Chapter 2

Concept and Application of Green and Hybrid Infrastructure

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Abstract Recently, Japan has suffered extraordinary damage from typhoons, heavy rains, and megafloods, each of which has exceeded the upper limit of control by managed infrastructure for flood mitigation. First, I present a conceptual framework of hybrid infrastructure at the watershed scale, combining (1) fundamental green infrastructure (GI), composed of forests and wetlands in the watershed; (2) additional multilevel GI, such as flood control basins; and (3) existing engineered disaster prevention infrastructure, such as dams and artificial levees. Second, I introduce the disaster risk reduction function of natural forests and wetlands and three representative traditional flood control measures: discontinuous levees, overflow embankments, and flood protection forests. This GI should be properly allocated and maintained at the watershed scale to reduce damage by megafloods. The multiple types and functions of GI may provide essential habitats for wildlife and recreational opportunities for local residents and others. Finally, I address key points for planning, implementation, and governance of GI at the watershed scale.

Keywords Hybrid infrastructure · Flood control · Climate change · Ecosystem services · Biodiversity · Ecological network

2.1 Introduction

Flood protection strategies using current gray infrastructure, such as dams and artificial levees, face limits and are not able to protect human lives and assets from megafloods (e.g., exceeding 100-year return interval) exacerbated under climate change. Here, I define gray infrastructure (GYI) as engineering infrastructure associated with water resources, such as water and wastewater treatment plants, pipelines, and reservoirs. Recently, Japan has been experiencing large flood disasters

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Fig. 2.1 Flooding of the Abukuma River by Typhoon Hagibis, Sukagawa city, central Japan (Ministry of Land, Infrastructure, Transport and Tourism, Japan)

every year associated with typhoons and seasonal rains, which have exceeded the river discharge that the infrastructure was designed to deal with (hereafter I call it “design flood discharge”). Therefore, floodwater spilled over the artificial levees and inundated farmlands and residential areas (Fig. 2.1).

There are two alternatives to respond to the increasing floodwater discharge: one is increasing the design flood discharge by conventional measures, such as construction of dams, excavation of channel sediment, setback of levees, and enhancement of levee height, and the other is keeping the design flood discharge at the current level while providing green infrastructure (GI) outside of the levees including forests on the hillside slopes and wetlands on floodplains to store rainwater and retain spilled floodwater there. Here, GI can be defined as “a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services such as water purification, air quality, space for recreation and climate mitigation and adaptation” (European Commission 2016) (Fig. 2.2).

The revision of design flood discharge to a higher level is not easy. Reservoir dams have been built without considering future climate changes in design flood discharge. Floodwater control by levees and channelization started from downstream reaches (urban areas) where densely populated cities and towns are located and progressed to upper reaches (rural areas) where farmlands are developed. However, there are many rural areas in Japan where flood control measures have not yet been completed. Thus, if we raise the design flood discharge in response to climate change, we must restart flood control management again from the downstream reaches and leave upstream rural areas unprotected for a long time. Even if we can fulfill the flood control management corresponding to a certain higher level,

Fig. 2.2 Multi-functionality of GI and linkages at the watershed scale

intense flooding exceeding the revised management level is likely to occur under climate change. It is not realistic to revise the design flood discharge continuously and repeatedly.

When we explain green infrastructure (GI), we tend to situate GI as an opposing and conflicting concept against gray infrastructure (GYI). In some sense, this is true, but exaggerating the differences between GI and GYI may hinder productive discussions. Rather, under climate change, these two infrastructure types should complement each other and contribute to a comprehensive land-use plan that simultaneously provides amenities, convenience, and safety to local towns, cities, and communities (Green Infrastructure Association (Japan) 2017, 2020). For example, we consider that forest ecosystems are one of the most important types of GI and function to regulate water discharge from a basin. In Japan, someone who is opposed to dam construction may argue that forests are a surrogate for large dams (GYI); therefore, dam construction is not necessary if we leave forests in upper basins. This type of emotional argument is not productive; rather, we should manage plantation forests to keep appropriate tree densities and soil infiltration rates to reduce the dependence on water regulations by dams.

