Ecological footprint evaluation of Japanese domestic food consumption considering water footprint

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Abstract Ecological footprint (EF) is widely used for evaluating the sustainability of human activities, because of its comprehensiveness and understandability. However, conventional EF has excluded some important environmental loads (e.g., water resources used for food production). This study proposes an improved EF indicator, which includes water footprint (WF) and evaluates Japanese domestic food consumption. The WF is converted to EF by a coefficient that indicates the scarcity of water resource relative to its land area in each country. EF of WF can duplicate on other land category other than fishing ground when summing up to calculate total EF. The results suggest that EF of Japanese domestic food consumption is about 7 times greater than that of the Japanese land area, and 1.5 times greater than Japanese land area, excluding fishing grounds. In other countries EF of WF exceeds other land categories, whereas in Japan is lower than that of other land categories.

1 Introduction

Ecological footprint (EF), which is measured on the basis of land area usage, is an important sustainability indexes because it is a comprehensive and easily understandable means of evaluating the scale of human activity as a value of land area used. EF is now widely used to evaluate the sustainability of global, national, and regional bioconsumption. World Wide Fund [1] reported that global EF corresponds to 1.5 times of global biocapacity. Ministery of Land Infrastructure Transport and Tourism (MLIT) [2] estimated the Japanese EF at the prefectural level, and they concluded that it was 7.82 times greater than the Japanese land area.

This report also suggested that food consumption is a key contributor of EF and accounts for 18% of all EF in Japan.

EF estimation typically considers the following 6 categories: cropland, grazing land, forests, fishing grounds, carbon-uptake land, and built-up land [3]. Fresh-water consumption is an important environmental load in food consumption. However, this aspect was not included in the conventional EF estimation. This study proposes an EF indicator, which considers the water footprint (WF) and available water resources in food-producing countries. Moreover, we also analyzed the EF of Japanese food consumption by using the proposed method, and included future estimations.

2 EF indicator considering WF

2.1 EF and WF

EF is an index that describes the scale of the consumption of various natural resources and the environmental load of the land area. The EF is an useful index, because it evaluates the percentage by which the biocapacity of the earth/countries/local areas has exceeded. The 5 categories that have been considered in conventional EF are crop land, grazing land, forest, carbon-uptake land, and built-up land; all of which encompass land and water resources. Carbon-uptake land is a virtual footprint, based on the assumption that anthropogenic carbon dioxide is mostly absorbed by forests.

Freshwater consumption is an important index, which measures the scale of human activities. WF can be described as water-resource consumption that affects the economy of the country. If the EF and WF are treated as 1 index, EF will be the more comprehensive sustainability index.

The WF has to be converted into land-area usage during EF estimation. This study assumes that utilization of freshwater amounts to its usage from catchment areas, which is later used for human activity. This method can take into account the scarcity of water resources.

The virtual land use in conventional EF and carbon-uptake land can be combined with other land categories,. In other words, a certain land area cannot belong to two or more land categories simultaneously. However, the catchment area for WF can belong to other land categories. Conventional land categories can be used as water catchment areas. For example, rain-fed cultivation can be interpreted as an agricultural activity that requires using water from the catchment area that takes up cultivable land. Thus, irrigated cultivation requires a catchment area larger than the land used for cultivation, because the additional catchment area is needed to store water for irrigation.

On the basis of this concept, we compared water catchment areas with other land categories, excluding fishing grounds, and used the larger areas as the land EF (Fig. 1).

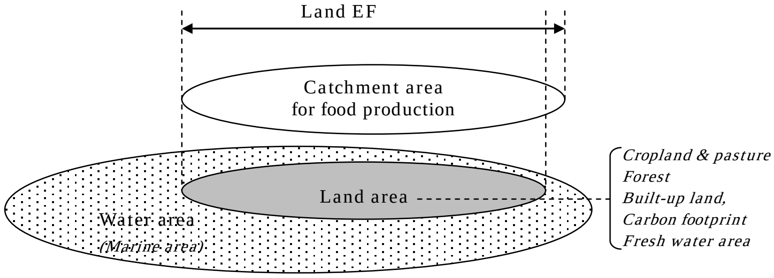

Fig.1: Concept of calculating ecological footprint (EF) considering the water footprint (WF). In this case, the catchment area exceeded the total area of 5 land categories. Total EF area is the sum of the catchment area and water area (marine area).

