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Combined climate and nutritional performance of seafoods

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ABSTRACT

National authorities in many countries advise their populations to eat more seafood, for health and sometimes for environmental purposes, but give little guidance as to what type of seafood should be consumed. The large diversity in species and production methods results in variability both in the nutritional content and in the environmental performance of seafoods. More targeted dietary advice for sustainable seafood consumption requires a better understanding of the relative nutritional benefits against environmental costs of various types of seafood. This study analyzes the combined climate and nutritional performance of seafood commonly consumed in Sweden, originating all over the world. Nutrient density scores, assessed by seven alternative methods, are combined with species- technology- and origin-specific greenhouse gas emission data for 37 types of seafood. An integrated score indicates which seafood products provide the greatest nutritional value at the lowest climate costs and hence should be promoted from this perspective. Results show that seafoods consumed in Sweden differ widely in nutritional value as well as climate impact and that the two measures are not correlated across all species. Dietary changes towards increased consumption of more seafood choices where a correlation exists (e.g. pelagic species like sprat, herring and mackerel) would benefit both health and climate. Seafoods with a higher climate impact in relation to their nutritional value (e.g. shrimp, Pangasius and plaice) should, on the other hand, not be promoted in dietary advice. The effect of individual nutrients and implications of different nutrient density scores is evaluated. This research is a first step towards modelling the joint nutritional and climate benefits of seafood as a concrete baseline for policy-making, e.g. in dietary advice. It should be followed up by modelling other species, including environmental toxins in seafood in the nutrition score, and expanding to cover other environmental aspects.

1. Introduction

Transforming food production and consumption patterns is central for reaching several of the UN Sustainability Development Goals as food is responsible for a significant part of global environmental and human health problems (EEA, 2016; Gordon et al., 2017; Poore and Nemecek, 2018). National authorities in many countries currently recommend increased consumption of seafood due to their beneficial nutritional value and health effects (NCM, 2014;Gonzalez Fischer and Garnett, 2016). Seafood is often promoted as a more sustainable alternatives to red meat, which, for environmental and health reasons, is recommended to be restricted in a sustainable diet (Scarborough et al., 2014; Tilman and Clark, 2014; WCRF/AICR, 2018). Seafood is the most globalized food commodity with diverse production systems involving thousands of species that are fished or farmed and processed into a multitude of products traded and shipped around the globe (FAO, 2018). This diversity leads to high variability both in environmental impacts and in the nutritional value of seafood both between and within species and production methods (Öhrvik et al., 2012; Mungkung et al., 2014; Waite et al., 2014; Troell et al., 2014; Seves et al., 2016; Hilborn et al., 2018; Parker et al., 2018). Hence, identifying the most nutritious and least environmentally impactful seafood options is important to enable a transition

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towards more healthy and sustainable diets.

Dietary advice has, to date, mainly been based on health aspects, but more recently has also incorporated environmental sustainability as an additional dimension (Gonzalez Fischer and Garnett, 2016). Sweden is one of few countries in the world giving dietary advice based on both health and environmental performance (Gonzalez Fischer and Garnett, 2016). Dietary recommendations for improved health and reduced environmental impact are in many ways consistent, e.g. in terms of recommended consumption of vegetables vs. livestock products (Reynolds et al., 2014; Nelson et al., 2016). However, seafood consumption is often perceived as a dilemma due to its complexity and concerns about potential trade-offs between positive health effects and environmental impacts such as ecosystem impacts of fisheries or aquaculture (Mitchell, 2011; NCM, 2014; Farmery et al., 2017). The complexity of seafood, caused by a large diversity in species, production methods, nutritional content as well as the potential risk of negative health effects due to environmental toxins (Persson et al., 2018), makes it difficult to draw general conclusions. The uncertainty and confusion resulting from these complexities hinders consumers and health practitioners in their efforts to understand, identify, and support sustainable seafood consumption (Farmery et al., 2018). To give clearer and more detailed advice on what seafood to eat, beyond “have seafood 2–3 times per week”, it is important to better understand the relative nutritional benefits against environmental costs of various types and sources of seafood.

Further to the confusion it has caused for consumers, the complexity of global seafood production has also led to seafood often being excluded from food system and dietary studies (Meybeck and Gitz, 2017), despite its importance for human nutrition. When seafood is included in diet studies, their environmental impacts are often either poorly differentiated (Tilman and Clark, 2014) or assessed incompletely (Farmery et al., 2017). In parallel to the shortcomings that trouble much of the current research on sustainable and healthy diets, sustainability studies of seafood often lack any consideration of either the nutritional or health aspects of the products being assessed (Pelletier et al., 2009; Driscoll et al., 2015; Hornborg et al., 2018; Ziegler et al., 2018). Indicators for measuring nutritional quality of the outputs of food production, including seafood, were reviewed by Bogard et al. (2018). A few initial attempts to describe the nutritional profile of seafood in combination with sustainability indicators have been made by Avadí and Fréon (2015) and Seves et al. (2016) but when nutritional aspects of seafood products are considered they are typically reduced to coarse indicators such as energy or protein content (Tilman and Clark, 2014; Hilborn et al., 2018; Parker et al., 2018; Poore and Nemecek, 2018). The importance of including a more complete assessment of the nutritional value when analyzing and comparing the environmental performance of food systems has been identified and addressed (Saarinen et al., 2017; Hallström et al., 2018). The failure to consider these issues within seafood sustainability studies, and subsequent analyses that they inform, risks leading consumers, policy-makers and future research in the wrong direction. For example, it could promote the consumption of seafood products that have relatively low environmental impacts but also relatively low nutritional value. Alternatively, higher-impact seafood options could be omitted or removed from recommendations, despite providing comparably high nutritional benefits. In such instances, motivation to implement management and/or technological improvements to mitigate environmental impacts might be undermined if the benefits of doing so are perceived to be minimal.

