Green Infrastructure in Tokyo

Keidai Kishimoto and Wanglin Yan

Abstract The term "green infrastructure" refers to the aspects of land use and planning that utilize the diverse functions of natural ecosystems to bring social, ecological, and economic benefits to human society. People hike and jog in green spaces and obtain fresh vegetables grown on the land. Freshwater springs up from the ground. Whether or not people notice nature's services, natural ecosystems are one of the few natural resources available in urban areas. Without them, cities would just have gray infrastructure, concrete, and asphalt. It is important to be aware of the significant contributions of green infrastructure to urban systems. Does Tokyo have green infrastructure, does it need more, and what efforts are being made to create more? Which governmental plans and initiatives have introduced green infrastructure components? This chapter describes changes in Tokyo's natural ecosystems over time; the significance, definition, and strategies for green infrastructure in Tokyo and Japan; existing green infrastructure in Tokyo; and efforts to revitalize it.

Keywords Green infrastructure · Land-use change · Urban development

1 Natural Ecosystems Lost as Tokyo Metropolitan Area Urbanized

1.1 Green Space Loss

Tokyo Metropolitan Area began a long period of growth in 1603 when the shogun Tokugawa Ieyasu made Edo the principal capital of Japan. During the Edo period

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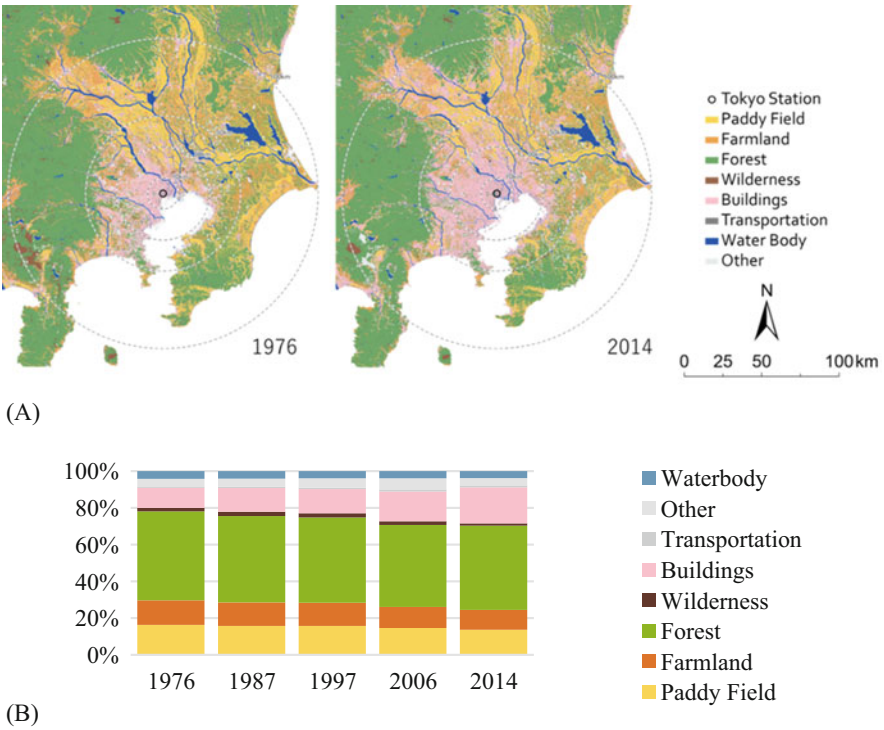

Fig. 1 Land-use changes over time in the Kanto region. (Source: Authors created using digital national land information from Ministry of Land, Infrastructure, Transport and Tourism). (**a**) Land use in 1976 and 2014. (**b**) Land-use change from 1976 to 2014

(1603–1867), it became one of the largest cities in the world. Once industrialization began in the nineteenth century, Tokyo Metropolitan Area faced several phases of urbanization: (1) urbanization with the construction of modern urban systems in cities (1860s to 1910s); (2) suburban development after the Great Kanto Earthquake and the Second World War (1910s to 1950s); (3) rapid urbanization and suburbanization with the building of urban infrastructure during a period of rapid economic growth (1950s to 1980s); and (4) urbanization and suburbanization with further enhancement of urban functions (1980s to 2010s) (Tokyo Metropolitan Government 2020). Tokyo Metropolitan Area is still today one of the world's largest cities, on par with New York and London.

