Regional Value of Provisioning and Regulating Services from Water in Japan

Tomohiro OKADERA[1*] and Masataka WATANABE[2]

[1]*Center for Regional Environmental Research, National Institute for Environmental Studies,*
16-2 Onogawa, Tsukuba, Ibaraki 305-8506, Japan
[2]*Keio University,*
5322 Endo, Fujisawa, Kanagawa 252-0882, Japan
**e-mail: okadera@nies.go.jp*

Abstract

This study aims to demonstrate factors of changes in ecosystem services in Japan by quantifying the value of those ecosystem services. We focus on ecosystem services related to water and evaluate their economic value by region in 1985, 1995 and 2005. Our results show their economic value in Japan to have nearly doubled from 1985 to 2005. In addition, we found that regulating services, especially flood control, account for high percentages of the total economic value (TEV) and have become the major factor boosting TEV from 1985 to 2005 in Japan.

Key words: economic value, ecosystem service, provisioning service, regulating service, water

1. Introduction

The Millennium Ecosystem Assessment (2005; MA) explained the linkage of biodiversity to ecosystem services by identifying an asymptotic relationship between biodiversity and ecosystem functions, and developed a framework for ecosystem assessment at the global and sub-global scales. Subsequently, the Japan *Satoyama Satoumi* Assessment (2010; JSSA) applied that framework to the evaluation of ecosystem services in Japan, divided into six regions. The JSSA concluded that the resiliency of ecosystem services had been declining due to changes in the *satoyama* and *satoumi* over the last fifty years and suggested the creation of a new "commons" for sustainable development. However, the JSSA did not assess the value of the ecosystem services, but posed it as a future issue. In addition, the MA also did not pay much attention to the economics of ecosystem change, though it mentioned the importance of the value of ecosystem services. Therefore, an international initiative named the "Economics of Ecosystems and Biodiversity" (TEEB, 2010) developed an approach to evaluating the value of ecosystem services.

For valuation of ecosystem services, it is necessary to identify the processes, functions, services, benefits and value of ecosystems (TEEB, 2010). However, ecosystems consist of various elements and components, so it is next to impossible to define all of them. Therefore this study focuses on ecosystem services related to water, such as water supply, flood control and so on, for two reasons. The one is that water is suitable for evaluating ecosystem services comprehensively because it is the only component related to all classifications of ecosystem services such as provisioning, regulating, cultural and supporting services (Millennium Ecosystem Assessment, 2005). The other is that water is one of the most important common properties in Japan, so it is beneficial to analyze changes in water-related ecosystems for the consideration of the new commons (Japan *Satoyama Satoumi* Assessment, 2010).

Against this background, this study aims to evaluate temporally (1985, 1995 and 2005) the value of ecosystem services of water and analyze changes in them by prefecture in Japan. This paper first explains the methodology used to define ecosystem services and quantifies them in multi-year intervals. Finally, we discuss our research and provide conclusions.

2. Methodology

2.1 The processes, functions, services, benefits and values of water ecosystems

Ecosystem services are defined by identifying processes and functions (TEEB, 2010), thus we first identify them for water (Fig. 1). On the basis of hydrology, precipitation in forests is where the whole process of water starts and some water goes into the evapotranspiration process while the rest is stored by the forests. Then a part of the stored water is withdrawn for irrigation, industrial use and tap water for households and livestock whereas

