The Myth of 'Sustainable Development': The Ecological Footprint of Japanese Consumption

by

Yoshihiko Wada

B. A. Yokohama City University, 1985

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Abstract

Japan has often been cited as an example of a nation which is achieving the objectives of 'sustainable development' as advocated by the Brundtland Commission. Various commentators believe that Japan attained rapid economic growth (at least until the current economic crisis which began in the early 1990s) while simultaneously protecting its environment, particularly after the oil crisis in 1973. However, this perspective ignores the fact that Japan's economic 'miracle' still involves the consumption of large quantities of low-entropy natural resources, and makes heavy use of the ecosphere's assimilative capacity for high-entropy wastes.

Monetary analyses are excessively abstracted from biophysical reality and are therefore incapable of providing ecologically meaningful indices of sustainable development. Various biophysical approaches to assessment of sustainability have been proposed to fill the gap. In this dissertation, I use one of these, 'ecological footprint analysis,' to reassess the Japanese success story. The ecological footprint (EF) of a specified population has been defined as "the aggregate area of land and water ecosystems required continuously to produce the resource inputs and to assimilate the resource outputs of that population wherever on earth the land/water may be located." It provides a useful sustainability indicator in the form of the difference between a given country's ecological footprint and its domestic area of ecologically productive land/water. The gap between the two represents that country's 'ecological deficit' or 'sustainability gap.'

Data from 1880 indicate that the per capita Japanese EF in the pre-industrial era was about 0.4 hectares (ha). By 1991 it had risen to 4.7 ha per person. Far from 'decoupling from nature,' the historic trend has seen a ten-fold increase in Japan's per capita load on

the ecosphere. Japan is running a massive ecological deficit with the rest of the world. Moreover, since there are only about 1.5 ha of ecologically productive land and 0.5 ha of ecologically productive ocean per capita on Earth, Japanese material standards cannot be extended to the entire world population without depleting natural resource stocks. I conclude that the current level and form of Japanese resource consumption would be unsustainable if every country tried to do the same. Global society needs to consider alternative development paths that will reduce resource consumption by the inhabitants of high-income countries while enhancing their quality of life.

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Chapter 1

Introduction

This chapter includes: 1) the problem statement, which explains why this research is worth pursuing; 2) a statement of the purpose of this study; and 3) an explanation of method, i.e., the analytical tool which is employed to serve the stated purpose.

1.1 Problem Statement: Is Technological Sustainability Sustainable?

At the dawn of a new millennium, many investigators believe that the global community is faced with the formidable challenge of making the transition to sustainable development. The term 'sustainable development' was popularized by the World Commission on Environment and Development (WCED), perhaps better known as the Brundtland Commission. In its 1987 report, *Our Common Future*, the WCED defined sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED 1987, p. 43). The Commission argued that in order to achieve global sustainable development "more rapid economic growth in both industrial and developing countries" was necessary, based on the assumption that

> a continuation of economic growth and diversification . . . will help developing countries mitigate the strains on the rural environment, raise productivity and consumption standards, and allow nations to move beyond dependence on one or two primary products for their export earnings. (*Ibid.*, p. 89)

Hence, the Commission argued that "a five- to tenfold increase in world industrial output can be anticipated by the time world population is stabilized sometime in the next century" (*ibid.*, p. 213).

This interpretation of 'sustainable development' as dependent upon economic growth still dominates mainstream political thinking. Indeed, the currently dominant sustainable development movement "exhibits a clear bias in support of ongoing [economic] growth" (Zovanyi 1998, p. 7). In the face of the recent economic implosion of much of Asia and of other parts of the world, various ways of re-stimulating economic growth are being debated internationally. For example, Japan is being urged by other G7 countries to revamp its financial sector and reassert its role as the engine of Asian growth (*Wall Street Journal* 1998a, p. A19; 1998b, p. A2). The United States has especially insisted that Japan should revitalize its own sluggish economy so that it could boost growth in crisis-hit Asian countries (*Wall Street Journal* 1998c, p. A18). Lawrence Summers, current U. S.'s Deputy Treasury Secretary, and former Chief Economist at the World Bank, has stated:

> The most important contribution Japan could make to the restoration of stability and growth in Asia is to take the steps necessary to strengthen domestic demand, deregulate its economy and open it up to imports. (*Wall Street Journal* 1998d, p. A2)

Scholars like Yamazawa (1998), Tajika (1998, p. 23), and Shishido and Nakajima (1999), as well as various international organizations such as the World Bank and the International Monetary Fund (IMF), also believe that as Japan stabilizes, and begins again to invest and spend in the region, the effect will be to kickstart other stalled Asian economies out of the present recession.[1]

The Brundtland Commission did recognize that the level of growth that it posits as

[1] In response to strong demand from G7 countries, the IMF, and the World Bank, Japan's finance minister Kiichi Miyazawa announced the 'Miyazawa Plan' in October 1998 just before the meeting of Asia-Pacific Economic Cooperation (APEC) held in Kuala Lumpur, Malaysia. This plan promised to provide $30 billion in order to promote economic stability in financially troubled Asian neighbours. The World Bank president James Wolfensohn praised this plan (*The Financial Express* 1998).

required "has serious implications for the future of the world's ecosystems and its natural resource base." The commission therefore noted that "industries and industrial operations should be encouraged that are more efficient in terms of resource use, that generate less pollution and waste, [and] . . . that minimize irreversible adverse impacts on human health and the environment" (WCED 1987, p. 213). In short, we can interpret the Brundtland Commission's operational definition of 'sustainable development' as promoting further economic growth in both industrial and developing countries while increasing efficiency in resource use and reducing pollution and waste generation.

In this context, the Brundtland Commission and others hold up Japan as an example for developing countries to follow. They argue that Japan achieved rapid economic growth (at least until the current crisis began in the early 1990s) while steadily improving the material efficiency of its economy, particularly after the oil crisis in 1973 (WCED 1987, p. 216). Indeed, the Commission applauded Japan for constantly improving the productivity of resources and switching its industrial production away from material-intensive products and processes. The Brundtland Report provided evidence for this remarkable achievement by stating, "Japan used only 60 per cent as much raw materials for every unit of industrial production in 1984 as it used in 1973" (WCED 1987, p. 216).

Drucker (1986) was the first to argue that advanced economies were apparently dematerializing. He claimed to observe a world-wide trend in which industrial development was being 'uncoupled' or 'decoupled' from resource consumption and pollution, and regarded Japan as a good example of just such an encouraging process, particularly after the oil crisis in 1973 (p. 773). Authors including Maddock (1994) and

Lee (1997) pushed the argument further: Japan seemed to show that through human ingenuity and clever use of technology, a small, densely populated country could generate enormous wealth from little of its own land and few indigenous resources without degrading environmental assets. For example, Maddock (1994) of the University of Wales stated:

> Japan's recent environmental record is by international standards exemplary. One recent World Bank report described it as an environmental paragon. Most OECD countries have in the past decade or so managed to reduce emissions of sulphur dioxide, one of the two acid rain gases. Japan alone has reduced emissions of nitrogen oxide, the other acid rain gas. Exceptional response to the energy crisis in the 1970s has decreased its energy coefficient such that it is by far the most energy-efficient country in the world and, as a consequence, its emissions of CO_2 per unit of GNP fall well below those of other nations. Whereas Japan accounts for 14 percent of world GNP it emits less than 5 percent of carbon dioxide emissions. Inland water quality of Japanese rivers as measured by Biological Oxygen Demand and Nitrate concentration are amongst the best of all the OECD nations.
>
> Japan's record is important in its own right, but it also serves to meet the first obligation of a leader, to provide a model attractive to potential followers. Japan, it appears, has broken the link between economic growth and environmental decay, once considered almost an iron law of development. (pp. 40-41)

Lee (1997), a Korean scholar, presented his view as follows:

> Japan succeeded in mitigating industrial pollution in the 1970s, and has continued to achieve its economic growth. Japan, thus, can be considered as a model country which has succeeded in integrating the environmental values and the objectives of economic development (growth). (p. 72)

The Japanese government also praised its own 'achievement' by stating:

> Japan is expected to contribute to the realization of sustainable development at global level by utilizing its own experiences, technology, and strong economy which enabled Japan to achieve economic growth while overcoming pollution problems. . . . Judging from our past experiences, it is possible to achieve environmental

> protection and economic growth simultaneously. (Environment Agency, Japan. 1992, pp. 220-221)[2]

If true, this would suggest that we should be able to achieve ecologically sustainable rapid economic growth all over the world; indeed, these authors implied that if all countries imitated Japan, global sustainability would be achieved.[3]

Unfortunately, this perspective seems oblivious of the fact that the Japanese 'miracle' still requires the extraction and processing of large quantities of low-entropy natural resources, much of them outside the country, and makes heavy use of the ecosphere's common-pool capacity to assimilate high-entropy wastes.[4] Indeed, consumption by the Japanese, as they enjoy a high material standard of living, has an enormous impact all over the world. It is therefore questionable whether Japan's economic achievement represents a valid model for other countries to follow.[5]

The Brundtland version of sustainable development has received some criticism from academia, non-governmental organizations (NGOs) and practitioners. For example, Hueting (1990) expresses his concern that in the Brundtland report "economic growth [is]

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[2] The World Bank (1992) also praises Japan's postwar experience by stating that Japan succeeded in curbing industrial pollution while achieving rapid economic growth through heavily investing in pollution control technologies (p. 92).

[3] Indeed, Ueta (1993) observes that "Within both Japan and the international community, there is an increasing tendency to perceive Japan's postwar experience of economic growth and environmental policies as a model of 'sustainable development' (p. 253). He is skeptical of this perspective.

[4] 'Entropy' is "A measure of unavailable energy in a thermodynamic system" (*Webster's Collegiate Dictionary* [1948 Edition] cited in Georgescu-Roegen 1971a, p. 77). Berman (1981) defines it as: "Measure of randomness or disorganization" (p. 353). Murota (1989) offers another definition: entropy is a measure of the dispersion of heat or matter. Intuitively, it is akin to the concept of 'random disorder' (p. 204). An example of low-entropy natural resources is petroleum. Within petroleum, heat energy is concentrated and it is readily available for human use. Once petroleum is burnt, low-entropy heat and matter are transformed into high-entropy waste heat and exhaust gases.

[5] The same argument can be made about all advanced high-income economies. I use Japan to illustrate my case because (among other things) others have used it to argue the opposite (Drucker 1986; the WCED 1987; the World Bank 1992; Maddock 1994; Lee 1997).

identified with an increase in welfare" (p. 109). He argues that stimulating economic growth would not solve the problems of poverty and environmental degradation in developing countries. He concludes that:

> The only solution ... seems to be to adapt the nature of our activities and the number of our species to the carrying capacity of the planet. For this, what we need least is an increase in national income. (p. 115)

Goodland (1991) of the World Bank supports Hueting's claim by stating that:

> It seems unlikely that the world can sustain a doubling of the economy, let alone Brundtland's five- to ten-fold increase.... The global ecosystem, which is the source of all the resources needed for the economic subsystem, is finite and has limited regenerative and assimilative capacities. (p. 16)

Daly (1994) also argues that since "we have moved from 'empty-world' to 'full-world,' -- a world relatively full of human beings and their artifacts" (p. 22), Brundtland's growth-bound 'sustainable development' is not biophysically feasible (Daly 1996a, p. 194). Timberlake (1989) also expresses a skeptical view of the Brundtland report by stating, "The claim that we can have economic growth without damaging the environment is a sheer statement of opinion" (p. 122). Rees (1992) states that Brundtland's work was just a political document whose scientific foundation was fragile because it "was influenced little by science of any kind" (p. 4). Meadows *et al.* (1992) criticize the highly political aspect of the report by stating:

> the World Commission on Environment and Development [has] not been able to say, straightforwardly, "the human world is beyond its limits," or to grapple seriously with the question of reducing throughput. (p. 100)

1.2 Purposes: Testing the Conventional 'Sustainable Development' Model

The purpose of my dissertation is to examine whether there is enough Natural Capital to sustain the Japanese model on a global or national basis. Natural Capital is defined as "non-produced means of producing a flow of natural resources and services" (Daly and Cobb 1989, p. 72). Thus, my purpose statement can be rephrased as: to test whether Japan's requirement for natural resources and services is balanced with the supply from nature.

This study also intends to examine the fundamental question of whether the whole concept of 'sustainable development' as defined and elaborated by the Brundtland Commission is biophysically realistic under prevailing conditions. Even though Japan is considered by Brundtland and others to be a good model of 'sustainable development,' the present study sets out to test whether Japan's model is ecologically sustainable by the criteria of the ecological footprint analysis. If Japan as a model case does not turn out to be sustainable, Brundtland's claim that the technology-driven growth-oriented approach necessarily leads to sustainability must be rejected.

I am aware that there are several possible dimensions of sustainability to consider, such as the economic, social, and ecological dimensions. My study has only assessed the 'Japanese model' using the ecological criterion. Some may argue that we should not assess sustainability of a human economy through a single dimension. However, this argument is refuted by Liebig's 'Law of the Minimum,' which states that "systems and processes are governed by [the] *single necessary factor* in least supply" (Wackernagel and Rees 1997, p. 15). Applied to sustainability, this means that if ecological sustainability of a human economy is at risk, then the whole economy cannot achieve sustainability even though other aspects of sustainability are attained. For these reasons, it is sufficient to conclude whether the current Japanese economy is sustainable based on the findings of this biophysical study of the 'Japanese model.'

1.3 Methods: Ecological Footprint Analysis

Economic assessments of progress toward sustainable development are usually based on monetary analyses (e.g., Pearce and Atkinson 1993). However, such analyses are excessively abstracted from biophysical reality. Therefore, they can say little of interest about the state of the biophysical resources and the ecosystemic structures, processes, and interrelated functions upon which healthy and sustainable national and global economies are necessarily based. Thus, monetary analyses alone cannot provide ecologically meaningful indices of sustainable development (Wackernagel and Rees 1995[6]; Rees 1998; Rees and Wackernagel 1999). A fatal defect of mainstream monetary analysis is that it does not take into consideration profound and universal implications of thermodynamics for human economy, particularly the Law of Increasing Entropy. Detailed discussions on this topic will be presented in Chapter 3.1 and 3.2.

In order to fill the gap, various biophysical approaches to assess ecological sustainability have been proposed which take into account the laws of thermodynamics. Vitousek *et al.* (1986) suggested the use of appropriated 'Net Primary Production (NPP)' to assess the total 'load' of human economy on the biosphere. Material Flow Accounting (MFA), invented by R. U. Ayres and further developed by the Wuppertal Institute, Germany, the National Institute for Environmental Studies, Japan, and the World

Resources Institute in the United States, is considered to be one of the promising accounting systems for assessing environmental sustainability (WRI 1997; Moriguchi 1998, pp. 107-122). Moldan *et al.* (1997) list various other sustainability indicators.

In this thesis, I illustrate the use of 'ecological footprint [EF] analysis' as a sustainability measure. This method, developed by William Rees, Mathis Wackernagel and other students of Dr. Rees at the University of British Columbia (UBC), can be used to assess the long-term ecological sustainability status of individual nations and even the global economy (Rees and Wackernagel 1994; Wackernagel 1994; Wackernagel and Rees 1995[6]; and Rees 1996). It is a human ecological approach that combines key features of both productivity-based methods and physical flows analysis. Details of the concept of ecological footprint analysis are presented in Chapter 3.3.

This introductory chapter has explained the reasons why this case study is worth conducting, followed by the purpose of the research, and a brief explanation of the research method which I employed in this dissertation. The next chapter presents overview of the changes in both the Japan's economy and the quality of the environment, as well as environmental policies and movements during the post Second World War period. Chapter 3 looks at a new approach for analyzing physical phenomena, the reasons why the conventional mainstream perspective is incapable of measuring long-term ecological sustainability accurately, followed by an explanation of the concept of 'ecological footprint' analysis. I also explain how this analytical framework has been recognized and utilized in Japan and the world so far. Chapter 4 explains concrete methods, calculation procedures and its basis, as well as the limitations of my case study. This is followed by the results of the case study. The conclusion chapter presents analysis, constraints and policy implications drawn from the case study, followed by directions for further study.

Chapter 2

Japan's Economic Growth and Environmental Quality: 1945-1990s

This chapter presents background information on the economy and environment of Japan, which are examined in detail by my case study. Japan's high growth period in the postwar can be divided into pre 1973 oil shock and post 1973 oil shock. Most environmental discourse tends to argue that Japan adjusted both its economic strategy and environmental deterioration by shifting quickly from heavy 'polluting' industry, which was material-intensive, to high tech knowledge-intensive industry and a service based economy. In this chapter, I would like to present empirical evidence and an overview of the changes in both the Japanese economy and the environment, and the links between them, during the post Second World War period. The purpose of this chapter is to suggest that Japan as the model of 'sustainable development' is open to question when we explore the empirical data and information on environmental quality as well as energy and material dependency.

2.1 Economic Growth, Industrial Structure, and Environmental Debates up to 1973

(1) National Reconstruction and Rapid Economic Growth: 1950s-Early 1970s

The Second World War ended in 1945. Major cities across the country had been devastated by the air bombing conducted by the Allied forces during the war. Reconstruction as well as economic growth through increased industrial production were considered the most urgent national goals at that time. The following 15 years are considered to be the period of reconstruction and the beginning of rapid economic recovery (Kasai 1984). The 1960s mark the early phase of rapid economic growth (Tsuruta 1984). The Income Doubling Plan was announced in 1960 by the Ikeda Cabinet

(Kanamori, ed. 1978. pp. 107-108). This plan aimed at doubling the national income in ten years, while ensuring full employment, reducing regional disparities, and improving the nation's living standard. The plan also proposed to build up a massive Pacific Industrial Belt by linking existing industrial areas, namely Tokyo, Nagoya, Osaka, and Kita-Kyushu, along with constructing new industrial complexes in relatively under-developed areas between the four cities (Huddle *et al.* 1987, pp. 91-92). At the beginning of this decade, the nominal Gross Domestic Product (GDP) was 16.7 trillion yen, as shown in Table 1, yet in the next decade it grew to be 75.3 trillion yen. Using a 1980 constant price, the real GDP grew from 61.7 trillion yen to 160.0 trillion yen during the 1960s, with an annual average growth rate of 10.0% during these years (Economic Planning Agency, Japan 1997, p. 14). This means that the goal of doubling GDP was therefore successfully achieved in 1968, two years ahead of schedule (*ibid.*, p. 92).

Table 1 Historical Change of Japan's Nominal and Real GDP and Per Capita GDP

Year	1960	1965	1970	1975	1980	1985	1990	1995
Nominal GDP (Japanese yen, trillion)	16.68	33.77	75.30	152.36	245.55	324.29	438.82	488.52
Real GDP (1980 Japanese yen, trillion)	61.65	95.08	159.94	199.11	245.55	289.76	365.98	391.85
Average growth rate of Real GDP (% per year)	(55-60) 9.0	(61-65) 9.1	(66-70) 10.9	(71-75) 4.5	(76-80) 4.3	(81-85) 3.4	(86-90) 4.8	(91-95) 1.4
Nominal GDP Per Capita (Japanese yen, thousand)	179	345	726	1,366	2,102	2,686	3,552	3,890
Real GDP Per Capita (1980 Japanese yen, thousand)	661	971	1,542	1,785	2,102	2,400	2,962	3,121

Sources: Economic Planning Agency, Japan 1997, pp. 14, 48-49. Real GDP and per capita GDP figures were calculated by the author using data from the same source. Population data used for computing per capita GDP were from OECD 1999.

Table 2 shows the increase in the production and import of selected basic materials and energy, as well as the production of automobiles in terms of physical units.

Table 2 Production and Import of Selected Industrial Materials, Energy, and Automobiles in Physical Terms

Product	Designation	Units	1955	1960	1965	1970	Increase from 1955 to 1970 (%)
Iron and steel	Production	million tonnes	9.40	22.14	41.16	93.32	993
Vinyl chloride	Production	thousand tons.	32	258	483	1,151	3,597
Petroleum	Import	million kl	9.27	31.12	83.28	195.73	2,111
Electricity	Max. output	million kw	14.51	23.66	68.26	112.29	774
Automobiles	Production	thousand units	13	165	696	3,179	24,454

Source: Ministry of International Trade and Industry (MITI), cited in Hoshino 1992, p. 67, Table 2.2. The specific title or the date of the original source were not specified.

The production of these selected commodities increased rapidly from 1955 to 1970. Increase in iron and steel production was almost ten-fold. Vinyl chloride production expanded 36 times. Petroleum import increased 21-fold. Electricity generation capacity became 7.7 times larger. The increase in automobile production was most noticeable: its production capacity in 1970 became 245 times that in 1955.

Japan's rapid economic growth drew international attention. Some foreign intellectuals such as Stone (1969) and Kahn (1970) in the U. S. A. described Japan's fast growth as an 'economic miracle.'[6]

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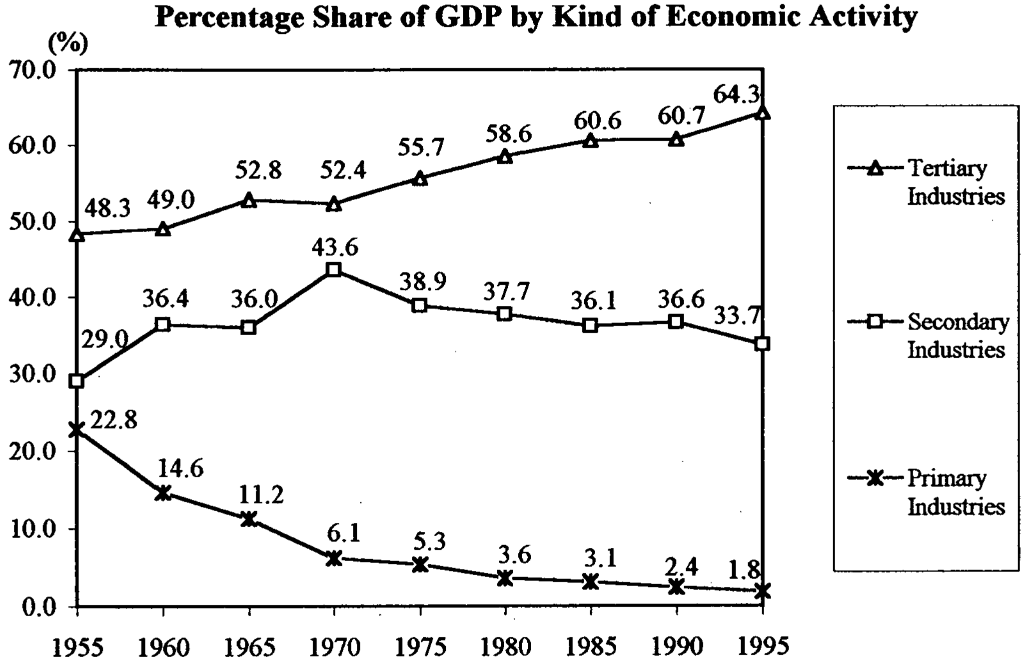
[6] Scholars do not universally use 'economic miracle' to describe the rapid economic growth of post-war Japan (Johnson 1982, pp. 3-34). For example, Patrick and Rosovsky (1976) in the U. S. A. were explicit in criticizing the use of the word 'miracle' by stating:

> What happened to Japan's economy after World War II cannot be described as miraculous. The Japanese are not a nation of supermen who can do everything in the economic sphere better than anyone else. No single factor can explain the success of recent years; the explanation lies, rather, in a variety of factors that were unusually favorable up to the early 1970s.... Thus, rapid economic growth is the consequence not of some mysterious oriental secret, but of a combination of favorable internal and external circumstances and supportive public policy. (p. 920)

(2) Changes in Japan's Industrial Structure between the 1950s and Early 1970s

As Japan went through this economic growth, its industrial structure changed. Figure 1 shows the historical shift in the industrial structure of Japan between 1955 and 1995. This graph illustrates percentage shares of primary, secondary, and tertiary industrial sectors in terms of GDP.[7]

Figure 1 Changes in Industrial Structure of Japan (1): Percentage Share of GDP by Kind of Economic Activity



Sources: Office of the Prime Minister, Japan. ed. 1970. p. 492. Table 324.
Economic Planning Agency, Japan. 1997. pp. 60-61.

Japan's primary industries, namely agriculture, forestry, and fisheries, have shown constant and swift decline for the last 40 years. They had a share of 22.7% in 1955, which dropped to 6.1% in 1970. As of 1995, this share had further shrunk to only 1.8%. Due to

[7] Percentage data for the years 1955, 1960, and 1965 were drawn from Net Domestic Product (NDP) at factor cost (Office of the Prime Minister 1970, p. 492) because the statistical data of GDP by kind of economic activity in these years were not readily available.

the decline in the agricultural sector, the self-sufficiency rate of cereals for human consumption went down from 93% in 1955 to 74% in 1970 (Yano Tsuneta Memorial Foundation 1986, p. 190).

Secondary industries, including mining, manufacturing and construction, contributed 29.0% of the national production in 1955. The share of these industries peaked at the level of 43.6% in 1970. However, the share has dropped since then and in 1995 it was 33.7%.

The tertiary industrial sector means those industries which were not included in the categories of primary or secondary industries and in Japan these comprise electricity, gas, water supply, wholesale, retail trade, finance, insurance, real estate, transport and communication, other services, and public administration (Ministry of International Trade and Industry [MITI] 1986, p. 14). In 1955, tertiary industries as a whole had a share of 48.3%, and this share has increased almost constantly since then.

Figure 2 presents changes in industrial structure in more detail. Noticeable changes observed between 1955 and 1970 are:

1) a rapid decline in the agriculture, forestry, and fisheries industries (from 22.8% to 6.1%);

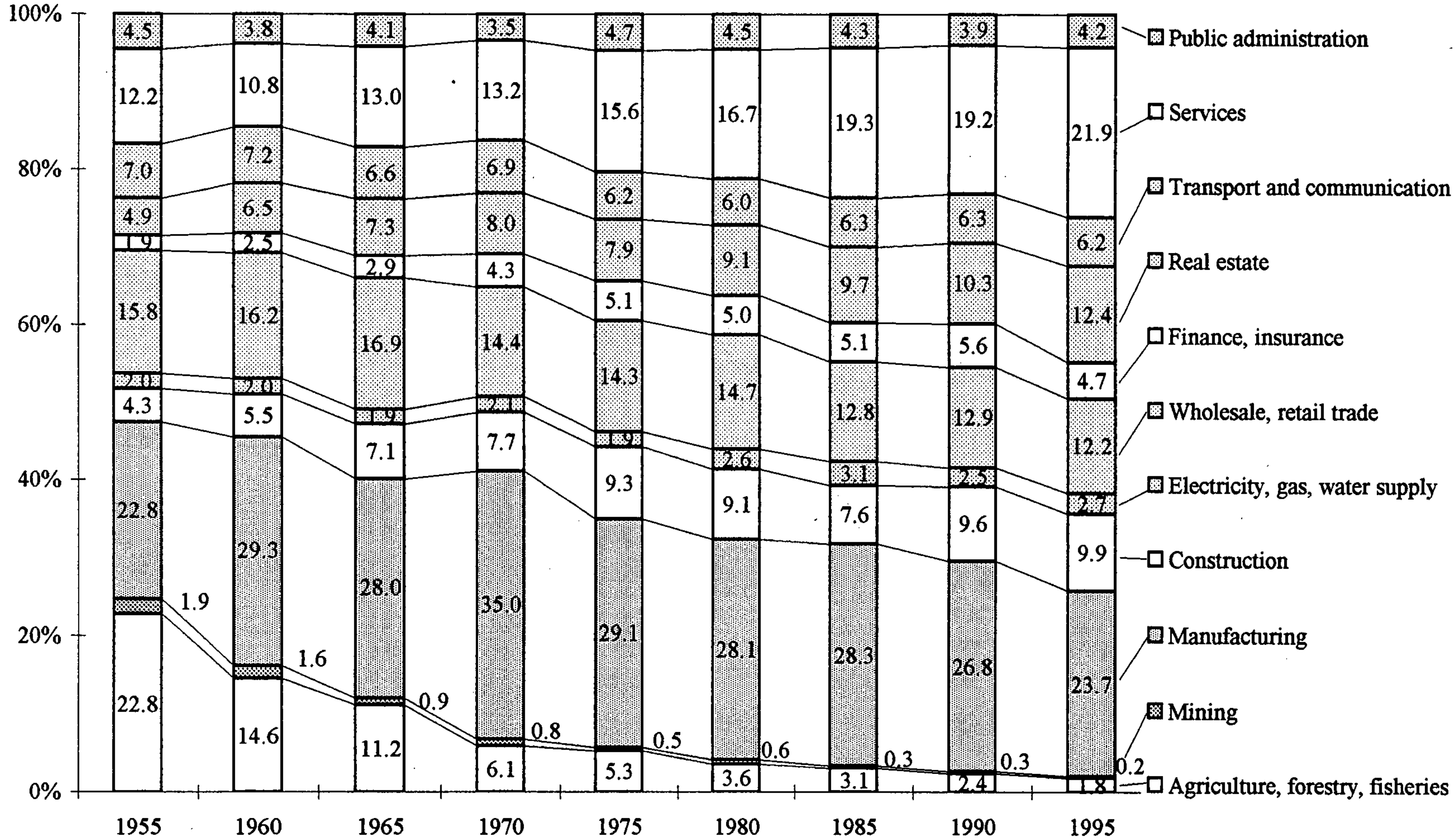
2) a rapid expansion of the manufacturing industry (from 22.8% to 35.0%);

3) a rapid increase of the construction industry (from 4.3% to 7.7%);

4) a rapid growth of the real estate industry (from 4.9% to 8.0%); and

5) a rapid growth of the finance and insurance industries (from 1.9% to 4.3%).

Figure 2 Changes in Industrial Structure of Japan (2): Percentage Share of GDP by Kind of Economic Activity (Breakdown of Figure 1)



Sources:
Office of the Prime Minister, Japan. ed. 1970. p. 492. Table 324.
Economic Planning Agency, Japan. 1997. pp. 60-61.

It is worth taking a closer look at the manufacturing sector since it is one of the major factors affecting environmental quality. The manufacturing industry as a whole increased its share of GDP rapidly from 1955 until the early 1970s. However, this trend ended following the oil crisis in 1973 (as shown in Figure 2).

Table 3 shows changes in the share of shipment value of the manufacturing total for some selected subsectors between 1955 and 1970.[8] (In this table, the total shipment value of the manufacturing sector, not the total GDP, corresponds to 100%.) During the period between 1955 and 1970, there is a declining trend in such 'light manufacturing industries' as textiles and apparel, and in food industries. There was an especially sharp decrease in the textiles and apparel industry as its shipment value share of the manufacturing total fell from 17.5% to 7.8% between 1955 and 1970.

Table 3 Share of Various Industries within the Manufacturing Sector in Japan: 1955 and 1970 (% Value of Shipments)

Light Manufacturing Industries			***Material Supply Manufacturing Industries***			***Process-Oriented Manufacturing Industries***		
	1955	**1970**		**1955**	**1970**		**1955**	**1970**
Food	17.9	10.4	Paper & pulp	4.2	3.3	Metal products	3.3	5.4
Textiles & apparel	17.5	7.8	Chemicals	11.0	8.0	General machinery	4.6	9.9
			Iron & steel	9.6	9.5	Electric machinery	3.7	10.6
			Petroleum & coal products	1.9	2.6	Transport equipment	5.5	10.5
			Non-ferrous metals	4.1	4.4			
Sub-total	**35.4**	**18.2**		**30.8**	**27.8**		**17.1**	**36.4**
Manufacturing Total	**100.0**	**100.0**		**100.0**	**100.0**		**100.0**	**100.0**

Source: Ohkawa and Kohama 1989, p. 301, Table 8.3.

[8] Table 3 is a shortened version of the original table in Ohkawa and Kohama (1989), which included data for every five years, thus showing the general trends in industrial structure. For the sake of brevity, I have only provided here the data for two important years: 1955 illustrates the industrial structure of the period of post-war recovery and the beginning of economic growth; 1970 illustrates the situation just before the oil crisis in 1973.

Within the category of so-called 'heavy manufacturing industries,' 'material supply manufacturing industries' as a whole declined slightly (from 30.8% in 1955 to 27.8% in 1970), while 'process-oriented' manufacturing industries expanded their shipment value shares significantly (from 17.1% to 36.4%). Examples of material supply industries that declined were paper and pulp (from 4.2% to 3.3%), chemicals (from 11.0% to 8.0%), and iron and steel (from 9.6% to 9.5%). Some exceptions were the subsectors of petroleum and coal products (from 1.9% to 2.6%), and non-ferrous metals (from 4.1% 4.4%). These heavy industries that declined were, presumably, energy and resource intensive and so could be considered as typical 'polluting' industries.

Examples of 'process-oriented' heavy industries whose share expanded were metal products (from 3.3% in 1955 to 5.4% in 1970), general machinery (from 4.6% to 9.9%), electric machinery (from 3.7% to 10.6%), and transport equipment (including automobiles, aircraft, and ships) (from 5.5% to 10.5%). These subsectors produce so-called 'high value-added' products, and on the surface at least are less polluting than the other 'smokestack' industries such as steel and petro chemicals.

In summary, the industrial structure of Japan between the 1950s and early 1970s can be characterized as follows:

(1) a steady and swift decline in the contribution of most primary industries such as agriculture, forestry and fisheries;

(2) an expansion of secondary industries such as construction and manufacturing sectors. Within the manufacturing sector, light manufacturing subsectors declined. By comparison, 'process-oriented' and 'high value-added' manufacturing industries more than doubled in the GDP share. The shares of resource intensive 'material supply' manufacturing industries (e.g., chemicals, iron and steel, and pulp and paper industries) decreased slightly. It is important to note that despite the small relative decline in 'material supply' manufacturing industries, the absolute volume of production of these industries

grew during this period (as shown in Table 2); and

(3) a gradual increase in tertiary industries including finance, insurance, real estate, and other service industries.

(3) Environmental Problems Between the 1950s and Early 1970s

Rapid industrialization from the mid-1950s increased the demand for non-agricultural labor, causing substantial and swift outflow of agricultural labor from rural to urban areas (Minami 1986, p. 286). Urban population in Japan accounted for 37.3% in 1950, and almost doubled to 72.1% in 1970 (Minami 1981, p. 216). The fast urbanization as well as rapid industrialization caused various urban problems including air, water, noise, and vibrations pollution (Ui 1992).

Let us take a closer look at the historical changes in environmental quality, together with policies and citizens' movements during the course of the rapid economic development period. We have seen that the real GDP grew at the annual rate of 9.0% in the latter part of the 1950s. Behind this apparently positive trend, the problems of industrial pollution became intensified in some areas as early as the late 1950s. One of the most severe and tragic examples was 'Minamata Disease,' discovered in the city of Minamata on Kyushu Island in 1956 (Ui 1992, p. 110). This was caused by an organic mercury compound included in effluent discharge from a chemical fertilizer manufacturer called 'Nihon Chisso.' This industrial pollution claimed the lives of 987 victims as of December 1990 (*ibid.*, p. 131), and many more have since suffered from "symptoms such as severe convulsions, intermittent loss of consciousness, repeated lapses into crazed mental state, and then finally permanent coma" (*ibid.*, p. 110).

Another extreme case was the Yokkaichi Asthma Case. Among residents in

Yokkaichi City in Mie Prefecture, the number of asthma sufferers increased rapidly soon after a nearby petroleum refinery complex started its operation in 1960 (Miyamoto 1987, pp. 19-20). The Minamata Disease Case, Yokkaichi Asthma Case, Niigata Minamata Disease Case, and Itai-itai Disease Case in Toyama turned into symbolic icons of industrial pollution in Japan (Szasz 1994, p. 84). They are regarded as the 'Four Most Severe Industrial Pollution Incidents' in Japan (Teranishi 1994, pp. 208-209).