Urbanization resulted in a significant reduction in green space in Tokyo Metropolitan Area. Figure 1a shows land-use maps in 1976 and 2014, and Fig. 1b shows changes in percentage of each land-use type. In the entire Kanto region, urban land use expanded greatly during this period, from a ratio of 10.9% to 19.6%. In Tokyo Metropolitan Government Area, built-up areas accounted for the majority of land use, rising from 34.1% to 45.9% during the period, with increases also in Kanagawa

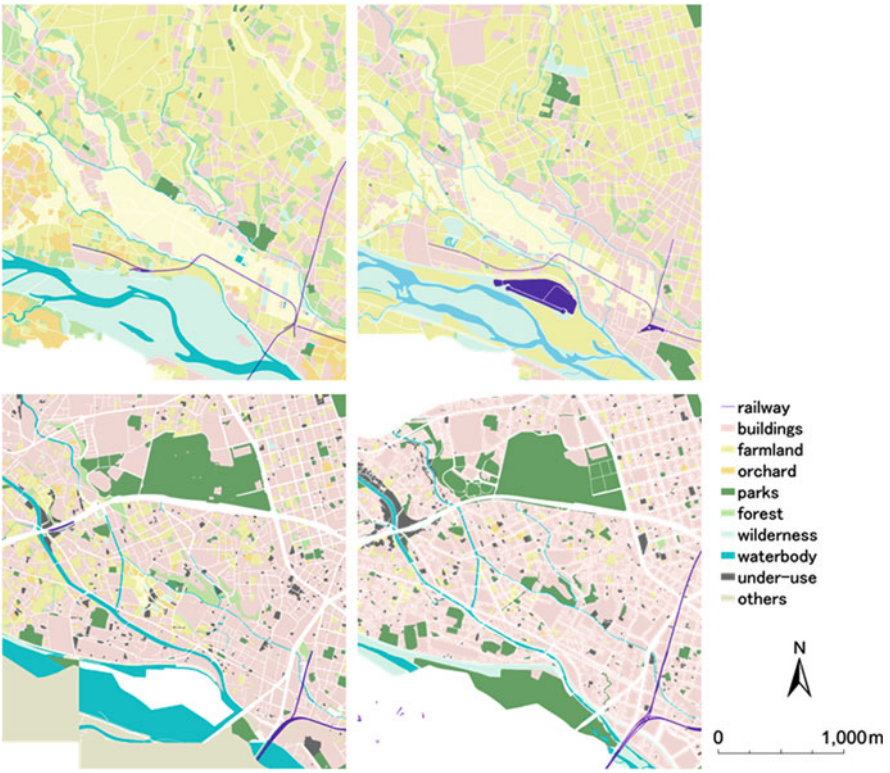

Fig. 2 Historic land-use changes in Setagaya City, Tokyo: *Above left*, 1929; *right*, 1955; *below left,* 1986; *right*, 2016. (Source: Authors created using the land-use data from the Bureau of Urban Development of Tokyo Metropolitan Government (1986 and 2016) and authors (1929 and 1955) based on topographic map)

Prefecture (from 23.2% to 36.4%), Saitama Prefecture (from 16.7% to 29.5%), and Chiba Prefecture (from 10.4% to 21.1%). The ratio of area covered by rice paddies decreased from 16.3% to 13.6% (a decrease of 16.5%), and by field from 13.3% to 10.8% (a decrease of 19.0%) in the Kanto region. In Tokyo Metropolitan Government Area, rice paddy area decreased by 83.2% during the period, and field by 60.3%, signs of the immense pressure of development on urban agriculture. In Kanagawa Prefecture as well, the situation was extreme, with a 48.3% decrease in rice paddy area and 33.7% decrease in field, while forest area decreased from 48.4% to 45.8%. The expansion of Tokyo Metropolitan Area occurred mainly at the expense of agriculture (especially urban agriculture). Correspondingly, the proportion of green space declined.

