Research article

Analysis of Urban Ecosystem Services Considering Conservation Priority

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Abstract Many cities lose their green space and ecosystem services, especially in developing countries, which represent a problem as serious as an environmental pollution. Japan has also experienced the problem as a result of rapid economic growth. A system to assess ecosystem services and to create conservation maps in urban area was developed for use as a policy suggestion for urban planning. Nine ecosystem services were calculated by proxy variables in the studied area, Nagoya city, Japan. After selecting a subset of relatively and highly independent proxy variables, five ecosystem services significantly decreased before and after a period of strong economic growth (1955 and 1997). Distributions of the ecosystem services had trends of fragmentation indicated by a cluster analysis. Conservation priority maps created by using the conservation planning software called Zonation were presented. In the eastern and western areas, ecosystem services decreased with the loss of green space indicated by the authors in a previous study. The conservation priority level of the central area was relatively high due to the loss of green space. The results of this study are helpful planning for green space and offset-evaluating system.

Keywords Geographical Information System, green space, landuse, Nagoya, Zonation

INTRODUCTION

Many cities lose their green space (parks, agricultural fields, and secondary forests) and related ecosystems due to an increase in population, industry, and business, especially in developing countries. This loss represents a problem as serious as an environmental pollution. Japan has also experienced the problem as a result of rapid economic growth. Currently, the green space in many Japanese cities is still over 10% of the land area. However, it appears that the quality of this green space, as measured by characteristics such as continuousness and ecological complexity, has not remained high.

Ecosystem services (e.g., Costanza et al., 1997; Millennium Ecosystem Assessment, 2005), defined as goods and services provided by ecosystems to human society, are essential for a sustainable society. Green space in urban areas, including grass, agricultural, and forest ecosystems, provides ecosystem services such as biodiversity conservation, air and water purification, climate mitigation, disaster control, and cultural services (recreation, landscape, etc.). However, ecosystem services from these ecosystems decrease with urban development.

From a socioeconomic point of view, setting ecosystem conservation priorities is an effective way to maximize ecosystem services and/or biodiversity under economic constraints. Many software programs have been applied to conservation planning for biodiversity, including C-Plan, Marxan, and Zonation. Moilanen et al. (2011) researched competing land uses (in terms of their biodiversity, carbon storage, agricultural production, and urban area) in Great Britain using Zonation software. Fan and Shibata (2014) applied Zonation to the evaluation of ecosystem services in a river basin and found that forest ecosystems should be prioritized, especially for the water supply service that they provide, for Hokkaido, Japan.

In a previous study (Ooba and Hayashi, 2014), the authors indicated that land use in Nagoya, Japan differed before and after a period of strong economic growth, with the green space in Nagoya, including agricultural fields and forests, decreasing drastically. Those results mentioned that the provisioning of ecosystem services also decreased drastically; however, quantitative evaluation was not performed. In addition, conservation policy suggestions would be useful for the remaining green space, especially information on the areas that are the most important for maintaining or enhancing ecosystem services based on detailed geographical and quantitative research.

OBJECTIVE

The aim of this study is the development of a system to assess ecosystem services in urban areas and create maps of ecosystem conservation priorities for use as a policy suggestion for urban planning.

METHODOLOGY

Study Area and Data Set

The study area (the city of Nagoya) is the same area as the previous study (Ooba and Hayashi, 2014). The annual average temperature and precipitation are 15.8°C and 1,535.3 mm, respectively. With a population of approximately 2,260,000, metro Nagoya (ca. 32,600 ha) is Japan's fourth largest city and is representative of urban Japan.

Digital maps of land use in 1955 and 1997 at a 10 m resolution were developed in the previous study. The maps categorized 5 types of land use: water surface, built-up urban (residential and industrial) areas, roads, agricultural fields, and forest. In this study, green space was defined as the agricultural field and forest land uses. A digital elevation map (10-m resolution) was also used to estimate prevention of soil erosion. The following geographical processing and calculations were performed using ArcGIS 10.2.