2.2 Methodology of estimating the EF considering the WF (in case of food consumption)

2.2.1 Cropland and grazing land

The EF of cropland and grazing land is estimated using equation (1).

$$EF_a = \sum_i \sum_j \frac{x_{ij}}{p_{ij}} \qquad (1)$$

Where EF_a = cropland EF (ha); i = commodity; j = country; x_{ij} = domestic consumption of commodity i produced in the country j (t); p_{ij} = yield of commodity i in country (t/ha).

For livestock products, cropland and grazing land that are used to produce feed for livestock production are estimated using equation (2).

$$p_{livestock} = y_{livestock} \Big/ \left(\sum_f \sum_j \frac{x_{f,j}}{p_{f,j}}\right) \qquad (2)$$

Where $p_{livestock}$ = land productivity of livestock products (t/ha), f = commodity of feed (including pasture) $y_{livestock}$ = domestic livestock production (t)

Land productivity seems to be affected by the availability of water resources in each country. Thus, EF of croplands and grazing lands is influenced by the water resources. However, this does not pose problems of double counting with WF.

2.2.2 Fishing ground

Equation (3) shows calculation of EF for fishing grounds, based on existing research [2]. This equation first allocates demands by commodity to the water area by J_{iq}, estimates net fish catch by L_q, estimates primary production to yeild unit weight of commodity i . EF is estimated by primary production per unit area.

$$EF_m = \frac{x_i J_{iq}(1+L_q)\cdot 10^{(M_{iq}-1)}}{9N_q} \qquad (3)$$

Where EF_m = water area for fishery production (ha); q = water area; J_{iq} = existing probability of commodity i in water area; L_q = by-catch discard rate in water area q; M_{iq} = trophic level of commodity i in water area q; N_q = primary production per unit area in water area q (tC/ha).

The EF of fishing ground is divided into freshwater fishing ground EF_{mf} and marine fishing ground EF_{mo}, as shown in equation (4).

$$EF_m = EF_{mo} + EF_{mf} \qquad (4)$$

2.2.3 Carbon-uptake land

Carbon-uptake land is the land area that absorbs carbon dioxide, and generally comprises of the forest area. This study estimates the life cycle of carbon-dioxide emission and its relation to food production, and imports and divides it by global average carbon uptake of forest land to calculate EF as given in equation (5).

$$EF_{CO2} = \frac{\sum_i \sum_j (c_i + sD_j)x_{ij}}{C} \qquad (5)$$

Where EF_{CO2} = carbon-uptake land (ha); c_i = lifecycle emission of producing commodity i (tCO_2/t); s = emission factor from maritime trade (tCO_2/tkm);

D_j = transportation distance from country j to consuming country (km); C = average carbon uptake of forest land (tCO_2 / ha)

2.2.4 Water footprint

In this study, EF of WF is assumed as catchment area, formulated as equation (6).

$$EF_{vw} = \sum_j \sum_i \frac{vw_i x_{ij}}{d_j} \qquad (6)$$

EF_{vw} = EF of WF (ha); vw_i = unit water usage for producing commodity i (m^3 / t); d_j = renewable water resource per land area of country j (m^3 / m^2).

This equation assumes that the conversion factor from WF to EF is renewable water resource per land area, which reflects the average water scarcity in each country. EF of WF is calculated by adding the water catchment areas used for producing each commodity.

2.2.5 Evaluation of EF considering WF

The EF considering the WF is calculated by equation (7).

$$EF_{all} = \max\left\{ f_a EF_a + f_m EF_m + f_{CO2} EF_{CO2}, f_{vw} EF_{vw} + f_{mo} EF_{mo} \right\} \qquad (7)$$

Where EF_{all} = EF considering the WF (ha) and f = equivalence factor of each land category.

Tab.1: Equivalence factors of land categories.

