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First approach to the Japanese nitrogen footprint model to predict the loss of nitrogen to the environment

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Abstract

Humans increase the amount of reactive nitrogen (all N species except N_2) in the environment through a number of processes, primarily food and energy production. Once in the environment, excess reactive nitrogen may cause a host of various environmental problems. Understanding and controlling individual nitrogen footprints is important for preserving environmental and human health. In this paper we present the per capita nitrogen footprint of Japan. We considered the effect of the international trade of food and feed, and the impact of dietary preferences among different consumer age groups. Our results indicate that the current average per capita N footprint in Japan considering trade is 28.1 kg N capita^{-1} yr^{-1}. This footprint is dominated by food (25.6 kg N capita^{-1} yr^{-1}), with the remainder coming from the housing, transportation, and goods and services sectors. The difference in food choices and intake between age groups strongly affected the food N footprint. Younger age groups tend to consume more meat and less fish, which leads to a larger food N footprint (e.g., 27.5 kg N capita^{-1} yr^{-1} for ages 20 to 29) than for older age groups (e.g., 23.0 kg N capita^{-1} yr^{-1} for ages over 70). The consideration of food and feed imports to Japan reduced the per capita N footprint from 37.0 kg N capita^{-1} yr^{-1} to 28.1 kg N capita^{-1} yr^{-1}. The majority of the imported food had lower virtual N factors (i.e., Nr loss factors for food production), indicating that less N is released to the environment during the respective food production processes. Since Japan relies on imported food (ca. 61%) more than food produced domestically, much of the N losses associated with the food products is released in exporting countries.

S Online supplementary data available from stacks.iop.org/ERL/9/115013/mmedia

Keywords: consumer, footprint, Japan, nitrogen, virtual nitrogen factor, international trade

1. Introduction

Nitrogen (N) is an essential nutrient, but reactive nitrogen (Nr, defined as all nitrogen compounds except N_2) can cause many environmental problems (e.g., smog, climate change, water pollution) when concentrations exceed certain thresholds (Galloway and Cowling 2002). Humans create more Nr than natural terrestrial Nr creation, and do so primarily through food and energy production processes (Galloway *et al* 2003). The main sources of Nr are cultivation-induced biological nitrogen fixation (several forms of Nr), fossil fuel combustion (NO_x), and fertilizer use (NH_3) (EPA 2011, Mueller *et al* 2014). Nr application as fertilizer is necessary to sustain a growing population, so it is important to balance the environmental costs and societal benefits of Nr.

The N-calculator is a tool that allows individuals to calculate their personal N footprint (Leach *et al* 2012). The 'footprint' is a parameter to help determine human impacts on the environment. The N-calculator takes in information about an individual's resource consumption in the food, housing, transportation, and goods and services sectors, and compares an individual's footprint to the national average. Per capita N footprints have been calculated for the US, Netherlands, Germany, and the UK using the N-calculator model (Leach *et al* 2012, Stevens *et al* 2014). N footprints have also been calculated for China and the EU using different approaches (Gu *et al* 2013, Leip *et al* 2013). Calculating footprints for more countries allows us to better understand the global N cycle and conditions within each country. Country-specific footprints are also important to give users a more accurate footprint estimate. This paper presents the first Japanese N-calculator.

Japan has a highly developed economy and large population (127.5 million people) (Statistical Handbook of Japan 2013). Recent gross domestic product (GDP) in Japan was 490–520 thousand billion yen (Statistical Handbook of Japan 2013), making it the third largest country by GDP (after the US and China).

Numerous studies have linked Nr from Japanese agriculture and industry environmental problems in Japan (Shibata *et al* 2001, Mishima 2002, Shindo *et al* 2003, Konohira *et al* 2006, Oda 2006, Oda and Matsumoto 2006, Shindo *et al* 2009, Mishima *et al* 2010). For example, Shindo *et al* (2009) reported that an increase in livestock consumption from the early 1960s to mid-1980s resulted in an increased Nr load in both terrestrial and aquatic systems in Japanese archipelago. This is the first study to link individual resource consumption in Japan to Nr losses.

