Time series Changes and Future Prospects of Green space and the Ecosystem Services

— Case Study of Funabashi City in Tokyo Metropolitan Area, Japan —

Natsuki ITO[1], Yuki SHIBATA[1], Satoru SUGITA[2],
Kiichiro HAYASHI[3], Makoto OOBA[4]

1 *Toho University,* 2 *Chubu University*, 3 *Nagoya University,*

4 National Institute for Environmental Studies

In Funabashi City, which is located in Tokyo Metropolitan Area (TMA), Japan, the population has been increasing since 1960s and then the population increase has led to a greens pace reduction. However, recent studies predict that the city's population will see a declining trend in the coming decade. The purpose of this study is to clarify how the development of Funabashi City after the 1990s has changed / will change the provisions of the ecosystem services (ESs). To evaluate this, we took the following three categories of the ESs into consideration: provisioning, regulating and cultural services. Core to this assessment, we estimated long-term changes in green space distribution and the provisions of the ESs for the study area. Furthermore, we predicted how the provisions of the ESs would change in the future based on several depopulation scenarios.

Keyword: Urban green space, Ecosystem services, Depopulation, GIS analysis, Funabashi, Japan

1. Introduction

Over the past half century, the population of the Tokyo Metropolitan Area (TMA) has increased with population increase commensurate with a reduction in green spaces around the urban area. In the TMA, the 2,190 km^2 of green space including farmlands, forests and urban parks were lost over a 38 year (1965-2003) period, translating to a 22% loss in green space (MLIT, 2006). Table 1 reports relevant population growth rates and green space reduction estimates and shows for bedroom suburb areas (*i.e.*, locations 20--50 km from the Central Business District "CBD" of Tokyo) that owing to high economic growth periods since the 1960s, the rapid population growth has led to the definitive destruction of suburban green zones, including forests and farmlands (Table 1.). However, national population data indicated a downward turn of Japanese total population in 2005 and declining trends will be appeared in some suburban areas around Tokyo in the coming decades. One of the most typical settlements in the Tokyo suburban area is Funabashi City, and its population data indicate the city's population will soon be facing a declining trend.

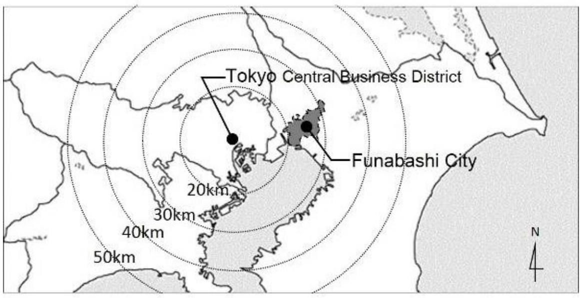

Fig 1. Funabashi City in Tokyo Metropolitan Area

As populations decline, there will be a possibility to enhance the benefits and opportunities of the provisions of the ecosystem services (ESs) through green space conservation, in depopulating areas. The purpose of this study is to clarify how the development of Funabashi City has changed the provisions of the ESs since 1996 and to visualize the long-term future changes of green space distribution and the provisions of the ESs for various population scenarios.

2. Analysis framework

2.1 Overview of Funabashi City

In order to estimate future patterns and trends for urban green space and the provisions of the ESs in the TMA, we focused on Funabashi City, as a typical suburban city in the TMA, which was located 20-30 km east from the Tokyo CBD (Figure 1, Table 2).

2.2 Analysis method

This study applies time-series geographic information system (GIS) analysis whereby land use and population distribution geographical

Table 2. Overview of Funabashi City

Area Surface	85.64 km^2
Designated Urbanization Area Surface	54.56 km^2
Urbanization Control Area Surface	31.08km^2
Population (2016)	624,473Pop.
Population Density	7.292/km2

※City official paper in 2016

Table 3. Definition of land use types and items

Land use Type	Items of land lot
Green space	Paddy Field, Farm, Grazing Land, Grassland, Forest, Green Park
Urban Land Use	Residential Area, Commercial Area, Industrial Area, Transportation Facilities, Public Space, Education, public welfare Area, Building Plot, Unbuilt Area, Parking Lot ,Military Area, Road, Railway
Water Area	River, Surface of water, Waterway, Beach, Riverbed

digital data were collected and then statistically analyzed (Figure 2). As a first step in the GIS analysis, we distinguished the 21 land use categories (Table 3) for every single land lot polygon (1996; 44,608 polygons, 2001; 42,820

