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Impact of feed raw material to climate and eutrophication impacts of Finnish rainbow trout farming and comparisons on climate impact and eutrophication between farmed and wild fish

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A B S T R A C T

This study presents environmental impacts of rainbow trout production in Finland, when different raw materials for feed are used. The scenarios under consideration in this study are the present scenario, feed composition in 2009 and scenarios where Baltic herring is used as feed raw material resulting in nutrient circulation in the Baltic Sea area. The system boundaries included production of fish feed and feed raw materials and transports of them. Also considered were hatcheries, fish farming, fish processing and packaging, but these factors were assumed to be the same for all the scenarios. The environmental impacts considered were climate impact and aquatic eutrophication.

According to the results, the present eutrophication impact of rainbow trout fillet is 40 kg PO_4-eq/ton, when economic allocation was used between fillet and by-products of gutting and filleting. The eutrophication impact of the rainbow trout product chain in 2009 and 2016 were the same: the higher canola oil content increased eutrophication impact as much as the impact was reduced by lower phosphorus and nitrogen emissions of the fish farming stage during years 2009–2016. If all the fish-based raw materials for feed are replaced with Baltic Herring, the total eutrophication impact would be −48 kg PO_4-eq/ton, when using 2009 feed formulations, but when using 2016 feed formulations the impact would be only −5 kg PO_4-eq/ton because of lower fish raw material contents. The fuel consumption used when catching the Baltic herring capturing is about the same as catching the raw materials of fish meal and fish oil from the oceans, so changing the raw material from ocean-based fish to Baltic herring does not have an effect on climate impact of rainbow trout. Also the substitution of fish oil for canola oil does not cause major changes in climate impact.

Scenarios where fish are caught and used directly for human consumption show that even more nutrients are omitted from the Baltic Sea in relation to the obtained amount of fish fillet and the climate impact is also lower than in farmed rainbow trout, but uncertainty with regard to the results is high because of limited fishing fuel consumption data. Nevertheless it is not likely that the Finnish consumption of domestic small caught fish, like Baltic herring, will increase because consumer behaviour has changed and people prefer to eat salmonids or other fillet-size fish instead.

Allocation was found to be critical when calculating environmental impacts of seafood products and in this study economic allocation was preferred. One major question, which was not concerned, is that how to take into account local impacts of fish farming, because life-cycle assessment (LCA) is known to be a limited method for assessing local environmental impacts. That is essential when considering production licenses for fish cultivation in the Baltic Sea.

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1. Introduction

Eutrophication is the main environmental problem in Finnish rainbow trout (RT) production based on previous life cycle assessment (LCA) studies, which have also pointed out that fishing is an important method to remove nutrients from water systems and to reduce aquatic eutrophication (Grönroos et al., 2006; Seppälä et al., 2001; Lillsunde, 2001). Fish farming stage has been found the most significant contributor to eutrophying emissions, while other environmental impacts are dominated by impacts on aquaculture feeds and feed use efficiency (e.g. Pelletier et al., 2009; Grönroos et al., 2006). For the cage farming of RT in the Baltic Sea, majority of fish-based feed ingredients have been sourced outside the Baltic Sea and its drainage area thus resulting in net nutrient import to the sea. Using regional marine ingredients in fish feed would potentially create a closed nutrient loop within which aquaculture would re-circulate existing nutrient sources, introducing fewer new nutrients into the Baltic Sea catchment area (Anon., 2014). Using cost-effective, regional ingredients would also be beneficial to the regional economy. These assumptions have been put into practice and in Finland in 2016 a fish meal factory was developed using fish captured from the Baltic Sea as feed raw material.