In addition to these severe cases, there were more pollution incidents throughout the nation which caused less severe health damages but compromised the livability and amenity of some urban regions. According to Miyamoto (1987, pp. 18-22), air in major cities was extremely polluted in the 1960s and 1970s due to rapid industrialization without the installation of adequate pollution abatement equipment. For example, in Yodo Ward in Osaka City, the average density of sulfur dioxide (SO_2) was as high as 0.189 ppm in 1960 (*ibid.*, p. 18). Current maximum allowable density is 0.040 ppm (Environment Agency, Japan 1996, pp. 45-47). Thus, at that time, residents were forced to breathe extremely polluted air which exceeded today's allowable level by 4.7 times. The annual average density of SO_2 in 15 monitoring stations across the country is decreasing more recently (Table 4).

Table 4 Annual Average Density of Sulfur Dioxide (SO_2) (ppm)
(Average for 15 continuously-monitoring general environments air monitoring stations)

Year	1965	1970	1975	1980	1985
Annual average (ppm)	0.056	0.043	0.024	0.016	0.011

Source: Metropolitan Environment Improvement Program 1994, p. 23.

In many cases, pollution victims encountered corporate denials and collusion of government and industry which publicly denied the existence of serious illness caused by industrial pollution (Upham 1987, p. 29). In the 1960s, citizens started a social movement against pollution (McKean 1981, pp. 17-20; Miyamoto 1987, p. 20; Iijima 1993, p. 20). The Japanese central government, however, reacted to the situation rather slowly. In the late 1960s and early 1970s, a series of environmental laws was enacted: the Basic Law for Environmental Pollution Control in 1967; the Special Law for Deliverance of Pollution Victims in 1969; and the Law of Dealing with Pollution Conflicts in 1970 (Shimin Enerugi Kenkyujo 1994, p. 77). A Diet session held in 1970 was called 'Pollution Diet' since it focused on environmental policies, and eventually a series of fourteen laws regarding pollution abatement and control measures were adapted during this Diet session (McKean 1981, pp. 20-21; Iijima 1993, p. 23). As a result, installation of pollution abatement devices such as desulferization equipment was accelerated (Environment Agency, Japan 1977, pp. 46-80). The result became noticeable in the late 1970s (see Table 4 above, Table 6 and Figure 4 below). In 1971, the Environment Agency was established.[9]

In the early 1970s, victims of pollution celebrated victories in court challenges. For example, their success in the Yokkaichi Asthma gave a severe shock to Japanese industry. Gaining momentum, the Environment Agency enacted the world's first Pollution Health Damage Compensation Law in 1973. During this period, the so-called 'Four Most Severe Pollution Law Suit Cases' were finalized, ending in victory for the plaintiffs (McKean 1981, p. 20; Miyamoto 1987, p. 24).

[9] Before the Environment Agency was established in 1971, the Ministry of Health and Welfare was the main ministry of pollution control regulations.

2.2 The Japanese Economy of Post-1974 and the Environmental Debate

(1) Slow-Down of Economic Growth after the Oil Crisis

Due to the first oil crisis in 1973, the real growth rate slowed down in the 1970s to 4.4% (see Table 1). In the 1970s, the nominal GDP grew from 75.3 trillion yen (in 1970) to 245.6 trillion yen (in 1980). This means that the real GDP, using a 1980 constant price, between 1970 and 1980 grew from 160.0 trillion yen to 245.6 trillion yen, a 1.5-fold increase. Between 1981-86, the growth rate went down to 3.4%. The latter half of the 1980s showed a spirited recovery of the economy, with an average growth rate of 4.8%, based upon a 'bubble' increase in speculative asset prices (e.g., stocks and property). During the decade as a whole, the nominal GDP grew from 245.6 trillion yen (in 1980) to 438.8 trillion yen (in 1990) and the real GDP, using a 1980 constant price, between 1980 and 1990 increased from 245.6 trillion yen to 366.0 trillion yen, another 1.5-fold increase. In 1992, the 'bubble' economy burst in Japan and the annual real growth rate between 1990-1995 fell to only 1.4% (calculation by the author based on Economic Planning Agency, Japan 1997, p. 14).

(2) Industrial Structure Post-1974

The primary industries continued to lose their share of GDP (from 6.1% to 1.8%) during the period between 1970 and 1995 (Figure 1). The share of the secondary industries peaked in the early 1970s at the level of 43.6% of GDP, and continued to decline throughout the 1970s, 1980s and 1990s. The share dropped to 33.7% as of 1995. By contrast, the tertiary industries continued to expand their share of GDP from 52.4% (in 1970) to 64.3% (in 1995).

Within the secondary sector, only the construction industries increased its GDP share from 7.7% in 1970 to 9.9% in 1995 (see Figure 2 in the previous section). Among all manufacturing sectors, light and material supply industries declined in relative shares of manufacturing total after the 1973 oil crisis (see Table 5 below which presents changes in the shipment value share of the manufacturing total for the selected subsectors between 1955 and 1984).[10] The only exceptions were petroleum and coal products industries. These energy-based industries increased their shipment value shares from 2.6% in 1970 to 5.4% in 1984.

Before the oil crisis, the shipment value shares of all the process-oriented manufacturing industries increased. However, after the oil crisis, metal products and general machinery industries lost their shares. During this period, only highly technological, and high value-added industries have grown rapidly. For example, the electric machinery industry expanded its shipment value share from 10.6% (in 1970) to 15.4 (in 1984). The rate of increase in transport equipment industry was somewhat lower; still, its shipment value share increased from 10.5% to 12.7%.

[10] Table 5 is an extention of Table 3 above which is a shortened version of Ohkawa and Kohama (1989, p. 301, Table 8.3). The trends are clearly shown in Ohkawa and Kohama (1989) which provided data of every five years. For the sake of brevity, I have only provided here the data for three important years: 1955 illustrates the industrial structure of the period of post-war recovery and the beginning of economic growth; 1970 illustrates the situation just before the oil crisis; and 1984 is illustrative of the post oil crisis situation.

Table 5 Share of Various Industries within the Manufacturing Sector in Japan: 1955, 1970, and 1984 (% Value of Shipments)

Light Manufacturing Industries				*Material Supply Manufacturing Industries*				*Process-Oriented Manufacturing Industries*			
	1955	1970	1984		1955	1970	1984		1955	1970	1984
Food	17.9	10.4	10.8	Paper & pulp	4.2	3.3	2.9	Metal products	3.3	5.4	4.7
Textiles & apparels	17.5	7.8	4.5	Chemicals	11.0	8.0	8.0	General machinery	4.6	9.9	8.8
				Iron & steel	9.6	9.5	6.8	Electric machinery	3.7	10.6	15.4
				Petroleum & coal products	1.9	2.6	5.4	Transport equipment	5.5	10.5	12.7
				Non-ferrous metals	4.1	4.4	2.8				
Sub-total	**35.4**	**18.2**	**15.3**		**30.8**	**27.8**	**25.9**		**17.1**	**36.4**	**41.6**
Manufac-turing Total	**100.0**	**100.0**	**100.0**		**100.0**	**100.0**	**100.0**		**100.0**	**100.0**	**100.0**

Source: Ohkawa and Kohama 1989, p. 301, Table 8.3.

Japan's industrial structure between 1974 and the early 1990s can be summarized as follows:

(1) a steady and gradual decline in the share of primary industries;

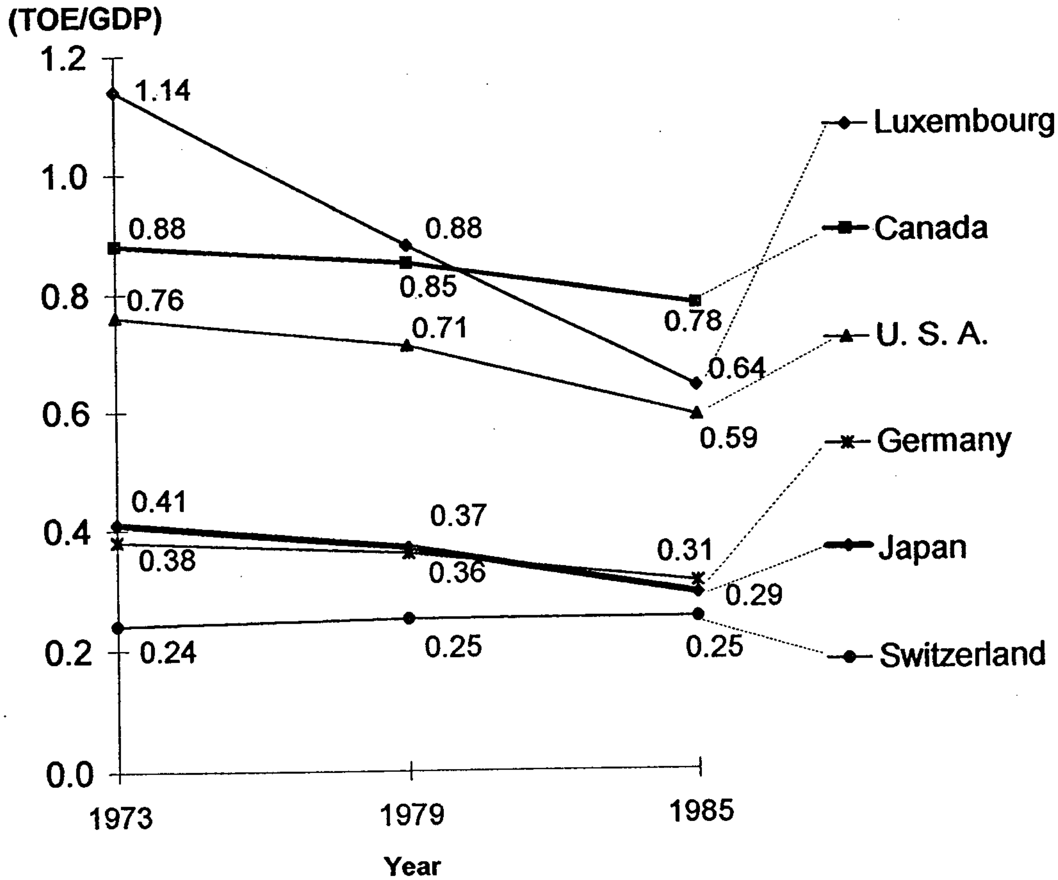
(2) a gradual decline in secondary industries during this period, except for the construction industry. Within the manufacturing sector, light manufacturing industry continued to decline. 'Material supply' manufacturing industries (e.g., paper and pulp, iron and steel, and non-ferrous metals industries) as a whole have also declined. 'Process-oriented' manufacturing industries as a whole have increased slightly. However, this trend was limited only to the 'high-tech' and high value added subsectors (e.g., electric machinery, and transport equipment industries). More conventional 'low-tech' process-oriented industries (e.g., metal products, and general machinery subsectors) have decreased their shipment value shares; and.

(3) a faster increase in tertiary industries as a whole than the pre-1973 period. In particular, real estate, and other service industries have grown substantially.

(3) Environmental Performance and Debates

As might be inferred, the switch in industrial structure following 1974, together with a reduction in overall ratio of growth caused industrial production to fall dramatically. Moreover, the Brundtland Report praised Japan because of its achievement in steadily improving resource-use efficiency and switching industrial production "away from heavily material-intensive products and processes," particularly after the oil crisis in 1973 (WCED 1987, p. 216), thus achieving the objectives of 'sustainable development.' Indeed, some data seem to endorse this claim. For example, Figure 3 shows the international comparison of energy intensity per real GDP.

Figure 3 Energy Intensity of Economies (Tonnes of Oil Equivalent [TOE] Consumed per Real GDP [1980 US dollar])



Source: Tominaga *et al.* 1989, p. 125, Table 2-1-9.

Data show that Japan is one of the most energy efficient nations among developed countries. In terms of efficiency gained during the 12 years (1973-1985), Japan ranks second after Luxembourg.

Table 6 shows the comparison of SO_2 and NO_2 emission per unit of real GDP.

Table 6 National Emission of SO_2 and NO_2 (Tonnes per Unit of Real GDP [billion US $ (1990 constant price and exchange rate)])

	SO_2 emission				NO_2 emission			
	1970	1980	1990	Reduction from 1970 to 1990 (%)	1970	1980	1990	Reduction from 1970 to 1990 (%)
Japan	**3.8**	**0.6**	**0.3**	**92**	**1.3**	**0.7**	**0.4**	**66**
Canada	23.3	10.7	5.8	75	4.8	4.5	3.4	30
U. S. A.	8.7	5.5	3.8	57	5.8	5.5	3.5	40
Germany	3.7	2.4	0.6	85	2.3	2.2	1.6	32

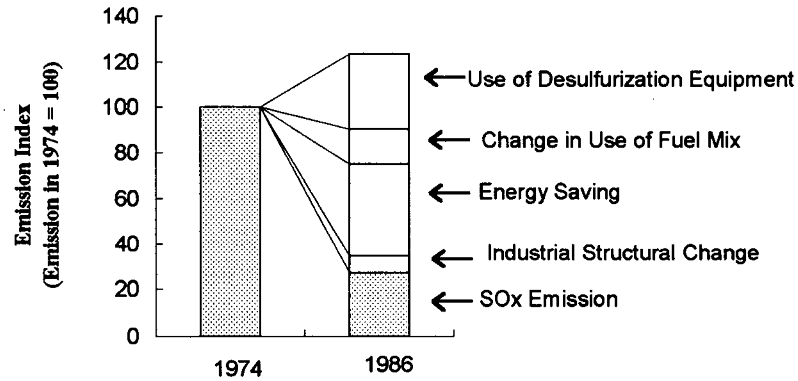
Sources: GDP data were from OECD 1999. Emission data were from World Resources Institute 1994, p. 367, Table 23.5.

Note: Calculation was conducted by the author. Data on GDP were expressed in terms of expenditure in US $ with exchange rate and price levels of 1990.

As this table shows, Japanese emission into the atmosphere of SO_2 and NO_2 per unit of GDP is the least among major industrialized countries. The reduction rates for the 20 years between 1970 and 1990 are also shown in the table. Japanese reduction rates were the highest among these countries both in SO_2 and NO_2 emissions.

Figure 4 shows the factors linked with SO_x reduction between 1974 and 1986.

Figure 4 SOx Emission: Factors Linked to the Reduction Between 1974 and 1986 in Japan



Source: Environmental Agency, Japan 1990. *Quality of Environment in Japan*. Vol. 1 (General Issues). p. 128.

We observe that energy saving, use of desulfurization, and change of fuel mix were the major factors of emission reduction. By contrast, the structural changes in industry made a relatively smaller contribution to this achievement.

These data seem to suggest that Japanese economy has been more energy efficient and less polluting than many other industrialized countries. However, these data are very misleading since they do not account for energy consumption or pollutant emission outside the country. Japan imports a large amount of products which requires a high level of resource consumption and waste generation overseas. Japan's domestic 'success' might be resulted from the relocation of energy intensive and 'polluting' industries from Japan to overseas. Therefore, it is questionable whether the Japanese economy is truly environmentally sustainable, even though it appears to be so.

During the later part of the 1970s and 1980s, due partly to the world-wide economic slump and partly to the downfall of progressive local governments (which favoured more stringent regulations) throughout Japan, environmental policies lost significant momentum (Miyamoto 1987, pp. 32-51, Ueta 1994, p. 231). During that period, revitalization of the economy was once again made the highest priority in Japan. The Environment Agency could not fight effectively against this backlash from the industries and development oriented ministries such as the Ministry of International Trade and Industry (MITI). For example, this political backlash has rigidified and limited the governmental criteria for the official recognition of industrial pollution victims as Minamata disease patients. (Miyamoto 1987, pp. 133-137). Since 1977, an extremely rigorous clinical examination has been required in the screening procedure for identifying 'officially recognized patients.' As a result, the proof of causal relation has become highly difficult, especially for the patients with less serious symptoms and/or complications (*ibid.*, pp. 134-136). There were 2,731 victims who are still seeking official recognition as Minamata disease patients as of December 1990 (Environment Agency, Japan 1991, p. 113).

The most symbolic defeat for the Environment Agency was the forced revision in 1987 to the famous Pollution Health Damage Compensation Law which had been enacted in 1973 (Ueta 1994, pp. 255-256). Having received consistent and strong pressure from the Federation of Economic Organizations (Keidanren) since its birth, the Environment Agency ultimately yielded to the conservative and reactionary force, and submitted a draft bill to the Diet for revision to the law which put an end to recognizing any new recipient of air pollution damage compensation (Miyamoto 1987, pp. 33-34).[11]

[11] The underling reason for this decline can be linked to the sudden and forced resignation of a highly-ranked bureaucrat, Mr. Takakichi Yanase, in 1977, then the Director of Planning and Coordination Bureau of the Environment Agency. He was stubborn and consistent when it came to issuing development permits. If the conditions were not met, he would refused to offer a permit even if there were strong pressure from politicians and large businesses. Mr. Shintaro Ishihara, a development-

This political backlash began to influence court decisions in the late 1970s and 1980s. The decisions began to favour polluting facilities and industries, contrary to the trend of decisions made in the early 1970s which were in general more benign and compassionate towards the victims of pollution (Miyamoto 1987, pp. 32-36). As of 1992, a total of more than 3,000 people continue to be engaged in lawsuits claiming compensation for health damages due to ambient air pollution (Asaoka 1992, p. 119).

In 1977, the OECD published *Environmental Policies in Japan*. It concluded that "Japan has won many pollution abatement battles, but has not yet won the war for environmental quality" (OECD 1977, p. 83). The Japanese government paid attention to the first half of this sentence. Some scholars believe that this report became one of the triggers for backlash in environmental regulations (Miyamoto 1987, pp. 32-36; Teranishi 1993, pp. 243-244, 1994, pp. 214-215).

Another phenomenon which has been observed in the late 1970s and 1980s was the relocation of 'polluting' industries from Japan to overseas sites, especially in Asian countries (Kim 1992, pp. 27-40; Iijima 1993, pp. 29-30). Terada (1992) states that "More than 1,000 Japanese companies established their branch factories in Asian countries between 1972 and 1985. Many of them were engaged in 'polluting' manufacturing industries" (p. 103). For example, in 1977 Kawasaki Steel Company relocated a factory to Mindanao in the Philippines due to a strong citizens' movement against air pollution in

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oriented, right-wing and influential politician, was appointed to be the Minister of Environment in December, 1976 by the then Prime Minister, the late Takeo Fukuda. Mr. Ishihara decided to dismiss Mr. Yanase from the Environment Agency. Nobody could stop the unjust forced resignation that resulted. Young bureaucrats became intimidated by this incident and learned that if they explicitly and boldly opposed pressure from the development side, they would be expelled from the mainstream bureaucracy (Mainichi Shimbun Shakaibu [Mainichi Newspaper Social Affairs Department] 1980, pp. 183-189).

Chiba City. Soon after the factory began its operation on the new site, local residents started to suffer from severe air pollution as well as water contamination caused by effluent discharge from the factory (Sumi 1989, pp. 159-160; Yokoyama 1990, Ch. 7; Hiraoka 1993). It is important to note that the relocation of 'polluting' industries has been sometimes supported by the public financial scheme of the Japanese government, the so-called 'Official Development Assistance' (ODA) (Sumi 1989, pp. 159-189; Harada 1996, pp. 91-92).

In the 1990s, the situation surrounding the environment has changed slightly. Due to the United Nations Conference on Environment and Development (UNCED), popularly-known as the Earth Summit, held in Rio de Janeiro, Brazil in 1992, citizens, businesses and government in Japan reacted positively to global environmental concerns. 'Sustainable development' and 'sustainability' became well-known terms, at least among concerned citizens, university students, academics, and international development specialists. The biggest achievement of all was the enactment of the Environmental Basic Law in 1993. The main objective of this new Law was to straighten out the shortcomings of two existing basic laws, namely the Basic Law for Environmental Pollution Control which was legislated in 1967 (and revised in 1970) and the Natural Environment Preservation Law which was enacted in 1972 (Miyamoto 1995, p. 156-181). In 1997, national legislation on Environmental Impact Assessment was enacted (Shimazu 1997).[12] The importance of voluntary activities and non-profit organizations (NPOs) or non-

[12] Until 1997, environmental impact assessment had been conducted based only on the Cabinet Resolution in 1984, as well as bylaws in some progressive prefectures. However, the assessment procedures have been biased toward the proponent of development project (Hobo 1994, 42-43).

governmental organizations (NGOs) became widely recognized by Japanese citizens as a result of the tragic disaster of the Hanshin Earthquake in 1995. The enactment of the Non-Profit Organization Activity Promotion Act in 1997 enabled NPOs to obtain stable legal status more easily, which benefited environmental NPOs. The United Nations Conference on Climate Change (COP3) held in Kyoto in 1997 was also a boost for the environmental protection movement in Japan.

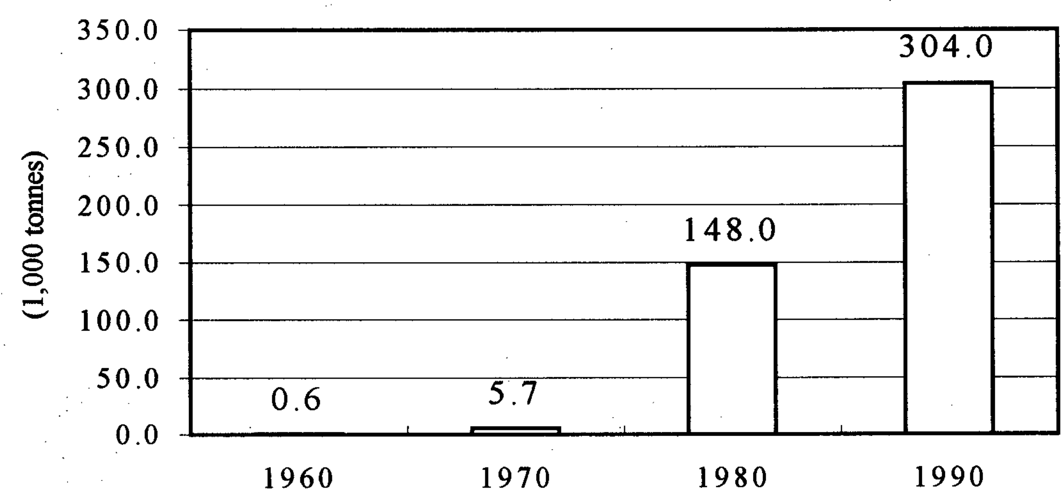
However, various environmental problems for which Japan is responsible are still unsolved. For example, the relocation of 'polluting' industries to Asia became more intense in the late 1980s (Kwong 1992, pp. 50-51). Direct foreign investment (DFI) by Japanese manufacturing industries to South East Asia was accelerated after the announcement of Plaza Accord in September 1985 which strengthened the Japanese yen considerably (Yasuba 1991, p. 128). One of the 'exported' polluting industries is the recycling operation involving used batteries and computers shipped from Japan for the purpose of extracting metals such as mercury and platinum. For example, a mercury recycling facility in Taiwan was blamed for brain damage to nearby kindergarten children; the epidemiological research conducted by the local university proved that there was a (significant) correlation between the mercury content in the blood and the lowered intelligence quotient of the children involved (Ueta 1992, pp. 70-73).

Natural resource appropriation by the Japanese has caused environmental and social problems in Asia and other regions in the world. For example, large areas of foreign forests have been destroyed through Japan's import of forest products (Ishi 1988, pp. 86-87, 95-98; Furusawa 1995, pp. 62-63; Kumazaki 1996, pp. 75, 78-79). Kuroda and

Nectoux (1989) report that 28.7% of tropical forest timber traded globally in 1986 went to Japan (p. 43, Figure 2). It is estimated that the cutting of rainforest in Sarawaku, Malaysia has affected the lives of approximately 200,000 local residents, including aboriginal tribe people called the Penang (Kwong 1992, pp. 54-59).

Japan depends heavily on fisheries resources from abroad as well. Intensive shrimp aquaculture in tropical Asia, Latin America and Africa is known to have caused extensive and serious destruction of coastal ecosystems, particularly mangrove forests (Murai 1988; Environment Agency, Japan 1991, pp. 275-277; Furusawa 1995 , pp. 62-63; Goldsmith 1996, p. 84; Ahmed 1997). Approximately 33 percent of all the exported shrimp from these regions in 1985 were carried into markets in Japan (from FAO 1985 cited in Murai 1988, p. 196). The shrimp import by the Japanese was expanding even further since then as Figure 5 illustrates.

Figure 5 Japan's Import of Shrimp

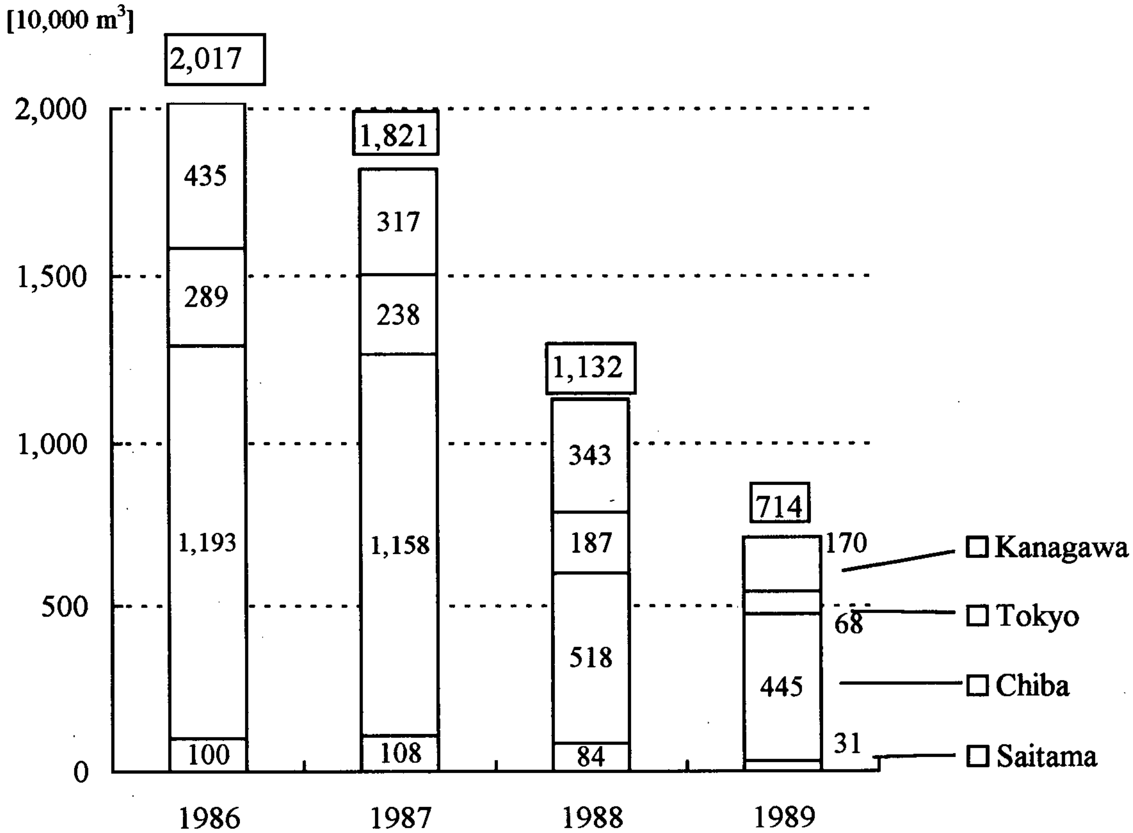


Sources: MITI, White Paper on International Trade. Multiple years.
Murai 1988, pp. 2, 175.

Since mangrove forests offer excellent habitat for juvenile fish, "the consequences of mangrove destruction are catastrophic for local fishing communities" (Goldsmith 1996, p. 84).

Solid wastes disposal in domestic land has also become a serious problem. Disposal of industrial wastes amounted to 236 million tonnes in 1975. In 1992 it had increased to 403 million tonnes (Environment Agency, Japan 1996, p. 428). This represents a 70% increase in 17 years. General wastes (household wastes, office waste, and human excrement) amounted to 50 million tonnes in 1992 (*ibid.*, p. 422). On a per capita basis, the average Japanese produced 1.104 kilograms of waste from households and offices per day in 1992 and it was 1.033 kilograms in 1975 (*ibid.*, p. 423); amounting to a 7% increase in 17 years. Construction of solid waste disposal facilities (disposal sites and incinerators) has become increasingly difficult because of residents' opposition and lack of open spaces. As a result, the remaining life expectancy (accommodation capacity) of industrial wastes and general wastes disposal sites has been reported to be only 2.3 years, and 8.1 years respectively as of 1993 (National Land Agency, Japan 1997, p. 199). In particular, the shortage of final waste disposal sites in metropolitan areas is alarming. For example, Figure 6 illustrates the decreasing capacity of disposal sites in the Tokyo Metropolitan Area (TMA) including Tokyo, Saitama, Chiba, and Kanagawa prefectures from 1986 to 1989. Due to the severe shortage of waste sites in the TMA, industrial wastes generated in this area have been transported to remote areas such as Tohoku and Hokuriku regions (Environment Agency, Japan. 1991. pp. 218-219).

Figure 6 Remaining Capacity of Industrial Solid Waste Disposal Sites in Tokyo Metropolitan Area



Source: White Paper of Health and Welfare (Date not specified), cited in Environment Agency, Japan. 1991. *Quality of the Environment Report 1991* . p. 218. Figure 3-1-22.

The shortage of disposal sites is one of the causes of illegal dumping of industrial solid wastes. According to the police authority, a total of 1.3 million tonnes of illegal dumping of industrial solid wastes was reported throughout the nation in 1995 (Environment Agency, Japan 1996, pp. 428-429).

The impacts of environmental estrogen (or endocrine disruptors) on reproductive systems and its other health effects have recently become well-known in Japan in recent years (Kayama 1997; Iguchi 1998). In addition, dioxin pollution from incinerators for the disposal of industrial and household solid wastes is strongly perceived as one of the most serious social problems in Japan nowadays (Yokota 1999; Tanahashi 1999); dioxin pollution of soil from herbicide use is also a problem (Wakimoto 1999).

Another emerging environmental problem is disturbance to ecosystems through public works (Hobo 1994, pp. 42-43). Public works include publicly financed civil engineering projects such as (1) construction of industrial infrastructure such as irrigation, highways, seaports and airports; (2) national land preservation projects such as construction of dams and river dikes; and (3) provision of housing. The main purpose of public works is often to stimulate a sluggish economy. As a result, useless or even harmful projects are sometimes approved if there are potential economic benefits. For example, Ui (1997) reports that public works in Okinawa are causing environmental damage. The most disastrous case of all is that of the 'agricultural foundation improvement projects.' These projects create new farmland by cutting semi-tropical forest. Due to these projects conducted throughout Okinawa, red soil pours into the marine environment, destroying coral reef and killing fish.[13]

These problems are caused by the economic system of mass production, mass consumption and mass disposal which is dependent on science and technology as well as the import of massive resources. This system has characterized Japanese high-consumption life styles in the 1990s (Kato 1997, pp. 9-15).

Table 7 summarizes the characteristics of Japan's post war economic development, the environmental quality and the environmental policies and movements, drawing

[13] McCormack (1996) describes various problems caused by public works in Japan such as political, financial, and moral, as well as environmental (pp. 25-77).

attention to the marked shift that occurred after 1974.

Table 7 Features of Japan's Post War Period

	Pre 1973 Oil Crisis	Post 1974
Economic Production	Rapid economic growth at the annual rate of 9.0 to 10.9%.	Slowed economic growth. Maintenance of the annual rate of 3.4 to 4.5% in the late 1970s and 1980s. In the early 1990s, this decreased to 1.4%.
Industrial Structure	Rapid growth in manufacturing industries. Process-oriented industries such as machinery industries grew especially fast. Tertiary industries also grew steadily. Primary sectors and light manufacturing industries declined rapidly.	The growth of manufacturing industries slowed down. More sophisticated, technology-intensive, high-value added manufacturing industries grew rapidly. Secondary industries gradually lost their shares. Tertiary industries grew rapidly.
Environmental Quality, Citizens' Movements, and Policies	Severe industrial pollution began to emerged in the late 1950s. Rise of citizens' activism against industrial pollution. Industrial pollution abatement legislation enacted in the late 1960s and early 1970s. Installment of various pollution abatement equipment increased. Victories of industrial pollution victims in court decisions.	Improvement of air and water quality. Improvement in energy efficiency. Backlash in industrial pollution regulations due to economic slump, and nation-wide conservative political atmosphere. New types of environmental problems occurred, such as 'export' of polluting industries, increased appropriation of foreign resources, shortage of solid waste disposal sites. Problems caused by affluent, high-consumption life style. Roles of NPOs became known to many citizens.

As mentioned in the previous section, the Brundtland Commission and others have praised Japan as an example for developing countries to follow because Japan seems to have succeeded in achieving economic growth while simultaneously protecting its environment. However, as we have explored in this chapter, there are many environmental issues that Japan has not solved. Therefore, it is questionable whether Japan can be a model for a nation both ecologically and economically sustainable.

This chapter covered some empirical evidence and an overview of the changes in both the Japanese economy and the environment, and the links between them, during the post Second World War period, drawing attention to the notable shift that occurred after the oil crisis in 1973. Chapter 3 explains a new approach or a paradigm for analyzing physical phenomena, and spells out the reasons why the conventional mainstream perspective is incapable of accurately measuring long-term ecological sustainability. This is followed by an explanation of a new analytical framework of 'ecological footprint' which is based on the central principle of the new paradigm.

Chapter 3

A Perspective: Theoretical Background of Ecological Footprint Analysis

This chapter discusses the crucial implications of the theory of thermodynamics for human economic enterprises, the reasons why conventional neoclassical economics cannot be an effective tool to measure ecological sustainability, and why the concept of 'ecological footprint' is a useful alternative to mainstream economic analysis.

3.1 Relevance of Laws of Thermodynamics

The Laws of Thermodynamics, especially the Entropy Law, have profound historical implications not only for the human economy but also for the way in which we perceive the world. Natural and social scientists in different fields, such as chemistry (Soddy), ecology (H. Odum), sociology (Cottrell) and economics (Georgescu-Roegen, and Murota) have pointed out the importance of the Laws of Thermodynamics. Along the same lines, Rifkin (1980) states:

> Now a new world view is about to emerge, one that will eventually replace the Newtonian world machine as the organizing frame of history: the Entropy Law will preside as the ruling paradigm over the next period of history. Albert Einstein said that it is the premier law of all of science; Sir Arthur Eddington referred to it as the supreme metaphysical law of the entire universe. (p. 6)

He claims further that,

> In fact, the Entropy Law transcends the modern world view with a force of conviction that is every bit as convincing as was the Newtonian world machine when it replaced the medieval Christian world view of the Roman Church. (p. 6)

A worldview, or paradigm, determines the way in which we relate to the environment. With today's environmental challenges, it is worth examining critically our worldviews--both old and new--which form the very foundation of our everyday decisions and behaviors. First, let us explore a new worldview which is derived from the laws of thermodynamics.

(1) The First Law of Thermodynamics (Law of Conservation of Matter and Energy)

The First Law of Thermodynamics is known also as the Law of Conservation of Matter and Energy (Georgescu-Roegen 1971b, p. 5). This law states that within a closed system the total amount of mass or energy remains the same even though one form of mass or energy may have transformed into another. Ehrlich *et al.* (1993) state,

> If energy in one form or one place disappears, the same amount must show up in another form or another place. In other words, although transformations can alter the *distribution* of amounts of energy among its different forms, the *total* amount of energy, when all forms are taken into account, remains the same. (p. 69)

Georgescu-Roegen (1971c, p. 177) puts it simply: "matter and energy can neither be created nor destroyed."