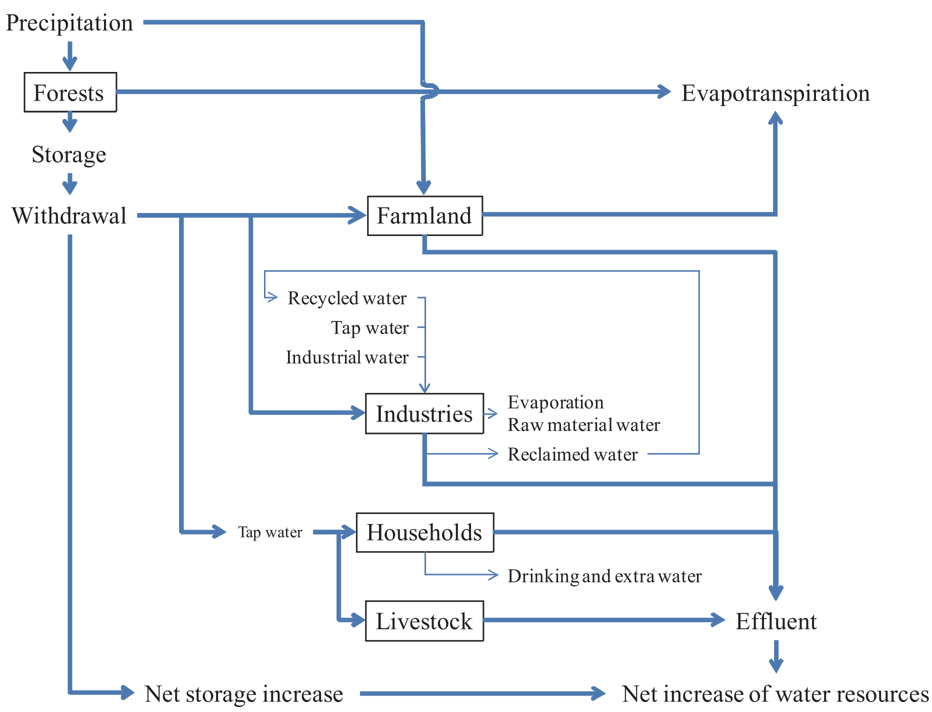

Fig. 1 The processes and functions of water (based on annual water flow).

Table 1 The processes, functions, services, benefits and values of water ecosystems.

Ecosystem process	Ecosystem function	Ecosystem service	Benefit	Value
Precipitation to forests	Supporting primary production and creatures in forests	(Supporting service)	(Undefinable)	(Undefinable)
Evapotranspiration of forests and farmland	Evapotranspiration	Temperature adjustment	Saving from damage caused by temperature (energy) change	Energy price-based value
Water storage of forests	Water retention	Flood control	Avoiding various losses from floods	Avoidance cost-based value
Precipitation onto farmland and withdrawal	Provisioning water	Water supply	Water use	Use value of water
Net storage increase and net increase of water resources	If the indices indicate a negative trend, we learn about a tendency toward water shortage. On the other hand, if they indicate a positive trend, the water has a potential for other ecosystem functions and services.			

the rest is stored (net storage increase). The withdrawal from farmland, industries, households and livestock and precipitation into farmland are discharged via consuming processes, such as production of crops, livestock and industrial goods and daily life activities. Finally the discharged water is recharged as net increase of water resources. Furthermore we define the linkage among processes, functions, services, benefits and values of the ecosystem (Table 1). Then we estimate their value, such as that of water supply, flood control and temperature adjustment by using the approach described below.

2.2 Quantification of the physical ecosystem services of water

We define the physical ecosystem services of water based on the water budget method as follows.

2.2.1 Precipitation into forests and farmland

Precipitation into forests is calculated by multiplying the forest or farmland area by annual precipitation. We estimate the annual precipitation based on observational data by prefecture. However, the annual precipitation based on a simple average of observed values possibly has issues with conformity because the numbers of observed points differ by prefecture and time of year. Thus that has to be estimated on the basis of the meteorological data named "Mesh Climatic Data 2000" (Meteorological Agency, 2002), which are data on annual precipitation in 1km grids based on observed values for thirty years in Japan, by using the deviations between the observed value of a monitoring point in a target year and the data on the mesh where the monitoring point existed in "mesh climatic data 2000."