Figure 2 shows land-use changes around the Futako-Tamagawa Station in Setagaya, 15 km from Tokyo Station. In the 1929 map, rice paddies covered most of the lowland, while field covered most of the plateau, giving the area a rural, rustic

Table 1 Categories of ecosystem services and Tokyo example

Category	Services	Tokyo example
Provisioning services	Food	Urban agriculture (see chapter 9, Fig. 3a) or fishing
	Raw materials	
	Freshwater	Spring (Fig. 3b)
	Medicinal resources	
Regulating services	Local climate and air quality regulation	Mitigating heat island
	Carbon sequestration and storage	
	Moderation of extreme events	Dry well (Fig. 3c)
	Wastewater treatment	
	Erosion prevention and maintenance of soil fertility	Kokubunji Cliff
	Pollination	
	Biological control	
Habitat or supporting services	Habitats for species	Biodiversity (Fig. 3d)
	Maintenance of genetic diversity	
Cultural services	Recreation and mental and physical health	Recreation along riverbeds (Fig. 3e)
	Tourism	
	Esthetic appreciation and inspiration for culture, art, and design	
	Spiritual experience and sense of place	"Jinja" (shrine) forests (Fig. 3f)

Source: Authors created using TEEB—The Economics of Ecosystems and Biodiversity (2011)

appearance. The 1955 map shows the early stages of housing development, when fields around the station area was being converted to housing. Economic growth in the latter half of the 1950s led to rapid urbanization, and the city expanded significantly starting in 1986. As a result, many agricultural irrigation waterways were lost. By 2016, urbanization had expanded even further from the station, and as in the rest of the Kanto region, it progressed at the expense of agricultural land use.

The history of urban development described above has led to a reduction in the size and scale of intact green spaces, especially in agricultural land use, as well as a decline in their quality and continuity. The Tokyo Metropolitan Area suffered great losses of green spaces, as the next section explains.

1.2 Ecosystem Services Loss

Natural ecosystems, even in cities, provide various services locally, regionally, and globally, known as ecosystem services. These ecosystem services are beneficial for their many uses, for ethical and esthetic reasons, and for educational purposes (Bolund and Hunhammar 1999). Ecosystem services have been clustered into 4 major categories and 17 subcategories, as shown in Table 1 (The Economics of

Ecosystems and Biodiversity 2011). How have ecosystem services changed with urban development and reduced green space?

The Ministry of the Environment identified four factors driving an ecosystem crisis in Japan: (1) human activities such as urban development and overuse, (2) reduction of human–nature connections in *satoyama*—traditional Japanese landscapes with mosaic land-use including semi-natural ecosystems (Ichikawa et al. 2006; Takeuchi et al. 2003), (3) human impacts such as the introduction of invasive species and chemical substances, and (4) changes in the global environment such as climate change (Ministry of the Environment 2012, 2016).

Among the four drivers, urban development, as shown in "Green Space Loss" section, has had the most destructive effect on living things, and it continues to exert significant influence, even though urban development pressure has decreased in recent years (Ministry of the Environment 2016). Today, urban development is now easing in impact (Numata 2014), and flora and fauna appear to be thriving better in the city. Meanwhile, negative impacts of the second and third causes, under use of *satoyama* and invasive species, are severe (Numata 2014). *Satoyama* landscape, mosaic with rice paddies, secondary forests, and ponds, is a habitat for many plants and animals. Improvement of agricultural methods and depopulation of rural areas influence on use of *satoyama*. The conversion to an unmanaged and abandoned area results in the loss of biodiversity (Uchida et al. 2018; Iwachido et al. 2020) and a healthy natural environment. The magnitude of impact by climate change is now recognized scientifically (IPCC 2014; Ministry of the Environment 2016). Plants and animals are forced to change their phenology and habitats (Primack et al. 2009; Ibáñez et al. 2010).

