculture are considered in the analysis, and the fact that marine aquaculture is assumed to have a zero freshwater usage, makes the analysis incomplete. Feed resources used in marine aquaculture contain agriculture compounds, which results in a freshwater footprint. To correct this shortcoming we complement the approach taken by Gephart and her colleagues by estimating the freshwater footprint (WF) for crops used for feeding marine aquaculture. We show that this is critically important when estimating the true freshwater footprint for marine aquaculture, and that it will be increasingly so in the future. We also further expand on aquaculture's dependency on fish resources, as this was only briefly touched upon in the paper. We do so because changes in availability of fish resources will play an important role for feed development and thereby for the future freshwater footprint of marine aquaculture.

Keywords: marine protein, aquaculture, freshwater

Stagnant capture fisheries

Global wild fish catches have for some time been at, or near, the limits of what aquatic ecosystems can be expected to provide naturally (FAO 2012, UNHRC 2012). Gephart and her colleagues give reference to studies arguing that global fish stocks can be rebuilt and future yields increased. To balance these predictions one should consider that other sources foresee limited future increased yields from capture fisheries and instead describe a trajectory predicting reduced biomass but greater economic values (World Bank-FAO 2009). Also important to stress here is the uncertainty

Table 1. Marine aquaculture production—fed animal species and also main extractive animal species; volumes of feed and percentage of production based on commercial feed (based on Tacon *et al* 2011).

Marine species	Production 2010 (tonnes)	Feed used (tonnes)	Percent (%) on compound feeds
Salmon	1577 019	2050 125	100
Shrimps	3787 706	5757 313	95
Milkfish	808 559	727 703	45
Marine fish (except mullets)	1762 225	2444 206	73
Marine fish (mullets)	138 130	191 586	73
Tilapia	60 851	87 930	85
Mussels	1802 682	—	—
Scallops	1727 105	—	—
Oysters	4486 804	—	—

related to how depleted fish stocks may respond to any rebuilding process because of our incomplete understanding of time lags and nonlinearities and thresholds in transition dynamics (Worm and Branch 2012).

The fact is that the world's increasing demand for fish in recent decades has depended on aquaculture and today almost half of all fish[5] consumed comes from farming (FAO-FISHSTAT 2013). Aquaculture will contribute an even larger share in the future. It is important to note that one third of global catches are destined for reduction and transformation to fishmeal and fish oil, of which most (58.8% fishmeal; 90% fish oil; Jackson and Shepherd 2012) is used by the aquaculture sector, including both freshwater and marine farming. The controversial issue related to the aquaculture industry's usage of forage fish (i.e. small pelagic forage fish) is mentioned by Gephart *et al* but how availability of these resources may affect future aquaculture development needs to be discussed more specifically. Thus, reducing the share of wild fish in feeds is a major priority for the aquaculture industry, driven mainly by prices and a realization that it is a limited resource. Significant progress is being made in identifying alternative feed ingredients, such as protein and lipid rich crops, yeasts and micro-algae (Klinger and Naylor 2012). The forage fish will possibly in the future also be less available for the aquaculture industry as direct human consumption of these fish should increase and their importance for sustaining the diversity of marine food webs is increasingly recognized (Smith *et al* 2011). These considerations with respect to the future role of capture fisheries in providing aquafeed resources will influence the development of marine aquaculture and also its freshwater footprint.

Marine aquaculture development

There exists a large diversity of marine aquaculture species and culture systems, and these have different environmental performance and generate different impacts (Hall *et al* 2011, Klinger and Naylor 2012, Troell *et al* 2014). Raising large carnivorous fish species, such as salmon, tuna and grouper, requires sizable inputs of fish resources, but the competition for these resources is high as also carp mono- and polyculture systems in China use significant amounts of fish feed inputs in the form of fishmeal (in 2008 carps consumed 7.4% of total fishmeal supplies; Tacon *et al* 2011). On the other hand, filter feeding species, such as clams, oysters, mussels and scallops, accounting for 58% of marine and brackish water animal aquaculture production, do not need any artificial feed inputs (FAO 2014). It is anticipated that climate change through warming will have a direct effect on aquaculture production, but also indirect effects e.g. ocean acidification may pose future challenges for marine farming (de Silva 2013, Branch *et al* 2013). Thus, besides directly threatening shellfish aquaculture, acidification risks disrupting marine food webs that support the production of fish species used for fishmeal and fish oil in aquaculture feeds. However, compared to farming on land, the sea will probably dampen the acute effects of temperature rise. Evolving disease and parasite dynamics/pressures and heightened storminess, also linked to climate change, add further to the challenges, as well as increased coastal pollution.

While not directly affected by freshwater constraints, marine aquaculture is also impacted indirectly by climate change through its dependence on crop-based feeds (Troell *et al* 2014). Today's production of marine fish and shellfish to a large extent already relies on terrestrial feed components, and the trend is towards increased dependence on agricultural crop-based compound feeds. Table 1 presents major marine aquaculture species groups with freshwater footprints arising from their dependence on feeds compounded from various crops. For comparison, the main non-fed marine animal groups are also included. The amounts of feeds used and the percentage of farming depending on commercial feeds are also presented.

Aquaculture and freshwater consumption

Direct water use by aquaculture can be divided into consumptive water use (the sum of reductions of stream flow, groundwater and water removed in the form of farmed biomass), and total water use, which includes precipitation, runoff, seepage and additions by management (Boyd *et al* 2007). The consumption relates mainly to freshwater farming and existing estimates for on-farm water usage by marine aquaculture, e.g. cages, net pens and raceways are

[5] Fish including both finfish and shellfish.