2.2.2 Evapotranspiration in forests and farmland

We define evapotranspiration by precipitation and evapotranspiration rates, which are parameters dividing evapotranspiration (mm) by precipitation (mm), in forests and farmland. In general evapotranspiration data are categorized into three groups: real monitoring data, estimated data and satellite data. The annual evapotranspiration of some forests in Japan was monitored at twelve sites from 1931 to 1988 (Kondo & Watanabe, 1991). The monitoring data are the most reliable, but they are very local and it is impossible to apply them directly to the whole of Japan, which of interest here. Furthermore, Kondo *et al*., (1992) has attempted to estimate a dataset on regional evapotranspiration by the heat budget method, based on the local monitoring data of 1986-1990, but it is difficult to collect regional evapotranspiration data of the same quality in Japan since the dataset lacks data from eight prefectures. Thus we use satellite data (MOD16) of MODIS (Sun *et al*., 2009; Wang *et al*., 2011) to avoid the issue of the regional gap in the data. However, we can get MOD16 from 2000 to 2006. Thus, we estimate the evapotranspiration in 1985 and 1995 by using the rate of change of pan evaporation, for example we estimate the rate in Hokkaido in 1985 as 1.2 since the daily pan evaporations in Hokkaido were 2.3 mm in 2000 and 2.7 mm in 1985, for the year based on the targeted years, (Meteorological Agency, 2001, 2007a), monitored from 1961 to 2002, on the basis of the year 2000 (Meteorological Agency, 2007b).

2.2.3 Water storage of forests and runoff from farmland

Water storage of forests and runoff from farmland are defined by subtracting evapotranspiration from the precipitation into forests and farmland.

2.2.4 Irrigation water flow

Annual irrigation water is estimated by multiplying farmland area by the withdrawal per farmland area. The withdrawals per farmland area are defined by the reported data (Water Resource Department, Water and Disaster Management Bureau, Ministry of Land, Infrastructure, Transport and Tourism, 2011). Then we assume a part of the irrigation water goes into the evapotranspiration process and the other drains as effluent.

2.2.5 Industrial water flow

Water input to industries consists of tap water supplied by municipal waterworks (hereafter, called tap water), industrial water supplied by industrial waterworks (hereafter called industrial water), recycled water recovered in the companies' own reclamation plants (hereafter called recycled water) and water withdrawn from ground and surface water, whereas the output is defined as evaporation, raw material water, reclaimed water and industrial wastewater. On the basis of statistical data (Ministry of Economy, Trade and Industry, 2011), we first estimate the total water input by multiplying the value of industrial shipment by water requirement per industrial shipment by sector, then define tap water use, industrial water use, withdrawal and recycled water by their respective shares against water requirement. In a similar way, the items of industrial water output are also calculated by their share of evaporation, raw material water, reclaimed water and industrial wastewater against water requirement.

2.2.6 Domestic water flow

The withdrawal volume for household use is calculated by multiplying the population by annual withdrawal per capita. Annual withdrawal per capita is the effective water amount per capita and the withdrawal ratio, which is the ratio of the amount of water withdrawn against the effective water amount, (Water Resource Department, Water and Disaster Management Bureau, Ministry of Land, Infrastructure, Transport and Tourism, 2011). Furthermore, we assume the effective water amount is discharged as domestic wastewater.

2.2.7 Water flow in the livestock sector

Water use for livestock is quantified by allocating the total water use of livestock in Japan (Water Resource Department, Water and Disaster Management Bureau, Ministry of Land, Infrastructure, Transport and Tourism, 2011) to each prefecture based on the number of livestock (Ministry of Agriculture, Forestry and Fisheries, 2007). In addition, we assume the whole of water input for livestock is discharged as livestock wastewater.

2.2.8 Net storage increase and net increase of water resources

The net storage increase of forests is defined by subtracting withdrawal from the water storage of forests. In addition, withdrawal is found by the summation of irrigation water, industrial withdrawal from surface and ground water, withdrawal by households and water for livestock. Furthermore, the net increase of water resources is defined by adding the effluent to the net storage increase of forests. The effluent consists of runoff from farmland, agricultural effluent, industrial wastewater, domestic wastewater and livestock wastewater.

