Food nitrogen footprint reductions related to a balanced Japanese diet

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Abstract

Dietary choices largely affect human-induced reactive nitrogen accumulation in the environment and resultant environmental problems. A nitrogen footprint (NF) is an indicator of how an individual's consumption patterns impact nitrogen pollution. Here, we examined the impact of changes in the Japanese diet from 1961 to 2011 and the effect of alternative diets (the recommended protein diet, a pescetarian diet, a low-NF food diet, and a balanced Japanese diet) on the food NF. The annual per-capita Japanese food NF has increased by 55% as a result of dietary changes since 1961. The 1975 Japanese diet, a balanced omnivorous diet that reportedly delays senescence, with a protein content similar to the current level, reduced the current food NF (15.2 kg-N) to 12.6 kg-N, which is comparable to the level in the recommended protein diet (12.3 kg-N). These findings will help consumers make dietary choices to reduce their impacts on nitrogen pollution.

Keywords: dietary choice; food consumption; healthy traditional diet; nitrogen footprint; sustainable diet; *washoku*

1. Introduction

Humans are responsible for more than half of global nitrogen (N) fixation, mainly through fertilizer production and agricultural biological N fixation (Fowler et al., 2013). However, the majority of intentionally fixed N to produce food and feed is lost to the environment as reactive N (Nr; all species of N except N_2), with only 17% consumed by humans in food (UNEP & WHRC, 2007). The global population growth with stable per-capita Nr loss is, in turn, causing continuous Nr accumulation in the environment (Galloway et al., 2014). Nr accumulation above the planetary boundary (Steffen et al., 2015) contributes to various environmental problems (Sutton et al., 2011; Erisman et al., 2013).

The N footprint (NF) is an indicator of the impact of human activities in terms of the total amount of Nr released to the environment as a result of resource consumption (Leach et al., 2012). Stevens et al. (2014) reported that food has a larger impact than energy in terms of the NF, and suggested that, of all scenarios tested, a reduction in protein intake to that recommended by the World Health Organization (WHO) and United States Department of Agriculture could significantly reduce the UK NF. Taking fish and seafood as an example (in this study, the term "fish and seafood" is used collectively to include inland and marine, finfish, mollusks, crustaceans, and derived products), Oita et al. (2016b) suggested actions to reduce NF by eating food items in lower NF subcategories, while reducing animal protein intake. Alternative diets suggested to date have been limited to reducing protein intake or giving up meat and other categories with a high NF (e.g. Galloway et al., 2014; Stevens et al., 2014; Westhoek et al., 2015; Shibata et al., 2017).

Diets tightly link human health to environmental problems (Tilman and Clark, 2014; Nesheim et al., 2015), including N pollution. The traditional Japanese diet, *washoku*, which was added to UNESCO's Intangible Cultural Heritage list in 2013, is characterized by high consumption of soybean products, fish, seaweed, vegetables, fruit, and green tea (Shimazu et al., 2007). Although *washoku* includes its cultural aspects notably seen in annual events, it also refers to typical daily meals, which are commonly characterized by the *ichiju-sansai* style (consisting of a soup, rice, and three side dishes, or more broadly defined as "food using fresh fish and vegetables, cooked to use the potential of its ingredients and containers, and deeply related to seasonality and annual rituals"; Kohsaka, 2017). Studies have shown that this traditional daily diet provides health benefits, such as reduced risk of cardiovascular disease and diabetes (Shimazu et al., 2007; Guo et al., 2012), while increasing life expectancy (Yamamoto et al., 2016). In 1960, the typical Japanese diet was largely in accordance with traditional dietary patterns (Lands et al., 1990); however, significant changes have occurred over the past 50 years (see Table 1 in Yamamoto et al., 2016). The traditional Japanese diet currently has a share of roughly 60% of meals served at Japanese home (Kohsaka, 2017). The 1975 diet, which incorporated Japanese Western cuisine (*yoshoku*, in which Western ingredients, such as pork and beef, are cooked using Japanese techniques) with traditional Japanese cuisine, has been reported as a balanced diet that delays senescence more effectively than the 1960 diet and the current Japanese diet (Yamamoto et al., 2016). However, it remains unclear how changes in food consumption patterns could reduce food NF without cutting out certain food categories, while improving health and overall enjoyment of food.