Here, we assessed the combined climate and nutritional performance of seafood commonly consumed in Sweden. For this purpose, we used existing data on nutritional content and aggregated these data into a nutrient density score. We assessed the sensitivity of nutrition scores to each component and implications of calculating the nutrient density score in different ways. In parallel, we assembled a database of greenhouse gas (GHG) emission data from published life cycle assessment (LCA) studies of seafood systems augmented judiciously with additional data made available from authors. From amongst these, we have selected studies that have employed consistent methodologies and then sought the best possible match between available data on production method and country of origin. A ratio was then calculated between the climate impact and nutrient density score. Results provide important insights to the large differences within the heterogenous seafood group in nutritional values, climate impact and combined climate -nutrition performance.

2. Methods

2.1. Assessment of nutrient density

Several methods for assessing the nutrient density of foods and diets have been suggested (Hallström et al., 2018), but to date none of these methods have been applied to characterise the differences between seafoods and compare them to alternative animal-source foods. These methods were also poorly adapted to capture the nutritional attributes of seafood. Therefore, we calculated the nutrient density of seafoods using a total of seven different nutrient density scores (referred to as NDS-A to NDS-G). We selected one of the seven scores (NDS-C) that best reflected the purpose of the study. All calculations of the seven nutrient density scores and the rationale for choosing to present NDS-C are provided (Tables S7–S12) as a basis for further method development. The most critical methodological choices included:

(i) The selection of nutrients included in the score, i.e. inclusion or exclusion of nutrients not present in seafood or not (e.g. fibre and ascorbic acid) and inclusion or exclusion of anti-nutritional or toxic compounds (e.g. dioxins, methylmercury)
(ii) The design of the algorithm, i.e. whether to calculate the sub-scores for desirable nutritional attributes and non-desirable nutritional attributes as separate mean values or sums, and whether to calculate the score as the difference, or ratio of desirable and non-desirable attributes
(iii) The reference amount, i.e. whether to calculate the nutrient content per unit of mass or calorific energy
(iv) Weighting, i.e. whether all nutrients are weighted equally or adjusted based on their relative abundance or deficiency in the population's diet (measured as the relation between average and recommended intake levels).
(v) Capping, i.e. whether content of desirable nutrients that exceed daily recommended intake levels is credited or not.

The selected nutrient density score was based on the Nutrient Rich Food model (Eq. (1)) (Drewnowski, 2009), which is the most commonly used score in the literature and one of few methods that has been validated against health parameters (Hallström et al., 2018). This score considers the actual content of desirable and non-desirable nutrients per 100 g and relates it to the reference values of nutrients and then weighs them into one index. For the results presented here, no weighting or capping was applied. The motivation for choosing the selected nutrient density score, as well as the resulting nutrient density scores for each of the methods evaluated is presented in supplementary materials (Tables S7–S12).

$$\text{Nutrient density score} = \sum_{i=1}^{x} \frac{Nutrient\ \ i}{DRI\ \ i} - \sum_{j=1}^{y} \frac{Nutrient\ \ j}{MRI\ \ j} \tag{1}$$

where x is the number of desirable nutrients, y is the number of non-desirable nutrients, Nutrient i/j is the content of nutrient i or j per 100 g of uncooked (raw) seafood product, DRI is the Daily Recommended Intake of desirable nutrient i and MRI is the Maximum Recommended Intake of the nutrient to limit intake of j.

The nutrients included were limited to those for which recommended or upper intake levels are specified by the Nordic Nutrition Recommendations (NCM, 2014). Reference values were available for 20 vitamins and minerals and in addition to these we included four energy providing nutrients; carbohydrates, saturated fats, omega-3 fatty acids, and protein. Two of the 24 nutrients included (Table S4), sodium and saturated fatty acids, were categorized as non-desirable nutrients while all others were categorized as desirable nutrients. Toxic compounds such as methyl-mercury and dioxins were not included due to lack of data. Nutrient content data were taken from the food database of the Swedish Food Agency (SFA, 2018a) which includes a total of 145 seafoods, defined by species, mode of preparation and in some cases production method and origin, and refers to the nutrient content of the edible part of the food. Products not meeting our criteria, e.g. regarding product form (cooked or prepared seafood) and relevance (species that are not relevant on the Swedish market), were excluded, leaving 37 seafood products that were analyzed (Table S1). In cases when species-specific nutrient data were missing in the Swedish food database, nutrient data were complemented by data from equivalent food databases provided by other countries (Table S5). The reference values (Table S4) were based on Daily Recommended Intake (DRI) levels of nutrients for desirable nutrients and Maximum Recommended Intake (MRI) levels for non-desirable nutrients according to the Nordic Nutrition Recommendations 2012 (NCM, 2014). The same nutrient density score was also calculated for the most common alternative animal source foods: beef, pig, chicken and eggs (additional information is found in supplementary materials).

