Research article

Equivalency and Similarity Assessment of Forest Ecosystem Services by a Multi-Point Field Survey in Nagoya City, Japan

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Abstract Urban forests provide a variety of benefits to citizens, including micro climate regulation, soil erosion regulation, and wildlife habitats. Under the biodiversity offset system, the equivalency and similarity of biodiversity and ecosystem services (BD/ESs) are important but controversial issues. The purpose of this study is to develop a simple method to assess aspects of the equivalency and similarity of forest BD/ESs and consider their applicability to biodiversity conservation policy. The study was conducted on a selection of 41 forests in Nagoya City. Several combinations of forests were recognized as similar providers of BD/ESs. Historical land-use change was also important in assessing forest equivalency and similarity for biodiversity conservation policy.

Keywords ecosystem service, biodiversity, forest, Japan, GIS

INTRODUCTION

Urban forests provide many benefits to citizens, including micro climate regulation, soil erosion regulation, and habitats for wildlife. According to the Millennium Ecosystem Assessment (MA, 2005), these benefits can be summarized as ecosystem services (ESs) provided to human society. There are several types of forest, including urban parks, secondary forests, and natural forests. Each plays a different role in providing biodiversity (BD) and ESs. Despite their proven benefits, urban forests in Japan have been decreasing over the past several decades. Biodiversity offsets (BO) are a policy instrument developed to compensate for the loss of BD by development activities (BBOP, 2013). Madsen et al. (2010) summarized the global state of BO systems, and reported that the USA and Australia are experienced in this field. In contrast, there is no legal requirement to conduct BO in Japan on the national scale, although a basic guideline of the environmental impact assessment law recommends compensating for the impacts of a development project on BD (MOE-J, 2014).

Many issues related to the BO system have been identified, including metrics, ecological equivalency, and no-net loss (Maron et al., 2012; Bull et al., 2013; Koyama and Okabe, 2017). Additionally, the positive outcomes of BO have occasionally been overestimated (Pickett, 2013; Gibbons et al., 2017). Nevertheless, BO has been recognized as a biodiversity conservation policy and its potential use has been studied (MOE-J, EIA Division, 2014), with a focus on important issues such as gains and losses of biodiversity in the BO system. Many BO related assessment methods have been implemented and studied (Quétier and Lavorel, 2011), including the Habitat Hectares method (The State of Victoria, https://www.environment.vic.gov.au/native-vegetation /native-vegetation), and the BioBanking assessment methodology (The State of New South Wales, http://www.environment.nsw.gov.au/biobanking/assessmethodology.htm), both in Australia. Another study focused on the development of objective and transparent BO assessment methods

(Gibbons et al., 2009). Koyama and Okabe (2017) summarized many issues related to the potential application of the BO system in Japan. Several case studies have also touched on the applicability of BO methods in Japan (Hasegawa and Hayashi, 2014; Ito and Hayashi, 2014). However, not only species, habitat, and ecosystems, but also the similarity of potential ESs needs to be considered in the future (MOE-J, EIA-Division, 2014; Koyama and Okabe, 2017). In the study on supporting and regulating ESs, Yonekura et al. (2014) categorized forests into several types based on a simple field survey for 52 forests in Nagoya. Hayashi and Ooba (2017) analyzed the categorization of cultural ESs (CESs) based on a multi-point field survey for 180 forest sites in Nagoya City. These studies were limited both in the scope of ESs covered and in the assessment items included in the survey. A comprehensive assessment of BD/ES potential is needed in order to develop a simple assessment method.

OBJECTIVES

The purpose of this study is to develop a simple method, one that could be used in the development of biodiversity conservation policy, to assess the equivalency and similarity aspects of forest BD/ESs. To this end, a case study was done in Nagoya City using a multi-point field survey. The scope of this study was expanded to cover a variety of BD/ESs, in contrast with the study of Hayashi and Ooba (2017), which focused only on cultural ESs.

METHODOLOGY

Study Method

Nagoya City (city hall: 35.181°N, 136.906°E) is the third largest city in Japan. The study area is presented in Fig 1. The average annual temperature and precipitation in 2017 were 15.9°C and 1701.5 mm (Japan Meteorological Agency, http://www.data.jma.go.jp/obd/stats/etrn/index.php).

