# Creation and Research Utilization of SHI-RA-BE Forest as Green Infrastructure

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## Summary

After we created "SHI-RA-BE" Forest in 2019, as a research and development field for green infrastructure and biodiversity conservation in the landscape of Takenaka R & D Institute, three years have passed. For example, in "Rainscape" and "Supporting for green space planning considering urban birds", the targeted effectiveness of each technology could be quantitatively evaluated after the creating. "Restoration of grassland" and "Conservation for endangered species" suggested findings that contribute to future landscape planning. Also, in "Urban agriculture", voluntary participation in vegetable garden activities was found to be effective in stimulating communication.

**Keywords: green infrastructure, biodiversity, landscape, symbiosis with natured**

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## 1 Introduction

In Japan, confronted with social challenges such as population decline, natural disasters, and shortages of financial and human resources, local governments and companies are increasingly focusing on "green infrastructure." This shift follows the implementation of measures by the Ministry of Land, Infrastructure, Transport and Tourism in 2015. Green infrastructure represents a novel concept that emphasizes the multifaceted functions of nature and devises various methods for its utilization towards fostering a sustainable society. It is envisaged as an efficient means of utilizing social capital and a new approach to generating funds for bolstering social and economic activities. Furthermore, at the 15th Conference of the Parties to the United Nations Convention on Biological Diversity (COP15) in 2022, the 2030 Global Biodiversity Framework was adopted, aiming to achieve a nature-positive state by 2030. This ambition underscores a future global economy that will not only concentrate on decarbonization but will also intensify investments in nature and advance a nature-positive economy. For corporations, engaging in green infrastructure and biodiversity conservation is transitioning from mere social contribution endeavors to critical imperatives for business continuity.

Considering these efforts, we have established "SHI-RA-BE forest" in the Takenaka R&D Institute on the institute premises as a research and development field for green infrastructure and biodiversity conservation. The aim of SHI-RA-BE is to improve the corporate value of our customers by developing and implementing technologies that harness the diverse functions of nature and offer solutions to a variety of social issues. In this study, we present the effects of the technologies utilized at SHI-RA-BE, which was established three years ago, along with the outcomes of research activities spanning multiple areas.

## 2 Rainwater storage and infiltration technology: Rainscape

### 2.1 Overview

In recent years, urban areas have faced frequent flooding due to torrential rains and typhoons, alongside water pollution issues stemming from combined sewer systems overflowing during rainy periods. These challenges are attributed to reduced rainwater infiltration areas as a result of urbanization and the impacts of climate change, with expectations of worsening conditions in the future. In response, national and local governments have advocated for the underground infiltration of rainwater and have implemented measures aimed at preventing its flow into sewers and related systems.

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Increased attention has been directed towards integrating flood control with community development by employing rain gardens, which leverage nature's multifunctional properties, as an urban flood prevention method. While the application of rain gardens in Japan is growing, there remain scant instances of their efficacy being substantiated in actual-scale structures, and the lack of sufficient data for design, maintenance, and management persists as a challenge. In response, our company has developed a rainscape that addresses urban flooding by harnessing nature's multifunctional attributes. At SHI-RA-BE, we have implemented a full-scale rainscape covering a water catchment area of 2,500 m² to assess its performance (as depicted in Photo 1). Figure 1 illustrates the layout of the rainscape at SHI-RA-BE, which is segmented into four areas with varying overflow heights by an underground weir. Initially, water levels rise individually in each section during the onset of rainfall. However, as precipitation increases, these sections merge with an adjacent pond to form a unified water surface. The rainscape is placed adjacent to the pond, and during heavy rains, the rainscape joins with the pond to temporarily store and infiltrate rainwater.