RT is the most important cultivated fish species in Finland with a production volume of 13 900 tons in 2015 of. and catch of Baltic herring (BH) was 131 000 tons in 2014 (Natural Resource Institute Finland, 2016), so the catch is enough to support the present fish-based raw materials in RT feed in the entire Finnish Baltic Sea cage farming industry. Utilising BH as RT feed is a reasonable way to utilise the capacity of natural resources of BH. Impact of other changes in feed composition between 2009 and 2016 was also assessed, because of replacement of fish-based ingredients as plant-based ingredients. Also climate impact and eutrophication impact were assessed in scenarios that average larger fillet fish and BH are directly used as a human food, when nutrients are also removed from the Baltic Sea. Before the fishmeal factory main part of the BH catch ended up to fur animal feed. In the future BH could also be exported as feed and be used outside the Baltic Sea area.

Life-cycle assessment has been widely used in investigating environmental impacts of aquaculture, especially salmonid production. A good review article to show the differences in LCA results of fish farming is Pelletier et al. (2009), where climate impact of salmon varies between 1.79 and 3.21 kgCO2-eq/kg salmon and eutrophication impact between 41.0 and 74.9 g PO4-eq/kg salmon. Also Winther et al. (2009), Papatryphon et al. (2003), Grönroos and Silvenius (2006) and Ellingsen and Aanondsen (2006) have conducted LCA-studies on salmonids. So the area has been widely investigated before, but this study provides new information of nutrient circulation in restricted circumstances and impact of replacement fish based raw material on climate and eutrophication impact of RT fillet.

When concerning the results of LCA-studies of seafood, allocation has been found a major factor, as presented in Winther et al. (2009) and Silvenius et al. (2012). In the field of life cycle assessment of seafood there has been no international consensus concerning the issue so far, but the British Standards Institution (2012) has published a standard for climate impact assessment for seafood, and recommends system expansion and mass allocation (PAS 2050–2:2012). Prior to that standard, Papatryphon et al. (2003) used economic allocation, Eyjólfsdóttir et al. (2003) used mass allocation and Winther et al. (2009) used mass allocation, but also sensitivity assessment by using economic allocation.

2. Materials and methods

The study was carried out by conducting on an LCA for Finnish RT fillet and caught fish produced in Finland for different scenarios: the present system (RT_{2016}), where feed included fish caught from the Oceans, captured wild fish from the Baltic Sea for direct human consumption (WF), and for RT fed with the fish raw materials originating from the Baltic Sea ($RT_{BSf2016}$) as well as scenarios for these for 2009 feed (RT_{2009} and $RT_{BSf2009}$). The captured fish species were in addition to BH typical captured fillet size fish species in the Baltic Sea area (pike, perch, pikeperch and European whitefish). The standardised (ISO 14040 and ISO 14044) LCA methodology was used in each case. The functional unit was one ton of skinless fillet of fish. National Statistics of RT production, nutrient emissions, fuel consumption of BH fisheries were used for data sources to inventory data calculations as well as interviews to net-cage production companies, fish meal factories, hatcheries and feed production companies. After data collection the inventory data was calculated based on the obtained data and after that impact assessment was made by multiplying the emissions as characterization factors and in addition, transports and effect factors when considering eutrophication.

2.1. System boundaries and data sources

The system boundaries of cultivated fish included feed raw materials production, feed production, hatchery, fish farming, fish gutting and filleting, packages production and transports of the materials and fish. The fillet yields for the investigated fish are presented in Table 1. The system boundaries of the caught fish include the fuel consumption of the fisheries, ice production, production of packages, fish gutting and filleting and transports of materials and fishes. The maintenance and production of fishing vessels and nets and other fishing equipment were excluded from all the studied systems. The impact categories were aquatic eutrophication and climate change. The used feed contents are announced in Table 2.

In the $RT_{BSf2009}$ and $RT_{BSf2016}$ scenarios, it was assumed that fish meal and fish oil were manufactured using Finnish BH raw material. Otherwise the feed recipe was the same as in the reference systems ($RT_{ref2009}$ vs $RT_{BSf2009}$ and RT_{2016} vs $RT_{BSf2009}$). The inventory for the fish meal and fish oil production processes was from an existing process in Denmark in 2010 (confidential).