2.2. Assessment of climate impact and combined metric

We compiled impact assessement and methodological data from published seafood LCAs that fulfilled certain criteria (e.g. that absolute results could be extracted). The country of origin and mode of production for commonly consumed seafood products in Sweden was determined using statistics on Swedish seafood production and trade (Ziegler and Bergman, 2017). If no more specific information was available, it was assumed that imported seafood originated in the dominant production method in the country of origin (FAO, 2018; Fiskeridirektoratet, 2018; SLU, 2018). Greenhouse gas emission results were then extracted from the compiled studies that were most representative of Swedish consumed seafoods, ensuring to select values from studies employing similar methodologies (Table S2). In some cases, several studies of equal quality were available, in other cases less representative data (either in terms of species and/or production technology and/or country of origin) had to be used.

In cases where LCA studies were not available for the selected species, alternative approaches to estimating GHG emissions were used. If fishery-specific fuel data were available in a global fuel consumption database (Parker and Tyedmers, 2015), GHG estimates were calculated following Parker et al. (2018). In a few cases this was also done to enable translation to a common system boundary.

Only attributional studies using or allowing the use of mass-based allocation between co-products and excluding land use and land use change were used, as these method choices were considered to have the largest influence on results. We did not attempt to fully harmonize GHG results with respect to other method choices (such as version of IPCC characterization factors used or minor changes in system boundaries) which would have been ideal, as this was not considered to be feasible based on the information provided in the studies. The variability and uncertainty in results owing to minor differences between studies is discussed. We compiled data from published LCA studies aligning with a specific product consumed in Sweden in terms of both country of origin and mode of production or data from published LCA studies for a product similar to that consumed in Sweden and in cases when no suitable LCA was available, we estimated GHG emission from fuel use data. We hence identified and assembled three categories of GHG emission data , indicated in Table 1. Results are presented in relative terms and in ranked form.

Values given per unit of live weight were translated to the common basis edible yield using species-specific factors for edible yield (mainly from FAO 1989), allocating all emissions to the edible part, a version of mass-based allocation assuming co-products are not used, which was chosen to obtain reliable relative results between products that took into account the edible yield of the products, rather than exact absolute results. Emission values for alternative animal source foods, used as reference points, refer to Swedish average production methods based on published LCA data (Table S3). More details on the selection and calculation of GHG data are presented in the supplementary material.

For the integrated assessment, the ratio between the climate impact and nutrient density score was calculated by dividing the climate impact per kg seafood by the nutrient density score. The combined score ranks the products according to their climate impact related to their nutrient density and shows which seafoods give the highest nutritional value at the lowest climate impact and vice versa. In order to highlight important issues to consider in addition to climate impact and nutrition, it is indicated which of the 37 species are listed as ‘avoid’ by the Swedish WWF seafood guide (WWF, 2018) e.g. due to overfishing as well as the species for which the Swedish Food Agency recommends limitations in consumption due to content of toxic compounds such as methyl-mercury and dioxins (SFA, 2018a). For species which originate from various sources ranked differently by the WWF (such as cod from different areas and caught by different gears), the colour coding of the dominant source on the Swedish market was used.

3. Results

The relative nutrient density, climate impact and combined climate-nutrient performance of the analyzed seafoods as well as the alternative animal protein sources is illustrated in Table 1 and in Fig. 1.

3.1. Nutrient density of seafood

The products analyzed had markedly different nutrient profiles, even within sub-groups of seafood such as whitefish or closely related species such as cod and whiting. The ranking of the nutrient density of the analyzed seafoods is shown to the left in Table 1 (additional results in Tables S9–S12). Pelagic species like herring and mackerel were among the most nutritious species, but the most nutritious seafood of all was, somewhat surprisingly, oysters. Oysters are particularly high in vitamin B12, zinc, selenium, copper, iron and calcium (100 g of oyster giving 900, 600, 100, 70, 50 and 10% of the daily recommended intake, respectively) while being

Table 1
Orange/pink cells indicate species classified as ‘avoid’ in the Swedish WWF consumer guide (WWF, 2018) due to unsustainable production practices (the dominant source on the Swedish market). Grey cells indicate species for which consumption is recommended to be limited due to potential content of toxic compounds (SFA, 2018a) and/or levels of nutrients exceeding upper daily recommended intake levels (NCM, 2014). Brown cells have both sustainability and health concerns, white cells have neither.