Photo 1 Rainscape in SHI-RA-BE Forest

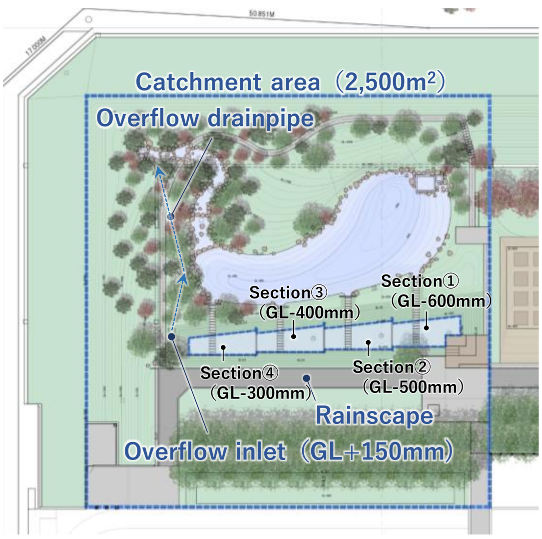


Fig. 1 Layout of the Rainscape in SHI-RA-BE Forest

## 2.2 Verification of effectiveness

To determine the rainfall state, we placed a tipping rain gauge on the premises and recorded the rainfall at 15-minute intervals. Additionally, in the rainscape, pressure-type water level sensors were placed on the bottom of sections (1) - (4) and recorded water level fluctuations at one-minute intervals to determine the rainwater storage and infiltration amount during heavy rains as well as the changes in the infiltration amount over long operation periods. Rainwater that accumulates during heavy rains quickly infiltrates underground, returning it to a normal state. However, when puddles remain on the ground surface for long periods of time, they become breeding locations for mosquitoes, causing health and sanitation risks. Therefore, maintaining prompt drainage functions even after multiple heavy rains and implementing appropriate maintenance when the infiltration capacity decreases are important factors.

## 2.3 Results and discussion

During the 2019 heavy rains in Chiba Prefecture, the SHI-RA-BE rainscape received the equivalent of the average monthly rainfall for October (219 mm) in just 12 hours. Fig. 2 shows a photograph of the water storage situation and a graph of the rainfall accumulation. During the 10 hours of continuous rainfall, a total of 236 $m^3$ of water was stored and infiltrated in this rainscape area, which was equivalent to 43% of the total rainfall in the catchment area. When the storage and infiltration capacity of the planted area excluding the rainscape and pond (67.5 $m^3$) and the adjusted capacity of the pond (60 $m^3$) are added to this, a total storage and infiltration capacity of 363.7 $m^3$ is obtained. Therefore, the catchment area achieves the rain storage height of 100 mm/$m^2$

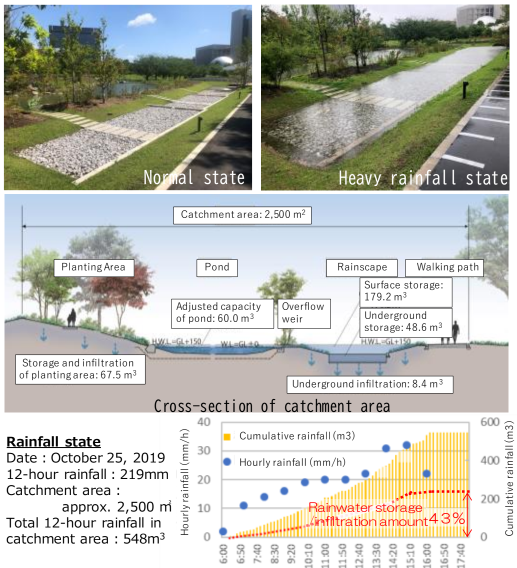


Fig. 2 Storage and infiltration water volume during heavy rainfall in Chiba

recommended by the “Rainwater utilization technical standards” published by the Architectural Institute of Japan.