As a result of these four factors and an ecosystem crisis, ecosystem services in Japan are considered to be worsened over the past 50 years (Ministry of the Environment 2016). Table 2 shows an assessment of changes in ecosystem services made by a committee set up by the Ministry of the Environment with the help of 120 researchers. The reports showed that among providing services, matsutake mushrooms were reduced to 1% of their peak level, while the marine fisheries were reduced to about 30% of their peak level, and groundwater recharge, one of the regulating services, was reduced by about 8% (Ministry of the Environment 2016). Conversely, interest in natural environments has increased these days.

Thus, the supply of ecosystem services is declining, though it benefits our lives and well-being. How should the remaining green spaces be positioned? What can cities do? The concept of *green infrastructure* has been developed to solve these questions. The following chapter describes "green infrastructure" concept in Tokyo.

Table 2 Changes in ecosystem services in 50 years. ++: up, +: slightly up, 0: not changed, −: slightly down, ——: down,?: insufficiently evaluated

		Past 50–20 years	Past 20 years to today	Use level
Provisioning services	Agriproducts	——	−	Under use
	Forestry	+	−	Under use
	Fishery	+	−	Overuse
	Freshwater		0	Overuse
	Wood	−	0	Under use
	Material	−	−	Under use
Regulating services	Climate regulation		−	
	Air control		0	
	Water flow		−?	
	Soil control	0		
	Disaster moderation	+?	0?	
	Biological control		−?	
Cultural services	Religious festivals	——	−	
	Education	−	0	
	Landscape		−	
	Traditional entertainment, arts	−	−	
	Tourism, recreation	+	−	
Disservice	Animal damage		+	

Source: Authors cited and arranged using the Ministry of the Environment (2016)

2 Significance of Green Infrastructure and Strategies

2.1 What Is Green Infrastructure?

The term *green infrastructure* refers to land use and planning/management that can be used to achieve positive social, ecological, and economic outcomes for human society, utilizing available diverse ecosystem services. The concept of green infrastructure varies regionally in definition and perception due to social, ecological, and economic differences. Research in the USA emphasizes improving urban stormwater management, for example, while in Europe the focus is more on improving ecosystems and ecological networks. Japan has its own definition of green infrastructure, a combination of the European and US approaches, a result of reevaluating traditionally recognized, multifaceted functions of green infrastructure, and a broader recognition of diverse services provided by nature, including disaster

prevention and mitigation (Iwasa and Nishida 2017). In particular, the 2013 Great East Japan Earthquake was a major event that added impetus to the discussion of green infrastructure (Iwasa and Nishida 2017).

The evaluation and creation of green infrastructure should first recognize the magnitude of ecosystem services provided and the diversity of those services and include a comprehensive understanding of local ecosystems. Green infrastructure supports as many diverse species, as much mitigation of heat islands, and as much carbon fixation as possible. A component of green infrastructure should be designed to provide more diverse services and catalyze synergies at the same time. In addition, policymakers should develop green infrastructure respecting and shaped to local ecosystems. It would be a disservice, for instance, to introduce exotic species or grow vegetables unsuitable to the local environment without prior assessment.

The significance of green infrastructure has been studied academically in Japan. This is evident in the various efforts, both formal and informal, to establish new groups within academic societies (e.g., the Japanese Institute of Landscape Architecture and the City Planning Institute of Japan), to create new networks among researchers and municipalities beyond academic communities (e.g., the Green Infrastructure Association), and to develop regional networks (e.g., the Green Infrastructure Study Group in Setagaya).

2.2 Strategy for Green Infrastructure in Japan

The focus on development of green infrastructure to maximize and support ecosystem services is being promoted mainly by the national government, local governments, and private companies.