For the fuel consumption values for fish raw material catch used in meal and fish oil of the LCA Food database (www.lcafood.dk, 2011) were used. The fuel consumption of the fisheries of BH was based on fuel consumption of trawling in Finland according the statistics of the Finnish Game and Fisheries Research Institute in 2008 (Table 3). The fuel consumption associated with the fishing process of larger caught fish was modelled based on inshore fishermen profit and loss account analysis data measured by the Finnish Game and Fisheries Research Institute. In the RT_{BSf} system the production process of fish feed was assumed to be the same as that of conventional fish feed.

It was assumed that the soybeans were produced in west central part of Brazil and inventory data of soya cultivation was from

Table 1
The fillet yields of the investigated fish species.

Fish species	Fillet yield, %	Source
Rainbow Trout	52	Vihervuori and Ahvonen, 1997
Atlantic salmon	59	Vihervuori and Ahvonen 1997
Baltic herring	43	Vihervuori and Ahvonen, 1997
Pike	39	
Perch	39	
Whitefish	49	Vihervuori and Ahvonen, 1997
Pikeperch	42 (48–51)	

Table 2
The feed raw material contents in 2009 and 2016 (Personal comments Arvonen, Biomar Ltd 2010, Finer, Raisio Ltd. 2010, Vielma, Luke, 2016).

Year	2009, %	2016, %
Fish meal	30	15
Soyprotein	13	15
Other soymeals	5	5
Corn gluten	5	5
Other plant proteins (pea, horse bean, sunflower, wheat etc proteins)		6
Animal by-products (blood meal, poultry by-product meal)		5
Wheat meal	13	13
Fish oil	22	10
Canola oil	9	23
Rest (vitamins, minerals)	3	3

Table 3
Fuel consumption of the fisheries used in the study.

Fish raw material	Fuel consumption, l/t fish
Raw materials for fish meal and fish oil	66
Baltic Herring	55
Captured fish (pike, perch, pikeperch and whitefish)	296

Ecoinvent (Jungbluth et al., 2007) and da Silva et al. (2010) were used. The production of soy meal was assumed to take place in Brazil, and Ecoinvent data was used for the process. The data from soy concentrate production was assumed to use as much energy as the parting process of soy meal and soy oil, as was noticed in the study by Seppälä et al. (2001). The fish farming stage include hatcheries, construction materials, nutrient emissions and nitrous oxide emissions (Table 4). Nutrient emissions were based on statistics of feed consumption, phosphorus and nitrogen contents of feed and characterization of climate and eutrophication impact was made based on Table 5.

3. Calculations

3.1. Characterisation factors and impact assessment

When assessing the eutrophication impacts, nutrient flows to and from the sea were considered and converted to the PO_4-equivalents by using the characterisation factors of Seppälä et al. (2004) and Heijungs et al. (1992) (Table 4). Only the eutrophiction impact on the Baltic Sea was dealt with. For climate impact characterisation, i.e. equivalency factors of Solomon et al. (2007) were used.

3.2. Allocations

Allocation is needed in several points of the product system of RT and other fish products. The allocation between fish meal and fish oil was done by using mass allocation. The allocation between soymeal and soybean oil and canola meal and canola oil was done based on their monetary values as is the case in the Ecoinvent database. Economic allocation was used for main products and by-products of gutting, filleting and fishing.

4. Results

4.1. Climate impact of different scenarios

The climate impact of the conventional RT (RT_{2016}) was 5470 kg CO_2-eq/t, of which 53% originated from feed raw material production in 2016 (Fig. 1). The share of feed production was 5%, the fish farming functions 32%, gutting 0.4%, packages 3%, transports 5% and filleting 2%. Around 28% of the total climate impact originated from the product chain of fish meal and fish oil, and one remarkable part was nitrous oxide emissions of fish farming, which was 24%. The value for climate impact in 2009 $RT_{2009,}$ was 5400 kg CO2-eq/t, and it was lower because of the replacement of the fish oil by canola oil. Climate impact of BH-based feed was almost same as conventional feed in both scenarios because almost the same fuel consumption of fishing. In addition, the dioxin removal from BH raw material was not assumed to increase the climate impact either. The changes in recipes between 2009 and 2016 did not affect to climate impact of RT.