The results of ongoing water level monitoring since the completion of construction in September 2019 showed that among the heavy rainfall events that have occurred in the last three years, the above-mentioned heavy rains in Chiba Prefecture in October 2019 and the heavy rains associated with Typhoon No. 2 in June 2023 reached a water level of GL+150 mm, which corresponds to the overflow inlet. Fig. 3 shows the changes in rainfall and water level during the heavy rains associated with Typhoon No. 2 in June 2023 (a rain duration of 34 hours and cumulative rainfall of 264 mm). Intermittent rainfall began at approximately 1:30 AM on June 2, and fluctuations in the water level in the rainscape were observed. The water level in the rainscape rose sharply due to 65.5 mm of heavy rainfall in the three-hour period from 12:00 PM on June 2 to 3:00 AM on June 3, and the rainscape water level was found to be fully saturated at 5:30 AM on June 3. Water level fluctuations after the end of the rainfall event confirmed that approximately 2.5 days elapsed before the stored water was completely infiltrated and the rainscape returned to normal conditions (GL-600 mm) from the fully saturated state (GL+150 mm). Actual measurements confirmed detailed water level changes that could not be determined as of 2019, and it was shown that the rainscape maintained its high infiltration capacity even in its fourth year of operation.

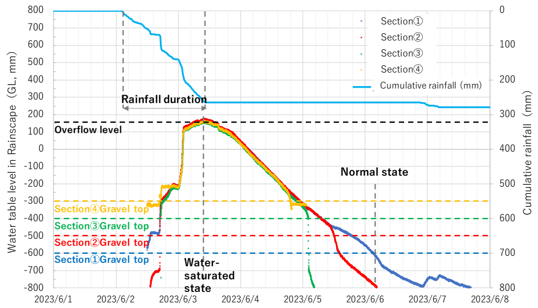


Fig. 3 Cumulative rainfall in June 2023 and changes in water levels in the Rainscape

## 3 Green space planning support technology using birds as indicators

### 3.1 Overview

Green space planning support technology, utilizing birds as indicators[1)], concentrates on birds as markers of urban biodiversity. It models the occupancy probability of each species based on bird habitat data, selects appropriate target species relative to the surrounding environment, and aids in creating an environment favored by these species[2)]. Before renovation, SHI-RA-BE featured an inorganic environment with solar panels installed on waste land. Post-renovation, green spaces and waterscapes, mindful of the local landscape and biodiversity, were introduced. For a plan accommodating birds, the process began by identifying the core green space around the planned site. This was achieved by utilizing multispectral satellite images to delineate areas with significant green coverage. Subsequently, the basic avifauna of the site was assessed. Habitat models specific to each bird species (as shown in Fig. 4) and the outcomes of natural environment surveys, regularly undertaken by Inzai City, served as the foundation. These resources facilitated the estimation of each species' occupancy probability based on variables such as the area covered by specific trees and shrubs within and around the project site. This information was pivotal in selecting realistic target species for each landscape (refer to Table 1). The final step involved designing a landscape and choosing tree species that the target species prefer.

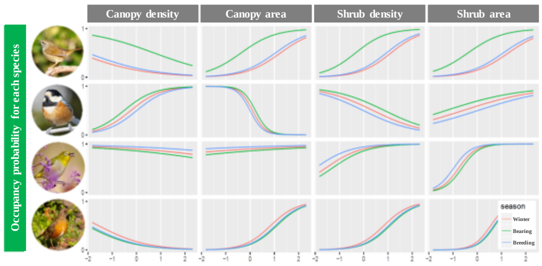


Fig. 4 Habitat model for each bird species
*The horizontal axis is the standardized value of each explanatory variable.

Table 1 List of target species at each landscape

| Target landscapes | Target species |
|---|---|
| Forest with open floor | Bull-headed Shrike, Great Tit, Oriental Greenfinch, Japanese Pygmy Woodpecker, Daurian Redstart, Azure winged Magpie |
| Forest with layered structure | Long-tailed Tit, Japanese White-eye, Pale Thrush, Red-bellied Thrush, Hawfinch, Black faced Bunting, Varied Tit |
| Water area | Spotbill Duck, ***Little Egret, Grey Heron, Common Kingfisher, Grey Wagtail, Blue Rock Thrush*** |
| High grassland | Japanese Bush Warbler, Meadow Bunting, Fan-tailed Warbler |
| Low grassland | Dusky Thrush, ***Eurasian skylark,*** Water Pipit |

