Assessment of ecosystem services with land use maps: Conservation priorities under several greening scenarios in Nagoya City

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Abstract: A system was developed to screen for regional-scale offset sites based on an integrated evaluation of terrestrial ecosystem services (ES). A Geographic Information System (GIS) database was developed detailing land use in the study area in central Japan. Habitat potential and four categories of ES were assessed using the GIS database with unit values. The conservation ranks of the ecosystems were evaluated through a conservation planning software. The proposed system can indicate spatially important and critical ecosystems on the geographical maps of the research area. The authors show the importance of continuity of ecosystems, especially in urban areas, and the methodology is applicable for evaluating ES in other settings.

Keywords: Conservation priorities, ecosystem services, forests, Nagoya, urban planning

Introduction

Population decline leads to multiple problems in urban areas: shrinking residential areas, infrastructure and security problems, and difficulties in maintaining formerly populated areas. The well-being of residents living in urban areas is related not only to artificial services such as transportation, accessibility of communal and commercial facilities, and security, but also to natural services provided by ecosystems (landscape, recreation, and so on) and rich biodiversity.

Aichi Prefecture installed the mitigation system, “Aichi Method,” which is the first system of biodiversity offsets in Japan. The prefecture provided a quantitative assessment tool, as well as mitigation recommendations to create an ecological network by compensation between development and offset sites. However, the tool does not refer to quantitative spatial statistics and ecosystem services.

Geographic Information Systems (GIS) are often used to spatially evaluate ES. However, integrated quantitative evaluation tools, which would encompass all ES concepts, are still at the research and development stage. A number of conservation planning support software packages that use GIS were developed and applied with the goal of conserving certain species. For example, Moilanen et al. (2011) used Zonation software to analyze biodiversity, carbon storage services, agricultural supply services, and competitive land use in cities in Great Britain. In the current study, we apply a spatial assessment scheme by using a relatively simple method to estimate ES in Nogaya City (Ooba et al., 2015), with input data primarily dependent on the land use map. This information may be useful for mitigation systems, including the Aichi Method.

Study Objectives

The objective of this study was to assess ecosystem services and compare current and future scenarios. Quantitative and geographical evaluation of ecosystem services is useful for identifying high-priority conservation sites. Ecosystem services were estimated in the GIS from proxy variables using primary values nearly the same as those used in the previous study (Ooba et al., 2015). Conservation priority maps were compared to validate the scenarios,

Methodology

Study area

Nagoya City is located in central Japan. With an area of approximately 32,600 ha and a population of approximately 2,260,000, Nagoya City is the fourth largest city in Japan (Yokohama City, 2016).

Methods of ES estimation

The methods used in the current study are similar to those employed in the previous study (Ooba et al., 2015). A digital land use map of Nagoya in 1997 with a 10 m mesh was used to categorize five land use types: surface water, residential and industrial areas (collectively categorized as urban areas), roads, agricultural fields, and forests (Fig. 1ab).

The following five variables were selected as proxies for ecosystem services: carbon sequestration, food supply, soil erosion, a cultural variable, and a biodiversity variable (Table 1). Cultural services were estimated through a web-based survey. The economic value of recreation was estimated by a calculation of generalized round-trip costs per capita, based on required costs such as transportation and transfer facility use costs (Ooba et al., 2016). Four major green areas in Nagoya City (area range: 6.18 to 84.9 ha) were selected and the generalized round-trip costs to the green areas as well as other attributes were studied through a survey in 2014 (2,800 samples from Aichi Prefecture). The results of the survey were used to estimate the economic values of the cultural services. The economic value V (10^6 JPY ha^{-1} y^{-1}) per unit of area was estimated using the following equation:

$$V = a\,A^b, \tag{1}$$

where A is area (ha) and a and b are parameters obtained by the regression calculation ($b < 0$). Services were evaluated for green spaces with an area of 1 ha or greater.

These variables were estimated at the Japanese standard mesh defined by Japan Industrial Standard, corresponding to approximately a 1 km-grid.

The estimated values are shown as different units, so for comparison purposes, values were convert to a binary scale (0, 1) by maximum and minimum value. Soil erosion variables have negative effects (high variables means high negative ecosystem services), so the variable was reversed by multiplying by −1.and converted into a binary scale. Although all of the ES variables have exponential distributions, the variables were logarithmically converted to normalize the distribution before the binary conversion. The 0 value variables are replaced by a minimum value of the corresponding ES distribution due to the logarithmic conversion.