In Japan, rice makes up the largest share of agricultural production by weight followed by sugar beets, potatoes, Japanese radishes, cabbages, and onions. Chickens, pork and beef are the dominant meat products. Marine fisheries account for 76% of fish produced in country, the rest coming from aquaculture and inland fisheries. The average per capita food consumption in Japan is 2500 kcal $capita^{-1}$ d^{-1}, primarily from rice (ca. 580 kcal), meats (ca. 390 kcal), oils (ca. 340 kcal), and wheat (ca. 330 kcal). The total domestic energy supply of Japan ranged from 22 600 to 23 600 PJ from 1995 to 2010, primarily from petroleum, coal, natural gas and nuclear sources (Statistical Handbook of Japan 2013).

International trade of food and feed is one of the strongest drivers of global N circulation (Galloway *et al* 2008, Lassaletta *et al* 2014). Japan relies heavily on imported food and feed (ca. 61% for food, ca. 75% for feed) which are increasing relative to internal production (Statistical Handbook of Japan 2013). Countries produce food differently and with varying nitrogen use efficiencies, so it is important to consider the environmental impact of international trade on the Japanese N footprint. Also, trade causes the food production and consumption to occur in different locations, complicating the N footprint calculation and raising important geopolitical and equity questions.

An individual's N footprint is largely influenced by his/her choices in food, energy, transportation, and goods and services sectors (Leach *et al* 2012). Individual behaviors may be influenced by a variety of personal, social, and economic factors, including age. Japan is an aging society; a diminishing population of young people is supporting a growing population of older people. Comparing the N footprints of different age groups could provide valuable insight into both current and future Japanese N footprints.

Our primary research questions are:

(1) On average, how much Nr is released per capita in Japan?
(2) How does the international trade of food and feed impact the Japanese N footprint?
(3) How does the Japanese N footprint change for different consumer age groups?

2. Materials and methods

2.1. Calculation of the N footprint

We applied the N-calculator developed by Leach *et al* (2012). This study assessed the recent N footprint in Japan during 2000s using the available data as explained below (Supplement table 1). The analytical framework and calculation methods are the same as Leach *et al* (2012).

The following equation expresses the general concept used to calculate an individual's N footprint:

$$FP_{ind} = FP_{avg} \times AU_{ind}/AU_{avg}, \quad (1)$$

where FP_{ind} is the individual footprint for food, energy, transportation, and goods and services, FP_{avg} is the average per capita footprint for the country, AU_{ind} is the individual use in each sector, and AU_{avg} is the average per capita use of each sector for a country.

This equation is used for each component of an N footprint: food production, food consumption, housing, transportation, and goods and services. The sum of these components gives the total individual N footprint.

The food N footprint consists of consumption and production. We used food supply data (average consumption per capita and N content of the food consumed) from [FAOSTAT] Food and Agricultural Organization of the United Nations Statistical Database (2009) to calculate the consumption footprint. Losses that occur after a food product is available for consumption (e.g., waste during transportation, at the retailer, and with the consumer) were subtracted from the initial food supply to determine the amount of food consumed. The nitrogen removal via denitrification in sewage treatment was also subtracted from the food consumption N

Table 1. Virtual N factors (VNF) of major food categories in Japan, US and Europe[4]. The VNF is a unit-less ratio of Nr released to the environment during the food production process per unit of Nr consumed.

Food category	Japan[1] without trade	Japan[1] with trade	US[2]	Europe[3]
Animal products				
Poultry meat	10.7	6.0	3.2	3.2
Pigmeat	12.9	6.7	4.4	4.4
Bovine meat	27.3	12.4	7.9	7.9
Fish and seafood	1.7	2.9	4.1	2.9
Milk and dairy products	3.9	2.7	4.3	3.9
Crop products				
Cereals	3.3	1.5	1.4	1.3
Vegetables	4.6	5.5	9.6	8.2
Starchy roots	6.1	4.9	1.5	1.1
Legumes	2.8	1.3	0.5	0.5

[1] This study.
[2] Leach *et al* (2012), updated.
[3] Stevens *et al* (2014): note that the European factors are a US/Europe hybrid. They used US data for the first few steps of the food production process, European data for the remaining steps.
[4] The values in US and Europe do not include the effect of trade.

footprint. We used a weighted average, assuming 31% of sewage plants in Japan remove 50% of N through advanced sewage treatment, and the other 69% of plants remove 25% of N through normal sewage treatment (Oda and Matsumoto 2006, Kankyo sangyo shinbun Co. Ltd 2013).

