Assessment of ecosystem services using land-use maps

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Abstract: To assess problems of urban green space and plantation forests in Japan, we conducted visualization of ecosystem services and compared current ecosystems to those from 1955. Quantitative and geographical evaluations of ecosystem services were estimated from proxy variables using primary values. Conservation priorities were calculated from the result of ecosystem services evaluations including habitat quality.

Keywords: Ecosystem service, forest, Japan, Nagoya, Toyota

Introduction

Ecosystems provide food; materials; natural services such as carbon absorption, water supply management, water quality control, and disaster control; and cultural services. Ecosystem services are defined as the goods and services derived from ecosystems that are used by human society, and they are essential for a sustainable society (Millennium Ecosystem Assessment, 2005). When a site is developed, not only habitats but also local ecosystems may be greatly affected. In such cases, related ecosystem services may change both qualitatively and quantitatively.

As a result of serious environmental problems experienced during rapid economic growth, many cities in Japan are now gradually restoring green spaces (parks, agricultural fields, and secondary forests). Green spaces constitute more than 10% of land areas in Tokyo and Osaka; Nagoya, the chief central Japanese city, comprises 20% green space. However, green space in urban areas still encounters qualitative problems such as fragmentation and separation from mountainous areas (Ooba and Hayashi, 2015).

In Japan’s mountainous areas, the total area of forest has been kept constant. After 1945, a policy to convert natural forests and agricultural fields to artificial forests was implemented. These plantation forests are now mature, and a substantial volume of timber has accumulated. However, poor harvesting and regeneration of such plantations have resulted in a degraded forest industry. Timber and wood materials from outside of Japan have an economic advantage compared to domestic products. The human population in rural areas has decreased due to industrial transformation during periods of economic growth, with a concomitant decline in the labor force and industry related to forestry. Considering the extensive ecosystem services that might be provided by a mature forest ecosystem, there is need for a system able to maintain or restore the environmental quality of plantation forests.

Study objective

The objective of this study was visualization of ecosystem services and comparison of current ecosystems with those from 1955, in typical urban and mountainous areas. A geographical information system (GIS) was used to develop a database for terrestrial ecosystems in these areas, based on land-use maps. In our first-step analysis, we assumed that ecosystem type was mainly determined by landuse type. The variety and quantity of ecosystem services were estimated from proxy variables using primary values. Finally, conservation priorities were calculated from the result of ecosystem services evaluations.

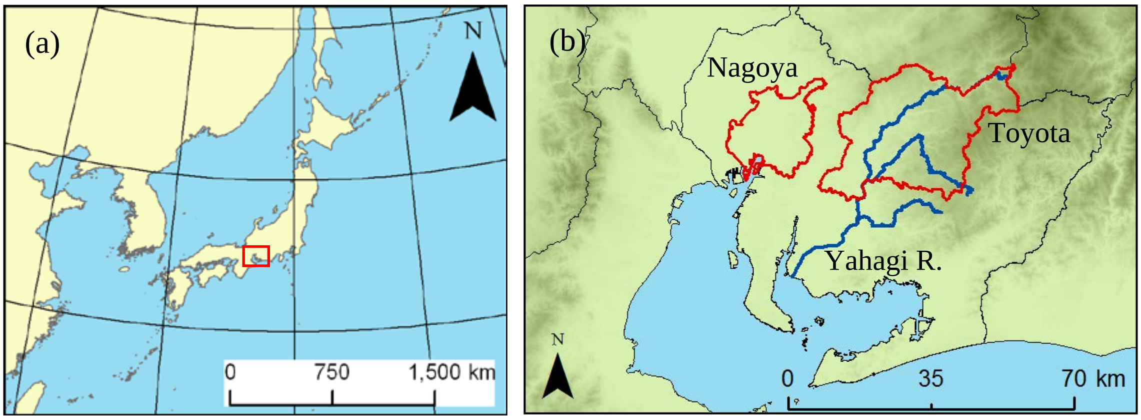

Fig. 1 (a) Location and (b) Studied area (Nagoya and Toyota City, and Yahagi River)

Methodology

Study area

Nagoya and Toyota City were selected as typical urban and mountain areas, respectively, and both are located in central Japan. Nagoya City (ca. 32,600 ha) represents urban Japan with a population of about 2,260,000, and is the fourth largest city in Japan. Toyota City, located northeast of Nagoya, contains urban and industrial areas along the lower reaches of the Yahagi River. The upstream area of the city is mainly covered by forest. The Toyota City population and area are 420,000 and 91,850 ha, respectively.

