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Assessing the inclusion of seafood in the sustainable diet literature

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Abstract

The literature on sustainable diets is broad in its scope, and application yet is consistently supportive of a move away from animal-based diets towards more plant-based diets. The positioning of seafood within the sustainable diet literature is less clear. A literature review was conducted to examine how the environmental impacts of seafood consumption are assessed and what conclusions are being drawn about the inclusion of seafood in a sustainable diet. Seafood is an essential part of the global food system but is not adequately addressed in most of the sustainable diet literature. Aquaculture, the world's fastest growing food sector, was considered by very few papers. Seafood consumption was commonly presented as a dilemma due to the perceived trade-offs between positive health outcomes from eating seafood and concerns of overfishing. A number of studies included seafood as part of their sustainable diet scenario, or as part of a diet that had lower impacts than current consumption. Most of the indicators used were biophysical, with a strong focus on greenhouse gas emissions, and very few studies addressed biological or ecological impacts. The assessment of seafood was limited in many studies due to relevant data sets not being incorporated into the models used. Where they were used, data sources and methodological choices were often not stated thereby limiting the transparency of many studies. Both farmed and wild-capture production methods need to be integrated into research on the impacts of diets and future food scenarios to better understand and promote the benefits of sustainable diets.

KEYWORDS
aquaculture, food, greenhouse gas emissions, life cycle assessment, nutrition, wild-capture

1 | INTRODUCTION

The global food system is a major contributor to global environmental change, driven by demand for food from an increasingly larger and wealthier population (Godfray et al., 2010; Tilman et al., 2001). Concern over the environmental impacts of food production, and recognition of the need for more sustainable food systems (HLPE, 2014a, International Panel of Experts on Sustainable Food Systems,

Ghoti papers
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Etymology of Ghoti
George Bernard Shaw (1856–1950), polymath, playwright, Nobel prize winner, and the most prolific letter writer in history, was an advocate of English spelling reform. He was reportedly fond of pointing out its absurdities by proving that "fish" could be spelt "ghoti." That is: "gh" as in "rough,""o" as in "women" and "ti" as in palatial.

2015), has driven efforts to measure and compare product environmental footprints to identify opportunities for improvement. Life cycle assessment (LCA) has been widely used to assess the environmental performance of food to better understand a range of environmental impacts generated from the production and supply of food products (Curran, 2012; Notarnicola et al., 2017). Given that food consumption patterns are a result of both supply- and demand-side factors, a consumption-oriented approach to LCA has emerged, which can complement LCAs of specific products to help understand the environmental implications (Heller, Keoleian, & Willett, 2013) and nutritional impacts (Stylianou et al., 2016) of dietary choices. Results from LCAs of specific food products are commonly combined to determine the impacts of whole diets and help promote sustainable patterns of consumption (Girod, van Vuuren, & Hertwich, 2014; Hertwich, 2005).

Consideration of environmental impacts in food and nutrition policy is important (FAO, 2010a; Joseph & Clancy, 2015, Pray, 2014), and environmental sustainability guidelines have been integrated into the national dietary advice of some countries, including several European countries (German Council for Sustainable Development, 2013, Health Council of the Netherlands, 2011, Nordic Council of Ministers, 2012), Brazil (Ministry of Health of Brazil, 2014) and Qatar (Seed, 2015). The process of integrating health and sustainability outcomes in dietary advice in other countries, however, has been less successful. The Dietary Guidelines Advisory Committee in the USA recommended that sustainability be taken into account when determining the government's dietary advice (Dietary Guideline Advisory Committee, 2015). However, this advice met with opposition (Merrigan et al., 2015) and sustainability was not included in the final 2015 Dietary Guidelines for Americans. In Australia, the inclusion of criteria for environmental sustainability in the Australian Dietary Guidelines 2013 met with criticism (NHMRC, 2013b) and a section on food, nutrition and environmental sustainability was appended to the final publication (NHMRC, 2013a).

Research on "sustainable diets" and how modifying consumption patterns can mitigate environmental impacts at both the individual and food system levels has increased dramatically in the past decade (Auestad & Fulgoni, 2015; Heller et al., 2013; Jones et al., 2016; Merrigan et al., 2015; Tilman & Clark, 2014). The FAO defines sustainable diets as those with "low environmental impacts which contribute to food and nutrition security and to healthy life for present and future generations. Sustainable diets are protective and respectful of biodiversity and ecosystems, culturally acceptable, accessible, economically fair and affordable; nutritionally adequate, safe and healthy; while optimising natural and human resources" (FAO, 2010b). A sustainable diet consists of several interconnecting components, which have been outlined through a number of conceptual frameworks (FAO, 2010b, Johnston, Fanzo, & Cogill, 2014; Jones et al., 2016). Food systems are complex social–ecological systems (Prosperi, Allen, Cogill, Padilla, & Peri, 2016; Tendall et al., 2015), and a simplified summary of these components is presented in Figure 1. Due to the broad yet interconnected nature of sustainability and human diets, research in this field has evolved along multiple disciplinary lines and is difficult to assimilate due to the disparate frameworks and approaches used (Auestad & Fulgoni, 2015). Despite this disparateness, the sustainable