In this study, we assessed the impact of dietary changes on the food NF in Japan in terms of both the environment and health. We determined the changes in per-capita protein intake in Japan and calculated the resulting changes in food NF with corresponding changes in food consumption patterns. We then performed analyses of four alternative dietary scenarios (1) the recommended protein diet, (2) pescetarian diet, (3) low-NF food diet, and (4) balanced Japanese diet.

2. Materials and methods

The per-capita "food NF" is defined as the total amount of Nr released to the environment as a result of an average individual's food consumption, excluding fuel-combustion-related Nr (Leach et al., 2012). Food NF can be divided into two parts: food production and food consumption. Food production NF is determined by food N intake multiplied by virtual N factors (VNFs; the amount of Nr released to the environment during production per unit of N intake), while food consumption NF represents N intake minus denitrification N removal in sewage treatment. Nr in food waste after the final purchase by consumers is incorporated to VNFs so that accounted for in food production NF.

We determined food NFs for Japan using food protein supply data from the Food and Agriculture Organization of the United Nations (FAO) for 1961–2011 (FAO, 2015), VNFs, average food waste rates and fed-aquacultured rates for Japan (Table 1; Shibata et al., 2014; Oita et al., 2016b; see detailed food categories corresponding to FAO categories in Table 2), and an average rate of denitrification in sewage treatment of 32% (Oda and Matsumoto, 2006). In this study, the term "meat" includes edible offal as per the FAO categories. A common bottom-up approach, called the N-Calculator method (Leach et al., 2012), was employed using N intake as a starting point as determined by Eq. 1:

$$N_{\mathrm{int}\_i} = P_{\mathrm{supplied}\_i} \times (1 - R_{\mathrm{wasted}\_i}) \times 0.16, \quad (1)$$

where N_{int_i} is N intake represented by the protein content of food item i, P_{supplied_i} is supplied food protein (g capita^{-1} year^{-1}), and R_{wasted_i} is the average food waste rate for food item i. We then calculated food production NFs using Eq. 2 and food consumption NFs using Eq. 3:

$$NF_{\mathrm{prod}\_i} = N_{\mathrm{int}\_i} \times VNF_i, \quad (2)$$

$$NF_{\mathrm{cons}\_i} = N_{\mathrm{int}\_i} \times (1 - R_{\mathrm{dinit}}), \quad (3)$$

where NF_{prod_i} is the food production NF of food item i, VNF_i is the VNF of food item i, and R_{dinit} is the average rate of denitrification during sewage treatment (32%).

Japanese NFs in the case of four alternative dietary scenarios were compared to that of the current average Japanese diet (the 2011 diet).

(1) Recommended protein diet: protein intake reduced to the level recommended by the Ministry of Health, Labour and Welfare, Japan (JMHLW) (53 g cap^{-1} day^{-1} for an average adult), with the current dietary composition (Kido et al., 2012).

Table 1 Virtual nitrogen factors (VNFs), food waste rates, and fed-aquacultured rates for Japan.

Food category	VNF[a]	Food waste rate[b] (%)	Fed-aquaculture rate[c] (%)
Cereals	1.5	10	–
Legumes	1.3	9	–
Vegetables	5.5	20	–
Starchy roots	4.9	20	–
Tree nuts and other oil crops	1.3	9	–
Plant products not included elsewhere[d]	5.5	20	–
Fish and seafood	–	16	–
Freshwater fish	–	–	58
Fed aquacultured	4.3	–	–
Captured and non-fed aquacultured	0.2	–	–
Marine fish[e]	–	–	5–6
Fed aquacultured	3.4	–	–
Captured and non-fed aquacultured	0.2	–	–
Crustaceans	–	–	50
Fed aquacultured	7.6	–	–
Captured and non-fed aquacultured	0.2	–	–
Molluscs[f]	0.2	–	0
Dairy products and milk	2.7	3	–
Eggs[g]	6.7	39	–
Poultry meat	6.0	31	–
Pig meat	6.7	39	–
Bovine meat	12.4	39	–
Other meat including offal[h]	8.4	36	–

[a] VNFs for categories other than fish and seafood represent VNFs for "Japan with trade" in Shibata et al. (2014), while VNFs for fish and seafood represent VNFs for parameter set J in Oita et al. (2016b).