*Bold Italic: Species listed on the Red List of Chiba Prefecture

### 3.2 Verification of effectiveness

(1) Route census

We conducted a route census (a method for surveying the number of species of flora along a predetermined route) in the survey area. We

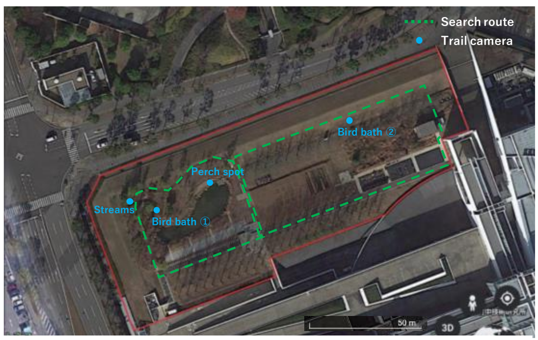


Fig. 5 Location of bird survey

confirmed the birds that appeared within approximately 25 m on either side of the route based on visual inspection and vocalization while walking along the route indicated by the green dotted line in Fig. 5. The route census comprised a 30-min survey conducted 12 times per month throughout the year. We conducted the census at the same frequency before completion of construction (November 2017–October 2018) and for three years after the completion of construction (May 2020–April 2023).

(2) Automatic recording with a trail camera

Trail cameras that automatically record photographs in response to detecting the body heat of animals were installed at streams, perches near aquatic areas, and in front of bird baths (blue circles in Fig. 5). A total of four devices were installed to monitor birds using watering areas (Fig. 5). Monitoring using trail cameras was conducted throughout the year from October 2021 after the completion of construction.

### 3.3 Results and discussion

The route census confirmed the presence of 24 bird species per year before construction. However, the number of species increased significantly after construction, with 32 species in the first year after construction, and 34 species in both the second and third years after construction; a total of 41 species were confirmed in the route census in the three years after construction. Additionally, trail cameras confirmed four new species that were not observed during the route census, bringing the total number of species confirmed in the three years since construction to 45.

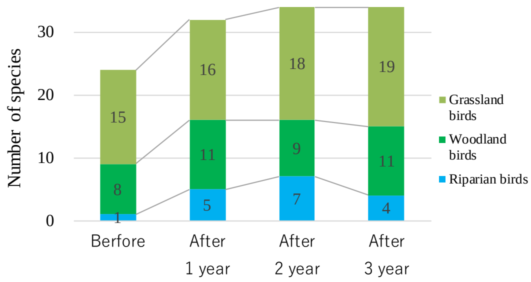


Fig. 6 Number of bird species observed in each year

Regarding the species composition, we found an increase in riparian and woodland bird species due to the newly created aquatic areas and increased forest areas (Fig. 6). Despite the decrease in open environments such as grasslands after construction, an increase in birds that prefer open environments, such as black faced bunting *Emberiza spodocephala*, was also observed, indicating a steady increase in bird diversity across a variety of landscapes.

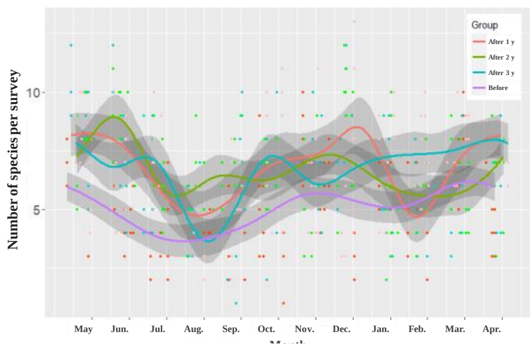


Fig. 7 Number of bird species in each year by GAMM

Fig. 7 shows the monthly variation in the number of species observed per survey using a generalized additive mixed model. The number of species observed per survey increased in nearly all months, indicating that land creation improved the quality of the green space and the biodiversity improved throughout the year.