There are very minor exceptions to the first law; this law still holds in most of the cases. As Ayres (1978) elaborates,

> Until the discovery of radioactivity and of Einstein's equivalency law [$E = mc^2$], it was assumed that the law of conservation of mass and energy applied *separately* to each chemical species, and to energy. This is now known to be strictly inaccurate, since mass can be converted into energy by fusion or by fission. The inverse process is also possible, as exemplified by the creation of an electron-positron pair or a nucleon-antinucleon pair. However, disregarding these exceptional cases, the first law of thermodynamics does hold separately for each chemical species, as well as to aggregates. (p. 38)

The first law has provided the theoretical basis, i.e., 'materials/energy balance principle' for the actual accounting of resources use. Ayres (1978) states:

> [T]he so-called materials/energy balance principle states that the sum

> total of materials and energy extracted from the natural environment as raw materials must exactly balance the sum total of materials and energy returned to the environment as waste flows, less any accumulation in the form of capital stocks and products inventories. (p. 38)

For example, Material Flow Accounting (MFA), invented by Ayres and further developed by the Wuppertal Institute, Germany, is considered to be one of the important accounting systems for assessing the environmental sustainability of an economy (WRI 1997; Bringezu 1997; Moriguchi 1998, pp. 107-122). Using similar methods, the Japanese Environment Agency has reported the Material Balance (MB) of the Japanese economy every year since 1992 in its Quality of the Environment Report (Environment Agency, Japan 1996, pp. 262-268; Moriguchi and Yoshida 1997). According to the Japanese Environment Agency, Japan (1996), the materials and energy brought into the Japanese economy in 1994 amounted to 2.30 billion tonnes, including virgin materials extracted from the natural environment [in domestic and foreign lands] and the recycled materials (p. 266). This means that an average Japanese consumed 18.6 tonnes of materials and energy in 1994. The total amount of the output from the economy and the accumulation within the economy was exactly in balance with the total amount of inputs: 0.10 billion tonnes were exported as commodity; 0.09 billion tonnes were recorded as food consumption; 0.4 billion tonnes were used as energy consumption; 0.26 billion tonnes were recorded as industrial wastes; 0.05 trillion tonnes were household wastes; 0.22 billion tonnes were recycled; and 1.18 billion tonnes were accumulated as manufactured capital[14] stock (p.

[14] Manufactured capital is often called 'man-made capital' (MMK). Since this term may imply gender bias, I use the term 'manufactured capital' instead.

266).[15]

Life Cycle Assessment (LCA) is another application of the materials/energy balance principle derived from the first law of thermodynamics. LCA assesses the environmental impacts associated with the entire life cycle of a certain manufactured commodity as comprehensively as possible. It looks at material/energy inputs as well as outputs during such stages as: extraction of raw materials; manufacturing of crude materials; processing into the final products; distribution and retail sales; usage by the consumers; and disposing or reuse or recycling (Nishioka *et al.* 1994, p. 7).

As one of the powerful modeling tools in fisheries science, the ECOPATH model has been developed by Polovina (1984a) and his colleagues in the 1980s. Based on their work, the ECOPATH II computer software has been developed further by Christensen and Pauly since 1989 (Pauly 1996, pp. 33-36). These ECOPATH tools enable researchers to construct biomass balance models of aquatic ecosystems. ECOPATH tools make it easier to analyze complex biomass fluxes among ecosystem components or species at various trophic levels. A number of mass-balance models in different ecosystems have been built using the ECOPATH tools (Polovina 1984b; Christensen and Pauly 1992a, 1992b; Christensen and Pauly, eds. 1993; Pauly and Christensen, eds. 1996). The ECOPATH model also bases its foundation on the implications of the first law of thermodynamics.

(2) The Second Law of Thermodynamics (Entropy Law)

Rudolf Clausius, a German physicist, contributed significantly to the advancement of

[15] In fact, these figures do not include some hidden but essential items such as the oxygen used for energy extraction from burning fossil fuels, and eroded soils. Extended material flow account which includes these hidden materials for the Japanese economy was calculated by Moriguchi and Yoshida (1997).

thermodynamics and established the concept of entropy in 1865, based on the work of precursors such as French scholar Sadi Carnot (Georgescu-Roegen 1971b; Murota 1979; Martinez-Alier 1987; Murota 1987a, 1995a). The Second Law of Thermodynamics is called the Entropy Law (Georgescu-Roegen 1971b, p. 6; Murota 1989, p. 200), or the Law of Increase of Entropy (Prigogine and Stengers 1984, p. xxix), or the Law of Increasing Entropy (Murota 1992, p. 255). Entropy is a measure of the dispersion of heat or matter (at the molecular level). Intuitively, it is akin to the concept of random disorder. The entropy σ of heat, for example, is represented by the following equation:

$$\sigma = q / T \text{ (kilocalorie/Kelvin)}$$

with a heat value of q kilocalories and at T°K (Kelvin, which is the scale of absolute temperature) (Murota 1989, p. 204).

William Rees describes the modern general interpretation of the second law of thermodynamics as follows:

> The second law of thermodynamics states that the 'entropy' of any isolated system spontaneously increases. That is, concentrations of material are dispersed, available energy is dissipated, gradients disappear, and structural order and integrity break down. Eventually, no point in the system can be distinguished from any other. (Rees 1997a, p. 307)

Indeed, in our daily lives we observe "irrevocable qualitative degradations . . . as a continuous turning of order into disorder" (Georgescu-Roegen 1971b, p. 6). For example, water heated in a kettle gradually gives away accumulated heat and its temperature eventually becomes the same as room temperature. If you leave a bicycle outside for a very long period of time, you will observe that metal parts such as the chain and gears become rusty, and that rubber parts decay. That generic account seems to be applicable specifically to simple non-biotic physical and chemical systems. What of more complex systems such as living systems like plants and animals? According to Schneider and Kay (1994),

> At first glance, living systems seem to defy the second law of thermodynamics. . . . because they display marvelous levels of order created from disorder. For instance, plants are highly ordered structures, which are synthesized from disordered atoms and molecules found in atmospheric gases and soils. (p. 1)

However, as Rees (1997a) points out, complex living systems are also governed by the same law of entropic decay (p. 307). The way living systems can sustain highly ordered structures is explained by Schneider and Key (1994). They state that "highly ordered stable complex systems can emerge, develop and grow at the expense of more disorder [entropy] at higher levels in the system's hierarchy" (abstract and p. 2). Rees (1997a) rephrases,

> Complex, self-organizing, self-producing systems can maintain or increase their internal order by importing available energy/matter (essergy) from their host environments (surroundings) and exporting degraded energy matter back into those environments. (pp. 305, 307)[16]

This notion is very important. This means that (1) living organisms can survive only by importing low-entropy matters and exporting high-entropy matters to the environment, i.e., by decreasing internal entropy and increasing external entropy; and (2) because of the existence of living organisms on the Earth, the rate of dissipation of matters and energy [or rate of entropy increase] at the global level is greater than it would be without living

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[16] Systems that maintain themselves in dynamic non-equilibrium through the continuous dissipation of essergy extracted from their host systems are called 'dissipative structures' (Prigogine and Stengers 1984, p. 12-14). In the past, instead of 'essergy' (low entropy energy / matter), 'negative entropy' or 'negentropy' was used by scholars like Schrödinger (1955). By definition, however, entropy cannot be negative. The smallest figure entropy can take is zero (Murota 1991a, pp. 164-166).

creatures on the planet. Tsuchida and Murota (1987) go on to describe entropy balance in greater detail. "The production of an ordered object from unordered, raw materials requires the input of low entropy sources, which turn into high entropy wastes *in excess of* the created low entropy" (p. 12, author's emphasis).

Tsuchida and Murota (1987) empirically computed the entropy balance of ecocycles. They have broken down the calculation into (i) photosynthesis by plants and cynanobacteria, and (ii) decomposition of organic matters by bacteria and fungi within topsoils.

(i) Photosynthesis by Plants and Cynanobacteria

Their calculation shows that by receiving sunlight (low entropy energy) on the surface of the Earth, plants emit *net* entropy of 16,566 cal/deg/mol during the process of fixation of one mol of CO_2 (Tsuchida and Murota 1987, p. 19, and see appendix 1). This observation exactly corresponds to the above-mentioned theory that plants, as self-organizing, complex systems, maintain themselves by importing essergy[17] from the surrounding environment and exporting high entropy wasted heat (*in excess of* the created low entropy) back to their surroundings.[18]

(ii) Decomposition of Organic Matters by Bacteria and Fungi

Decomposition reaction is another example of a *net* entropy increasing process. Tsuchida and Murota's calculations show the *net* increase of entropy of decomposition

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[17] Odum (1983) defines 'essergy' as follows.

> Essergy is a concept defined to evaluate the ability of energy sources and combinations to do work. It is the "available energy" to do work. It is the sum of the energies, each multiplied by the fraction of each energy that can be converted into mechanical work. (p. 266)

[18] Water plays an important role in this process for the disposal of the thermally degraded heat of solar energy. To fix one mol of CO_2, 522.3 mols of water (H_2O) are used (Tsuchida and Murota 1987, p. 18).

process to be 381.8 cal/deg/mol, where

$$[CH_2O]+O_2 \rightarrow CO_2 + H_2O(g) + \varepsilon$$

takes place ((*g*) means gaseous form, ε means heat discharged).

The combined effects of (i) and (ii) mean that each revolution of the ecocycle brings about a *net* increase in entropy amounting to 16,905 kcal/deg/mol (Tsuchida and Murota 1987, p. 21, and see appendix 1 for more details).[19] Interestingly, Murota (1987a) estimated that "the entropy generation σ (eco) of the ecosystem [on the Earth] as a whole is about one per cent of the global entropy generation σ_{gen}" (p. 196).

Erwin Schrödinger (1955) stresses the importance of the disposal of high entropy waste heat by living organisms into the environment, in the revised edition of his book, *What is Life?* He states, "And that we give off heat is not accidental, but essential. For this is precisely the manner in which we dispose of the surplus entropy we continuously produce in our physical life process" (p. 5).

We have observed that high-entropy waste heat is continuously being dissipated to the surface of the Earth by living things. What happens to the waste heat after being emitted from plants and animals? Does it get accumulated in the atmosphere? Scholars of the Society for Studies on Entropy in Japan such as Tsuchida, Murota, and Tamanoi have come to a conclusion that the Earth is being kept fit for habitation because the waste heat is being disposed to outer space through the hydrological cycle interacting with the

[19] This computation is normalized to one mol of carbon dioxide. In this, each mol of carbon dioxide gas of 300 ppm is fixed as organic matters by photosynthesis and they, in turn, are decomposed into carbon dioxide gas of 1 atm at first, and furthermore diffused into the carbon dioxide gas of the initial state of 300ppm. This computation was carried out under the assumption that sunlight reaches a plant and that 80% of it goes into the water vaporization while the remaining 20% of it is conveyed to air (Tsuchida and Murota 1987, p. 21).

atmosphere (see Tsuchida and Murota 1987, pp. 33-34, Endnote 9). For example, Murota (1987a) states that,

> the ecosystem is renewable as an open steady cycle owing to the open steady nature of the Earth itself. This is because the water and air cycles on the Earth contribute to take excessive thermal entropy away from its surface and to dispose of it towards the outer space. (p. 185)

Murota (1987a) and his colleagues use the term 'water planet earth' in order to emphasize the importance of water cycles for the maintenance of habitable environment on the Earth (p. 185). They have calculated the heat balance of the Earth. Current average Earth surface temperature is approximately 288°K (=15°C). In the absence of water and air cycles, the average temperature would be 304°K (=31°C) (Murota 1987a, pp. 186-190), which is 16°C higher than the current Earth surface temperature. This is an unbearable temperature for most of the living organisms on the Earth.[20] For example, even a 3°C rise in the average global temperature would eradicate 7 to 11% of wild vegetation species in the United States and Canada (CASA 1996, p. 29). Fish species would be forced to be extinct due to the rise of air and water temperature. For example, the survival rate of Pacific salmon is known to be sensitive to thermal changes (Welch *et al.* 1998a; Welch *et al.* 1995). A doubling of atmospheric CO_2 and a corresponding rise in the global mean temperature of 1.5°C-4.5°C (UNEP 1993, p. 13) could eliminate most, if not all, suitable

[20] According to Murota (1999a), "This kind of statement is true for mammals, fish, and many other living beings, of which ordinary people like me are usually aware. But there also are many species of thermophilic bacteria in the earth system. For example, some sulfur bacteria live in hot springs (on lands as well as under the deep sea) as hot as 90°C or so. More than that, some scientists recently speculate that a great amount of biomass comparable with the total biomass hitherto known on the earth are in the deep earth. They are thermophilic, i.e., they like extremely hot environment. Traditionally, the deep earth has been considered to be a hell without any life. Such a view, however, is now under the process of major revision in natural sciences of the world facing the 21st century."

habitat for Pacific sockeye salmon (Welch *et al.* 1998b). As the evidence suggests, a global temperature rise of 16°C would be catastrophic for many living beings.

(3) Implications of the Second Law for Human Economy

So far, I have discussed the second law implications for non-biotic physical and chemical systems as well as for the living systems such as plants, decomposers and animals. What about the implications for humans and human economy? In fact, human economy is a complex, far-from-equilibrium, self-organizing system, just like any other living system. Thus, human economy is also "subject to the second law of thermodynamics" (Rees 1998, p. 50), i.e., a universal law of "a *continuous* and *irrevocable* qualitative degradation" (Georgescu-Roegen 1971b, p. 6). The major difference between human economies and other living systems is that the former performs, not only biological metabolism, but also 'industrial metabolism' (Ayres and Simonis, eds. 1994). Despite that difference, human economies are still governed by the law of increasing entropy. Based on this recognition, a new school of thought, namely 'ecological economics' emerged in the 1980s.[21] This is also called 'economics of entropy' in Japan.

The general implication of the second law of thermodynamics for human economy was first given perhaps by Soddy (1912, 1926, 1934). More recently, Georgescu-Roegen explains along the same lines,:

> what goes into economic process represents *valuable natural resources* and what is thrown out of it is *valueless wastes*. But this qualitative difference is confirmed, albeit in different terms, by a particular (and peculiar) branch of physics known as thermodynamics. From the viewpoint of thermodynamics, matter-

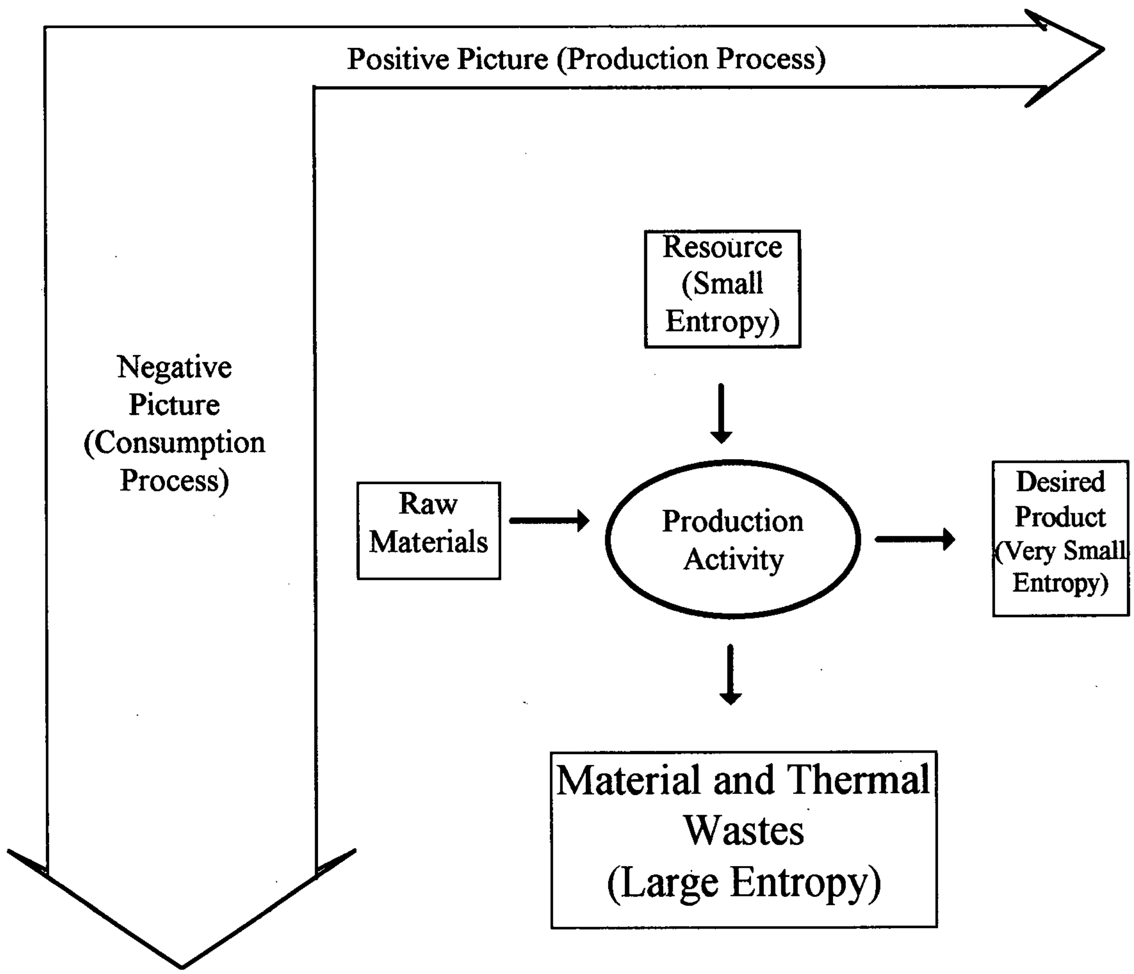
[21] However, Hall disagrees with this view. He states "'ecological economics' is a large umbrella that includes very many things, most unconnected with the second law of thermodynamics" (Hall 1999, personal communication).

> energy enters the economic process in a state of *low entropy* and comes out of it in a state of *high entropy*.[22] (1971a, pp. 76-77)

Daly restates simply: "The structure and order (low entropy) of the economy is maintained by imposing a cost of disorder on the ecosystem" (1991a, p. 34).

Contrary to ecological economics, conventional economics--neoclassical economics, and Marxist--look at only the former part, i.e., the maintenance of structure and order, without paying much attention to the latter part, i.e., valueless wastes and the costs of disorder on the ecosphere. Tsuchida and Murota (1987) illustrate this in the next diagram.

Figure 7 Thermodynamic Process of Production: Its Positive and Negative Picture



[22] Tsuchida and Murota (1987) also describe the implication of entropy law as "The consumption at large is equivalent to the generation of entropy and the production necessarily accompanies such consumption as of bringing about the increase in entropy of a given system as a whole" (p. 12).

Tsuchida and Murota call the former aspect of economic process the "positive picture" which is expressed as the horizontal process in Figure 7. They call the latter the "negative picture" of production (the vertical process, above). It is important to note that, without exception, the "positive picture" is always accompanied by the "negative" one. That is, along side with the manufacturing process of desired products, creation or emission of high-entropy wastes into the environment always takes place. This "negative picture" of increasing entropy is an inevitable and irreversible process. Once fuel energy is burnt, high-entropy waste heat and fumes are emitted into the environment. You cannot easily transform them back to the original low-entropy forms. (It is not impossible to do it. However, you are required to bring in additional low-entropy energy and matter which will simultaneously generate another negative picture, leading to a further increase in total entropy.)

It is important to pay attention to the fact that this negative picture is significantly larger than the positive picture, as illustrated by the difference of the width of each arrow. We may recall the previous discussion on living systems, which highlighted that the generation of high-entropy mass/energy is significantly larger than the creation of ordered structures. Human economy is no exception. The importance of the negative picture becomes apparent and self-evident through the second law of thermodynamics. But we tend to overlook this profound reality. Indeed, mainstream economics has focused attention on the positive picture alone, while long ignoring the negative one of the irrevocable process of entropic decay.

Despite the fact that the negative picture always emerges whenever the positive picture takes place, the survival of human economy has been maintained. This is, in fact, possible only because the ecosphere, the system one level higher than us, provides indispensable and unique life-supporting services for us. These services include provision of low-entropy matters and energy, and absorption of high-entropy wastes. As Rees puts it,

> By this interpretation of entropy law, the economy is but one level in a nested hierarchy of systems in which the survival of each sub-system is dependent on the productivity of the system immediately above. For economy, the superior system is the ecosphere. (Rees 1998, p. 50)

Rees further elaborates upon the implications of entropy law to the human economy:

> This relationship is no problem for either the economy or the ecosphere as long as material consumption and residuals production by the former does not significantly exceed resource production and waste assimilation by the latter. (Rees 1998, p. 50)

However, when this balance is lost, environmental problems emerge. Daly describes the origin of environmental problems in general:

> The high-entropy wastes often interfere with the functioning of natural capital[23] and inhibit the life-supporting services rendered by air, water, and soils. Pollution also inhibits the ability of manmade capital to render services . . . . As the stock and its maintenance throughput grow, the increasing disorder exported to the ecosystem will at some point interfere with its ability to provide natural services. As we add artifacts we gain services from them, but beyond some point we pay a price in terms of diminished natural services from the ecosystem. (Daly 1991a, p. 34)

The human economy's consumption of low-entropy matters and creation of high-entropy waste must be balanced with the resource production and waste assimilation

[23] 'Natural capital' refers to "a stock [of natural assets] that yields a flow of valuable goods and services into the future" (Costanza and Daly 1992, p. 38).

capacity of the ecosphere. This balance principle is based on recognition of the second law of thermodynamics, and is a very important imperative for sustainability. Otherwise, human economy will not be sustained because of the diminished ability of ecosphere's provision of life-supporting services, as Daly (1991a) pointed out (p. 34). This balance principle is the basis for the ecological economics and for the ecological footprint analysis. The details of the ecological footprint concept will be explained in Section 2.3.

Here let me conclude this section of 2.1 by presenting an insightful notion derived by a far-sighted Japanese economist, Kei Shibata. Just after World War II, discovering serious inherent problems in industrial civilization, Shibata conceived the Law of Calamity of Destruction (1953). In his powerful statement, worth quoting at length, he states:

> Modern industrial civilization is a civilization of iron and coal and oil. Even if we assume that the population will increase no more, and that there are no other changes in the levels of livelihood for people, such as the real wages for laborers, we must each year devour gigantic quantities of iron, coal, oil, and all other so-called 'exhaustible' wealth. For example, in the year 1950, the principal countries of the capitalist world alone produced 12 billion tons of coal and 4.85 billion tons of crude oil . . . . To say that they 'produced' coal and oil sounds very good to the ear, so people think of this in the same way as the act, from long ago, of utilizing the 'inexhaustible' capacity of the land to 'produce' grains in the same way each year based on the land's capacity, which remains there without being lost, but extracted coal and crude oil are already lost forever . . . . The more that modern civilization depends upon so-called exhaustible wealth, such as iron, coal, oil, and others like these, and the more it intensifies this characteristic, the worse the situation will become. And when the situation becomes very bad . . . . not only will one eventually cease to make a profit, but it will become impossible to maintain real wages. This is what I mean by 'destruction's calamity.' (pp. 65-67, cited in Murota 1992, pp. 250-251)

Even if Shibata did not use the word 'entropy,' his statement implies that if we keep using low entropy matters and energy, we may reach a point where costs exceed benefits because of the accumulated high-entropy matter and energy. Shibata began to explore the inherent problems of modern industrial civilization, i.e., the negative picture of the mass production in early 1950s. However, in the historical context of continuous economic growth in Europe, North America and Japan, mainstream economists did not pay his warning substantial attention until the 1970s. Shibata's farsightedness should be highly appreciated by present-day scholars (Murota 1992, p. 249-257; Murota 1995a, p. 13-15; Murota 1995b, p. 202-203).

3.2 Limitations of Conventional Economics: Need for an Alternative

This section attempts to demonstrate the reasons why traditional mainstream economics, namely neoclassical economics, is fundamentally incapable of coping with the environmental challenges. By doing so, I make a case for an alternative.

(1) Mechanical Worldview: Foundation of Neoclassical Economics

Neoclassical economics has its roots in the Cartesian and Newtonian mechanical worldview (paradigm). As Georgescu-Roegen (1971b) describes it:

> The whole truth is that economics, in the way this discipline is now generally professed, is mechanistic in the same strong sense in which we generally believe only Classical mechanics to be.
>
> In this sense Classical mechanics is mechanistic because it can neither account for the existence of enduring qualitative changes in nature nor accept this existence as an independent fact. Mechanics knows only locomotion, and locomotion is both reversible and qualityless. (p. 1)

He concludes that "these artifacts succeeded so well with their grand plan that the conception of the economic process as a mechanical analogue has ever since dominated economic thought completely" (p. 2). He also states, "In this representation, the economic process neither induces any qualitative change nor is affected by the qualitative change of the environment into which it is anchored" (p. 2). Murota (1985) also presents a similar account: "conventional modern economic theories tend to illustrate the economic processes to be mechanistic and reversible" (p. 120). As these scholars claim, in the traditional mainstream economics which is based on a Newtonian mechanical worldview, irreversible and qualitative changes of nature were (and still are) not fully incorporated into the model (Georgescu-Roegen 1971b, pp. 1-4, 281).

Nakamura (1995) uses an intuitive analogy in order to make the same point. He compares a relationship between Newtonian physics and thermodynamics to the relation between conventional economics and ecological economics. According to Nakamura, Newtonian physics is suited to describe the movement of astronomical bodies in absolute space. However, since it is impossible for Newtonian physics to provide adequate explanations of motion in space with friction--the existence of friction transforms motion energy into heat energy--thermodynamics had an important role to play in accurately analyzing the world with friction. Likewise, the conventional economic model, which is based on a qualityless and mechanistic worldview, is capable of describing only the person-to-person (firm-to-household, firm-to-firm) economic relationship. In the viewpoint of many, this model, however, has proven itself to be incompetent in outlining the relationship between human economy and the ecosphere which involves a process of entropic qualitative decay of energy and materials (Nakamura 1995, pp. 149-150).

Historically, an eminent neoclassical economist in the early twentieth century criticized economic models for being built as analogous to the models of Newtonian physics and advocated the construction of economic theory based on evolutionary biology and historical characters of the actual economy. Alfred Marshall (1920) was among economists in the past who "intuited that biology, not mechanics, is the more true Mecca of economists" according to Georgescu-Roegen (1971b, p. 11).[24] However, Marshall's idea was not followed by his successors. Daly and Cobb elaborate this point by stating,

> Alfred Marshall, the founder of neoclassical economics, was highly sensitive to the historical character of the actual economy. Nevertheless, economists on the whole wanted economics to become increasingly scientific, and their idea of science was based on physics rather than on evolutionary biology. That meant that economics had to focus on formulating models and finding laws "governing" present economic behavior rather than seeking laws "governing" the changes of economic systems or asking about contingent historical matters. As a result, when useful models have been found and when hypotheses have proved successful, they are treated as analogous to the models and hypotheses of the physicist. Their limitation to particular historical conditions is neglected. Leon Walras, in his *Elements of Pure Economics*, undertook "to do for economics what Newton had done two centuries earlier for celestial mechanics" (1954: Maital 1982, p. 15). In the twentieth century, economics has followed Walras. Milton Friedman notes of economists that "we curtsy to Marshall, but we walk with Walras" (1949, p. 489). (Daly and Cobb 1989, p. 30)

Since economics began to "walk with Walras", it has continued to elaborate its theories imitating "the mechanistic model, i.e., the model of 'matter in motion' that is: all changes and everything else that is found in the world are explained in terms of context-independent units of matter changing relative location" (Cobb 1992, Lecture July 8th), without taking account of qualitative changes of matter and energy.

(2) Assumed Reversibility of Natural Capital

The 'mechanistic' economic model assumes reversibility and malleability of physical

[24] Marshall's original text reads: "The Mecca of the economist lies in economic biology rather than in economic dynamics" (1920, p. xii, within 'Preface of the Eighth Edition'). I used the edition of 1962.

phenomena (Uzawa 1983[7], pp. 338-339; Tabeta 1994, p. 174) whereas the reality is different. Once coal is burnt, it is almost impossible to recreate the original coal. Most fabricated machines (e.g., automobiles and computers) can be recreated if destroyed. However, it requires additional inputs of low-entropy resources and human skills, subsequently accompanied by the irreversible process of increase in high-entropy heat and matter, as explored in Section 2.1.

Biophysical assets generally cannot be restored if destroyed [on a scale of any utility to human economies], or even where possible, the cost of restoration is extraordinary (Uzawa 1983[7], pp. 338-339). For example, once a tropical forest is cut down, the thin topsoil layer often will be lost very quickly. Once topsoil is lost, it is very difficult to restore it. At the extreme, once a species is extinguished due to overexploitation or excessive disturbance, it is impossible to bring it back to life (Jacobs 1993, p. 83).

Irreversible damages can occur not only to ecosystems but also to human health and society. For example, Minamata Disease was discovered in Minamata City in Kumamoto Prefecture in Japan in the 1950s (Ui 1992). This disease was found to have been caused by mercury discharged by Chisso Company's Minamata Factory. Since the 1950s, more than eleven thousand Minamata disease victims have been identified (Miyamoto 1987, p. 134). Nearly one thousand of them have died as of December 1990 (Ui 1992, p. 131). The lost lives can never be restored. Many of the remaining patients still suffer from degraded health. The deteriorated physical health and wounded hearts of the patients and their families are difficult to heal.

Contemporary economists have not paid enough attention to this irreversible nature of entropic decay in natural capital and human health (Hanayama 1978, pp. 190-192). As mentioned in the earlier section, Alfred Marshall's efforts failed to hamper the economists' increasing inclination towards the mechanistic Newtonian worldview which assumes reversibility of every physical phenomena. Georgescu-Roegen states,

> And even though Marshall's antimechanistic proclivities were reflected mainly in his famous biological analogies, we must impute to them his salient discovery of the irreversibility of long-run supply schedules. Unfortunately, Marshall's teaching caused no lasting imprint and the fact that irreversibility is a general feature of all economic laws received no attention. (1971b, p. 11).

Due to this bias of mechanistic reversibility, mainstream economic models cannot provide adequate accounts of irreversible events that are associated with all real economic systems, and cannot escape from presenting only partial and inaccurate pictures of these biophysical phenomena. Thus, their prescriptions for policy changes tend to be ineffective. Compensation and restoration measures should be considered only the second best option. Prevention of destruction and degradation of ecological heritage should come as the first priority because the restoration is difficult and expensive due to the irreversible nature of biophysical phenomena (Tabeta 1994, pp. 173-175; Tabeta 1995, pp. 56-61). Tabeta (1994, 1995), a Japanese scholar of the Society for Studies on Entropy, argues that it is urgently necessary to restore and maintain a balance between 'prohibition rules' and 'freedom rules' (which is a basis of market economies) in order to prevent irreversible destruction. Tabeta (1994) states that prohibition rules are very important requirements for securing the survival of the stable and sound freedom rules in the future (p. 209).

(3) Homo economicus

"Mechanistic science is based on the assumption that matter is made up of individual parts" (Merchant 1992, p. 68). The advancement and success of mechanistic Newtonian physics have had great influence on traditional economic theory in terms of the image of persons in a society as extremely individualistic and rational. Mainstream economics assumes that person in a society acts rationally in order to maximize his/her self-interests. Daly and Cobb (1989) state "The most important abstraction to contemporary economic theory is that of *Homo economicus* from real flesh and blood human beings" (p. 85). According to Daly and Cobb (1989), *Homo economicus* is a "self-enclosed individual whose relations to others are external" (p. 184) who "act[s] [rationally] so as to optimize [his/her] own interests . . . . The assumption is that rationality largely excludes other-regarding behavior" (p. 5).

The exclusion of "other-regarding behavior has deep, although conflicting, roots in the Western theological understanding of human nature" (Daly and Cobb 1989, p. 5). They explain,

> Theologians have held that other-regarding action is an ethical ideal, but many, especially after St. Augustine, have seen self-regarding behavior as dominant in the actual "fallen" condition. This fallenness was strongly accented by the Reformers and their followers, encouraging general suspicion of claims to genuinely other-regarding action in Protestant cultures. It is not surprising that the philanthropist Robert Owen, living in such a culture, rejected Christianity for its individualism (Polanyi [1944] 1957, p. 128). Catholic theology followed St. Thomas in giving more credence to socially concerned, community-building aspects of human activity.
>
> In Calvinism, the skepticism about human virtue was connected with the suspicion of earthly authority in both church and state. The relation to God was conceived as immediate and decisive. This led to a claim to personal autonomy in both secular and religious affairs and restrictions on government interference. (Daly and Cobb

1989, p. 5)

Indeed, during an earlier era of capitalism, Calvinism has gone hand in hand with modern economics in promoting individualistic ethics and worldview. In this respect, the Catholic church took a somewhat different approach. Daly and Cobb (1989) observe,

> Modern economic theory originated and developed in the context of Calvinism. Both were bids for personal freedom against the interference of earthly authority. They based their bids on the conviction that beyond a very narrow sphere, motives of self-interest are overwhelmingly dominant. Economic theory differed from Calvinism only in celebrating as rational what Calvinists confessed as sinful.
>
> Calvinism encourages other-regarding behavior as truly Christian even while warning against believing too readily in its reality. Catholicism encourages other-regarding behavior as a natural virtue. (p. 6)

As capitalism and the market system became more and more pervasive in the world, neoclassical economics began to displace traditional Christian thinking and started to undermine Christianity's feedback function against excessive self-interest seeking behavior. Daly and Cobb (1989) continue,

> When Christianity was dominant, these forces checked blatantly self-seeking activity, although they certainly did not prevent it. But, economists have taught us to think that checks on self-interest are both unnecessary and harmful. It is through rational behavior, which means self-interested behavior, that all benefit the most. Well-meaning attempts by government to oppose or check such behavior actually do more harm than good. As this belief displaces traditional Christian thinking, and as the market in which these principles are applied takes over a larger and larger role in society, the psychological, sociological, and ecological problems noted by critics of the economists have become more acute. (p. 6)

The tendency to perceive a person as *Homo economicus* has proven problematic from social and ecological points of view. This distorted perception needs to be reconsidered. Here, let us discuss another profound presumption of neoclassical economic theory which is infinite growth without taking account of the ecosphere's carrying capacity.

(4) Unlimited Growth

Conventional economics assumes that an economy is a completely closed circular system where a pendulum movement between production and consumption continuously takes place (Georgescu-Roegen 1971a, p. 75). In other words, goods and money circulate indefinitely between households and firms (Georgescu-Roegen 1971b, p. 281). In this model, the law of increasing entropy has been totally ignored (Rees 1997a). Conventional economists have also not paid much attention to the fact that the ecosphere's ability to supply low-entropy matters (natural resources) is limited because they trust that human ingenuity can solve the problem of resource scarcity, if there is a solution, through science and technology. Economists believe, therefore, that economic growth can continue without limit (Suzuki 1989, p. 163). For example, Barnett and Morse (1963) reject the general scarcity of natural resources:

> Advances in fundamental science have made it possible to take advantage of the uniformity of energy [/] matter -- a uniformity that makes it feasible without preassignable limit, to escape the quantitative constraints imposed by the character of the earth's crust. . . . Nature imposes particular scarcities, not an inescapable general scarcity. Man is therefore able, and free, to choose among an indefinitely large number of alternatives. . . . Science, by making the resource base more homogeneous, erases the restrictions once thought to reside in the lack of homogeneity. . . . The reservation of particular resources for later use, therefore, may contribute little to the welfare of future generations. The social heritage consists far more of knowledge, equipment, institutions, and far less of natural resources, than it once did. (pp. 11-12)

More recently, Simon (1981) expressed his notably strong view against the notion of 'finite' resources.

> Incredible as it may seem at first, the term "finite" is not only inappropriate but is downright misleading when applied to natural resources, from both the practical and philosophical points of view. (p. 47) . . . There is no necessity either in logic or in historical trends to suggest that the supply of any given resource is "finite." (p. 50)

Indeed, economic growth has long been the central theme of neoclassical economists, as Lewis (1955) state: "First it should be noted that our subject matter is growth, and not distribution" (p. 9).