The national government has over time positioned green infrastructure to be included in policy for various federal lands and social conditions. First, in 2014, the Fundamental Plan for National Resilience mentioned the disaster prevention and mitigation functions of natural ecosystems (Cabinet Secretariat 2014). In 2015, the Second National Spatial Planning initiative noted green infrastructure in the "appropriate management of national land," and the Fourth Priority Plan for Social Infrastructure Development promotes green infrastructure for "improvement of the quality of life" (Cabinet Secretariat 2015; Ministry of Land, Infrastructure, Transport and Tourism 2015, 2020). Furthermore, the Fifth Basic Environment Plan, adopted in 2018, recognized that green infrastructure development "improves resilience" (Ministry of the Environment 2018). In response to these directions, the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) established a strategy to promote green infrastructure and activated nationwide efforts for stakeholder collaboration (Ministry of Land, Infrastructure, Transport and Tourism 2019).

Local governments have adopted policies to promote green infrastructure, and some are frontrunners in implementing various initiatives. Setagaya City, for example, set the goal in its 2018 Green Master Plan to increase the green coverage of the municipal area to 33% by 2032 (Setagaya City 2018). Another example is the

"Setagaya Dam Initiative," which aims to maintain and increase the amount of rainwater infiltration in the city by preserving rainwater infiltration surfaces, including agricultural land, and assisting in installing rainwater infiltration facilities. There are also many citizen science projects, including surveys of flora and fauna, and compiling the data for use in policymaking.

Private companies can also be important actors in creating and managing green infrastructure in cities. One example is Tokyu Corporation, which operates railways in the Tokyo area and has developed many retail and office complexes along its rail lines. Its Futako-Tamagawa Rise and Minami-Machida Grandberry Park are major developments that incorporate green infrastructure elements featuring biodiversity, walkability, and water infiltration. AEON Corporation is a major retailer in Japan that works with citizens to plant native trees, among many other initiatives.

3 Tokyo's Urban Green Infrastructure: A Treasure for Resilience and Adaptation

Above, we learned that Tokyo has had a long-term trend of losing green space and agricultural land to urbanization, and that it needs green infrastructure to more fully benefit from the ecosystem services nature provides. In this section, we summarize the state of green infrastructure in Tokyo.

3.1 Remnant and Conserved Green Infrastructure

Traditional green infrastructure includes many green spaces. Forested land is the most common land type that provides excellent ecosystem services, however, as shown in Fig. 1a, there is not much forest land left in most urban areas. In some places, though, such as Setagaya City, notable areas of forest land have been retained, as shown in Fig. 3b. Tokyo has a complex mix of plateaus and lowlands that contribute to the unique culture of the area.

Natural springs bubble up at the base of terraces or ridges and the end of an alluvial fan and have become the location of many historical parks and residences. In the past, people used the springs for refreshment of body and mind, while today they also continue to keep urban ecosystems healthy and landscapes beautiful. At the same time, however, the long-term reduction of permeable surfaces and the overuse of groundwater has caused groundwater levels to drop and spring water availability to decline. In Setagaya City, forests along the Kokubunji Cliff Line have been designated as scenic areas in order to preserve landscapes, due to the presence of historic houses, natural springs, and a diversity of species living in the rich habitat.

Many Shinto shrines and Buddhist temples are located at the edge of a plateau, where they have a good view and are less likely to be damaged by floods. The term

Fig. 3 Images of landscapes and nature providing ecosystem services in Tokyo (refer to Table 1 for descriptions of labels (**a**) to (**f**)). (Photo credits: Keidai Kishimoto)

chinju no mori refers to a forest or grove around a *jinja*, or Shinto shrine. Many shrines have buildings for worship, offices, an approach or promenade, and the sacred forest or grove. These treed areas play a key role as the setting for spaces for worship, festivals, and biodiversity. *Chinju-no-mori* in Tokyo contribute to urban greenery and create networks of green areas (Fujita 2007). Buddhist temples as well often are often surrounded by groves of ancient trees. The lands of the Imperial Palace, residence of the imperial family, is a vast green space covering an area of 2.3 sq. km. Even though it is in the center of Tokyo, it is rich with diverse species such as the raccoon dog (Kuramochi et al. 2014) and helps to mitigate the heat-island effect (Ministry of the Environment 2006). Of the mitigation of heat-island impacts,

the greenery of the Shinjuku-Gyoen park, or the former Imperial Park, in summer cools surrounding temperatures by 2–3 °C (Narita et al. 2004).

