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Assessing the Dependence of an Urban System in Japan on Forest Ecosystem Services: A Case Study

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Abstract

With the progress of urbanization, the importance of biodiversity conservation and sustainable ecosystem service use in urban systems has been entirely acknowledged. We are recognizing the need to redesign city systems from the viewpoint of the relationship between urban activities and natural ecosystems. In this study, we evaluated the dependence of human activities within a large metropolitan region on ecosystem services. Our evaluation focused on the civilian sector (which consists of business and residential activities) of the municipalities of Osaka prefecture, Japan. This study applied a framework known as Ecosystem Services Use (ESU), an ecological footprint-based evaluation method, in order to identify the characteristics of Forest Ecosystem Service Use (FESU) by a municipality. FESU was estimated in hectares by integrating various statistics on human activities and using conversion functions that reflect the features of the urban systems of each municipality. The results showed that $FESU_{CO2}$, the variable representing the forest area needed to compensate for carbon dioxide emissions, represented the largest portion of total FESU in all municipalities, indicating that energy consumption through urban activities plays a significant role in increasing dependence on forest ecosystems. Additionally, a cluster analysis was performed with variables related to municipality character, FESU, and external dependence. The 43 municipalities of Osaka were clustered into five groups. By applying the ESU framework, this case study demonstrates a viable method of quantitatively evaluating the dependence of urban activities on ecosystem services and helps us understand the sustainability of cities' use of ecosystem services.

Keywords
Urban systems, ecosystem services, forest ecosystem, civilian sector, ecological footprint

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INTRODUCTION

Linking Urban Systems and Ecosystems

Urban activities require a large amount of natural resources derived from surrounding ecosystems, such as food, water, and timber, as well as the sequestration of carbon dioxide, other oxidized substances, and waste. These benefits are known as "ecosystem services". Recently, the role of city and local governments in conserving ecosystems that support urban activities has received global attention. Human activities are placing increasing pressure on ecosystems through both the direct and indirect effects of urbanization and civilization, and the consumption of ecosystem services is also increasing rapidly. Thus, it is clear that urban systems greatly depend on various types of ecosystem services and cannot be sustained without appropriate use.

The Need to Evaluate the Dependence of Urban Systems on Ecosystem Services

In accordance with this trend, the development of tools for identifying and evaluating the relevance of urban activities and ecosystems has been highlighted, and many types of research are emerging on this topic. For example, one major accomplishment in this regard is the City and Biodiversity Outlook (CBO) by the Convention on Biological Diversity (CBD 2012). This program conducts a global assessment of the links between urbanization, biodiversity, and ecosystem services. It aims to provide knowledge of urban social-ecological systems (SESs), find innovative ways to reduce vulnerability, and enhance the resilience of cities. The release of scientific analysis and assessment reports continues. Three of the latest CBO studies focus on urban ecosystem services, indicating that most ecosystem services consumed in a city are generated by ecosystems located far outside the cities themselves (CBO 2015).

Furthermore, the Economics of Ecosystems and Biodiversity (TEEB) project analyzed the economic potential of biodiversity and ecosystem services and released the TEEB Manual for Cities: Ecosystem Services in Urban Management (TEEB 2011). This manual proposed various management activities and recommended guidelines for applying the concept of ecosystem services to policy decision making on a regional scale. The TEEB project offered practical suggestions to improve the welfare of inhabitants at local, city, and regional levels.

The CBD's City Biodiversity Indicator (CBI) project has also taken a lead role in encouraging local governments to expand their engagement with ecosystem management (CBD 2008). Based on workshops involving experts in the field, the CBI manual was developed as a self-assessment tool for managing urban biodiversity and ecosystem services. The action plan of the Convention of Biological Diversity (COP10) recommended using this tool to evaluate city–ecosystem linkages. In the latest version of the CBI user manual (CBD 2014), three categories, comprising 23 indicators, were identified: native biodiversity, ecosystem services, and governance and management. Simultaneously, it has also been noted that the CBI has a shortage of evaluative measures and that measures for ecosystem services, including biodiversity as an aspect of supportive services, should be added (Kato 2011).

Working from this background, we conducted a case study of forest ecosystem services in Osaka, the second-largest prefecture in Japan and one that can be considered to be representative of urban cities in developed countries. The study had three main objectives: (1) to quantify the amount of the city's dependence on forest ecosystem services, (2) to evaluate the externalities of forest ecosystem service use, and (3) to discuss the characteristics or factors of cities' dependence on ecosystem services.

MATERIALS AND METHODS

Indicators to Evaluate Dependence on Forest Ecosystem Services

In this study, we adopted an ecological footprint-based indicator to estimate the amount of dependence on internal and external ecosystem services in Osaka. Ecological footprint (EF) is a measure representing environmental impacts caused by human activities in developed urban land areas (Wackernagel and Rees 1995). Recently, the applicability of EF in evaluating ecosystem services has been discussed comprehensively (Wiedmann and Barrett 2010). EF can compare the land area required to satisfy the needs of human activities with the actual land area available within the defined boundaries. Additionally, when demand exceeds supply, this is called "overshoot," and it means that the system is unsustainable. The concept of overshoot in EF theory enables the nonscientific community to understand external dependence on ecosystem services.

In our study, we employed *Ecosystem Services Use* (*ESU*), an ecological footprint-based framework, (Shaw et al. 2010) to evaluate the balance of demand and supply of ecosystem services. Figure 1 illustrates the basic *ESU* framework. This framework was originally developed to support an understanding of linkages between social and natural ecosystems via ecosystem service use. The *ESU* framework first divided the interventions of human activities and ecosystem services into two categories based on the concepts of TEEB (TEEB 2011) and the Natural Capital Protocol (Natural Capital Coalition, 2016). Production and consumption in urban systems depend on the provisioning of ecosystem services (input dependence); they also impact regulative services through pollutant emissions (output dependence). Input dependence and output dependence are known as "dependence" and "impact" in the TEEB and the Natural Capital Protocol. This conceptualization facilitates a comprehensive understanding and prioritization of the links between urban systems and forest ecosystems.

Another advantage of the *ESU* framework is that it allows for evaluation of both stock and flow aspects. Ecosystem services are usually evaluated in flow units, such as annual water recharge units [m^3 y^{-1}]. However, in terms of designing management strategy, we have two management options: flow management, such as preventing overuse of timber products, and stock management, a form of conserving forest ecosystems, to sustain the supply of ecosystem services, as does conventional EF. Using this framework, we evaluate both the demand flow of urban ecosystem services (e.g., [t Cy^{-1}]) and the required stock of ecosystems to support them (e.g., [ha]).