The food production N footprint was calculated based on food intake (i.e., food supply minus food waste) and the amount of N lost during the production of that food, presented as virtual N factors (VNFs). Virtual N includes losses such as fertilizer not incorporated into the plant, crop residues, feed not incorporated into the animal product, processing waste, and household food waste (Leach *et al* 2012; supplement figure S-1). We calculated the VNFs as a ratio of Nr released to the environment during food production per unit of Nr consumed, by food type. We estimated these factors for the following major food categories (based on FAO food categories): pigmeat, poultry meat, bovine meat, fish, milk, rice, vegetables, starchy roots, and legumes. For other food categories, we assigned the VNFs to a calculated VNF with the most similar food production process. The production process for each food category was analyzed at each stage of the process. The energy component of the food N footprint (i.e., the Nr released from fossil fuel combustion associated with food production) was calculated using an environmentally extended input output analysis that used national emissions data for Japan (Kitzes 2013). Further details of the calculation method for the food N footprint are available in Leach *et al* (2012).

To calculate Japanese VNFs, we consulted government statistics, reports, and academic publications from Japan. Data sources are listed in the supplement table S-1. We used data on N flow and stocks at each step of the food production process for major food categories; these data were collected from statistics and reported values (supplement table S-1, S-2 and S-3). For example, N fertilizer and manure application to cropland ranged 58–427 and 20–120 kg N ha^{-1} y^{-1}, respectively (Mishima 2002, Mishima *et al* 2010). We assumed that there was no recycling of carcass waste for bovine meat because this is prohibited in Japan due to bovine spongiform encephalopathy (Ozawa 2012). For data not available for Japan, we used parameters from the US VNFs (Leach *et al* 2012).

Energy consumption from burning fossil fuels produces nitrogen oxides (i.e. NO_x). Energy is primarily used in three consumption areas: housing (e.g., cooking, heating, cooling), transportation (e.g., car, train, plane, public transportation) and goods and services (energy used to provide goods and services such as social welfare programs and public park maintenance). We combined bottom-up and top-down approaches to calculate the energy consumption N footprint. The bottom-up approach estimates the N released from energy use in housing and transportation based on an individual's activity (e.g., kwh electricity consumed) and the related emission factors (e.g., NO_x emission factor). The top-down approach is used to calculate the part of the energy N footprint that is not covered by the bottom-up approach, such as for food energy (e.g., on-farm energy usage, transportation, catering services), utility infrastructure, goods and services. National emissions data and an environmentally-extended input–output analysis (Kitzes 2013) were used for the top-down approach. Further details for the calculation of the energy consumption N footprint are also available in Leach *et al* (2012).

2.2. Incorporation of food and feed import into the N footprint

We incorporated the import of foods in the Japan VNFs:

$$VNF_{trade} = SSR \times VNF_{in\text{-}country} + (1–SSR) \times VNF_{import}, \quad (2)$$

where VNF_{trade} is the VNF with food trade (import), SSR is the self-sufficiency rate of each food category, $VNF_{in\text{-}country}$ is the VNF without food trade, and VNF_{import} is the VNF in the exporting country. Multiple countries (e.g., US, Brazil, Australia) export food to Japan. Since the VNFs for most of these exporting countries are not yet available, we used the VNFs for the US to represent countries with industrialized production systems. This analysis will be updated when the VNFs in other exporting countries become available.