[b] Shibata et al. (2014), except fish and seafood. Values reported by Leach et al. (2012) for fish and seafood were used by Shibata et al. (2014).

[c] Parameter set J in Oita et al. (2016b).

[d] Applied values for vegetables.

[e] Marine fish includes FAO categories of demersal fish, pelagic fish, and "marine fish, other".

[f] Molluscs includes FAO categories of cephalopods and "molluscs, other", both of which are considered not to be fed aquacultured.

[g] Applied values for pig meat.

[h] Calculated average of poultry meat, pig meat, and bovine meat.

Table 2 Food categories and included FAO categories.

Food category	FAO category in the Food Balance Sheet[a]
Cereals	"Cereals - Excluding Beer," Alcoholic Beverages
Legumes	Pulses, Soybeans
Vegetables	Vegetables
Starchy roots	Starchy Roots
Tree nuts and other oil crops	Tree nuts, Oil crops (excluding soybeans)
Plant products not included elsewhere	Sugar & Sweeteners, Vegetable Oils, "Fruits - Excluding Wine," Stimulants, Spices
Freshwater fish	Freshwater fish
Marine fish	Demersal fish, Pelagic fish, “Marine Fish, Other”
Crustaceans	Crustaceans
Molluscs	Cephalopods, “Molluscs, Other”
Dairy products	"Milk - Excluding Butter," Animal fats
Eggs	Eggs
Poultry meat	Poultry meat
Pig meat	Pig meat
Bovine meat	Bovine meat
Other meats, including offal	Mutton & Goat Meat, "Meat, Other," “Offals, Edible”

[a] FAO (2015)

(2) Pescetarian diet: meat protein intake substituted for fish and seafood protein. Total protein intake equivalent to the current level.

(3) Low-NF food diet: protein intake of meat, dairy, egg, and fed-aquacultured fish and seafood substituted by legume protein and captured/non-fed-aquacultured fish and seafood protein. Total protein intake equivalent to the current level.

(4) Balanced Japanese diet: protein intake equivalent to the 1975 level, with the dietary composition at that time. Corresponds to a traditional Japanese-based diet incorporating Japanese Western cuisine.

3. Results

3.1 Protein intake

Between 1961 and 2011, the per-capita protein intake in Japan showed three trends: a steady increase from 1961 (64.6 g day^{-1}) to 1989 (81.6 g day^{-1}) followed by a slight decrease from 1989 to 2001 (79.8 g day^{-1}) and a moderate decrease from 2001 to 2011 (72.0 g day^{-1}; Figure 1). The first period (1961–

1989) represents a period of growth in food consumption, particularly meat (+ 360%), dairy and eggs (+ 183%), and fish and seafood (+ 71%), with the exception of a reduction in cereals (- 25%) and legumes (- 11%). In the second period (1989–2001), meat consumption continued to rise by 12%, while fish and seafood consumption started to decrease by 7%. Consumption of dairy and eggs levelled off, while that of cereals and legumes continued to decline. During the third period (2001–2011), although meat consumption continued to increase by 8%, fish and seafood consumption further decreased by 27%, and all other categories decreased slightly.

The relative proportion of each category in terms of total protein intake changed drastically across the 50-year period (Figure 1 and Table 3). In 1961, cereals and legumes represented more than 60% of the total protein intake, while fish and seafood were the main source of animal protein. In contrast, by 1975, the percentage of cereals and legumes dropped to about 50% of the total protein intake, while dairy, eggs, and meat increased to 42% of the animal protein intake, complemented by the consumption of fish and seafood. In 1989 and 2001, cereals and legumes represented only about 40% of the total protein intake, while meat, dairy and eggs increased to about 25% of the total, increasing the share of animal protein to more than 50% of the total. In 2011, while contributions of vegetable products remained stable, those of meat, dairy, and eggs increased to nearly 60% of the animal protein intake.