A suite of GI measures provide various ecosystem services across a watershed (Fig. 2.2). Our future land-use plan should be built from the viewpoint of how we can create a best mix of advantages provided by GI and GYI at the watershed scale. The objective of this chapter is to devise climate change adaptation strategies for disaster prevention and biodiversity conservation using GI in Japan. More specifically, I will (1) introduce a conceptual framework for hybrid infrastructure at the watershed level with concrete evidence of previous research results, (2)

reevaluate Japanese traditional measures from the viewpoint of climate change adaptation, and (3) propose a best mix of GI and GYI at the watershed scale mainly focusing on flood protection and biodiversity conservation.

2.2 Conceptual Framework for Hybrid Infrastructure

First, I would like to define gray, green, and hybrid infrastructure at local and landscape (or watershed) scale. GYI at the local scale is represented by artificial elements, such as dams and channelization, whereas an individual natural ecosystem, such as a patch of wetland and forest, is at opposite end of the naturalness spectrum (Fig. 2.3). A mixture of natural and artificial elements, such as gardens and parks, is regarded as hybrid infrastructure. At the landscape (or watershed) scale, urban areas are built by various GYI, whereas wilderness areas consist of diverse natural ecosystems (Fig. 2.3). In this spectrum, a mosaic distribution of natural (or

Fig. 2.3 Definition of green, gray, and hybrid infrastructure at local and watershed scale (adapted from Green Infrastructure Association (Japan) ed. (2020))

Fig. 2.4 Conceptual framework of gray (a), green (b), and hybrid infrastructure (c). Shaded and white areas denote the safety zones created by gray and green infrastructure (GI), respectively. The area denoted by GI-1 is the fundamental GI, while GI-2 is an additional multilevel GI. (a) and (b) are modified from Onuma and Tsuge (2018) (from Nakamura et al. 2020)

seminatural) and artificial ecosystems in a suburban and rural watershed can be referred to as hybrid infrastructure.

GYI elements, such as dams and artificial levees, usually assure 100% disaster protection until the magnitude of the disaster reaches the upper limit of the management plan, though unexpected risks associated with structural flaws and human errors still exist. However, once the magnitude exceeds the upper limit, the GYI will have no additional flood mitigation function; for example, floodwater will spill into residential areas where artificial levees are breached (see Fig. 2.1). Thus, the safety-magnitude curve for GYI has a rectangular shape (Fig. 2.4a). In contrast, I expect the response of GI to show a gradually decreasing trend. In addition, the disaster prevention function of GI may be sustained longer than that of GYI (Onuma and Tsuge 2018). However, the response curve of risk reduction against disaster magnitude by GI at the local scale is not well studied and can vary depending on the kind of GI (Fig. 2.4b). The uncertainty of the function is high for GI.

In the past, we have discussed the advantages and disadvantages of GYI and GI and compared them to determine which approach was better. Sometimes, such

debates are not productive and promote the polarization of opinions between gray and green approaches. Here, I discuss a combination of GYI and GI with the aim of applying GI for disaster control in a society at high risk of various natural disasters, as is the case in Japan. I present a hybrid, combining the two types of infrastructure at watershed scale in Fig. 2.4c. In this conceptual diagram, GI-1 represents the fundamental GI composed of forests and wetlands in the watershed, while GI-2 is additional multilevel GI, such as flood control basins that function when floodwater exceeds the design flood discharge determined by artificial levees. In this diagram, an increase in the combined area of GYI and GI guarantees safety, even at a very high magnitude of flooding.