Table 1. Proxy variables for ecosystem services and summary of estimation methods

ES	Estimation	Method details[1]	Unit	Weight[2]
Support	Carbon sequestration	3.09(F)	t/y ha	0.200
Provision	Food production	2.98(A)	t/y ha	0.180
Regulation	Reduction of soil erosion coefficient compared to bare soil	$S = 65.41\sin^2\theta + 4.56\sin\theta + 0.065$ C = 1 (U), 0.33(A), 0.0085(F)	-	0.207
Culture	Economic value of green space	Value per unit area as green belt area A (ha) $V = 3.0184A^{-0.437}$	10^6 JPY/y	0.209
Habitat	Continuity of green space	ArcGIS tool (Focal statistics) proximity with 2 km radius	-	0.205

[1] Land use codes: U, roads and urban areas; F, forestland; and A, agricultural land. A detailed description of parameters and equation can be found in Ooba et al. (2015)

[2] The values that are of average importance to ES are used for the integration of ES

Table 2. Land use change scenarios

Scenario	Change of agricultural and forest area
BAU	Business as usual (no change)
1 (Greening)	Increase in forest area in every grid (total citywide increase of 5%)
2 (Corridor)	Increase in forest in the eastern area of the city. Restoration of semi-natural ecosystem and development of natural corridors for biodiversity near surface water (rivers and ponds). The rate of incense is the same as for Scenario 1 (5%).

Scenarios and conservation priorities

In comparison to the current evaluation of ES in Nagoya (BAU scenario, Table 2), two future scenarios are considered. Scenario 1 (greening) considers the growth of green space in all grids of the city (Fig. 1c). Scenario 2 (corridor) considers increases in the rate to be high green space in the eastern region of the city (Fig. 1d). In both scenarios, the net rate of green space increase is assumed to be approximately 5%. In Scenario 2, it is assumed that ES near water areas will be enhanced by afforestation or greening over a relatively large area (larger than 1 ha) to restore a semi-natural ecosystem and develop natural corridors for biodiversity conservation inside the city.

Using the calculated proxy variables for ES and biodiversity, an integrated evaluation was carried out using the Zonation software, which calculates conservation priorities (Moilanen et al., 2012). The software identifies the mesh with the greatest overall loss when one grid is removed. By repeatedly removing the identified mesh and searching among the remaining grids for the grid with the maximum loss, conservation priorities are determined by the Core Area Zonation algorithm, which minimizes loss by assigning high rank to spatially continuous and high weight ES. The number of species is calculated to evaluate biodiversity loss. The value of ES is calculated in the current study to evaluate the loss.