Land category	Equivalence factor	Source
Cropland	2.51	[3]
Grazing land	0.46	
Forest area	1.26	
Built-up land	2.51	
Fishing ground	0.37	
Water catchment area	1.16	This study

Equivalence factors convert land-use area, which has different potential bioproductivity, to equivalent areas having average bioproductivity. The equivalence factor of the WF is defined as an average of equivalence factors of other land categories, excluding marine fisheries. This assumes that all land areas including inland water are water-catchment areas, which are used in calculating the average water resources available per land area of each country (d_j in equation (6)). This water consumption inhibits the bioproductivity of the whole water-catchment area. Consumption of all renewable water resources indicate that no water can be used for bioproduction in water catchment areas, and this amounts to blockage of potential bioproductivity in all water catchment areas. Table 1 shows the equivalence factors of land categories.

This study compares converted EF of croplands, grazing lands, fishing grounds, and carbon-uptake lands with that of WF and fishing grounds other than freshwater fisheries. The larger EF is the total EF.

3 Case study: evaluation of Japanese food consumption

3.1 System description

This case study aimed to evaluate the present and future EF of the Japanese food consumption pattern. The base year of estimation is 2002. The future scenario targets the year 2015. Commodities in estimation include cereals, vegetables, beans, fruits, sugar, fats and oils, fishes and shellfishes, and meat. This case study includes the production and import of raw food materials; however, the environmental load encountered because of food processing and energy consumption in restaurants is not considered in the study.

3.2 Data and sources

Data on food production, import, and consumption in 2002 were collected from national statistics and literatures [2, 4-5].

Data on the future production/consumption scenario in 2015 was based on the Basic Plan for Food, Agriculture, and Rural Areas [6] by the government of Japan, as shown in Table 2.

Emission factors [7] and unit water usage related to food production are based on input-output analysis. WF per production contains blue and green WF; the gray WF is not considered. In this case study, water use abroad is substituted by Japanese domestic data.

Tab.2: Food consumption scenario in Japan

Commodity	2002		2015	
	Consumption (1000 t)	Domestic production (1000 t)	Consumption (1000 t)	Domestic production (1000 t)
Rice	9,460	8,890	10,080	9,690
Wheat	6,200	830	6,520	800
Barley	2,450	220	2,580	350
Sweet potatoes	1,070	1,030	1,200	1,160
Potatoes	3,790	3,070	4,160	3,500
Soybean	5,310	270	5,110	250
Vegetables	15,920	13,270	17,250	14,980
Fruits	8,770	3,880	8,420	4,310
Dairy products	12,170	8,380	13,180	9,930
Beef	1,330	520	1,660	630
Pork	2,350	1,250	1,860	1,350
Chicken	1,900	1,230	1,720	1,250
Egg	2,640	2,530	2,500	2,470
Sugar	2,590	870	2,550	840
Fats, oils	2,910	770	2,810	770
Fishes, shellfishes	11,110	5,160	11,040	6,990
Seaweed	210	140	200	140
Mushroom	500	390	530	410

Tab.3: Water resource data in some countries

	Land area (million ha):A	Renewable water resource (km3/year) [10]:B	B/A(m)
Japan	37.8	420	1.11
China	956	2,897	0.30
Thailand	51.3	410	0.80
Canada	997	2,902	0.29
US	963	3,069	0.32
Australia	774	492	0.06
Argentina	278	814	0.29

Data on water resources of food-producing countries were obtained from the Food and Agriculture Organization [8]. d_j in some food-producing countries are shown in Table 3.

3.3 Results

Fig. 2 shows the EF in each land category in 2002. Domestic EF of WF did not exceed EF of land use and carbon footprint; however, the former is almost 2 times higher than the latter in countries other than Japan. EF areas of land use and carbon footprint were approximately similar on average food consumption patterns in Japan. Food transportation accounted for 46% of the carbon footprint.

The larger area between EF of WF and other EF area in Fig. 2, is taken into account to total EF, in Fig. 3. The EF of Japanese food consumption covers an area 3.7 times larger than the total land area of Japan, and if the fishing grounds are excluded, then this area is 1.9 times larger. In Japan, 70% of the EF comes from import trading partners, although 60% of their dependence on food supply is on a per calorie basis.

Future EF is estimated as shown in Fig. 4. If the Japanese government is able to achieve the political plan drafted for 2015, the EF of Japan will slightly increase (3.8%), and its international dependence will decline because of Japan's improved self-sufficiency ratio. Shift of EF from other countries to Japan will mainly occur in the fishing grounds. In other countries, the WF will decrease by 3.0% abroad, while carbon-uptake land will increase by 13.7%. This result suggests that the reduction of environmental load and improvement of the self-sufficiency ratio should be planned simultaneously to ensure sustainable food consumption.