Quintile*	Ranking based on nutrient density**	Ranking based on climate impact	Ranking based on combined climate and nutritional impact
1	Oysters, farmed	Alaskan pollock[3]	European sprat
	European eel	Pink salmon[3]	Atlantic mackerel
	European sprat	European sprat[2]	Atlantic herring (Baltic)
	Lobster	Atlantic herring (Baltic)[1]	Atlantic herring
	Atlantic mackerel	Atlantic herring[1]	Pink salmon
	Atlantic herring (Baltic)	Atlantic mackerel[1]	Alaskan pollock
	Atlantic herring	***Egg***	Perch
	Perch	Whiting[3]	***Egg***
2	Atlantic salmon, farmed	Pike-perch[3]	Roe (from cod)
	Trout, farmed	Hoki[3]	Pike-perch
	Roe (from cod)	Perch[3]	Atlantic salmon, farmed
	Gilt-head seabream, farmed	Cape hake[3]	European eel
	Pike-perch	Turbot[3]	Haddock
	Cephalopods	Roe (from cod)[1]	Atlantic cod
	Whitefish (Coregonus)	Atlantic cod[1]	Saithe
	European seabass, farmed	***Chicken***	Cephalopods
3	Tilapia, farmed	Haddock[1]	Oysters, farmed
	Pink salmon	Pike[3]	Whitefish (Coregonus)
	Haddock	Saithe[1]	Trout, farmed
	Arctic char, farmed	Atlantic salmon, farmed[1]	Whiting
	Rainbow trout, farmed	Cephalopods[3]	Pike
	Saithe	Whitefish (Coregonus)[3]	Turbot
	Norway lobster	Trout, farmed[2]	***Chicken***
	Atlantic halibut	Rainbow trout, farmed[1]	Hoki
4	***Egg***	***Pork***	Rainbow trout, farmed
	Atlantic cod	European eel[3]	Lobster
	Northern prawn	European hake[3]	Cape hake
	Pike	Gilt-head seabream, farmed[2]	Gilt-head seabream, farmed
	Pork	Arctic char, farmed[2]	***Pork***
	Beef	European seabass, farmed[2]	Arctic char, farmed
	Plaice	Tilapia, farmed[1]	European seabass, farmed
	European flounder	Lobster[1]	European hake
5	European hake	Scallops[3]	Tilapia, farmed
	Turbot	Atlantic halibut[3]	Atlantic halibut
	Whiting	Oysters, farmed[2]	European flounder
	Chicken	European flounder[3]	Plaice
	Alaskan pollock	Pangasius, farmed[1]	Scallops
	Hoki	Plaice[3]	***Beef***
	Cape hake	***Beef***	Northern prawn
	Scallops	Northern prawn[1]	Norway lobster
	Pangasius, farmed	Norway lobster[1]	Pangasius, farmed

*Quintile 1 provides results for seafoods with highest nutrient density (NDS-C), lowest climate impact and lowest climate impact per nutrient density.
**Details on nutrient density scores of analyzed seafoods are provided in Supplementary Materials. [1] Climate data based on species specific LCA data for dominating production method and origin, [2] Climate data based on LCA data for similar species, dominating production or origin, [3] Climate data based on species or gear specific fuel consumption data following the method of Parker et al. (2018).

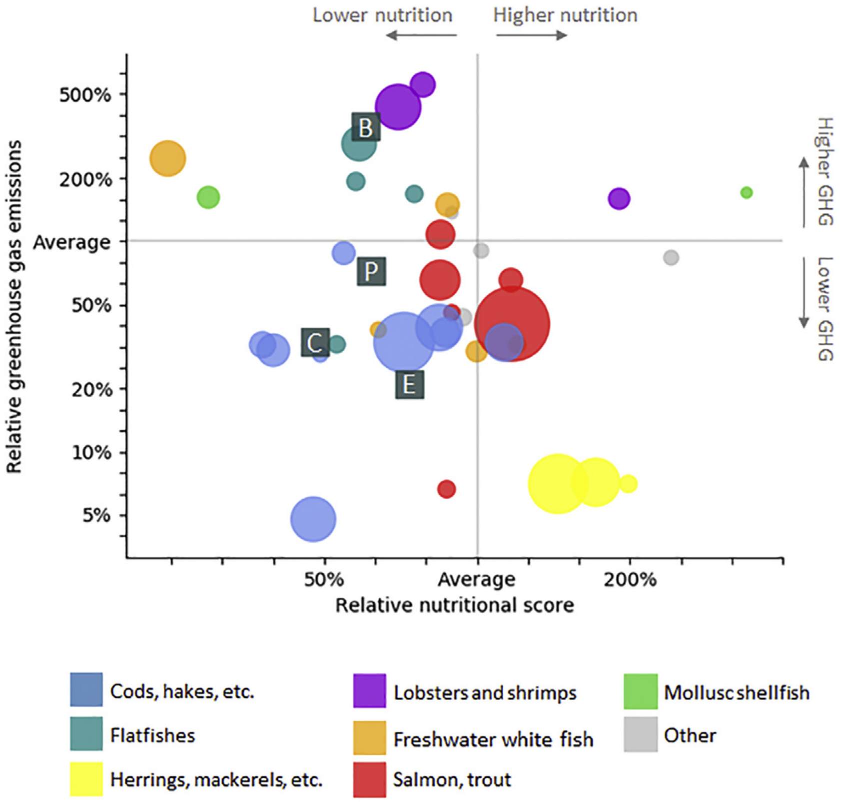

Fig. 1. Combined nutrient density and climate impact of seafoods analyzed. Log transformed data scaled around average representing the median of all seafoods. Bubble size reflects Swedish consumption rates from Ziegler and Bergman (2017) on a continuous scale, i.e. each bubble has its own size. B = beef, P = pork, C = chicken, E = egg.