How much should we expand or reduce the areas of GYI or GI to meet present and future needs as we face climate change? We have to evaluate the effectiveness of hybrid infrastructure in terms of disaster prevention, biodiversity protection, and social and economic values to determine which combination is best in a given natural and social condition. If the area of GYI is expanded, high levels of disaster control may be achieved, but there may be losses in biodiversity and the hometown landscape and increases in maintenance costs. Historically, Japan has been losing forest and wetland GI-1 through overharvesting of forest resources and land conversion from wetland to agricultural fields (Nakamura et al. 2017). As a result, the peak flood discharge has gradually elevated, and Japanese government has had to compensate for the water retention ability that natural ecosystems provided in the past with GYI, such as dams and artificial levees. The combination of GYI and GI may change depending on future land use. We may preserve or rebuild GI using abandoned farmlands at lower cost in rural areas. In contrast, it may be difficult to restore natural ecosystems in highly populated urban areas, and GYI therefore still plays an important role in disaster risk reduction with a limited introduction of GI represented by gardens and city parks.

2.3 Attenuation of Flood Peaks by Forest and Wetland Ecosystems (Examples of GI-1 in Fig. 2.4c)

Natural forests and wetlands have the ability to reduce the disaster risk by attenuating and delaying flood peaks. The mechanism and detailed information are introduced in other chapters, and I will briefly explain their functions as GI-1 in Fig. 2.4c. These natural and seminatural ecosystems function to keep flood risks low by storing rainwater on hillslopes and floodplains at a watershed scale.

In one such example, Tsukamoto (1985) investigated how water discharge changed in association with urbanization and loss of forest cover (Fig. 2.5). From this figure, we understand that the peak discharge increased during floods, while the low-flow discharge decreased in the urbanized watershed. On the other hand, during the beginning of a series of rainfall events, the peak discharges from the forested watershed were greatly attenuated, and the low-flow discharge was slightly

Fig. 2.5 Comparison of hydrographs between urbanized and forested basins (from Tsukamoto 1985)

increased. However, these effects were not clearly observed at the end of the sequence of rainfall events; the degree of peak discharge attenuation was reduced, and the low-flow discharge was greatly increased. The timing of flood peaks is almost simultaneous with rainfall peaks in the urbanized watershed throughout the investigated period in part because of their extensive paved surfaces. In contrast, delays in flood peaks can be observed in forested watersheds, especially at the end of the sequence of rainfall events. This is because most of the precipitation was absorbed by the forest soil and retained in the soil pores at the beginning of a series

of rainfall events, and thereafter, precipitation added to the forest soils at the end of rainfall events was rapidly released from macropores and transported by saturated subsurface and surface flow. Thus, the flood risk reduction provided by forests may vary over time during a rainfall event. However, forest ecosystems certainly function as GI-1 and can stabilize variations in stream discharge.

Japan has traditionally recognized the functions of forest ecosystems, including the abovementioned hydrological effects, and developed forest protection laws starting in 1897. In contrast, in the past, wetlands have not been acknowledged as GI, but rather considered unproductive lands. Due to the lack of knowledge of wetland ecosystem services, wetlands have been converted to agricultural lands. Approximately 60% of the original wetlands in Hokkaido, a northern island in Japan, have disappeared over the last 50 years (Nakamura et al. 2005). However, people have gradually recognized the importance of the ecosystem services that wetlands provide, including biodiversity conservation, flood control, and improvement of water quality. In general, wetlands develop in relatively flat areas where streamwater and rainfall are retained, whereas forests become established not only in flat areas, but also on steep terrain. However, currently remaining forests are mainly on relatively steep land because most flat areas have been developed for other land uses. Thus, the remaining wetlands in flat areas are highly valued and should be retained and restored to capitalize on their capability of stormwater retention. In contrast, forests on steep slopes, where the hydraulic gradient is high, have lower water retention capability.

