論　文　要　旨 Dissertation Abstract

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専攻 Major 環境リスクマネジメント専攻	学籍番号 Student ID 12TF005	氏　　名 Name 種田 あずさ Oita Azusa

論文題目 Dissertation Title	Improvement of Nitrogen Footprint Models: Analysis for Seafood and International Trade （窒素フットプリントモデルの改良－水産物および国際貿易に着目して）

Humans are transforming the global nitrogen cycle by creating more reactive nitrogen (Nr; all species except N_2) than is created through natural processes every year. The excess Nr is created mainly by fertilizer use and fuel combustion. Since nitrogen is essential to grow crops, fertilizer use has been on a drastic increase to feed an ever-growing world population exhibiting increasing preference for animal products. However, the excess Nr in the environment has various negative effects, including eutrophication, climate change, acidification, and human health problems. The level of current human effects upon the cycle is roughly three times beyond the plant's safe operating space. Given the excess nitrogen contributing to the severe degradation of the marine ecosystem, urgent action is committed at the Rio+20 summit and included in Sustainable Development Goals.

The concept of footprint has been developed to analyse the resource requirements throughout the whole life cycle, initially as ecological footprint, followed by carbon footprint, water footprint etc. Two types of approaches have been applied to calculate environmental footprints in the literature: bottom-up and top-down approaches. Bottom-up approach refers to both a process-based life cycle analysis using detailed descriptions of individual production processes and a coefficient analysis based on analyses of individual production processes. The advantages of the approach are simplicity for understanding and sensitivity for accessing difference in product level. It is widely used in practical business. However, this approach does not trace the entire industrial supply chain, leading to inter-sectoral cut-off and inter-regional cut-off. Top-down approach refers to both a mass balance analysis based on national statistics and an economic input–output (IO) analysis using hierarchical models with total factor multipliers based on national economies to determine embodied effects per unit of production. The advantages of the approach are comprehensiveness for its coverage and, for IO analysis, capability for tracing the entire supply chains. Single-region IO (SRIO) analysis can capture inter-sectoral cut-off, and multi-region IO (MRIO) analysis can capture both inter-sectoral and inter-regional cut-offs. However, these methods are limited by the numbers of sectors in the IO database used, in analysing detailed consumption. It is commonly used in analyses on the national and supra-national level.

The nitrogen footprint (NF) concept has been introduced to show consumers' contributions to nitrogen pollution. NF measures the total amount of Nr emitted as a result of resource consumption. The previous NF model for individuals (the N-calculator method) consists of food NF and energy NF. Food NF was calculated by a flow-based model (bottom-up approach) with coefficients for efficiency, recycling, etc. Energy NF was calculated by a combination of bottom-up approach using activity data and emission factors and a national level SRIO analysis. It has been applied to inhabitants, nations, institutions and specific food products, and extended to nitrogen emissions neutrality. Per-capita NFs have been calculated for the USA, the Netherlands, Germany, the UK, Japan, Austria, Portugal and Tanzania, but no studies revealed the global situation and the places affected by the NFs. Food was found to be the most dominant component and per-capita NFs for countries vary because of their diets. However, fish and seafood is calculated in a simple way similar to livestock, despite the share in the total protein intake (6.4%) similar to that of poultry meat.

In order to achieve significant reduction in Nr emissions by global integrated nitrogen management, this study focuses on the global analysis of NF (Chapter 2) and NF of seafood (including finfishes, crustaceans and mollusks, both inland and marine; Chapter 3), providing more detailed information for policy makers and consumers on their food choices to reduce their NFs.