Evaluation of Ecosystem Services

Several variables were calculated as proxies for supply of ecosystem services from the studied area (Table 1) at the resolution of the Japanese standard mesh defined by the Japan Industrial Standard, corresponding to approximately 1 km. The following variables were calculated using an area-based primary unit for each land use: carbon sequestration, prevention of eutrophication, food supply, air purification, climate mitigation (contribution to increase of air temperature), infiltration rate, and prevention of soil erosion. The detailed calculations used to generate these values are indicated in Table 1. For cultural services, a proxy variable was estimated from the distance to the nearest relatively large green space (recreation index), defined as an area larger than 1 ha. A proxy for biodiversity conservation was estimated from the continuousness of green space (biodiversity index) by using Focal Statistics in ArcGIS and setting the proximity radius to 2 km. For the 1997 data set, these 9 variables were converted to normalize values due to difference of units by subtracting the mean and dividing by the standard deviation. Some variables (prevention of eutrophication, climate mitigation, prevention of soil erosion, and distance to a large green space) were of the opposite scale to the other variables. These variables were reversed by multiplying by −1. For comparison to 1997, the variables for 1955 were normalized by the statistics of 1997.

A matrix of correlation coefficients among all proxy variables was generated to identify linear relationships. After selecting a subset of relatively highly independent proxy variables, a cluster analysis was performed using the k-mean method for the 1997 data set to clarify the characteristics of ecosystem services at each mesh cell in the city. For the 1955 data set, each mesh cell was reclassified and compared to the result for 1997 to obtain the differences between the two years. These calculations were performed using statistical software (Excel statistics, Social Survey Research Information, Japan) in Microsoft Excel 2013.

Table 1 Proxy variables of ecosystem services in urban area

Name	Cat*	Estimation Method	Values or Details	Unit	Ref.
Carbon sequestration	S	Primary unit	3.09(F)	t/y	1
Prevention of eutrophication**	S		16.5(U), 42(A), 3.8(F)	kg-N/y	2
Food supply	P		2.98(A)	t/y	3
Air purification	R		0.00615(A), 0.011(F)	t-NO_2/y	1
Climate mitigation**	R		6(U), −2.9(A), −1.3(F), 2(W)	°C	4
Rain infiltration	R		12.7(U), 89.3(A), 258.2(F)	mm/h	5
Prevention of soil erosion**	R	S and C coefficient in RUSLE [6]	$S = 65.41\sin^2\theta + 4.56\sin\theta + 0.065$ C = 1 (U), 0.33(A), 0.0085(F)	-	6 7(A) 8(F)
Recreation **	C	Distance of relatively large green space	Enquired distance for large green space (A and F) polygon (> 1ha)	m	9
Biodiversity	S	continuousness of green space	Focal statistics (proximity radius 2 km) (ArcGIS spatial tools)	-	9

Abbreviation: U: Urban area and road, A: Agricultural area, F: Forest area, W: Water surface
** Category of ecosystem services: Supporting (S), Provisioning (P), Regulating (R), Cultural (C)*
*** Opposite scale. High value of the variable indicated negative effect about the concerned ecosystem service.*
1. Ogawa et al. (2003)
2. Japan Sewage Works Association (1997)
3. Aichi prefecture (2012)
4. Yokoo et al. (2003)
5. Murai and Iwasaki (1975)
6. Renard et al. (1997), RUSLE: Revised Universal Soil Loss Equation.
7. Ogawa et al. (2005)
8 Kitahara et al. (2000)
9 Li (2014)

Algorithm of Calculating Conservation Priority

The conservation planning software Zonation provides several algorithms to determine conservation priorities (e.g., core-area zonation). The authors chose the simplest algorithm, the additive benefit function, which calculated the sum of all calculated values of ecosystem services for each mesh cell and produced a mesh-map of the sums. In this study, the input values were the proxy values of ecosystem services. The weight and cost for each proxy variable were assumed to be 1.0 (the default). For a technical reason, the raster data for Zonation were created at a 500-m mesh converted from the above mentioned approximately 1-km mesh.

RESULTS AND DISCUSSION

Ecosystem Services Evaluated by Proxy Variables

Nine ecosystem services were estimated at a 1-km mesh for 1955 and 1997 for Nagoya city (data not shown). The matrix of correlation coefficients among all proxy variables was also calculated. The variables calculated from the digital maps of land use type using the primary units exhibited high correlations with the other variables calculated by the same method. On the other hand, the variables calculated using ArcGIS had low correlations with the former variables. For further analysis, the following five variables of which correlation coefficients were less than 0.6 were selected: carbon sequestration, food supply, prevention of soil erosion, recreation index, and biodiversity index. The food supply variable was the only proxy of a provisioning service that was selected; it was chosen over prevention of eutrophication, which displayed a high correlation with food supply.