Moreover, a survey using a newly installed camera conducted after the completion of construction showed the presence of night heron *Nycticorax*, baikal teal *Anas formosa*, ural owl *Strix uralensis*, and Eurasian woodcock *Scolopax rusticola*, which were not observed in the route census. Although significant effort was required for the route census (30 min × 12 times/month), trail cameras were able to confirm species that were not observed in the route census, suggesting the usefulness of surveys using trail cameras as a supplement to conventional human surveys.

Of the 25 target species selected prior to construction, 23 species were confirmed to have arrived after the completion of construction. Fan-tailed warbler *Cisticola juncidis* that were selected as target species in the high grassland area and water pipit *Anthus rubescens* that was selected in the low grassland area were not confirmed; however, many of the target species were confirmed to have arrived. Thus, the habitat model could effectively predict the species that arrived after construction to a certain extent.

## 4 Research on the restoration of semi-natural grassland

### 4.1 Overview

In the Hokuso region where SHI-RA-BE is located, grazing grounds known as “maki” for breeding warhorses of the shogunate were present until the Edo period. Hiroshige Utagawa’s woodblock print, “Thirty-Six Views of Mt. Fuji: Shimousa-Koganebara” depicts the vast grassland of a "maki" at the time[3]. However, semi-natural grasslands have been disappearing nationwide since the period of high economic growth due to the end of "satoyama"-like uses for livestock feed, materials for thatched roofs, and materials for compost applied to fields, as well as due to land development[4]. Given this historical and cultural background as well as social issues, research on methods for restoring semi-natural grasslands is ongoing in SHI-RA-BE.

## 4.2 Methods

In this study, we focused on "hay transfer," which is a semi-natural grassland restoration method involving the spreading of grass clippings[5]. In 2020, we established 28 quadrats of 2 m × 2 m in an area of approximately 300 $m^2$, as shown in Fig. 8. The test conditions for the base soil with a thickness of 200 mm (semi-natural grassland A topsoil and site-generated soil transferred from a planned development site in Inzai City), greening materials (grass clippings transferred from semi-natural grasslands B and C in nearby Shirai City and Inzai City), and the greening method (greening material input method and amount) were set as summarized in Table 2. In October 2021, we received grass clippings that were generated during the maintenance of semi-natural grasslands B and C; after air-drying in the shade, the clippings were introduced to the quadrats in December of the same year. We conducted a vegetation survey using the Braun-Blanquet method[6] on 28 quadrat plots, identified species names from maps, and recorded changes in the number of grassland plant species, percentage of alien species, and vegetation cover.

## 4.3 Results and discussion

In this test, the largest number of grassland plant species was found under the condition in which topsoil from semi-natural grassland A was used and grass clippings from semi-natural grassland B were spread out at a collection area weight ratio of 1. The percentage of alien species also tended to be low under these conditions (Figs. 9, 10). The number of grassland plant species did not increase in plots where grass clippings were plowed into the soil or where the amount of grass clippings applied was tripled. It is possible that plowing simply reduced the number of seeds that could germinate from underground. Moreover, as the vegetation cover was suppressed in the tripled grass clippings plot, the mulching effect may have suppressed plant germination and growth (Fig. 11). In semi-natural grassland B, which mainly provided the material used in this experiment, a vegetation survey during grass mowing in October 2020 confirmed the presence of 21 species of grassland plants. In this study, 13 species (61.9%) of grassland plants derived from the grass clippings were confirmed, including *Geranium krameri*, *Arundinella hirta*, *Sophora flavewscens*, and *Sanguisorba officinalis*. This verified the effectiveness of spreading grass clippings. We also confirmed 14