Table 1. Population growth and green space reduction (Hashizume, 1979)

Area	Population growth rate 1960-1970 [%]	Green space reduction rate 1960-1970 [%]	Green space rate in 1970 [%]

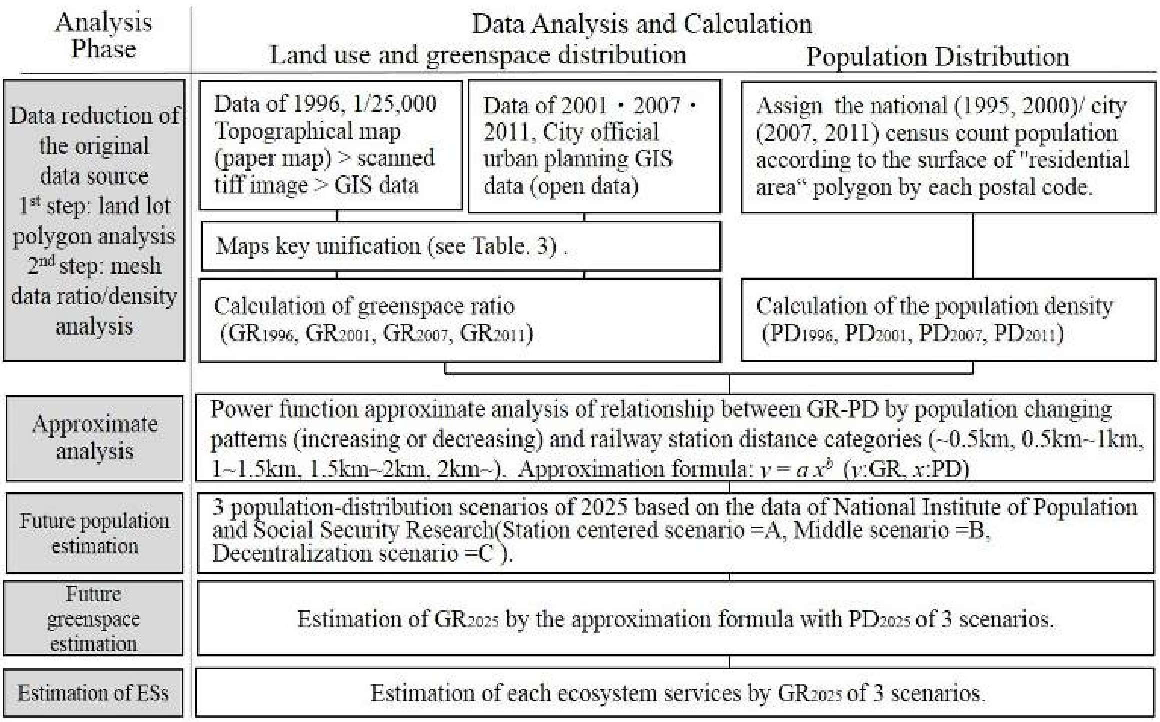

Fig 2. Data sources and analysis framework

polygons, 2007; 68,642 polygons, 2011; 153,905 polygons) in the study area. As a second step, we counted all the land lots on a 100m square mesh (in total 9,103 meshes), and then we calculated the surface ratio of green space in each mesh "GR_i" and the population density of each mesh "PD_i" at four time points (i: 1996, 2001, 2007, 2011).

Regulating services

(Totsuka and Miyake, 1991)

U_{CO_2}: CO_2 absorption (t/year)

U_{SO_2}: SO_2 absorption (t/year)

U_{NO_2}: NO_2 absorption (t/year)

U_{CO_2} (t/ha・year) = $0.4 \times Pg$

U_{SO_2} (t/ ha・year) = $20.7 \times C_{SO_2} \times Pg$

U_{NO_2} (t/ ha・year) = $15.5 \times C_{NO_2} \times Pg$

C_{SO_2}: Atmospheric SO_2 density ($\mu g/cm^3$) = 0.002ppm※3 (=52×10^{-7} $\mu g/cm^3$)

C_{NO_2}: Atmospheric NO_2 density ($\mu g/cm^3$) = 0.018ppm※3 (=44×10^{-6} $\mu g/cm^3$)