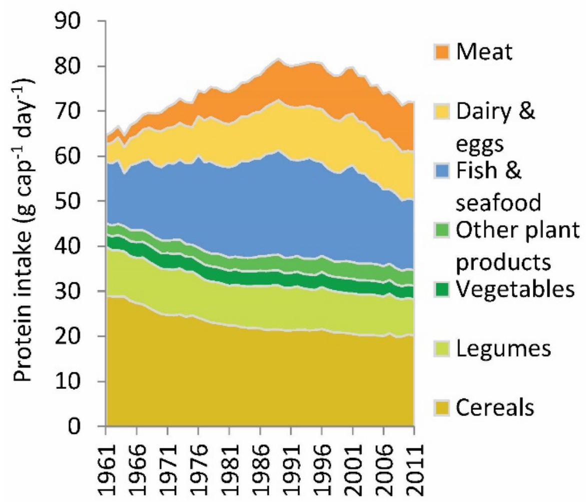

Figure 1 Protein intake (g cap^{-1} day^{-1}) in Japan according to major food groups between 1961 and 2011 (FAO, 2015).

Table 3 Changes in the composition of protein intake in Japan between 1961 and 2011 (g cap^{-1} day^{-1}).

Food category	1961		1975		1989		2001		2011	
Cereals	29.0	(45%)	24.7	(34%)	21.6	(26%)	20.6	(26%)	20.2	(28%)
Legumes	11.0	(17%)	9.7	(13%)	9.7	(12%)	9.0	(11%)	8.0	(11%)
Vegetables	2.7	(4%)	3.3	(5%)	3.4	(4%)	3.2	(4%)	3.0	(4%)
Other plant products	2.5	(4%)	2.7	(4%)	3.5	(4%)	3.7	(5%)	3.5	(5%)
Fish and seafood	13.6	(21%)	18.2	(25%)	23.2	(28%)	21.6	(27%)	15.7	(22%)
Dairy and eggs	3.9	(6%)	7.9	(11%)	11.1	(14%)	11.4	(14%)	10.5	(15%)
Meat	2.0	(3%)	5.4	(8%)	9.2	(11%)	10.3	(13%)	11.1	(15%)
Bovine meat	0.4		0.8		2.0		2.5		2.1	
Pig meat	0.3		1.7		2.7		3.0		3.4	
Poultry meat	0.3		1.6		3.2		3.8		4.7	
Other meat including offal	1.0		1.3		1.3		1.0		0.9	
Subtotal of animal protein	19.5	(30%)	31.5	(44%)	43.5	(53%)	43.3	(54%)	37.3	(52%)
Total protein intake	64.6	(100%)	71.9	(100%)	81.6	(100%)	79.8	(100%)	72.0	(100%)

Note: Values for each meat item were rounded up to obtain the total meat.

3.2 Per-capita food nitrogen footprints

In 2011, the per-capita food NF in Japan was calculated as 15.2 kg-N yr^{-1} using VNFs for Japan (Figure 2, Table S1), as the sum of food production NF (12.3 kg-N yr^{-1}) and food consumption NF (2.9 kg-N yr^{-1}). Meat represented 35% of the total food NF, followed by dairy and eggs (19%), cereals (17%), and fish and seafood (9%). Calculated using constant VNFs for Japan, the per-capita food NF increased from 1961 (9.8 kg-N yr^{-1}) to 1989 (15.7 kg-N yr^{-1}) with the increase in protein intake, and continued to increase with the continuous rise in meat consumption, reaching a peak in 1995 (16.4 kg-N yr^{-1}). The NF then levelled off until 2000, after which there was a slight decrease to the current level. Thus, although protein intake and resultant food N intake in 2011 was only 11% greater than that of the 1961 diet, the total food NF increased by 55%.