There is another important difference between conventional EF and *ESU*. In the conventional EF framework, each ecosystem service is assigned to one ecosystem type where the ecosystem service is generated. For example, timber-provisioning services are assigned to the forest ecosystem, and crop-provisioning services are assigned to the agro-ecosystem. Thereafter, the amount of land area of each ecosystem is converted to the global hectare, and these figures are aggregated into the total EF. For example, representative EF research on a national scale is conducted by the Global Footprint Network (GFN 2008). For Japan, some regional-level EF analyses have been performed, such as for the Hokkaido region (Itou and Takahashi 2006) and the Shiga prefecture (Nakano and Wada 2007). On the other hand, the *ESU* framework considers the fact that an ecosystem provides multiple ecosystem services. For instance, forest ecosystems can simultaneously provide wood, food, provisioning, climate control, and water regulation services. Thus, *ESU* reveals the detailed components of ecosystem service use for each city. We adopted the *ESU* framework because this study aims to determine the characteristics of Osaka's overall dependence on ecosystem services.

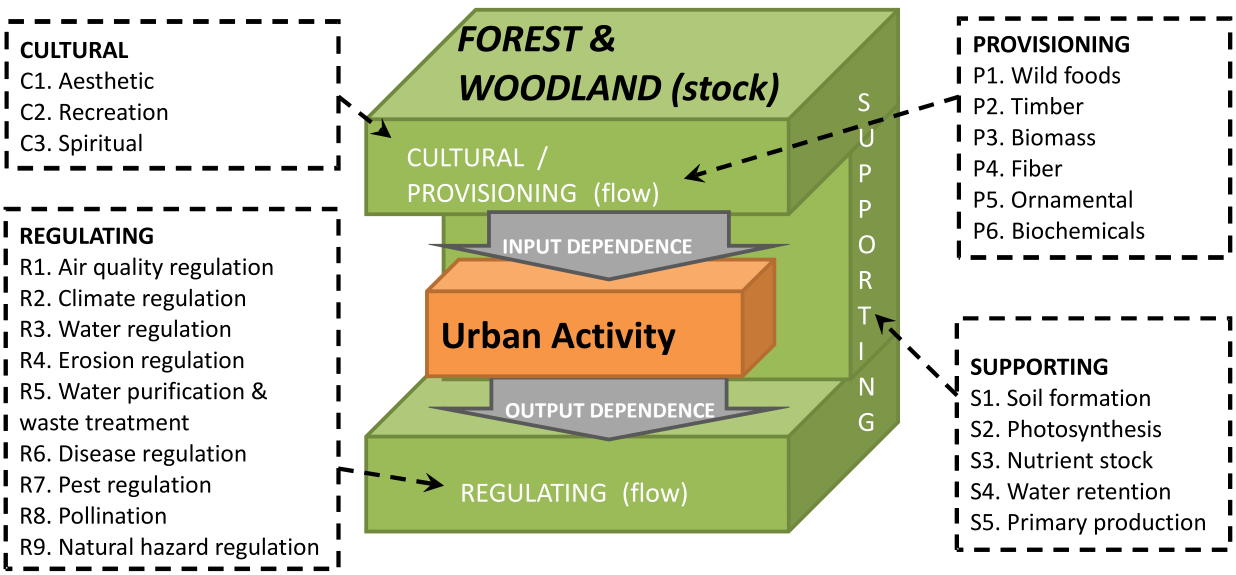

Figure 1 Relationships between urban activity and forest ecosystem services

Note: This is a conceptual image of the link between urban activities and forest ecosystem services, using the *ESU* framework. Urban activities in the center of the figure require various types of ecosystem services from forest stocks, which are divided into two types of flows: "input dependence" and "output dependence." In urban activities, many types of natural resources flow into urban systems, and urban activities strongly depend on provisioning and cultural services. Urban systems also discharge many types of waste material and energy, which impact natural capital conditions and depend on purification services. We need to quantify the relation between urban activities and forest ecosystems according to two aspects, "input and output dependence," and "stock and flow," to bundle management options.

The Case Study Area

Scale of Research Area and Scope of Urban Activities

Most Japanese cities are highly developed. Thus, a massive amount of ecosystem services is used to support city activities. Because of their history of rapid urbanization, these cities were developed intensively and have poor ecosystems within their boundaries. For this reason, they rely heavily on ecosystem services generated by ecosystems located outside the cities. To become a self-sufficient, sustainable eco-region, it is essential for urban cities to increase their self-sufficiency, reduce dependence on external ecosystem services, and build systems of cooperation between urban and rural areas.

It is important to analyze human activities in an urban setting and to evaluate cities' ecosystem dependence usefully to describe the meaning of dependence at a personal level. Therefore, in this study, municipalities in the Osaka prefecture were selected as a case study area. Osaka consists of 43 municipalities and is the second-smallest prefecture in Japan, occupying approximately 1,899 km^2 or only 0.5% of Japan's total land area. However, its population was 8.8 million in 2011, and its gross regional product was 36 trillion yen in 2010 (both approximately 7% of Japan's total). These figures imply that Osaka has intensive human activities. This analysis will identify representative features of dependence on ecosystem services by a major city in a developed country.

We also focused on the civilian sector as a representative category of urban activities. In general, human activities can be divided into four major sectors: industrial, civilian, transportation, and energy generation. The civilian sector comprises the residential sector, including common domestic activities, and the business sector. The other sectors provide products and services to people across the country and even internationally, and their demands on ecosystem services extend beyond the local area. By contrast, the civilian sector basically provides local services to local people (such as education and daily commodities), and these activities demand local ecosystem services. The civilian sector, especially its business subsector, tends to represent the largest part of GDP in developed countries. For these reasons, it seems reasonable to select the civilian sector in order to understand the dependence of urban activities on ecosystem services.

Forest Ecosystem Services Inventory

Japan's main terrestrial ecosystem is forest, and forest ecosystems offer various kinds of ecosystem services. We selected forest ecosystems as the representative source of ecosystem services provided to urban systems. The balance of *FESU* (*Forest Ecosystem Service Use*) was evaluated in this study based on the *ESU* framework described above (Shaw et al. 2010).

Forest ecosystems have many functions essential for supplying various ecosystem services. The long-term objective of this study is to merge all categories of forest ecosystems to gain a holistic understanding of ecosystem service use; however, since our knowledge is currently limited, provisioning and regulating ecosystem services were chosen as the most foundational services for urban systems. Timber supply services (timber for construction, furniture, and making paper) constitute provisioning services. CO_2 absorption and NO_x and SO_x buffering were chosen as air- and climate-regulating services. In the following section, these dependencies on wood for construction, furniture, paper and pulp, absorption of carbon dioxide, and nitrogen and sulfur decomposition, are represented as $FESU_{Wc}$, $FESU_{Wf}$, $FESU_{Wp}$, $FESU_{CO2}$, and $FESU_{N/S}$, respectively. The calculation processes used to estimate the values of these indicators are explained below.

Estimation of *FESU*

Wood Construction Provisioning Services

On a yearly basis, approximately 18 million tons of timbers are harvested in Japanese forests, and the demand for wood for use in construction is mostly for timber. In this section, equations for estimating the amount of forest area needed to supply construction wood to each municipality in Japan are presented.