Urban agriculture, in particular, still supplies vegetables, fruits, and other food despite the intense pressure of urban development. While food provisioning in Tokyo itself has declined over the long term with the loss of farms, in recent years urban agriculture has become more recognized as a land use that society values and belongs in cities, and efforts are being made to conserve and promote it (Ministry of Agriculture, Forestry and Fisheries and Ministry of Land, Infrastructure, Transport and Tourism 2016; Tokyo Metropolitan Government 2017). Detailed evaluation and changes are explained in chapter "Urban Agriculture as a Tool for Adapting Cities for the Future" of this volume.

Besides these areas of greenery, trees and home gardens can be widely found on private land. As one of the significant areas supporting urban habitats (Rudd et al. 2002), they function as a place for household food production and as a place for rainwater infiltration (Yokota and Niwa 2020).

It is desirable that these be left untouched by urban development and continue to be conserved through proper land management, by considering the functions of green infrastructure that can improve the quality of life and contribute to resilience.

3.2 Built Green Infrastructure

A significant amount of new green infrastructure has been created in cities as a result of technological improvements and greening policies. Rooftop greening is a major greening strategy being employed, and green rooftops in Tokyo currently amount to as much as 2,508,000 sq. m (Tokyo Metropolitan Government, 2022), with many large commercial facilities and offices greening their rooftops. Rooftop greenery is used by birds (Motegi and Yanai 2004) and as a place for allotment gardens. In Tokyo, new construction and expansion of buildings of a certain size are required to be greened according to ordinances of the Tokyo metropolitan government and municipalities. Figure 4 shows the annual trends in ground and rooftop greening since the early 2000s, with 150,000–200,000 sq. m of greenery being created in most years.

Futako-Tamagawa Rise is a large retail and residential complex that opened in 2015, with its design including rooftop greening inspired by the original local environment. In addition to evoking the Tama River which runs nearby in the décor and design, the development used local plants, stones, and other materials from the Tama River basin. The complex's rooftop greening projects provide habitat to help conserve an endangered plant species known as kawara-no-giku (*Aster kantoensis Kitam.*). These efforts contribute to the local ecological network as a green stepping stone connecting the Tama River and Kokubunji Cliff Line. The rooftop greenery is popular for shoppers, residents, and office workers. For its contributions to the natural environment and urban development, Futako-Tamagawa Rise has received LEED for Neighborhood Development (LEED ND) Gold

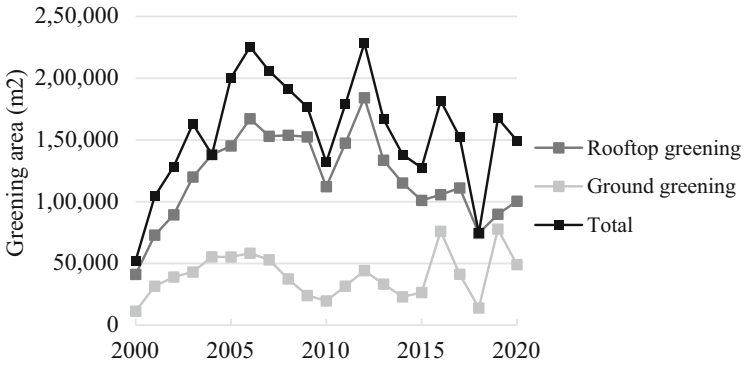

Fig. 4 Area of green rooftops on private developments of more than 1000 sq. m and on public developments more than 250 sq. m. (Source: Author created using Tokyo Metropolitan Government (2022))

certification, as well as AAA rating under the Japan Habitat Evaluation and Certification Program (JHEP), the highest ranking in this environmental certification system.