4.2. Eutrophication impact of different scenarios

The eutrophication impact of RT fillet was 40 PO_4-eq/t RT fillet and the part of the fish farming was 93%. The impacts of feed raw material production were 4% and hatcheries 2% (Fig. 2.). The eutrophication impact of $RT_{BSf2009}$ scenario was −47.5 kg PO_4-eq/t for 2009 and −4.9 kg PO_4-eq/t for $RT_{BSf2016}$, so they differed

Table 4
Data sources of sub-processes related to fish farming.

Sub-process	Notes	Data Source
Hatcheries		Personal comment, Puttonen, Taimen Oy., 2011 (fish farming company)
Fish farm nutrient emissions		Statistics of Centre of Economic Development, Transport and the Environment of south-west Finland (Personal comments, Kallioniemi, 2009, 2010)
Fish farming nitrous oxide emissions	1.69 kgN_2O-N/kg fish	Hu et al. (2012)
Data on fuel consumption due to fish farming-related boat traffic		Kankainen et al., 2007, Setälä et al., 2009
Data on electricity consumption due to fish farming-related boat traffic		Kankainen et al., 2007, Setälä et al., 2009
Amounts of different construction materials in fish farming	Life span of materials was assumed to be 20 years	Saari, Oy MG-Trading Ab, personal comment
Inventory data of plastics		The Plastics Europe, 2009
inventory data of other construction materials		Ecoinvent database
Emissions of transports		VTT, 2011
Inventory data for rapeseed and wheat	Yields, fertilizers, lime	Pro Agria database, 2007
Machinery data for field cultivation	Fuel consumption	MTT Agrifood Research Finland based on Grisso et al. (2007).
Processing of rapeseed oil	Economic allocation	Personal comments, Niemelä, 2008, Sundström, 2008, Raisio ltd.

Table 5
Characterisation factors for the emissions to the atmosphere (a) and to waters (w) within the impact categories of climate change and aquatic eutrophication.

Variable	Characterisation factor	
	Aquatic eutrophication (PO_4 eq kg^{-1})	Climate impact (CO_2 eq kg^{-1})
CO_2(a)		1
CH_4(a)		25
N_2O(a)		298
NH_3(a)	0.04	
NO_x(a)	0.015	
N(w)	0.35[a]	
P(w)	1.1[b]	
Source:	Seppälä et al., 2004	Solomon et al., 2001

[a] For total N: equivalency factor 0.42, transport factor 0.92, effect factor 0.9.
[b] For total P: equivalency factor 3.06, transport factor 1.0, effect factor 0.36.

remarkably from RT_{ref}, because more nutrients were removed from Baltic Sea with BH Catch than emitted from fish farming stage.

4.3. Environmental impacts of the captured fish (WF) scenarios compared to RT

The climate impact was 812 kg CO_2-eq/ton BH fillet used directly for human consumption. The average climate impact of captured European whitefish, pike, perch and pikeperch is higher than BH, approximately 2670 kgCO_2-eq/ton fish but lower than RT (Fig. 3).

However, climate impact of Finnish captured fish fillet varies remarkably depending on transport distances, amounts of transported fish, fishing equipment and amounts of catch.

Comparisons between the different fish products shows that fishing of BH and larger captured fish catches decrease nutrients from the Baltic Sea even more (Fig. 4) than in the feed 2016 scenario, where BH is used as raw material for RT production: −52 kg PO_4-eq/t for BH and −60 kg PO_4-eq/t for average larger fish fillet.