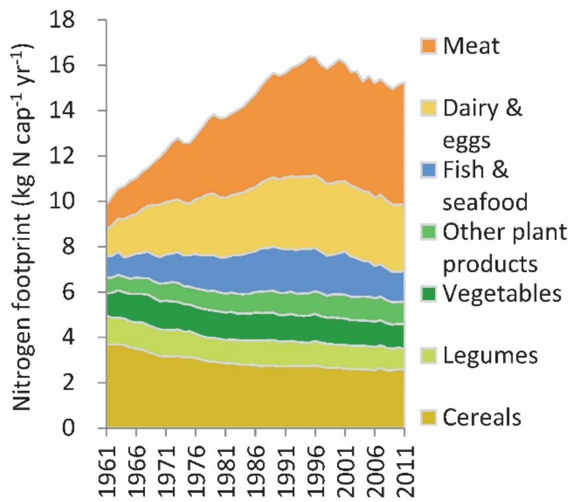

Figure 2 Impact of dietary changes between 1961 and 2011 on the food nitrogen footprint in Japan, calculated using constant virtual nitrogen factors (VNFs in Table 1) (kg-N cap^{-1} yr^{-1}).

3.3 Scenario Analysis

How changes in food choices affect the food NF was subsequently determined using four dietary scenarios (Figure 3, Table 4). The amount of Nr released to the environment can be reduced by lowering our protein intake and consuming food with a lower VNF. On a per-capita basis, lowering food protein intake to the JMHLW recommended level in line with the current dietary pattern decreased the food NF to 12.3 kg-N yr^{-1}, while maintaining an equivalent level of protein intake with a pescetarian diet (a diet without meat) reduced the food NF to 10.8 kg-N yr^{-1}. Consuming only low-NF food, while maintaining an equivalent level of protein intake was the most effective choice of all scenarios tested, reducing the per-capita food NF to 8.3 kg-N yr^{-1}. The 1975 balanced Japanese diet, with an almost equivalent amount of protein, also reduced the food NF to 12.6 kg-N yr^{-1}.