It may be interesting to pay attention to historical roots of what we might call growth fanaticism. They can be found in the relationship between Western religious thinking and expansion of capitalist economies. Max Weber (1958) analyzed the historical role of Protestantism, particularly that of Calvinism (which started in the 16th century), in the advancement of capitalism and economic growth. Weber states:

> The idea of man's duty to his possessions, to which he subordinates himself as an obedient steward, or even as an acquisitive machine, bears with chilling weight on his life. The greater the possessions the heavier, if the ascetic attitude toward life stands the test, the feeling of responsibility for them, for holding them undiminished for the glory of God and increasing them by restless effort. The origin of this type of life also extends in certain roots . . . back into Middle Age. But, it was in the ethic of ascetic Protestantism that it first found a consistent ethical foundation. Its significance for the development of capitalism is obvious. (p. 170)

He continues,

> This worldly Protestant asceticism, as we may recapitulate up to this point, acted powerfully against the spontaneous enjoyment of possessions; it restricted consumption, especially of luxuries. On the other hand, it had the psychological effect of freeing the acquisition of goods from the inhibitions of traditionalistic ethics. It broke the bonds of the impulse of acquisitions in that it not only legalized it,

> but (in the sense discussed) looked upon it as directly willed by God. . . . And even more important: the religious valuation of restless, continuous, systematic work in a worldly calling, as the highest means to asceticism, and at the same time the surest and most evident proof of rebirth and genuine faith, must have been the most powerful conceivable lever for the expansion of that attitude toward life which we have here called the spirit of capitalism.
>
> When the limitation of consumption is combined with this release of acquisitive activity, the inevitable practical result is obvious: accumulation of capital through ascetic compulsion to save. (pp. 170-172)

This religious belief of a Protestantism which emphasized the importance of ascetic attitude (which includes limitation of consumption) gave permission for the accumulation of the fruit of this asceticism, i.e., wealth. As a result, Protestant ethics facilitated development of capitalism and economic expansion in Europe since the 16th century. In this historical context, a limit to economic growth due to resource scarcity was, in fact, somewhat recognized by earlier classical economists like Ricardo and Malthus in the seventeenth, eighteenth and early nineteenth centuries. Malthus' seminal *Essay on the Principle of Population* (first edition, 1798) is the best example of this recognition. However, having been deluded by the marvelous technological advancement of the Industrial Revolution of 18th-19th century, neoclassical economists have dropped the notion of natural resource scarcity from their analytical framework, and begun to build economic models based on the assumption of unlimited resource supply. Repetto *et al.* (1989) explain this point:

> In 19th century Europe, steamships and railroads were markedly lowering transport costs while foodgrains and raw materials were flooding in from North and South America, Australia, Russia, and the imperial colonies. What mattered to England and other industrializing nations was the pace of investment and technological change. (p. 2)

Under this geopolitical and historical context, resource scarcity was not a concern for most of the neoclassical economists. Thus, unlimited economic growth was perceived as a non-refutable assumption.[25] Above is the historical background explanation as to why the mainstream monetary analysis has been constructed without relevant physical dimensions.

However, Georgescu-Roegen (1971b), Meadows *et al.* (1972), Daly (1977, 1991a, 1991b), Goodland (1991, 1996) and others assert that the world has reached its limit for accommodating further growth. From these perspective, growth is not desirable for the sake of social well-being, nor possible from entropic and ecological points of view. Evidences to support this argument are mounting (for example, Pauly *et al.* 1998 with respect to the world fish stock). As Birch and Cobb (1990) claim, "If economic growth cannot be continued indefinitely, economic theories geared to growth need to be re-examined" (p. 294). Our generation needs to go through a fundamental shift of worldview from the 'expansionist' one to the 'ecological' one, which may be as profound as the Copernicus shock in the 16th century.

(5) Limitation of Monetary Valuation of Natural Capital and Its Goods and Services

In (1), I discussed some of the serious defects of mechanistic mainstream economic models, which cannot account for qualitative changes of the environment. One may claim, however, that prices in the marketplace reflect the qualitative values of natural assets; that even though market prices fail to reflect true environmental costs, internalizing the 'externality' will solve the problem, and that therefore, the neoclassical monetary analysis

[25] This perspective is also called "expansionist worldview" as opposed to "ecological worldview" (Taylor 1992).

can fully accommodate qualitative environmental changes. What follows is an argument against this claim.

According to Rees and Wackernagel (1999, p. 47), money valuation (regardless of how monetary values are assigned) cannot reflect in any comprehensive sense true qualitative values of natural capital itself, nor those of goods and services provided by 'natural capital'--particularly those associated with biophysical resource scarcity. 'Natural capital' refers to "a stock [of natural assets] that yields a flow of valuable goods and services into the future" (Costanza and Daly 1992, p. 38).[26] Examples of natural capital are forest, soil, ozone layers, and petroleum. Let us take forest as an example of natural capital. Goods and services provided by forest are: timber; climate regulation; carbon sink functions; water regulation; flood control; biodiversity; and existence values (Rees and Wackernagel 1999, p. 47). There are at least the following ten reasons why financial analyses are fundamentally flawed in assessing true values of natural capital.

#1 *Consumer Prices Poorly Reflect Physical Scarcity and Systems Fragility*

Physical scarcity is often poorly reflected in consumer prices (Hall 1992, pp. 109-110). In other words, consumer prices are often not sensitive enough to be able to notify us of resource scarcity. Pearce *et al.* (1989) explain that "The cost of producing any good or service tends to be a mixture of priced 'inputs' (labour, capital, technology) and unpriced [or under-priced] inputs (environmental services)" (p. 154). Rees and Wackernagel (1999) elaborate on this point: "the market price is often more an indicator

[26] Natural capital was earlier defined by Daly and Cobb as "nonproduced means of producing a flow of natural resources and services" (1989, p.72). Here, I employ Costanza and Daly (1992)'s definition which is more functional. Natural capital is divided into two kinds: renewable (e.g., fish, forests), and non-renewable (e.g., petroleum and mineral) (Daly 1996b, p. 80).

of producer costs or exogenous market factors than of remaining quantities of [low entropy] stock in question" (p. 48). For example, technological innovation increases efficiency and leads to a decline of marginal cost of resource exploitation. Rees and Wackernagel (1999) substantiate their argument by providing the following example,

> low fuel costs, electronic fish-finders, and high-tech factory freezer-trawlers enabled industrial fishers to access previously inaccessible stocks of North Atlantic groundfish, maintaining supply (and low prices) even as the stocks were depleted. (p. 48)

Rees and Wackernagel (1999) conclude that "If the contribution of stock depletion to price is relatively small, markets will provide a weak signal of incipient biophysical scarcity and unsustainability" (p.48).

Other examples of exogenous market factors are: variable demand, the intensity of competition among suppliers, the price of substitutes, processing and transaction costs (Rees and Wackernagel 1999, p. 48), as well as weather in competing regions, trade policy, population and income growth in market areas, among others (Rees and Wackernagel 1999, ms p. 2).

Another example which demonstrates the deficiency of monetary analysis for assessing environmental sustainability is a study on high-tech agriculture in British Columbia, Canada (Wada 1993). I computed the financial as well as ecological sustainability of hydroponic greenhouse tomato production, and compared that with the conventional field tomato production. I assessed profitability by employing financial analysis. I employed ecological footprint analysis to assess ecological sustainability. My case study found that hydroponic agriculture was far more successful in terms of monetary/financial analysis compared with field operations. The net profit per hectare of growing area of greenhouse operations is 2 to 9 times higher than that of the field operations (p. 41). However, the study also found that high-tech agriculture is extremely ecologically unsustainable, since hydroponic operations require inputs of large quantity of low-entropy energy and matters. "Hydroponic operations required 14 - 21 times more land than conventional open field operations to produce the same output" including all the ecological footprints of various inputs (p. ii, pp. 38-40). My study showed that ecologically unsustainable practices are justified by monetary analysis as long as:

> (1) prices of production inputs (e.g., natural gas, liquid fertilizer, equipment) are set sufficiently low;
>
> (2) demand in market areas is strong enough (B. C. greenhouse owners send their tomatoes even to New Jersey or Florida *by air* if the price is favorable!); and,
>
> (3) prices of substitutes, i.e., field tomatoes from B. C. and other regions, are not too low.

This study showed that high-tech agriculture is a prime example of apparent economic success which is, in fact, ecologically unsustainable. My case study demonstrated that the apparent yields of hydroponic greenhouse agriculture are partially a reflection of underpriced resource inputs, a form of subsidy which is not sustainable (Wada 1993, p. ii, and see also Wackernagel and Rees 1995[6], pp. 108-109; Rees 1997b, pp. 56-58).

#2 Globalization of Market and Inequitable Income Distribution Facilitate Stock Depletion

Even though price does go up beyond the reach of ordinary consumers, there are an increasing number of extremely rich consumers, in an expanding global economy, who can afford to purchase expensive natural commodities. For example, one large tuna was purchased by a Japanese buyer at the price of 80,000 dollars (Brown 1995). "In these circumstances, price simply fails to prevent biophysical scarcity, even extinction" (Rees and Wackernagel 1999, p. 49). In other words, even when there is a strong price signal of resource scarcity in the market, that does not necessarily lead to depressing the aggregate demand because of affluent individuals and global transportation, and the result is a degradation of the quality of ecosystems.

#3 An Erroneous Assumption of Perfect Knowledge and Informed Choices

Money values and efficient markets assume perfect knowledge and informed choices on the part of producers and consumers. However, this assumption fails for many essential goods and services provided by nature, because of the difficulty of understanding interrelated functions of complex ecosystems. Further discussion will be presented in the subsequent section of 'externality.'

#4 Dominance of Human Value Judgment

Monetary evaluation depends heavily on value judgment of human-beings. However, natural assets *per se* have their own "intrinsic value," regardless of existence of human-beings or market places created by human-beings (Pearce *et al.* 1989, p. 61). They define "intrinsic value" as "a value that resides 'in' something *and that is unrelated to human beings altogether*" (p. 61). These intrinsic values are not fully and accurately reflected by the anthropocentric monetary analyses.

#5 Problems of 'Externality'

Qualitative changes of natural assets did not have space in the model of conventional economics: they were something 'external' to their model. Traditional economists once supposed that the market can accommodate the qualitative changes of the environment. However, the market has been proven to be imperfect. Sometimes the market does not even exist for some critical natural capital (such as air, water, and so on). Pearce *et al.* (1989) state:

> many environmental products, services and resources do not get represented in the price mechanism. This effectively amounts to them being treated as "free goods", i.e., they have zero prices. It follows that an *unfettered* price mechanism will use too much of the zero-priced good. Resources and environmental goods will become degraded on this basis alone, i.e., because the price mechanism has wrongly recorded environmental goods as having zero prices when, in fact, they serve economic functions which should attract positive prices. (p. 154)

As a last resort, traditional economists introduced the term 'externality' to mean (positive and/or negative) values which are not reflected in the marketplace. By 'internalizing' the so-called externalities, neoclassical economists thought that their model could comfortably accommodate qualitative values of ecological assets. However, the internalization of externalities associated with natural capital has proven to be difficult because of the inherent difficulties of agreeing on true values of natural capital and the goods and services derived from the capital in monetary terms. This is mainly because of the difficulty in perceiving and understanding interrelated functions of complex ecosystems. Vatn and Bromley (1994) explain:

> Environmental assets are, to large extent, characterized by their quintessential invisibility - their *functional transparency*. Functional transparency means that the precise contribution of a functional element in the ecosystem is not known -- indeed is probably unknown -- until it ceases to function. . . . For instance, nitrogen cycles in wetlands are not obvious until they are destroyed and we then begin to discover the serious implications. (p. 133)

This "functional transparency" causes "a non-trivial loss of information" (p. 130) in conducting hypothetical monetary valuation of ecological assets, i.e., "contingent valuation" (Vatn and Bromley 1994, p. 130).

Uzawa (1983[7]) comments on another problem associated with the calculation of 'external costs.' He claims that the deviation between the presumed or perceived reversibility and the actual irreversibility of natural capital distorts the cost-benefit calculations. He states:

> The irreversibility [of environmental assets] does not take [external] costs' calculation into account when cost-benefit analyses are performed. Rather, cost-benefit calculations are conducted under the assumption that all the scarce resources are reversible and malleable, which is a fundamental shared assumption of neoclassical theory. Cost-benefits are calculated based on the perceived expectation or prediction on various market and economic conditions for the future. However, the expectation and the reality generally diverge from each other, especially when the relevant resources exhibit irreversibility in reality. This diversion significantly undermines the validity of cost-benefit analysis. (pp. 338-39)

Daly and Cobb (1989) state that the introduction of 'externality' into the neoclassical model proves that the neoclassical school admits that their model needs some repair especially when dealing with ecological crisis. Daly and Cobb claim that just a minor repair is not enough and suggest that construction of a new model is necessary, one which can embrace the reality of the ecosphere:

> Externalities are ad hoc corrections introduced as needed to save appearances, like the epicycles of Ptolemaic astronomy. Externalities do represent a recognition of neglected aspects of concrete experience, but in such a way as to minimize restructuring of the basic theory. As long as externalities involve minor details, this is perhaps a reasonable procedure. But when vital issues (e.g., the capacity of the earth to support life) have to be classed as externalities, it is time to restructure basic concepts and start with a different set of abstractions that can embrace what was previously external. (Daly and Cobb 1989, p. 37)

#6 Irreplaceability of Natural Capital with Manufactured Capital

If resources (low entropy matters and energy) become scarce, the market will fix the situation. The hike in price of scarce resource encourages conservation of that resource and stimulates invention of a man-made substitute. Human ingenuity can create substitutes without problems. For example, Stiglitz (1982) states:

> these benefits of technical change more than offset the disadvantages we bequeath to future generations in the form of a smaller stock of material resources. (p. 174)

This optimistic assumption of neoclassical economists may be applicable to some instances, but does not necessarily mean that it is applicable to all the cases. Some critical natural capitals are irreplaceable by manufactured capitals. For example, you cannot easily replace wetland, which purifies contaminated water that goes through it. The ozone layer cannot, at least in the foreseeable future, be replaced with new materials (Wackernagel and Rees 1995[6], pp. 36-38).

#7 Monetary Analyses Do Not Distinguish Between Substitutable Goods And Complementary Goods

On the financial balance sheet, all prices are added or subtracted as if goods that are priced the same have equal absolute importance to human life. However, substitution does not always come as easily between natural products and human-made artifacts. The values and utility of manufactured capital (e.g., fish-boats) depend on natural capital (fish stocks), and the converse is not true. The illusion of commensurability promoted by monetary analysis exposes slowly reproducing natural capital to market pressures. Natural capital should not be treated as substitutable goods, but as complementary goods or prerequisite for manufactured capital (Wackernagel and Rees 1995[6] p. 36, pp. 46-47). Monetary analyses are not capable of distinguish these three different features of natural capital.

 # 8 Problems of Discounting

Despite the fact that "discounting is a messy and disputed business about which economists themselves disagree" (Daly and Cobb 1989, p. 152), the practice of discounting is widely applied to financial and economic analyses such as cost-benefit analysis and project appraisal for publicly and privately financed investment projects (see Dixon *et al.* 1986; Price 1993; Dixon *et al.* 1994). Discounting is defined by Price (1993) as "any process of revaluing a future event, condition, service or product to give a present equivalent (present value)" (p. 4). In practice, "Selection of the proper discount rate is both difficult and contentious" as Lave and Gruenspecht state (1991, p. 683). However, a more controversial issue is whether discounting *per se* is ethically and ecologically justifiable because of the increasing concerns for the survival of future generations due to rapid depletion of natural capital.

Supposedly, there are several reasons for discounting. British economists Pearce *et al.* (1989) summarize that there are two basic rationales for discounting the future:

> (i) the social time preference rationale [which] says that people simply prefer the present to the future because of pure impatience, risk of death, uncertainty about the future and diminishing marginal utility of consumption. This is the social time preference rate of discount (STPR);
>
> (ii) the social costs of capital argument [which] says that we should discount the future at the rate of return achievable on the last unit of capital investment in the economy. This is the social opportunity cost rate of discount (SOCR). (p. 134)

Discounting is conducted based on the above-mentioned reasons. However, ecological economists supply severe criticism against discounting. For example, Daly

(1996b) claims:

> discount rate is a numerical way of expressing the value judgment that beyond a certain point the future is not worth anything to presently living people. The higher the discount rate, the sooner that period is reached. The value of the future to future people does not count in the standard approach. (p.36)

Summarizing Hampicke (1991), Harvey (1993), and Price (1993), Rees and Wackernagel (1999) argue that:

> [T]he total value of many forms of natural capital (e.g., forests and soils) and natural income (e.g., carbon sink functions) is probably underestimated today even as nature is being depleted . . . since the practice of discounting reduces the weight of future values of nature's services in today's decision calculus. (p. 49)

Rudolf de Groot (1994) also presents the same claim:

> A discount rate of 5% effectively means that the value of a given function 30 - 40 years from now is considered to be near zero today. However, the benefit of the "work of nature" will last in perpetuity when used in a sustainable manner, and the "economic lifetime" of these goods and services can (or should) not be calculated in the same manner as is customary for man-made goods and services which usually lose their economic value after about 20 years. Therefore, placing discount rates on the functions of natural ecosystems ignores the interests of future generations. (p. 161)

Pearce *et al.* (1989) admit that "there is a genuine concern that, with discounting, catastrophic future costs are not given their true importance" (p. 136). They present an example of a proposed project "which involves a significant probability of a major catastrophe through soil contamination in a hundred year's time." The present value of the expected cost is calculated so low (due to the positive discount rate) that the decision on the justification of the project is not likely to be swayed (p. 136). They also provide another example of radiation hazard, which illuminates the fact that discounting "shifts the burden of costs to future generation, and [that] it precludes future generations from inheriting created natural wealth" (p. 137). Ishigami presents a similar argument that the use of a high discounting rate results in justifying the current utilization of problematic nuclear power generation because the future management costs of radioactive wastes become almost negligible due to discounting at a high rate (personal communication on January 19th, 1999). Monetary analysis is normally accompanied by the practice of discounting the future. Because of this common custom, standard monetary analysis suffers from deficiency in promoting long-term ecological sustainability.

#9 Apparent Unlimited Money Growth Obscures Limits to Economic Growth

Money has no relevant physical dimensions, but can be 'created' indefinitely. This leads us to think that there is unlimited potential for money growth, which "obscures the possibility that there may be physical limits to economic growth" (Wackernagel and Rees 1995[6], p. 47). Nevertheless, the human economy has continued to grow to the extent that it seems to have reached the optimal scale with respect to the global carrying capacity, as Georgescu-Roegen (1971b), Meadows *et al.* (1972), Daly (1977), Goodland (1991) and others have claimed. Daly and Townsend (1993) argue the necessity to recognize the optimal *scale* of economy's load onto the ecosphere, as well as the optimal *allocation* of resources within the economy. They use the analogy of a boat's Plimsoll line to illustrate their point:

> When the watermark hits the Plimsoll line the boat is full, it has reached its safe carrying capacity. Of course if the weight is badly allocated the waterline will touch the Plimsoll mark sooner. But, eventually, as the absolute load is increased, the watermark will reach the Plimsoll line even for a boat whose load is optimally allocated. Optimally loaded boats will still sink under too much weight -- even though they may sink optimally! (p. 8)

Perceived potential for infinite growth of monetary assets may mislead human beings into continuously adding more and more excessive physical load to the only 'boat' we have. If this boat sank, what would be the use of that money?

#10 Market Excludes Those Who Cannot Participate in The Market

The market may treat well those who can participate. However, it can be hostile to others who cannot because of the lack of financial resources (exclusion of low income groups) or even due to the fact that they are too young to participate or because they are not born on the Earth yet (exclusion of future generations). The market is certainly not a democratic system since it totally excludes certain segments of society.

For all above reasons, we can assert that monetary valuation has serious limitations for evaluating natural capital and its goods and services. Thus, the monetary valuation cannot be an effective tool for assessing ecological sustainability.

(5) Need for Alternative Economics

So far in Chapter 3, I have discussed the implications of thermodynamics for human economies and then have described the limitations of conventional mainstream economics in accommodating the newly realized implications of economic processes which became visible through understanding the theory of thermodynamics. I have attributed the serious limitations of traditional neoclassical economic analysis to its features of (1) using mechanical worldviews, (2) assuming reversibility, (3) perceiving persons as *Homo economicus*, (4) having an unlimited growth mentality, and (5) applying monetary valuation of natural assets and qualitative changes, an incompetent method.

Due to the realization of serious inherent defects in the current economic paradigm, many commentators have advocated the necessity of creating a new economic model based on a new 'ecological and holistic paradigm' which incorporates the implications of the Law of Entropy, among them Georgescu-Roegen (1971b), Murota (1979, 1985, 1987b, 1990, 1995b), Daly (1977, 1991b, 1996b), Martinez-Alier (1987), Costanza (1989), Daly and Cobb (1989), Rees (1990), Goodland *et al.*, eds. (1991), Hornborg (1992), Cleveland (1993), and Murota *et al.*, eds. (1995).[27] Creation of this new economics requires a very fundamental shift from the Newtonian mechanical paradigm to this new holistic paradigm. Mere revisions to the old mechanical economic model were perceived insufficient by the scholars who have collaborated in creating this school of thought, namely ecological economics. The central premise of ecological economics is that far from being separate from nature, human beings are integral components of the ecosystems that support them (Costanza 1989, pp. 1-3; Rees 1990; Jacobs 1993, pp. 1-15; Cleveland 1993, pp. 26-28, 36-37). Folke *et al.*'s (1994) definition of ecological economics is worth presenting here:

> a transdisciplinary field of study that addresses the relationships between ecosystems and economic systems in the broadest sense, in order to develop a deep understanding of the entire system of humans and nature as a basis for effective policies for sustainability. (p. 2)

In order to facilitate the development of ecological economics, the International Society of Ecological Economics (ISEE) was created; it launched its journal, *Ecological Economics*, in 1989 (Turner *et al.* 1997, p. 25).[28] Its Canadian chapter, the Canadian Society for

[27] Recent new findings in quantum theory and chaos theory have come to provide profound implications on economic thought (Rees 1997c). I am aware of this trend. However, I will limit my discussion only to implications of Law of Entropy.

[28] In Japan, an academic society, the Society for Entropy Studies was established as early as 1983 (Society for Entropy Studies 1997).

Ecological Economics (CANSEE), was created in 1993. In recent years, ecological economics is gaining recognition not only from the academia but from other segments of the society as Turner *et al.* (1997) describe:

> A numbers of ecological economics research institutes have also been established. Both governmental and nongovernmental organizations have begun to make appointments in the fields, and environmental authorities are increasingly asking for an ecological economics perspective. (p. 25)

3.3 The Second Law of Thermodynamics and Ecological Footprint Analysis (Land and Ecosystems as Solar Collector)

In Chapter 3.1, I presented the laws of thermodynamics and its significant implications for human economic life. In Chapter 3.2, I explained the reasons why the conventional mainstream economic paradigm has been incapable of incorporating the ramifications of the laws of thermodynamics, thus proving to be ineffective of promoting long-term ecological sustainability. By doing so, I clarified the rationales for the newly emerging school of thought, ecological economics, which is based on a new paradigm of thermodynamics. In this section of 3.3, I first attempt to present a description of 'ecological footprint' analysis, a new analytical framework based on the central principle of ecological economics. Secondly, I present explanation of how the concept has been recognized in Japan and the world. Some examples of application of the concept are also presented.

(1) The Concept of Ecological Footprint Analysis

If we want to assess the ecological sustainability of human economies or cities, analytical tools or indicators should adequately account for the modern interpretation of the second law of thermodynamics, i.e., entropy law. These indicators should be able to compare:

(i) the economy's requirements for low-entropy materials and energy (i.e., essergy), and the magnitude of its high-entropy waste generation

with

(ii) the capability of ecosphere to continuously provide the low-entropy essergy and to assimilate high-entropy waste (i.e., carrying capacity of ecosphere).

If an economy is to be sustainable indefinitely, these two should balance each other. The importance of this balance principle has already been made clear by the discussion in Chapter 3.1 Section (3).

An ecological footprint is, in fact, a proxy for (i). In order to adequately construct a proxy for (i), ecological footprinting explicitly builds on traditional trophic ecology. We begin by constructing what is, in effect, an elaborate food-web connecting any specified human population to the rest of the ecosphere. This 'niche analysis' involves quantifying the low-entropy material and energy flows required to support that population and identifying significant sources and sinks. As might be expected, the human food-web differs significantly from those of other species. In addition to the material and energy required to satisfy the metabolic requirements of our bodies, the human food-web must also account for our 'industrial metabolism,' the material demands of the economic process (Ayres and Udo, eds. 1994).

Ecological footprinting is further based on the fact that many material and energy flows (resource consumption and waste production) can be converted into productive land- and water-area equivalents which produce low-entropy matter and absorb high-entropy wastes. Topsoil (in addition to primary producers and water) serves as a main entity or mechanism for producing some important low-entropy matter and disposing of high-entropy one (Murota 1985, pp. 162-163; Tsuchida and Murota 1987; Murota 1991a, pp. 166-167, and Murota 1991b, pp. 119-121).[29] Indeed, topsoil (which consists of a variety of decomposers) along with primary producers in effect constitute a 'solar collector' (Rees 1997a, p. 305) or a 'solar receptor' for the human enterprise and for other species. This combination enables the ecosphere to capture low entropy energy from the sun, and to produce essergy and assimilate wastes. If we can quantify the size of topsoil-covered biologically productive land area required for producing essergy to sustain a human economy, then, this figure will serve as a proxy for (i). Some water areas are also biologically productive. Thus, these productive aquatic areas are also included in the calculation of ecological footprint.

Thus, the ecological footprint of a specified population is defined as: *the area of land/water required to produce the resources consumed, and to assimilate the wastes generated by that population on a continuous basis, wherever on Earth that land may be located.* It therefore includes the area appropriated through commodity trade and the area needed to produce the referent population's share of certain free land- and water-based services of nature (e.g., the carbon sink function of forest land). In other words,

[29] The importance of topsoil cannot be overemphasized. It is worthwhile to listen to comments on topsoil made by Ivan Illich, a very influential philosopher and historian in the 20th century. According to Murota (1995b, pp. 50-58), Illich and his colleagues announced "Declaration on Soil" in Germany in 1990. Murota presents the following phrase from the declaration, "We stand not on the globe but on the soil. We are born from the soil and we bequeath our excreta and our body to the soil. . . . We, as philosophers, explore around our feet, because our generation has lost the very foundation of our existence which should be the soils and virtues"(*ifda dossier*. Vol. 81 [1991 April/June Issue], cited by Murota [1995b, pp. 50-51]).

ecological footprinting estimates the area of productive ecosystems all over the world whose biophysical output is appropriated for the exclusive use of a defined human population (Rees and Wackernagel 1994; Wackernagel 1994; Wackernagel and Rees 1995[6]; and Rees 1996).

At the same time, we can obtain a proxy for (ii), which is the available productive land and water area.

Then, we can compare the proxy for (i), the quantified area required to supply the economy, with a proxy for (ii), the available land area. Subsequently, we will be able to tell if an economy is really sustainable in terms of entropy. If the former is smaller or equal to the latter, then the economy is ecologically sustainable. But if (i) is larger than (ii), then that economy is not sustainable, since high-entropy matter/energy just keeps accumulating in the immediate surrounding of the economy.

In other words, one measure of national sustainability is the difference between a given country's ecological footprint and its domestic area of ecologically productive land/water. The gap between the two represents that country's 'ecological deficit' with the rest of the world (Rees 1996). Whereas national deficits can temporarily be made up by trade or accumulation of pollutants or run down of fuel (etc.) stocks, it should be obvious that not all countries can run ecological deficits indefinitely. Areas with surplus productivity must be available somewhere to accommodate the deficits of over-consuming countries. The world as a whole cannot for long support an ecological deficit or 'sustainability gap.'[30]

[30] Studies show that at present there is, in fact, a global sustainability gap. This contemporary ecological deficit is being made up by depleting remaining 'natural capital' stocks – fish stocks, forests, ground-water, soils, etc. (Goodland 1991; Weber 1995; Wackernagel and Rees 1995[6]; Wackernagel *et al.*

This study employs ecological footprint analysis and the ecological deficit concept to assess the sustainability of the Japanese economy. I calculated the consumption-based ecological footprint of the average Japanese resident as well as that of Japan as a whole.

The ecological footprint per capita can be compared with per capita available land and water area on the planet. There are currently approximately 1.51 ha of productive land (Wackernagel and Rees 1995[6]) and 0.51 ha of productive aquatic ecosystem available per capita on the planet (Wada and Latham 1998). In equity terms, these could be called the 'fair land share' (FLS) and 'fair aquatic share' (FAS) respectively (Rees 1996; Wada and Latham 1998).[31] The difference between the per capita ecological footprint and the FLS/FAS is called 'per capita ecological deficit.' By using the concept of per capita ecological deficit, we can measure the global ecological sustainability of a population's consumption fairly, regardless of the extent of the land mass which that population occupies. Otherwise, a nation with small land territory may be unfairly blamed for its large national ecological deficit.

(2) Acceptance and Applications of the EF Concept in Japan and the World

Ecological footprint analysis is being applied and tested by researchers in Canada and other countries (Rees 1992; Wada 1993; Larsson *et al.* 1994; Rees and Wackernagel 1994; Wackernagel 1994; Wackernagel and Rees 1995[6]; Rees 1996; 1997b; Folke *et al.* 1997; Kautsky *et al.* 1997; Wackernagel *et al.* 1997; Walker and Rees 1997; Folke *et al.* 1998; Parker 1998a, 1998b; Wada 1998a, 1998b; Wada and Latham 1998; Wackernagel *et*

1997; and Wackernagel *et al. 1999*).

[31] Details of calculation are given in Chapter 4.3 *Basis of Calculation, Assumptions and Missing Data*, (7).

al. 1999).

Japan's Environment Agency has so far recognized the usefulness of ecological footprint analysis as an educational tool and included one short paragraph explaining the concept and the calculation results of the Canadian ecological footprint in its *1996 and 1999 Quality of the Environment Report (General Issues)* [Heisei 8-nendo and Heisei 11 nendo Kankyo Hakusho: Sou-setsu] (1996, pp. 269-270; 1999a, pp. 280, 282).[32] The Science and Technology Agency has also expressed interest in the concept. The agency has carried out a study on the possibility of applying this concept in Japan (Takayama 1996). However, the government has to date taken no concrete actions.

Some NGOs and semi-professional journals in Japan have asked me to write articles which introduced the basic concept of ecological footprinting (e.g., the Asian Population and Development Association, the Association of Research on Trade and Industry, and the Global Environment Forum) (Wackernagel *et al.* 1995; Wada 1995, 1997). Some environmental NGOs have requested me to deliver seminars on ecological footprint application to Japan. Those are: the Japan Center for Sustainable Environment and Society (JACSES), Friends of the Earth Japan, and the People's Research Institute on Energy and Environment - Nagano Resource Center.

Also, some Japanese academics have expressed interest. For example, Fukui (1998), Horiuchi (1998), and Yamamoto (1998a) cited a number of articles and a book written on

[32] In fact, there was some opposition against the ecological footprint concept within the Japanese government. The Ministry of Agriculture, Forestry, and Fisheries did not want the Environment Agency to include the calculation results of the Japanese ecological footprint in the *1996 State of the Environment Report*. Therefore, only the introduction of the concept and the Canadian figures were included in the report. In the 1999 report, the Japanese ecological footprint figures were included at last.

the ecological footprint analysis. Horiuchi invited the present author to write a book chapter (Wada 1998b) on global carrying capacity and ecological footprint which was included in a book edited by him and published by a publishing house in Tokyo (Horiuchi, ed. 1998). The National Institute for Environmental Studies (NIES) in Tsukuba, Japan hosted a Canadian Geography professor, Paul Parker from the University of Waterloo, Ontario for six months, where he conducted a time-series analysis of the Japanese ecological footprint between 1961 and 1995 (Parker 1998a, 1998b). His study seems to have cultivated further interest among Japanese researchers (personal communication with NIES researchers, e.g., Moriguchi, Morita, Terazono, and Yamagata on August 1, 1997).

The ecological footprint concept has gradually become known to the world. The Canadian government frequently uses 'ecological footprint' in its *State of the Environment Report.* The Association of Finnish Local Authorities (1996) reports that the local Agenda 21 work of one of the member municipalities is built around the ecological footprint concept (pp. 12-13).[33]

The concept of ecological footprint has made a strong impact on an actual court decision in India with regard to its aquaculture industry. In December 1996, the Supreme Court of India made a decision that large-scale shrimp aquaculture operations should be banned based on ecological footprint analysis (Ahmed 1997). Dr. Carl Folk of the Beijer

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[33] A similar concept, 'Environmental Space' is being promoted by the Netherlands' Friends of the Earth (Buitenkamp, et al. eds. 1993). Environmental space (or Environmental Utilization Space) is defined as:

> a concept which reflects that at any given point in time, there are limits to the amount of environmental pressure that the earth's ecosystems can handle without irreversible damage to these systems or to the life support processes that they enable. This suggests to search for the appropriate threshold levels beyond which actual environmental systems might become damaged in the sense indicated above, and to regard this set of deductively determined critical values as the operational boundaries of the environmental space. (Weterings and Opschoor 1994, p. 3)

International Institute, Sweden was summoned to testify in the trial. He used ecological footprint analysis in order to demonstrate how heavy a burden is imposed on aquatic ecosystems by large-scale shrimp aquaculture (personal communication with Ms. Khusi Kabir and Mr. Alfredo Quarto on November 22, 1997).

The Earth Council, Costa Rica commissioned Wackernagel and his colleagues (1997) in Mexico to compile a report for submission to the Rio+5 conference held in New York in 1997. The report is called *Ecological Footprints of Nations: How Much Nature Do They Use? -- How Much Nature Do They Have?* This report contains the calculation results of ecological footprints of the 52 large countries (both from developing and industrialized countries) containing 80 percent of the world population. According to them, as of 1993, the human economy as a whole uses over 33 percent more resources and eco-services than the global ecosphere can accommodate comfortably. That means the global ecological deficit amounts to more than one third.

The phrase 'ecological footprint' appeared in an official document of the United Nations when the 1996 United Nations Conference on Human Settlements (HABITAT II) was held in Istanbul, Turkey. The Report (UNCHS 1996) submitted to this conference stated,

> We commit ourselves to the goal of sustainable human settlements in an urbanizing world by developing societies that will make efficient use of resources within the carrying capacity of ecosystems . . . . (Article 42, p. 24)
>
> We further commit ourselves to the objectives of: . . .
> (j) Promoting changes in unsustainable production and consumption patterns, particularly in industrialized countries, population policies and settlement structures that are more sustainable, reduce environmental stress, promote the efficient and rational use of natural resources - including water, air, biodiversity, forests, energy sources and land - and meet basic needs, thereby providing a healthy living

> and working environment for all and reducing the *ecological footprint* of human settlements. . . . (Article 43, p. 25; emphasis supplied)

In this chapter, we have explored a new paradigm based on the laws of thermodynamics, and its implications for the human economy. We have also discussed why the conventional economic paradigm is incompetent in facilitating ecological sustainability of human economic enterprises, creating the need for an alternative economic model which incorporates the implications of law of thermodynamics. Then, I have presented an explanation of 'ecological footprint' analysis which is based on the new paradigm. Lastly, I have presented an explanation of how the ecological footprint concept has been recognized and applied in Japan and in the world. The next chapter will clarify concrete research procedures and definitions of terms, as well as the basis, assumptions and limitations of analysis.

Chapter 4

Methods, Definitions, Basis of Calculation, Assumptions and Missing Data

This chapter explains methods and procedures for conducting the case study of Japanese consumption, That is the definitions of terms, the basis and assumptions of calculations, how missing data are dealt with, and the limitations of the analysis. The following spreadsheets are attached in the appendices:

1. Agricultural Land (which includes Cropland and Pasture Land) (Appendix B)
2. Forest Land (Appendix C)
3. Living Aquatic Resources (Appendix D)

4.1 Methods

I calculated the consumption-based ecological footprint of the average Japanese citizen as well as Japan as a whole. The calculation was based on 1990 data, unless otherwise stated.

The land/water area appropriated for the Japanese consumption was divided into the following categories: cropland, pasture, forest, CO_2-sink land [energy land], degraded land, and aquatic area.[34] These terms will be defined below.

The commodities consumed by the Japanese population are produced both domestically and in foreign lands. For accuracy, 'trade-corrected data' are required for the calculation of countries' ecological footprints. Trade-corrected data are obtained from: Domestic Production - Exports + Imports. The Excel computer spreadsheet was used for this purpose. The usual calculation procedure was as follows:

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[34] Data were mainly drawn from: Association of Agriculture and Forestry Statistics 1993; Food and Agriculture Organization of the United Nations (FAO) 1993, 1994a; Ministry of Agriculture, Forestry and Fisheries (MAFF), Japan 1992; Ministry of International Trade and Industry (MITI), Japan 1992; National Land Agency, Japan 1992.