Business Sector: The forest area needed to supply construction wood for the business sector's activity ($FESU_{Wcij}\_bus$) in each municipality was estimated as follows:

$$Wc_{ij}\_bus = \sum_{k}\left(A_{ij} \times r_{jk} \times w_k\right) \quad (1)$$

$$FESU_{Wcij}\_bus = Wc_{ij}\_bus/\left(a \times Y_w\right) \quad (2)$$

where Wc_{ij}_bus is the annual amount of construction wood used in business sector i in municipality j [t y^{-1}], A_{ij} is the annual total constructed floor space in business i in municipality j [m^2 y^{-1}] (MLIT 2006–2010), r_{jk} is the proportion of buildings constructed by building structure k in municipality j (MLIT 2006–2010), w_k is the amount of wood contained in building structure k per unit floor space [t m^{-2}] (Nagaoka et al. 2009), a is the production efficiency from round wood to construction wood (MAFF 2010), and Y_w is the weighted average forest yield factor, based on the composition of tree species in the Osaka prefecture [t y^{-1} ha^{-1}] (FA 2010; Yata et al. 1978).

Residential Sector: The forest area needed to meet the construction wood demand for the residential sector ($FESU_{Wcij}\_res$) in each municipality was estimated as follows:

$$Wc_j\_res = \sum_{l}\sum_{k}(w_k \times B_{jkl}/L_{kl}) \quad (3)$$

$$FESU_{Wc}\_res = Wc_j\_res/(a \times Y_w) \quad (4)$$

where Wc_j_res is the annual amount of construction wood used in the residential sector in municipality j [t y^{-1}], B_{jkl} is the annual total floor space of building structure k in house type l in municipality j [m^2] (MLIT 2010), w_k is the amount of wood contained in building structure k per unit of floor space [t m^{-2}], L_{kl} is the anticipated lifetime of building structure k in house type l [y] (Tanikawa and Imura 2001; Oikawa and Urabe 2002), a is a production efficiency factor from round wood to construction wood, and Y_w is a forest yield factor [t y^{-1} ha^{-1}] (the same value as in the equation (2)).

Furniture Wood Provisioning

Like construction wood, furniture wood is provided by processing round wood. In this section, the equations for estimating the amount of forest area needed to supply furniture wood are presented.

Business Sector: The forest area needed to supply furniture wood for the business sector's activity ($FESU_{Wfij}\_bus$) in each municipality was estimated as follows:

$$Wf_{ij}\_bus = K \times F_i \times \sum_m (b_m \times w_m) \times c_{ij} \tag{5}$$

$$FESU_{Wfij}\_bus = Wf_{ij}\_bus / (a \times Y_w) \tag{6}$$

where Wf_{ij}_bus is the annual amount of furniture wood used in business i in municipality j [t y^{-1}], K is the weighted average furniture price based on furniture type [million yen^{-1}] (METI 2010), F_i is the annual purchase of furniture in the business sector i [million yen y^{-1}] (Osaka Prefecture 2010), b_m is the proportion of sales of furniture m for all types of furniture (METI 2010), w_m is the basic unit of wood used for furniture m [t set^{-1}] (JAWIC 2003), c_{ij} is the proportion of employees in business i in municipality j (Osaka Prefecture 2005), a is production efficiency from round wood to construction wood (the same value appears in both the equations (2) and (4)), and Y_w is a forest yield factor [t y^{-1} ha^{-1}] (again in both equations (2) and (4)).

Residential Sector: The forest area needed to supply furniture wood for the residential sector's activity ($FESU_{Wfj}\_res$) in each municipality was estimated using these equations:

$$Wf_j\_res = \sum_n \sum_m (w_m \times R_{mn} \times N_{jn} \times b) \tag{7}$$

$$FESU_{Wf}\_res = Wf_j\_res / (a \times Y_w) \tag{8}$$

where Wf_j_res is the annual amount of furniture wood used in the residential sector in municipality j [t y^{-1}], w_m is the basic unit of furniture wood used for furniture m [t set^{-1}], R_{mn} is the annual number of purchases of furniture m by household type n [set $household^{-1}$ y^{-1}] (MIAC 2008, 2009), N_{jn} is the number of households of type n in municipality j [household], b is the proportion of wooden furniture to the total amount of furniture m (METI 2010), a is a production efficiency factor from round wood to construction wood, and Y_w is a forest yield factor [t y^{-1} ha^{-1}].

Wood Pulp for Paper Provisioning Ecosystem Services

Wood pulp use for paper represents 42% of overall wood consumption, equal to the percentage for construction wood. Paper and paperboard are made from pulp by hand or machine. In this section, the equations for estimating the amount of forest area needed to supply wood for paper are presented.

Business sector: The forest area needed to supply wood for paper used by the business sector ($FESU_{Wpij}\_bus$) in each municipality was estimated using these equations:

$$Wp_{ij}\_bus = P_i \times L \times c_{ij} \times d \times (1 - e) \tag{9}$$

$$FESU_{Wpij}\_bus = Wp_{ij}\_bus / X_w \tag{10}$$

where Wp_{ij}_bus is the annual amount of papermaking wood used in business sector i in municipality j [t y^{-1}], P_i is the annual purchase of paper, paperboard, and processed paper product in business sector i [million yen y^{-1}] (METI 2010), L is the weighted average price of paper, paperboard, and processed paper products [t・million yen^{-1}] (Osaka Prefecture 2010), c_{ij} is the proportion of employees in business sector i in municipality j, d is the round wood conversion factor from paper pulp [m^3 t^{-1}] (MAFF, 2008), e is the paper recycling rate (PRPC 2005), and X_w is the annual production of round wood per forest area [m^3 y^{-1} ha^{-1}] (FA 2010).

Residential sector: In this section, the method of calculating the amount of forest area needed to supply wood for paper used by the Osaka residential sector ($FESU_{Wpij}\_res$) is presented. $FESU_{Wpij}\_res$ is calculated as follows:

$$Wp_j\_res = Q_j \times f \times d \quad (11)$$

$$FESU_{Wpj}\_res = Wp_j\_res / X_w \quad (12)$$

where Wp_j_res is the amount of timber used for making paper used by the residential sector in municipality j in one year [t y^{-1}], Q_j is the number of inhabitants in municipality j [person] (Osaka Prefecture 2010), f is the amount of annual paper consumption per inhabitant [t $person^{-1}$ y^{-1}] (METI 2010; Osaka Prefecture 2005), d is the ratio of log conversion into paper pulp [m^3(log) t^{-1}], and X_w is an annual production volume of logs per forest area [m^3 y^{-1} ha^{-1}].

CO_2 Regulating Ecosystem Service

Vegetation also performs the function of assimilating carbon dioxide (photonic synthesis), to absorb minerals from outside by using photon energy and to photosynthesize carbohydrates such as glucose or starch. In this process, vegetation absorbs CO_2 and gives out oxygen. This function is one of the most important ecosystem services that forest ecosystems provide in terms of climate change mitigation. We refer to it here as "CO_2 absorption services." Forest ecosystems play a major role as a regulating ecosystem service provider. In this section, we present the method of calculating the forest area used to absorb CO_2 in the *ESU* framework, referred to as $FESU_{CO2}$.