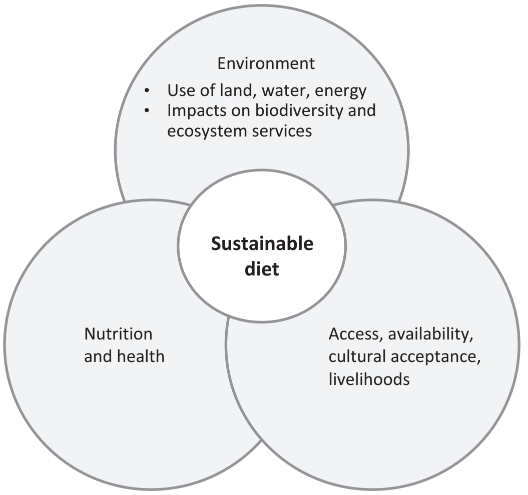

FIGURE 1 Interconnecting components of a sustainable diet showing key elements of environmental sustainability

diet literature is consistently described as being supportive of a need to move away from animal-based diets towards more plant-based diets (Auestad & Fulgoni, 2015; Erb et al., 2016; Hallström, Carlsson-Kanyama, & Börjesson, 2015; Heller et al., 2013; Meier & Christen, 2013). Animal agriculture typically compares unfavourably to plant-based foods due to the additional requirement of converting feed into meat. The feed conversion ratio (FCR), a measure of the quantity of feed required per unit of livestock or aquaculture production, varies substantially between animals. Measures of FCR generally demonstrate that species produced through aquaculture are more efficient converters of feed into animal tissue than poultry, pigs and cows (Forster & Hardy, 2001), although some deficiencies have been noted in this measure of efficiency (New & Wijkstrom, 1990).

Seafood (fish and invertebrates from wild-capture fisheries and aquaculture) is an important part of the food system, supplying up to 20% of animal protein intake for more than 2.9 billion people and providing a crucial nutritional component of diets in some densely populated countries where total protein intake levels may be low (FAO, 2014). Seafood is also a source of essential micronutrients, including vitamins D, A and B, minerals (calcium, phosphorus, iodine, zinc, iron and selenium), especially from many small fish species that are consumed whole (HLPE, 2014b). Interest in seafood as a source of nutrition historically has focussed on fish oils, as fish are the only major source of the very long-chain polyunsaturated fatty acids, eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA; Lund, 2013), commonly referred to as marine Omega-3 fatty acids. Consumption of marine Omega-3 has been linked to protection from heart disease (Lee, O'Keefe, Lavie, & Harris, 2009; Nichols, Petrie, & Singh, 2010); however, the same health benefits have not been linked to Omega-3 supplements (Nestel et al., 2015).

Growth in seafood production currently outpaces population growth (FAO, 2014), with an increasing share sourced from aquaculture, which has been the world's fastest growing food production sector for more than four decades (Tveteras et al., 2012). Aquaculture expanded at an average annual rate of 7.8% between 1990 and 2010, greatly exceeding the rate of poultry, pork, dairy, beef and grains over the same period (Troell et al., 2014). Global consumption of seafood is approximately 19.2 kg per person, although this amount varies substantially between countries (Smith et al., 2010) and is generally lower than the amount recommended by national dietary guidelines for positive health outcomes (Christenson, O'Kane, Farmery, & McManus, in press).

While seafood consumption is promoted as part of a healthy diet (Gerber, Karimi, & Fitzgerald, 2012, HLPE, 2014b; van Dooren, Marinussen, Blonk, Aiking, & Vellinga, 2014), and it is argued that seafood can continue to make a positive contribution to the food system (Béné et al., 2015; Frid & Paramor, 2012; Garcia & Rosenberg, 2010; Olson, Clay, & Pinto da Silva, 2014; Troell et al., 2014), the role of seafood in a sustainable diet is less clear. Seafood is regularly excluded from debate on food security (Béné et al., 2015; Thilsted et al., 2016) and food systems research (see, e.g., Allen & Prosperi, 2016; Erb et al., 2016; Head et al., 2014; International Panel of Experts on Sustainable Food Systems, 2015; McKenzie & Williams, 2015; O'Riordan & Stoll-Kleemann, 2015, Reisch, Eberle, & Lorek, 2013), despite its substantial contribution to global diets and potential for future growth. This exclusion may reflect the challenge of comparing a traditionally wild food source with agriculture, and the great variance between marine and terrestrial environments, which has resulted in studies on the ecology of these systems developing as largely separate intellectual endeavours (Webb, 2012). Concerns over pressure on wild fish stocks have fuelled claims that seafood consumption is not sustainable (Brunner, Jones, Friel, & Bartley, 2009; Clonan, Holdsworth, Swift, Leibovici, & Wilson, 2012; Greene, Ashburn, Razzouk, & Smith, 2013; Jenkins et al., 2009; Selvey & Carey, 2013; Thurstan & Roberts, 2014) and dietary recommendations for fish intake have been described as the most widely recognized conflict between health and environmental sustainability (Macdiarmid, 2013).