Nakamura et al. (2020) used the hydrological model GETFLOWS to simulate the effects of the Kushiro Mire on the water discharge of the Kushiro River in Hokkaido. The Kushiro Mire is the largest wetland complex in Japan, extending across approximately 26,000 ha. Three typhoons accompanied by heavy rains arrived in the Kushiro region from August to September 2016, producing three major flood peaks. The authors used the model to calculate water discharge for the case in which approximately 55% of wetlands were converted to residential lands. The simulated hydrograph of the modified wetlands showed a higher peak discharge, sharper rising and descending limbs, a 2-day earlier arrival of the peak, and a lower low-flow discharge than those of the present situation in which wetlands exist without 55% area-based land conversions (Fig. 2.6). The peak discharges of the simulation cases for the present and for the partial loss of wetlands were 390 and 580 m³/s, respectively. The results of the model simulation clearly demonstrated that the Kushiro Mire acts as GI-1 (a large natural reservoir) that attenuates the peak discharge during floods.

As shown above, forests and wetlands in a watershed are fundamental GI that stabilize water discharge and substantially attenuate flood peaks. Thus, if we lose these GI-1 features, we will face a risk of flooding and have to compensate with more GYI. However, these GYI features lead to high maintenance costs and may not be economically feasible in depopulating societies, such as Japan and other countries.

Fig. 2.6 Attenuation of flood peaks by the Kushiro Wetland. The fit of the simulation results to the observational hydrograph (a) and comparison of the simulation results with and without wetland green infrastructure (b) (from Nakamura et al. 2020)

2.4 Traditional Measures Against Large Floods (Examples of GI-2)

Japan has developed traditional flood control measures since the sixteenth century. These are nature-friendly technologies and are recognized as GI from the present perspective. Unfortunately, however, the significance and necessity of those measures for flood control have been forgotten since modern technologies were introduced from European countries in the Meiji era (1868–1912), which promoted channelization and artificial levee construction to convey floodwaters rapidly from headwater basins to river mouths. However, these modern technologies are vulnerable to megafloods, which easily exceed the design flood discharge. The Typhoon Hagibis disaster in 2019, for example, brought a huge amount of rainfall, and the floodwater level exceeded the upper limit of the artificial levees. As a result, artificial levees breached at 140 locations, and the floodwater broadly spilled into residential areas (see Fig. 2.1). The estimated flood damages were enormous.

Fig. 2.7 Traditional flood control measures in Japan

Modern technologies for flood control tend to constrain floodwater in river channels by artificial levees, while traditional flood control measures do not confront flood power directly, but rather reduce it by the spread of the floodwaters over surrounding land-use areas, mainly agricultural lands. Thus, some of the floodwaters will be stored and retarded in land-use areas and slowly released when the floodwater level gradually recedes. This idea contrasts with modern techniques that focus on how rapidly floodwater can be discharged from basins. In the modern flood control framework, local and national governments tend to increase the heights of artificial levees to sustain safety in adjacent land-use areas once flood disasters occur. However, this policy encourages people to live closer to rivers and develop surrounding land-use areas more intensively. Under this situation, once artificial levees are breached by a large flood, the damage is enormous.

Here, I introduce three representative traditional flood control measures: discontinuous levees (*Kasumitei* in Japanese), overflow embankments (*Etsuryutei*), and flood protection forests (*Suiborin*) (Fig. 2.7). These measures still exist along Japanese rivers, but are greatly reduced through replacement with modern technologies. When the Japanese government now applies traditional measures to flood control, the intentional spillage of the floodwater into designated areas is required for some extraordinary floods exceeding the design flood discharge. The traditional measures including the designated areas should function as GI. In contrast, in modern techniques, we cannot predict where continuous artificial levees will break once the floodwater level exceeds the levee height. This may lead to serious disasters when levee breaches occur in intensively developed and populated areas. We should avoid this situation by learning the advantages of traditional measures and adopting GI.