Table 2. List of agriculture crops used in marine aquaculture and volumes in tonnes. Freshwater consumption per crop (FW) and calculated water footprint (WF).

Crop source	Amount (tonnes)	FW ($L\ g^{-1}$)	WF (m^3)	WF (km^3)
Soybean	1222 284	2.3	2811 252 400	2.8113
Wheat	2442 380	1.6	3907 808 421	3.9078
Corn	103 249	1.6	165 198 408	0.1652
Pea	40 467	1.6	64 746 857	0.0647
Paddy rice	892	1.6	1 427 512	0.0014
Sorghum	251	1.6	402 226	0.0004
Rapeseed/ Canola	430 525	2.3	990 208 021	0.9902
Fababean	11 252	2.3	25 880 582	0.0259
			Sum:	7.9669

only minor. Freshwater is also consumed downstream in the value chain (i.e. in processing, packaging, distribution and retailing), the amounts used being largely dependent on the type of product. Marine land based re-cycling systems are energy intensive but indirect water consumption for energy production is usually not considered. Freshwater aquaculture generally consumes less freshwater compared to production of terrestrial animals (Phillips *et al* 1991, Brummett 1997, 2006, Verdegem *et al* 2006). However, the consequences of freshwater use (i.e. competition with other food systems or drinking water) are hard to estimate as it greatly depends upon geographic location, temporal variations and source of the water (Blackhurst *et al* 2010).

Indirect freshwater usage in marine production instead mainly relates to dependence on compound feeds (also true for freshwater aquaculture: Verdegem and Bosma 2009). Gephart and her colleagues neglected this by setting the marine freshwater footprint to zero. Verdegem *et al* (2006) estimated feed-associated freshwater use to 15.4 $m^3\ kg^{-1}$ fish, assuming a fish protein content of 32% and a Food Conversion Ratio of 2 (i.e. 2 kg of feed are required to produce 1 kg of farmed fish). Due to the many variables concerning water scarcity, including water requirements for different crops, farming method, irrigation efficiency, access to renewable water resources and the complexity of accounting for water pollution, it is difficult to generalize water use in aquaculture (or for that matter in livestock production). The average numbers presented by Verdegem *et al* (2006) also included freshwater aquaculture and to accurately supplement the study by Gephart and colleagues we need only focus on marine aquaculture production. We cannot follow the methodology used by Gephart and colleagues and have instead chosen to illustrate the freshwater dependence through feeds by presenting volumes of agriculture inputs to marine aquaculture production. We identify all marine aquaculture species groups depending on compound feeds and identify the crop composition in the feeds for the different species groups (such as Tacon *et al* 2011, Troell *et al* 2014). The main agriculture resources used in marine aquaculture through compound feeds are shown in table 2. It shows that the aquaculture sector uses a significant volume of food quality crops and by-products (co-products). The overlap of resource between the aquaculture, livestock and poultry sector seems to be large and soybean and maize constitute the main food crops of importance for marine aquaculture. The amount of crop resources used for marine aquaculture will probably increase in the future as (1) overall aquaculture production will increase; (2) the share of aquaculture production using commercial pelleted feeds will increase; and (3) the availability of fish protein resources will be limited (stable or declining fish stocks, insufficient fish processing wastes).

An approximate calculation of total WF for the feed crops used in marine aquaculture (for 2010) was done using the same conversion factors ($L\ g^{-1}$) used by Gephart and colleagues (i.e. originally from Mekonnen and Hoekstra 2010). Volumes of crops used in feeds and the amount of freshwater needed to produce these resulted in a total water footprint estimated to 8 $km^3\ yr^{-1}$ (table 2). This is much smaller compared to the overall WF for marine foods estimated by Gephart and colleagues (300–390 $km^3\ yr^{-1}$) but still of significance and not zero.

If we estimate agriculture input to all aquaculture (i.e. including also freshwater aquaculture, Troell *et al* 2014) then the WF for this would be much larger. Global aquaculture dependent on compound feeds uses approximately 40 million tonnes (Troell *et al* 2014) of feeds and using same methodology as for the marine aquaculture production, but only using the 15 most used feed ingredients (by volume) the WF would be almost 70 $km^3\ yr^1$. In addition, the agriculture inputs used for above estimations are only the plant compounds that are used in aqua feeds. An additional WF would arise from the usage of animal by-products (marine and terrestrial) in aquaculture feeds. The complexity of aquaculture's WF is further increased as processing wastes are recirculated and used as aquaculture feed inputs. However, this data is probably difficult to get hold of and most probably constitute only a minor addition to the water footprint. A final point with respect to water footprint of aquaculture is that a large part of global production remains based on farm-made feeds and these are not included in the calculations above (Hasan *et al* 2007). The volume of farm-made feeds used in the global aquaculture sector is estimated to be in the range of 18–31 million tonnes per year (Hasan *et al* 2007) and used mainly in freshwater/brackish water systems.

Conclusion

Consumption of capture fisheries products as well as extractive aquaculture animal species results in a negligible water footprint compared to consumption of e.g. terrestrial animals or crops and, thus, reduces pressure on freshwater resources. However, consumption of marine aquaculture products based on compound feeds has a water footprint (not zero as assumed by Gephart *et al*), and this will become larger if the dependence on agriculture resources remains, or continues to increase, become larger. It is important to point out that the WF of aquaculture is generally smaller than that of most terrestrial animals and thereby constitutes a more favorable outcome from a freshwater perspective. Finally, as Gephart and colleagues highlighted, it is difficult to say anything specific about how the consumption in one country contributes to water savings due to trade. Imports of terrestrial meat or crops may originate from regions not being water stressed—and this is also the case for aquaculture products. The context specific situation related to where water has been extracted is important to consider when discussing about resulting environmental and social effects.

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