In view of the perceived conflict between consuming seafood for positive health outcomes and concerns of overfishing, and given the historical exclusion of fisheries and aquaculture from food system discourse, the published literature on sustainable diets is examined here to determine how seafood is incorporated and assessed. Previous reviews of the sustainable diet literature have examined environmental impacts of dietary change (Auestad & Fulgoni, 2015; Hallström et al., 2015; Reynolds, Buckley, Weinstein, & Boland, 2014), and the measurement of sustainable diets (Heller et al., 2013; Jones et al., 2016), although none have specifically reviewed the role of seafood. This study provides a systematic review of studies that assess the environmental impact of dietary scenarios that include seafood. The objectives are to (i) examine how seafood is addressed within the sustainable diet literature, in terms of what types of seafood and production methods are included and what impacts are addressed and (ii) summarize the conclusions on the role of seafood in a sustainable diet more broadly. The findings from the sustainable diet literature review are discussed in relation to contemporary research on seafood sustainability and the barriers to, and options for, more adequate inclusion of seafood within research on sustainable diets are proposed, as well as opportunities for increased sustainable seafood production.

2 | METHODS

Peer-reviewed published articles included in this review were identified in March 2016 through conventional keyword searching strategies using Scopus, Web of science and Google Scholar. The search term "sustainable diet$" was used to identify studies published in the past 10 years (2010–2016). We also identified studies through examination of the references in review articles on sustainable diets (Auestad & Fulgoni, 2015; Hallström et al., 2015; Heller et al., 2013; Jones et al., 2016; Reynolds et al., 2014) to capture those studies that may have been missed through use of a single search term. A total of 878 studies were identified in the first stage of the review. The studies were searched for mention of seafood, fish, shellfish or aquatic products in the context of a sustainable diet in any part of the publication. Of the studies that contained these key words (n = 504), most (>75%) were excluded as they did not include seafood as an identifiable part of either an actual or modelled diet, for example where seafood was included as part of a "meat" category, or only made reference to seafood or fish briefly in the text. Studies were also excluded if they were not related to human diets, for example those relating to sustainable diets for aquaculture species or if they were not published in English in peer-reviewed journals.

3 | RESULTS

Forty-seven publications were identified for inclusion in this review (Supplementary information, Tables S1–S3). Publications that met the requirements for inclusion were either quantitative assessments of diets and products (n = 32), review articles (n = 3) or qualitative discussion papers (n = 12). The three review articles identified opportunities and limitations relating to the use of LCA in assessing sustainable diets (Auestad & Fulgoni, 2015; Hallström et al., 2015; Jones et al., 2016); therefore, these issues are not examined in detail here. However, some fishery and aquaculture specific LCA issues are discussed below.

The focus of this review is on the methods, results and conclusions relating to environmental impacts of diets. The results are presented as follows: brief overview of the methods used in the studies of modelled or actual diets; general results of quantitative studies comparing diets; results relating to individual impacts assessed (estimated greenhouse gas emissions [GHGe], energy use, fresh water, eutrophication, land use and biological impacts); and general conclusions drawn in the literature from both the quantitative assessments and qualitative discussion papers.

3.1 | Methods used in quantitative studies comparing products or diets

Of the 32 studies that included a quantitative assessment of products or diets, 22 were based on process LCAs. In these studies, the potential environmental impacts of producing food products was modelled directly or sourced from published literature. The impacts of individual food items were then aggregated to reflect consumption patterns at the diet or adult meal level. Another of the studies that included modelled or actual diets used the ecological footprint (EF) method where a composite indicator is employed to measure the anthropogenic impact by considering the different ways in which environmental resources are used (Ruini et al., 2015). EF is measured in terms of global hectares or square metres and is calculated as the sum of all the cropland, grazing land, forest and fishing grounds required to: produce the food and energy required for human activities; absorb all wastes emitted; and provide sufficient space for infrastructure. The authors justified the use of the EF method based on the unit of measure being easier to visualize and understand compared with other indicators, and the methods' ability to consider several environmental impacts simultaneously.

Three further studies used economic input–output analysis as an alternative to process-based LCAs. Hendrie, Ridoutt, Wiedmann, and Noakes (2014) GHGe for the average Australian adult diet and alternative dietary scenarios using an environmentally extended input–output model of the Australian economy. This method was deemed appropriate by the authors because of the national scale of the study and its focus upon food categories rather than individual food products. Tukker et al. (2011) estimated the difference in impacts between the European *status quo* and three simulated diet baskets using an environmentally extended input–output database, and Weber and Matthews (2008) used input–output LCA to analyse all relevant emissions of greenhouse gases in the supply chains of food products. The advantages for such an analysis included its ability to handle large bundles of goods, as well as reducing cut-off error, whereby the emissions from processes that are believed to contribute little to the total are excluded, which is considered to be one of the major drawbacks of process-based LCA (Williams, Weber, & Hawkins, 2009). Another challenge of using LCA to compare different products or diets is the influence of methodological choices on results. Differences in choice of functional unit, system boundaries, impact assessment methods and choice of allocation factors can all influence results and should be clarified within the study (Henriksson, Guinée, Kleijn, & Snoo, 2012). These issues are discussed in more detail in several sustainable diet review papers (Auestad & Fulgoni, 2015; Hallström et al., 2015; Jones et al., 2016).