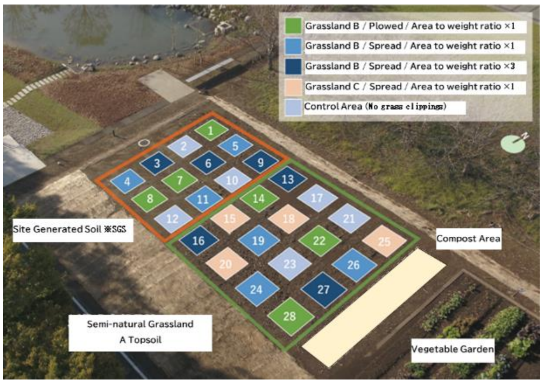


Fig. 8 Layout of quadrat

Table 2 Trial condition

| Base Soil | Greening materials | Greening Method: How to insert | Greening Method: Input amount | Number of plots |
|---|---|---|---|---|
| Site Generated Soil | Semi-natural Grassland B | Plowed | × 1 | 3 |
| | | Spread | × 1 | 3 |
| | | | × 3 | 3 |
| | Control | None | - | 3 |
| Semi-natural Grassland A Topsoil 200mm | Semi-natural Grassland B | Plowed | × 1 | 3 |
| | | Spread | × 1 | 3 |
| | | | × 3 | 3 |
| | Semi-natural Grassland C | Spread | × 1 | 4 |
| | Control | None | - | 3 |
| Total | | | | 28 |

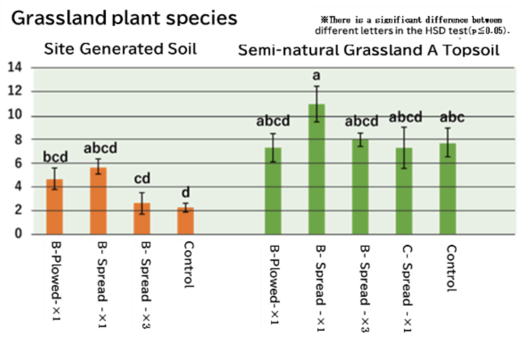


Fig. 9 Amount of grassland plant species in each condition

Month

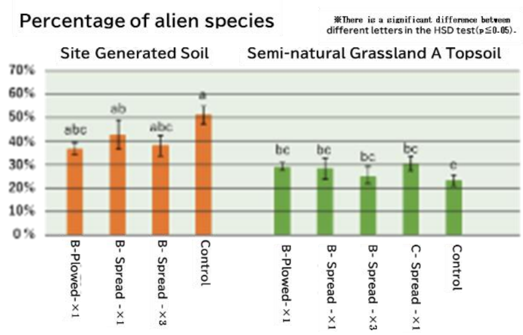


Fig. 10 Percentage of non-native species in each condition

species of grassland plants derived from buried soil seeds contained in the topsoil from semi-natural grassland A. However, the percentage of alien species increased in the site-generated soil, and it was thought that the seed potential of the soil where the grass clippings were spread had a large impact on the final result.

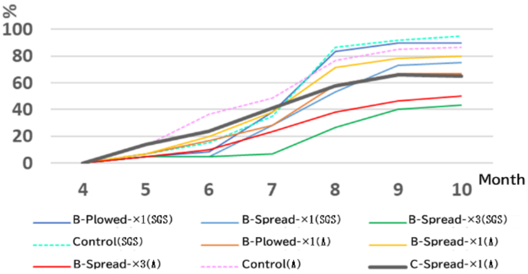


Fig. 11 Percentage of green cover in the first year of each condition

## 5 Evaluation of the multi-functionality of urban agriculture

### 5.1 Overview

The multifaceted functions of urban gardens, such as community building and stress relief, have attracted attention in recent years[7]. At SHI-RA-BE, we established a 100 $m^2$ organic vegetable garden in 2019 (Photo 2). Employee volunteers spend approximately 30 min gardening once a week, helping with cultivation, harvesting, cooking, and holding social events within the facility while receiving guidance from local organic farmers (Photo 3). Their garden contains a wide range of cultivated items, including soft leafy vegetables, root vegetables, summer vegetables, beans, and potatoes; the cultivated plants are selected based on the wishes of the participants. The harvest is mainly distributed to participants and staff, and some items are also used on-site for cooking and events. A compost bin is located adjacent to the organic vegetable garden, where fallen leaves, grass clippings, crop residue, etc. generated on-site are converted into compost and used in the vegetable garden, thereby contributing to a circular economy.