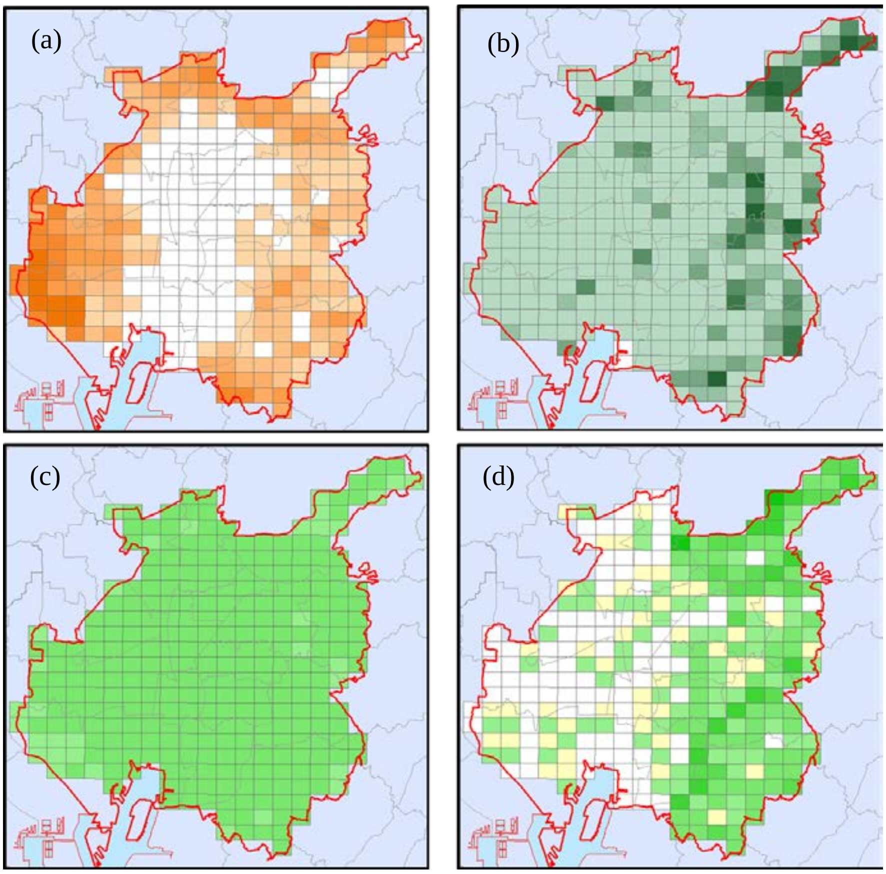

Fig. 1. (a) Grid area rate of agricultural area in Nagoya City. (b) Rate of forest area. (c) increase rate in Scenario 1 Greening and (d) increase rate in Scenario 2 (corridor).

Results and Discussion

The weight of the ES obtained through the web questionnaire was estimated from a five-point scale (Ooba et al., 2016) and used to integrate each ES value in the current study (Table 1). The costs and other Zonation parameters were set to default values.

The ES map of Nagoya is shown in Fig. 2. Cultural services were estimated based on Eq. (1), a = 3.0184, b = −0.437 (R^2 = 0.63). Value per unit area decreases as area increases, but because it is multiplied by area, the area and value of the cultural services increase gradually. Carbon sequestration was high in eastern Nagoya City and Moriyama, where there are many woodland areas. Food production was high in western Nagoya, where there are relatively large areas of paddy and farmland. Cultural services and habitat quality tend to be low in the central area but high in the surrounding areas.

Conservation priorities as calculated by the Zonation software are shown in Fig. 2. Priority tends to be high in the surrounding areas, such as Higashiyama, Moriyama, and western Nagoya City. Several green spaces, such as Atsuta Shrine, which is isolated inside the city, also earned high priority. In Scenario 1, forest land use increases in every mesh (but continuity is not recalculated), while surface water located in the selected mesh (Fig. 2) is replaced by forest land use and the recreation value and continuity are recalculated in Scenario 2. It should be noted that labor costs for the management of green space are the same in both scenarios.

Compared to the current map (Fig. 3), the priority of the Scenario 1 is almost the same, because the relatively continuous forests and isolated forests have the same values. However, in Scenario 2, the isolated forest was less important than in Scenario 1 and green spaces in the eastern region of Nagoya are assigned higher priority than in Scenario 1.