($PV=nRT$, MW; SO_2=64, NO_2=46, P:=1(Pa), R= 0.0082, T=298(K))

Table 4. Pg: Total amount plant production

(t/ha・year) (Totsuka and Miyake, 1991)

Paddy field	18
Farm	20
Grazing land	13
Glass land	16
Forest	67
Green park	10

Provisioning services

Gross of agricultural production (JPY/mesh)

$= 73.2\, x_i + 6.99 \times 10^2\, y_i$

x_i : Area of Paddy Field in mesh i (m^2)

y_i : Area of Farm in mesh i (m^2)

Table 5. Agricultural production

(Ministry of Agriculture, 2014)

	Area (ha)	Production in Funabashi (JPY)	Production (JPY/m^2)
Paddy Field	123	900×10^6	73.2
Farm	1120	$7{,}830 \times 10^6$	699

Cultural services

Green park utility; (pt/mesh) $= Pop_i \times Pt_i$

Pop_i: Population of mesh i

Pt_i: Point of liner distance to the closest green park of mesh i

Distance	*pt*
0km	7
0~100m	6
100~200m	5
200~300m	4
300~400m	3
400~500m	2
500m over	1

Box 1. Estimation method of Ecosystem Services

For the next phase, we classified all meshes by the population behavior patterns (*i.e.* increasing or decreasing) and 5 station-distance categories (*i.e.*0-0.5km, 0.5km-1.0km, 1.0km-1.5km, 1.5km-2.0km, 2.0km-). Then we applied a power function approximate formula:

$$y = a\,x^b \; (y_i\text{: Ave. } GR_i,\ x_i\text{: Ave. } PD_i)$$

which gave us the estimation of GR_{2025} by using PD_{2025} calculated from 3 population-distribution scenarios for 2025 (Scenario A: Station-centered scenario, B: Middle scenario, C: Decentralization scenario, see upper section of Table 8). These 3 scenarios were designed on the basis of a population forecast given by IPSS (National Institute of Population and Social Security Research)※1 (2013) and Chiba Prefecture Official※2 (2016). Finally, we calculated the changes of provisions of each ES including Regulating services (absorption of CO_2, SO_2, NO_2; t/mesh) (Totsuka and Miyake, 1991), Provisioning services (agricultural production; JPY/mesh) and Cultural services (green parks utility; pt/mesh) by using evaluation formula listed in Box 1 (Box 1 contains Table 4, Table 5 and Table 6.).

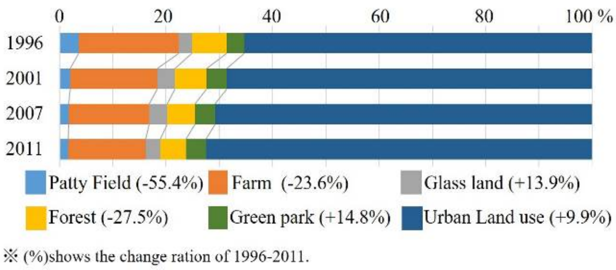

Fig 3. Time Series changes of land use items 1996-2011

Table 7. Result of Approximate Analysis

$y = a\,x^b$ (y_i: GR_i, x_i: PD_i)

Population behavior		Station distance	*a*	*b*	R^2
	Increasing	0~0.5km	0.0007	-1.158	0.9502
		0.5~1km	0.0043	-0.872	0.9652
		1~1.5km	0.0050	-0.846	0.9978
		1.5~2km	0.0343	-0.473	0.9127
		2km~	0.0148	-0.570	0.5645
	Decreasing	0~0.5km	0.8332	0.4436	0.9881
		0.5~1km	0.4279	0.2541	0.8127
		1~1.5km	0.5338	0.2087	0.9974
		1.5~2km	1.2155	0.2564	0.9005
		2km~	0.3853	-0.0800	0.7040