low in sodium and saturated fat, the non-desirable nutrients. The nutritional values for oysters in the Swedish database were consistent with those provided by FAO (FAO, 2016) and it values for all of the nutrients stated above were high for several oyster species, why we conclude that the results we found for oysters are relevant. Mackerel has the highest content of omega-3 fatty acids (especially high in EPA and DHA), followed by eel (especially high in DPA) and farmed salmon and rainbow trout, which are all close to or over the daily recommended intake per 100 g. It proved difficult to find general patterns to group seafood based on their nutrient density. For example, seafood with both the highest and lowest nutrient density scores are found in the groups finfish, crustaceans and molluscs, fatty and lean species, as well as wild-caught and farmed species. The seafoods with the lowest nutrient densities, including many whitefish species (hake, cape hake, turbot, whiting, hoki, Alaskan pollock and Pangasius), are on the same level as chicken and this result is either attributed to lower content of desirable nutrients or higher content of non-desirable nutrients (e.g. scallop and Pangasius had higher levels of sodium) in relation to other seafoods.

Frequent and/or high consumption of lobster and European eel, two of the species with the highest nutrient density, should be avoided from a health perspective due to the high content of iodine in lobster and vitamin A in European eel. Iodine and vitamin A are desirable nutrients with positive health effects when consumed in moderate levels but can have toxic health effects when upper recommended intake levels are exceeded (NCM, 2014). The potential content of other toxic compounds may also influence the health impact of seafood (Bonito et al., 2016). In Sweden limited consumption of certain types of seafood is recommended in areas with high levels of methyl-mercury and dioxins (e.g. fish from lakes and herring from the Baltic sea) (SFA, 2018a). The species for which restrictions apply are highlighted in Table 1. Ten species (e.g. European eel, whiting and pike) were assessed as species to avoid eating by the Swedish WWF seafood guide (highlighted by colour coding in Table 1), indicating that they are overfished or even depleted (as in the case of eel) or that fishing methods with considerable ecosystem impacts are used.

The influence of individual nutrients on the final nutrient density score varied between seafoods analyzed (Tables S11 and S12). Nutrients with the highest average contribution were, in falling order: vitamin B12, selenium, vitamin D, niacin, phosphorous, iodine and omega-3 fatty acids, with other nutrients having a low impact on the nutrient density score: vitamin C, fibre, folate, calcium, iron, riboflavin, vitamin A and saturated fat contributed on average just 1% or less to the final nutrient density score C (Table S11).

The nutrient density scores and relative ranking of seafoods based on the seven alternative methods evaluated are shown in Tables S9 and S10. Our results show that the relative influence of individual nutrients as well as the final nutritional value of seafoods to some extent varies depending on which nutrient density score is used. Implications and pros and cons of different methodological choices are further discussed in section 3.4 and in supplementary materials.

3.2. *Climate impact of seafood*

Climate impact was available in an LCA representing the source of Swedish consumption for 14 of 37 seafoods, representing 89% of the consumption of those species in 2015. For seven species, results from an LCA of a similar species or type of production was used (representing 1% of consumption) and the remaining 16 species were approximated using species- or gear-specific fuel use estimates, representing 9% of consumption. The variability in species, stocks and production methods is reflected in the range of GHG emissions of seafoods (Table 1, mid-column), with small pelagic species such as herring and mackerel, and Pacific semi-pelagic species such as Alaska pollock and pink salmon among the top performers. Crustaceans , flatfishes, scallops and oysters had the highest climate impact, due to a combination of resource-intensive production technologies (scallop, halibut, shrimp and Norway lobster) and/or low edible yield (scallop and oyster). Within other groups of seafood found in between these two extremes, such as whitefish and salmonids, GHG emissions vary considerably depending on production method (i.e. farming, with various technologies, and fishing, with various fishing methods).

3.3. Combined climate and nutritional impact of seafood

The ranking of analyzed seafoods based on their combined climate and nutritional impact is shown on the right-hand side of Table 1. By combining the two datasets demonstrating GHG emissions per nutrient density of each type of seafood, new patterns emerge, where seafoods can be grouped into four major categories, those that are 1) high in nutrients and low in GHGs, 2) high in nutrients and high in GHGs, 3) low in nutrients and low in GHGs and 4) low in nutrients and high in GHGs (Fig. 1). Dietary advice should particularly focus on promoting the first category. Examples of species with high nutrient density and low climate impact (group 1) include small pelagics (e.g. European sprat, Atlantic herring, Atlantic mackerel) and perch. In contrast, crustaceans, flatfishes, Pangasius, and scallops provide little nutritonal value compared to the climate costs of their production. For some species (e.g. cape hake, Alaska pollock, hoki, whiting), with a low nutrient density and low climate impacts, a conflict exists between climate and nutritional performance. No overall correlation was found between nutrient density and climate impact. Graphs with higher resolution in terms of species (for each seafood category) are shown in the supplementary file (Figs. S1–S8).