3.2 | Results of quantitative studies comparing actual and modelled diets

Over half the studies (n = 26) assessed seafood as part of an actual or modelled diet (Table S1), and a further six made product-based assessments set in a dietary context (Table S2) and are discussed under specific impacts below. In a number of the quantitative assessments of actual or modelled diets, seafood formed part of the more sustainable diets, or diets with lower environmental impacts than the average diet (Table 1). Diets consisting primarily of seafood and vegetal foods minimized environmental impacts (Gephart et al., 2016), and seafood- and vegetable-rich diets had optimal synergy between health and sustainability (van Dooren et al., 2014). Shifting towards a Mediterranean-type or other more plant-based diets such as pescatarian diets (a diet that includes only vegetables and seafood) had favourable impacts on the environment and health (Table 1).

Several studies did not include fish as part of their more sustainable diet scenarios, but most of these diets reportedly did not meet national dietary guidelines (Table 1). Donati et al. (2016) suggested the complete substitution of meat and fish with vegetal proteins in their dietary model to constitute an affordable and environmentally sustainable diet for young adults, although they noted that from a nutritional point of view this recommendation may not be adequate and a detailed assessment of micronutrients would be required. Similarly, an "optimized diet" which reduced the overall environmental footprint (GHGe, energy and land use) by about 21% excluded both meat and fish; however, the diet failed to meet the recommendations for intake of Omega-3 fatty acids (Tyszler, Kramer, & Blonk, 2015). One study that specifically excluded seafood in their sustainable diet scenario, but managed to meet recommended dietary guidelines, included an increase in consumption

TABLE 1 Summary of diet scenarios examined in quantitative studies and relationships between seafood, environmental performance and health

Diet type	Includes seafood	Reduces impacts from average diet	Meets dietary guidelines	Source
Environmentally sustainable (minimized footprint)	Y	Y	Y	Gephart et al. (2016), Hess et al. (2015) , Horgan, Perrin, Whybrow, and Macdiarmid (2016), Macdiarmid et al. (2012), Masset, Vieux, et al. (2014), Temme et al. (2015)
	N	Y	N	Donati et al. (2016), Stehfest et al. (2009), Tyszler et al. (2015), van Dooren et al. (2014), Vieux et al. (2013), Wilson et al. (2013)
	N	Y	Y	Fazeni and Steinmüller (2011)
Pescatarian diet/ Mediterranean (high seafood, low meat content)	Y	Y	Y	Eshel and Martin (2006), Ruini et al. (2015), Saez-Almendros et al. (2013), Scarborough et al. (2014), Tilman and Clark (2014), Tukker et al. (2011), van Dooren and Aiking (2015), van Dooren et al. (2014)
Nordic diet (high seafood content)	Y	Y	Y	Röös et al. (2015), Saxe (2014)
Based on dietary guidelines	Y	N	Y	Tom et al. (2016), Tukker et al. (2011)
	Y	Y	Y	Green et al. (2015), Hendrie et al. (2014), Jalava et al. (2014), Stehfest et al. (2009), van Dooren et al. (2014)

of vegetable oil to overcome the lack of Omega-3 and Omega-6 fatty acids. It was not clear, however, how much oil would need to be consumed to meet dietary guidelines and if this level of consumption would be realistic (Fazeni & Steinmüller, 2011). In their assessment of 16 different diets, Wilson, Nghiem, Ni Mhurchu, Eyles, and Baker (2013) found that including seafood in a sustainable diet was necessary to meet dietary guidelines for health although the greatest reductions in environmental impacts were made in diets that did not adhere to health guidelines and may therefore not meet the FAO definition of a sustainable diet as one that is nutritionally adequate.

3.3 | Contributions to climate change—GHGe

All studies except two examined GHGe, some of them (*n* = 13) as a single indicator (Tables S1 and S2). Diets rich in fish had lower GHGe than meat diets, but higher than vegetable diets (Eshel & Martin, 2006; Saez-Almendros, Obrador, Bach-Faig, & Serra-Majem, 2013; Scarborough et al., 2014; Tilman & Clark, 2014; van Dooren et al., 2014; Vieux, Soler, Touazi, & Darmon, 2013). Replacing red meat and dairy with fish, chicken, eggs or vegetables 1 day a week was more effective in reducing GHGe than buying locally produced food for 1 week (Weber & Matthews, 2008).

The lower-carbon diets modelled by Masset, Vieux, et al. (2014b) had reduced animal products, including fish. Some seafoods can have moderate to high GHGe in comparison with other food groups (Drewnowski et al., 2015; Green et al., 2015; Temme et al., 2015; Tom, Fischbeck, & Hendrickson, 2016), and other seafood, as carbon emissions of different fish and other seafood species vary substantially (Carlsson-Kanyama & González, 2009; Gephart et al., 2016; Masset, Soler, Vieux, & Darmon, 2014; Nijdam, Rood, & Westhoek, 2012). Few studies indicated what species were actually included in the seafood category, and whether they were from wild capture or aquaculture. Examining the original source of the LCA data can help clarify what seafood was examined; however, not all studies indicated the source of the data.

Only three studies examined a range of seafood and provided clear references (Nijdam et al., 2012; Tilman & Clark, 2014; Tom et al., 2016). Scarborough et al. (2014) reported emissions for a range of seafood; however, all seafood types were assigned the same value which was sourced from secondary data based on emissions from farmed salmon and trout, imported tuna and shellfish, and UK cod (Audsley et al., 2009).