Methods

Digital land-use maps of Nagoya in 1955 and 1997 at 10 m mesh level were developed (Ooba and Hayashi, 2015). The maps were used to categorize five types of land use: water surface, residential and industrial area (urban area), road, agricultural field, and forest. Green space was defined as agricultural fields and forest. Digital land-use maps of Toyota City were also developed in 2009, from a previous land-use map (100 m-mesh, NLNI). A map from 1955 was created by the same method used for Nagoya: paper maps (Geospatial Information Authority of Japan) were digitized and land-use types were estimated by the maximum-likelihood method (ArcGIS 10.2, ESRI). Finally, the result was corrected by manual comparison to the original land-use map. Digital elevation maps (10-m grid, Geospatial Information Authority of Japan) were used for estimation of soil erosion. It was assumed that elevations were almost the same in both years studied.

The following variables were selected as proxy for ecosystem services (Table 1): carbon sequestration, food supply, soil erosion, a cultural variable ("Recreation", defined by proximity to a relatively large green space), and a biodiversity variable (defined by continuity of green space). These variables were estimated at the Japanese standard mesh as defined by the Japan Industrial Standard, corresponding to about a 1-km mesh.

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

Name	Estimation Method	Values or Details	Unit	Ref.
Carbon sequestration	Primary unit	3.09 (forest)	t/y/ha	2)
Food supply		2.98 (agricultural fields)	t/y/ha	1)
Prevention of soil erosion*	$S \times C$: S and C coefficient in RUSLE [8]	$S = 65.41\sin^2\theta + 4.56\sin\theta + 0.065$ C = 1 (urban area), 0.33 (agricultural fields), 0.0085 (forest)	-	8) 6) 2)
Recreation *	Distance to relatively large green space	Distance from a mesh to large green space polygon (> 1 ha)	m	
Biodiversity	Continuity of green space	Focal statistics (proximity radius 2 km) (ArcGIS spatial tools)	-	3)

** Opposite scale; low value of the variable indicates favorable ecosystem service.*

Carbon sequestration and food supply were estimated by area-based unit values (Table 1). The proxy for soil erosion incorporated S (slope) and C (cover) coefficients of the revised universal soil-erosion equation (Renard et al., 1997). The proxy for cultural service was estimated distance to relatively large green space (accessibility of recreation area; larger than 1 ha). The proxy for biodiversity conservation was estimated from continuity of green space using focal statistics (ArcGIS), and setting the proximity radius at 2 km (Li, 2014). These variables were normalized for the data set of 1997 for Nagoya and 2009 for Toyota, using the mean and standard deviation of the data set. Soil erosion and distance to large green space were on a scale opposite to those of the other variables. The variables were reversed by multiplying by −1. For comparison to 1997, the variables for 1955 were normalized to the statistics of 1997.

Prioritizing conservation of ecosystems is a better way to maximize ecosystem services under socioeconomic constraints. The authors used conservation planning software called Zonation (Moilanen et al., 2012), which provides several algorithms to determine conservation prioritization. The assigned conservation value uses the proxy values of ecosystem services, and calculates a sum of all values for each mesh. The resulting mesh map was ordered by these sums (the additive benefit function, incorporating the total values of meshes). It was assumed that weight and cost for each proxy variable was 1.0 (default). For technical reasons, raster data for Zonation was created at 500-m mesh converted from the above mentioned quasi-1-km mesh.

Results and discussion

The cross-comparison table for land use (Table 2) indicates that between 1955 and 1997, green space decreased drastically in Nagoya: 32% of agricultural fields were converted into urban areas now making up the northern and western parts of the city. The largest land use change from 1955 to 1997 affected provisioning services (agricultural products). However, valuation of agricultural ecosystem services in the urban area obviously declined during rapid economic growth. Forest area also decreased from 1955 to 1997 (7%), possibly reflecting the switch from woody biomass to fossil fuels, reducing ecosystem services related to carbon sequestration.