R^2: determination coefficient

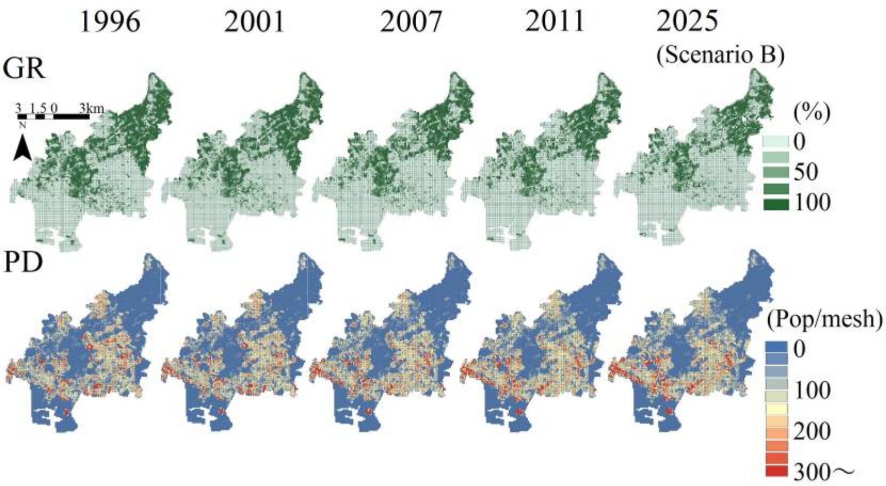

Fig 4. Time Series changes of population density and green space ratio

3. Result of analysis

3.1 Time series Changes in 1996-2011

For the first phase of this analysis, we calculated and visualized the time series changes of population density distribution and area surface for each land use item (Figure 3, Figure 4). The upper section of Table 8 shows the population and green space change data for several station distance categories. As Figure 3 and Table 8 show, total population of the city increased 13.4% over 15 years (1996 compared to 2011), where green space continuously decreased (by 21.5%) owing to the 9.9% increase of urban land use. Notably, the area of paddy field was down by half (-55.4%), and farm and forest areas were decreased more than 20% in this period. On the other hand, the area of grassland and the green park showed increases of 13.9% and 14.8% respectively. The increase of grassland was assumed to be due to the closure of factories and warehouses in suburban areas and the green park increase was due to the positive urban park improvement program of the municipal government.

Station distance category results in Table 8 show that the population in 2011 for the station distances >1.5 km showed slight downward trends. Nevertheless, the green space data for those areas showed decreases (e.g., 1.5km～2km: -15.8%, 2km～: -11.7%), but values were lesser in

Table 8. Green space ratio and the ESs in 2025 by population distribution scenarios

	Station distance categories	2011 (%: 1996 level)	2025 (%: 2011 level) Scenario A	Scenario B	Scenario C
Population (2011: Pop.) (2025: Pop. growth)	～0.5km	217,121 (+20.7%)	+13,500 (+6.2%)	+9,000 (+4.1%)	-10,000 (-4.6%)
	0.5km～1km	257,932 (+14.7%)	+12,000 (+4.7%)	+8,000 (+3.1%)	-12,400 (-4.8%)
	1km～1.5km	109,725 (+3.7%)	-23,000 (-21.0%)	-17,600 (-16.0%)	+12,300 (+11.2%)
	1.5km～2km	23,335 (-4.1%)	-6,500 (-27.9%)	-3,900 (-16.7%)	+3,700 (+15.9%)
	2km～	4,981 (-1.8%)	-1,400 (-28.1%)	-900 (-18.1%)	+1,000 (+20.1%)
	Total	613,094 (+13.4%)	607,763 (-0.88%)		
Green space ratio (%)	～0.5km	12.0 (-36.5%)	11.2 (-6.7%)	11.4 (-4.6%)	11.7 (-2.1%)
	0.5km～1km	20.1 (-27.8%)	19.3 (-3.9%)	19.6 (-2.6%)	19.9 (-1.2%)
	1km～1.5km	30.3 (-19.5%)	28.9 (-4.8%)	29.3 (-3.6%)	27.7 (-8.6%)
	1.5km～2km	42.7 (-15.8%)	39.3 (-8.0%)	40.8 (-4.6%)	39.9 (-6.7%)
	2km～	60.1 (-11.7%)	61.7 (+2.7%)	60.4 (+0.5%)	54.2 (-9.9%)
	Total	27.0 (-21.5%)	26.0 (-3.7%)	26.3 (-2.6%)	25.4 (-6.0%)
Green space area (km^2)		23.4 (-21.5%)	22.5 (-3.7%)	22.8 (-2.6%)	22.0 (-6.0%)
SO_2 absorption (t/year)		6.63 (-24.1%)	6.39 (-3.7%)	6.45 (-2.7%)	6.21 (-6.3%)
NO_2 absorption (t/year)		42.0 (-24.1%)	40.5 (-3.7%)	40.9 (-2.7%)	39.4 (-6.3%)
CO_2 absorption (10^3C-t/year)		24.6 (-24.1%)	23.7 (-3.7%)	24.0 (-2.7%)	23.1 (-6.3%)
Green park utility (10^6pt)		3.27 (-12.3%)	3.24 (-0.98%)	3.24 (-0.96%)	3.25 (-0.83%)
Agric. Production (10^6JPY)		8,744 (-23.5%)	8,387 (-4.1%)	8,488 (-2.9%)	8,253 (-5.6%)