5. Discussion

Many arguments support the use of BH as a raw material for RT feed: using BH as raw material for fish meal and fish oil prevents nutrient flows to the Baltic Sea from outside the Baltic Sea area. Secondly, also climate impact is approximately the same as using conventional raw materials. From the national point of view it also improves the economy and employment status of the Finnish archipelago area. BH-based fish meal and fish oil could also become export products for the Finnish fisheries sector.

Further, climate impact and eutrophication impact of caught fish are lower than for farmed fish based on this study. On the other hand the calculation data have very many uncertainties, but the fuel consumption values for net fishing are, however, quite neat the values that Schau et al. (2009) have presented. The value for BH fishing by trawling used in our study was quite the same as the Norwegian pelagic trawl (Schau et al., 2009). The fuel consumption in small-scale fishing has also been found to vary in Finland (Silvenius et al., 2015, Silvenius, 2014).

The climate impact of the RT_{ref} was 4090 kg CO2-eq/t fillet typical for cultivated salmonids, when nitrous oxide emissions of the fish farming stage are not taken into account, so near the values that e.g. Pelletier et al., 2009, Winther et al. (2009), Papatryphon et al. (2003) have presented.

One result of the study was that there has not been found remarkable difference in carbon footprint, when different feed recipes has been used. So the replacement of fish-based raw materials as plant-based raw materials does not impact on climate impact based on this study, but increased use of by-products of fish industry as fishmeal raw materials and cultivation of soya in areas, where land use change causes high climate impact can effect on the results.

One major question in utilizing these results concerns the suitability of LCA to assess regional environmental impacts as eutrophication (Grönroos et al., 2006), which have impact on e.g., fish cultivation production licenses in the Baltic Sea. The reason is that LCA seldom takes into account local circumstances e.g. flow conditions, behaviour of the nutrients in local scale. Further, there is still a substantial need to develop techniques to better understand the behaviour of nutrients associated with fish farming and fish stocks near fish farms.

Levels of fish meal and oil are globally declining in salmonid feeds, which decrease the reached environmental benefits. The amounts of fish-based protein in RT feed are now approximately

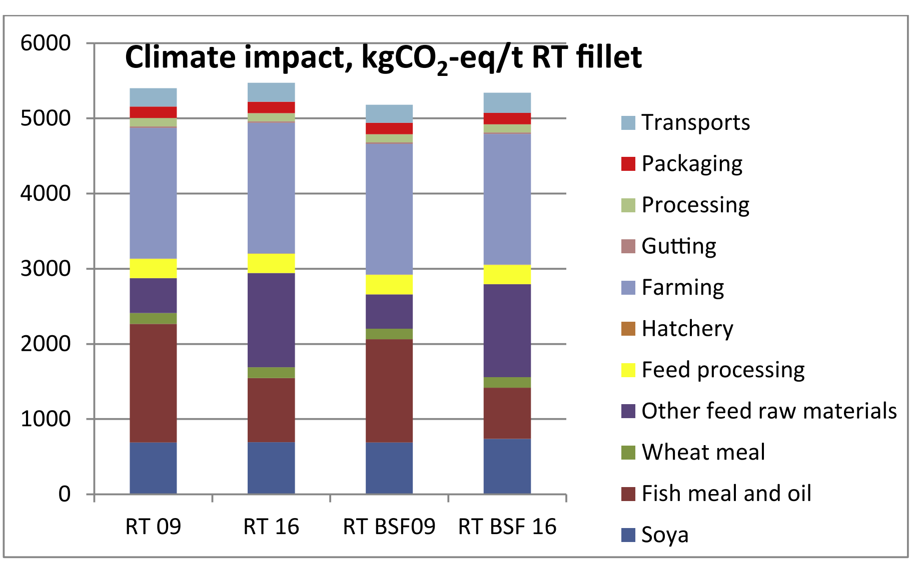

Fig. 1. The climate impact of Rainbow trout fillet divided into product stages, kgCO_2-eq/t fillet.