2.4.1 Discontinuous Levees

The discontinuous levee was devised and developed by Shingen Takeda (Fig. 2.7), who was a military commander from 1521 to 1573. Discontinuous levees still existed along 54 rivers among the 109 major large rivers in 1987 in Japan (Okuma 1987). The roles of discontinuous levees differ among the locations where those measures were set. According to Okuma (1987), discontinuous levees built on high gradient ($>1/500$) alluvial, gravel-bed rivers aim to return floodwaters that spill over upstream levees and/or are generated from tributaries and inlands to the mainstem of the river. For example, many discontinuous, overlapping levees may be constructed over 1–2 km reaches, such as on the Tedor River, Ishikawa Prefecture (Fig. 2.8). In this case, even when the first levee closest to the river channel is broken by a flood, other levees situated behind the first levee will function to return the floodwater to the main channel repeatedly. This is a form of multiple protection measures.

In contrast, discontinuous levees built on low gradient ($<1/1000$) alluvial, sand-bed rivers aim to store floodwater by the backwater effect between discontinuous levees during periods of high discharge. Due to the gentle gradient of the riverbed, the storage capacity and retention effect of floodwater are expected to be large, and, therefore, substantially reduce the flood peak in the mainstem river.

Fig. 2.8 Discontinuous levees (denoted by red lines) in the Tedor River, Ishikawa Prefecture

In both cases, natural confluences of mainstem and tributaries are maintained with discontinuous levees, and, thereby, the natural connectivity of the mainstem and tributaries can be sustained; otherwise, we have to build GYI, such as floodgate and sluice gate, to manage the discharge of tributaries into the mainstem. In general, there is an elevational gap between the water level of the mainstem and floodgate, and, therefore, it is difficult for fish to migrate into tributaries through the sluiceway. The open spaces created by the discontinuous levees function as GI and have been used for flood protection forests or agricultural lands. Moreover, the measure allows floodwater to inundate GI repeatedly, and, therefore, provides habitats for wetland plants and animals.

Currently, few local people and engineers understand the multiple functions of discontinuous levees; thus, many were changed to continuous levees following the approach of dam construction and flood control channels. In this way, functions originally provided by GI were replaced by those of GYI. However, Japan has recently experienced breaches of continuous levees, resulting in large flood disasters influenced by climate change.

The use of discontinuous levees represents the needed shift in Japan from a focus on constraining floodwater to the river channel to accepting more flow over floodplains. This is similar to a shift in thinking evident in Europe where the objectives are to cope with climate change and biodiversity conservation (Buijse et al. 2002). River managers in Japan and other developed countries should learn more about the advantages of traditional GI measures and keep them in our river landscape. Rather than the replacement of GI by GYI, we should consider the best mix of the two measures.

2.4.2 Overflow Embankment

The overflow embankment was devised and developed by Kiyomasa Kato, who was a military commander from 1562 to 1611. This measure determines in advance where the floodwater overflows the artificial levees (Fig. 2.7). Together with an overflow embankment, a secondary levee was constructed to receive the floodwaters, and the areas surrounded by the overflow embankment and receiving levees can function as GI-2.

Unfortunately, these traditional measures also tended to be removed after the introduction of modern technologies, such as strong embankment and road construction, and areas of GI have been developed as farmland and/or residential areas (Tanabe and Okuma 2001). However, most of the current artificial levees in Japan have not been equipped with overflow embankment system; therefore, we do not know where the floodwater will overflow the levees, which results in increased damage and delayed evacuation of residents. Thus, once the levees are partially breached by overbank flow, the exposure risk to flood damage increases. According

to Nakajima et al. (2013), who conducted hydraulic simulations to evaluate the flood control effects of overflow embankments and discontinuous levees in the Jobarugawa River in Kyushu, the flood level in the mainstream did not change with increasing water discharge when floodwater overflowed these facilities.

2.4.3 Flood Protection Forest

Flood protection forests are one of 17 kinds of protection forests prescribed by the Japan Forest Law established in 1897. Flood protection forest is defined as riparian forests (including bamboo forest) located within, on, or outside of the levees (Fig. 2.7). Forests function to reduce damage to residential areas and farmlands behind levees during floods (Matsuura et al. 1988).