magnitude than for station distance <1.5 km.

3.2 Relationship of PD and GR

With respect to results of the approximate analysis (*i.e.*, exploring the relationship between PD and GR), we obtained formulas for each station distance category with results separated based on population increasing and decreasing areas (Table 7). Overall, these formulas mean the multiplier factor *b* provides the change in value of green space ratio GR against the changes of population density PD. The results show a trend that the more distant from the station, the less green space ratios decrease for an increasing population. They also suggest that green spaces within 2.0 km of the station were in a gradual decline in spite of population decreasing.

In contrast, for areas where the population has been decreasing, *b* values are expectedly positive for most station distances. However, for results more than 2.0 km distant of the station, the value of *b* is turned to negative. This result shows that green spaces of those areas have been increasing slightly against the population decrease.

3.3 Green space and Ecosystem services in 2025

We estimated the green space ratio of each station distance category and the citywide provisions of ES with respect to each population distribution scenario (Table 8). Green space ratios in 2025 for the scenarios considered are slightly decreased from the 2011 level, where Scenario B shows the least change (-2.6%) and Scenario C, which representing the widespread distribution of population shows the most significant decrease (-6.0%) among the three scenarios.

For results relating to the provisions of the ESs estimation, the patterns (*i.e.*, decreasing ratios) of the amount of regulating services and provisioning services correspond closely to the patterns reported for green space (Regulating services (CO_2 absorption, SO_2 absorption, NO_2 absorption); Scenario A:-3.7%, B:-2.7%, C:-6.3%, Provisioning services (Gross of agricultural production); Scenario A:-4.1%, B:-2.9%, C:-5.6%). However, the results returned for Cultural services (Green park utility) show difference that are lesser in magnitude and are similar regardless of GR differences among the scenarios (Scenario A:-0.98%, B:-0.96%, C:-0.83%).

4. Conclusion

From these results, we can deduce that there is a fair chance for increase the green space around the suburban area in the population-decreasing era.

From the estimation of the green space ratio and the provisions of the ESs in 2025 by three population distribution scenarios, we found that the total green space area of the station-centered scenario will be smaller than the area of middle scenario. The total provisions of the ESs of each scenario were also estimated that will change in similar order as the green space area of each scenario.

Based on these results, we can conclude that there is a possibility of green space increase among the population declining suburban area. However, even if the population growth is focused on the urbanization are, the green space area around the suburban will not increase effectively. It also suggests that green space restoration measures in the area work effectively for green space increase.

※1: IPSS forecasted a decline in the Funabashi city population of 5,400 by 2025.

※2: Chiba Prefecture Official forecasted a 17,000 population increase among the urbanization area (almost fall under the station distance categories 0km-0.5km and 0.5km-1km) by 2025.

※3: Annual average value indicated by Funabashi-city Environmental Report 2013.

Acknowledgment

This work is supported by the Collaboration Research Program of IDEAS, Chubu University IDEAS201632.

References

MILT: Ministry of Land, Infrastructure, Transport and Tourism (2006) “Current situation and problems of Greenland Policy”

Naomichi HASHIZUME (1979) “Open Land in Tokyo Metropolitan Area” Komazawa geography 15, 83-92.

IPSS: National Institute of Population and Social Security Research (2013) “Japanese Regional demographic forecast Report”.

Chiba Prefecture Official (2016) “Urban Masterplan of Funabashi Urban Are”.

Tostuka. Tsugumu and Miyake. Hirishi (1991) “Air purification function of green space” Japan Society for Atmospheric Environment, 26(4), A71-A80.

Ministry of Agriculture (2014) “Agricultural output value by municipalities in 2014 (estimation)”