2.3 Valuation of the ecosystem services

Ecosystem services have ecological value, socio-cultural value and economic value (Millennium Ecosystem Assessment, 2005). Numerous studies have developed various valuation methods so far and they reveal the difficulty of estimating ecological and socio-cultural value (TEEB, 2010). Thus this study focuses on the economic value of ecosystem services. Valuation methods of economic value are categorized as direct market valuation approaches, revealed preference approaches and stated preference approaches, and we should choose and apply a suitable method depending on the kind of ecosystem services and the object of our survey since they each have advantages and disadvantages, such as uncertainties and limitations (TEEB, 2010). Here, we chose the direct market valuation approach because it has the advantage of being easily applied to multiple years by using time-series market data and it suits the objective here. We subsequently explain the valuation approach for temperature adjustment, flood control and water supply, as below.

2.3.1 Temperature adjustment

Evapotranspiration from forests and farmland serves ecosystem services as temperature adjustment, and we assume that the people surrounding these forests obtain benefits of being saved from damage caused by temperature change. Thus this study defines the value of temperature ecosystem services based on energy price:

$$EV_{\mathrm{TA}} = EP \times EH \times R\,(cp, ar) \qquad (1)$$

where EV_{TA} is the economic value of temperature adjustment by prefecture (yen/m^3), EP is the energy price (yen/ thousand kcal) of crude oil in Japan (The Institute of Energy Economics, Japan, 2011) and EH is the evaporation heat of water (2,267MJ/m^3). In addition, $R(cp, ar)$ denotes a regional coefficient defined by energy consumption pattern (cp) and the adjacent rate (ar) between residential or business areas and forests or farmland. The energy consumption pattern is set by statistical data such as prefectural consumption prices of electricity or gasoline (Bureau of Statistics, Ministry of Internal Affairs and Communications, 2011). The adjacent rate is calculated on the basis of the GIS database (National Institute for Agro-Environmental Sciences, 2011).

2.3.2 Flood control

Water storage of forests has the function of water retention and produces ecosystem services such as flood control. As a result, the people downstream get the benefits of avoiding loss of life, capital and various opportunities. Thus the value of flood control is found by avoidance cost which is one of the cost-based methods:

$$EV_{\mathrm{FC}} = AC \times R \qquad (2)$$

where EV_{FC} is the economic value of flood control by prefecture (yen/m^3), AC is the avoidance cost of flood control by dams by prefecture (yen/m^3) and R is a regional coefficient. AC is based on the statistical data of usable capacities and damage reduction amounts by flood control dams (Japan Dam Foundation, 1987, 1996, 2006). R is the adjacent rate between forests and residential or business areas or farmland (National Institute for Agro-Environmental Sciences, 2011).

2.3.3 Water supply

The economic value of water supply is defined by the use value of water as shown in Table 1; however, the value differs depending on usage. Therefore, this study estimates the value of irrigation water, industrial water and tap water separately. The value of irrigation water is calculated by the water charge and fee for water withdrawal called "*ryusui senyuu ryou*" (RSR) for farmland. The water charge is estimated by using the farmland area and water charge per unit farmland area (Ministry of Agriculture, Forestry and Fisheries, 2004, 2011). RSR is enacted by regulations based on the River Law by prefectures in Japan. Thus we built an RSR database by surveys of literature on all of the regulations. In addition, we assumed the value of precipitation onto farmland to be the same as that of irrigation water.

The price of industrial water differs with the source of water. In the case of using tap water, we apply water rates by prefecture (Ministry of Health, Labour and Welfare, 1987, 1997, 2007). When we use industrial water, we adopt the unit price of water supply of an undertaking of the industrial water system by prefecture (Ministry of Internal Affairs and Communications, 1986, 1997, 2007). The value of withdrawal by industries is defined by RYR for industries based on the database as above. In addition, the value of recycled water is assumed to be zero, because we could not obtain cost data on water recycling systems.