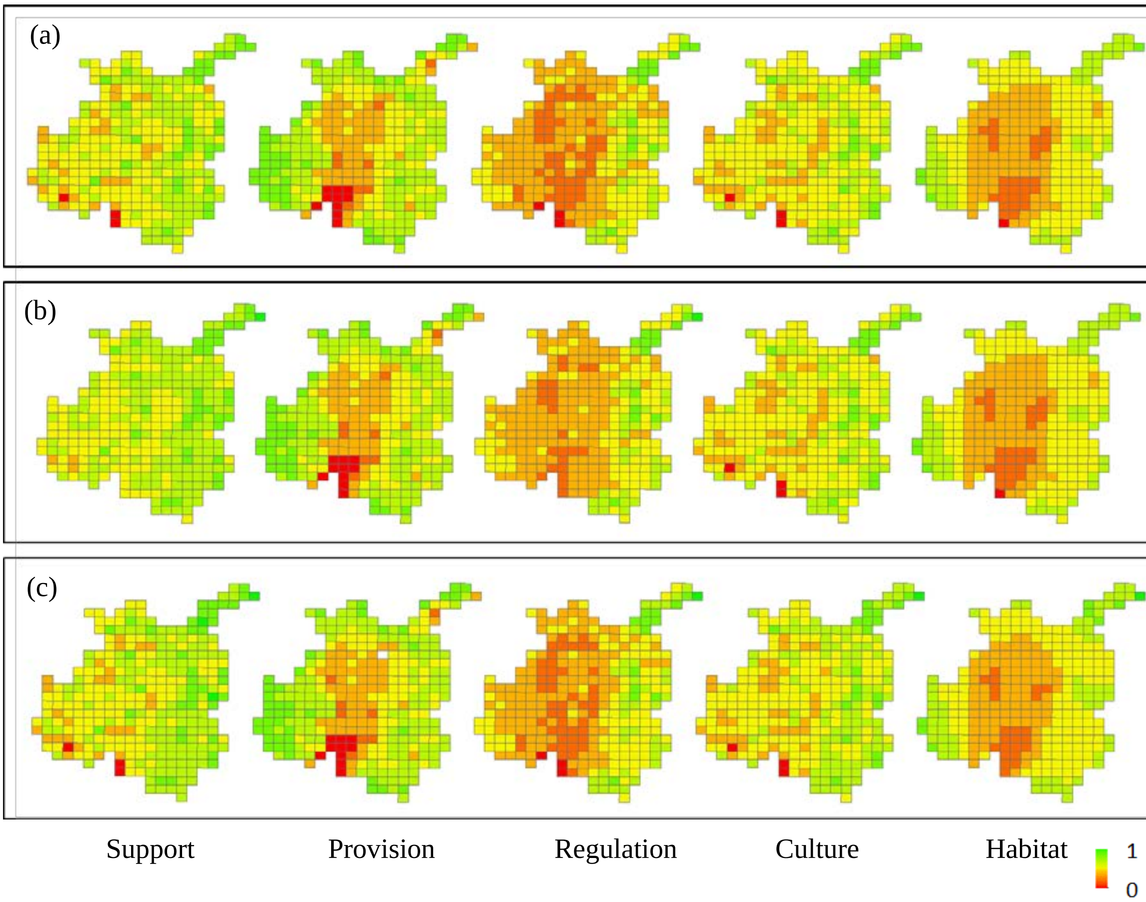

Fig. 2. Relative values of ES under the three scenarios: (a) BAU, (b) Scenario 1 (greening), and (c) Scenario 2 (corridor).

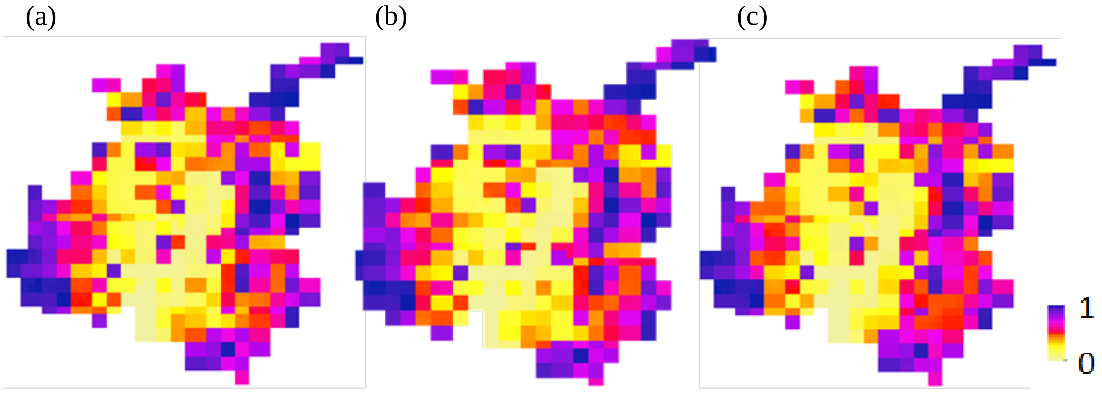

Fig. 3. Conservation priority maps of ES under the three scenarios: (a) BAU, (b) Scenario 1 (greening), and (c) Scenario 2 (corridor).

Conclusion

A number of issues should be addressed regarding the future of green spaces as urban areas shrink. Currently, it is difficult to conserve continuous green space inside urban areas. However, if urban populations continue to decrease, green space formerly used for residential, business, and industrial purposes may appear. As noted in the results from Scenario 1, increasing sparse green space inside cities does not drastically affect ES. However, if an aggregation plan like that used in Scenario 2 is applied, urban ES may change substantially.

Acknowledgements

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