We determined the SSR of each food category using the food balance sheet provided by [FAOSTAT] Food and Agricultural Organization of the United Nations Statistical Database (2009):

$$SSR = (\text{in-countryfoodproduction})/(\text{net food supply}). \quad (3)$$

Most livestock feed in Japan is also imported from foreign countries. Since the N released during the production of the imported feed differs from that in Japan, those factors (i.e., N uptake for feed crops, processing and recycling of feed N) were replaced using the factors for the exporting country. We calculated VNFs of animal products (i.e., poultry meat, pigmeat, bovine meat, and milk) with feed import using the self-sufficiency rate for feed (SSR_f):

$$VNF_{\text{in-country\_feed}} = SSR_f \times VNF_{\text{in-country}} + \left(1 - SSR_f\right) \times VNF_{\text{feed-import}}, \quad (4)$$

where $VNF_{\text{in-country\_feed}}$ is the VNF with feed import, and $VNF_{\text{feed-import}}$ is the VNF calculated using the feed factors (uptake, harvest, and recycling) in the exporting country. All other factors are the same as those in the $VNF_{\text{in-country}}$. Again, we used the US feed crop factors for $VNF_{\text{feed-import}}$ to represent countries with industrialized production systems. We assumed a 25% of self-sufficiency rate for feed based on the recent average in Japan ([MAFF] Ministry of Agriculture, Forestry and Fisheries 2011).

For animal products, we first calculated the $VNF_{\text{in-country\_feed}}$ (equation (4)), and then used the values (as $VNF_{\text{in-country}}$ in equation (2)) to determine the VNF_{trade} (equation (2)). We compared the N footprints using the $VNF_{\text{in-country}}$ and VNF_{trade} to discuss the impacts of trades on the N footprint.

2.3. Calculation of the food N footprint for different age groups

Food intake data by food category for different age groups ([MAFF] Ministry of Agriculture, Forestry and Fisheries 2011) was used for this analysis. These food consumption statistics are based on a nation-wide survey. The relative ratios of the age group's food intake (annual amount per capita) to the Japanese average were used to determine the food (protein) consumption in each food category. We compared the food N footprints for different age groups (20s, 30s, 40s, 50s, 60s and >70). We used the VNFs with trade included (equations (2)–(4)) for those calculations.

3. Results

3.1. VNFs

Table 1 gives VNFs in Japan with and without trade, and VNFs of US and Europe (Leach *et al* 2012, Stevens *et al* 2014). The European VNFs were calculated using US/Europe hybrid factors (Stevens *et al* 2014). The VNFs of poultry meat, pigmeat and bovine meat in Japan are much higher than vegetables, cereals, fish and seafood, and milk and other dairy products. The VNFs for poultry meat, pigmeat, and bovine meat in Japan are higher than those in US and Europe. Incorporating trade reduces these VNFs: poultry meat (44% decrease), pigmeat (48% decrease) and bovine meat (55% decrease) (table 1). Incorporating trade also reduced the VNFs for milk and dairy products (31% decrease), cereals (55% decrease), starchy roots (20% decrease) and legumes (54% decrease). However, trade increased the VNF for fish and seafood (70% increase) and vegetables (20% increase).

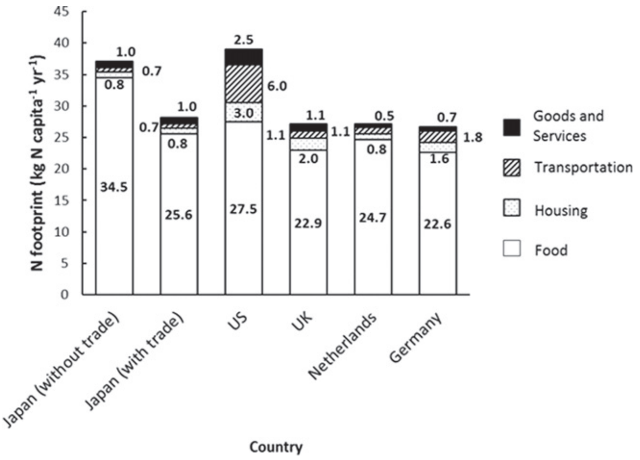

Figure 1. Average N footprint per capita in Japan (without and with food trade), US[1], UK[2], Netherlands[1] and Germany[2]. The N footprints for other countries do not incorporate food trade. [1]Leach *et al* (2012). [2]Stevens *et al* (2014).