In Toyota City, a decrease of agricultural area was also indicated (Table 2). For the area located in the lower basin of the Yahagi River, conversion of agricultural land to residential and industrial areas occurred. However, in contrast to Nagoya, part of the agricultural area in the upstream area was converted to forest, and the ratio of agricultural to forest area increased compared to 1955 (4%).

Proxy variables for ecosystem services (carbon sequestration, food supply, soil erosion, recreation area, and continuity of green space) are indicated for the two cities and two reference years (Fig. 2). Ecosystem services decreased from those of 1955 due to decreased agricultural area in both cities, and to decreased forest area in Toyota City. In Nagoya, the decrease in agricultural and forest area caused the decrease of all proxies of ecosystem services. In contrast, some proxies (carbon sequestration, soil erosion, and biodiversity index) increased with an increase of the forest area in the upstream area of the Yahagi River (Toyota City).

Integrated priority maps, prepared using Zonation and calculated from the five variables, are presented in Fig. 3. In Nagoya, the conservation priority level of the marginal areas of the city was high in 1955, derived from adjoining agricultural and forest ecosystems. To the east, particularly the southeast and northeast, these high-priority areas had almost disappeared by 1997. The western areas remained a high conservation priority. Compared to the east, the west and northeast areas were also assigned high priority. It is notable that the conservation priority level of the central area is relatively

Table 2 Percentage of land use in Nagoya and Toyota City

	Nagoya		Toyota	
Year	1955	1997	1955	2009
Water surface	5	5	2	1
Residential and industrial area	36	57	5	13
Road	2	19	2	0*
Agricultural field	38	6	21	11
Forest	17	10	70	74