Several of the seafoods with high nutrient density and low climate impact are already consumed in relatively high quantities in Sweden (e.g. herring, mackerel and salmon). For other species, such as European sprat and perch, current levels of consumption are low and could be increased. More sustainable seafood choices could also be achieved by reducing the intake of seafood with low nutrient density and high climate impact. Shrimp (northern prawn), Pangasius and plaice are examples of such seafoods which are consumed in high quantities in Sweden. For species with a high nutrient density, and high impact, it is important to focus on reducing climate impact, but it is also important to note that a smaller amount of these species can fulfil the same nutritional needs as a larger portion of a less nutritious seafood.

3.4. Impact of different ways to calculate the nutrient density score

The nutritional value of seafoods as well as the relative importance of individual nutrients varied depending on the nutrient density score used (Tables S9 and S10). However, the choice of nutrient density score generally did not alter the ranking of seafoods with highest and lowest scores. An exception was when the nutritional content was related to the energy content of the product rather than mass (NDS-E). With this approach the nutrient density score of lean seafood was increased (e.g. cephalopods, haddock, saithe) whereas several fatty fishes, often recommended from a health perspective due to their content of omega-3 fatty acids, were ranked lower due to their high energy content. While this approach can be motivated to account for portion size when comparing foods and to restrict total energy intake (Hallström et al., 2018), we find it inappropriate for seafood due to the positive health effects associated with fatty fish and secondly because portion sizes of seafood generally do not differ between fatty and lean fish. The design of algorithm also had a large impact on the nutrient density score, and especially affected the relative influence of desirable and non-desirable nutrients on the final score. Non-desirable nutrients had a larger influence on the score if sub-scores for desirable and non-desirable nutrients were calculated as mean values (NDS-A, NDS-B) compared to as sums, and if the score was calculated as the ratio (NDS-D) instead as the difference between desirable and non-desirable nutrients. The ranking of seafoods containing higher levels of sodium (e.g. roe from cod, Northern prawn) and saturated fat (e.g. European eel, Atlantic mackerel) was highly affected by the design of algorithm. The choice of nutrient density score also depends on its practical features and thereby usefulness. Two of the methods evaluated (NDS-A and NDS-B) resulted in negative nutrient density scores which can be challenging to interpret and use in further calculations, especially when combined with environmental LCA data (Hallström et al., 2018; Saarinen et al., 2017).

Weighting (NDS-F) is an interesting and useful option for adjusting the nutrient density score to the nutritional status of the studied population. In a Swedish perspective, this means that nutrients lacking in the diet (e.g. vit. D, selenium, iron) will have a larger influence on the final score compared to nutrients for which requirements are fulfilled or exceeded. Which nutrients are critical varies considerably both between different parts of the world (e.g. high- and low-income countries) and between groups in the population (e.g. due to gender and age). Whether to use weighting or not thus depends on the specific scope of the study and whether results should be generalizable or specific for a certain region or population.

Capping (NDS-G) is another noteworthy option for avoiding crediting overconsumption of nutrients. High intake levels of nutrients do not always provide additional benefits for health and can even be harmful, e.g. high intake of vitamin A and iodine. To calculate nutritional content levels exceeding DRI as 100% of DRI is a way to account for these aspects. Capping is further advocated to avoid extreme values for a single nutrient from influencing the total score and thereby disproportionally compensate for low intake levels of other nutrients (Vieux et al., 2013). Indeed, the content of single nutrients accounted for more than half of the total effect on the final score for some seafoods. This was the case for vitamin B12 in Atlantic herring from the Baltic sea (analyzed by NDS-C), where the influence was reduced from 53 to 19% when capping was applied (Table S12). However, the use of capping is motivated especially for nutrients which cannot be stored in the body and are not lacking in the overall diet. The effect of capping on nutrients generally lacking in the diet, and which are eaten in high amount at rare occasions (e.g. vitamin D) needs to be further analyzed.

4. Discussion

4.1. Nutritional and climate performance of seafoods

This study aimed to give new insights on how to guide towards a more sustainable seafood consumption in Sweden by combining climate impact and health aspects, thus motivating the inclusion of as many species important for Swedish consumption as possible. We have identified a number of species with high nutrient density and/or low climate impact which could consequently be promoted for increased consumption in dietary advice. Pelagic fish like sprat, herring and mackerel are top performers and as long as not contaminated with environmental toxins or overfished, they are highly nutritious and sustainable animal source foods, the latter of which was also concluded by Hilborn et al. (2018). Oysters, eel, and lobster were somewhat higher in climate impact, but had the highest nutrition scores of all seafoods included. However, of these species, only oysters can be consumed without limitations as the other species contain nutrients with toxic effects at high intake levels (SFA, 2018b). Eel is also a highly depleted species globally (WWF, 2018). Despite the fact that the nutritional quality of farmed seafood an potentially be affected by feed composition, there were no consistent differences between farmed and fished seafoods neither in terms of nutrient density, climate impact or the combined metric, thus, both types of production span the entire range of the list. Species that could be promoted more based on our findings are European sprat, mackerel, herring and perch (the latter if caught in uncontaminated waters). The long-distance imported Pacific species pink salmon and Alaska pollock had a lower nutritional density, but still ranked high due to very low climate impact. The species that are consumed most in Sweden today, Norwegian farmed salmon and wild-caught cod, are intermediate in terms of both nutrient density and climate impact. Crustaceans, flatfishes and farmed whitefish (Tilapia and Pangasius) should not be promoted for consumption by dietary advice since they have a relatively high climate impact in combination with a low nutritional value. It is important to note though, that only one value per species and nutrient is presented in the Swedish database and we do not know if there is a difference between e.g. Tilapia farmed in different locations, fed different feeds, grown to different sizes etc. Due to the large range in nutrient density, a small amount of one of the more nutritious seafoods could give the same nutritional benefits as a larger quantity of the less nutritious seafoods, an aspect that could be taken into account in dietary advice.