3.2. Average N footprint in Japan

The total N footprint with and without trade in Japan was 28.1 and 37.0 kg N capita^{-1} yr^{-1}, respectively (figure 1). In both cases, the food N footprint (including production and consumption) made up over 90% of the total N footprint. Contributions from housing, transportation, and goods and services were each about 1.0 kg N capita^{-1} yr^{-1} (ca. 3%–4% of the total N footprint) or less (figure 1).

3.3. Food N footprint for different age groups

Figure 2 shows the annual intake (kg capita^{-1} yr^{-1}) of major food categories per capita for different age groups in Japan ([MAFF] Ministry of Agriculture, Forestry and Fisheries 2011). Younger age groups tend to consume more meat and fewer vegetables, fish and seafood compared to older age groups, especially those over 70. The 20s age group consumed about 40% more meat (all animal meats) than the country-wide average in 2008, while the >70 age group consumed about 40% less (figure 2). Due to these consumption differences, the 20s age group had the highest food N footprint (27.5 kg N capita^{-1} yr^{-1}) and the >70 age group had the lowest (23.0 kg N capita^{-1} yr^{-1}) (figure 3).

4. Discussion

4.1. Characteristics of the Japanese N footprint

The food N component dominated the total Japanese N footprint, ahead of energy, transportation and goods and services components (figure 1). The same fact is evident in previous studies of other countries (Leach *et al* 2012, Stevens *et al* 2014). However, the Japan VNFs for animal products both with and without international trade were much higher than those for other countries (table 1). In the US model, the portions of N uptake for feed crops and N accrued in the animal were 82% and 20%–45%, respectively (Leach

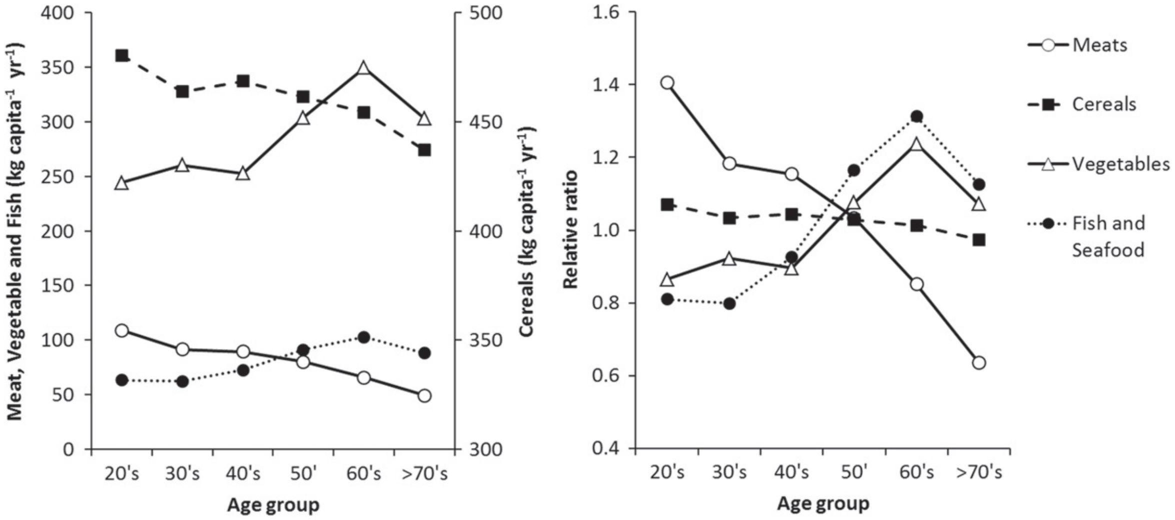

Figure 2. Food intake per capita for different age groups in 2008 (kg capita^{-1} yr^{-1}) ([MAFF] Ministry of Agriculture, Forestry and Fisheries 2011) and the relative ratio of food intake (amount with respect to the country-wide mean) are illustrated in left and right, respectively.