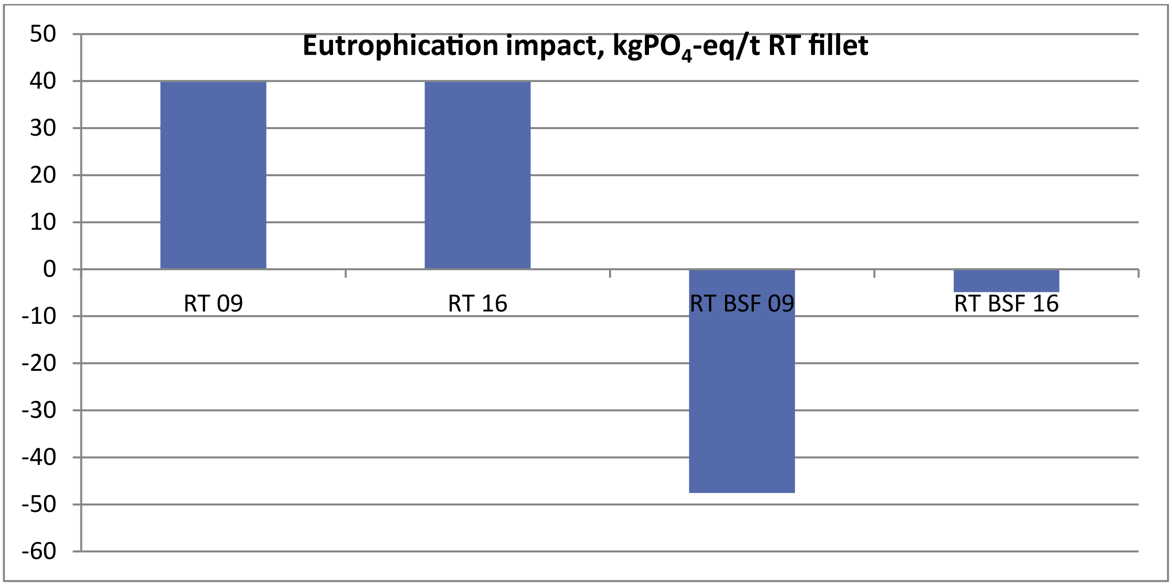

Fig. 2. Eutrophication impacts of Rainbow trout fillet divided into product stages, kgPO_4-eq/ton fillet.

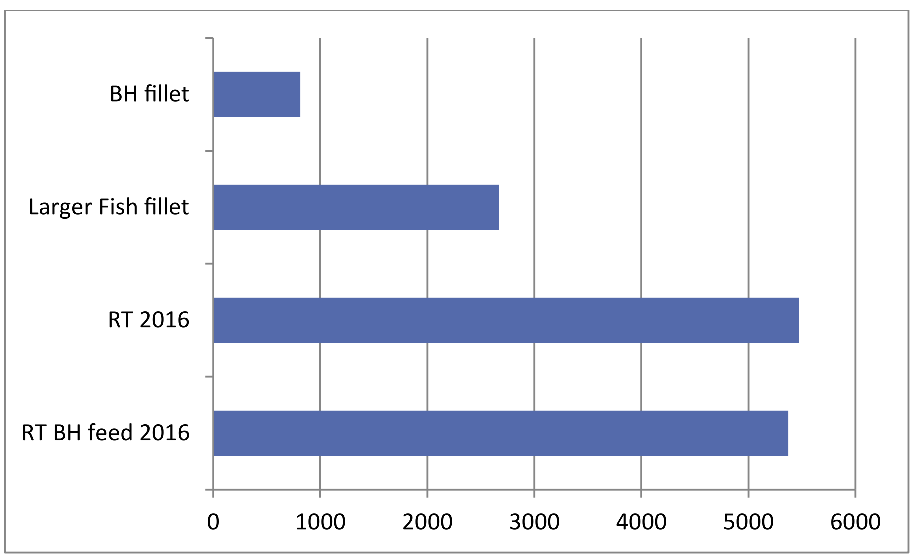

Fig. 3. The climate impacts of different Finnish fish products, kgCO_2-eq/t fillet. The figure for larger fish fillet is an average climate impact of pike, pikeperch, perch and European whitefish fillet.

half of the total protein content of the feed. Therefore, future Baltic Sea-sourced fish feeds would either differentiate from other diets by containing high fish meal and oil levels, causing them likely to be more expensive, or if containing similar levels of fish meal and oil than regular diets on market, be less favourable in terms of net nutrient load than calculated in the present study.