3.4 | Energy use

Five studies examined the energy impacts of diets (Tables S1 and S2). Fish consumption was associated with increased energy use as a result of fuel use during fishing (Tyszler et al., 2015) and due to feed production for farmed fish (Tom et al., 2016). In contrast, adoption of the Mediterranean diet, which includes a higher intake of fish than the current Spanish diet, by the Spanish population was estimated to reduce energy consumption by 52% from current dietary patterns (Saez-Almendros et al., 2013).

3.5 | Freshwater use

Eight studies compared the water footprints of diets (Tables S1 and S2), two of which examined water use as a single indicator (Hess, Andersson, Mena, & Williams, 2015; Jalava, Kummu, Porkka, Siebert, & Varis, 2014). Reducing animal products in the diet offered the potential to save water resources (Gephart et al., 2016; Jalava et al., 2014). Water footprints of fish were low (Tom et al., 2016) or assumed to be zero (Gephart et al., 2016; Hess et al., 2015). Aquaculture was excluded by one study as the required water footprint data were not available (Jalava et al., 2014). A water footprint of seafood was also not available in the database used by Gephart et al. (2016). They instead calculated water use based on global production of the top cultivated aquaculture products (excluding aquatic plants) using the total feeds for each product group, the composition of feeds for each product group and the water footprint of the inputs. The authors noted that the water footprint of seafood would be higher if all relevant aspects of water use for seafood production were included, such as during processing and evaporative losses from ponds.

3.6 | Eutrophication

Eutrophication of water and soils was identified as a central issue in animal husbandry and aquaculture (Nijdam et al., 2012); however, this impact category was only addressed by two studies (Masset, Soler, et al., 2014; Tukker et al., 2011). Fish was grouped with meat and eggs in the study by Masset, Soler, et al. (2014) so it was not possible to determine the contribution of fish to freshwater eutrophication; however, dietary scenarios that reduced eutrophication as a result of reducing the intake of red meat and replacement with chicken, fish and cereals were identified by Tukker et al. (2011).

3.7 | Land use

Twelve studies that include seafood in their assessments addressed the issue of land use (Tables S1 and S2); however, only three of these studies provided details on land use for the production of seafood (Gephart et al., 2016; Nijdam et al., 2012; Tilman & Clark, 2014). Pescatarian diets required less land use than meat-based diets (Gephart et al., 2016; Tilman & Clark, 2014). No studies recorded land use for wild-capture seafood although Nijdam et al. (2012) noted that bottom trawling may have an effect on large areas of the seabed. Land use for aquaculture was similar to that of pulses, eggs and poultry (2–6 m^2 year kg^{-1}; Nijdam et al., 2012). It was unclear whether the studies that did not report land use values for seafood assumed no land was used, or excluded seafood from this part of the analysis due to lack of data.

3.8 | Biological indicators

Only one study addressed biodiversity (Röös, Karlsson, Witthöft, & Sundberg, 2015) using a measure of biodiversity damage potential (BDP) based on differences in species richness between agricultural

TABLE 2 Themes for seafood identified in the sustainable diets literature

Theme	Source
Dietary recommendations to eat more fish are (potentially) unsustainable	Clonan et al. (2012),Horgan et al. (2016),Lang (2014), Merrigan et al. (2015), Reynolds et al. (2014), Riley and Buttriss (2011), Selvey and Carey (2013), Westhoek et al. (2011)
Consuming seafood presented as a conflict between health and environmental sustainability	Alsaffar (2015), Clonan and Holdsworth (2012), Macdiarmid (2013), Macdiarmid et al. (2012), Mitchell (2011), Riley and Buttriss (2011), van Dooren et al. (2014)
Express concern over environmental/biotic impacts of fishing	Buttriss and Riley (2013), Carlsson-Kanyama and González (2009), Clonan et al. (2012), Garnett (2011), Gephart et al. (2016), Heller et al. (2013), Mitchell (2011), Nijdam et al. (2012), Ruini et al. (2015), Tukker et al. (2011), Tyszler et al. (2015)
Advocate consumption of sustainable wild-capture seafood	Buttriss and Riley (2013), Clonan et al. (2012), Macdiarmid (2013), Reynolds et al. (2014), Riley and Buttriss (2011), Tyszler et al. (2015)
No scope for increased production/consumption	Fazeni and Steinmüller (2011), Jalava et al. (2014), Stehfest et al. (2009)
Use of wild-capture fish for aquafeed should be reduced	Reynolds et al. (2014), Selvey and Carey (2013), Westhoek et al. (2011)
Use of crops for aquafeed will increase footprint of seafood	Gephart et al. (2016), Westhoek et al. (2011)

and natural land use of the biome. In this study, land requirements for food production (m^2 year/kg food eaten) were calculated from FAOSTAT and a BDP value from the type of land use (BDP/kg food eaten) was determined. However, no land use or BDP was recorded for fish and no explanation provided. Another study indicated that the model used, E3IOT, was not capable of assessing the impacts on biotic depletion and was thereby not fully able to take into account potential positive or negative impacts of enhanced fish consumption in dietary scenarios (Tukker et al., 2011).