While the climate impact can change, e.g. be reduced through management and technological improvement (Parker et al., 2017; Ziegler and Hornborg, 2014), and lead to changes in the ranking, the nutrient content, although variable over season and geography, cannot be regulated in the same way for wild fish. The nutritional composition of farmed fish can, as indicated earlier, to some extent be influenced through the feed. It is crucial to have access to complete and representative data on the nutrient content of all seafoods on the market to be able to do this type of assessment. Clearly, improvement efforts to reduce the climate impact of seafoods from both fisheries and aquaculture will be most beneficial if spent on the most nutritious forms of seafood.

4.2. Seafood in relation to other animal source foods

This study focuses on the comparison between different seafoods. However, to put our results in perspective Table 1 and Fig. 1 also provide reference points for beef, pork, chicken and eggs (Table 1, Fig. 1). Compared to most of the seafoods analyzed, the land-based animal source foods have lower nutrient density scores. In fact, there are 21 species of seafood that have a higher nutritional density per climate impact than beef, pork and chicken.

The relative influence of individual nutrients also varies between the food groups, with vitamin D, iodine, selenium, omega-3 fatty acids, sodium and copper having a larger impact on the nutrient density score for seafoods, whereas niacin, riboflavin, iron and saturated fat generally are more important for beef, pork, chicken and eggs. The finding that the importance of individual nutrients for the nutrient density scores varied between seafood and land-based animal source products is noteworthy, especially considering that most studies that have analyzed the nutrient density of foods (including both seafood and land-based animal products) did not include several nutrients of special importance for seafood (vitamin D, iodine, selenium, omega-3 fatty acids, copper) in their assessment (Hallström et al., 2018). The selection of nutrients in previous assessments thereby seem poorly adapted to reflect the nutritional quality of seafood which may implicate an underestimation of its nutritional value. From a climate perspective, eggs and chicken are placed in the first and second quintile, respectively, indicating that their emissions are comparable to the 15 seafoods analyzed with lowest GHG emissions. The higher GHG emissions for pork and especially beef, makes most seafoods preferable from a climate perspective. Our results are consistent with other studies comparing GHG emissions of animal-based foods (Hilborn et al., 2018; Poore and Nemecek, 2018; Tilman and Clark, 2014).

4.3. Uncertainty and reliability

Compiling data from diverse LCA studies to make broad comparisons presents a challenge in resolving the effects of different methodological choices such as co-product allocation and study scope (Hallström et al., 2015). Here, we used GHG data from studies that were broadly similar with respect to major methodological choices and from which emissions could be extracted or calculated per edible part of a seafood product at farmgate or landing. When data were not available, LCA input data (fuel) were transformed to GHG emissions. Hence, data gaps resulted in variation in data source types and quality of matching (the three levels of data quality are indicated in Table S2). Using fuel-based estimations of GHGs excluded uncertainty in some cases as it allowed us to calculate GHGs related to a common functional unit; however, using a general equation to transform fuel consumption to GHG emissions obviously adds other uncertainties. In addition, there is uncertainty related to the fuel data itself and what it represents. Consistently selecting LCA input data instead of characterized results would further limit uncertainty from variance between studies, but would also limit the number of species included (because life cycle inventory data is less frequently available) and would be a more time-consuming process. It is difficult to estimate the magnitude of these aggregate uncertainties, but it is important to recall that our aim was not generating absolute GHG results, but a robust ranking of seafoods, which is also why we present results in quintiles and relative to the average in Fig. 1.

The reliability of nutrient density scores is largely dependent on the quality of underlying nutrition data, which may vary by both age and methods used (Johansson, 2018). The age of nutrition data used in this paper varied, with 70% of the data generated between 2004 and 2015 and 30% are older than 1989. It has also been found that nutritional content of seafood varies considerably between different databases (Johansson, 2018).

4.4. Policy implications

Despite the lack of data and uncertainties described above-what have we learned and how can the results of this study be used? We found vast differences in both dimensions studied (nutrition and greenhouse gas emissions) as well as in the combined metric. The species in the lower right square of Fig. 1 are the best-performers from both perspectives that should be promoted through e.g. dietary advice. This could be done directly by stating them as examples of seafood that you can eat more of. The large differences in nutritional content can be implemented in dietary advice in different ways. Firstly, high content of specific desirable nutrients in a species can be communicated directly (“eat cod if you need iodine” or “have oysters if you need zinc”) as the position of the Swedish Food agency is that it is better to get your nutrients through food than supplements. Secondly, the suggested quantities could be directly related to their nutrient density, i.e. less of more nutrient-dense seafoods may be sufficient, while more is needed of less nutrient-dense ones to provide the nutrient benefits expected from seafood intake. The concept of relating consumption advice to nutritional desity is an interesting aspect that could be taken all the way to fisheries management, prioritizing more nutritious species over less nutritious ones. The nutritional benefits generated by fisheries have been more in focus in regions more dependent on seafood as a protein source, and it has been suggested that fisheries policy should become “nutrient-sensitive” (Golden et al., 2016).