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In Chapter 2, the NFs for 188 countries are calculated as the sum of direct and indirect emissions they induce through their consumption, to air (ammonia NH_3, nitrogen oxides NO_x, consisting of NO and NO_2, and nitrous oxide N_2O; from all industries), and to water (nitrogen potentially exportable to water bodies Nwp, mainly potentially discharged nitrate NO_3^- from agriculture and sewage). Emissions data estimated from international fertilizer association data and FAOSTAT production and emissions data with coefficients from IPCC are linked to a global MRIO database of domestic and international trade for 15,000 sectors to calculate the NFs for nations. Per-capita footprints range from under 7 kg N yr^{-1} in some developing countries to over 100 kg N yr^{-1} in some wealthy nations. Four populous nations bear 49% of the global Nr emissions in their territories (China 20%, India 11%, USA 10%, and Brazil 6.1%), followed by another six nations (Russia, Pakistan, Indonesia, Australia, Mexico, and Argentina) bearing additional 12%. On the other hand, 46% of global emissions are induced by China (19%), India (11%), the USA (10%) and Brazil (6%), and additional 13% by another six nations (Japan, Russia, Indonesia, Germany, Mexico, and the UK). Roughly a quarter of the global NF comes from commodities that were traded across country borders. The main net exporters have significant agricultural, food and textile exports, and are often developing countries, whereas important net importers are almost exclusively developed economies. The results show that substantial local nitrogen pollution is driven by demand from consumers in other countries.

In Chapter 3, a new NF model is proposed to evaluate the impact of seafood in detail. The new model is applied to Japan as a case study, and the important parameters are explored for more accurate evaluation of NF of seafood. The new model tracks the feeding steps in detail, considering differences among fed aquacultured seafood, non-fed aquacultured seafood (mainly bivalves and filter-feeding carp), and captured seafood. The new model evaluates the Japanese food NF of fed aquacultured seafood as 0.7 kg N cap^{-1} yr^{-1}, ca. 45% of that of all seafood, whereas the previous model evaluates it as 3.36 kg N cap^{-1} yr^{-1}, ca. 90%. The key factors for assessing the NF of seafood are found to be the proportions of fed aquaculture and of plant protein in feed. In order to enable food choices that will effectively reduce nitrogen release, the virtual N factors (per intake reactive nitrogen release during production) for different seafood are provided as 0.2 (non-fed aquacultured and captured), 4.8 (freshwater and diadromous fish), 3.9 (demersal fish), 3.4 (pelagic fish and other marine fish), and 8.2 (crustaceans). The results show that eating more non-fed aquacultured and captured seafood and less fed-aquacultured shrimps and prawns could reduce our nitrogen load from food consumption as effectively as choosing poultry (virtual N factor of 3.4) instead of beef (8.5).

In Chapter 4, further discussion is conducted on the main findings and the methodology of each chapter, and scenario analysis on different diets is performed to explore the options for more sustainable diets. The results in Chapter 2 and FAOSTAT food balance data indicate that Asian countries including Japan and South Korea have relatively low per-capita NFs for NH_3 and Nwp, because of their diets with less meat. Using the new model developed in Chapter 3, four different diet scenarios are tested: (1) “Recommended level protein”, cutting protein consumption down to the level recommended by Ministry of health, Labour and Welfare of Japan; (2) “Pescetarian”, consuming more fish and seafood to replace the current protein consumption from meat; (3) “Low NF food”, consuming more legumes and fish and seafood that is non-fed aquacultured or captured, to replace the current protein consumption of meat, dairy, egg, and fed aquacultured, fish and seafood; (4) “Balanced Japanese diet”, consuming food as did in 1975, which is said to be good balanced in nutritional studies. All scenarios reduce the current food NF by more than 15%, and “Low NF food” scenario is the most effective choice among the all, dropping by 45%. These results show that not only by reducing the amount of protein we take, but also by choosing low NF food, we can reduce our food NFs. The above findings contribute to an integrated risk management to deal with trade-offs, including nitrogen pollution, stock depletion, human health, carbon emissions, etc.

NF can measure the environmental load of Nr for an individual level to the global level. It helps policy makers and consumers to understand that, through our choices on food and other commodities, we can achieve reduction targets of the human-induced Nr and to mitigate nitrogen pollution both in our local areas and in the areas where our food and other commodities come from.

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