Business sector: The method of calculating the amount of forest area needed to absorb the CO_2 ($FESU_{CO2ij}\_bus$) emitted through business sector activity in each municipality is calculated as follows:

$$E_{ij} = A_{ij} \times e_i \quad (13)$$

$$C_{ij} = E_{ij} \times \sum_p \left(c_p \times r_p\right) \times g \quad (14)$$

$$FESU_{CO_2ij}\_bus = C_{ij} / Y_c \quad (15)$$

where E_{ij} is the annual energy consumption of business sector i in municipality j [GJ y^{-1}], A_{ij} is the number of employees of business sector i in municipality j [person] (Osaka Prefecture 2010), e_i is the annual energy consumption per employee of business sector i in one year [GJ $y^{-1}person^{-1}$]

(METI 2009, Osaka Prefecture 2010), C_{ij} is the annual CO_2 emission of business sector i in municipality j [tCO_2 y^{-1}], c_p is the carbon emission coefficient of energy type p [tC GJ^{-1}] (METI 2009, MOE 2008), r_p is the proportion of energy type p consumption to total energy consumption (METI 2009), g is the conversion factor from carbon mass to CO_2 mass (or 44/12), and Y_c is the CO_2 absorption amount of unit forest area (0.97 [tC ha^{-1} y^{-1}]) used in the GFN (2008).

Residential sector. The method of calculating the forest area needed to absorb the CO_2 ($FESU_{CO2ij}\_res$) emitted by the residential sector's activity in Osaka is as follows:

$$E_{jp} = \sum_{l}\sum_{n}(N_{jln} \times e_{lnp}) \tag{16}$$

$$C_j = \sum_{p}(E_{jp} \times c_p) \tag{17}$$

$$FESU_{CO_2 j}\_res = C_j / Y_c \tag{18}$$

where E_{jp} is the annual consumption of energy type p in municipality j [GJ y^{-1}], N_{jln} is the number of household type n in the houses of type l in municipality j [house], e_{lnp} is the unit of energy type p consumption by households of type n in houses of type l [GJ $house^{-1}$ y^{-1}], C_j is the amount of CO_2 emissions in municipality j [tCO_2], c_p is the carbon emission coefficient of energy type p [tC GJ^{-1}] (METI 2009, MOE 2008), and Y_c is a CO_2 absorption amount of unit forest area [tC ha^{-1} y^{-1}], the same coefficient as in equation (15).

Forest Area Needed for Buffering NO_x and SO_x

NO_x and SO_x are emitted into the atmosphere as a result of many types of energy-generating processes. As a result, NO_x and SO_x descend and are deposited on the forest surface. In this process, forest ecosystems initiate the carbon exchange reaction between NO_x or SO_x and positive ions, such as calcium and potassium, which exist on the tree canopy. This process has a canopy buffering capacity. In this section, we explain the method of calculating the amount of forest area needed to buffer NO_x and SO_x. This area is referred to as $FESU_{N/S}$.

Business sector: The calculation process to determine the forest area needed to buffer NO_x and SO_x ($FESU_{N/Sij}\_ope$) emitted through the activity of the business sector in each municipality is as follows:

$$N_{ij} = E_{ij} \times \sum_{p}\left(n_p \times r_p\right) \tag{19}$$

$$S_{ij} = E_{ij} \times \sum_{p}\left(s_p \times r_p\right) \tag{20}$$

$$FESU_{N/Sij}\_bus = f(N_{ij}, S_{ij}) \tag{21}$$

where N_{ij} is the annual NO_x emission of business sector i in municipality j [NO_x-kg y^{-1}], n_p is the NO_x emission coefficient of energy type p [NO_x-kg GJ^{-1}] (KEPCO 2011; Nansai and Moriguchi 2012), r_p is the proportion of energy type p to total energy consumption (METI 2009), S_{ij} is the annual SO_x emission of business sector i in municipality j [SO_x-kg y^{-1}], and s_p is the SO_x emission coefficient of energy type p [SO_x-kg GJ^{-1}] (KEPCO 2011; Nansai and Moriguchi 2012).

$FESU_{N/Sij}$ is calculated by assigning values of N_{ij} and S_{ij} to the conversion function (21). This is a non-linear function suggested by (Shaw et al. 2010) based on critical loads. The critical load is the maximum acceptable amount of NO_x and SO_x deposition without causing any negative influence on forest ecosystems. The critical load for the forest areas in Osaka was determined by (Yamashita and Ito 2009).

Residential sector: The method of calculating the forest area needed to buffer NO_x and SO_x from residential sector activity in Osaka ($FESU_{N/Sij}$*_res*) is as follows:

$$N_j = \sum_p \left(E_{jp} \times n_p\right) \quad (22)$$

$$S_j = \sum_p \left(E_{jp} \times s_p\right) \quad (23)$$

$$FESU_{N/Sj}\_res = f(N_j, S_j) \quad (24)$$

where N_j is the annual NO_x emission in municipality j [NO_x-kg y^{-1}], E_{jp} is the annual consumption of energy type p in municipality j [GJ y^{-1}] (the same as the figure in equation (16)), n_p is the NO_x emission coefficient of energy type p [NO_x-kg GJ^{-1}], S_j is the annual SO_x emission in municipality j [SO_x-kg y^{-1}], and s_p is the SO_x emission coefficient of energy type p [SO_x-kg GJ^{-1}]. $FESU_{N/Sij}$ is calculated using the balance of N_{ij} and S_{ij} in equation (24), which is the same as in equation (21).

Analysis of External Dependence in Ecosystem Services

As noted above, because most major cities have few remaining natural ecosystems, they rely largely on external ecosystems. On the other hand, small, local cities surrounding the center of the region have potential to provide their own ecosystem services from internal ecosystems. To design naturally symbiotic cities, we must understand cities' different forms of dependence on ecosystem services from outside the region in order to establish effective management strategies. From this viewpoint, we first conducted a cluster analysis by using demand- and supply-side variables of *FESU* to view the characteristics of Osaka's demand-supply balance. We then evaluated the feature of each cluster using the external dependence indicator *r* to check the externality of the cities, where External dependence indicator shows how much overshoot city's *FESU* comparing with their forest stock within cities as below. The variables used in cluster analysis are as follows.

Demand-side Variables

First, we set the business sector's variables. *FESU* per employee [ha $person^{-1}$] of *FESU* type i in municipality j is a proxy variable for the characteristics of the business sector. The working style changes with the variety of business structures; it affects *FESU* intensity and the links between forest ecosystem services and urban activities. For instance, the composition in Osaka, the largest central city in this region, mainly consists of wholesale and retail trade sectors (32%) and general public administration (25%). On the other hand, Chihaya Akasaka village (population of 5,000 people) consists mostly of information and communications (31% accommodations, and 22% eating and drinking services). In general, information and communication technologies, such as data centers, save paper consumption related to $FESU_{wp}$ but promote electricity use related to $FESU_{co2}$. The phase of introducing information technology differs according to area, and it affects the efficiency of *FESU*.

Second, we selected *FESU* per resident for each municipality [ha person^{-1}] of *FESU* type i in municipality j, to reflect residential sector characteristics. (Japan is a rapidly aging society). On the other hand, urbanization continues as young people in particular move from rural to urban areas. Usually, urban people live in buildings containing few wood biomasses, in contrast to rural houses. These characteristics of age distribution and dwelling environment affect *FESU* patterns through energy consumption, depending on insulation, thermal source, and wood material use.