The root systems of trees and bamboo hold soils on levees and reduce flood velocity, thereby protecting riverbanks and levees from scouring and facilitating sediment deposition and driftwood retention. The floodwater running through protection forests is filtered and slowed, and, therefore, even if it inundates residential areas, the damage to houses and farmlands is greatly reduced. On the other hand, there is an argument that flood protection forests may add roughness elements to water flow, which may increase floodwater depth and increase the flooding risk. Moreover, they may not be able to withstand the flood power and may become a source of driftwood, which may increase the risks of wood-laden flooding. Also, floated large wood may damage riparian forest. In this situation, river managers may decide to cut flood protection forests. There are many uncertainties regarding the physical functions of flood protection forests and trade-offs to balance, and therefore further research is required.

To maintain the traditional GI, the understanding and cooperation of local communities and river managers are essential. Local residents who inhabit areas of GI may suffer flood damage repeatedly, and some watershed communities and government agencies should support them and compensate for this damage. In general, these GI features are situated in rural areas in the upstream and midstream reaches of the mainstream and tributaries. Thus, inundation by floodwater in upstream and midstream reaches certainly slows the arrival time of flood peaks and reduces the flood discharge in downstream reaches where cities and towns are generally situated. In this situation, people in urban areas should financially offset the damages in rural areas, and GI should be managed and maintained through the cooperative efforts of communities over the whole watershed. The education of river managers is also important. Young river managers may not know the functions and advantages of traditional GI in river management. We should publicly explain how these measures are applicable as an adaptation strategy for climate change.

2.5 Hybrid Infrastructure at Watershed Scale

The Japanese government has introduced new flood control management policies twice using hybrid (green/gray) infrastructure. There are some differences between these two management policies and the hybrid infrastructure concept in the present paper; the former strongly focuses on flood control measures by GYI, while the latter stresses GI having multi-functionalities including biodiversity conservation at a watershed scale. The first is called “Sogo-chisusui,” which means comprehensive flood control measures. The measures focus on flood control in urbanized areas where the flood peaks were elevated as a result of land-use development in the 1970s, as shown in Fig. 2.5. During rapid economic growth in the 1960s and 1970s, asphalt pavement covered roads in urban areas and buildings were constructed. Streams in urban areas were channelized, and sewer systems were installed. Most of these facilities are impermeable and drained rainwater into sewer systems without allowing the water to penetrate into soils. The water flowing through drainage pipes reaches the straightened stream channel. Thus, the current water management policy aimed to flush out rainwater as fast as possible. As a result, flood peaks quickly increased, even if the amount of precipitation did not change (Fig. 2.5).

To control elevated streamflows in urban areas, the government had to change the policy from flushing rainwaters rapidly to retaining rainwaters in GI, such as woods, parks, gardens, and ponds, and in GYI, such as stormwater retention facilities underneath buildings. Then, the water is released slowly into the groundwater system. Additionally, the stream channels were partially widened, and sidewalk and parking pavement was changed to permeable materials. However, some of the recent stormwater retention facilities were built as GYI, which aims only at flood control without considering other functions, such as the provision of habitats for wildlife and recreational opportunities. Parks and schoolyards were built to function as stormwater retention facilities whose grounds were excavated and lowered relative to the surrounding areas.

After the introduction of the above flood control policy called “Sogo-chisusui,” natural restoration or rehabilitation projects began in the 1990s, reflecting the world-wide movement to consider the protection of biodiversity and natural landscapes. These projects replaced concrete disaster prevention measures in streams, such as ground sill and revetment, with measures composed of stones which are more natural materials than concrete. The stream channel was partially broadened, and the vertical side slopes of the streambank were reformed to gentle slopes with some tree plantations. In the 1960s and 1970s, Japanese rivers and streams have been channelized and straightened for urban and agricultural land-use development and flood control. However, in the 1990s to 2000s, some of the straighten rivers are restored to original meandering rivers and wetlands by restoration projects. The river restoration projects function as an adaptation strategy to spread floodwater over floodplains and reduce the peak discharge of floods (Nakamura et al. 2014).