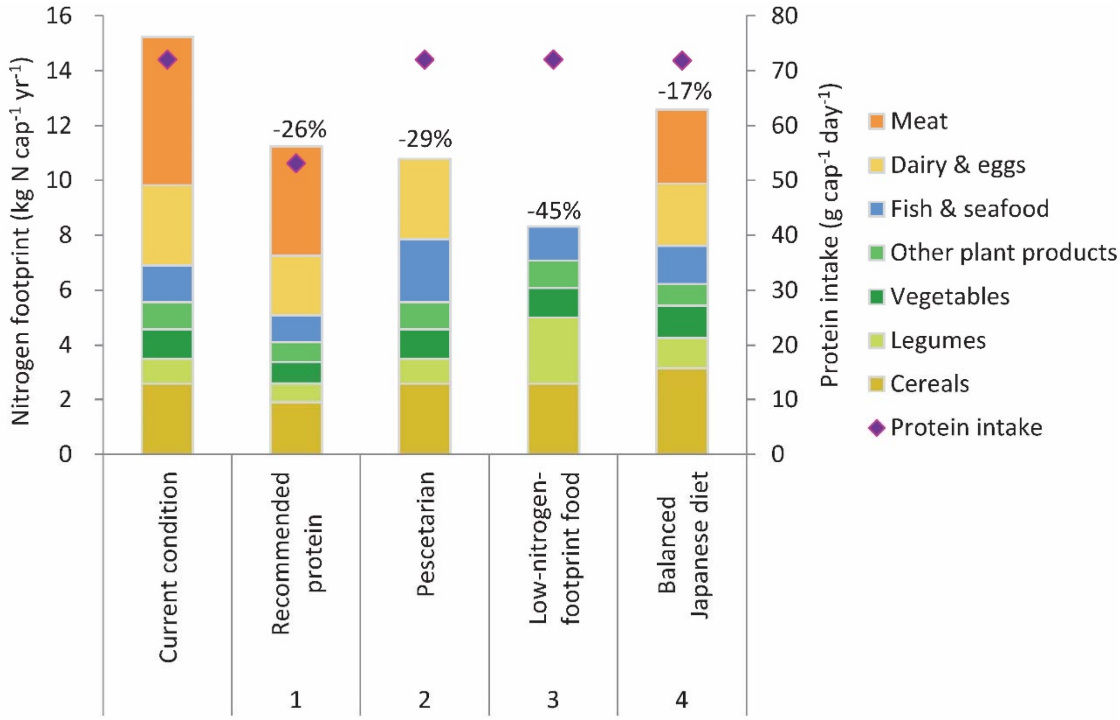

Figure 3 Food nitrogen footprints and total protein intake under four dietary scenarios according to each food category. Current condition: Japanese food consumption patterns in 2011; Scenario 1: protein intake reduced to the level recommended by the Ministry of Health, Labour and Welfare, Japan (Kido et al., 2012); Scenario 2: meat protein intake replaced by fish and seafood; Scenario 3: protein intake from meat, dairy, eggs, fed-aquacultured fish and seafood replaced by legumes, fish and seafood (non-fed-aquacultured or captured); Scenario 4: a balanced Japanese diet as in 1975 (traditional Japanese-based diet incorporating Japanese Western cuisine). The percentages shown above each plot indicate the degree of nitrogen footprint reduction compared to the current condition.

Table 4 Comparison of the composition of protein intake for alternative diets (g cap^{-1} day^{-1}).

Food category	Current (2011)		Recommended protein		Pescetarian		Low-NF food		Balanced Japanese diet (1975)	
Cereals	20.2	(28%)	14.9	(28%)	20.2	(28%)	20.2	(28%)	24.7	(34%)
Legumes	8.0	(11%)	5.9	(11%)	8.0	(11%)	21.1	(29%)	9.7	(13%)
Vegetables	3.0	(4%)	2.2	(4%)	3.0	(4%)	3.0	(4%)	3.3	(5%)
Other plant products	3.5	(5%)	2.6	(5%)	3.5	(5%)	3.5	(5%)	2.7	(4%)
Fish and seafood	15.7	(22%)	11.5	(22%)	26.8	(37%)	24.2	(34%)	18.2	(25%)
Dairy and eggs	10.5	(15%)	7.8	(15%)	10.5	(15%)	0	(0%)	7.9	(11%)
Meat	11.1	(15%)	8.2	(15%)	0	(0%)	0	(0%)	5.4	(8%)
Bovine meat	2.1		1.6		0		0		0.8	
Pig meat	3.4		2.5		0		0		1.7	
Poultry meat	4.7		3.5		0		0		1.6	
Other meat including offal	0.9		0.6		0		0		1.3	
Subtotal of animal protein	37.3	(52%)	27.5	(52%)	37.3	(52%)	24.2	(34%)	31.5	(44%)
Total protein intake	72.0	(100%)	53.1	(100%)	72.0	(100%)	72.0	(100%)	71.9	(100%)

Note: Values for each meat item were rounded up to obtain the total meat.