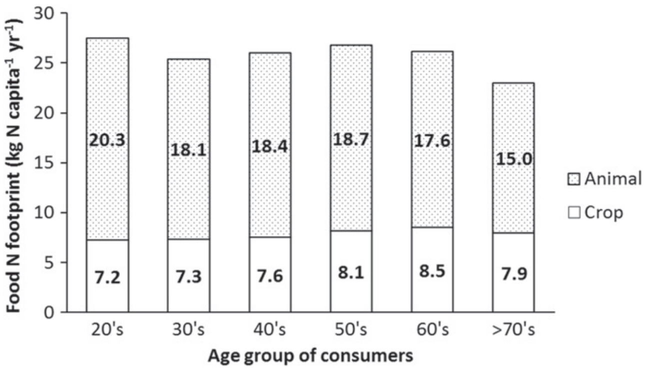

Figure 3. Food N footprints for different age groups in Japan. Food production N footprint assumes food and feed trade.

Table 2. Comparison of annual supply of major food categories per capita (kg capita^{-1} yr^{-1}) in Japan, the United States, the United Kingdom, The Netherlands, and Germany.

Food category	Japan	US	UK	Netherlands	Germany
Animal products					
Meats	43.5	120.2	84.2	85.5	88.1
Fish and seafood	54.3	24.2	21.2	19.7	15.2
Milk and dairy products	84.8	280.3	288.9	378.8	369.9
Crop products					
Grain	107.5	109.8	115.9	84.6	110.6
Vegetables	104.7	122.9	89.4	82.8	92.9
Potatoes	21.5	56.9	104.5	94.2	72.0
Legumes	8.9	7.7	4.8	2.4	2.6

Data source: [MAFF] Ministry of Agriculture, Forestry and Fisheries (2009) statistics of agriculture, forestry and fishery.

et al 2012). The Japanese value for uptake of N in feed crop (ca. 59%) was lower than the US, as was the N accrued in the animal (ca. 14%–39%). These values drive the VNFs, so small difference may account for large VNFs for animal products in Japan compared to the US. Terada *et al* (1998) and Choumei *et al* (2006) also reported lower rates of N accrued in beef cattle in Japan (ca. 12%–13%). Our results suggest that in general animal food consumption in Japan causes more N to be released compared to that in the US and Europe.

On the other hand, the VNF for fish and seafood in Japan was lower than for other countries (table 1). This is likely due to the dominance of marine fisheries (pelagic, offshore, and coastal) over aquaculture and inland fisheries in Japan. The VNFs for milk and vegetables without trade in Japan was also lower than those for other countries (table 1), suggesting that these production systems in Japan are relatively less N-intensive than in other countries. Japan could lower its overall N footprint if it were able to produce more fish and seafood, vegetables, and milk in-country.

The annual supply of meat and dairy products in Japan is quite low compared to the US and Europe (table 2). However, the supply of fish and seafood in Japan is much higher than other countries. The high VNF for meat products balances with the relatively small amount of meat available for consumption. The reverse is true for fish and seafood: more fish and seafood available for consumption balances the lower VNF of those products. Overall, our results indicated that the Japanese food N footprint was comparable to or higher than other countries because of the high animal product VNFs (figure 1).

4.2. Impact of trade on the Japanese N footprint

We compared the N footprint in Japan considering trade to those in other countries without trade (figure 1) because food self-sufficiency in these other countries (127, 72, 66, 92% for US, UK, Netherlands, Germany, respectively, [MAFF] Ministry of Agriculture, Forestry and Fisheries 2011) was much