6. Conclusions

Results of the life cycle assessments showed that environmental benefits would occur on the scale of the whole Baltic Sea area if BH would be used as trout feed, because it decreases nutrient flows to the Baltic Sea from outside the area. If Baltic Sea aquaculture were regulated by net nutrient load, use of Baltic Sea-sourced feed ingredients would result in increased RT production. Further, this article founds remarkable environmental benefits for using caught fish instead of cultured fish for human consumption, when both climate and eutrophication impact has been taken into account. This article is not concentrating on local environmental impacts, which has to be taken into account in spatial planning of fish farming. Good regulation would take into account both local ecosystem resiliency and larger scale life cycle effects. The replacement of ocean fish, such as BH as a source of fish meal and oil did not have a remarkable effect on climate impact. For climate impact, this study is different from many other studies because it points out the significance of nitrous oxide from the farming stage into climate impact calculations for aquaculture. In the future, however, more investigation is needed both for modelling climate impact of small-scaled fisheries of lakes and coastal areas, which are typical for Finland, as the assumption of the are based on very

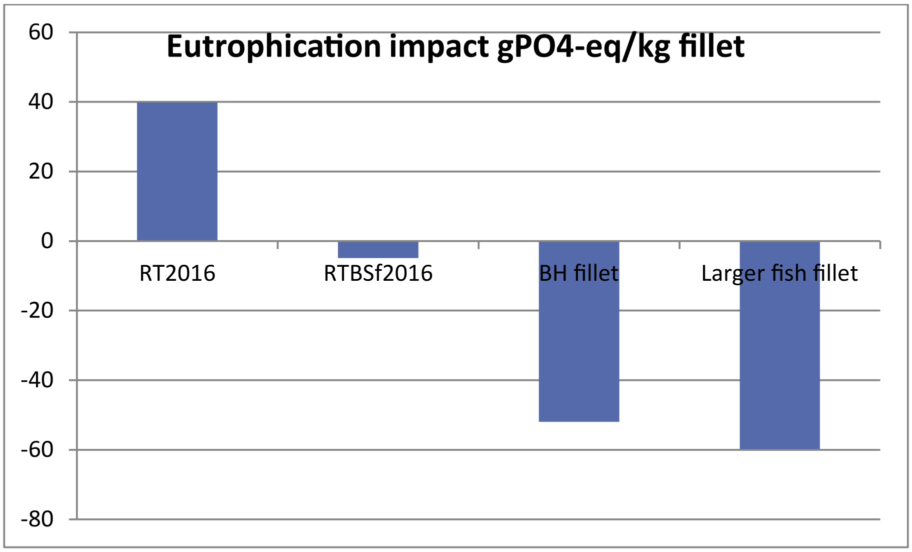

Fig. 4. The eutrophication impacts of different Finnish fish products, kg PO_4-eq/t.

narrow fuel consumption and transportation data. Also additional measurements for nitrous oxide emissions are needed for aquaculture concerning different aquaculture technologies, cultivated species and circumstances, because it is known that existing data does not covering all the alternatives and the emissions are assumed to be very important concerning climate impact of aquaculture products. When talking about environmental impact categories in Finnish case, the eutrophication impact is much more important than climate impact covering 1–2% of the total nutrient loads of Finland, when the part of the climate impact is as low as one per mille of the total greenhouse gas emisions of Finland.

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