Permeable pavement and rain gardens are also attracting attention in Japan, and their use is gradually spreading. Japan faces typhoons and heavy rainfall every year and should work to prevent inland flooding in cities. Setagaya City, for example, is promoting green infrastructure development to prevent inland flooding by providing support for such efforts.

Minami-Machida Grandberry Park is a large integrated retail development with retail and park space that opened in 2019 in front of a suburban transit station. In addition to the smooth integration of the station, retail facilities, and park, it includes a range of planted vegetation of mainly native species, open spaces such as plazas, and rainwater infiltration including "rain gardens." The project is one of the most progressive examples of green infrastructure in development planning and has received various awards in addition to LEED ND Gold certification.

Many other initiatives can be observed in the region, such as park space, green walls, rooftop vegetable gardens, and de-culverting. The green infrastructure that has been created is generally small-scale and local, and it often is adapted along with land-use changes and building renovations or redevelopment projects. Thus, on the grand regional scale of land management and resilience these initiatives may not seem so significant, but they do contribute to the improvement of the quality of life for residents of the surrounding communities. New opportunities to expand green infrastructure may arise as cities shrink or become less dense due to declining birthrates, the aging of society, and declining population.

4 Rediscovering Land Resources for Green Infrastructure

Green infrastructure plays a crucial role in future visions for cities. Initiatives need to include not only short-term but also as medium- and long-term consideration. Thus, an important question is where cities can find the spatial resources needed for green infrastructure.

4.1 Small-Scale Changes

For small-scale changes, vacant and underused land can be converted to green infrastructure. Examples include vacant lots, parking lots, and rooftop spaces. They play roles mainly in mitigating heat island, networking ecological patches as "stepping stones" for living things, and healing our minds.

One of the potential land resource is parking lots. Tokyo has many flat paved and multi-story parking lots for vehicles, and many flat parking lots for bicycles. Flat parking lots that tend to be vacant for long hours of the day could potentially be greened. Recent years, they are gradually increasing in retail and public facilities; however, Tokyo has not yet seen many greening projects for parking lots. Figure 5 shows a large percentage of urban areas are occupied by parking lots, excluding

Fig. 5 Parking lots in Futako-Tamagawa. (Source: Author created using the land-use data by Setagaya City 2016)

parking lots for detached houses, condominiums, supermarkets, etc. It seems that there is still much room for improvement in the greening of parking lots in Tokyo.

4.2 Large-Scale Change

There are many challenges in building green infrastructure on a large scale in cities, but more and more possibilities are emerging to include it as a new strategy to cope with natural disasters. Japan has seen an increase in the severity of flood damage in recent years, especially in low-lying land and other areas exposed to high disaster risk.

Correspondingly, the Japanese government enacted legislation on watershed management in 2021, which designates areas with a high risk of flooding and regulates land-use changes and building use in these areas. It also expands schemes for induce of relocation of housing for disaster prevention, recommends frameworks to secure land for water retention and recreational functions, and promotes the preservation of urban green spaces. A supplementary resolution by the House of Representatives stated that "the idea of green infrastructure should be promoted to make use of the diverse functions of the natural environment and contribute to the formation of an ecological network by actively conserving or restoring the functions of ecosystems that contribute to the reduction of disaster risks" (House of Representatives 2021). These legislative references to the concept of watershed and water management strengthen the rationale for preserving existing urban green spaces and also provide opportunities to discuss efforts to establish water retention and recreational areas in high-risk areas and land use after relocation for disaster prevention. Although these efforts will not produce major changes in the short term, they can be a step forward in promoting green infrastructure initiatives from a long-term perspective.