3.9 | Seafood sustainability conclusions—discussion papers and quantitative assessments

Twelve discussion papers were identified from the literature on sustainable diets that included seafood (Table S4), two of which focussed specifically on seafood and sustainable diets (Clonan et al., 2012; Mitchell, 2011). Eleven of the studies quantitatively assessing diets or products also provided a discussion on seafood sustainability (Tables S1 and S2). Seven emerging themes were identified (Table 2), each of which was mentioned in at least two discussion papers or studies. Although several authors advocated for a greater role of sustainable wild-caught seafood, the themes generally reflect quite negative beliefs about seafood and many studies in this literature describe seafood consumption as unsustainable, or present it as a trade-off between health and environmental sustainability (Table 2). In their review of the sustainable diet literature, Reynolds et al. (2014) concluded that the intake of fish should be reduced to reduce the environmental effects of the global diet. Arguments to limit seafood consumption were based on concern that marine fish populations are fully or over-exploited (Clonan et al., 2012; Lang, 2014; Riley & Buttriss, 2011; Westhoek et al., 2011) and that aquaculture expansion relies largely on fishmeal, which further depletes fish stocks (Selvey & Carey, 2013).

Several studies with modelled diets did not allow for any future increase in seafood consumption based on the assumption that the oceans are fished to the maximum level, with no capacity for greater wild fish harvest, and made no allowance for an increase based on growing aquaculture production (Fazeni & Steinmüller, 2011; Jalava et al., 2014; Stehfest et al., 2009). Reynolds et al. (2014) stated that growing demand for fish will be met, but only if fish resources are managed sustainably and the animal feeds industry reduces its reliance on wild fish. The reliance of wild fish for aquafeeds was viewed as problematic by several authors (Selvey & Carey, 2013; Westhoek et al., 2011). One study suggested that future shifts in the composition of aquaculture feeds away from wild-capture inputs may lead to increased land, water and nitrogen footprints (Gephart et al., 2016). Heller et al. (2013) recommended further examination of the role of sustainable aquaculture in the light of the sector's increasing contribution to seafood supply.

4 | DISCUSSION

One of the biggest challenges for the future food system is the sustainability of protein sources such as meat and fish (Clonan & Holdsworth, 2012). The results of dietary comparisons almost unanimously conclude that animal-based foods have greater environmental impact than plant-based foods (Heller et al., 2013). The findings regarding the messages conveyed in the sustainable diet literature relating to seafood consumption support claims that information on seafood sustainability can be conflicting and misleading (Olson et al., 2014). This review of the sustainable diet literature revealed that many studies on the environmental impacts of dietary change that include seafood are not transparent in their data sources, and include seafood in a manner that reflects neither the large variation within the seafood category nor seafood-specific impacts.

4.1 | Barriers and opportunities to incorporating seafood into sustainable diet research

Not all studies of sustainable diets include seafood (see, e.g., Brunelle, Dumas, & Souty, 2014; Doran-Browne, Eckard, Behrendt, & Kingwell, 2015; Erb et al., 2016; Goldstein, Hansen, Gjerris, Laurent, & Birkved, 2016; Kernebeek, Oosting, Feskens, Gerber, & Boer, 2014; Marlow, Harwatt, Soret, & Sabaté, 2015; Raphaely & Marinova, 2014; Reisch et al., 2013; Sabaté, Sranacharoenpong, Harwatt, Wien, & Soret, 2015; Temme et al., 2013). The reasons behind the exclusion were not always clear; however, a lack of data was cited (e.g., Marlow et al., 2015). A number of studies that did include seafood were also limited by lack of relevant data in standard food databases. The Danish LCA food database was cited by several authors and is one of the only LCA libraries to include data on seafood. Several studies used individual published LCAs to construct averaged data for seafood or relied on external data sets including from the Barilla Centre for Food and Nutrition or from Greenext Service consultants. Consideration of the different impact assessment methods used in LCA, as well as the choice of functional unit, system boundaries and allocation factors, is essential when comparing LCA results. Evidence of consideration of these important aspects, and uncertainty analysis on how they influence results, was strongly lacking.

Most studies reviewed here did not include details of the contribution of seafood to water footprints. The data sets by Mekonnen and Hoekstra (2010, 2011, 2012) were cited by authors comparing the fresh water use of foods, although these data sets do not include seafood. The water footprint of the major farmed species of fish and crustaceans, representing 88% of total fed production, has been determined (Pahlow, van Oel, Mekonnen, & Hoekstra, 2015) and this type of data needs to be incorporated into future assessments of sustainable diets.

The source of data for a number of studies was not reported, reinforcing the need for greater transparency around data use in the sustainable diet literature. Reporting the data source is also necessary to ascertain whether both wild-capture and aquaculture species are considered in the research. The sustainable diets literature broadly fails to distinguish between seafood on the basis of whether it is wild-caught or aquaculture-grown, an important consideration given that the main environmental impacts of capture fisheries and aquaculture differ markedly and pose different risks to sustainability of production (Jennings et al., 2016).