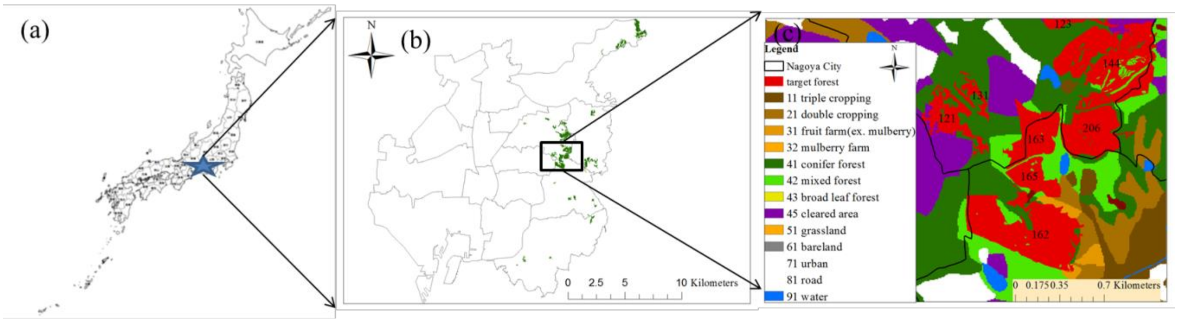

Fig. 1 Maps of (a) Japan with Nagoya City as a star symbol, (b) Nagoya City outlined in black and forest in green, and (c) a sample of targeted forests with 1955 land use map

Source: Forest by Nagoya green coverage GIS (Nagoya City) and 1955 Land-use maps by GSI (1955)

In this paper, forests were defined as the continuous tree crown area within a forest area ≥1 ha. Based on the Nagoya green coverage GIS (geographic information system) data provided by Nagoya City, around 200 forests (of around 240 total forests in the city) have been surveyed since 2012. The survey items included species; the diameter at breast height (DBH ≥ 5cm); tree height; litter thickness; over-, mid-, and understory canopy cover (assessed visually); and naturalness. The items, proxies, methods, and data are summarized in Tables 1 and 2. The carbon stock estimation method is explained below. The surveys were conducted in a similar manner to Hayashi and Ooba (2015). A second round surveys (referred to hereafter as the 2nd survey) on the same forests was begun in 2016, including additional items and expanding the survey coverage to a 300 m^2 area. In some cases, the location of the site had to be changed to allow the extension of survey coverage area. For several forests, new 200 m^2 sites were set up in addition to the original 100 m^2 sites. In this study, the results from the 2nd survey were used along with several first round results that had enough data for this analysis. Bamboo was counted as one independent species, and the number of individual trees included the number of individual bamboo trees (counted only within 100 m^2 and converted to the 300 m^2 value). The 2nd survey is not yet complete for all targeted forest sites. For this study, 41 forest sites were selected.

Table 1 BD/ES items, proxies, methods and data

BD/ES	Item	Proxy	Method	Data
BD	Conservation area	C_A	Check special green conservation areas designated by Nagoya City and Aichi Pref.	Nagoya City urban planning information providing service, URL: http://www.tokei-gis.city.nagoya.jp/
	Habitat size	Forest area	Continuous tree crown areas (≥ 1ha)	Nagoya green coverage GIS(Nagoya City)
	Species diversity	Simpson' DI	Details in Table 2	
	Naturalness	Naturalness	Subjective judgement on a scale of 1 to 5 scale by the author	Based on field survey
RES	Micro climate regulation	Forest volume	Details in Table 2	
	Soil erosion regulation	Forest flow cover	Details in Table 2	
SES	Carbon Stock	C-Stock	Details in the main text	
	Soil formation	Litter (thickness)	Three points in each 100 m^2 area and averaging the results of several visits	Based on field survey