Supply-side Variables

Depending on the quality of forest management, forest ecosystem service flow is generally proportionate to the amount of forest stock. The total percentage of forest cover in the Osaka prefecture is 28.5 %. However, the range is 0 to 94%, depending on the geographical characteristics of municipalities. As a supply-side variable of *FESU*, we selected the percentage of forest cover for each municipality, calculated by equation (21).

$$Percent\ of\ forest\ cover_j = FC_j / LA_j \quad (21),$$

where FC_j is the forest area within municipality j [ha], LA_j is the total land area, including forest areas within municipality j [ha].

External Dependence Indicators

Finally, we added an external dependence indicator for ecosystem services outside the region as an externality proxy, to express the demand-supply balance of forest ecosystem services for each municipality. Here, dependence on ecosystem services from outside ecosystems is estimated as follows:

$$FESU_{ij} = FESU\_bus_{ij} + FESU\_res_{ij} \quad (22)$$

$$r_{ij} = (FESU_{ij} - FC_j)/FESU_{ij} \quad (23)$$

where $FESU_{ij}$ is the summation of *FESU* type i of business and residential sectors in cluster j [ha], r_{ij} is the external dependence of *FESU* type i on outside forests of cluster j, and FC_j is the forest area within cluster j [ha].

RESULTS AND DISCUSSION

FESU of municipalities in Osaka Prefecture

First, *FESU* calculations per employee [ha person^{-1}] in the business sector are shown in Figure 2. The Information and Communication sector has the largest *FESU*, and $FESU_{Wp}$ accounts for 72% of the total *FESU* of these businesses. In most businesses, $FESU_{CO2}$ accounts for the greatest part of *FESU*, since carbon dioxide emission caused by energy consumption is a dominant aspect of business activity. In the case of Food and Beverages Service/Accommodation, $FESU_{CO2}$ accounts for 89% of total *FESU*.

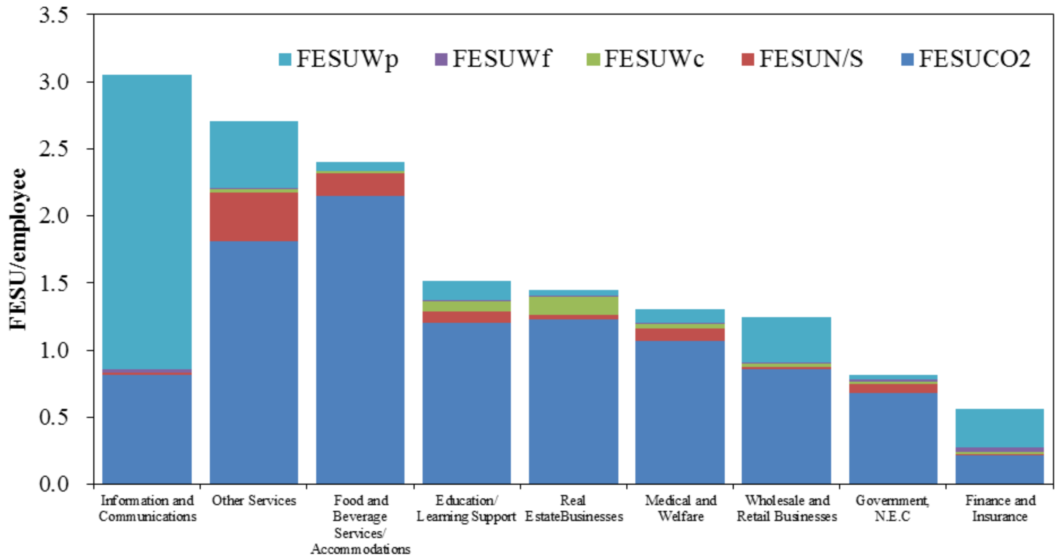

Figure 2 *FESU* per employee in nine types of businesses

Second, *FESU* per capita [ha $person^{-1}$] values in the residential sector of each municipality in the Osaka prefecture are shown in Figure 3. This result also indicates that $FESU_{CO2}$ accounts for a large proportion of *FESU* in all municipalities. The second largest *FESU* is *FESUwc*. However $FESU_{CO2}$ and *FESUwc* have large standard deviations (0.02 and 0.22, respectively), within the municipalities. This result reflects that lifestyle and land use characteristics differ by city. For instance, Ibaraki (the 12^{th} city), is a commuter town for people who work in the main business area. These people generally live in apartment buildings made of non-timber materials, such as concrete and iron, and use high amounts of energy to regulate room temperature, instead of using an air regulation ecosystem service. Based on this result, it is evident that urban energy consumption plays a huge part in the increasing dependence on ecosystem services. At the same time, energy saving contributes toward mitigating climate change. In addition, furniture and paper consumption, and the nitrogen and sulphur load, has little impact on the use of ecosystem services. Furthermore, we see a weak correlation between population size and *FESU* per capita, which implies that the urban population has much more responsibility for managing external forest ecosystems.