The values of all of the selected variables decreased from 1955 to 1997, which was related to a decrease in green space from 55% of the total city area to 16% (Ooba and Hayashi, 2014). The distribution of the supply of ecosystem services also changed, becoming sparse and isolated in 1997.

Classification of Supply of Ecosystem Services

The distribution of classified mesh cells from the selected 5 proxies is indicated in Fig. 1. Because the number of classes is arbitrary in the k-mean method, the authors chose 5, which was the same as the number of classified types in the original land use maps. The following labels were used in referring to the land use maps: core urban area, urban area, agricultural area, forested area, and green area. Between the dates of the two land use maps, urban areas expanded and agricultural and forested areas contracted complementarily. In 1997, green areas (mixture of urban area and green space area) appeared as a result of the fragmentation of green space.

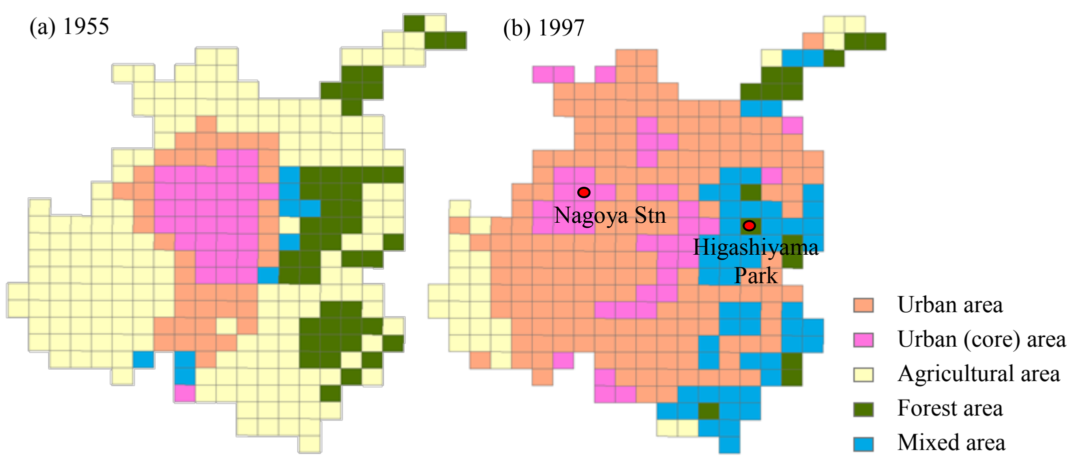

Fig. 1 Classification from the proxy variables of ecosystem services

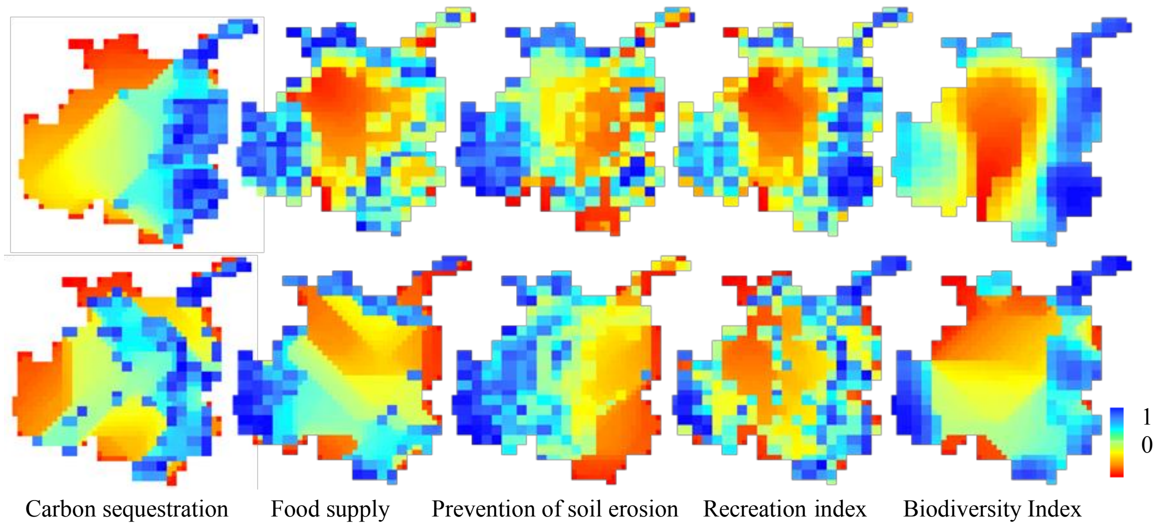

Fig. 2 Relative priority ranks (0-1) of the selected ecosystem services

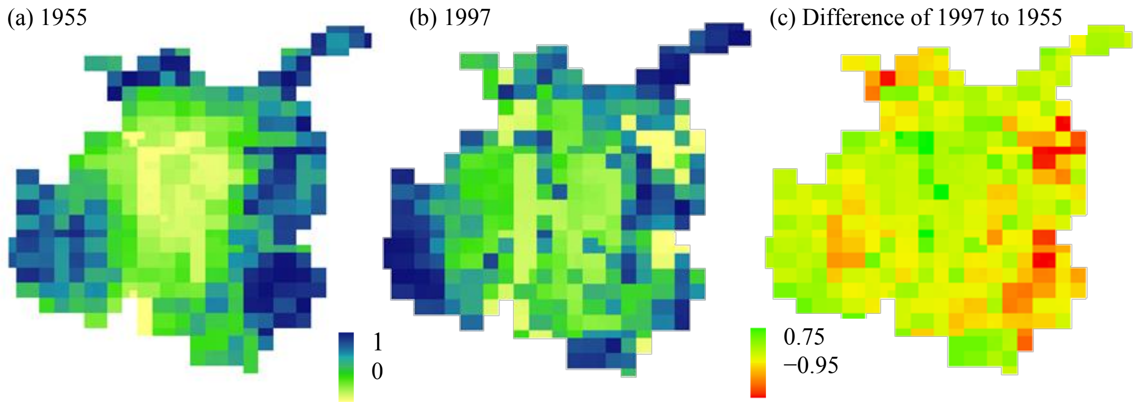

Fig. 3 Relative priority ranks and difference of integrated ecosystem services

Conservation Priorities

Priority maps for each of the 5 selected proxies were calculated using Zonation and are presented as Fig. 2. The maps represent the conservation priority order of each mesh cell for each proxy variable (the blue colored cells supply the most ecosystem services). In 1955, the mesh cells on the east and west sides in the city had relatively high values in the all ecosystem services, whereas almost half the cells in those areas had low values in 1997.

Integrated priority maps, presented as Fig. 3, were also calculated from the 5 variables using Zonation. The conservation priority level of the marginal area of the city is high levels in 1955 provided from both agricultural and forest ecosystems. This east, especially east-south and east-north, high priority area almost disappeared by 1997. The west area remained a high priority. Compared to the east area, the west and northeast areas were also assigned high priority. Fig. 3(c) presents the differences between the two years. This indicates an overall loss of ecosystem services, which is consistent with the pattern observed above for each individual ecosystem service. It is notable that the conservation priority level of the central area is relatively high due to the loss of green space in the marginal area.