Table 2 BD/ES estimation methods

ESs	Description	Formula
Species diversity	The diversity of species is an important indicator for explaining the ecological community diversity. Hasegawa and Hayashi. (2014) compared several diversity related indexes including Simpson' Diversity index (*Simpson's DI*) to the results of a BO assessment methodology. In this study, *Simpson' DI* was used to explain within-habitat diversity in Formula 1 (Simpson, 1949; Morishita, 1996; Ohgaki, 2008). Individual species and the number of the species were used to calculate *Simpson' DI*.	$Simpson'DI = 1 - \Sigma\left(\frac{n_i}{N}\right)$ (1) N : number of individuals n_i : number of each species
Micro climate regulation	Hiruta and Ishikawa (2012) studied the heat-reduction effect by green spaces, which compared three indicators: forest canopy coverage, tree volume, and ground coverage. They concluded that tree volume had the largest effect on the heat-reduction, especially for daytime in summer. Our study focused on the micro climate regulation in a summer daytime. Forest volume was picked out as a proxy in this study by Formula 2 using forest cover and average tree heights (DBH ≥ 5 cm) (Kobayashi et al., 2016). The height of bamboo trees (only 5 selected bamboo trees were measured in the bamboo forest) were included in the average tree heights and forest cover.	$V_i = 10^4 * (C_{ov}H_{ov} - (1 - C_{ov})C_{mid}H_{mid}) + (1 - C_{ov})(1 - C_{mid})C_{und}H_{und}\}$ (2) V_i : forest volume in 100 m^2 site i (m^3/ha) C_{ov} : overstory cover (10 m<) C_{mid} : midstory cover (10 m≥, >5 m) C_{und} : understory cover (5 m≥, > 1m) H_{ov} : average height of overstory trees (m) H_{mid} : average height of midstory trees (m) H_{und} : average height of understory trees (m)
Soil erosion regulation	For soil erosion regulation, Chu et al. (2010) studied the relationship between forest floor cover and soil erosion. They concluded that the total forest floor cover (understory and litter cover) was correlated with soil erosion rate in the case of Tanzawa mountain area, Japan. In this study, forest floor cover was selected as a proxy for soil erosion regulation. Forest floor cover was the totaled score of understory tree (0 to 1 m height), grassland, bamboo grass and fern coverages with litter coverage averaged by several visits through the field survey in 100 m^2 site by the author's visual judgement.	$C_{forest} = C_{und} + \{(1-C_{und})C_{lit}\}$ (3) C_{forest} : forest floor cover(%) C_{lit} : litter cover(%) C_{und} : understory cover (%, understory tree (0-1m), grassland, bamboo grass and fern)

In Hayashi and Ooba (2017), CES forest use in Nagoya was evaluated subjectively (n=180). Seven CES items (CES7) were developed, taking into account four basic parameters: forest area, scenic districts (S_D), shrine or temple (S_T), and major attraction facilities listed by the city (A_F). Then a clustering analysis was conducted to categorize forests into several types. The results of the clustering analysis were used as the CES values in this study.

For the carbon stock survey, DBH (≥ 5 cm) and the tree height (*H*) were measured by a 15 m tree height pole (SK measurement pole AT-15, Senshin Industry Co.) supported by a Laser range finder (Nikon Laser 550A S) to calculate above ground biomass (*AGB*) as in Kobayashi et al. (2019). First, DBH and *H* were measured for each tree in a 100 m^2 area. *H* was only measured for 100 m^2 sites, so the H of the 300 m^2 sites were estimated by Formula 4 (Matsumura, 2003). The values of a and b were estimated by using the DBH and H values for conifer-, deciduous- and evergreen broad leaf trees measured in the 100 m^2 area. The values of DBH and H used to estimate a and b were taken from the 41 forests for which a 100 m^2 area had been surveyed, along with values from additional four sites in the city (in total 45 sites). Yamamoto (1985) and Matsumura (2003) compared several tree height curves including Näslund, Allometry referring to Nishizawa (1972). In this study, the Näslund equation was used for coniferous, deciduous, and evergreen forests based on Matsumura (2003). These results are summarized in Table 3. By using DBH and H, the *AGBs* of each tree were estimated based on Tadaki et al. (2004) in Formulas 5 and 6. Underground biomass was assumed to be one fourth of *AGB* and the carbon content of the biomass was assumed to be 4/9 of the total biomass as in Tadaki et al. (2004). According to Tadaki et al. (2004), the AGB_{con} was estimated to apply for Japanese red pine (*Pinus densiflora*). This was tentatively used for other conifer trees in this study.

For the *AGB* of bamboo trees, Okuda et al. (2006) developed a simple estimate (Formulas 7 to 9). Averaged DBH of bamboo trees for 5 selected individuals were used for the estimation, multiplied by the number of bamboo trees in each 100 m^2 site with 4/9 of carbon content. In the case of no bamboo tree in a 100 m^2 site, a 100-300 m^2 converted figure was used as a 100 m^2 value.

Lastly, the number of dead trees was roughly estimated by Formula 5 and 7 on the 100 m^2 sites by visual estimation of the DBH (≥ 5 cm) and length of dead trees, and using the average *H* of bamboo trees. After that, all the carbon contents including tree carbon, tree *AGB* of bamboo and dead trees were summed to obtain carbon stock per ha.