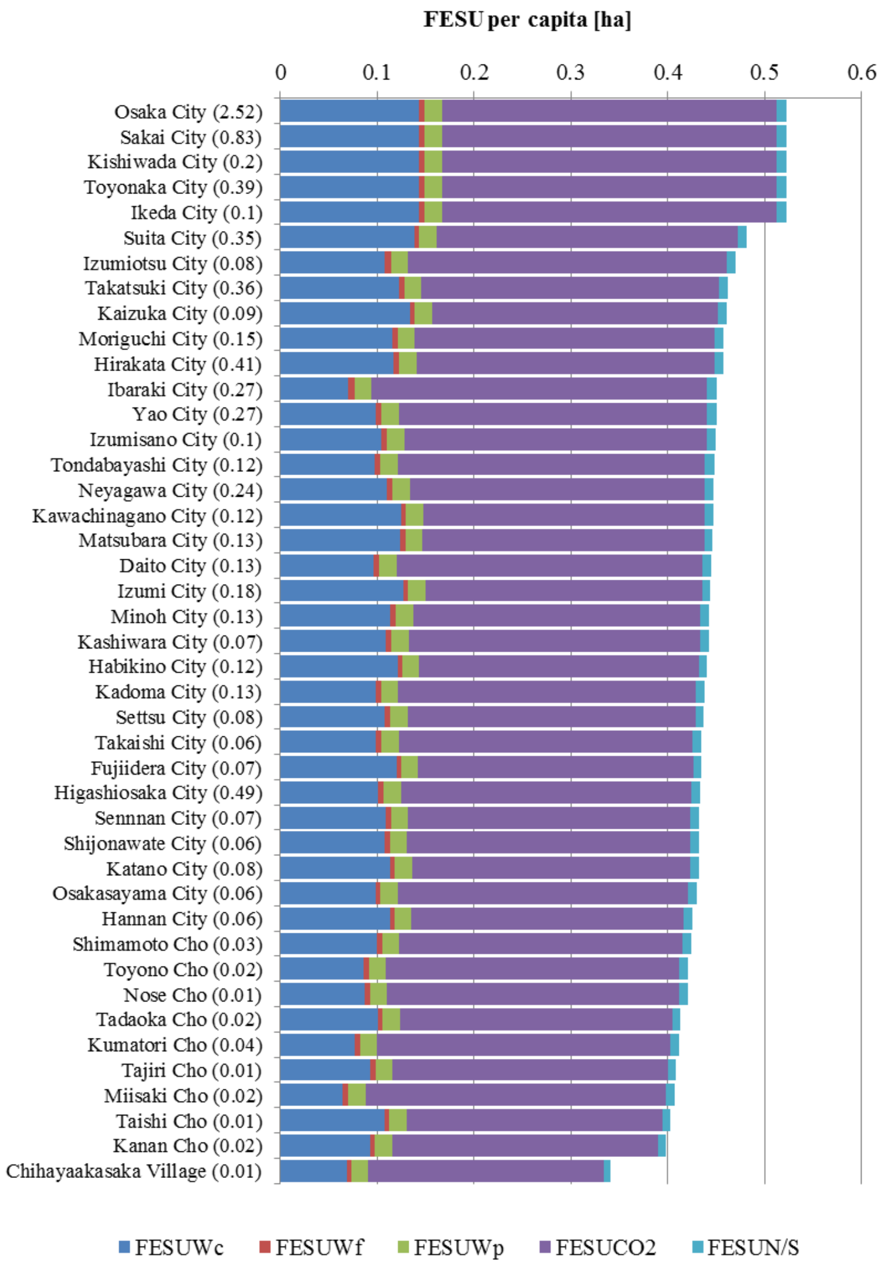

Figure 3 *FESU* intensity by municipality

Note: the number after a city's name is the city's population (in millions).

Finally, the balance of *FESU* per area [ha per km^2] in the business and residential sectors of each municipality in the Osaka prefecture is shown in Figure 4. This figure reveals that each area, except Osaka city (the center of this region), has approximately the same *FESU* balance between residential and business sectors. The business sector is responsible for 52 % of the total *FESU* in Osaka's municipalities, while the *FESU* of residential sectors account for 48% of the total in municipalities with low overall *FESU* values. This suggests that both residential and business sectors have an equal responsibility to manage the sustainability of ecosystem services in this region.

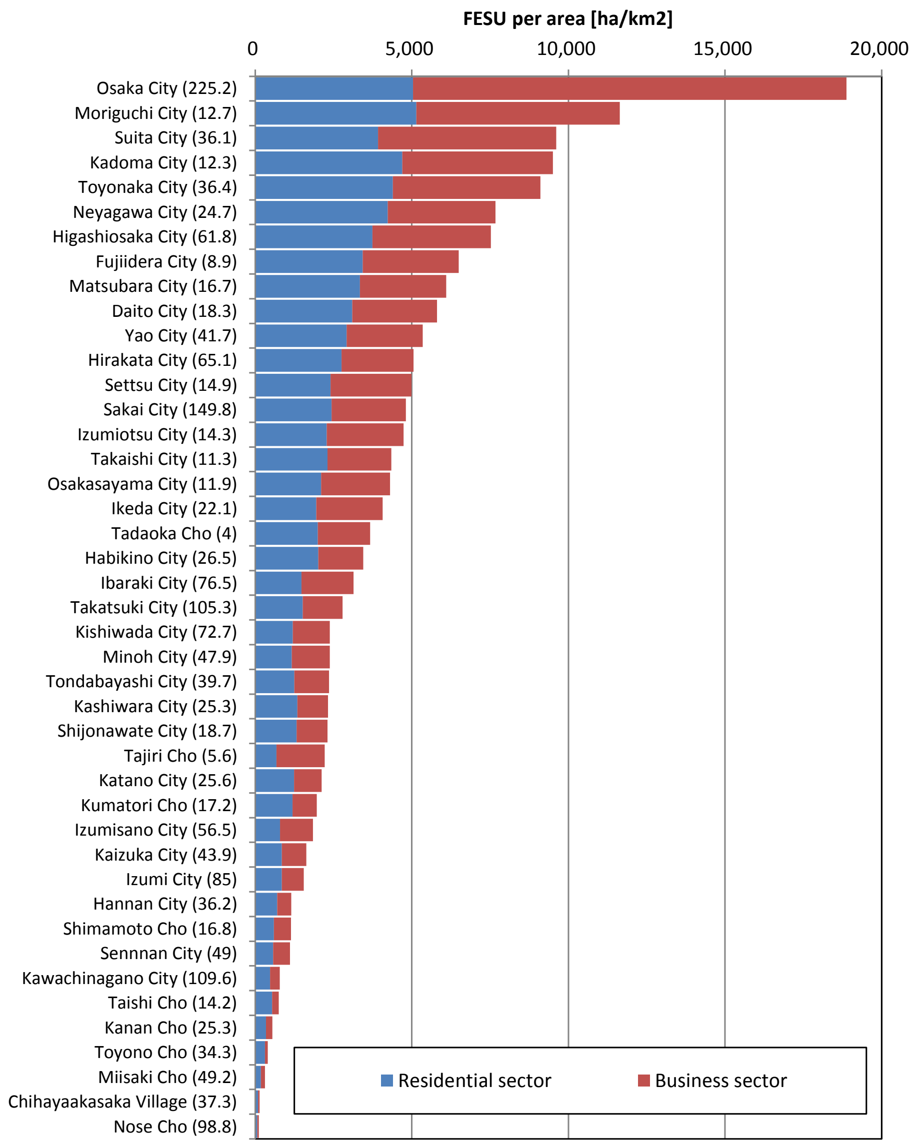

Figure 4 *FESU* residential and business sector balances by municipality

Note: the number after each city's name is the size of each municipality (km^2).

Characteristics of External Dependence on Forest Ecosystem Services

The results of the cluster analysis are shown in Figures 5 and 6. We employed a k-means clustering method and decided the number of clusters by a within-cluster sum of squares. Municipalities in Osaka were clustered into five groups, according to their characteristics (shown in Figure 5), and each cluster has the characteristics of forest ecosystems and *FESU* in Figure 6. It should be noted that *FESU* value is averaged per capita and per employee; thus, we cannot compare values directly across sectors. Cluster 1 is the residential area located at the foot of the mountain, surrounded by river and forest. Half the land cover is forest and the activity level is in the middle level comparing with other clusters. Clusters 3 and 5 are in rural areas, where old wooden houses are located, especially typical Japanese and old traditional landscape "*satoyama*" (UNU 2010), which remain in Cluster 5. On the other hand, Cluster 2, in the middle part, is the central urban area of the Osaka prefecture, where mainly commercial buildings are located. Cluster 4 is a heavy industrial area, in which many energy-intensive buildings, such as chemical plants, are located. Figure 6 illustrates the value of each *FESU* type by cluster and sector. We can see the distribution of *FESU* characteristics in each cluster. *FESU's* output dependence is larger than input dependence, and $FESU_{CO2}$ is the dominant factor of external dependence in all clusters and sectors. The residential sector has a second peak in *FESUwc* through house building, and the business sector has large *FESU* in paper consumption.