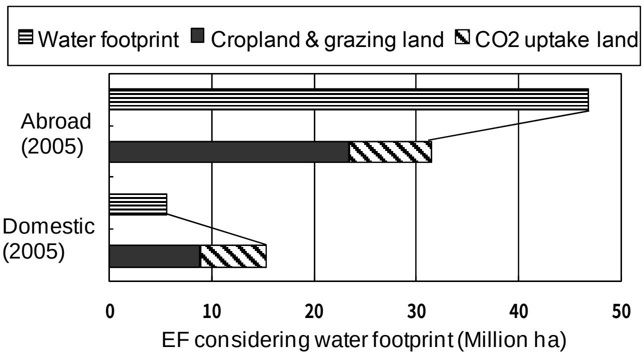

Fig.2: EF of Japanese food consumption, excluding marine area

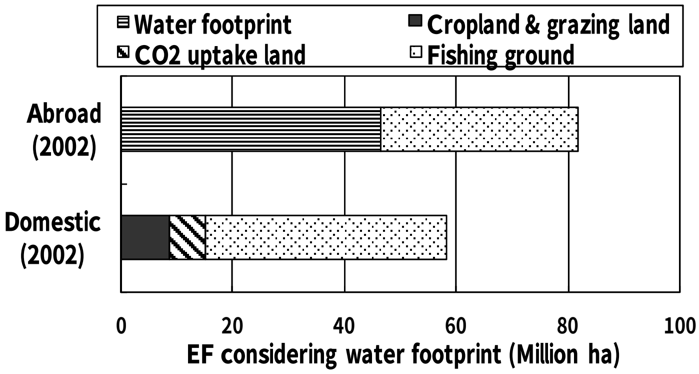

Fig.3: Total EF of Japanese food consumption in 2002

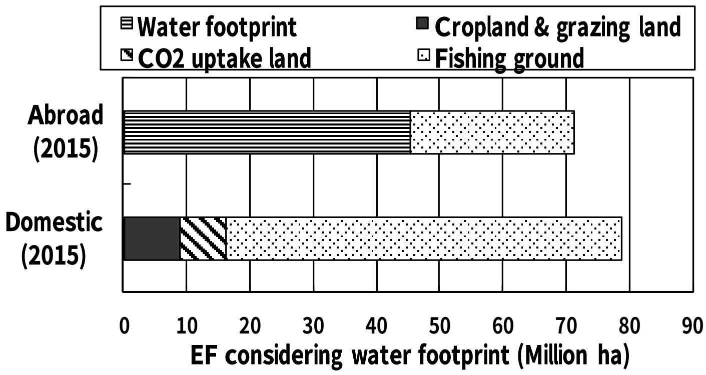

Fig.4: Total EF of Japanese food consumption in 2015

4 Discussion and conclusion

The proposed EF indicator, which considers WF as the index of sustainability in water use, reflects the state of water resources situation in each country. For regional- or national-level assessment, in countries having water-consuming processes but limited water resources, the EF will increase beyond the conventional EF. In other processes, the new EF and conventional EF will have identical footprint areas theoretically.

The calculation procedure for the new EF retains the simplicity of conventional EF calculation, and takes into consideration the water resources available in the country; data that is easily accessible. However, total EF would change depending on the data on water resources. (e.g., catchment-area water level or countrywide water levels). Case studies must be conducted to verify the effect of the evaluation scale.

The equivalence factor of WFs that have been taken into consideration in this study, include average land categories, excluding fishing grounds. This seems to be the most representative value, because water shortage affects all categories of bioproduction. We should also examine alternative equivalence factors (e.g., maximum bioproductivity of other land categories that equals to maximum productivity of cropland) to determine the most suitable factor.

This case study on Japanese food consumption demonstrates the features of the proposed EF. This study provides quantitative evidence that water-resource consumption is strongly associated with sustainability of food consumption. In this case study, we have assumed that future technology would be similar to the present technology and have taken into account only the consumption patterns. Dynamic life cycle assessment modeling can be applied to analyze the situation and propose the future course of sustainable food consumption.

5 References

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