** Road area cannot be classified using coarse mesh (100 m)*

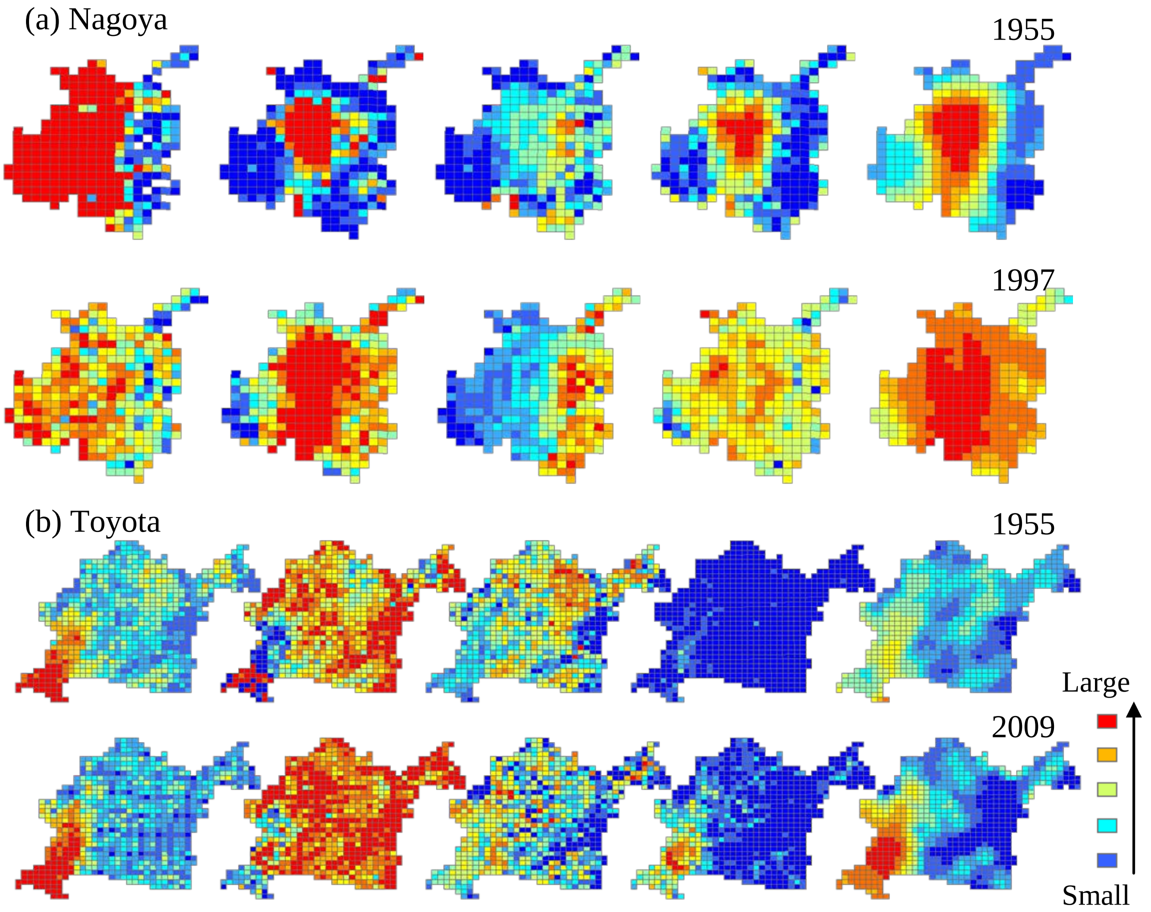

Fig. 2 Normalized value of proxy variables for ecosystem services (left to right: Carbon Sequestration, Food Supply, Soil Erosion, Recreation Index, Biodiversity Index) in (a) Nagoya and (b) Toyota City

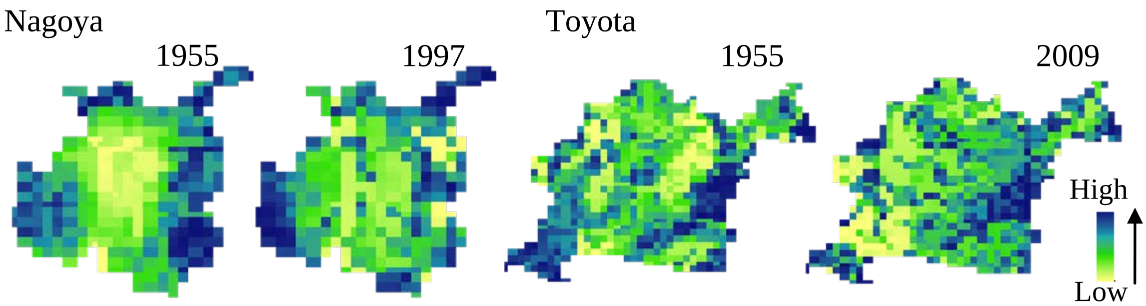

Fig. 3 Relative priority calculated from integrated evaluation of ecosystem services

high due to the loss of green space in the marginal regions (northeast, east and southeast areas).

In Toyota City, ecosystem service supplied mainly from the south-western area (agricultural area) and north-eastern area (agricultural and forest areas) in 1955. However, the development in the south-western part resulted in a loss of ecosystem services similar to that resulting in Nagoya. Compared to the current downstream area, the upstream area covered by forest provides abundant ecosystem services. In this case, plantation forest played key roles in ecosystem services in Toyota. In 1955, the forests in those areas were secondary forests or young plantation forests, confirmed from the original land-use map, and also by aerial photographs. The quality and quantity of ecosystem services provided by that young forest must be different from those provided by the mature (50-60 year old) current forest. This calls for accurate evaluation of current ecosystem services from the forest in future studies, which should, at least, involve detailed survey of changes in the plant cover in the area.

In this study, visualization of ecosystem services over the municipalities was provided. This is helpful for future research about ecosystem services, and for stakeholders involved in ecosystem management and conservation. Moreover, this provides an informative guide for citizens to consider neighboring land uses and ecosystems.

Conclusion

In this study, quantitative and geographical evaluation of ecosystem services was conducted in a typical urban and typical mountainous area (Nagoya City and Toyota City). Of agricultural fields, 28% were converted into urban area in northern and western parts of Nagoya, and a similar decrease was also observed in Toyota. The comparison of land use before and after the rapid economic growth in Japan indicated that decreased green space reduced ecosystem services in highly developed areas. In the north-western part of Toyota City, enhancement of ecosystem services occurred due to the conversion of agricultural fields to forest (4% increase) and matured forest. Accurate evaluation of the ecosystem services being provided by the region should be conducted based on a detailed survey of the changes in plant cover that have occurred there.

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