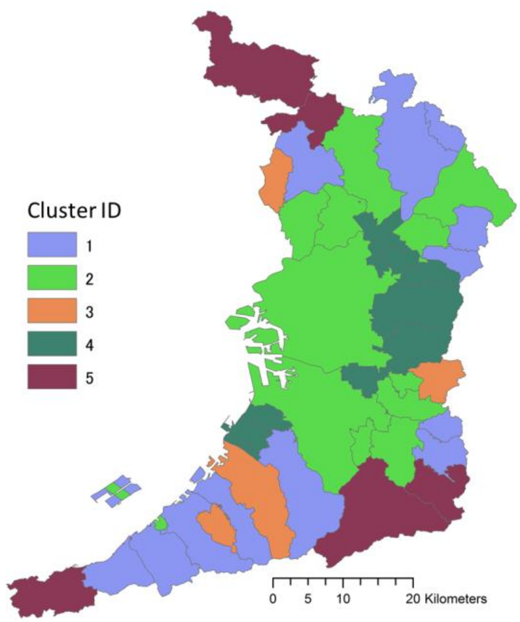

Figure 5 Mapping result of cluster analysis

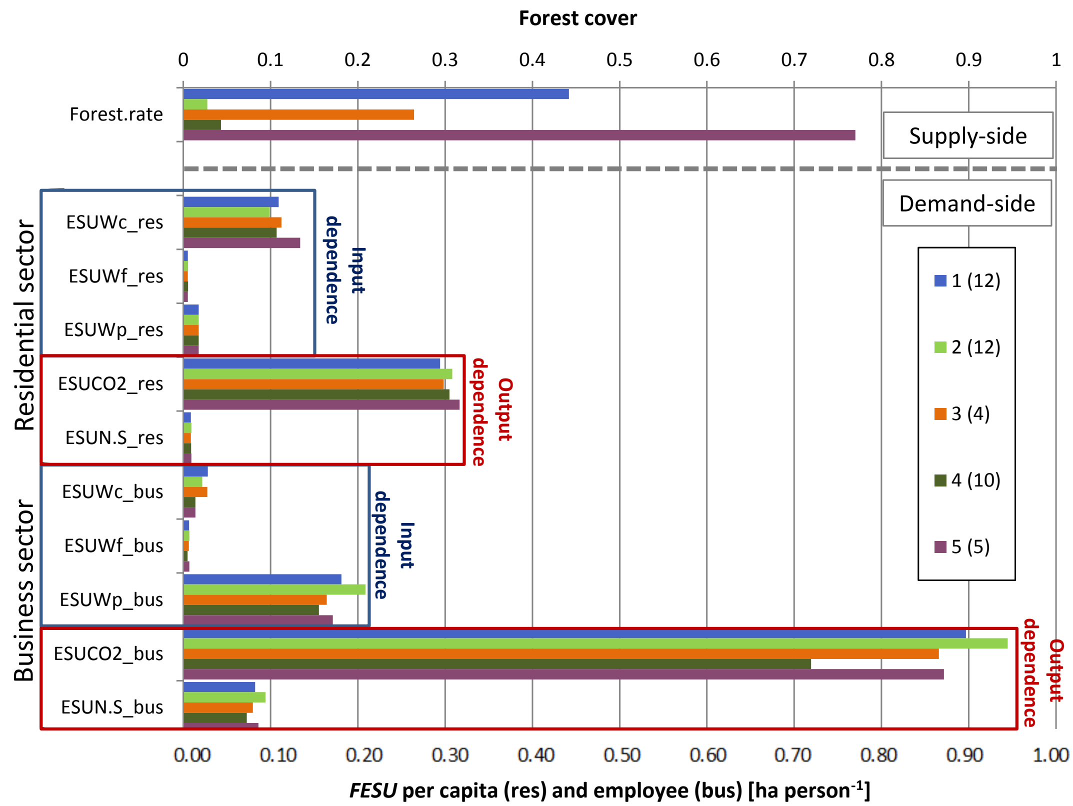

Figure 6 Characteristics of forest ecosystem services use by clusters

Finally Table 1 shows the external dependency of each *FESU* type. Positive value means that the *FESU* type has external dependence, and negative value means that FESU is within the capacity of the cities. Bar size in each cell is a relative scale row -wise. As seen in Clusters 2 and 4, commercial and industrial areas in the Osaka prefecture have a relatively imbalanced demand-supply structure and wholly depend on external forest ecosystems. And as seen in Clusters 1 and 3, these cities have forest stock that is barely able to supply wood furniture needs. Even Cluster 5, which has the best demand-supply balance, cannot satisfy $FESU_{CO2}$.

Table 1 External dependency by *FESU* type

		r value				
	N	FESUWc	FESUWf	FESUWp	FESUCO2	FESUNS
cluster 1	12	0.770	-2.805	0.581	0.950	0.130
cluster 2	12	0.994	0.912	0.991	0.999	0.982
cluster 3	4	0.929	-0.199	0.874	0.985	0.740
cluster 4	10	0.995	0.923	0.993	0.999	0.984
cluster 5	15	-1.092	-39.660	-3.984	0.457	-8.347

FUTURE RESEARCH

Applying the *ESU* framework, this paper has presented a method of quantitatively evaluating the level of external dependence of urban activities on forest ecosystem services. This method is applicable to urban areas in developed countries, where the reconstruction of naturally symbiotic cities is planned, and also in developing countries, where urbanization is progressing and cities can still take action to incorporate services from existing ecosystems, thereby enabling a faster transition to environmental sustainability. The next step for this research is (1) to reveal additional city attributes, which affect *FESU* tendencies, such as transportation systems, education, and income level; (2) to connect the ESU regional input/output analysis, to grasp the origin of external ecosystem services; and (3) to apply this evaluation framework to other areas and to verify its utility, supporting the development of symbiotic strategies. The aim is to contribute to the development of indicators used to evaluate human activities (especially in urban areas), such as by the CBI.

CONCLUSION

In this study, a case study to assess the degree of dependence of urban activity on forest ecosystem services was conducted. An ecological footprint-based framework called *Forest Ecosystem Services Use* (*FESU*) was used for the evaluation. This study evaluated variations of dependence on forest ecosystem services in the municipalities of Osaka, targeting the civilian sector (composed of the business and residential sectors) in its analysis. To assess the dependence of each municipality from several viewpoints, a cluster analysis was performed, with variables representing the features of demand and supply of forest ecosystem service by municipality. Two main results were found in this analysis. First, dependence on CO_2 absorption services accounted for a large proportion of total ecosystem services use. Second, municipalities were clustered into five groups, with most of the municipalities constituting a large city that should modify its urban activities to balance the demand and supply of forest ecosystem services within its boundaries. These results show that the *FESU* framework is capable of delivering a meaningful assessment of the level and nature of a region's dependence on ecosystem services. This framework could contribute toward improvement of the methods used to evaluate the impact of human activities and to create a sustainable society capable of coexisting with nature.

LITERATURE CITED

CBD. (2008). City Biodiversity Index http://www.cbd.int/authorities/gettinginvolved/cbi.shtml.