5 Discussion and Conclusion

There is a huge gap between the global environmental crisis and the world's actual goals in response. In 2015, the Paris Agreement on climate change included the goal of limiting the global temperature rise to 2 °C above preindustrial levels. The same year, the Sendai Framework for Disaster Risk Reduction called for a significant reduction in disaster-related deaths, victims, and economic losses. By 2019, however, Japan had only reduced its CO_2 emissions by 14%, although it announced the goal of reducing emissions by 46% by 2030 (both relative to 2013) (Ministry of the Environment 2020). Meanwhile, Japan has experienced more natural disasters from extreme weather, including a major landslide in Hiroshima City in 2014, and heavy rains and powerful typhoons in East Japan in July 2018. Japan also experiences earthquakes, such as the 2018 Hokkaido Eastern Iburi Earthquake, the 2016

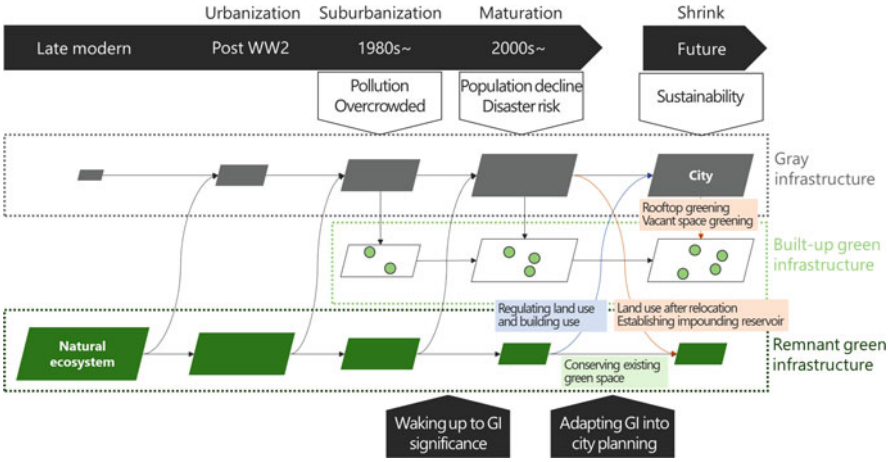

Fig. 6 The future of green infrastructure in shrinking cities. (Source: authors)

Kumamoto Earthquake, the 2011 off the Pacific coast of Tohoku Earthquake, etc. Green infrastructure can help mitigate damage from such disasters.

On the positive side, technological advances have made cars more fuel-efficient and eco-friendly, home appliances more energy-efficient, and power generation more renewable energy-based. Japan has also made social capital improvements such as drainage channels and higher embankments to redirect and hold back floods. Investment in technological developments and social infrastructure needs to continue, but there are limitations to what can be accomplished with these types of investments. Japan also faces aging infrastructure, so it must spend a large amount of money just to replace existing infrastructure, but the population is also declining while financial burdens are increasing.

Against that background, this chapter has described how Tokyo planners realized that, while natural ecosystems have suffered as a result of urbanization, if properly utilized, the various ecosystem services can help not only replace but also enhance conventional technological development (Fig. 6). Tokyo started working on green infrastructure later than some other countries, and its strategy focuses on Tokyo's own unique green infrastructure by utilizing traditional spaces such as shrine and temple forests and new built-up spaces. This attitude toward green infrastructure is an attempt to adapt to social change and risk, which is an important aspect of the title of this book.

In fact, this is not the first time that Tokyo has tried to use greening in the adaptive city; inspired by London's example, green belts were introduced after the Second World War, and while some remain, many have been lost to urbanization. As the problems being faced become increasingly complex and urgent, we cannot afford to repeat the mistakes of the past.

In a report on green infrastructure, the Science Council of Japan (2020) identified current issues as (1) overall planning for the construction of an "adaptive city" using

green infrastructure, (2) development of the necessary technologies, and (3) research, development, and decision-making for multiple protections. These could be restated as (1) a strategy for the development of green infrastructure for the entire Tokyo metropolitan area; (2) remote-sensing methods for the development of green infrastructure, the downscaling of climate change prediction to the municipal level, and other technological developments; and (3) the creation of urban multi-protection green infrastructure that can mitigate disasters such as earthquakes and tsunamis and improve biodiversity (Science Council of Japan 2020). It is hoped that Tokyo, with its limited habitable area relative to population and its exposure to annual monsoon-related and geological-related disasters, can be a leader in the research and development of green infrastructure and promote it throughout Asia and the world.

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