The value of domestic water is calculated by water rates by prefecture (Ministry of Health, Labour and Welfare, 1987, 1997, 2007). In addition, these water rates are adopted as the value of water used by livestock, since stock-raising farmers use tap water for their business.

2.3.4 Limitations and conditions

This study does not assess the value of precipitation into forests because that has a lot of ecosystem services, so it is impossible to define the value uniquely, though it is one of the most important ecosystems in terms of supporting services. Furthermore, we don't define the value of net storage increase and net increase of water resources where they may have non-use value, since it is difficult to identify their functions, services and benefits as ecosystems. However, the indices are useful to the understanding of the physical impacts of regional water shortages or droughts.

3. Results and Discussion

The total economic value (TEV) of ecosystem services of water in 2005 had increased about twofold from 1985 to 2005 as shown in Fig. 2, where the TEVs were 12.8, 15.9 and 25.4 trillion yen in 1985, 1995 and 2005 respectively. During these two decades, the economic value of flood control consistently accounted for large shares of the TEV (44%-70%). The economic value of temperature adjustment held second place in 1985 (36%) and 2005 (24%) in the TEV whereas that of 1995 was indicated at 9% because the price of crude oil in 1990 was very cheap, around 1.19 yen/thousand kcal in 1995, as opposed to 4.34 yen/thousand kcal in 2005. The share of the economic value of water supply against TEV was 13%-20%, and the economic value was nearly flat.

Table 2 shows that the spatial distribution of the TEV in Japan changed in the period between 1985 and 2005. In 1985, Oita Prefecture held first place in TEV with a share of 7% of the whole of Japan, but the TEV of

Kagoshima Prefecture in 1995 (9%) became the most valuable in Japan, and then that share expanded to 24% of the TEV in Japan by 2005.

At the same time, temporal changes in TEV also differed by prefecture. The temporal change rate is defined by average rate of change from the epoch (1985 or 1995). In the period of 1985-1995 the TEV of Kochi prefecture ballooned up with a growth rate of 121.1% per year, whereas that of Okinawa Prefecture dropped down with a decreasing rate of –7.3% per year. Similarly during the term of 1995-2005 the TEV of Saga Prefecture significantly grew, with a growth rate as 55.1% per year whereas that of Oita Prefecture dropped, with a decreasing ratio of –8.6% per year.

Here, we itemize the TEVs of the five prefectures with notable changes as above, *i.e.*, Kochi, Saga, Oita, Kagoshima and Okinawa, in Fig. 3. Our results show the prefectures to have common tendencies so that changes in the economic value of flood control correlate closely with the changes in TEV in all of the prefectures. Furthermore, it reveals that the TEV and changes in TEV as shown in Table 2 are the result of changes in the value of flood control, because the value of flood control in the highest prefectures, Oita in 1985 and Kagoshima in 1995 and 2005, was the highest in 1985, 1995 and 2005, respectively. In addition, the highest growth rates in Kochi in 1985-1995 and Saga in 1995-1985 were clearly caused by rapid increases in the value of flood control, whereas the most negative growth rates in Okinawa in 1985-1995 and Oita in 1995-2005 were caused by a sharp decline of the same.