First, data on domestically produced commodities were obtained in tonnes (*d*). Secondly, quantity exported (or more precisely mass) was identified (*e*). Thirdly, the quantity of each imported commodity was obtained (*i*). Net consumption of that commodity by the Japanese population (*n*) was calculated from $n = d - e + i$. These quantities were then converted into corresponding land areas by using conversion factors, in most cases, land productivity figures.[35] When there were conflicting data on productivity, I employed the highest figure, which has tended to make my results conservative, i.e., to underestimate the ecological footprint of the Japanese consumption. Net land area required for the production of each commodity consumed by Japan (*N*) was calculated by the formula: $N = D - E + I$, where *D* represents domestic land area for the domestic production of a commodity, *E* means domestic land area used for the exported portion of the commodity, and *I* denotes the foreign land area which was used for the production of the commodity imported to Japan. Lastly, per capita land requirement of commodity (*C*) was calculated by $C = N / P$, where *P* represents the population of Japan. Population data were from 1990, namely, 123,540,000 (WRI 1994, p. 268, Table 16.1).

For example, Table 8 shows the calculation of net consumption of agricultural products '*n*' by Japan, and the corresponding land area '*N*.' The last column '*C*' designates the per capita land requirement for the consumption of agricultural products. Data for rice and other cereals for human consumption are given as examples in Table 8.

[35] Most of the land productivity figures were obtained by calculation using data in Ministry of Agriculture, Forestry and Fisheries (MAFF), Japan.(1992) and Tominaga *et al.* (1989).

Table 8 Spreadsheet for Calculating Land Area Necessary to Support Japanese Consumption of Agricultural Products

	d	*e*	*i*	*n*	*D*	*E*	*I*	*N*	*C*
	Quantity Domestic Production	Quantity Exported from Japan	Quantity Imported from Abroad	Net Quantity Consumed in Japan	Land Area for Domestic Production	Land Area for Producing Exported Products FROM Japan	Land Area for Producing Exported Product TO Japan	Land Area for Supporting Japanese Net Consumption	Land Area Per capita for Supporting Japanese Consumption
unit -> item	1,000 tonnes	1,000 tonnes	1,000 tonnes	1,000 tonnes	1,000 ha	1,000 ha	1,000 ha	1,000 ha	ha
rice	10,499	0.016	18	10,517	2,074	0.003	6	2,080	0.017
other cereals	1,302	348	10,233	11,187	399	98	3,466	3,767	0.031

Special consideration was paid to the analytic particulars of Japan. For example, the Japanese consume large quantities of aquatic (mostly marine) resources. The marine and freshwater areas that produce these commodities were therefore incorporated in as much detail as possible in the calculation of the total eco-footprint.

4.2 Definitions of Terms

(1) Cropland

Cropland is defined as agricultural land that provides primary products such as grains, vegetables, and non-edible materials for human consumption but also feed crops for consumption by animals (excluding grasses). Since ecological footprint analysis is based on trophic ecology, areas for feed and forage production were also considered. The areas of confinements for livestock and dairy production were not included since they were assumed negligible and the data were not readily available. The land areas for feed grass production were not considered in this cropland category. However, the grassland areas were accounted for in the category of 'Pasture Land.'

Non-edible materials produced on the 'cropland' encompass such products as textiles (e.g., cotton, silk), natural rubber, tobacco, flowers, and bulbs, among others.

(2) Pasture Land

Pasture land is a land for growing grasses for animal consumption. These animals produce not only food items (e.g., meats, dairy products, and eggs), but also wool.

(3) Forest Land

Forest Land produces such primary products as timbers for building and furniture materials, and pulp chips for paper production.

(4) CO_2-sink Land (Energy Land)

CO_2-sink land is land where carbon dioxide is sequestered by forest trees, and it is sometimes called 'energy land' since most of the CO_2 is emitted from burning of fossil fuels. However, this study included CO_2 emitted from burning solid waste in incinerators, as well as from decomposition of limestone ($CaCO_3$) during the production process of cement and steel (Environment Agency, Japan, Planning and Coordination Bureau, Department of Global Environment, ed. 1992, pp. 7-11). The term 'CO_2-sink land' is more accurate in this context.

(5) Degraded Land (Built Environment)

Degraded land is the urbanized area (e.g., houses, buildings, roads, factory and facility sites, solid waste dump sites, and so on) which was previously eco-productive land, but from which the bio-productivity is forgone owing to its current use.

(6) Aquatic Area

Aquatic areas include ocean and freshwater areas which provide primary production for all trophic levels of aquatic living resources consumed by the Japanese.

(7) Fair Land Share (FLS) and Fair Aquatic Share (FAS)

As mentioned in Chapter 3.3, global per capita available biologically productive terrestrial land and water area on the planet are called the "fair land share" (FLS) and "fair aquatic share" (FAS) respectively.

4.3 Basis of Calculation, Assumptions and Missing Data

(1) Cropland

Rice

The quantity of domestic production (10,500,000 tonnes) and its land requirement (2,070,000 ha) were obtained from Ministry of Agriculture, Forestry and Fisheries (MAFF), Japan 1992, p. 66 (total of wet-field rice and dry-field rice).

The quantity of exported rice (16 tonnes) was obtained from MAFF (1992, p. 504) and Ministry of International Trade and Industry (MITI), Japan (1992, p. 15). The land area for production of exported rice was obtained through dividing exported quantity by the average land productivity of domestic rice (5.09 tonnes/ha/year) (MAFF 1992, p. 66), which turned out to be 3 ha.

The quantity of imported rice (18,000 tonnes) was from MAFF 1992, p. 510 and MITI 1992, p. 146. The land area for production of this imported rice was obtained by dividing imported quantity by the world average land productivity of rice production (3.220 tonne/ha/year) (Tominaga *et al.*, eds. 1989, p. 494), which was calculated to be 6,000 ha.

Other Cereals

Other cereals include wheat, six-raw barley, two-raw barley, naked barley, oats, and buckwheat. The quantity of domestic production of these cereals (1,300,000 tonnes) was obtained through adding the data for respective crops listed in MAFF 1992, pp. 68, 73, 75. (Buckwheat data were missing, thus not included in this calculation. However, there must have been production of buckwheat since planted area data were available.) The land area for domestic production (399,000 ha) was calculated using the same source. Land area for buckwheat production was included in the calculation.

The quantity of exported cereals other than rice (348,000 tonnes) was from MITI 1992, p. 15. (However, MAFF 1992, p. 504 presents a somewhat lower value, 329,000 tonnes. This difference results because this value does not include the quantity of bakery products such as bread and biscuits. I employed data by MITI 1992.) The land area for production of exported cereals was obtained by dividing exported quantity by the average land productivity of the above-mentioned five cereals other than buckwheat (3.53 tonnes/ha/year), which was calculated to be 97,000 ha. Land productivity of five cereals (excluding buckwheat) was calculated by dividing the total production quantity by the total land area for the production. (Data were from MAFF 1992, pp. 68, 73, 75.)

The quantity of imported cereals other than rice (10,200 tonnes) was from MITI 1992, p. 146. The land area for production of these imported cereals was obtained by dividing imported quantity by world average land productivity (2.952 tonnes/ha/year), which turned out to be 3,470,000 ha. The world average land productivity employed here was calculated as average of wheat and corn (1985 data from Tominaga *et al.*, eds. 1989, pp. 492, 498). Feed and forage crops were not included in this imported data. For these products, please refer to other categories below, namely, "Feed & Forage Crops Used for

Domestic Production of Meat, Dairy Products & Eggs, Excluding Grass," and "Feed & Forage Crops Used for Foreign Production of Meat, Dairy Products & Eggs, Excluding Grass."

Potatoes and Sweet Potatoes

There are three kinds of potatoes produced in Japan, namely, sweet potatoes, spring-planted potatoes, and autumn-planted potatoes. The quantity of domestic production (4,950,000 tonnes), and its land requirement (176,000 ha) were obtained by adding the data for respective crops listed in MAFF 1992, p. 73.

The quantity of exported potatoes was very small (1,200 tonnes). Data were from MAFF 1992, p. 504. The land requirement for the production of the exported potatoes was obtained through dividing the exported quantity by the average land productivity of domestic potatoes (24.500 tonnes/ha/year) (Tominaga *et al.*, eds. 1989, p. 502.), and turned out to be 0.05 ha.

The quantity of imported potatoes (147,000 tonnes) was from MAFF (1992, p. 511). (There was no import of sweet potatoes.) The land area was calculated in the same way as for rice and other cereals. The imported quantity was divided by the world average land productivity of potatoes (14.830 tonnes/ha/year) (Tominaga *et al.*, eds. 1989, p. 504), which turned out to be 10,000 ha.

Elephant Foot (Konnyaku Imo)

Elephant Foot is raw material for producing Konnyaku, a gelatinous food product. The quantity of domestic production of elephant foot (89,000 tonnes), and its land requirement for domestic production (11,000 ha) were from MAFF 1992, pp. 98, 99.

The exported quantity was listed as zero. The quantity of imported elephant foot was 26,000 tonnes (MAFF 1992, p. 512). This figure is the one for processed Konnyaku products, not for elephant foot itself. But, I assumed that the weights of raw materials and the processed products were the same. In order to obtain the land area, the imported quantity was divided by the national average land productivity of domestic elephant foot. This turned out to be 3,000 ha. (I was not able to obtain a world average of land productivity. Therefore, I employed the national average figure, assuming that the world average was the same as the national one.)

Pulses and Beans

Pulses and beans produced domestically are soy beans, red beans, kidney beans, and peanuts. The quantity of domestic production (409,000 tonnes) and its land requirement (257,000 ha) were from MAFF 1992, pp. 74, 75.

The exported quantity was listed as zero. The quantity of imported pulses and beans was 177,000 tonnes (MAFF 1992, pp. 510, 511). Import includes dried products of peas, red beans, kidney beans, and mung beans. In order to obtain the land area, the imported quantity was divided by the world average land productivity of pulses and beans (1,230 tonnes/ha/year, from Tominaga *et al.*, eds. 1989, p. 508). This turned out to be 143,000 ha. Coffee and cocoa beans were treated as different categories below.

Vegetables

This category of vegetables includes not only common vegetables (such as carrots, Japanese radishes, lettuces, onions, peppers, spinach, and tomatoes) but also edible burdocks, lotus root, taros, yams, strawberries, melon, watermelon, green soybeans, and green pod kidney beans. The quantity of domestic production (14,510,000 tonnes) was taken from MAFF (1992, pp. 76-89). The land area for domestic production (625,000 ha) was taken from p. 106 of the same source.

The quantity of exported potatoes was very small (1,600 tonnes, from MAFF 1992, p. 504). The only exported product listed in this category was dried Shiitake mushrooms. I was not able to obtain land area of this product *per se*. Thus, I divided the exported quantity by the national average of land productivity of vegetable in general. The calculation result was 100 ha.

On the other hand, the imported quantity was not small (1,001,000 tonnes). This quantity represents 7.2% of domestic consumption of vegetables. Data were from MAFF (1992, pp. 510, 511). The land area was calculated in the same way as other crops. The imported quantity was divided by the national average land productivity of vegetables, which turned out to be 43,000 ha. (I assumed national and world productivity figures to be the same.)

Fruits and Nuts

The domestic production (4,730,000 tonnes) was taken from MAFF (1992, pp. 90-96). Domestically produced fruits and nuts include citron, apples, grapes, pears, peaches, plums, chestnuts, kiwi, and so on. The land area for domestic production (346,000 ha) were from the same source (p. 106).

The export was 27,000 tonnes (MAFF 1992, p. 504). This includes mandarin oranges, apples, and persimmons, among others. The land area for production of the exported fruits and nuts was obtained through dividing the exported quantity by the national average land productivity of fruits, which turned out to be 2,000 ha.

The imported quantity was much larger (1,840,000 tonnes) than export (MAFF 1992, p. 510). The land requirement was calculated in the same way as for other crops. The imported quantity was divided by the national average land productivity of fruits, which turned out to be 134,000 ha. (I assumed national and world productivity figures to be the same.)

Tea

The quantity of domestic production of tea (413,000 tonnes), and the land area for the production (59,000 ha) were obtained from MAFF 1992, p. 98.

The quantity of export was 300 tonnes (MAFF 1992, p. 504). The land area for the production of the exported tea was obtained through dividing the exported quantity by the national average land productivity of tea, which turned out to be 40 ha.

The imported quantity was much larger (14,000 tonnes), which was obtained from MAFF 1992, p. 510. The land area was calculated in the same way as other crops. The imported quantity was divided by the national average land productivity of tea, which turned out to be 2,000 ha. (I assumed national and world productivity figures to be the same.)

Coffee

All 310,000 tonnes of coffee consumed in Japan were imported from abroad (MAFF 1992, p. 511). Coffee products can be broken into several different commodities, such as coffee beans, coffee extract, instant coffee, and others. Coffee beans account for 93.9 percent of all coffee products.

One thousand tonnes of these were exported after processing (MAFF 1992, p. 504), as roasted coffee and coffee extract.

The remainder was consumed in Japan in the amount of 309,000 tonnes. The land area for producing this amount of coffee was obtained through multiplying the world total planted area of coffee (10,440,000 ha, 1985 data, Tominaga *et al.*, eds. 1989, p. 473) by Japan's consumption share (5.1%). This was computed to be 535,000 ha. Consumption share by Japan (5.1%) was obtained through dividing Japan's consumption (309,000 tonnes) by the world total consumption (6,030,000 tonnes, 1985 data, Tominaga *et al.*, eds. 1989, p. 563).

Cocoa

The land area for producing cocoa consumed in Japan was obtained through multiplying the world total planted area of cocoa (5,090,000 ha, 1985 data, Tominaga *et al.*, eds. 1989, p. 474) by Japan's consumption share (4.5%). This turned out to be 228,000 ha. Consumption share by Japan (4.5%) was calculated through dividing Japan's consumption (84,000 tonnes, MAFF 1992, pp. 505, 511) by the world total consumption of 1,880,000 tonnes (1985 data, Tominaga *et al.*, eds. 1989, p. 564).

Alcohol

The quantities of domestic production, export and import of alcohol products were taken from MAFF (1992, pp. 504, 512). Raw materials for domestic alcohol production were included in other categories, such as rice and other cereals. Thus, only export and import were considered in the ecological footprint calculation. According to Table 66 in FAO 1990, the world average productivity of wine was 7 tonnes/ha/year. I tentatively employed the wine productivity figure for other alcohol products, since productivity data for other alcohol products were not readily available.

Sugar Beets and Sugar Canes

The quantity of domestic production (5,980,000 tonnes), and its land requirement (111,000 ha) were taken from p. 99 of MAFF (1992).

The quantity of exported processed sugar products (1,900 tonnes) was obtained from MAFF (1992, p. 504). The quantity of raw materials (sugar beets and sugar canes) for this production was calculated to be 21,000 tonnes. Its conversion rate was obtained through dividing total world production of sugar beets and sugar canes (1,220,000,000 tonnes) by the total world production of raw sugar (112,800,000 tonnes) which turned out to be 10.9. This means that in order to produce 1 tonne of raw sugar, 10.9 tonnes of sugar beets/canes were required. Next, the land requirement of sugar beet and cane production used for the exported sugar products was calculated. The quantity of the required raw material was divided by the world average land productivity of sugar beets and sugar cane (53.6 tonnes/ha/year), which turned out to be 400 ha. For the world average land productivity of sugar beets and sugar cane, I used the weighted-average of the world average productivity figure of the respective crop (1985 data), from Tominaga *et al.*, eds. 1989, pp. 558-559.

Imported products such as raw sugar and molasses amount to 2,310,000 tonnes (MAFF 1992, p. 511). Its raw material requirement was calculated to be 25,090,000 tonnes, using the same conversion rate of 10.9 as the exported products. Lastly, its land requirement was calculated to be 468,000 ha (using the world productivity figure of 53.6

tonnes/ha/year).

Seed for Edible Oil Production

The domestic canola (which used to be called 'rape') seed production amounted to 1,660 tonnes. Its land requirement was 925 ha (MAFF 1992, p. 97). The only exported oil product is sesame oil which amounted to 688 tonnes (MAFF 1992, p. 505). Its land requirement was calculated through dividing exported quantity by the weighted-average of the land productivity figures of soy and canola (1.73 tonnes/ha/year). That turned out to be 400 ha. The land productivity of sesame was not available. Therefore, I utilized the weighted-average productivity figure of soy and canola, major raw materials for edible oil production. With regard to soy, the world average land productivity was used which was 1.930 tonnes/ha/year (1985 data. Tominaga *et al.*, eds. 1989, p. 510). With regard to canola, the average land productivity in Canada, a major canola oil exporter, was employed -- 1.240 tonnes/ha/year --since the world average was not available (1990 data, Statistics Canada 1991, p. 358).

The imported raw materials for edible oil production, such as soy and canola amounted to 6,770,000 tonnes (MAFF 1992, p. 512). Its land requirement was computed to be 3,920,000 ha, by dividing the imported quantity by the weighted-average of the productivity figures of soy and canola (1.73 tonnes/ha/year).

Vegetable Oil Products

The domestic production of edible oil amounted to 1,720,000 tonnes (MAFF 1992, p. 471). However, I did not include the land requirement of its production, because it was already included in the previous category of oil seed. Otherwise, it would be a double-counting.

A small amount of export of edible oil was reported (4,000 tonnes, MAFF 1992, p. 505). In order to obtain its land requirement, the amount of its raw material was computed first. As stated in the previous item, oil seed, most of the raw material for edible oil processing is imported from abroad. About 6,770,000 tonnes of raw material are required for the 1,720,000 tonnes of edible oil produced in Japan. From these figures, I obtained a production ratio of 1: 0.25 (raw material: final product). Conversely, this means that 3.93 tonnes of raw material is needed to produce one tonne of edible oil. The quantity of exported edible oil was multiplied by 3.93 in order to obtain the quantity of raw material (soy beans and canola). This turned out to be 15,700 tonnes. This figure was divided by 1.73 tonnes/ha/year (the weighted-average of the productivity figures of soy and canola) which led to 9,000 ha.

Imported edible oil amounted to 440,000 tonnes (MAFF 1992, p. 512). Deriving its land requirement employed the same calculation process was employed as the one for exported edible oil. The result was 1,001,000 ha.

Tobacco

The domestic production of tobacco and cigarette was 81,000 tonnes. Its land requirement was 30,000 ha (MAFF 1992, p. 97). Exported cigarettes amounted to 4,600 tonnes (MITI 1992. p. 15). In fact, the exported cigarettes were recorded in numbers of rolls, namely 6,670,000,000. This figure was converted into tonnage by using conversion ratio of 0.69 kilogrammes per 1,000 cigarettes. This ratio was obtained by weighing "Highlight (King-size)" with a precision scale. Filter parts were, of course, excluded from this weighing.

The quantity of imported tobacco/cigarettes was 116,000 tonnes (MITI 1992, p. a148). Among that quantity, leaf tobacco was recorded in the amount of 80,000 tonnes. The number of imported cigarettes was 51,760,000,000. Conversion from number to tonnage was carried out by using the same conversion ratio, i.e., 0.69 kg/1,000 cigarettes. The land requirement of imported tobacco/cigarettes was calculated to be 43,000 ha. The world average productivity of tobacco was employed, assuming that the Japanese domestic productivity is the same as the world average. (Also an assumption was made that the weight/volume ratio of leaf tobacco and that of cigarettes were the same.)

Flowers (Cut-Flowers, Bulbs, Seeds)

Data on domestic production of cut-flowers and bulbs were listed in MAFF 1992, pp. 103-105 in terms of cultivated areas and numbers of products. The total cultivated area was calculated to be 9,000 ha. For the purpose of obtaining the total weight of these products, assumptions were made that each cut-flower weighs 50 grammes, and that each bulbs weighs 40 grammes. The total quantity of these products turned out to be 189,000,000 tonnes. By using these total figures of land requirement and quantity, average domestic productivity was calculated, which turned out to be 21,000 tonnes/ha/year. This productivity figure is very high compared with other agricultural crops. However, this is understandable, considering the fact that many flowers and bulbs are produced in greenhouses where intensive production and several harvests are carried out per year.

Export of cut-flowers was nil. Bulbs were exported, however, and the total number was recorded to be 7,810,000 (MAFF 1992, p. 505). The weight of each bulbs was again assumed to be 40 grammes. The total weight of exported bulbs was calculated to be 300 tonnes. The land requirement was calculated to be 20 ha, using the average domestic productivity of cut-flower and bulbs.

Import of these products was recorded to be 12,000 tonnes (MAFF 1992, p. 512). The land requirement was calculated to be 600 ha (assuming the domestic and the world productivity figures to be the same).

Rush

Rush is raw material for 'tatami' mats, and 'sudare' screens for household use. 'Tatami' mats are placed on the floors of Japanese traditional houses, particularly in living rooms and bedrooms. 'Sudare' are screens which are placed at windows. Domestic production of rush was 90,300 tonnes and its land requirement was 8,500 ha (MAFF 1992, p. 97). Export of rush or processed products was recorded to be nil. The import of 'tatami' was recorded as zero. 'Sudare' were imported and the quantity was 8,000 tonnes (MAFF 1992, p. 513.) The land requirement was calculated to be 800 ha (assuming the domestic and the world productivity figures to be the same).

Natural Rubber

The domestic production of natural rubber was recorded as nil. The export and import data of natural rubber were from MAFF 1992, pp. 505, 512. Export was very minimal, only 80 tonnes. The land requirement was calculated to be 40 ha. Import was 676,000 tonnes. The land requirement was calculated to be 375,000 ha, by using the world average productivity of natural rubber products, which turned out to be 0.554

tonnes/ha/year. This figure was obtained by dividing total quantity of world natural rubber production (4,250,000 tonnes, 1994 data) by the world total cultivated area (7,670,000 ha, 1980 data). These world production data were from Tominaga *et al.*, eds. 1989, p. 672.

Mulberry

Mulberry is the staple food for silkworms. The domestic cultivation area of mulberry was 60,000 ha (MAFF 1992, p. 107). The quantity of production was not available. Production and import of silk products are explained below.

Cocoons, Silk

Data on domestic production (25,000 tonnes) of raw silk and cocoons came from MAFF 1992, p. 120. The land equivalent was not included in this category since it has been already accounted for in the previous item, i.e., mulberry.

Data on the import of raw silk and cocoons specified 8,855 tonnes (MAFF 1992, p. 514). Import of silk yarn amounted to 1,710 tonnes (MITI 1992. p. 231). The total quantity of imported raw silk and yarn was 10,600 tonnes. Its land requirement was calculated to be 25,400 ha. Domestic productivity of raw silk (0.417 tonnes/ha) was employed for this calculation. Dividing 25,000 tonnes (domestic production of raw silk and cocoon) by 60,000 ha (domestic cultivation area of mulberry) gave 0.417 tonnes/ha/year.

Secondary silk products, such as silk cloth and silk garments were not included, partly because MITI (1992) did not distinguish materials used for secondary textile products, and also to avoid double-counting.

Cotton

Raw cotton used in Japan depends entirely on import. In 1990, the import amounted to 1,234,000 tonnes (FAO 1994b, p. 24). Of these, 98,000 tonnes of cotton were exported abroad (FAO 1994b. p. 24). Thus, the consumption in Japan was calculated to be 1,135,000 tonnes by subtracting the latter from the former. (Average cotton consumption by the Japanese was given as 9.4 kg [FAO 1994b, p. 25]). The land equivalent of Japan's cotton consumption was calculated to be 2,633,000 ha through dividing the consumption quantity by cotton's world average productivity of 0.431 tonnes/ha/year (Rechcigl 1982, Vol. 2, p. 289).

Meat, Dairy Products, and (Hen) Eggs

Within this section of crop land, explanation is given only for grains and other feed crops, and mixed feed materials used to produce meat, dairy products, and hen's eggs. Grass from pasture, another important feed, will be explained separately in the following section of pasture land. In the first eight rows of the spreadsheet, quantities of meat, dairy products, hen's eggs, and animal oils/fat were listed. All the data were from MAFF 1992 (domestic production: pp. 434-437, 141, 142; export: p. 505; import: p. 513).

Even though the quantity of animal oil/fat was listed in the spreadsheet, its land requirement was not considered, since the inclusion of both the land requirement for meat production and the one for animal oil production would constitute double-counting. Data on domestic production of animal fat were from Tominaga *et al.*, eds. 1989 (data year: 1987), since MAFF (1992, p. 471) did not provide clear explanation regarding materials for margarine and shortening production. Imported egg means liquid egg. Imported living animals such as horses, cows, and domestic poultry were not included since these imports were not large.

Feed and forage crops will be explained in the following two separate categories: (a) feed and forage crops used for domestic production of meat, and dairy products and eggs; and (b) other feed materials used for domestic production of meat, daily products and eggs (excluding grass and grains); (c) feed and forage crops used for these products produced in foreign countries.

(a) Feed and Forage Crops Used for Domestic Production of Meat, Daily Products and Eggs (Excluding Grass)

Domestically produced feed and forage crops include soiling maize (6,845,000 tonnes, 125,900 ha), sorgo (2,323,000 tonnes, 36,300 ha), Chinese milk vetch[36] (no quantity data listed, 2,320 ha), green oats (477,000 tonnes, 13,200 ha), green rye (no quantity data listed, 2,680 ha), mangold (17,200 tonnes, 325 ha), and turnips for feed (221,700 tonnes, 4,360 ha) (MAFF 1992, pp. 101, 102). The total quantity of these crops amounted to 9,890,000 tonnes, and total land requirement was 184,300 ha (MAFF 1992, pp. 101, 102).

Export of feed and forage crops was nil. Imported feed and forage crops include wheat (1,056,000 tonnes), barley (including naked barley) (1,256,000 tonnes), corn (11,750,000 tonnes) and sorghum (3,618,000 tonnes). The quantities of these crops were from MITI (1992, p. 146). The total of these imported crops amounted to 17,700,000 tonnes. Its land requirement was calculated by dividing each quantity by the world average land productivity of each feed crop. The world productivity data employed are as

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[36] Vetch is a plant of the pea family, one type of which may be fed to cattle.

follows. Wheat: 2.220 tonnes/ha/year; barley: 2.270 tonnes/ha/year; corn: 3.690 tonne/ha/year; and sorghum: 1.540 tonnes/ha/year (1985 data from Tominaga *et al.*, eds. 1989, pp. 492, 496, 498, and 499 respectively). The total land requirement for the production of imported forage crops turned out to be 6,563,000 ha. This figure alone is 1.5 times larger than the total area of Japanese domestic crop land.

(b) Other Feed Materials used for Domestic Production of Meat, Daily Products and Eggs, (Excluding Grass and Grains)

Feed materials other than grass and grains include bran (*nuka*), rice-cakes and meals (residues from rice processing, *abura kasu*), oil-seed cakes and meals (residues from oil production), and animal forage. Even though quantities were included in the spreadsheet, its land requirement was not considered, in order to avoid double-counting.

Domestic consumption of these materials (9,550,000 tonnes) was derived by subtracting total quantity of material used for compound and mixed feeds in Table (2), MAFF 1992, p. 59 (16,400,000 tonnes) from the Japanese total grain consumption (25,900,000 tonnes).

Exported quantity (177,000 tonnes) data were from MITI (1992, p. 15). Imported quantity (4,890,000 tonnes) data were from MITI (1992, p. 148).

The domestic production quantity was finally derived by the following formula which was converse to the normal computation: total domestic consumption of these materials minus import plus export. The calculation turned out to be 4,840,000 tonnes.

(c) Feed and Forage Crops used for Foreign Production of Meat, Daily Products and Eggs, Excluding Grass

Land requirement for the production of feed and forage crops which were used to feed foreign live stocks was computed as follows.

First, I obtained the imported quantity of each product: beef: 490,000 tonnes; pork: 352,000 tonnes; poultry: 301,000 tonnes; other meat (sheep, horse, etc.): 103,000 tonnes; dairy products: 233,000 tonnes; eggs: 13,000 tonnes (MITI 1992, p. 145). Lappé (1982) calculated the ratio between quantity of consumed feed crops in the U. S. A. and quantity produced of each kind of meat, of dairy products and of eggs in the U. S. A. The computed ratios were: beef: 16; pork: 6; poultry: 3: dairy products: 1; eggs: 3 (pp. 70, 463, 464, 465). She did not provide the ratio for other meat (sheep, horse, etc.). For other meat, I used the average of beef and pork which turned out to be 11. Then, these ratios were multiplied by the total weight of imported meat, dairy products and eggs. This process provided a rough figure for the weight of forage crops which were used to produce foreign meat, dairy products and eggs (12,258,000 tonnes). Finally, the land requirement was computed through dividing the total weight of forage crop by world average land productivity of forage production (2.950 tonne/ha/year) (1985 data, Tominaga *et al.*, eds. 1989, pp. 492, 498). The result was 4,152,000 ha, which is almost as large as the total area of Japanese domestic crop land.

(2) Pasture Land

Grass from Pasture

Grass produced in domestic pasture amounted to 34,100,000 tonnes. Its land requirement was recorded to be 838,000 ha (MAFF 1992, p. 100). The land productivity

(40.7 tonnes/ha/year) is much higher than the world average productivity of grassland (4.2 tonnes/ha/year, Esser 1992). A small amount of imported hay was recorded, which weighed 205,000 tonnes (MAFF 1992, p. 513). Its land requirement was calculated to be 38,600 ha by using the US hay productivity figure of 5.31 tonnes/ha/year, derived from 1975 data in Ensminger 1978, p. 217). Total land requirement for domestic consumption of grasses turned out to be 876,000 ha.

Eight thousand tonnes of meat (mostly poultry) was exported (MAFF 1992, p. 505). Its pasture land requirement was calculated to be 40 ha. Employing Lappé (1982)'s ratio, the quantity of grains fed for the production of this poultry was calculated to be 24,000 tonnes. Poultry diet composition was reported as: grain and other concentrates 94.4%; and roughages, i.e., grasses, 5.6% (Ensminger 1978 p. 217, Table 4-2). The following formula was used to calculate the quantity of grass consumption for this poultry production:

24,000 tonnes (grain consumption for poultry production) / 0.944 * 0.056
= 1,420 tonnes.

These 1,420 tonnes, the quantity of grass consumed, were divided by the domestic pasture land productivity, 39.1 tonnes/ha/year. This gave 40 ha.

Twenty-three thousand tonnes of dairy products were exported (MAFF 1992, p. 505). Its pasture land requirement was derived to be 1,580 ha. Calculation was carried out as follows. First, the ratio between the domestic production of meats and dairy products and the pasture land area for domestic consumption of grasses was derived, which turned out to be 14.5 tonnes/ha/year. Twenty-three thousand tonnes was divided by 14.5 tonnes/ha/yea, which derived 1,580 ha.

The pasture land requirement for foreign produced meat and dairy products was calculated as follows.

1) Beef: The diet composition of beef cattle was reported in terms of tonnage as: grain and other concentrates 17.2%; and roughages, i.e., grasses, 82.8% (Ensminger 1978 p. 217, Table 4-2). Lappé (1982) reports slightly different ratios: 25% for concentrates and 75% for grasses (p. 463). I employed the averages of these figures, which were calculated to be 21.1% and 78.9% respectively. The following formula was used to calculate the quantity of grass consumption for foreign beef production:

7,840,000 tonnes (grain consumption for foreign beef production) / 0.211 * 0.789 = 29,320,000 tonnes.

Its land requirement was calculated to be 6,442,000 ha. For deriving this land area, I used a land productivity figure of 4.55 tonnes/ha/year, which is a weighted average of land productivity of world grassland (4.20 tonnes/ha/year) and US hay productivity (5.31 tonnes/ha/year) (Formula: 4.55 = 4.20*0.684 + 5.31*0.316).

2) Pork: Swine diet composition was reported as: grain and other concentrates 84.7%; and roughages, i.e., grasses, 15.3% (Ensminger 1978 p. 217, Table 4-2). The following formula was used to calculate the quantity of grass consumption for foreign pork production.

2,110,000 tonnes (grain consumption for foreign pork production) / 0.847 * 0.153 = 381,000 tonnes.

Its land requirement was derived in the same way as the one for beef. The area was calculated to be 84,000 ha.

3) Poultry: Poultry (chicken and turkey) diet composition was reported as: grain and

other concentrates 94.4%; and roughages, i.e., grasses, 5.6% (Ensminger 1978, p. 217, Table 4-2). The following formula was used to calculate the quantity of grass consumption for foreign poultry production.

> 903,000 tonnes (grain consumption for foreign poultry production) / 0.944 * 0.056 = 54,000 tonnes.

The land requirement was calculated to be 12,000 ha.

4) Other meats (sheep and horses): Sheep and goat diet composition was reported as: concentrates 5.6%; and roughages, i.e., grasses, 94.4%. Horse and mule diet composition was: grain and other concentrates 23.0%; and roughages 77.0% (Ensminger 1978 p. 217, Table 4-2). I employed the average of these two sets of figures, which were: concentrate feed 14.3%; and roughages 85.7%. The same calculation process was employed as above in order to obtain tonnage of grasses and its land requirement. The results were: 6,790,000 tonnes and 1,492,000 ha.

5) Dairy products: The diet composition of dairy cattle was reported as: concentrates 33.8%; and roughages, i.e., grasses, 66.2% (Ensminger 1978, p. 217, Table 4-2). The same calculation process was employed as above in order to obtain tonnage of grasses and its land requirement. The results were: 456,000 tonnes and 100,000 ha.

6) Eggs: The diet composition of hens was not available. Here, I employed the same data as poultry, assuming that chicken and hens have the same diet composition. The same calculation process was employed as above in order to obtain tonnage of grasses and its land requirement. The results were: 2,000 tonnes and 1,000 ha.

Wool

Wool consumption and production in Japan depended entirely on imported materials.

Imports amounted to 195,000 tonnes (1990 data, from FAO, 1994b, p. 24). Exported products amounted to 18,300 tonnes (FAO, 1994b, p. 24). The remaining amount, 177,000 tonnes, was consumed in Japan. Average per capita Japanese wool consumption was 1.5 kg per year (FAO 1994b, p. 25).

The corresponding area for producing wool consumed by Japanese was obtained through dividing the quantity of consumption by the world average productivity of wool material, 0.0142 tonnes/ha/year (World average productivity figure was calculated by Wackernagel *et al.* 1993. pp. 66-67). The corresponding pasture area turned out to be 12,500,000 ha. (Data used by Wackernagel were from Rechcigl, ed. 1982, Vol. 2. p. 297, and Ensminger 1978, pp. 593-637).

(3) Forest Land

Data for forest products were from Association of Agriculture and Forestry Statistics (AAFS) 1993 and MITI 1992. For the calculation of land requirement of the imported timbers, forest annual growth rate of each climate zone was employed. I only classified into three climate zones, namely boreal, temperate, and tropical. Annual growth rate of each zone is as follows: 2.26 cubic meters/ha/year (boreal); 3.08 cubic meters/ha/year (temperate); and 10.50 cubic meters/ha/year (tropical) (Marland 1988. p. 39).

The calculation method for paper products was similar to that used in obtaining the land requirement for imported sugar products. It was necessary to know how much timber was required to produce one tonne of paper. I employed a conversion rate of 1.83 cubic meters of timber per tonne of paper (Wackernagel 1994, p. 294).

(4) CO_2-Sink Land

CO_2-sink land is defined as the land needed to absorb the carbon dioxide emitted during the burning of fossil fuels and solid waste, and during the manufacturing process for cement. CO_2-sink land is divided into two categories; [1] CO_2-sink land (Domestic), and [2] CO_2-sink land (Foreign). CO_2-sink land (Domestic) is the land area needed to absorb the CO_2 emitted by production processes in Japan; CO_2 emissions from the production of exported goods consumed abroad are excluded. CO_2-sink land (Foreign) is the land area needed to absorb CO_2 emitted from the production of goods imported from abroad. That is, I assume that Japan is responsible for the CO_2 emissions for the production of imported goods, even though these CO_2 emissions do not take place in Japan.