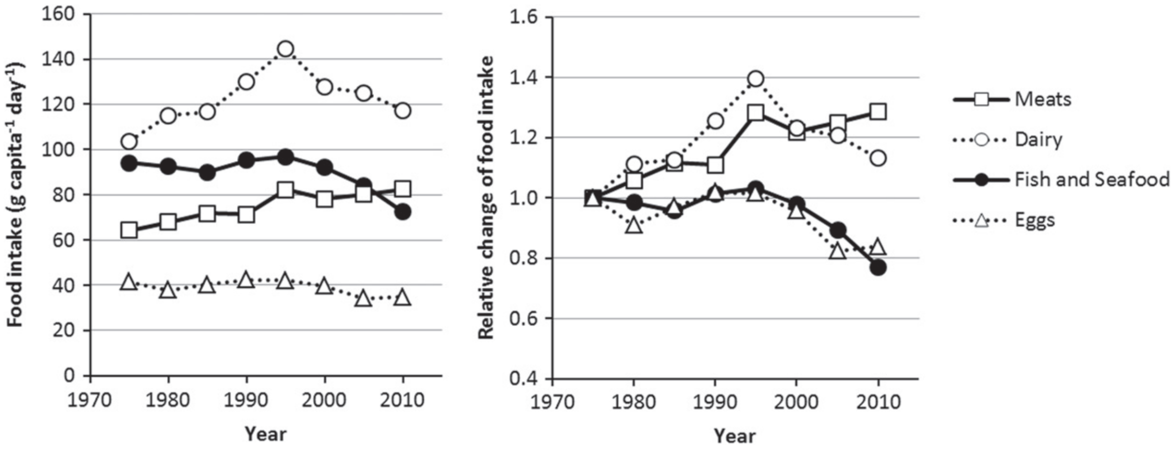

Figure 4. Temporal change in per capita average animal-product consumption for 1975–2012 (Ministry of Health, Labour and Welfare 2014). The left panel shows average total daily food intake (g capita^{-1} d^{-1}). The right panel shows the relative ratio compared to the food intake in 1975. Meat includes poultry, pigmeat, bovine and other meats. Dairy includes milk and other dairy products.

higher than that in Japan (39%). The total N footprint in Japan with trade was lower than the US and was comparable to values in the UK, Netherlands and Germany (figure 1). The US, UK, Netherlands and Germany (Leach *et al* 2012; Stevens *et al* 2014) were chosen for comparison because we used the same calculation methods (e.g., developed an N-calculator). The Japanese food N footprint with trade (25.6 kg N capita^{-1} yr^{-1}) was slightly lower than the US (27.5 kg N capita^{-1} yr^{-1}) and slightly higher than UK, Netherlands, and Germany (22.9, 24.7 and 22.6 kg N capita^{-1} yr^{-1}, respectively), although the statistical tests were not performed in this paper because of the lack of replicable sources. The sum of the other N footprint sectors in Japan (2.5 kg N capita^{-1} yr^{-1}) was comparable to values in the Netherlands (2.4 kg N capita^{-1} yr^{-1}), and lower than values in the US, UK, and Germany (11.5, 4.2, and 4.1 kg N capita^{-1} yr^{-1}), respectively.

Japan imports a large amount of food and feed, relative to internal production. Although Japan's self-sufficiency rate for rice is almost 100%, other crop and animal products were mostly imported (supplement figure S-2). Incorporating trade changed the VNFs for all food categories (table 1). Since the VNFs for animal products in Japan were much higher than those in the US, trade reduced the Japanese VNFs and the overall N footprint. The feed import with higher N uptake rates further reduced the VNFs. On the other hand, food imports with a higher VNF_{import} than $VNF_{in\text{-}country}$ such as fish and seafood and vegetables increased the Japanese VNFs (table 1).

These results clearly indicate that international trade plays a major role in the global N cycle. Exporting countries experience more local N losses from food production for international trade. For example, wheat is imported to Japan from the US. While this reduces the N loss occurring in Japan, it results in more N loss in the US. Recognizing issues of equitability in food production and consumption could open discussions and will be important in developing national and global N mitigation plans. Global Nr losses could also be reduced as a result of international trade when food is imported from a country with lower VNFs.

4.3. Relationship between age group and N footprint

Figure 4 illustrates long-term changes in national average food consumption for major animal products from 1975 to 2012 (Ministry of Health, Labour and Welfare 2014). Since the late 1990s, per capita meat consumption in Japan have increased slightly, while fish and seafood, and egg consumption have decreased (figure 4). Dairy consumption exhibits a larger variation and temporal spikes. These patterns suggest that the per capita food N footprint may increase from a general rise in meat consumption. Many factors drive food consumption patterns, including age (figure 3). Our results indicated that the youngest age group (20s) tends to have a larger food N footprint than the oldest age group (>70), primarily due to varying dietary preferences (figures 2 and 3). These differences in food preference could be influenced by other factors, such as economic status, nutritional demand, cultural background, or general lifestyle. Overall, food preference strongly influenced the size of food N footprints in Japan. Since the >70 age group had the lowest N footprint and the younger age groups had larger N footprints, Nr losses could increase in the future purely from dietary choices. Consumer choice plays an important role in determining the per capita N footprint.