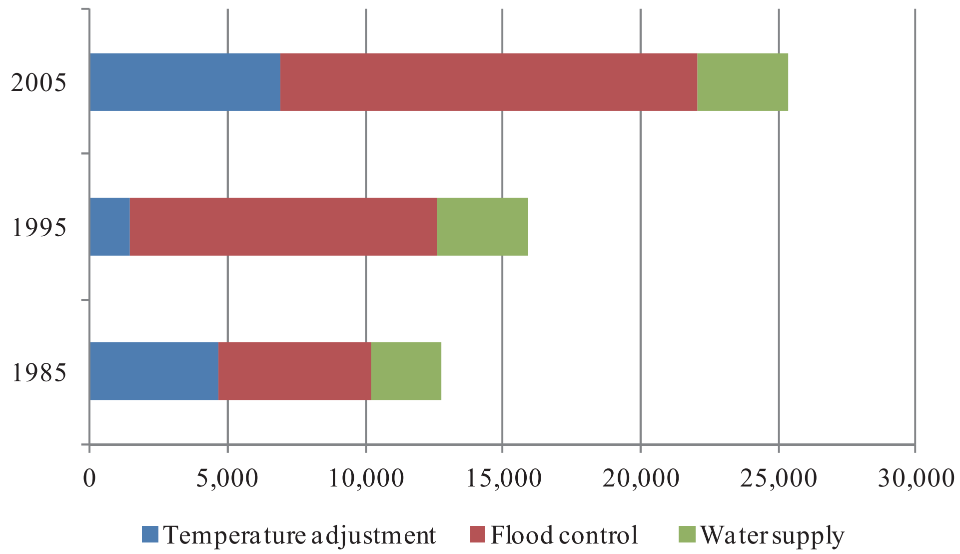

Fig. 2 The total economic value of ecosystem services from water in Japan (billions of yen).

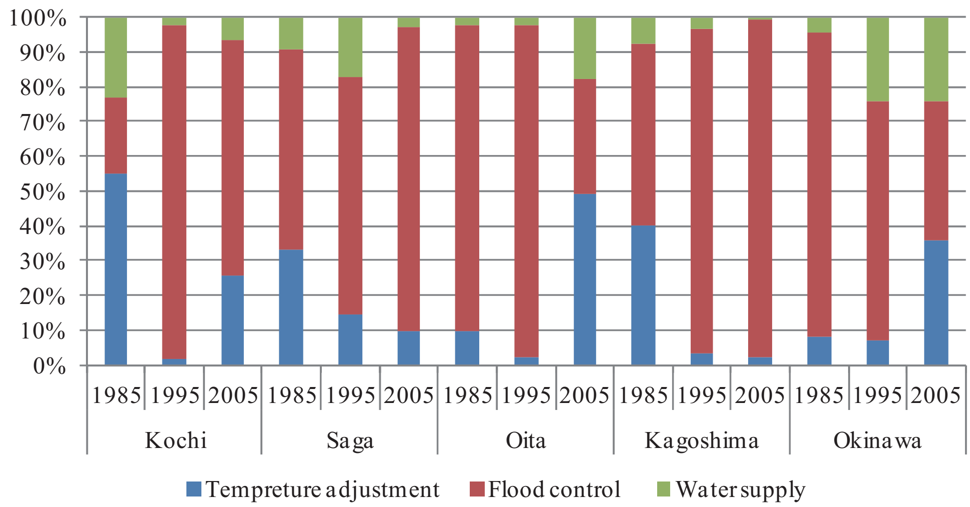

Fig. 3 Itemized TEV for five prefectures in Japan.

Table 2 Distribution and temporal change of the TEV of ecosystem services from water in Japan.