Studies identified in the literature review were also limited by models that did not adequately address biological issues, such as the biotic impacts of fisheries (Tukker et al., 2011; Tyszler et al., 2015). The under-representation of biological impacts, which are key components of sustainable diets, is not restricted to seafood and has been found across the sustainable diet literature (Jones et al., 2016). Modelling of fishing impacts on stocks and marine ecosystems has advanced in recent years (Plagányi et al., 2014), with several marine biotic resource use metrics under development for use in seafood LCAs (Cashion, Hornborg, Ziegler, Hognes, & Tyedmers, 2016; Emanuelsson, Ziegler, Pihl, Skold, & Sonesson, 2014; Langlois, Fréon, Delgenes, Steyer, & Hélias, 2014). The sustainable diet literature has failed to keep apace of these developments, presumably as a result of the historical separation of seafood from food system research and discourse, as well as the difficulty in comparing a wild food source to agriculture, and in applying methods for assessing impacts on land to the sea and vice versa. While biotic impacts of wild-capture seafood can be fishery specific, there is scope for improving comparison across marine and terrestrial systems (FAO, 2006; Farmery, Jennings, Gardner, Watson, & Green, in review; Langlois, Freon, Steyer, & Helias, 2016). Aquaculture systems may offer more opportunity for comparison with agricultural production, given that the shift towards crop-based feed ingredients fundamentally links seafood production to terrestrial agriculture (Fry et al., 2016), although more research is needed in this area to overcome significant challenges (FAO, 2006).

There is a clear need for improved integration of data on the impacts of food production on the land and sea, as well as for methodological standardization across different production systems. The inclusion of data on a range of wild-capture and aquaculture seafood species in LCA databases should be prioritized and would facilitate the inclusion of seafood in sustainable diet modelling. Data are now available to build a fisheries and aquaculture life cycle inventory library due to the recent growth in seafood LCAs.

4.2 | Implications of inadequate inclusion of seafood in sustainable diet research

The result of limited access to suitable fishery and aquaculture data is that some researchers modelling future sustainable diets are not allowing for any future increase in seafood consumption (Fazeni & Steinmüller, 2011; Jalava et al., 2014; Stehfest et al., 2009), while others refer to seafood only briefly in the context of it being unsustainable (see, e.g., Allen, Prosperi, Cogill, & Flichman, 2014; Alsaffar, 2015; Johnston et al., 2014). However, seafood plays, and will continue to play, an important role in the global food system, with annual per capita consumption projected to increase (World Bank, 2013). It is imperative that research on sustainable diets incorporates the most efficient and least environmentally damaging products within the seafood category, as within all food categories (Masset, Soler, et al., 2014).

Modelling diets on a narrow range of seafood overlooks the fact that wild-capture seafood can have very high or very low GHGe and energy footprints. For wild-capture species, the carbon emissions are directly linked to fuel consumption (Avadí & Fréon, 2013). Fisheries employing bottom trawls to target crustaceans and flatfish are fuel intensive, while fisheries targeting small pelagic species such as Peruvian anchovy (*Engraulis ringens*), are the most efficient (Parker & Tyedmers, 2014). These low-cost, small pelagic fish are also some of the richest sources of Omega-3 fatty acids; however, many are used for non-human uses such as bait or the production of fishmeal and oil due to limited demand for higher-value human consumption markets (FAO, 2014). The opportunity to include these types of seafood in models of sustainable diets is currently being overlooked.

Lack of data on water footprint values for fish (and seafood) was identified as a limitation by Vanham, Hoekstra, and Bidoglio (2013), who substituted meat for fish in their study of potential water saving through dietary change, thereby missing potential water savings from consuming seafood. Wild-capture seafood provides a unique source of food in that it requires little to no freshwater use and no pesticides, fertilizers or antibiotics. The freshwater savings that can be achieved through marine protein consumption (Gephart, Michael, & Paolo, 2014) are, therefore, also being overlooked in the sustainable diet literature.

The current focus of much of the sustainable diet literature on the unsustainable use of wild fish in aquafeed misses the fact that much of these fish are sourced from well-managed Peruvian anchoveta fisheries, which produce some of the least impact-intensive aquafeed ingredients (Pelletier et al., 2009). The replacement of wild fish ingredients by agricultural products may lead to increased environmental footprints for seafood from aquaculture, as anticipated by several authors (Gephart et al., 2016; Pahlow et al., 2015; Troell et al., 2014) and needs to be included in dietary models. The use of fish processing wastes and land-based by-products for feeds is increasing and will be an important feed ingredient in the future (World Bank, 2013). Using waste and by-products, combined with inputs from low-impact, well-managed fisheries, in aquafeeds may present a sustainable option for aquaculture production, which does not add to existing impacts from crop and livestock production.

Reducing the amount of fish oil in aquafeed also has implications for the final Omega-3 content of the farmed fish, with decreasing EPA and DHA levels recorded in farmed salmon (Nichols, Glencross, Petrie, & Singh, 2014; Sprague, Dick, & Tocher, 2016). While salmon still constitutes a good source of fatty acids, larger portion sizes are now required to satisfy recommended EPA and DHA intake levels endorsed by dietary guidelines. The shift in fatty acid content was not discussed in the literature examined; however, it is an important element of studies on health and sustainability. Most of the sustainable diet scenarios that did not include fish did not meet national dietary guidelines and may not meet the FAO definition of a sustainable diet as one that is nutritionally adequate. Reduced Omega-3 content of aquaculture products may mean that some diets that include seafood may also not meet national dietary guidelines. However, certain diets that do not always meet recommendations for Omega-3 intake can still be associated with positive health outcomes, such as vegetarian diets (Ha & de Souza, 2015).