Measuring the land needed for CO_2 assimilation is one of the difficult components of the calculation of ecological footprints. Domestic CO_2 emission data are usually readily available for most countries. However, 'trade-corrected data' are not easy to generate. For this purpose, data were mainly obtained through Dr. Moriguchi and his colleagues, Drs. Kondo and Shimizu of the National Institute for Environmental Studies in Tsukuba. In their research, Kondo *et al.* (1995) used international Input-Output tables to estimate the CO_2 emission in foreign countries for which the Japanese are responsible. Their estimate was based on the assumption that CO_2 emission rates per production unit in other countries are the same as the ones in Japan. In reality, however, Japan is relatively energy efficient and, thus, the CO_2 emission rates per production unit in foreign countries tend to be higher than those of Japan. Therefore, I employed a 60% increase in order to correct the data provided by Kondo *et al.* (1995). This increase was justified by Wada's calculation using Case B Scenario conducted by Kondo *et al.* (1994, p. 46). Kondo *et al.* (1994) tried to incorporate the higher emission rate for foreign production. Their corrected computation resulted in a 126% increase in the CO_2 emission associated with imported products, compared with the original non-revised figure (Case A Scenario). However, they also expressed some concern that this figure seemed to be too high (p. 48). Thus, I tentatively employed a correction coefficient of only 60%, approximately half of their figure.

The final stage was converting CO_2 emission figures into the land area required for absorption. My calculation was based on the rate: 1.42 metric tonnes of carbon are absorbed by 1 hectare of world average forest in a year (calculated by Wackernagel 1998, based on 1990 data obtained from Kalusche 1996; IPCC 1997a, 1997b).

The above calculations were performed for 1991. However, when data for 1991 were not available, 1990 data or data available from the next nearest year were used instead.

(5) Degraded Land (Built Environment)

Data on degraded land came from the National Land Agency (NLA) (1997, p. 2, Table 1-1-1). This table includes the miscellaneous category.[37]

(6) Aquatic Area

Calculating the aquatic area ecological footprint is another difficult but important component of the EF analysis of Japan. Calculation was carried out based on a detailed

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[37] Since detailed information of this category was not explained in the table, I requested the National Land Agency (NLA), Japan to provide the breakdown information. However, they told me that the detailed information was not available (NLA 1999). They did clarify that this category includes the area of solid wastes dump sites.

analysis of primary productivity requirements for the production of different commercial fish species including the bycatch (Wada and Latham 1998). Catch data were supplied by FAO (1994a). Import and export data came from FAO (1993). The data year was 1990.

Aquatic areas were divided into six systems, 1) OOS (Open Ocean Systems), 2) US (Upwelling Systems), 3) TS (Tropical Shelves), 4) NTS (Non-tropical Shelves), 5) CCS (Coastal & Coral Systems), and 6) FW (Freshwater Systems). Each system has its own features; in particular, primary productivities are very different. The productivity data employed are contained in the table below:

Table 9 Primary Productivity of Aquatic Areas

Aquatic Area	Primary Productivity (gC/m^2/year)
1) Open Ocean Systems	103
2) Upwelling Systems	973
3) Tropical Shelves	310
4) Non-tropical Shelves	310
5) Coastal & Coral Systems	890
6) Freshwater Systems	290

(Source: Pauly and Christensen [1995], p. 257, Table 2)

The same species can be caught in different ocean systems; some may be caught in open ocean systems, and others may be caught over shelves. Ideally, Japanese catch, import, and export data would distinguish areas where fishes were caught, but such data were not available. However, I was able to obtain world catch data which were grouped in different ocean systems. As a compromise, I employed the world average proportional share of catches in different ocean systems for each species which Japan caught, exported, and imported.

Weight of canned products was divided by 0.7 in order to obtain wet weight of live fish. Weight of dried products was divided by 0.25 to achieve the same purpose.

The world average bycatch rate is 27% (Alverson *et al.* 1994). I assigned bycatch ratios particular to each aquatic system. Specifically, Open Ocean Systems: 0.200, Upwelling Systems: 0.151, Tropical Shelves: 0.305, Non-tropical Shelves: 0.441, Coastal & Coral Systems: 0.314, Freshwater Systems: 0.000 (Calculated by Wada and Latham in 1995 using data from Pauly and Christensen 1995). Then I calculated the Primary Production Required (PPR) to support the fish population consumed by humans.

The formula is after Pauly and Christensen (1995):

$$PPR = [\ (\text{consumption} + \text{bycatch}) / 9\ ] * 10^{(TL - 1)}$$

The purpose of dividing (consumption plus bycatch) by 9 is to convert wet weight into carbon weight. TL is an average trophic level of a certain fish species. (TL - 1) represents the average number of trophic level transfers from primary production to catch. Average transfer efficiency of each transfer is 10% (Pauly and Christensen 1995 and references therein). An organism in a given trophic level requires, on average, ten times more primary production than does an organism of equal mass, one trophic level below.

When PPR becomes known, the aquatic ecological footprint can be calculated by using the following formula:

$$\text{Aquatic EF} = \text{PPR} / \text{Primary Productivity (PP) of the Area.}$$

(7) Fair Land Share (FLS) and Fair Aquatic Share (FAS)

The 'fair land share' (FLS) was calculated by dividing the total area of ecologically productive terrestrial land (8,696,700,000 ha in 1989-91), by the world population (5,759,300,000, which is 1995 estimate). This gave 1.51 ha/person (World Resources Institute 1994, pp. 284-285; Wackernagel and Rees 1995[6]).

The aquatic primary production required to sustain the reported world-wide catches, plus 27 million tonnes of discarded bycatch, amounted to eight percent of global aquatic primary production in the early 1990s (Pauly and Christensen 1995). To estimate 'fair aquatic share' (FAS), we first assumed that the eight percent of global marine primary production appropriated by humans is the maximum sustainable yield. This assumption was supported by the general decline of world fisheries (Pauly 1996). The FAS was calculated by distributing equitably among humans the aquatic area which supplies the primary production appropriated by the world's human population. It turned out to be 0.51 ha/person (Wada and Latham 1998).[38]

(8) Limitation of Analysis and Missing Data

Some items were not taken into the calculation of the Japanese ecological footprinting due to missing data and/or calculation difficulty. However, the omission would not be likely to change the conclusion.

(a) Foreign degraded land

Degraded land in foreign countries was not included due to difficulty in calculation and missing data. Such land includes golf courses, roads, airports, and hotel sites used by Japanese tourists.

Japanese consumption depends extensively on mining from foreign sites. For example, the Japanese import large quantities of iron ore (125,300,000 tonnes in 1990, MITI 1992, p. 163), coal (107,900,000 tonnes, MITI 1992, p. 188), copper ore

[38] Wackernagel and Rees (1995[6]) estimated Canadian aquatic ecological footprint and FAS by using a method which is slightly different from Wada and Latham (1998). In order to maintain consistency with the Japanese ecological footprint estimates, the figures of Canadian aquatic EF and FAS given here were derived using our method.

(3,523,000 tonnes, MITI 1992, p. 163), and phosphate rock for fertilizer (1,543,000 tonnes, MITI 1992, p. 173). The production of these raw materials in foreign countries cause environmental damages and destruction there. Also, Japanese cropland has increased its productivity, because of the application of phosphate fertilizer produced from imported rock. This has enabled Japan to require less agricultural land. Thus, I do recognize that it is unfair not to account for the foreign degraded land due to the production of phosphate rock. However, because of unavailability of data, the areas of mining sites abroad were not included in the calculation.

Nevertheless, CO_2 emission from the production of these materials was accounted for in the land category of CO_2-sink land. This was achieved by employing the foreign CO_2 emission estimates calculated by Kondo *et al.* (1995), who used the international Input-Output Tables (as previously explained in the section called 'CO_2-sink Land').

(b) Aquaculture

Neither national nor foreign aquaculture practices were considered, because there was a high possibility of double counting since large amounts of small fish are fed to cultivated fish in aquaculture. These small fish were already included in the calculation. Again, CO_2 emission from these overseas aquaculture operations was accounted for as CO_2-sink land.

(c) Manufactured Products

Production of manufactured goods such as automobiles, electronics, and chemical goods is a large part of Japanese economy. Some may have wondered in which land category these manufactured products are accounted for. CO_2 emission from the production of these commodities was accounted for in the CO_2-sink land category. I also included factory sites for production, and solid waste sites for the disposal of old equipment and old products in the category of (domestic) 'Degraded Land.' As mentioned above, foreign 'Degraded Land' for the production of raw materials and coals was not included in the calculation. This, and similar decisions above will tend to make my result conservative, i.e., to underestimate the footprint of the Japanese economy.

The Japanese economy depends also on export of these manufactured products. Total export accounts for approximately 10% of her total gross national products (GNP). Machinery export represents 75.0% in all exported products in 1990 in monetary terms (MITI 1992, p. 93). Computers and other electronics parts and products account for 30.0%. Automobiles accounts for 14.4%. Chemical products has share of 5.5% (MITI 1992, pp. 60, 93). These products are consumed by consumers in foreign countries. Thus, the CO_2 emission derived from the production of these goods was subtracted by employing the estimates of Kondo *et al.* (1995). However, 'degraded land' associated with the exported manufactured goods was not subtracted due to the potential complexity of the calculations required.

This chapter has explained methods and procedures for conducting the case study of Japanese consumption, definitions of terms, basis and assumptions of calculation, missing data, and limitation of analysis. The next chapter will present the calculation results.

Chapter 5

Results

This chapter presents the results of calculation of the ecological footprint that is required to support current Japanese consumption.

5.1 Total Ecological Footprint Necessary to Support Japanese Consumption

Available data concerning Japanese resource and commodity consumption were converted into corresponding land and water areas as described above. My results indicate that 345.8 million ha of productive land are required to produce the commodities and services currently consumed by the Japanese population. This total is approximately 9 times greater than the geographic land base of Japan (37.8 million ha). If I add the aquatic ecological footprint which is 234.5 million ha, the total ecological footprint of Japanese consumption becomes 580.3 million ha, roughly 15 times larger than the land mass itself (see Table 10). This means that Japan has an ecological deficit or 'sustainability gap' equivalent to approximately 14 times its domestic 'natural income' (total biophysical productivity).

Table 10 Ecological Footprint of Japanese Consumption (1990/91 Data)

	Ecological Footprint	Percentage of Total	Comparison with Total National Land Area	Existing Domestic Land Area by Category	Comparison with Existing Domestic Land
Land Category	million ha	%	times	million ha	times
Crop land	28.1	5	0.7	4.4	6.4
Pasture land	21.5	4	0.6	0.8	26.9
Forest land	22.2	4	0.6	25.3	0.9
CO_2 sinks (CO_2 from domestic sources)	199.3	34	5.3	25.3	7.9
CO_2 sinks (CO_2 emissions embodied in imports)	70.4	12	1.9	25.3	2.8
Degraded land	4.3	1	0.1	4.3	1.0
Terrestrial Area Total	345.8	60	9.2	-	9.2
Aquatic Area Total	234.5	40	6.2	-	6.2
Grand Total	580.3	100	15.4	37.8	15.4

(Revised from Wada and Latham 1998)

These biophysical data demonstrate that Japan's high level of consumption is made possible through the exploitation of large quantities of *external* primary productivity, i.e., through the appropriation of goods and ecosystems services produced by large areas of land and water outside the country. Contrary to conventional wisdom, Japan's economic prosperity is neither ecologically benign nor 'decoupled' from nature. On the contrary, it contributes significantly to the consumption and degradation of global ecological assets.

5.2 Sector by Sector Analysis

The largest portion of the ecological footprint of Japanese consumption turned out to be CO_2-sink Land. A land area of 199.3 million ha was necessary to absorb CO_2 emitted from domestic sources. The land area required for sequestering CO_2 from foreign sources was 70.4 million ha. The total area turned out to be 269.7 million ha. This accounted for 42% of Japan's total ecological footprint. In order to absorb CO_2 for which Japan was responsible, a forest area about 7.2 times as large as its national land was necessary.

The second largest eco-footprint was attributed to aquatic living resources consumption (40%). This consumption required appropriation of 234.5 million ha of aquatic area which is about 6.2 times as large as Japan's land mass. Fish high in marine food webs, i.e., tunas, bonitos, and billfishes, mainly from the open ocean, accounted for 65% of all the aquatic ecological footprint of Japan. Shrimp consumption accounted for 9%. This means that gourmet seafood consumption by the Japanese was contributing significantly to the appropriation of carrying capacity of the sea. Again, this figure did not necessarily include the ecological footprint associated with aquaculture production in

Japan and abroad. It is anticipated that the actual Japanese aquatic ecological footprint was somewhat larger than the one presented above.

The area of cropland necessitated by Japanese consumption was calculated to be 28.1 million ha, which accounted for 5% of the total ecological footprint. This area is equivalent to 70% of the Japanese territory and 6.4 times as large as Japan's domestic cropland. In other words, the self-sufficiency rate of agricultural products is only 15.6% as measured in ecological footprint (excluding products associated with pasture land).

Pasture land of 21.5 million ha was required to produce such commodities as wool, meats, and dairy products consumed in Japan. This area is comparable to 60% of Japan's land mass, and 26.9 times as large as domestic pasture land. This means that pasture land self-sufficiency rate was only 3.7%. Wool accounted for 58% of the total pasture land ecological footprint.

The total agricultural ecological footprint of Japan derived by combining the cropland and pasture land was 49.6 million ha which was 9.5 times as large as the domestic agricultural area utilized. Total agricultural self-sufficiency rate turned out to be 10.5% in terms of land area. This rate is significantly smaller than what we normally perceive it to be. For example, the Japanese Association of Agriculture and Forestry Statistics (AAFS) included a section on food self-sufficiency (1995, pp. 44-45). Their analysis showed that only 31% of grain was produced domestically (in terms of weight) for human consumption and feed, and that the feed self-sufficiency rate was 27% in terms of total digestible nutrients (TDN).[39] This analysis did not include non-edible agricultural

[39] Total digestible nutrients (TDN) system is a method of measuring energy values of various feedstuffs for livestock animals. TDN is defined as: the sum of the digestible protein, fiber, nitrogen-free extract, and fat x 2.25 (Ensminger 1978, pp. 243-244).

products. My analysis, however, included all the agricultural products including such non-food products as wool, cotton, and rubber. Including these indispensable items into self-sufficiency calculation and employing the ecological footprint concept have made us realize that Japan is extremely dependent on foreign agricultural land and that Japanese consumers live on a fragile soil foundation.

The forest land of 22.5 million ha was appropriated to satisfy the Japanese consumption of timber and paper. The area is equal to 90% of domestic forest area. However, Japanese consumption of these products depends heavily on foreign forest land. It appropriates 12.7 million ha of forest land from overseas. This amounts to nearly 60% of all the forest ecological footprint.

The area of degraded land was 4.3 million ha. This is approximately only 1% of the total ecological footprint of Japan. Table 11 shows breakdown of the degraded land.

Table 11 Breakdown of the Degraded Land (Built Environment) (thousand ha)

Roads, highways	1,140
Residential and Industrial areas	1,600
Residential areas	970
Industrial areas	160
Solid waste final disposal sites (General)	5
Solid waste final disposal sites (Industrial)	6
Miscellaneous	459
Total	4,340

Sources: National Land Agency, Japan 1997, p. 2, Table 1-1-1, and internal documents of the Ministry of Health and Welfare, Japan 1999, obtained through Environment Agency, Japan. 1999b).

5.3 Ecological Footprint Per capita

Table 12 and Figure 8 put the Japanese eco-footprint in perspective. The per capita Japanese ecological footprint comprises 2.80 ha of terrestrial ecosystems and 1.90 ha of aquatic ecosystems, for a total of 4.70 ha.[40] There are currently only about 1.51 ha of productive land (Wackernagel and Rees 1995[6]) and 0.51 ha of productive marine ecosystem available per capita on the planet (Wada and Latham 1998). (As mentioned earlier, we call these areas the "fair land share" (FLS) and "fair aquatic share" (FAS) respectively.) Then, the Japanese ecological footprint is 2.3 times the sum of FLS and FAS (2.02 ha per capita). This means that Japan's per capita 'sustainability gap' is equivalent to 2.7 hectares.

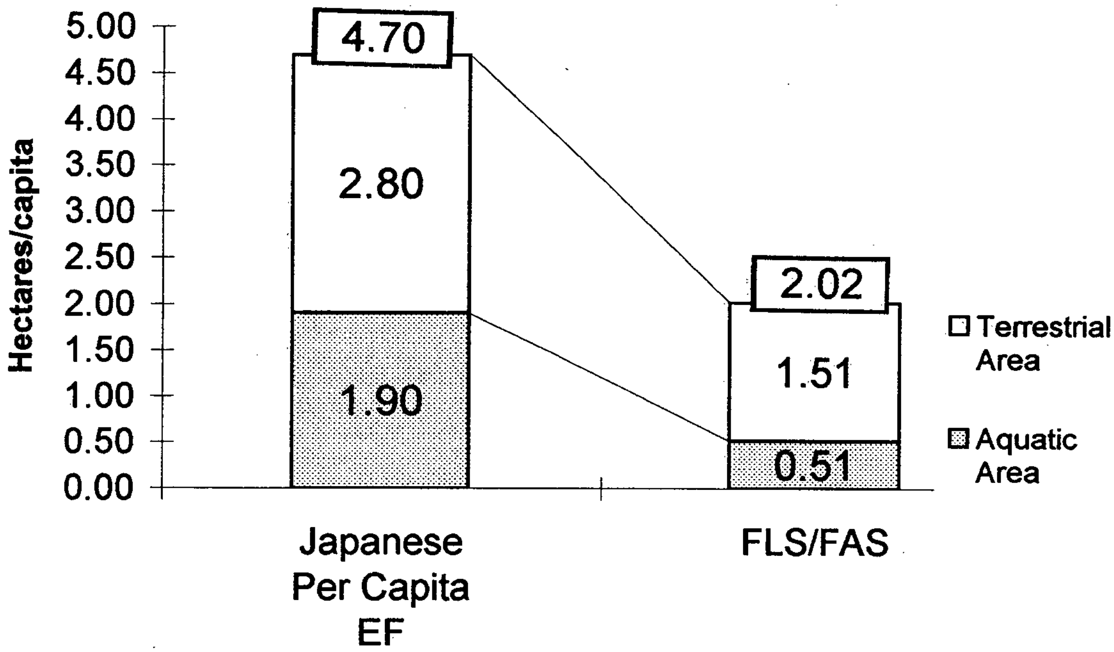
Table 12 Japanese Per capita Ecological Footprint (1990/91 Data)

Japanese Ecological Footprint (ha/capita)		FLS/FAS (ha/capita)
Cropland	0.23	
Pasture Land	0.17	
Forest Land	0.18	
CO_2-sink Land (Energy Land)	2.18	
Degraded Land (Built Environment, e.g., roads, houses, buildings, etc.)	0.03	
Total Terrestrial EF	**2.80**	**1.51**
Total Aquatic EF	**1.90**	**0.51**
Grand Total EF	**4.70**	**2.02**

(Revised from Wada and Latham 1998)

[40] The per capita Japanese ecological footprint in the pre-industrial era is estimated to be approximately 0.4 ha (1880 data).

Figure 8 Japanese Per capita Ecological Footprint and Fair Land Share / Aquatic Share



(Revised from Wada and Latham 1998)

This chapter has presented the results of ecological footprint of the Japanese consumption. This will be followed by discussing the thesis conclusions, implications for policy, and directions for further study.

Chapter 6

Conclusions

This chapter presents the conclusions of this case study. An explanation is made as to why the conventional "sustainable development" model is unsustainable, followed by discussions on policy implications towards creating truly sustainable civilization, and on directions for further research.

6.1 Analysis

(1) The Dominant Sustainability Model is Unsustainable

Biophysical analysis suggests that in a global context, the current consumption level of the Japanese people is unsustainable. Far from 'decoupling' economic growth from its biophysical and material requirements, Japan merely exports much of the requirements and impact of its production and consumption to other countries and the global commons. The per capita Japanese eco-footprint is such that if imitated by the populations of all other countries, the equivalent of 1.33 *additional* Earth-like planets would be needed to sustain global consumption (4.70 ha/capita [EF] divided by 2.02 ha/capita [available land / water] equals 2.33; 2.33 minus 1 [the existing Earth] equals 1.33 additional Earth-like planets).

This contradicts the conclusions that Pearce and Atkinson (1993) have reached through their monetary analysis. Their study measured sustainability of 18 countries by using 'weak sustainability' criterion. 'Weak sustainability' means that "the *sum* of man-made and natural capital can be maintained constant in some aggregate value sense" (Daly 1996b, p. 76). This criterion assumes the substitutability between man-made capital and natural capital (*ibid.* p. 76).[41] The study by Pearce and Atkinson (1993) concluded that economies such as those of Japan, Germany, the Netherlands, and the U. S. A. meet the criterion of 'weak sustainability,' since these countries save more than the depreciation on their man-made and natural capital (p. 106). My biophysical analysis has reached a conclusion that Japanese consumption is far from sustainable, which is completely opposite to the conclusions which were derived by monetary analysis.

Although I have used Japan as an illustrative case study, that country is by no means alone in imposing an inequitably excessive load on the ecosphere. For example, the citizens of Canada and the U. S. A. leave an even larger ecological footprint than the average Japanese.

Table 13 Canadian Per capita Ecological Footprint (1991 Data)

Canadian Ecological Footprint (ha/capita)		FLS/FAS (ha/capita)
Cropland	0.68	
Pasture Land	0.46	
Forest Land	0.59	
CO_2-sink Land (Energy Land)	3.01	
Degraded Land (Built Environment, e.g., roads, houses, buildings, etc.)	0.20	
Total Terrestrial EF	**4.94**	**1.51**
Total Aquatic EF	**0.64**	**0.51**
Grand Total EF	**5.58**	**2.02**

(Revised from Wackernagel and Rees 1995[6], pp. 82-83, and Wada and Latham 1998, p. 20)

For example, the Canadian terrestrial footprint is conservatively estimated at 4.94 ha per capita (revised from Wackernagel and Rees 1995[6], pp. 82-83), and its aquatic footprint at 0.64 ha (Wada and Latham 1998). The total minimum Canadian ecological footprint is

[41] "By contrast, 'strong sustainability' would require maintaining both man-made and natural capital intact separately, on the assumption that they are really not substitutes but complements in most production functions" (Daly 1991a, p. 250)

therefore 5.58 ha per capita.[42] Since there are only about 2.0 ha per capita of ecologically productive land and water ecosystems on Earth, a total of three such planets would be needed to sustain just the present global population if everyone consumed at the North American level.

My analysis demonstrates that an ostensible flagship (Japan) of the mainstream version of 'sustainable development' is, in fact, not sustainable. Economic dematerialization is simply not occurring under present market conditions. Other analysts come to a similar conclusion on this latter point. The most recent study of resource flows in a selection of high income countries (including the U. S. A. and Japan) found that the average citizen now requires 45-85 metric tons of natural resources (excluding air and water) *annually* – including 17 to 38 metric tons of direct material inputs – to produce his/her goods and services. While these countries have seen some reduction in the ratio of resource inputs per unit GDP since 1975, there has also been "in most, a gradual rise in per capita natural resource use." This assessment concludes that "meaningful dematerialization, in the sense of an absolute reduction in natural resource use, is not yet taking place" (WRI 1997, p. 2).

The conclusion of my study is also compatible with Goodland's claim that "Throughput growth is not the way to reach sustainability .... [since] the capacities of the biosphere's sources and sinks are being stressed." (1991, p. 16). My conclusion is also in harmony with Daly's argument that since "we have moved from 'empty-world' to 'full-world,'" (1994, p. 22), Brundtland's growth-bound 'sustainable development' is not

[42] More recent analysis brings this to more than 7 ha/capita (Wackernagel *et al.* 1997, 1999).

biophysically feasible (Daly 1996a, p. 194). Authors such as Murota (1979, 1987b), Inoue (1986), Timberlake (1989), Rees (1992, 1999), Meadows *et al.* (1992), Inada (1993), Furusawa (1995), Kato (1997), and Ayres (1998) support this conclusion as well. As explained above and in *6.2 Policy Implications,* the expansionist version of sustainability which assumes "a five- to ten-fold increase in world industrial output ... by the time world population stabilizes sometime in the next century" (WCED 1987, p. 213), is simply, biophysically, impossible given present definition.

(2) Limitations and Constraints of This Case Study

(a) Conceptual Limitation

This study demonstrated that the Brundtland version of 'sustainable development' is not, in fact, biophysically sustainable. Of course, there are several dimensions of sustainability, such as economic, social, and ecological. Some may argue that sustainability of a human economy should not be assessed through only one criterion. As stated previously in my purpose statement, indeed, my study did not include the economic and social dimensions. However, this argument is refuted by applying Liebig's 'Law of the Minimum' to sustainability. If ecological sustainability of a human economy is at risk, then the whole economy cannot achieve sustainability even though other aspects of sustainability are attained. For these reasons, the findings of this biophysical study of the Japanese consumption are sufficient to conclude that the current Japanese economy is not sustainable.

(b) Methodological Limitations

As mentioned in Chapter 4, some items were not taken into the calculation of the ecological footprint because of missing data and/or calculation difficulty. For example, degraded land in foreign land was not included. Such land includes roads, airports, golf courses, and hotel sites used by Japanese tourists. The areas of mining sites abroad were not included in the calculation as well, because of unavailability of data. Nevertheless, CO_2 emission from the production of these raw materials was accounted for in the land category of CO_2-sink land.

Neither national and foreign aquaculture practices were considered, because there was a high possibility of double counting since large amounts of small fish are fed to cultivated fish in aquaculture.

As briefly mentioned in Chapter 2, shrimp aquaculture is responsible for the destruction of coastal mangrove forests in tropical regions. In a matter of the past 15 years, export-oriented shrimp aquaculture has been rapidly expanding throughout Asia and in some part of Latin America and Africa (Goldsmith 1996, p. 84; Ahmed 1997, p. 2). These intensive shrimp-farm operations are extremely destructive, and have caused various environmental and social problems in these regions. For example, in order to accommodate the intensive aquaculture, mangrove forests which offer excellent habitat for juvenile fish have been destroyed extensively. So far, approximately half of the world's mangroves have already been cut down for this purpose (Goldsmith 1996, p. 84). Ahmed (1997) reports that the area of the world's mangroves lost to date is one million hectares (p. 30). Japan is the largest importer of shrimp from these regions (32.9% in 1985, from

FAO 1985 cited in Murai 1988, p. 196). Therefore, it is reasonable to claim that Japan is largely responsible for 32.9% of the environmental destruction of these coastal areas. That would mean that Japan is responsible for the loss of 329,000 ha of mangrove forests. On per capita basis, the Japanese contribution is 0.0027 ha/capita. This is larger than the per capita potato fields appropriated for Japanese consumption. Moreover, shrimp farm operations require much larger spatial ecosystem support than the pond itself. Larsson *et al.* (1994) report that semi-intensive shrimp aquaculture in Colombia requires an ecological footprint that is 35-190 times larger than the surface area of the farm. If we include this ecological footprint associated with shrimp aquaculture, the Japanese consumption of imported cultivated shrimp would necessitate 11.5 - 62. 5 million ha of aquatic area. The corresponding per capita area would be between 0.095 ha/*capita* and 0.51 ha/*capita*. These are large areas. These figures could have been added to the land category, 'Degraded Land' (Abroad). However, this was not included in the calculation due to remaining uncertainties. Again, CO_2 emission from these overseas aquaculture operations was accounted for as CO_2-sink land.

Production of manufactured goods such as automobiles, electronics, and chemical goods is a large part of Japanese economy. CO_2 emission from the production of these commodities was accounted for in the CO_2-sink land category. I also included factory sites for production, and solid waste sites for the disposal of old equipment and old products in the category of (domestic) 'Degraded Land.' As mentioned above, foreign 'Degraded Land' for the production of raw materials and coals was not included in the calculation.

The Japanese economy depends also on export of these manufactured products. These products are consumed by consumers in foreign countries. Thus, the CO_2 emission derived from the production of these goods was subtracted by employing the estimates of Kondo *et al.* (1995). However, 'degraded land' associated with the exported manufactured goods was not subtracted due to the potential complexity of the calculations required.

These omissions, however, would do little to change the conclusions, because these omissions tend to have underestimated the footprint figures of the Japanese consumption. If these missing figures were adequately incorporated, my conclusions would be even strengthened since the ecological footprint figure would be likely to become larger.

6.2 Policy Implications

(1) Reduction of Dependency on Carrying Capacity Overseas

My finding revealed that the appropriation of a large quantity of the carrying capacity of foreign land is necessary in order to sustain the Japanese economy. This means that Japan " 'appropriate[s]' the ecological output and life support functions of distant regions all over the world through commercial trade and natural biogeochemical cycles" and that the survival of this industrialized nation "depend[s] on a vast and increasingly global hinterland of ecologically productive landscapes" (Rees and Wackernagel 1996, p. 236). Japan's 'ecological deficit' is extraordinarily large, namely 14 times its land base (including its aquatic resource consumption). One of the most important insights drawn from this finding is that Japan's security has been compromised by its heavy dependency on foreign land. Catton (1980) warns the danger of excessive reliance on trade, i.e., heavy dependency on foreign carrying capacity by stating:

> As the ecological load increased beyond what could have been supported by the sum of the separate carrying capacities of the formerly insulated local environments, mankind's vulnerability to any disruption of trade became more and more critical. The aftermath of the crash of 1929 [i.e., the Great Depression] demonstrated that vulnerability. (p. 159)

Since developing countries are trying to industrialize themselves to catch up with G7 countries, the competition for global ecological output and services will become even more intense in the near future. This means that Japan will become even more exposed to the risk of resource shortages, including food products. The Japanese government needs to seriously reconsider its trade and industrial policies so that Japan will come to rely more on its own land and water. This means that Japan should reduce import as well as export. Otherwise, Japanese population will continue to live on a precariously imbalanced basis.

This policy implication is contrary to the mainstream political pressure from such countries as the U. S. A., and various international organizations such as the World Bank and the IMF. However, their perspective is based on a short-term, old and conventional neoclassical economics paradigm. My policy prescription may sound politically unrealistic. However, it is scientifically and biophysically realistic and feasible.[43]

[43] Neoclassical economists often advocate unrestricted international or inter-regional trade because they believe that it brings about higher efficiency which benefits all parties involved. This argument is based on the principle of 'comparative advantage.' Indeed, trade sometimes yields the benefits of specialized production through the increased economic efficiency, i.e., requiring less resource input per industrial output, thus emitting less pollutants (Hayami *et al.* 1999). However, trade can also cause problems. For example, trade can eliminate local resource constraints. This aspect of trade functions as an accelerator of the consumption and depletion of local and global resource bases (Rees 1994, pp. 12-18). Export of resources including food commodities sometimes raises their market price. This may jeopardize access to the necessary resources and food items among the poor in the resource exporting countries. Therefore, trade is not a panacea, but it can create ecological, social and ethical problems.

(2) Factor 5 or 10 Economy

To accommodate a projected population of 10 billion and a five to ten-fold increase in economic output, at least a five to ten-fold increase in energy and material productivity is needed. This realization has generated much discussion of the need to achieve a 'factor-5 economy' or 'factor-10 economy' (Yamamoto 1998b). Even the international Business Council on Sustainable Development has agreed that "industrial world reductions in material throughput, energy use, and environmental degradation of over 90% will be required by 2040 to meet the needs of a growing world population fairly within the planet's ecological means" (BCSD 1993).

I have attached some scenarios of the resource use reduction as Appendix E. These scenarios indicate that a technological fix alone is not enough to substantially reduce the ecological footprint of Japan to an equitable level.

(3) Ecological Fiscal Reform

To achieve such massive productivity gains would almost certainly require aggressive 'ecological fiscal reform' – steep and accelerating taxes on primary energy and raw material consumption accompanied by falling payroll and income taxes. Steadily rising costs would create the economic incentive needed for industry to launch a new technological revolution (von Weizsäcker and Jesinghaus 1992; Young and Sachs 1994; Rees 1995a, 1995b). Unfortunately, while the debate over such measures has started, after three decades of promoting the free market, governments are generally reluctant to embark on any approach calling for large-scale intervention in the economy.

(4) Decoupling Welfare from Growth: A Lesson from Kerala

Factor-10 thinking reflects industrial society's reliance on technological fixes. It avoids any re-evaluation of the fundamental values and behaviors that underpin the growth ethic and which generated the problem in the first place. It also avoids having to contemplate policies to redistribute existing wealth.

Is there any alternative? For example, instead of decoupling growth from 'the environment,' can we decouple welfare from growth?[44] The State of Kerala in India suggests that such a development path is possible. Kerala is a geographically small state, with a population of 30 million. The GNP/capita is only $387 US, one sixty-fifth of US level, and close to the Indian average of $350 (Alexander 1994a). Consequently, the per capita ecological footprint is estimated to be a sustainable 0.38 ha, which is less than one tenth that of Japan.

Despite this apparent poverty, Kerala's literacy rate is 95% – almost equivalent to the literacy rate in most industrialized countries. (The Indian average is 52% [Alexander 1996].) Kerala's life expectancy is 69 years for males and 71 for females, approaching the average for Canadian men and women at 72 and 79 years respectively. (The average figures for India are only 58 and 59 years [Alexander 1994a].) Other human development indicators also approach so-called 'first-world' levels (Drëze and Sen 1995).

The people in Kerala, rich or poor, appear to enjoy sufficient food, good health-care,

[44] The present tendency to equate welfare with income is a perversion of economics. Economic theory indeed starts from the assumption that people want to maximise their welfare, but welfare comprises a great deal more than expanded output and higher average incomes. If, at the margin, I value environmental quality, community stability, public health, safer cities, or beautiful public spaces more than increased production, and having these things leads to less production, then less production actually improves welfare. Growth that destroys more value than it creates is bad economics.

a quality public educational system, a vibrant democracy, and a stable population (Franke and Chasin 1989; Birch and Cobb 1990; Baird 1993; Alexander 1994a, 1994b, 1996; Kapur 1998). This is in stark contrast to the usual situation in other low-income countries. Apparently, Kerala's exceptional standard of living is based more on equity and investment in social capital (including sound public health and quality public education) than it is on material growth and private capital accumulation.[45]

The industrialized world has much to learn by analyzing the development paths of places like Kerala. Kerala is not necessarily a direct model for Japan or the U. S. A. or Canada. However, the Kerala experience shows that the consumer society is not a predestined inevitability. Alternatives are possible. Kerala may provide important lessons on how to create an ecologically sustainable civilization in the next century as global carrying capacity becomes increasingly limiting.

(5) Organizing EF Monitoring and Reporting Systems in Japan and Other Nations

The way we behave in society and the way economic policies are shaped are significantly dominated by monetary macro indicators such as gross domestic products (GDP). Because monetary analyses are so distant from ecological reality, our society is often mislead by these monetary indicators in dealing with ecological problems, as explained in Chapter 3. We are caught in an illusion, partly created by monitoring and reporting of GDP, that the human economy can grow forever. In the mentality occupied by the illusion that economic expansion can continue totally independent from the

[45] However, it is important to realize that Kerala is not isolated. With globalization, consumerism is emerging in Kerala as well and more and more people are adopting materialistic western models (Sooryamoorthy 1997).

ecosphere's limited ability to provide low-entropy matter and energy and to dispose of high-entropy waste matter and energy, ecological constraints (namely carrying capacity) are no longer valid. In order to counteract the strong force of the existing monetary indices, it is urgent that Japan (and other nations) establish a system of monitoring and reporting the economy's ecological sustainability by using non-monetary indicators. The ecological footprint can serve this purpose as shown in my analysis.

Monitoring and reporting of that footprint have to be conducted continuously and periodically. Ideally, the frequency of reporting should be once every three months, as is the case for GDP. However, at the beginning, the reporting could be carried out once a year, perhaps in the annual *Quality of the Environment Report* compiled by the Japan's Environment Agency.

Ecological footprint monitoring should be done not only at the national level but at local levels as well, because local 'autonomies' (governments) play significant roles in protecting the global environment. Indeed, the Agenda 21 adopted at the Earth Summit in 1992 urges each local authority to reduce its impacts on the environment by adopting 'a local Agenda 21' (UNCED 1992, p. 233).

For the calculation of ecological footprints, mass balance data, i.e., data on physical fluxes, must be systematically gathered by the national and the local governments. Experience in conducting research for this thesis and other projects indicate that the national data are usually readily available. However, data on material fluxes between prefectures or municipalities are usually not readily available. This is true not only for commodity import and export data but also in- and out-flows of industrial and household wastes across the borders between localities. Local governments should allocate resources to monitor regional trade of commodities, services as well as wastes, not only in monetary terms but also in physical and energy terms.