Table 3 Estimated equation parameters

	a	b
Evergreen broad leaf tree (n=586)	1.4089	0.2109
Deciduous broad leaf tree (n=210)	1.2622	0.2017
Conifer tree (n=16)	1.2092	0.2161

Note: R^2 values 0.918, 0.965 and 0.937, respectively.

$$\frac{DBH}{\sqrt{H}} = a + b * DBH \quad (4)$$

H : tree height

$$AGB_{br} = 0.0601*(DBH^2 * H)^{0.901} \quad (5)$$

$$AGB_{con} = 0.0278*(DBH^2 * H)^{0.990} \quad (6)$$

a, b : parameters ; AGB_{br} : AGB of broad leaf tree

AGB_{con} : AGB of Japanese red pine (*Pinus densiflora*)

$$AGB_{bam\text{-}cul} = 0.0845 * DBH^{2.2275} \quad (7)$$

$$AGM_{bam\text{-}bra} = 0.047 * DBH^{1.5989} \quad (8)$$

$$AGM_{bam\text{-}le} = 0.0097 * DBH^{1.8388} \quad (9)$$

$AGB_{bam\text{-}cul}$: AGB of bamboo culm; $AGM_{bam\text{-}bra}$: AGB of bamboo branch

$AGM_{bam\text{-}le}$: AGB of bamboo leaf

The proxies defined above were normalized by dividing each proxy value by the maximum value of that proxy, and then the equivalency and similarity of several aspects of the forest BD/ESs were evaluated. First, correlations among the proxies were investigated by the Pearson correlation and the Spearman’s rho. Second, the 41 sites were classified by forest type. Conservation areas were treated as a separate category. Third, for each forest type, forests were ordered by BD scores and categorized into four groups (A to D). Fourth, within each group forests in the same CES7 category defined by Hayashi and Ooba (2017) were compared to each other. Finally, the land-use changes from 1955 to 2017 were taken into consideration in conjunction with the distance between sites. The land-use maps of 1955 provided by the Geospatial Information Authority of Japan (GSI) were digitized for analysis on the 10 m grid scale approximately as in Kobayashi et al. (2016, 2019). Four land-use maps were used, namely Nagoya north, Nagoya south, Koromo, and Seto.

The statistical analysis was conducted using Excel version 2010 (Microsoft) and SPSS statistics v.22 (IBM). ArcGIS 10.4.1 (ESRI Japan Inc.) was used for the spatial analysis.

RESULTS AND DISCUSSION

The results of the correlations among the proxies are presented in the Table 4. BD (C_A) was well correlated with RES (Forest_volume) and SES (C-stock and litter). RES (Forest_volume) was significantly correlated with SES (C-stock). Generally, some of the BD proxies were positively correlated with some of RES and SES proxies. BD (C_A) showed a positive correlation with CES (shrine/temple and cultural heritage value; 0.471** and 0.473**, respectively) and a negative correlation with CES (daily recreation, holiday recreation and education; -0.343*, -0.499** and -0.387*, respectively by the Spearman's rho). In Nagoya, conservation areas were located mostly in shrine/temple and recreational activities were not common in these as a whole.

The most frequent forest type classification was forest type 2 (secondary forest composed of deciduous broad leaf tree), with 31 sites, followed by type 5 (evergreen broad leaf forest, 8 sites). Four type 2 sites were conservation areas, which are important for the protection of natural habitats and were thus treated differently. In total, 31 type 2 sites were used for further analysis.

After ordering by BD score, these 31 sites were categorized into 4 groups: A (BD <0.30); B (0.30≦ BD <0.45); C (0.45≦ BD <0.60); and D (0.60≦ BD). Fig. 2 shows the total score of each forest ordered by total score of BD, RES and SES. Within each group, these total scores were similar. However, the CES scores of the groups were very different. Fig. 3 compares the average scores in each group from A to D. The RES and SES scores of each group were similar except for BD (C_A and forest area).

Next, we employed the CES7 categories from Hayashi and Ooba (2017) to divide group B into sub-categories (B1 to B5). Fig. 4 presents the results of this categorization. The characteristics of the BD, RES, and SES scores were similar within sub-categories (Fig. 4 (a)). However, the CES proxy scores differed by sub-category (Fig. 4 (b)).