In recent years, Japan has experienced megaflood disasters due to climate change. A megaflood can easily exceed the design flood discharge of GYI (artificial levees

and dams). We experienced serious flood damage in broad regions of eastern Japan during Typhoon Hagibis in 2019. In 2020, the Japanese government announced the need for “Ryuiki chisui,” which is a new flood control concept at the watershed scale. This policy focuses on entire watershed areas from headwater basins covered by forests to midstream areas covered by farmlands to downstream areas where cities are situated. The policy encouraged active use of GI measures at the watershed scale. Natural forests in headwater basins (GI-1) should be preserved, and abandoned artificial forests should be managed by periodic thinning and pruning. Discontinuous levees, overflow embankments, and flood protection forests should be preserved, and land-use development in flood-prone areas should be restricted in midstream reaches (GI-2). Stormwater retention facilities and permeable pavement should be installed to compensate for the increase in water discharge volume caused by new developments.

This new policy matches the hybrid infrastructure concept presented in this chapter, but focuses on flood control with little emphasis on the multi-functionality and ecological network of GI as shown in Fig. 2.2. The Japanese government is still planning to build and/or reinforce GYI to adapt to climate change, and, therefore, it is unlikely that river managers will actively introduce GI at a watershed scale. One of the reasons why GI is not easily introduced is sectionalism between ministries and agencies. For example, the collaborative and coordinated actions between the Ministry of Land, Infrastructure, Transport and Tourism and the Ministry of Agriculture, Forestry and Fisheries of Japan is essential for flood control at a watershed scale, but it is hard to achieve due to strong divisions and cultural differences between administrative agencies. Another problem is the greater uncertainty and ambiguity of GI function for rainwater retention and floodwater control as compared to GYI. Thus, development of simulation models evaluating GI function quantitatively is required to find a best mix of GI and GYI for future river management.

2.6 Green Infrastructure Functioning as Ecological Networks

One of the important characteristics of GI is an interconnected network of green spaces (Maes et al. 2015). Dispersal and breeding success of red-crowned crane (*Grus japonensis*) using GI habitat provides an excellent example (Fig. 2.9). The red-crowned crane was distributed widely on the Japanese islands of Hokkaido, Honshu, and Kyushu at the beginning of the twentieth century. The population significantly declined to approximately 40 individuals with extensive farmland development of wetlands and overhunting (Masatomi and Masatomi 2018) and then recovered to approximately 1500 individuals with the help of artificial feeding during the winter season by local residents. The breeding and nesting sites of the cranes are concentrated in the Kushiro Mire (an example of GI-1 in Sect. 2.3), where

Fig. 2.9 Pair of red-crowned cranes that arrived in the Maizuru flood control basin in August 2012. The image in the upper right corner is an aerial photo of the entire basin

food and habitat limit the carrying capacity. The genetic diversity of the current population is low owing to the bottleneck effect (Masatomi and Masatomi 2018; Miura et al. 2013). Thus, the Ministry of the Environment plans to expand their nesting and breeding sites outside of the Kushiro region.

In the Chitose River watershed, six large-scale, flood control basins with areas of 150–280 ha were constructed to control extraordinary floods (acting as GI-2). These basins have also created a high-quality wetland landscape where many swans, greater white-fronted geese, and bean geese gather in the early spring. I, together with the Ecosystem Conservation Society of Japan, proposed restoring one of the flood control basins to wetlands dominated by a reed (*Phragmites australis*) that is preferred by the crane for nesting. A study that compared the abundance of different organisms (fish, aquatic insects, birds, and aquatic plants) among various water bodies (natural ponds, artificial channels, etc.) revealed that their abundance was highest in the flood control basins (see Chap. 12, Yamanaka et al. 2020). Thus, flood control basins have the potential to act as ecological networks for the conservation of the red-crowned crane on a large scale, employing the Kushiro Wetland as a hub wetland (GI-1) and flood control basins as satellite wetlands (GI-2). The GI networks promote migrations of cranes to extended areas, and add population stability in case of disaster, which may damage some habitats. In 2012, a pair of red-crowned cranes appeared in the Maizuru flood control basin, which is one of the six basins in the Chitose River watershed (Fig. 2.9). Since then, one or two pairs of

Fig. 2.10 Juvenile bird born in the Maizuru flood control basin in 2020

cranes have appeared in the Maizuru flood control basin and neighboring farmlands every year and finally overwintered, and one chick hatched in the Maizuru flood control basin in 2020 (Fig. 2.10).