Ecological footprint monitoring and reporting can be carried out either by a non-governmental organization (NGO), or the government, or a research institute. In any case, some experts must be trained to carry out eco-footprinting study and some budget must be secured for this purpose.

In order to raise public awareness regarding the effectiveness of the ecological footprint indicator, perhaps, it is a good idea to wisely mobilize journalists who are concerned about the problems of the environment and the global carrying capacity. In Japan, there is a non-profit organization, the Association of Journalists Concerned with Environment. Members of this organization may be cooperative towards this endeavor.

It is important to note that ecological footprint monitoring and reporting are meant to be utilized for shaping policies for the macro economy, industrial development, energy, agriculture, forestry, fisheries and urban planning, rather than just environmental policies. Here, we must reconfirm that the human economy is a sub-system in a nested hierarchy and that the extent that our economy can grow is determined by the superior system for the economy, namely the ecosphere (Rees 1998, p. 50).

(6) Educational Programs Using Ecological Footprinting

In Canada, environmental education programs exist that use ecological footprinting; Mr. Tim Turner runs the Sea to Sky Outdoor School for Environmental Education on B.C.'s Sunshine Coast, for example, where elementary and secondary school children learn the important connection between the ecosphere and their everyday lives as well as the limits of nature's capacity to produce resources and assimilate wastes (Sea to Sky Outdoor School for Environmental Education [date not specified]). They are also taught how large an ecological footprint their lifestyle leaves on the Earth. Mr. Turner was an ecology teacher in Vancouver's secondary school system who quit his teaching position to establish this private school dedicated to environmental education.

Mr. Jim Merkel and his colleagues have created the Global Living Project (GLP) Summer Institute in Winlow, B. C., where they have offered an annual summer course for university undergraduate and graduate students since 1996. The students learn how to live sustainably and harmoniously with the ecosphere. The curriculum includes bioregional mapping as well as ecological footprint calculations (Merkel 1999).

A Canadian journal for schoolteachers called *Green Teacher* published an issue featuring the ecological footprint concept (Wackernagel and Rees 1995). The content was written plainly so that teachers can use it in the classroom with a minimum of preparation and adjustment.

In fact, such environmental education is badly needed in Japan because the Japanese have been reported to demonstrate weakness in environmental improvement, which requires changes in social attitude and fundamental values. Barrett and Therivel (1991) observe that in Japan environmental gains have been most evident where technological solutions--e.g., flue-gas desulfurization equipment, catalytic converters, etc.--could be applied, but that less rapid progress has been made where environmental improvements required significant changes in social attitude and their values (pp. 45, 47). Barrett and

Therivel (1991) further argue that:

> Although the progressive financing and 'technology-forcing' legislation which Japan has implemented so successfully are essential to solving environmental problems, a more fundamental change in values is also needed to attain sustainable development. (p. 86)

Therefore, Japan urgently needs to introduce such programs of environmental education because they could potentially change citizens' values.

(7) Promoting a Paradigm Shift

I have made a case in Chapter 3 that the ecological crisis results from our obsession with and the spell of the old Newtonian mechanical paradigm. Each member of society needs to undergo a fundamental paradigm shift to an 'ecological and holistic paradigm'. How will we make it happen? I argue that 'paradigm shift education' is needed in all segments of society. Policy-makers, political leaders, corporate managers, company employees, university professors, university students, school teachers, and children; young and old, male and female--all must be exposed to a new paradigm, and given opportunities to contemplate its implications for their lives and policy-making.

For example, at undergraduate and graduate levels, a course on paradigm shift should be included as an essential core course for students in all disciplines, including arts, social sciences, natural sciences and engineering. It is a revolutionary task, and therefore it may be extremely difficult to introduce such a course. However, Daly and Cobb (1989) emphasize the importance and possibility of 'university reform' by stating, "One important institution in which fruitful changes are possible is the university. This is the home of many of the most influential economists as well as opinion-makers in other fields" (p. 357).

There is a unique educational movement for company managers and employees, which is promoted by a non-profit educational organization called 'The Natural Step' (TNS) (Lindahl 1998). "TNS was founded in Sweden in 1989 by Dr. Karl-Henrik Robert, an oncologist who noticed a significant increase in childhood leukemia cases and witnessed first hand the connection between human illness and toxins" (TNS 1998, http://www.naturalstep.org/what/what_what.html, p. 1).[46] "TNS is a non-profit environmental education organization working to build an ecologically and economically sustainable society" (*ibid.*, p. 1). TNS's mission is stated as follows:

> TNS offers a framework that is based on science and serves as a compass for businesses, communities, academia, governmental entities and individuals working to redesign their activities to become more [ecologically] sustainable. (TNS 1998, http://www.naturalstep.org/what/what_what.html, p. 1)

In summary, TNS sends volunteers to these entities and conveys messages written in a 'consensus document' which

> describes the basic knowledge of the biosphere's functions, and how society influences natural systems, and that humans are threatening themselves by deteriorating natural functions and, finally, that there are great possibilities to change the situation into an attractive sustainable society. (*ibid.*, p. 1)

In addition to the consensus document, TNS's framework consists of a set of system conditions for sustainability which are based on the First and the Second Laws of Thermodynamics. TNS implicitly tries to promote a paradigm shift to a broad audience. It would be very meaningful to conduct a research on how participants in the TNS programs accept the intended paradigm shift away from a mechanistic paradigm towards a

[46] TNS has its headquarters in Stockholm in Sweden. It has offices in Australia, Canada, the United Kingdom, the United States of America, and Japan (TNS 1998, http://www.naturalstep.org/what/what_intl.html, pp. 1-2).

more ecological and holistic one. The evaluation of the educational programs should be carried out in different contexts and in countries with different cultures and social backgrounds.

(8) Encouraging Investment in Natural Capital

So far the discussions have been focused on how to reduce Japan's ecological footprint through various measures ranging from monitoring the macro economy to educational programs. Let us now consider how we can restore or even revitalize the diminishing carrying capacity of ecosystems, as Daly (1991b, 1994) argued that we should promote new strategies for preserving and enhancing 'natural capital.'

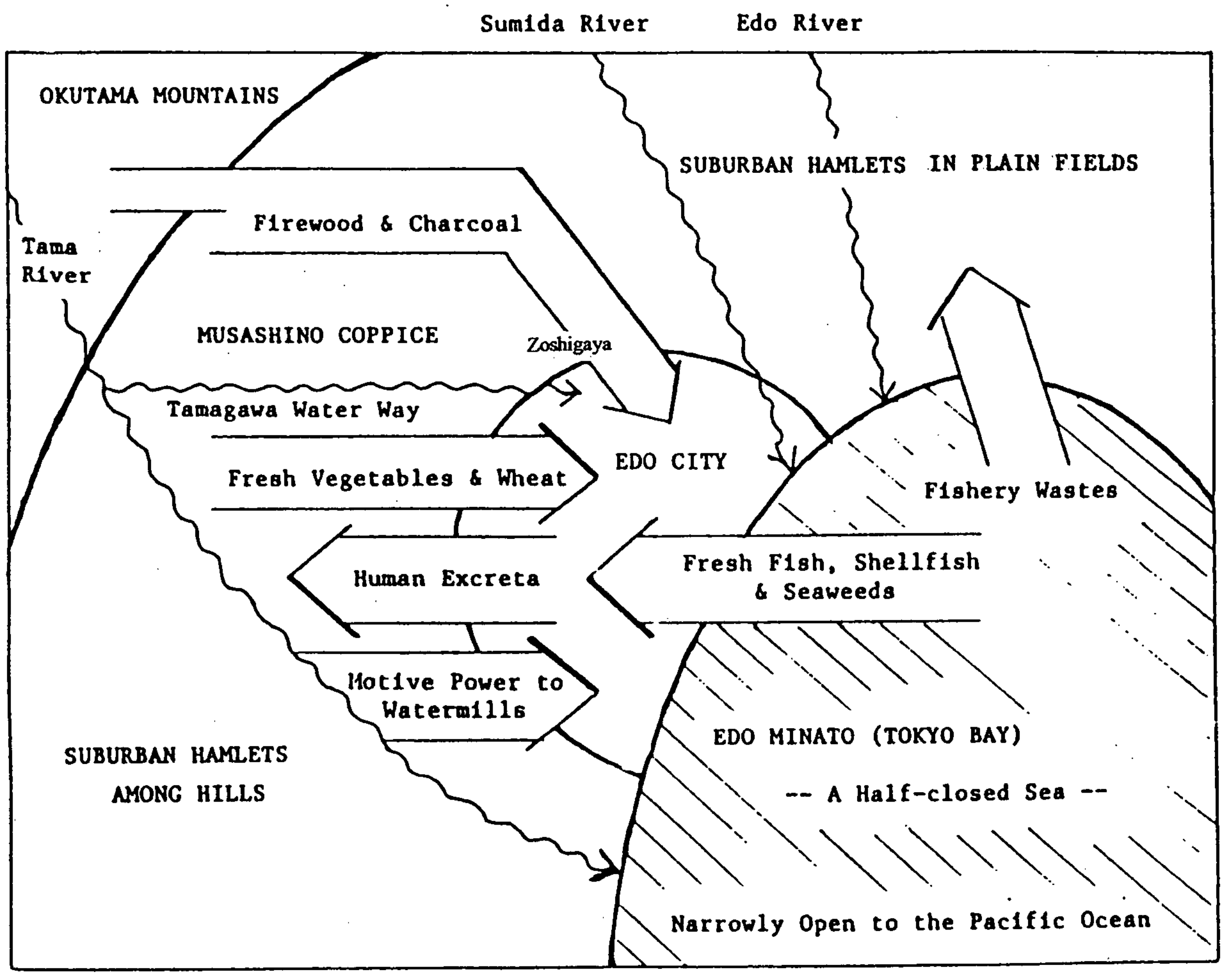
"Is 'Sustainable City' an Oxymoron?" This is the title of a journal article written by Rees (1997a). There seems to be an example where 'Sustainable City' was not an Oxymoron. The Greater Region of Edo, an old capital of Japan (now Tokyo), sustained a population of some three million people from the 17th - 19th centuries.[47] Tsuchida and Murota (1987) describe the Greater Edo Region as a typical example where ecocycle was not only maintained but also activated by the human economy in various forms. Because of activated ecocycles, high entropy matter / energy was effectively disposed of. For example,

> Tokyo Bay, a half-closed sea area, has had a tendency to [become eutrophic], resulting in great catches of [aquatic living resources, such as] fish, shellfish, and seaweeds. If Edo people did not bring them up ashore into the economy, excessive eutrophication would have forced that bay to become biologically polluted and to eventually die. People in Edo moved human excreta, and sea

[47] Here, I am not equating 'sustainable' with completely self-sufficient. I am aware that the Edo region imported a large amount of rice and other cereals from all over Japan. So, the ecological footprint of Edo region must have been larger than its geopolitical territory. By 'sustainable,' I mean that respecting the limits of biosphere's carrying capacity and even systematically and humbly facilitating enhancement of nature's productivity through recycling of nutrients and other materials.

products from geographically downstream to upstream areas, against the law of universal gravity. The latter area, in turn, provided the former with firewood and charcoal from mountains and suburban coppice, fresh vegetables, and grains from coppice-full hamlets, and hydro power to watermills whose number became astonishing large in the 19th century. (Tsuchida and Murota 1987, pp. 29-31) (see Figure 9 below.)

Figure 9 The Ecocycle of Edo and Early Tokyo Activated by the Human Economy



(This figure is a revised version of the one in Y. Tamanoi, A. Tsuchida, and T. Murota. 1984. "Towards an Entropic Theory of Economy and Ecology." *Econ. Appl.* Vol. 37, No. 2, pp. 294-298, cited in Tsuchida and Murota [1987]. p. 30.)

I am not suggesting that we revert to these pre-modern conditions. I am advocating, however, that our generation can learn much from their way of managing the human economy which was more biophysically efficient.

As discussed in Chapter 3, water and topsoil are crucial elements for ecocycles on Earth. Hydraulic cycles function as dissipative mechanism of high entropy (wasted) heat to the outer universe. Topsoil decomposes the wasted matters of plants and animals into inorganic minerals which become available again for plants and animals.

Tsuchida and Murota (1987) explored ways to enrich topsoil and to expand capability of entropy disposal and carrying capacity by enhancing material cycles between components within large ecosystems, such as human, bacteria, primary producers, herbivores and carnivores. For example, they documented the historical process of forestation in the suburban areas of Edo as a model for sustainable regional planning (see Figure 9 above). The suburban area is called Musashino, which is located in the west of Edo. It used to be a non-fertile unforested field. When people settled in and around Edo, kitchen and human waste was carried out of Edo to the adjacent vegetable growing area called Zoshigaya, which is located between Edo and Musashino. When the topsoil of the field became fertile with the inputs from kitchen and human waste, worms began to flourish. As the worms became abundant, birds gathered and flew to the west of Zoshigaya which is Musashino, where they left their droppings. Gradually Musashino became fertile land, shrubs and trees began to grow, and it eventually became a forest (Tsuchida and Murota 1987; Tsuchida 1992, 1995). (Droppings of birds are very effective fertilizer, which mainly contain ammonia nitrate). So, by using similar natural and non-industrial methods, we can increase cycles of nutrient and energy, leading to a net increase in primary production in the ecosphere, enhancing availability of essergy and increasing the entropy-disposing ability of the ecosphere (Tsuchida 1992; Murota 1995a, 1996). These ideas can be incorporated into the planning of sustainable communities and human economy.

In the meanwhile, the Research Committee on Recycling of Biological Waste, a semi-governmental advisory committee funded by the national administrative bodies such as MAFF, MITI, the Ministry of Construction, and Environment Agency, has published an interesting report (*Asahi Shimbun* 1999; *Mainichi Shimbun* 1999). The report states that the biological wastes (e.g., kitchen waste, livestock manure, sewage sludge, and food processing residues) generated in Japan amount to 280 million tonnes each year. All of these can be potentially used as compost for agricultural and other purposes. The report assures that this amount is more than enough to replace all the chemical fertilizers applied to the Japanese soils. Based on these findings, MAFF is planning to submit a bill which facilitates the recycling of livestock manure to the national Diet. This idea seems promising and feasible. However, a caution is needed. If the recycling is conducted using large amount of transportation energy, then the energy cost may exceed the benefit of energy saving of recycling these wastes (Tsuchida 1992).

6.3 Directions for Further Study

(1) Calculating Foreign Degraded Land and Aquaculture in More Details

As mentioned in Chapter 4.3, (8) Limitation of Analysis and Missing Data, the calculations in this dissertation did not fully incorporate the degraded land in foreign countries and aquatic areas to support aquaculture. These should be elaborated in the next study.

(2) Time Series Analysis of the Past Ecological Footprint

It would be useful to measure Japan's ecological footprint throughout the period of modernization. We could identify when Japan began to exceed its fair share of global carrying capacity. Parker (1998a, 1998b) calculated time-series ecological footprints of Japan from 1961 - 1995. His calculation indicated that in 1961 the ecological footprint of an average Japanese was 3.4 ha (1998b, p. 115). According to his analysis, Japan had already exceeded the total of FLS and FAS of that time, namely 1965, which he calculated to be 3.0 ha/capita (1998a, p. 5).

Allow *et al.* (1995) reported that there is an inverse U-shaped relationship between emission of some pollutants and per capita income. (This curve is called 'environmental Kuznets curve.') They also found that this model does not apply to certain substances such as CO_2, etc. Indeed, the inverted U-shaped curve has been observed by other authors. For example, the Metropolitan Environment Improvement Program (1994) funded by the World Bank and the United Nations Development Program states that ambient air quality has shown some improvement over the time as Japan gained economic power, in terms of levels of SO_2, CO, and Suspended Particulate Matter (SPM) (pp. 23-

24). It would be interesting to examine the relationship between increase in per capita income and ecological footprint through time-series analysis.

(3) Reassessing "Success Stories" at Various Levels

As we discussed the implications of the second law of thermodynamics, we realized that behind the 'positive pictures' of production, 'negative pictures' always occur. However, when we think of 'success stories,' we seldom think of the negative side of these successes. For example, the semiconductor industry is booming in many parts of the world, such as in Silicon Valley of California, in Japan and Taiwan. Despite the apparently 'clean' image of this high-tech industry, it is becoming evident that it is in fact a 'polluting' industry (Yoshida 1994, pp. 96-112). Ecological footprinting is a powerful tool for revealing negative aspects of the successes.

(4) Reassessment of Traditional Technologies and Management Systems by EF

Not only Edo, but also Japan, the country as a whole, had enjoyed a long history of sustainable living within our ecological limits up until one hundred years ago. Today, some tradition still survives in many of the rural areas in Japan in the forms of taboos and customary rules and practices with respect to communal natural resources use. Some traditional environmentally-friendly technologies still survive in some parts of Japan. For example, water and wind mills are being used for many purposes in Japan. These traditions are being rediscovered and documented by Japanese scholars, particularly by researchers who belong to the Society for Studies on Entropy who have explored many aspects of traditional wisdom especially from the viewpoint of entropy and ecocycles. For example:

- use of wild bird's droppings for reforesting mountains and fields and restoring farmland, suggested by Banzan Kumazawa, a feudal state bureaucrat and scholar in Okayama, specializing in resource policies in the 17th century (Murota 1985, 1989, 1991a, 1999b);

- water-soil matrix suggested by Join Shaku, Buddhist priest in the 18th century, who argued that regional water-land systems should be a crucial component in policy formation and decision-making (Murota 1989);

- sustainable energy use through recycling wax residues in Edo (Ishikawa 1993);

-sustainable coral reef fisheries management in Shiraho, Okinawa (Tabeta 1990);

- water and wind mill technologies (Murota 1985; Kouno 1997; Ushiyama 1997); and,

- charcoal production technologies (Murota 1985).

We could compute the ecological footprint of these traditional technologies and management styles comparing with apparently more efficient modern industrial technologies.

(5) Assessing EF of Alternative Life Styles

It would be very interesting to assess the ecological footprints of alternative life styles of such groups of people as the Amish, and of First Nations in North America and other parts of the world. We also need to study what conditions make it possible for them to maintain such lifestyles, despite the strong force of the globalization of the market economy.

(6) Assessing Values of Disarmament Through EF

War is not only one of the most uncivilized behaviors but also the most environmentally destructive. It is urgent to seriously consider ways to avoid military conflicts and ways to re-allocate financial resources from armament to welfare and natural capital restorations. In order to provide a powerful rationale for this endeavor, an assessment of military equipment and operations through ecological footprint analysis should be conducted.

(7) Learning More About Dynamics of Ecocycles

We urgently need to discover unknown mechanisms of ecocycles which have been disturbed by excess human intervention in recent years. By ecocycles, I mean the cycles of materials such as nitrogen (N), phosphorus (P), potassium (K), carbon (C), and water (H_2O) carried by ecosystems like salmon, etc. For example, the role of salmonid for transporting phosphorus and other nutrients back into upstream forests is being studied by such scholars as Sibatani (1986) and Murota (1997a, 1997b, 1999b) in Japan, Cederholm *et al.* (1986) and Bilby *et al.* (1996) in Washington State of the United States, and Johnston (1997) in B. C., Canada (Murota 1997a).

The purpose of the these studies is to find out ways to restore disturbed, stagnated or intercepted ecocycles which have lost the capacity to contribute to accumulating essergy and disposing high entropy wastes. As we have learned from entropy theory, restoration of ecocycles back into normal is a key to achieve a sustainable global environment (Murota 1997b). I believe that studying the mechanism of ecocycles as well as finding out how to restore the weakened or stagnated ecocycles is one of the most important fields for further research in ecological economics.

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Appendices

A. Excerpt from Tsuchida, Atsushi and Takeshi Murota. 1987. "Fundamentals in the Entropy Theory of Ecocycle and Human Economy." pp. 14-23. in G. Pillet, and T. Murota, eds. *Environmental Economics - The Analysis of Major Interface.* Geneva: R. Leimgruber.

B. Spreadsheet of Ecological Footprint Calculation of the Japanese Resources Consumption Associated with Agricultural Land (Cropland and Pasture Land)

C. Spreadsheet of Ecological Footprint Calculation of the Japanese Resources Consumption Associated with Forest Land

D. Spreadsheet of Ecological Footprint Calculation of Living Aquatic Resources Consumption by the Japanese

E. Technological Fix Scenarios

Appendix A

Excerpt from Tsuchida, Atsushi and Takeshi Murota. 1987.
"Fundamentals in the Entropy Theory of Ecocycle and Human Economy." pp. 14-23.

In the next two sections, we present the quantitative analysis of entropy disposal in the ecocycle.

III. *ENTROPY ACCOUNT OF PHOTOSYNTHESIS*

Plants are in the position of basic producer in the ecosystem. They grow on photosynthesis. Then, we start our entropy analysis from the one for photosynthesis. According to the standard way of describing the photosynthesis, we write the chemical equation:

(1) $$6CO_2 + 6H_2O + (\text{sunlight}) = C_6H_{12}O_6 + 6O_2$$

which shows that one mol of glucose and 6 mols of oxygen gas are produced by the expenses of 6 mols of carbon dioxide gas and of 6 mols of liquid water under the help of sunlight.

TABLE I. Entropy Values of the Matters Related to Photosynthesis and Combustion or Respiration under Standard State of 25 ^{o}C and 1 atm and Other States; (cal/deg/mol).

Matter	Standard Entropy	Entropy in Other States
CO_2	51.1	67.2 (300 ppm)
$H_2O(l)$	16.7	
$H_2O(g)$	45.1	52.1 (saturated vapor)
O_2	49.0	52.1 (21 % composition)
$[CH_2O]$ (glucose)	8.5	

Note. Values of standard entropy are taken from Nihon Kagakukai [The Chemical Association of Japan] (ed.). *Kagaku Binran - Kaitei San Ban [Table of Chemistry - Revised 3rd Ed.]*, Maruzen, Tokyo, 1984.

For the brevity of notation, we rewrite Equ. (1), by normalizing it for one mol of carbon dioxide, into the following form:

(2) $$CO_2(g) + H_2O(l) + \epsilon = [CH_2O] + O_2(g)$$

with $\epsilon = 111.7$ kcal/mol

where the symbols *(g)* and *(l)* after molecule formulae imply that the molecule in question is in either gaseous or liquid form, respectively, ϵ stands for the energy obtained from the sunlight, and $[CH_2O]$ means one-sixth mol of glucose. Note that CO_2 in (2) exists in the atmosphere at the density of 300 ppm and that O_2 in (2) is of 1 atm (atmospheric pressure).

Using the entropy values of principal molecules given in Table I, we can compute the magnitudes of entropy for both left- and right-sides of Equ. (2). For our tentative purpose at this stage, we assume that the entropy of sunlight is zero. Then, the results of computation are summarized in Table II. It shows that the process described by Equ. (2) is of net entropy decrease. From this, do we have to derive a conclusion that the photosynthesis is an exception of the law of entropy increase (i.e., the Second Law of thermodynamics)?

TABLE II. Entropy Account of Photosynthesis in Equation (2); (cal/deg/mol).

	Inputs	Outputs	Net Output
Matter and Energy	$CO_2+H_2O(l)+\epsilon$	$[CH_2O]+O_2$	Zero in Matters Zero in Energy
Entropy	CO_2 67.2 $H_2O(l)$ 16.7	$[CH_2O]$ 8.5 O_2 49.0	
Entropy Total	83.9	57.5	- 26.4 (Net Entropy Decrease)

Note. The entropy of light is assumed to be zero.

Of course not. One easy wayout from the dilemma of the seemingly entropy decrease in photosynthesis against the universal law of entropy increase is to assume the presence of something negative in entropy at the left hand side of Equ. (2). Schrödinger was one of them, or perhaps the first one who thought out a peculiar idea of the negative entropy of sunlight to counter the dilemma [6]. This idea, which had appeared in the first edition of his previously mentioned book, is still supported by many people. But it is not correct. The sunlight carries the positive entropy corresponding to its temperature (more exactly, absolute temperature) over to the Earth surface. If the negative entropy is carried over with it at the same time, only a logical confusion remains. In what follows, we demonstrate the correct way of approaching to the question.

Photosynthesis proceeds as the entropy increases in the form of thermalization of light. (Note that the light here does not necessarily have to be the sunlight. Artificial light with appropriate wave length *does* induce photosynthesis.) It is expressed by the chemical formula:

(3) $CO_2(g) + H_2O(l) + \epsilon' = [CH_2O] + O_2(g) + q$

with $\epsilon' = \epsilon + q$,

where ϵ' stands for the amount of energy of light inflow and q for the amount of generated heat in photosynthesis. If this heat generation is left alone, the body temperature of a plant rises. When it goes up above 30 ^{o}C, the plant stops a photosynthetic process. To evade such a situation, a plant usually removes the heat through transpiration of water. The formula of evaporation:

(4) $H_2O(l) + q_0 = H_2O(g)$

with q_0 = 10.5 kcal/mol

is well known.

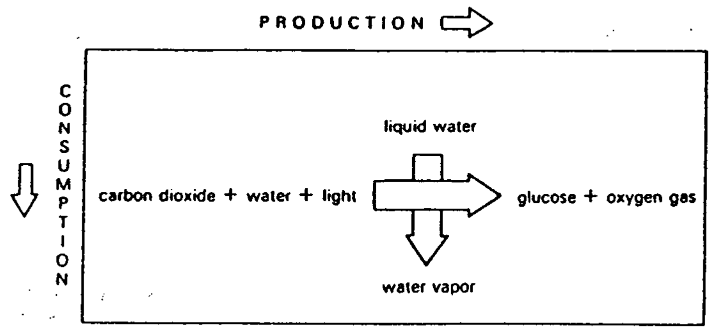

Fig. 2 – *Production and Consumption in Photosynthesis.*
Note. Entropy decreases along a horizontal move from the left to the right, and it increases along a vertical move from the top to the bottom.

By combining (3) with (4), we obtain Fig. 2 and the following equation:

(5) $CO_2(g) + (n+1)H_2O(l) + \epsilon' = [CH_2O] + O_2 + nH_2O(g) + q$

with $\epsilon' = \epsilon + q = \epsilon + nq_0$,

where one mol of $H_2O(l)$ is understood as a part of raw materials for glucose production and n mols of $H_2O(l)$ are the low entropy source for driving photosynthesis as an entropy increasing process.

Katsuki presented a preliminary attempt of deriving an entropy account of photosynthesis, and computed out that at least 4 mols of water is necessary for the production of one mol of glucose in order for it to be of non entropy-decreasing [7]. In our formulation for one sixth mol of glucose, his result corresponds to n = 4/6. But an actual process of photosynthesis seems to transpirate much more water. Then, we investigate this problem in more detailed manner.

The optimal wave length λ for photosynthesis is known to be about 0.65 micron. With such wave length, 8 mols of photons per one mol of carbon dioxide make photosynthesis practically possible. The energy of such photons is 44 kcal/mol. Hence, we get $\epsilon' = (8)(44) = 352$ kcal/mol. The requirement of Equ. (5) is $\epsilon' = \epsilon + nq_0$, which now reads:

(6) $352 = 111.7 + 10.5\ n.$

Solving this equation for n, we obtain n = 22.9. Using this value of n and other numerical data, we reach the entropy account of this optimal case of photosynthesis under the monochromatic light of wave length λ = 0.65 micron, which is summarized in Table III. Our result shows that the net entropy output of this case is strictly positive.

Next, we investigate the photosynthesis under the real sunlight. In this case, the necessary amount of sunlight widely varies depending on a species of the plant under consideration, and on many other environmental conditions. For our preliminary purpose, then, we assume that its amount ϵ' is 50 times as large as the combustion heat ϵ of $[CH_2O]$. This assumption corresponds to the standard case of outdoor plant growth. Kawamiya already tackled this problem [8]. Based on his analysis, we present an improved, refined result. In the same way as his, we first set he equation:

(7) $(50)(111.7) = 5{,}585 = 50\ \epsilon' = \epsilon + nq_0 = 111.7+10.5\ n$ (kcal/mol)

with n being unknown. Solving this equation for n, we get n = 521.3.

The precise value of entropy of the sunlight is also in need, free from the misleading concept of negative entropy. When the Sun emits the light, it simultaneously emits the entropy corresponding to the surface temperature of the Sun. But such sunlight degrades inside the atmosphere of the Earth due to the dirtiness of it and to other reasons. Since it is known that experimental solar furnaces of the best kind can harness the solar heat at the level of 3,000 ^{o}K, we define this as the effective temperature T_e of sunlight on the Earth, and assume that plant leaves receive the sunlight at this temperature level.

TABLE III. Entropy Account of the Photosynthesis under an Optimum Condition with the Monochromatic Light of Wave Length λ = 0.65 micron; (cal/deg/mol).

	Inputs	Outputs	Net Output
Matter and Energy	$CO_2+(n+1)H_2O(l)+\epsilon'$	$[CH_2O]+O_2+nH_2O(g)$	Zero in Matters Zero in Energy
Entropy	CO_2 67.2 $(n+1)H_2O(l)$ 399.1	$[CH_2O]$ 8.5 O_2 49.0 $nH_2O(g)$ 1,193.1	
Entropy Total	466.3	1,250.6	+ 784.3 (Net Entropy Increase)

Note. The computation is based on the values: ϵ' = 352 kcal/mol and n = 22.9. The entropy of light is also assumed to be zero in this Table.

Then, we arrive at the entropy account of the sunlight-driven photosynthesis in the form of Table IV. It clearly shows the net entropy increase again. Therefore, such a process can proceed in accord with the universal law of entropy increase.

In Table IV, (n+1) mols, i.e., 522.3 mosl of $H_2O(l)$ is the amount of water necessary for the fixation of one mol of CO_2. Most of this much of water is used for the disposal of the thermally degraded heat of solar energy. This model coincides with Kawamiya's which claims $(n+1)H_2O/[CH_2O]$ = 320 by assuming that cooling is made by water alone. However, disposal of such heat does not have to be made by water alone. Some part of it can be made by air. If we set up a model in which 80%

of the coolant are water and the remaining 20% of it are air, we can work out the required amount of water to produce one gram of glucose as:

(8) $0.8(n+1)H_2O/[CH_2O] = 250.$

TABLE IV. Entropy Account of the Photosynthesis by the Sunlight; (cal/deg/mol).

	Inputs	Outputs	Net Output
Matter and Energy	$CO_2+(n+1)H_2O(l)+\epsilon'$	$[CH_2O]+O_2+nH_2O(g)$	Zero in Matters Zero in Energy
Entropy	CO_2 67.2 $(n+1)H_2O(l)$ 8,772.4 ϵ'/T_e 1,816.7	$[CH_2O]$ 8.5 O_2 49.0 $nH_2O(g)$ 27,159.7	
Entropy Total	10,651.7	27,217.2	+ 16,565.5 (Net Entropy Increase)

Note. $\epsilon' = 50\ \epsilon = 5{,}585$ kcal/mol, n = 521.3, and $T_e = 3{,}000\ ^oK$, where T_e is the effective temperature of the sunlight on the Earth surface.

This result derived from our theoretical entropy calculus corresponds quite well to the often quoted experimental results, which show that plants transpirate water by 200-400 times as much as the photosynthetic products. Table V lists the observed data of transpiration ratios of several broad-leaved and needle-leaved trees.

Among the land plant species, there are some plants whose photosynthesis is made by air coolant rather than by water coolant. A typical example is the cactuses in deserts. Their photosynthesis is made in early morning. In the daytime, it is barely done in spite of the abundant sunlight. In such cases, plant growth is very slow. For the photosynthesis by air coolant is very difficult, while not impossible.

This observation leads us to recognize the crucial importance of water.

TABLE V. Transpiration Ratios for Selected Kinds of Trees in Growing Period; (Transpirated Water/ Dry Weight Production).

Tree Name	Average Transpiration Ratio
Birch	375
Ash	244
Alder	227
Oak	220
Beech	220
Average of Broad-Leaved Trees	257
Larch	213
Plains Pine	209
Mountain Pine	208
Spruce	193
Fir	145
Average of Needle-Leaved Trees	194

Note. The ratios in this Table are taken from F. YAMAZAKI. Mizu no Junkan ni tsuite no Memo [Series of Memoranda on Water Cycle]. *Dojo Joka Shisutemu [Soil Purification Systems]* 10 (3), 2-5, 1985.

IV. *ENTROPY ANALYSIS OF DECOMPOSITION AND ECOCYCLE AS A WHOLE*

Now that the entropy analysis of photosynthesis with transpiration being its driving force has been complete, we proceed to investigate the essential role of decomposition in the ecosystem and to make its entropy analysis.

If there exist only plants and green microbes on the Earth, then they continue their photosynthetic reactions, and eventually exhaust up the carbon dioxide in the atmosphere to result in the termination of their existence as living creatures. It is a widely accepted theory that in the olden times the density of carbon dioxide in the atmosphere was very high on the Earth as in the present case of other planets, but that such a large amount of carbon dioxide was fixed as coal reserves in the ground to maintain its low density state of some 300 ppm thereafter. Our above observation exactly corresponds to this theory.

But it must not be forgotten that on the Earth there exist animals and topsoil (collection of non-green microbes) which disintegrate and decompose, by using the oxygen gas of 0.21 atm, organic matters into the carbon dioxide gas of 1 atm and water. As shown in Table VI, this decomposition reaction is of an entropy increasing process, so that it can proceed from the entropy-theoretic viewpoint. As a result, the Earth allows th existence of the important cycle which is illustrated in Fig. 3. We name this cycle the *ecocycle* as a subsystem of the Earth system including human societies. This ecocycle, with one year being a period, circulates by taking up the sunlight and liquid water and by transforming them into heat and water vapor.

TABLE VI. Entropy Account of the Decomposition of Organic Matters; (cal/deg/mol).

	Inputs		Outputs		Net Output
Matter and Energy	$[CH_2O]+O_2$		$CO_2+H_2O(g)+\epsilon$		Zero in Matter Zero in Energy
Entropy	$[CH_2O]$	8.5	CO_2	51.1	
	O_2	52.1	$H_2O(g)$	16.7	
			ϵ/T_0	374.6	
Entropy Total		60.6		442.4	+ 381.8 (Net Entropy Increase)

Note. ϵ = 111.7 kcal/mol and T_0 = 298.15 °K.

Under the assumption that the sunlight reaches a plant and that 80% of it go into the water vaporization while the remaining 20% of it are conveyed to air, Table VII shows the entropy account associated with each revolution of the ecocycle. In this, each mol of carbon dioxide gas of 300 ppm is fixed as organic matters by photosynthesis and they, in turn, are decomposed into carbon dioxide gas of 1 atm at first, and furthermore diffused into the carbon dioxide gas of the initial state of 300 ppm. This completes our analysis of the ecocycle.

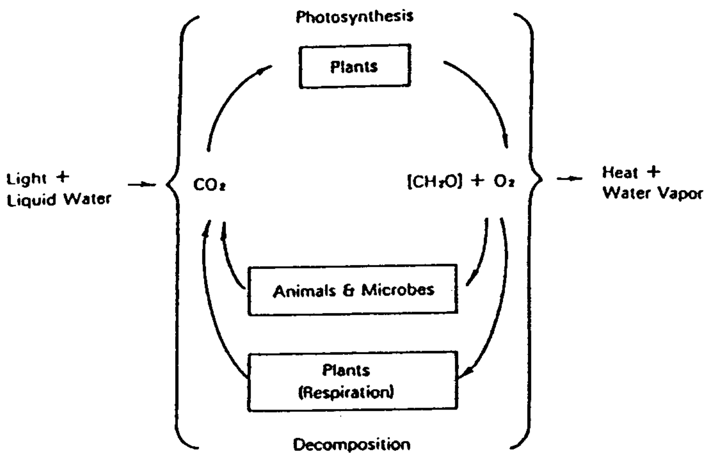

Fig. 3 - *Ins, Outs, and the Inside of the Ecocycle.*

TABLE VII. Entropy Account of the Ecocycle by Each Revolution; (The computation is normalized to one mol of CO_2).