CBD. (2012). The Launch of the Global City and Biodiversity Outlook. http://www.cbd.int/en/subnational/partners-and-initiatives/cbo

CBO. (2015). The Cities and Biodiversity Outlook. http://www.cbd.int/en/subnational/partners-and-initiatives/cbo

FA. (2010). Annual Report on Trends of Forest and Forestry, Statistics: Forest Agency, Ministry Of Agriculture, Forestry And Fisheries, Japan. http://www.rinya.maff.go.jp/j/kikaku/hakusyo/index.html.

GFN. (2008). Guidebook to the National Footprint Accounts 2008 Edition. Global Footprint Network, CA, USA.

Itou, A. and Takahashi, Y. (2006). Ecological Footprint and Inter-industry analysis –Methodology and the applications to Regional Policy –. Business Journal of PAPAIOS Inter-Industrial Relations 14:1:27-34. (in Japanese)

JAWIC. (2003). The Survey on Wood Products and Information, Statistics: Japan Wood Products Information and Research Center, pp 19.

Kato, M. (2011): How to use and improve the City Biodiversity Index, Journal of the Japanese Society of Revegetation Technology 36(3), 369-372. (in Japanese)

KEPCO. (2011). Information in Relation To the Environment, Data Sheet: Kansai Electric Power Co. Inc. Corporate Social Responsibility Report. (In Japanese) http://www1.kepco.co.jp/corporate/csr/data/data01.html.

MAFF. (2008). The Statistical Yearbook of Ministry Of Agriculture, Forestry And Fisheries. Ministry of Agriculture, Forestry and Fisheries, Japan.

MAFF. (2010). Timber Balance Sheets, Statistics: The Statistics of Ministry of Agriculture, Forestry and Fisheries of Japan http://166.119.78.61/j/tokei/kouhyou/mokuzai_zyukyu/index.html.

ME. (2008). The Emission Factors Of Electrical Power Supplier, Press: Ministry of the Environment, Press Release Documents. http://www.env.go.jp/press/press.php?serial=11956.

METI. (2010). Current Survey of Production, Statistics: Ministry of Economy, Trade and Industry, Manufacturing. http://www.meti.go.jp/statistics/tyo/seidou/result/ichiran/08_seidou.html.

METI. (2009). Survey of Energy Consumption Statistics, Statistics: Ministry of Economy, Trade and Industry, Manufacturing, Agency for Natural Resources and Energy. http://www.enecho.meti.go.jp/info/statistics/energy/kekka/21/21result-2.htm.

MIAC. (2009). Family Income and Expenditure Survey, Statistics: Ministry of Internal Affairs and Communications, Statistics Bureau, Director-General for Policy Planning (Statistical Standards) and Statistical Research and Training Institute. http://www.stat.go.jp/data/kakei/2.htm#new.

MIAC. (2008). Housing and Estimate, Statistics: Ministry of Internal Affairs and Communications, Statistics Bureau, Director-General for Policy Planning (Statistical Standards) and Statistical Research and Training Institute. http://www.stat.go.jp/data/jyutaku/2008/index.htm.

MLIT. (2006-2010). Statistics of Construction put-in-place in Japan. Ministry of Land, Infrastructure, Transport and Tourism, Japan

MLIT. Ministry of Land, Infrastructure, Transport and Tourism. (2010) Annual Report of Committee on statistics of building stock. http://www.mlit.go.jp/toukeijouhou/chojou/stockhoukokusyo.pdf

Nagaoka, K., Inadu, R., Tohgishi, Y., Tanikawa, H. and Hashimoto, S. (2009). Estimation Of Surface / Subsurface Material Stock Related To The Construction Sector of All Prefectures In Japan. Collection of papers of Committee on Environmental Systems 37:213-219. (in Japanese)

Nakano, K. and Wada, Y. (2007). Methodological Progress of Ecological Footprint analysis and Some Controversial Issues. Annual research report of Research Center for Sustainable and Environment, Shiga University. (in Japanese)

Nansai, K. and Moriguchi, Y. (2012). NOx, SOx and PM emissions factors of Japanese stationary sources (EF-JASS, ver.2), Center for Global Environmental Research, National Institute for Environmental Studies, Ibarakai, Japan.

Natural capital coalition. (2016). Natural Capital Protocol, http://naturalcapitalcoalition.org/protocol/

Oikawa, T. and Urabe, T. (2002). Research on controlling the construction waste (1) - The Stock and Lifetime of Buildings in the Tokyo's 23 Wards, Estimate for Future Building Demolitions -. Annual research report of The Tokyo Metropolitan Research Institute for Environmental Protection 182-190. (in Japanese)

Osaka Prefecture. (2005). Input- Output Tables 2005, Osaka Statistic Year Book. http://www.pref.osaka.jp/toukei/sanren_k/index.html

Osaka Prefecture. (2010). Osaka Statistic Year Book, Statistics: Osaka Prefecture. http://www.pref.osaka.jp/toukei/nenkan/tn10-04xls.html.

PRPC. (2005). The Used Paper Recovery Rate, Statistics: Paper Recycling Promotion Center, Japan. http://www.prpc.or.jp/menu05/linkfile/kaisyuritu.pdf.

Shaw, N. R, Matsui, T, Machimura, T, Kato, S., and Morioka, T. (2010). Connecting industry and ecosystems: A macro analysis of forest ecosystem service use in Japanese Industry sectors. Collection of papers of Environmental Information Science 24:213-218.

Tanikawa, H. and Imura, H. (2001) Quantification and Evaluation of Total Material Requirement Related To The Urban Construction: Case Study For Residential Development. Collection of papers of Japan Society of Civil Engineers 671:18:35-48. (in Japanese)

TEEB. (2010). TEEB FOR LOCAL AND REGIONAL POLICY MAKERS. http://www.iges.or.jp/jp/news/topic/pdf/1103teeb/teeb_d2_j.pdf.

TEEB. (2011). TEEB Manual for Cities: Ecosystem Services in Urban Management http://www.teebweb.org/publications/all-publications/

TEEB. (2012). The Economics of Ecosystems and Biodiversity (TEEB) in Local and Regional Policy and Management http://www.teebweb.org/publications/teeb-study-reports/local-and-regional/

UNU. (2010). *Satoyama* initiative http://satoyama-initiative.org/

Wackernagel, M. and Rees, W. E. (1995). Our ecological footprint: reducing human impact on the earth, New Society Pub.

Wiedmann, T. and Barrett, J. (2010). A Review of the Ecological Footprint Indicator—Perceptions and Methods, Sustainability, 2, 1645-1693.

Yamashita, K. and Ito, F. (2009). Adverse effects of acid deposition on ecosystems by the emission of nitrogen oxides in Asia, Theory & App. of GIS. 17: 1: 43-52. (In Japanese)

Yata, S., Nishimura, T., Kajita, H. and Mukudai, J. (1978). Physical and mechanical properties of thinned wood of Sugi grown in Wachi district, Kyoto Prefecture (Forestry). Kyoto Prefectural University Academic Report. Agriculture 30, 72-78. (in Japanese)