2.7 Important Points for Planning, Implementation, and Governance of GI

Here are three important points for the planning and implementation of GI at the watershed scale.

1. Forests in headwater basins, the stream network (main channel and tributaries) and farmlands in midstream reaches, and green spaces in cities should be properly allocated to exploit the multiple functions of GI (e.g., flood control, biodiversity conservation, and recreation) together with existing GYI measures (Fig. 2.2).

We should preserve natural and quasi-natural forests and wetlands still remaining in a watershed. The present natural ecosystems already perform ecosystem-based disaster risk reduction (Eco-DRR) (Figs. 2.5 and 2.6). Once we lose them, it takes enormous resources and time to restore them, and the restored ecosystems may never perform the multiple functions provided by the original ecosystems. The existing green parks and gardens should be preserved to maintain the retention capability for stormwater. In developed countries, abandoned tree plantations and farmlands will increase with depopulation in

the future (Kobayashi et al. 2020). The passive and active restoration of natural forests, grasslands, and wetlands after abandonment is one of the challenging options to maintain the functions of GI (Morimoto et al. 2017).

The confluences of the mainstream and tributary rivers are key areas for the installation of GI. Approximately 80% of levee breaches by the 2019 flood disaster associated with Typhoon Hagibis occurred within 1 km of the confluences of the mainstream and tributaries. Levee breach sites at confluences accounted for 112 (62 rivers) out of 140 (71 rivers) breach sites in total (Asahi Newspaper, November 8 in 2019). Confluences are vulnerable to floodwaters and provide diverse habitats for various plants and animals (Benda et al. 2004). Thus, the riverbed should be wide, and traditional flood control measures, such as discontinuous levees, overflow embankments, and flood protection forests, should be used at appropriate locations.

2. One of the most important characteristics of GI is multi-functionality. When GI is used for Eco-DRR, the ecological functions of GI that create a network system that provides habitats and migration routes for wildlife should be considered, taking into account surrounding green areas, such as riparian forests, street trees, and windbreak forests. This ecological network will offer recreational opportunities for walking, jogging, and cycling and will contribute to creating attractive urban and rural landscapes. Moreover, consumers may selectively purchase agricultural goods produced from local communities with many GI measures contributing to the preservation of biodiversity, reduction of flood damage, and provision of recreational opportunities.
3. Collaborative management of GI.

Natural ecosystems functioning as GI can be maintained by letting ecosystems undergo natural succession. However, parks, farmlands, and other seminatural GI may require management activities. Currently, local and prefectural governments may conduct maintenance of those GI, but collaborative management by local residents with the help of the government is recommended to obtain long-term stewardship of GI.

Disaster risks are determined by hazard, exposure, vulnerability, and social capacity building (United Nations International Strategy for Disaster Reduction 2017). Collaborative management contributes to capacity building. GI may provide common lands (commons) for local people and can provide various ecosystem services, strengthen community solidarity through collaboration activities, and nurture the power of community resilience against natural disasters. Although local Japanese villages used to have commons in the form of forests for firewood and grasslands, those lands were subdivided into individual ownerships, and the commons system sustained by collaborative management was abolished. However, as indicated in Fig. 2.2, we should build a new commons system at the watershed scale that connects people living in up- and midstream forestry and/or agricultural villages with people living in downstream urban cities through the management of GI. The system will facilitate the

exchange and cooperation of rural and urban people, which will promote social solidarity and economic benefits in local communities under normal circumstances and will provide evacuation shelters for urban people when they encounter serious disasters.

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