	Inputs	Outputs	Net Output
Water and Energy	$mH_2O(l)+\varepsilon'$	$mH_2O(g)+0.2\varepsilon'$	Zero in Water Molecules Zero in Energy
Entropy	$mH_2O(l)$ 7,105.9 ε'/T_e 1,861.7	$mH_2O(g)$ 22,126.0 $0.2\varepsilon'/T_o$ 3,746.7	
Entropy Total	8,967.6	25,872.7	+ 16,905.1 (Net Entropy Increase)

Note. m = 425.5, T_e = 3,000 °K, and T_o = 298.15 °K.

As one can see from Table VII, this ecocycle circulates to generate the entropy amounting to 16,905 kcal/deg/mol. Accordingly, it emits 425.5 mols of water vapor and 1,117 kcal of heat into the atmosphere. These emissions constitute a part of the water cycle as well as the air cycle as convection in the sense of the present authors' other works [9]. Surplus entropy disposal is undertaken by those cycles, as is quantitatively demonstrated in the new theory of the water planet Earth as an open steady system given in such recent works.

Then, what is the position of human beings in the ecocycle? In what follows, we consider this question both in its disruptive and creative aspects, with an emphasis being on the experiences in Japan.

Appendix B
Spreadsheet of Ecological Footprint Calculation of the Japanese Resources Consumption Associated with Agricultural Land (Cropland and Pasture Land)

Ecological Footprint of Consumption of An Average Japanese - Agricultural Land (Cropland and Pasture Land)

Yoshihiko Wada, UBC School of Community & Regional Planning, December 17, 1996

1990data Categories	Items	Mass Harvested by Japanese facilities (1,000tonnes)	Mass Exported from Japan to abroad (1,000tonnes)	Mass Imported from abroad (1,000tonnes)	Mass TOTAL Consumption by Japanese (1,000tonnes)	Agricultural Land Area for Production *Domestic* (1,000 ha)	Agricultural Land Area for export production *export* (1,000 ha)	Agricultural Land Area for Production *Imported* (1,000 ha)	Agricultural Land Total to support Japanese Consumption (1,000 ha)	Agricultural Land Per Capita (ha)
A: Cropland										
Vegetarian food, flower & industrial products										
food	rice	10,499	0.016	18	10,517	2,074	0.003	6	2,080	0.017
	other cereals(human consumption)	1,302	348	10,233	11,187	399	98	3,466	3,767	0.031
	potatoes & sweet potatoes	4,954	1.2	147	5,100	176	0.05	10	186	0.002
	elephant foot (kon'nyaku-imo)	89	0	*26*	115	11	0	3	14	0.0001
	pulses (beans)	409	0	177	586	257	0	143	400	0.003
	vegetables	14,508	1.6	1,001	15,507	625	0.1	43	668	0.005
	orchard fruits	4,727	27	1,835	6,560	346	2	134	478	0.004
product	tea	413	0.3	14	427	59	0.04	2	61	0.0005
	coffee	*0*	*1*	*310*	*309*	0	0	535	535	0.004
	cocoa	*0*	*3*	*87*	*84*	0	0	228	228	0.002
	alcohol (1,000 kilo litres)	*9,493*	*37*	*343*	*380*		5	49	44	0.0004
	sugar beet&cane	5,977	21	25,085	31,041	111	0.4	468	578	0.005
	(sugar&honey&sweets)	*898*	*8*	*2,311*	*3,201*					
	seed for oil prod.	1.7	0.7	6766	6,767	0.9	0.4	3,921	3,921	0.032
	(vegetable oils)	*1,721*	*4*	*440*	*2,157*	*0*	9	1,001	992	0.0080
	tobacco	81	4.6	116	192	30	2	43	71	0.0006
	flowers (incl.bulbs)	189	0.3	12	201	9	0.02	0.6	10	0.00008
	rush (igusa)	90	0	8	98	9	0	0.8	10	0.0001
	natural rubber	*0*	*0.08*	*676*	*676*	0	0.04	375	375	0.0030
textile	mulberry					60			60	0.0005
	cocoon,silk	*25*	*0*	*11*	*36*	0	0	25	25	0.00020
	cotton	*0*	*99*	*1234*	*1,135*	0	229	2,862	2,633	0.021
Meat, dairy products and eggs										
	animal meat	*2,146*	*8*	*1,246*	*4,193*					
	beef			*490*	*490*					
	pork			*352*	*352*					
	poultry			*301*	*301*					
	others (sheep, horse,etc.)			*103*	*103*					
	dairy products	*8,189*	*23*	*233*	*8,399*					
	eggs	*2,419*	*0*	*13*	*2,432*					
	animal oils, fat	*325*	*4*	*126*	*447*					
Feed crops needed to produce Domestic meat, dairy products and eggs							8.1			
	feed & forage crops	9,887	0	17,682	27,569	184	0	6,563	6,748	0.055
	(except grass)									
	Imported wheat			1,056				476		
	Imported barley			1,256				554		
	Imported corn			11,753				3,189		
	Imported sorghum			3,617				2,344		
	other feed materials	4,836	177	4,890	9,549	0	0	0	0	0.000
	(except grass and grains)									
Feed crops needed to produce Foreign meat, dairy products & eggs					12,258			4,152		
	For animal meat			11,986	11,986			4,060	4,060	0.033
	beef			7,840						
	pork			2,110						
	poultry			903						
	others (sheep, horse,etc.)			1,133						
	For daily products			233	233			79	79	0.001
	For eggs			39	39			13	13	0.00011
Other crops						90	0	0	90	0.001

	Cropland Domestic Total	Cropland Exported land total	Cropland Abroad Total	Cropland Total	Cropland Per Capita (ha)
A: Total of Cropland	**4,441**	**355**	**24,031**	**28,117**	**0.23**
	(1,000 ha)	(1,000 ha)	(1,000 ha)	(1,000 ha)	(ha)

Categories	Items	Mass Harvested by Japanese facilities (1,000tonnes)	Mass Exported from Japan to abroad (1,000tonnes)	Mass Imported from abroad (1,000tonnes)	Mass TOTAL Consumption by Japanese (1,000tonnes)	Agricultural Land Area for Production *Domestic* (1,000 ha)	Agricultural Land Area for export production *export* (1,000 ha)	Agricultural Land Area for Production *Imported* (1,000 ha)	Agricultural Land Total to support Japanese Consumption (1,000 ha)	Agricultural Land Per Capita (ha)
B: Pasture Land										
grass	**grass from pasture for domestically**	34,060	0	205	34,265	838	0	39	876	0.007
	animal meat	*2,146*	*8*		*2,138*		0.04		0	0.000000
	dairy products	*8,189*	*23*		*8,166*		1.58		-2	-0.000013
	eggs	*2,419*	*0*		*2,419*		0		0	0.0000
	animal oils, fat	*325*	*4*		*321*					
	grass needed to produce Foreign meat, dairy products & eggs									
	animal meat			36,541				8,030	8,030	0.065
	beef			29,316				6,442	6,442	0.052
	pork			381				84	84	0.001
	poultry			54				12	12	0.000
	others (sheep, horse,etc.)			6,790				1,492	1,492	0.012
	dairy products			456				100	100	0.0008
	eggs			2				1	1	0.000004
textile	wool	*0*	*18*	*195*	*177*	0	1,289	13,746	12,458	0.101

	Pasture Land Domestic Total	Pasture Land Exported land Total	Pasture Land Abroad Total	Pasture Land Total	Pasture Land Per Capita (ha)
B: Total of Pasture Land	**838**	**1,290**	**21,916**	**21,463**	**0.17**
	(1,000 ha)	(1,000 ha)	(1,000 ha)	(1,000 ha)	(ha)

	Agricultural land Domestic Total	Agricultural land Exported land Total	Agricultural land Abroad Total	Agricultural land Total	Agricultural land Per Capita (ha)
A & B: Total of Cropland & Pasture Land	**5,279**	**1,645**	**45,947**	**49,580**	**0.40**
	(1,000 ha)	(1,000 ha)	(1,000 ha)	(1,000 ha)	(ha)

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Appendix C
Spreadsheet of Ecological Footprint Calculation of the Japanese Resources Consumption Associated with Forest Land

Ecological Footprint of Consumption of An Average Japanese -Forest Land

Yoshihiko Wada, UBC School of Community & Regional Planning, June 15, 1995

1990 data					f.1. Forest land	f.2. Forest land	f.3. Forest land	f.t.Forest land	f.t.Forest land	Mass of
Items	Volume,Mass	Volume,Mass	Volume,Mass	Volume,Mass	Land Area	Land Area	Land Area	Total	Per Capita	Net Import
	Harvested	Exported	Imported	TOTAL	for	for	for			
	in Japanese	from Japan	from	Consumption	Production	Production	Production			
	forest	to abroad	abroad		*Domestic*	*Exported*	*Imported*			
					(1,000 ha)	(1,000 ha)	(1,000 ha)	(1,000 ha)	(ha)	(cubic meters)
Forest Product	(cubic meters)	(cubic meters)	(cubic meters)	(cubic meters)						
logs(excl. logs for pulp)	19,986,000	110,000	51,972,000	**71,786,000**	6,798	37	6,348	13,108		51,862,000
logs for pulp production	11,309,000	62,000	29,973,000	**41,282,000**	3,826	21	3,661	7,465		29,911,000
Total	31,295,000	172,000	81,945,000	**113,068,000**						
	(tonne)	(tonne)	(tonne)	(tonne)						
logs(excl. logs for pulp)	10,392,720	57,200	27,025,440	37,328,720						
logs for pulp production	5,880,680	32,240	15,585,960	21,466,640						
	(tonne)	(tonne)	(tonne)	(tonne)						(1,000tonnes)
pulp	0	0	2,894,484	2,894,484	0	0	1,898	1,898		2,894,484
paper	0	1,203,555	1,231,329	27,774		729	782	53		27,774
28,999	0.062	0.39	0.024		d.1.Forest land	d.2.Forest land	d.3.Forest land	Forest land	Forest land	**29,890,498**
9,082	0.019	0.14	0.003		*Domestic*	*Exported*	abroadTotal	Total	Per Capita(ha)	(1000 tonne)
20,252	0.043	0.06	0.003		(1,000 ha)	(1,000 ha)	(1,000 ha)	(1,000 ha)	(ha)	
411,964	0.876	0.98	0.858		10,623	788	12,689	**22,524**	**0.18**	
					21,145					
470,297	1.000		**0.888**		(million km2)	(million km2)	(million km2)	(million km2)		
(proportion of tropical timber within total imports of forest products)					0.11	0.01	0.13	0.23		
					Per Capita(ha)	Per Capita(ha)	Per Capita(ha)	Per Capita(ha)		
					0.09	0.01	0.10	0.18		
	Mass (wet weight (tonne))				PPR (biomass wet weight (tonne))					
	16,273,400	**1,292,995**	**46,737,213**	**61,717,618**	**31,870,408**	**2,363,493**	**45,679,259**	**81,087,558**		

Appendix D
Spreadsheet of Ecological Footprint Calculation of Living Aquatic Resources Consumption by the Japanese

Ecological Footprint of Japan's Living Aquatic Resources Consumption

1990 Data — Calculated by Yoshihiko Wada and Steve Latham, The University of British Columbia, Vancouver, BC, Canada, June 15, 1995

Eco-system	FAO Category	FAO code	Catch (tonne)	Imports (tonne)	Exports (tonne)	Total Cons. (tonne)	Discards (tonne)	Cons.+Disc (tonne)	TL-1	PPR (primary productivity required) ((wet wt)/9)*10^(TL-1) (Carbon tonne)	Primary Produc. of aquatic area (gC/m2/yr)	(tC/ha/yr)	Ecol. Footprint (EF) (ha)	EF/capita ha/capita	Eco-system	Per capita EF by eco-system (ha/capita)	Per capita discard EF by eco-system (ha/capita)
oos	krill	46	68,996	0	0	68,996	13,799	82,795	1.2	145,802	103	1.03	141,555	0.00115	oos	1.11743	0.22349
oos	tunas, bonitos, billfishes	36	512,966	212,073	52,864	672,174	134,435	806,609	3.2	142,043,284	103	1.03	137,906,101	1.11629	oos		
us	herrings, sardines, anchovies	35	2,039,867	23,307	27,228	2,035,945	307,428	2,343,373	1.6	10,365,706	973	9.73	1,065,335	0.00862	us	0.02200	0.00332
us	jacks, mullets, sauries	34	492,740	3,391	182	495,948	74,888	570,837	2.2	10,052,389	973	9.73	1,033,134	0.00836	us		
us	mackerels, snoeks, cutlassfishes	37	114,613	21,623	9,787	126,449	19,094	145,543	2.3	3,226,623	973	9.73	331,616	0.00268	us		
us	squids, cuttlefishes, octopuses	57	61,955	77,209	1,085	138,079	20,850	158,929	2.2	2,798,726	973	9.73	287,639	0.00233	us		
ts	shads	24	0	3,391	183	3,208	978	4,186	1.8	29,347	310	3.10	9,467	0.00008	ts	0.22495	0.06861
ts	herrings, sardines, anchovies	35	1,253,611	23,307	27,228	1,249,690	381,155	1,630,845	1.8	11,433,263	310	3.10	3,688,149	0.02985	ts		
ts	flounders, halibuts, soles	31	9,910	31,948	182	41,675	12,711	54,386	2.5	1,910,923	310	3.10	616,427	0.00499	ts		
ts	redfishes, basses, congers	33	37,620	57,846	182	95,284	29,062	124,345	2.5	4,369,048	310	3.10	1,409,370	0.01141	ts		
ts	miscellaneous marine fishes	39	197,296	3,391	182	200,504	61,154	261,658	2.5	9,193,729	310	3.10	2,965,719	0.02401	ts		
ts	jacks, mullets, sauries	34	163,631	3,391	182	166,839	50,886	217,725	2.3	4,826,876	310	3.10	1,557,057	0.01260	ts		
ts	mackerels, snoeks, cutlassfishes	37	48,515	21,623	9,787	60,351	18,407	78,758	2.3	1,746,030	310	3.10	563,236	0.00456	ts		
ts	tunas, bonitos, billfishes	36	219,842	94,279	22,839	291,283	88,841	380,124	3	42,236,035	310	3.10	13,624,527	0.11028	ts		
ts	squids, cuttlefishes, octopuses	57	278,796	77,209	1,085	354,920	108,251	463,171	2.2	8,156,410	310	3.10	2,631,100	0.02130	ts		
ts	sea-spiders, crabs	42	20,208	34,974	349	54,832	16,724	71,556	1.6	316,521	310	3.10	102,104	0.00083	ts		
ts	lobsters	43	380	9,079	182	9,277	2,830	12,107	1.6	53,553	310	3.10	17,275	0.00014	ts		
ts	squat-lobsters	44	0	3,391	182	3,208	979	4,187	1.6	18,520	310	3.10	5,974	0.00005	ts		
ts	shrimps, prawns	45	11,191	74,454	182	85,462	26,066	111,528	1.7	621,071	310	3.10	200,345	0.00162	ts		
ts	miscellaneous marine crustaceans	47	0	3,391	182	3,208	979	4,187	1.6	18,520	310	3.10	5,974	0.00005	ts		
ts	miscellaneous aquatic invertebrates	77	19,291	5,619	182	24,728	7,542	32,270	1.6	142,742	310	3.10	46,046	0.00037	ts		
ts	sharks, rays, chimaeras	38	16,373	3,391	1,084	18,679	5,697	24,376	2.6	1,078,261	310	3.10	347,826	0.00282	ts		
nts	cods, hakes, haddocks	32	1,120,865	56,301	947	1,176,218	518,712	1,694,931	2.8	118,825,432	310	3.10	38,330,785	0.31027	nts	0.48754	0.21501
nts	redfishes, basses, congers	33	175,823	57,846	182	233,487	102,968	336,455	2.4	9,390,396	310	3.10	3,029,160	0.02452	nts		
nts	jacks, mullets, sauries	34	295,646	3,391	182	298,854	131,795	430,649	2.8	30,191,242	310	3.10	9,739,110	0.07883	nts		
nts	herrings, sardines, anchovies	35	407,903	23,307	27,228	403,981	178,156	582,137	2	6,468,191	310	3.10	2,086,513	0.01689	nts		
nts	miscellaneous marine fishes	39	154,073	3,391	182	157,282	69,361	226,643	2.2	3,991,162	310	3.10	1,287,472	0.01042	nts		
nts	sea-spiders, crabs	42	20,208	34,974	349	54,832	24,181	79,013	1.3	175,169	310	3.10	56,506	0.00046	nts		
nts	lobsters	43	380	9,079	182	9,277	4,091	13,368	1.3	29,637	310	3.10	9,560	0.00008	nts		
nts	squat-lobsters	44	0	3,391	182	3,208	1,415	4,623	1.3	10,249	310	3.10	3,306	0.00003	nts		
nts	shrimps, prawns	45	11,191	74,454	182	85,462	37,689	123,151	1.3	273,020	310	3.10	88,071	0.00071	nts		
nts	horseshoe crabs	75	0	3,391	182	3,208	1,415	4,623	1.3	10,249	310	3.10	3,306	0.00003	nts		
nts	miscellaneous aquatic invertebrates	77	19,291	5,619	182	24,728	10,905	35,633	1.3	78,996	310	3.10	25,483	0.00021	nts		
nts	miscellaneous marine crustaceans	47	0	3,391	182	3,208	1,415	4,623	1.3	10,249	310	3.10	3,306	0.00003	nts		
nts	squids, cuttlefishes, octopuses	57	278,796	77,209	1,085	354,920	156,520	511,440	2.2	9,006,426	310	3.10	2,905,299	0.02352	nts		
nts	flounders, halibuts, soles	31	50,306	31,948	182	82,071	36,193	118,264	1.9	1,043,786	310	3.10	336,705	0.00273	nts		
nts	mackerels, snoeks, cutlassfishes	37	114,613	21,623	9,787	126,449	55,764	182,213	2.4	5,085,538	310	3.10	1,640,496	0.01328	nts		
nts	salmons, trouts, smelts	23	95,419	54,550	450	149,519	65,938	215,457	1.4	601,337	310	3.10	193,980	0.00157	nts		
nts	shads	24	0	3,391	182	3,208	1,415	4,623	1.4	12,903	310	3.10	4,162	0.00003	nts		
nts	miscellaneous diadromous fishes	25	0	3,391	182	3,208	1,415	4,623	1.4	12,903	310	3.10	4,162	0.00003	nts		
nts	sharks, rays, chimaeras	38	16,373	3,390	1,084	18,678	8,237	26,915	2.7	1,498,836	310	3.10	483,496	0.00391	nts		
ccs	abalones	52	12,549	4,537	182	16,903	5,308	22,211	1.1	31,069	890	8.90	3,491	0.00003	ccs	0.01800	0.00565
ccs	oysters	53	248,793	7,416	385	255,823	80,329	336,152	1.1	470,211	890	8.90	52,833	0.00043	ccs		
ccs	mussels	54	0	3,391	182	3,208	1,007	4,216	1.1	5,897	890	8.90	663	0.00001	ccs		
ccs	scallops	55	421,709	3,391	4,411	420,688	132,096	552,784	1.1	773,238	890	8.90	86,881	0.00070	ccs		
ccs	clams	56	177,998	90,305	182	268,120	84,190	352,310	1.1	492,813	890	8.90	55,372	0.00045	ccs		
ccs	miscellaneous marine molluss	58	0	3,391	182	3,208	1,007	4,216	1.1	5,897	890	8.90	663	0.00001	ccs		
ccs	flounders, halibuts, soles	31	22,961	31,948	182	54,726	17,184	71,910	1.8	504,132	890	8.90	56,644	0.00046	ccs		
ccs	miscellaneous marine fishes	39	133,981	3,391	182	137,189	43,077	180,266	1.8	1,263,782	890	8.90	141,998	0.00115	ccs		
ccs	herrings, sardines, anchovies	35	407,903	23,307	27,228	403,981	126,850	530,832	2.2	9,347,903	890	8.90	1,050,326	0.00850	ccs		
ccs	seaweeds	90	207	0	0	207	65	272	0	30	890	8.90	3	0.00000	ccs		
ccs	jacks, mullets, sauries	34	105,369	3,391	182	108,577	34,093	142,670	2.3	3,162,941	890	8.90	355,387	0.00288	ccs		
ccs	mackerels, snoeks, cutlassfishes	37	31,246	21,623	9,787	43,082	13,528	56,610	2.3	1,255,011	890	8.90	141,013	0.00114	ccs		
ccs	salmons, trouts, smelts	23	95,419	54,550	450	149,519	46,949	196,468	1.8	1,377,367	890	8.90	154,760	0.00125	ccs		
ccs	shads	24	0	3,391	182	3,208	1,007	4,216	1.8	29,555	890	8.90	3,321	0.00003	ccs		
ccs	miscellaneous diadromous fishes	25	0	3,391	182	3,208	1,007	4,216	1.8	29,555	890	8.90	3,321	0.00003	ccs		
ccs	lobsters	43	380	9,079	182	9,277	2,913	12,190	1.6	53,922	890	8.90	6,059	0.00005	ccs		
ccs	squat-lobsters	44	0	3,391	183	3,208	1,007	4,215	1.6	18,646	890	8.90	2,095	0.00002	ccs		
ccs	shrimps, prawns	45	11,191	74,454	182	85,462	26,835	112,297	1.6	496,736	890	8.90	55,813	0.00045	ccs		
ccs	miscellaneous marine crustaceans	47	0	3,391	183	3,208	1,007	4,215	1.6	18,646	890	8.90	2,095	0.00002	ccs		
ccs	sea-spiders, crabs	42	20,208	34,974	349	54,832	17,217	72,049	1.4	201,088	890	8.90	22,594	0.00018	ccs		
ccs	tunicates	74	0	3,391	183	3,208	1,007	4,215	1.4	11,765	890	8.90	1,322	0.00001	ccs		
ccs	miscellaneous aquatic invertebrates	77	19,291	5,619	182	24,728	7,765	32,492	1.4	90,685	890	8.90	10,189	0.00008	ccs		
ccs	horseshoe crabs	75	0	3,391	182	3,209	1,008	4,216	1.4	11,767	890	8.90	1,322	0.00001	ccs		
ccs	echinoderms	76	25,824	8,135	182	33,776	10,606	44,382	1.4	123,869	890	8.90	13,918	0.00011	ccs		
ccs	turtles	72	0	3,391	182	3,208	1,007	4,216	1.4	11,766	890	8.90	1,322	0.00001	ccs		
fw	miscellaneous freshwater fishes	13	25,030	0	0	25,030	0	25,030	2.1	350,121	290	2.90	120,731	0.00098	fw	0.03075	0.00000
fw	sturgeons, paddlefishes	21	0	0	0	0	0	0	2.6	0	290	2.90	0	0.00000	fw		
fw	river eels	22	39,983	205	0	40,188	0	40,188	2.6	1,777,681	290	2.90	612,994	0.00496	fw		
fw	salmons, trouts, smelts	23	125,119	67,083	351	191,851	0	191,851	2.6	8,486,377	290	2.90	2,926,337	0.02369	fw		
fw	shads	24	0	0	0	0	0	0	2.6	0	290	2.90	0	0.00000	fw		
fw	miscellaneous diadromous fishes	25	0	0	0	0	0	0	2.6	0	290	2.90	0	0.00000	fw		
fw	freshwater crustaceans	41	3,951	0	0	3,951	0	3,951	1.2	6,958	290	2.90	2,399	0.00002	fw		
fw	shrimps, prawns	45	11,191	71,063	0	82,254	0	82,254	1.2	144,848	290	2.90	49,948	0.00040	fw		
fw	freshwater molluscs	51	37,017	0	0	37,017	0	37,017	1.2	65,187	290	2.90	22,478	0.00018	fw		
fw	mussels	54	0	0	0	0	0	0	1.2	0	290	2.90	0	0.00000	fw		
fw	amphibians	71	0	0	0	0	0	0	1.2	0	290	2.90	0	0.00000	fw		
fw	miscellaneous aquatic invertebrates	77	19,291	2,228	0	21,520	0	21,520	1.2	37,896	290	2.90	13,067	0.00011	fw		
fw	cyprinids	11	22,611	0	0	22,611	0	22,611	1.7	125,915	290	2.90	43,419	0.00035	fw		
fw	cichlids	12	5,825	0	0	5,825	0	5,825	1.5	20,467	290	2.90	7,058	0.00006	fw		
Japan total			**10,353,733**	**1,809,531**	**244,711**	**11,918,563**	**3,448,409**	**15,366,962**		**472,302,846**			**234,808,689**	**1.90067**			**0.61608**
world total			**94,300,000**			**94,300,000**	**27,000,000**	**121,300,000**		**3,656,352,000**			**2,910,400,000**	**0.50534**			
Japan's share in the world			0.110			0.126	0.128	0.127		0.129			0.081	3.761			

Note: Abbreviations of ecosystems, etc.

oos: Open Oceanic Systems — **nts: Non-Tropical Shelves**

us: Upwelling Systems — **ccs: Coastal and Coral Systems**

ts: Tropical Shelves — **fw: Freshwater Systems**

TL: Trophic Level PPR: Primary Productivity Required = ((cons+discard wet weight)/9)*10^(TL-1)

Shrimp consumption calculation						shrimp con.t	shrimp discal	shrimp + discards									
						256,386	2,051,088	2,307,474		**84,516,668**			**20,826,318**	**0.17**			

Tuna consumption calculation															
oos	tunas, bonitos, billfishes	36	512,966	212,073	52,864	672,174	134,435	806,609	3.2	142,043,284	103	1.03	137,906,101	1.11629	oos
ts	tunas, bonitos, billfishes	36	219,842	94,279	22,839	291,283	88,841	380,124	3.0	42,236,035	310	3.10	13,624,527	0.11028	ts
Tuna total			732,808	306,352	75,703	963,457	223,276	1,186,734		184,279,319			151,530,628	1.23	

APPENDIX E
Technological Fix Scenarios

Many technologies have been suggested to be able to make resource use more sustainable. In this appendix, I use optimistic calculations of the ability of proposed technological advances to reduce Japan's consumption of natural capital to a level which is similar to the sum of Fair Land Share (FLS) and Fair Aquatic Share (FAS). CO_2-sink land [energy land] and aquatic ecological footprint were found to be the most important components of the total ecological footprint of Japan. For this reason, and for the reason that developing technologies are most likely to be effective in this area, I have focused my attention on policies and technologies that reduce the requirement for land-intensive energy production and services as well as the aquatic ecological footprint

a) Manure and Kitchen Waste Utilization for Biogas

Power for domestic use may be generated from organic kitchen waste as well as from the excrement of humans and animals reared by humans. Optimism has been expressed regarding technologies which are currently being developed toward this end (Kuwahara, 1992). To investigate the potential of this technology to reduce the ecological footprint of Japan, I determined the population of humans and of different domestic animals in Japan and multiplied these numbers by the biogas potentially produced by these organisms per year. This was added to the available biogas energy potentially derived from kitchen waste, and then converted into energy. These organic wastes would act as a CO_2 source if left unused by humans. Utilization of this energy source by humans means that less land is required to assimilate the CO_2 emitted by the burning of some other fuel. Therefore, biogas energy was then converted into hectare equivalents of CO_2-sink land.

The result of these calculations was an ecological footprint reduction of **0.016 ha/capita**. This is equivalent to a reduction of approximately **0.7%** of the CO_2-sink land area currently required by the Japanese economy. Based on these calculations, manure and kitchen waste utilization alone appears not to be an effective technological solution for the reduction of CO_2-sink land.

b) Photovoltaic Energy Conversion from Rooftops

Of the degraded land area, approximately 40% is roof space available for photovoltaic production. I created two scenarios for the utilization of photovoltaic energy. The first is one in which the electricity produced is assumed to be used immediately. There is a corresponding reduction of CO_2-sink land required as solar energy replaces that produced by the burning of fossil fuels. In my estimation, this reduction is **0.040 ha/capita**, a reduction of **1.8%**.

The second scenario involves storing energy as hydrogen for later use. Electricity is efficiently generated from solar energy only during the daytime, during periods of reduced cloud cover. Thus, the first scenario is vulnerable to variability, and the second scenario may be the more effective and realistic choice. If energy is stored as hydrogen, the conversion efficiency of sunlight into available energy drops 40% from that of the first scenario. This means that the potential reduction of CO_2-sink land is only **0.016 ha/capita**, a reduction of **0.7%**, if energy is stored.

c) Conversion of Energy from Wind

Generation of electricity is generally not possible in sites where the average wind speed is below 5.5 m/s (Pimental *et al.* 1994). The total available area of suitable for wind energy production was estimated to be 16% of Japan's terrestrial area (Nihon Koho Kyokai 1981 and additional calculation by Wada). This area was multiplied by the average production capacity of windmill sites per hectare which is 308 GJ/ha (Pimental *et al.* 1994). This form of electricity generation is benign with respect to CO_2 emissions. The reduction potential of wind energy on the required CO_2 land area is optimistically estimated to be **0.146 ha/capita**, or a **6.7%** decrease from the total.

As was observed for photovoltaic energy, this wind energy calculation is based on the presumption that the energy will be used immediately. Because wind production varies, this is unlikely to be always true, I also calculated the potential ecological footprint reduction when energy is stored in the form of hydrogen. In this case, a **0.085 ha/capita** reduction of the ecological footprint is potentially available, representing a **3.9%** reduction in CO_2 -sink land appropriated.

d) Geo-thermal energy production

Geo-thermal energy is obtained in the form of heat which is produced below the Earth's crust. It is possible to convert this heat into power. Japan is already utilizing almost 1% of its possible geo-thermal energy production (Nihon Koho Kyokai 1981). My finding is that **0.185 ha/capita** of CO_2 assimilation area could be subtracted from the Japanese ecological footprint if geothermal technology is utilized to its theoretical maximum. This constitutes a **8.5%** reduction from the total CO_2 -sink land appropriated by the average Japanese person.

e) Co-generation

Co-generation is another heat-based energy resource. When fuel is burned for electricity power generation purposes, much of the energy liberated is in the form of dissipated heat. The process of recovery and utilization of this heat is termed co-generation. I calculated the energy savings per capita per year to be 16.9 GJ if co-generation could be implemented to its maximum potential. This energy savings converts to per capita CO_2-sink land in the amount of **0.169 hectares**. That is another **7.8%** reduction in total CO_2-sink land required to sustain the lifestyle of the average person living in Japan.

f) Discard Reduction

In the calculation of the aquatic ecological footprint, it was found that there were three major categories of input: discards, tuna, and other species. Of the 1.90 hectares of aquatic surface area currently appropriated by the average Japanese person, **0.52** hectares may be attributed to discards of bycatch. This should be compared to the Fair Aquatic Share (FAS), which was calculated to be 0.51 hectares per capita. Bycatch and associated discards also have ecological effects such as the promotion of overshot quotas (Pauly 1995). With regards to the benefits of technological advance, I focus here on discard reduction.

One obvious scenario is the total elimination of discards. This would leave an overshoot of the FAS of 1.38 hectares. However, such optimism is unwarranted. Discarded items are those for which no market currently exists, those for which market prices discourage the utilization of valuable hold space, those which have been damaged beyond market value, and those items which are below a minimum size (Alverson *et al.* 1994). Current fishing technologies are often inherently associated with bycatch. This may be a reason for the apparent focus of research regarding discard-reducing technology on shrimp trawling. Shrimp trawling is presently responsible for much of the current world discard totals. It has been estimated that the discard rate is up to ten times the biomass of shrimp caught (Alverson *et al.* 1994). After surveying literature, I came across a more optimistic estimate that the discard biomass is eight times the biomass of shrimp caught. If this is an accurate assumption, the harvest of shrimp and the associated discards account for 7.9% of the aquatic footprint of Japan.

The turtle excluder device (TED) has been demonstrated to have potential use in excluding finfish from shrimp trawl landings (by the exploitation of size and behavioral differences). It has been estimated that discards of finfish may be reduced, optimistically, by as much as 60% (Alverson *et al.* 1994). If we project that the discards (associated with the shrimp which Japan catches and imports) is reduced by 60%, the total ecological footprint attributed to shrimp consumption of an average Japanese person becomes **0.08 hectares**. This translates to a **4.2%** reduction of the aquatic ecological footprint of Japan.

Combined, all of the technological fixes that have been proposed as methods to reduce the impact of Japanese consumption are significant. These are optimistic estimations. I was optimistic in calculating energy conversion efficiencies for these technologies, and I was optimistic that the ecological footprint required for implementation and maintenance of these energy savers was minimal (and was left unaccounted to a large degree). Also, economic restraints on implementation of these technologies was ignored. Furthermore, overlap between technologies was assumed to be insignificant. It is quite possible that energy reduction by one technology would actually compete with energy reductions by other technologies.

However, even if all of these technologies were implemented with optimistic results, there is still an overshoot of the world average footprint of between **0.13** and **0.22 ha/capita** (depending on whether or not it is assumed that energy from photovoltaic and wind sources are stored) for consumption of terrestrial biophysical productivity, and an overshoot of **1.28 hectares** in the aquatic environment. Does this mean that, aside from population reduction or severe reduction in personal consumption, there is no way to reduce the global area appropriated by Japan to equitable levels? Not necessarily. Although foreseeable technological advance did not achieve this goal in my study, and although reduction of human population and per capita rates of consumption would certainly have a significant influence, there is, perhaps, another alternative which, combined with technological advance, may reduce Japan's impact to sustainable and equitable levels. Another alternative is needed, since the options of population reduction and extreme consumption reduction would not be politically viable. This new alternative is altered (but not necessarily reduced) consumption patterns.

g) Tuna Restrictions

Consumption patterns may be driven by many factors, some of which are unlikely to change. This may be observed in Japan, where tradition and culture are influential in maintaining consumption patterns. In such a situation, change must perhaps be helped along by international pressure. An example of this may be found in the Japanese consumption of tuna. The consumption of tuna by the average Japanese person was found to represent 1.23 ha of bioproductivity. This is 64% of the Japanese ecological footprint in the aquatic environment. International concerns regarding the Western Atlantic Bluefin stock, and similar concerns regarding other stocks of tuna, were a great source of tension in 1991. Safina (1993) describes the international response to a proposed a 50% reduction in the quota for Atlantic tuna, and a 100% reduction in the directed catch of the Western Atlantic stock. Tuna importers (especially Japan) and tuna exporters were unwilling to support these restrictive tuna quotas. Threats eventually persuaded Japan to attempt to stop the import of tuna from all countries except member nations of the International Commission for the Conservation of Atlantic Tunas (ICCAT).

For my scenario of an altered consumption pattern, information regarding the source country of imported tuna was not available. Therefore, all imports and exports of tuna by Japan were subtracted from the calculation of the ecological footprint owing to consumption of tuna. In addition, the proposed 50% quota reduction was applied to Japan's open ocean catch. The resulting reduction in terms of the aquatic ecological footprint was equivalent to **0.72 ha/capita**. This is a **38%** reduction. To verify that this is not a net reduction, I calculated the land area required to replace this lost dietary protein, so that we will not have reduced the personal consumption, we will only have changed it. In this case, we changed the diet from tuna protein to an equivalent amount of soy protein produced terrestrially (calculated using conversion ratios provided by Kraus 1975), taking into account the reduced absorption ability of humans when consuming vegetable matter. To replace the tuna protein with soy protein, a per capita terrestrial footprint of **0.01 ha** would result. The ecological footprint thus, in this example, demonstrates a net decrease of **0.71 ha**. This is a reduction 0.19 ha greater than that resulting from the unrealistic elimination of all discards. Although this scenario shows how a simple change in a consumption pattern may drastically reduce the ecological footprint, even this change would be difficult to achieve in practice. This is exemplified by statements made by Japanese delegates to the conservation community: "This is the same sort of thing you [environmentalists and conservationists] did to us on whales, sea turtles, and driftnets, and we will not let this happen with bluefin tuna. If you succeed here, you will go on to the next species and the next until you destroy our food culture" (Safina 1993).

Choosing to fish lower on the food chain was not predicted to be a viable option for the reasons of increased variability (Pauly *et al.* 1998) and decreased economic motivation.

h) Is A Technological Fix Enough?

My analysis shows that a technological fix alone does not reduce Japan's ecological footprint to the extent that Japan becomes a fair sharer of the limited ecological capacity of the Earth. Substantial changes in consumption patterns of natural resources in various categories would be necessary to achieve an equitable and sustainable Japan.