4.4. Sources of uncertainty

In developing the Japanese N-calculator, we recognized some sources of uncertainty.

In incorporating trade into our calculations, we used the VNFs for the US as a representative country for countries with industrialized production systems. In reality, foods are imported to Japan from various countries. Poultry meat is mainly from Brazil and the US; pigmeat is mainly from the US, Canada, and Denmark; and bovine meat is mainly from Australia, the US, and New Zealand. If we were able to use the VNFs for those countries, we could improve the Japanese N footprint. Developing a database of VNFs for various countries could help to predict the global N footprint, as driven by international trade.

In calculating trade contributions to the N footprint, we also did not include N released from the transportation of imported foods (i.e., fuel combustion in planes, ships, trains). This value may be large for food and feed transported from far distances. These factors should be included in future calculations. Additionally, we did not include imported goods and services in our calculations. Although the contribution to the N footprint from goods and services is quite low, this may also be good to consider in future calculations.

In Japan, some dairy cattle are utilized as bovine meat after they are no longer useful for milk production (ca. 23%–24% of total beef production) ([MAFF] Ministry of Agriculture, Forestry and Fisheries 2013). This might happen in other countries, too. Bovine meat originating from dairy cattle could have a lower VNF than normal bovine meat because most of the N released during productive years has already been assigned to the process of milk production. Therefore, incorporating dairy cattle meat into the beef VNF would reduce the beef VNF.

4.5. Suggestions for improving the N footprint

There are several ways individuals and countries can decrease their contributions to N losses to the environment. Improving the nutrient use efficiency (NUE) of crop and animal production systems—especially during the initial production process (i.e., fertilizer uptake in plants, and animal N feeding efficiency)—would be one opportunity to reduce Japanese and other VNFs. Our results suggested the NUE management in the exporting country can contribute greatly to the N footprint of Japanese consumers. For example, if the N conversion efficiency in bovine meat is assumed to increase from 0.14 (factor for Japanese beef VNF) to 0.20 (factor for US beef VNF), the overall beef VNF would decrease from 27.3 to 19.0 (data not shown). This suggests that improving the N use efficiency of livestock is a very effective way to reduce the VNF in the Japanese agricultural system. Improved NUE management could not only reduce the footprint of Japanese consumers, but could also lessen the environmental burden placed on the exporting country. Improving NUE in Japan could also lessen N losses in-country.

Individuals can improve their personal N-footprint in a number of ways: changing food consumption patterns to limit intake of foods with high VNFs, consuming the recommended amount of protein, reducing activities that require the use of fossil fuels, etc.

5. Conclusions

We present the first approach to the development of the N-calculator tool for use in Japan in order to determine an individual's current nitrogen (N) footprint. We considered four sectors that contribute to this footprint: food, energy, transportation, goods and services, including the effect of food trade on the N footprint. We found that:

- The N footprint in Japan including trade was 28.1 kg N capita^{-1} yr^{-1}. The footprint was dominated by food production. Similar to other countries, energy, transportation, goods and services sectors made minor contributions to the Japanese N footprint.
- The total N footprint in Japan was comparable to European countries and smaller than the US. VNFs for animal products produced in Japan were relatively higher than previous studies.
- Incorporating international food and feed trade affected most VNFs and the overall food N footprint in Japan. Japan relies heavily on imported food (ca. 61%), so a large portion of the N lost during the food production process is lost to the environment in the exporting country.
- The food preferences between different age groups influenced the food N footprint. Younger age groups, who tend to prefer meat, have a higher N footprint than older age groups, who tend to prefer fish and seafood.
- If younger age groups continue to prefer meats, then Nr losses could increase even with improvements in NUE. Consumers can affect their N footprints through dietary choices.
- Some challenges for managing N pollution include limitations in technology for increasing crop NUE and the effects of trade on global Nr production.

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