4.5. Future research needs

In this study, the selection of seafoods is limited to species consumed in Sweden, which to a large extent also reflects European consumption. Several important species from a global perspective are missing, such as tuna, mussels, farmed shrimp and sardines. Consideration of more seafoods, including regionally consumed species and novel emerging production methods may bring additional interesting findings on the relative sustainability of seafood choices.

As previously mentioned, increased availability of high-quality data on nutritional content of seafoods as well as corresponding life cycle inventory data for those same products would be highly valuable. In addition to more complete data, there is a need to include additional important sustainability aspects of seafood such as stock exploitation and ecosystem impacts for fished seafood and eutrophication and biological risks connected to farmed seafood, including its role in the spreading of antimicrobial resistance (Henriksson et al., 2017). It is also important to further develop methods for calculation of the nutrient density of seafood and its importance from a whole diet perspective. Methods using additional health and quality indicators besides the nutritional content of food, that can capture e.g. the role of functional foods, genetic influences on food characteristics and consumers quality perceptions, are another area that requires further research efforts.

The environmental assessment of this study is limited to GHG emissions, complemented by the perspective of overfishing and ecosystem impacts according to the WWF. Although GHG emissions may serve as in indicator for additional environmental aspects for certain food groups (Kalbar et al., 2017; Röös et al., 2013), in particular for seafood (Ziegler et al., 2016), previous studies have shown that the relative ranking of different foods can vary greatly depending on the environmental issue or sustainability indicator considered (Hilborn et al., 2018; Poore and Nemecek, 2018; Jennings et al., 2016; Avadí and Fréon, 2015; Mungkung et al., 2014; Waite et al., 2014). Guidance for sustainable seafood consumption thus requires consideration of additional sustainability aspects, including both environmental, health and social dimensions.

A possibility to further improve the ability of nutrient density scores to measure dietary quality of seafood and predicting health impacts would be to include potential toxic compounds (e.g. methyl-mercury, dioxin) as non-desirable nutrients. Lacking availability of representative data as well as regional differences complicates the inclusion of toxic compounds in nutrient density scores, which is why we didn't include this aspect here (other than indicated in a simplified way in Table 1) or in previous analyses (Avadí and Fréon, 2015). Nutritional assessments lacking this perspective are inadequate and can at worst be misleading; hence it is important to analyze how data and methods can be further developed to allow for such assessments.

Further efforts are required to develop methods and indicators measuring the dietary quality of foods, as well as approaches to combine environmental and nutritional assessments. Dilemmas previously identified (Nicklas et al., 2014), that need to be analyzed further include how to value the nutritional quality of foods containing both desirable and non-desirable nutrients as well as foods containing high amounts of few nutrients in relation to moderate amounts of several nutrients. The selection of nutrients and design of algorithms most appropriate for assessments of the dietary quality within specific food groups and as well as in comparisons between food groups needs further exploration and should preferably be validated against reported health and disease outcomes.

5. Conclusions

While there are still important gaps in terms of coverage of seafood LCAs of global seafood production systems, this research is a first step towards modelling the joint nutritional and environmental benefits of seafood as a concrete baseline for policy-making, e.g. in dietary advice. Results can also be used in dietary or meal studies where seafood is one of many components, in certification, and to aid consumers, food industry and decision makers in supporting seafoods that benefit both environment and human health. The main findings of the study can be summarized:

- Seafoods consumed in Sweden differ widely in nutritional value and climate impact
- Seafoods with the lowest climate impact and highest nutritional score (e.g. sprat, herring, mackerel and perch) should be promoted in dietary advice from these two dimensions
- Northern prawn, Pangasius and plaice are examples of seafoods with low nutrient density and high climate impact, and should not be promoted in dietary advice
- Most seafoods had a higher nutrient density than beef, pork and chicken
- Most seafoods scored higher in the combined nutrient-climate metric meaning that they are more valuable as foods and give rise to lower emissions than land-based animal source foods
- Nutrients with highest impact on the nutrient density of seafood were, in falling order, vitamin B12, selenium, vitamin D, niacin eq., phosphorous, iodine and omega-3 fatty acids and these nutrients should be included to accurately reflect the nutritional value of seafoods
- This type of assessment depends on the availability of high-quality representative data regarding nutrient content and climate impact of all seafoods sold and consumed on the market analyzed
- To be able to fully incorporate these results into dietary advice, additional aspects such as other sustainability aspects (e.g. stock exploitation, eutrophication, biological risks, spread of antimicrobial resistance) and toxicity (e.g. methyl-mercury and dioxins) should be integrated into the metric

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2019.04.229.

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