Finally, the relative site distances were investigated using GIS, and sites within 100 m and 500 m of each other were selected for further analysis. After checking the shrine and temple location factor and the cultural heritage factor, which were traditional aspects, land-use changes from 1955 to 2017 were considered. The results are shown in Table 5. Six site combinations were recognized as being potentially similar. Referring to the old land-use maps, in several of the 100 m distance combinations, both sites were located within the same or neighboring forests in the past. This means that from the perspective of this analysis, these site

Table 4 Proxy correlations

	Forest_ volume	Forest floor cover	C-Stock	Litter
C_A	0.310 *	-0.108	0.419 **	0.353 *
Forest area	-0.001	0.079	0.243	0.175
Simpson' DI	0.047	0.301	0.242	0.305
Forest_ volume	1.000	0.062	0.532 **	0.147

**: Pearson Correlation is significant at the 0.05 level (2-tailed).*
***: Pearson Correlation is significant at the 0.01 level (2-tailed).*

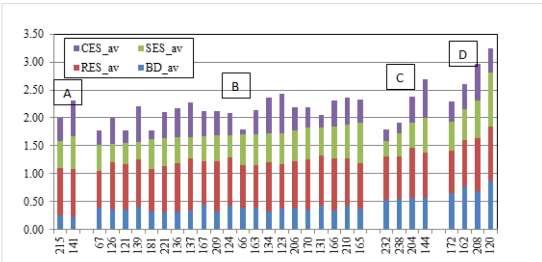

Fig. 2 BD, RES, SES and CES scores by site

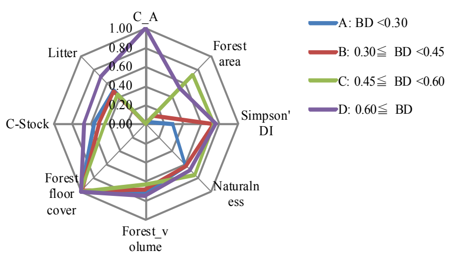

Fig. 3 Radar chart of BD, RES and SES for A to D

pairs had high similarity. Over the past several decades, these forest sites were fragmented by urbanization. Two site pairs within 500 m of each other were cemeteries in the past, according to the land-use data. More data on past forest locations (such as old aerial photographs) is needed. The equivalency and similarity assessment presented here could be used for a BO assessment once the scope of the BD/ES items has been extended.

CONCLUSION

This study focused on the development of a simple method for evaluating the equivalency and similarity aspects of forest BD/ESs through a multi-point field survey in Nagoya City. This method is potentially applicable to biodiversity conservation policy. Eight items from BD, RES, and SES, along with several CES items from Hayashi and Ooba (2017), were selected for assessment. Finally, several combinations were identified that were recognized as providing similar BD/ESs. Historical land-use change was found to be crucial to allow better judgement of forest equivalency and similarity in carrying out assessments for biodiversity conservation policy, which have been pointed out from the context of ES conservation in Ooba et al. (2015).

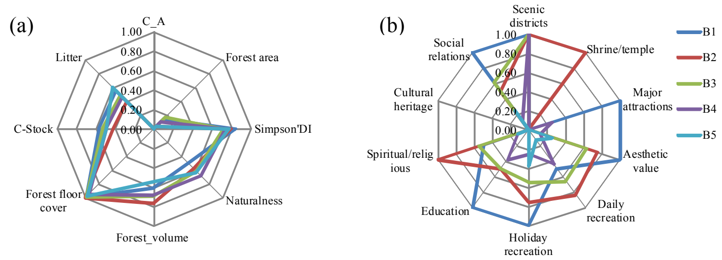

Fig. 4 Radar charts of (a) BD, RES and SES and (b) CES

Table 5 Equivalency and similarity aspects in forest type 2

Distance	Category	Sub-category	Site ID	Old land-use
≦100m	B	B3	163,165	Same mixed forest
	B	B3	163,206	Neighboring mixed and conifer forest
	B	B4	121,131	Same conifer forest
≦500m	B	B2	134,139	Same cemetery
	B	B2	137,139	Same cemetery
	B	B3	166,167	One was conifer forest with cleared area. The other was mixed forest. Both were separated by agricultural land

The remaining issues can be summarized as follows. First, this study only includes the survey results at 41 forests. Further field surveys covering the remainder of the forests in Nagoya City are needed. Second, in this study 8 BD/ESs items were used. However, after completion of the forest surveys, a wider variety of items should be considered. For example, fish-eye cameras, vegetation coverage by 50 m transect survey, and variable species distribution would be useful.

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