4. Discussion

4.1 Dietary changes and food nitrogen footprints over the past 50 years

Overall, the per-capita food NF in Japan has largely increased in the past five decades due to the growth in food consumption, especially animal protein, followed by a shift to a more meat-based diet. Our findings are in line with those of Shibata et al. (2014) who revealed that younger generations prefer diets with more meat and less vegetables. Similar trends in the environmental impact associated with increasing meat consumption have also been seen in other developed and developing countries (Alexandratos, 2006; Kearney, 2010). Increased consumption, especially of animal protein, is supported via imported food and feed, thereby increasing N levels in water bodies and air in food- and feed-exporting countries (Burke et al., 2009; Oita et al., 2016a) and in importing countries (Shindo et al., 2009; Lassaletta et al., 2014b). As Lassaletta et al. (2014a) suggested, the global disconnection between crop and livestock farming has further increased N pollution in both feed-exporting countries (e.g., Brazil) and feed-importing countries (e.g., China). In addition, given the increasing trend in fertilizer use (Nishina et al., 2017) and consumption of plant-protein-fed fish and seafood (Hardy, 2010), it is suggested that VNFs of crops, meat, fish, and seafood have all increased and will continue to do so in the future. As in previous studies on NF, our calculations do not include the protein supply of whale meat, which peaked in the 1960s (a per-capita daily supply of 1.0 g in 1960, 0.6 g in 1975, and 0 g in 1989; Ministry of Agriculture, Forestry and Fisheries of Japan, 1970, 1977, 1991), or game meat. Since the per-capita NF of whale meat was calculated as 0.04 kg N yr^{-1} in 1960 using similar assumptions to those for wild-caught fish, the effect of whale meat and game meat is thought to be marginal. Although the food NF in Japan has experienced a slight decline in the past decade when calculated using constant VNFs, further reductions are required to shift to a sustainable diet within the planetary boundary (de Vries et al., 2013; Steffen et al., 2015), thereby keeping surface water below the threshold level for eutrophication or acidification of aquatic ecosystems.

Our estimate of per-capita Japanese food NF of 15.2 kg-N yr^{-1} in 2011 is similar to the estimate of 16.5–18.1 kg-N yr^{-1} obtained by a top-down approach (Shindo and Yanagawa, 2017) that includes 1.3 kg-N yr^{-1} Nr denitrified in sewage treatment. These two estimates for 2011 are much less than 25.6 kg-N yr^{-1} in 2009 reported by Shibata et al. (2014). We applied the VNFs reported by Shibata et al. (2014), except for fish and seafood (taken from Oita et al., 2016b); accordingly, Shibata et al. (2014) may have overestimated the N intake in their calculation from the food protein supply in the FAO food balance sheet. In addition, the smaller VNFs for fish and seafood (Table 1; weighted average of 0.8) used in this study (Oita et al., 2016b; calculated for Japan accounting for trade) compared to the VNF of 2.9 in Shibata et al. (2014), calculated from the US values reported by Leach et al. (2012), partially explain the difference (Tables S1–S2).

4.2 Alternative diets

Dietary scenario analysis demonstrated that changes in food consumption patterns could result in further reductions compared to lowering protein intake to the JMHLW recommended level (53 g cap^{-1} day^{-1}). Most Japanese consume less than the upper limit of protein intake (118 g day^{-1}; Kido et al., 2012), while some have insufficient protein intake (Mean ± SD, 69.8 ± 23.2 g day^{-1}; JMHLW, 2013). In addition, studies suggest that elderly people require more than the recommended levels of protein

(Kobayashi et al., 2013; Levine et al., 2014). Therefore, changes in dietary patterns seem more favorable for many Japanese in terms of decreasing their food NF.

Comparing the pescetarian diet with the low-NF food diet, a shift to a plant and seafood-based diet was 1.5 times more effective in reducing the food NF in Japan. From a dietary and supply perspective, the pescetarian diet scenario consumes 1.7 times more seafood than the current level, while the low-NF food diet scenario consumes 1.5 times more. This represents 16% (pescetarian) and 5% (low-NF food) more than that of the 1989 diet. Understanding consumption at the country level would also be practical in terms of supply, if wild catch were to be recovered to that of the 1980s through appropriate and effective fisheries management (Ministry of Agriculture, Forestry and Fisheries, Japan, 2015a). That is, to put the pescetarian and low-NF diets into practice, only fish and seafood captured within biologically sustainable levels should be consumed. In the low-NF food diet scenario, legume consumption is 2.6 times greater than the current level and 92% more than the 1961 diet. Nevertheless, Japan has the potential to produce 2.4 times more soybeans than present levels (Ministry of Agriculture, Forestry and Fisheries of Japan, 2015b). This level of legume consumption is roughly the same as that of Niger in 2011 (FAO, 2015). Both scenarios represent an affordable diet, assuming consumption increases are mainly the result of wild-caught small pelagic fish and legumes. Considering the above three scenarios, the pescetarian diet is the most feasible option in Japan, while the low-NF diet has potential. In practice, both diets could be adopted once a week as a starting point, e.g., as a day without meat or a day without meat, dairy, eggs, or fed-aquacultured fish and seafood. The food NF decreases in proportion to the number of days an alternative diet is followed.