Outlook

A relatively simple method (primary units) was applied to estimate the supply of ecosystem services. Derived variables such as carbon sequestration and prevention of eutrophication were highly correlated with the other variables derived by the same method. For each estimate of supply of ecosystem services, more appropriate methods may be developed that depends not only on land use but also on other geographic, statistical, or process-based methods. For several services, especially those related to culture and biodiversity, innovative proxy variables and estimation methods are needed.

The default settings of the Zonation software program (weight and cost) were used in this study. For widespread applicability, these values must be determined by suitable methods: Cost may be estimated by building up the management costs of conserving an ecosystem. Weight may be estimated by social investigation, such as an economic survey or questionnaire about the value of the ecosystem.

In a more practical context, discussions about an offset system for development have begun, and many studies related to the design of such an offset system have been performed. Offset systems focused on conserving natural land uses or biodiversity have already been introduced in the United States, Australia, and many European countries. The authors place a special focus on offset systems based on assessing ecosystem services because the methodology for such a system provides not only on-site offset (offset sites located near the development site) but also off-site offset because the similarity of ecosystems is assessed by the supply of ecosystem services from the target ecosystems.

CONCLUSION

The authors' previous work revealed a drastic change in green space in Nagoya city from 1955 to 1997 (Ooba and Hayashi, 2014). This study included not only a quantitative evaluation of ecosystem services but also an integrated assessment of ecosystem services in this area. The supply of ecosystem services decreased along with the decreased area of green space. A high supply of ecosystem services present in the marginal area of Nagoya city in 1955 disappeared, while in the eastern area, loss of ecosystem services was relatively low. Conservation priority maps created using Zonation software were presented, which is helpful planning for green space and offset-evaluating system in the studied area.

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