	Distribution of TEV			Temporal change rate of TEV	
	1985	1995	2005	1985-1995	1995-2005
Hokkaido	4%	3%	2%	-15%	45%
Aomori	2%	2%	3%	62%	120%
Iwate	2%	1%	1%	0%	52%
Miyagi	2%	1%	1%	-34%	104%
Akita	1%	1%	1%	44%	66%
Yamagata	1%	1%	1%	-10%	73%
Fukushima	2%	2%	2%	27%	14%
Ibaraki	3%	4%	2%	46%	7%
Tochigi	2%	1%	1%	-50%	214%
Gunma	2%	1%	1%	-24%	122%
Saitama	2%	2%	3%	-21%	166%
Chiba	4%	2%	2%	-24%	55%
Tokyo	3%	2%	2%	8%	37%
Kanagawa	2%	2%	1%	-5%	47%
Niigata	3%	4%	6%	75%	131%
Toyama	1%	1%	1%	-8%	20%
Ishikawa	1%	1%	0%	-32%	16%
Fukui	1%	8%	3%	973%	-47%
Yamanashi	1%	1%	2%	-14%	337%
Nagano	3%	2%	2%	-23%	87%
Gifu	2%	1%	1%	-34%	116%
Shizuoka	2%	1%	2%	-19%	192%
Aichi	3%	2%	2%	-20%	78%
Mie	3%	2%	1%	-30%	-3%
Shiga	2%	1%	1%	-10%	-22%
Kyoto	1%	1%	1%	45%	-27%
Osaka	2%	2%	1%	7%	17%
Hyogo	4%	4%	3%	53%	13%
Nara	1%	2%	1%	205%	-36%
Wakayama	1%	2%	3%	147%	137%
Tottori	1%	1%	1%	30%	245%
Shimane	1%	1%	1%	-19%	130%
Okayama	1%	1%	1%	-28%	122%
Hiroshima	2%	1%	1%	4%	41%
Yamaguchi	1%	1%	1%	-48%	39%
Tokushima	1%	1%	1%	-6%	178%
Kagawa	1%	5%	2%	479%	-31%
Ehime	1%	1%	1%	-32%	151%
Kochi	1%	6%	1%	1211%	-68%
Fukuoka	7%	4%	3%	-31%	19%
Saga	2%	1%	4%	-23%	551%
Nagasaki	2%	1%	1%	-26%	-14%
Kumamoto	2%	1%	1%	-20%	15%
Oita	7%	7%	1%	23%	-86%
Miyazaki	1%	1%	1%	-51%	211%
Kagoshima	3%	9%	24%	212%	339%
Okinawa	5%	1%	1%	-73%	-1%
Total	100%	100%	100%	25%	59%

4. Conclusion

This study has investigated approaches to valuation of ecosystem services and applied them to analyze ecosystem services of water by prefecture in Japan temporally. Our results show the economic value in Japan has nearly doubled from 1985 to 2005 and the values of regulating services such as flood control and temperature adjustment have a large share in Japan. In addition, it reveals that regulating services, especially flood control, account for high percentages of the TEV and have becomes the major factor boosting the TEV from 1985 and 2005 in Japan. Therefore it is important to reflect the value of regulating services in the creation of the new commons and decision making at the national and regional levels in the future.

Acknowledgments

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Tomohiro Okadera

Tomohiro Okadera is a researcher at the Center for Regional Environmental Research, National Institute for Environmental Studies (NIES). He specializes in environmental economics with special interest in the interrelationship between socio-economic activities and water ecosystems. He has developed a water inventory method for the Yangtze River and Tokyo Bay area using input-output analysis models, water footprint analysis of energy production in Japan and China, and valuation of water ecosystems in Japan to date. At present he is attempting to apply these approaches to other Asian countries such as Mongolia and Thailand.

Masataka Watanabe

Dr. Masataka Watanabe is a Professor at the Graduate School of Media and Governance, Keio University, Japan. He is also a Visiting Professor at the Institute of Advanced Studies, United Nations University. He has been Chairman of the UNEP Asia Pacific Adaptation Network since October 2009. Prior to joining Keio University, he was Director of the Division of Water and Soil Environment at the National Institute for Environmental Studies, Japan, and was also appointed Professor at the Graduate School of Agricultural and Life Sciences, the University of Tokyo. He participated in the UN Millennium Ecosystem Assessment from 2000 to 2004 as Coordinating Lead Author of the Sub-Global Assessment. He is a member of numerous National Councils and Committees in the Japanese Government. He was awarded the Tien Shan Prize from the Government of China in 2003 for his scientific contributions. He received his PhD in Civil and Environmental Engineering from the Massachusetts Institute of Technology. He has authored more than 120 peer-reviewed international journal articles and two books.

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