This review of the sustainable diet literature revealed that future increases in seafood consumption are frequently viewed as unsustainable, in particular for wild fisheries. However, increasing seafood consumption is not necessarily contrary to good environmental stewardship of the oceans (Mitchell, 2011) and debate around the conflict between health and sustainability must also address sustainable pathways for increasing consumption in line with dietary guidelines and growing demand. Highlighted below are some examples of, and opportunities for, increased sustainable seafood consumption.

4.3 | Opportunities for including wild-capture seafood in future sustainable diets

Eating fish is often presented as a dilemma given that most fished stocks are either fully or over-exploited (Buttriss & Riley, 2013; Clonan et al., 2012; Fazeni & Steinmüller, 2011; Jalava et al., 2014; Lang, 2014; Riley & Buttriss, 2011; Selvey & Carey, 2013; Westhoek et al., 2011). It is clear that the opportunities for increasing production in fully fished stocks are limited; however, the predicted growth in seafood production is anticipated to come from aquaculture and not wild-capture fisheries (OECD-FAO, 2015). Some opportunities exist to increase the amount of seafood available without increasing catches, such as improved recovery and supply chain management to reduce waste, which can account for up to 50% of edible seafood supply (Love, Fry, Milli, & Neff, 2015). In addition, the 10% of stocks currently assessed as under-fished and the stocks that are not assessed by the FAO offer potential for increased production. Currently, overfished stocks offer another option to increase the amount of seafood available if fishing is properly managed and the stocks are rebuilt (FAO, 2014).

Sourcing seafood from stocks that are widely considered to be sustainable is a priority. Shifting fishing effort away from highly targeted stocks and towards currently underutilized species would reduce pressure on overfished species, result in fewer adverse ecosystem effects of fishing and increase overall fisheries production in the long term (Zhou, Smith, & Knudsen, 2014). The transition away from production based on currently overfished stocks may reduce supply in the short term leading to price increases. Demand-side management to support such a transition is needed, such as UK Dietary advice for people who regularly eat fish to consume as wide a variety as possible and experiment with less familiar species from underutilized stocks (Riley & Buttriss, 2011). New institutional and market arrangements, such as Community Supported Fishing (CSF) schemes that allow fishers to sell a wider range of species than is currently found in markets (Olson et al., 2014), will also facilitate transition to a lower dependence of seafood on overfished species.

4.4 | Options for including aquaculture in future sustainable diets

Studies examining current and future dietary scenarios need to address food from aquaculture on an equal basis with crops and livestock and allow for an expansion in seafood consumption, given that aquaculture is the world's fastest growing food production sector. An example of aquaculture being considered in future dietary scenarios is a recent study by Davis et al. (2016), where future growth in seafood demand was met by aquaculture production in their dietary scenarios. Fish from aquaculture have been labelled unsustainable due to the use of wild fish in aquafeeds (Brunner et al., 2009; Selvey & Carey, 2013) and there is concern that increasing amounts of fish will be caught for use in aquaculture feeds, to expedite the sector's expansion (Naylor et al., 2000). Yet, despite the growth in aquaculture production, demand for fishmeal and oil has remained steady or declined slightly in recent years (FAO, 2011). Demand does not necessarily drive production in wild-capture fisheries, as it does in other food sectors. Increased demand for seafood from fisheries where quotas are set and enforced will generally affect price but not production, particularly where regulation of production in these fisheries is not responsive to market conditions. Seafood from aquaculture production need not be excluded from sustainable diets solely due to the inclusion of wild fish in feeds. Furthermore, some aquaculture of finfish relies on feed inputs, which do not compete with human food needs. For example, grass carp and milk fish rely on inputs that humans do not or cannot consume, such as insect larvae, algae and terrestrial grasses (Olsen, 2011; Roberts et al., 2015).

Not all animals produced by aquaculture are reliant on feed. Bivalves, such as mussels and oysters, use natural ecosystems for food. Production methods requiring little or no feed inputs, such as many bivalve systems, would likely be included more often in minimized diets than seafood as a whole (Gephart et al., 2016). Although bivalve aquaculture presents its own unique impacts, such as the introduction of invasive species (Padilla, McCann, & Shumway, 2011), they may also have also positive environmental impacts such as reducing eutrophication in waterways and coastal areas (Rose, Bricker, Tedesco, & Wikfors, 2014). Polyculture systems also reduce feed use and environmental impact (Neori et al., 2004) while contributing to healthy diets (Thilsted et al., 2016) and may present a sustainable option for future food production.

5 | CONCLUSIONS

The supply of seafood from wild-capture fisheries and aquaculture faces many challenges, as do other food sectors, in order to be considered sustainable. Seafood can provide more sustainable food options than livestock, and in some cases crops, and failing to adequately include seafood in food sustainability, security and nutrition debate risks the promotion of potentially less sustainable and less healthy dietary choices. The debate around seafood consumption needs to shift from a sole focus on biological sustainability to also consider the contribution of seafood to the food system and how to maximize production in the most sustainable manner. Consideration of the sustainability of the linked human systems is also an important component of this field of research. Better inclusion of data on the environmental performance of seafood products in LCA databases and new methods allowing for comparisons across production systems are needed to identify diets to meet current and future demand for food with the least environmental impact.

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SUPPORTING INFORMATION

Additional Supporting Information may be found online in the supporting information tab for this article.

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