From a human health perspective, the balanced Japanese diet is more attractive than the other scenarios, since it delays senescence effectively (Yamamoto et al., 2016). This diet requires reduced consumption of meat, dairy and eggs, and an increase in rice and soybeans compared to the current diet. This was the typical diet of most Japanese in the 1970s, not requiring consumers, mostly omnivorous, to cut out any food categories. In addition, its loose restriction on ingredients leaves room for consumers to enjoy any kind of cuisine. The balanced Japanese diet therefore seems more feasible than other diet scenarios, such as the pescetarian and low-NF diets, especially in countries where Japanese cuisine or other similar plant-based food compositions have already gained popularity.

4.3 Towards a sustainable and healthy diet

We make food choices not only in terms of how environmentally friendly or healthy they are, but also based on culture, nutritional knowledge, price, availability, taste, and convenience (Tilman and Clark, 2014). The biggest obstacle to maintaining a balanced Japanese diet is time constraints (Melby and Takeda, 2014). To make it more practical for the consumer, the introduction of simple recipes and simple cooking methods could therefore be implemented, while at a more fundamental level, policies aimed at society are perhaps required. Overall, by combining the balanced Japanese diet with one day a week without meat, dairy, eggs, or fed-aquacultured fish and seafood could reduce our NF by more than 20%, or 386 Gg N year^{-1}, when scaled up to the Japan population.

Similar shifts away from a traditional diet based mainly on locally-grown cereals, pulses, fish and seafood, and olive oil to a more meat-based diet have also been seen in Mediterranean countries (e.g., Garcia-Closas et al., 2006) and are associated with greater environmental impacts (Sáez-Almendros et al., 2013). Lassaletta et al. (2014b) have reported that per-capita protein consumption in Spain had increased from 4.6 kg-N yr^{-1} (78.8 g-protein day^{-1} with 37% animal protein) in 1961–1965 to 6.4 kg-N yr^{-1} (109.6 g-protein day^{-1} with 64% animal protein) in 2005–2009. Compared to the balanced Japanese diet with 4.2 kg-N yr^{-1} (71.9 g-protein day^{-1}), the 1960s' Mediterranean diet has a similar animal protein ratio of roughly 40%, whereas they consume higher protein amount. These diets with relatively low animal protein ratios in line with the estimated highest sustainable protein consumption of per-capita protein consumption of 4–5 kg-N yr^{-1} with 40% animal protein by Billen et al. (2015). In response to the dietary shifts, movements such as the "slow food" movement, which originated in Turin, Italy (Medina, 2011), and the "real food challenge," a student network in the U.S. (Allen, 2010), are aiming to create more sustainable food systems through changes in consumption patterns. Encouraging feasible, healthy diets with relatively low NFs and other environmental impacts (e.g., greenhouse gas emissions and water use) could substantially reduce Nr emissions, while improving overall enjoyment of food and health.

Sustainable diets would ultimately need to incorporate socio-economic dimensions as well as environmental and nutritional health factors (Garnett, 2016). Further investigations are therefore needed to assess the impact of existing healthy diets in different regions and various sustainable food movements on the environment and on social and economic factors. The present findings are a step towards such transdisciplinary research.

Conclusions

Assessing a range of alternative diets can help consumers make healthier and more environmentally friendly dietary choices depending on their preferences. Our assessment of the effect of dietary changes on the food NF in Japan suggests that following the balanced healthy Japanese diet could reduce our food NF, addressing both environmental and health problems while improving overall enjoyment of food. The analysis of various scenarios provides omnivorous consumers a range of feasible food consumption patterns that could help reduce their NFs. Using this information as a guide, consumers can arrange recipes with a lower NF, while movements aimed at sustainable food systems can quantify the effects on N pollution. Thus, consumer actions associated with efforts to increase N use efficiency at the production level could substantially reduce human-induced Nr emissions.

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