The introduction of vegetable gardens in corporate green spaces may be increasing in Japan, but little research has specifically investigated the effects on employees of vegetable gardening on company premises. In this study, we aimed to evaluate the effects of vegetable gardening activities on company premises on employees' mental and physical health and revitalized communication.

Photo 2 Organic vegetable garden in SHI-RA-BE Forest

Photo 3 Harvesting activities in the Organic vegetable garden

### 5.2 Methods

First, we targeted 267 employees and conducted an online questionnaire (number of valid responses: 100) regarding their participation status over the past year and profile of mood states (POMS)[8]. We classified the number of times they participated in vegetable gardening activities into categories of high participation (participated once a month or more: 11 people), low participation (participated less than once a month: 20 people), and no participation (69 people), and we compared the POMS results for each group. Next, we surveyed the vegetable gardening activity participants using the depression and anxiety mood scale (DAMS)[9] via an online questionnaire on active and non-active days, and we compared the results.

### 5.3 Results and discussion

The initial analysis, derived from an online questionnaire completed by all employees, indicated that "high participation" in vegetable gardening activities yielded positive outcomes for POMS factors, including tension / anxiety and anger / hostility (Fig. 12). Subsequently, a detailed survey among participants of these gardening activities revealed a notable increase in the percentage of responses indicating "not at all applicable" for three "negative mood" factors (feeling blue, sad, or bad) and three "anxious mood" factors (feeling worried, anxious, and uneasy) on days when they participated in the activities (data omitted).

These findings imply that engagement in vegetable gardening, whether on an occasional or regular basis, may significantly contribute to alleviating negative mental states such as anxiety and tension among participants.

## 6 Ex situ conservation efforts for endangered species

### 6.1 Overview

The Inba Marsh, located in northwestern Chiba Prefecture, was once the habitat for 20 species of submerged plants[10]. However, the deterioration of water quality combined with the impacts of land reclamation projects led to the extinction of these species in the wild in 1994[11]. The biodiversity of wetlands and lakes across Japan is currently at a critical juncture.

In response to these pressing environmental concerns, one initiative we have undertaken at SHI-RA-BE involves the construction of an artificial pond. This pond, established in October 2019, encompasses a water surface area of 418 m² and reaches a maximum depth of 0.8 m. It utilizes rainwater and well water as its sources. Concurrently, we acquired a strain of submerged plant with local genetics, revived from a seed bank found in the lake bed soil of the Inba Marsh watershed. This acquisition was facilitated by the Chiba Prefectural Museum. Following this, we commenced demonstration experiments for ex-situ conservation (as illustrated in Photo 4).

### 6.2 Methods

The following species were transplanted into the pond on the specified dates: *Potamogeton dentatus* and *Potamogeton crispus* in October 2019; *Vallisneria denseserrulata Makino*, *Vallisneria asiatica*, *Potamogeton perfoliatus*, *Hydrilla verticillata*, and *Potamogeton pusillus* in June 2020; and *Potamogeton malaianus* and *Potamogeton anguillanus* in August 2020. To prevent the introduction of animals and plants from external sources to SHI-RA-BE during the transplantation process, a 1,000-liter tank was placed in another area of the premises. After a curing period and verification of the absence of contamination, the seeds were transplanted the following year.

### 6.3 Results and discussion

Table 3 and Photo 5 present the distribution of plants post-transplantation, surveyed in September 2022. Consistent with the findings reported by Hayashi et al. (2023), stable growth has been observed for *Potamogeton dentatus*, a species accorded high priority due to its status on the Red List of the Ministry of the Environment of Japan, indicating some success in ex situ conservation effortssuccess[12]. Furthermore, stable growth of *Hydrilla verticillata*, listed on the Chiba Prefecture Red List, has been confirmed in the pond. Conversely, *Potamogeton perfoliatus* and *Potamogeton anguillanus* were not found. Identifying management strategies that support the coexistence of dominant species with others remains an imperative objective for future

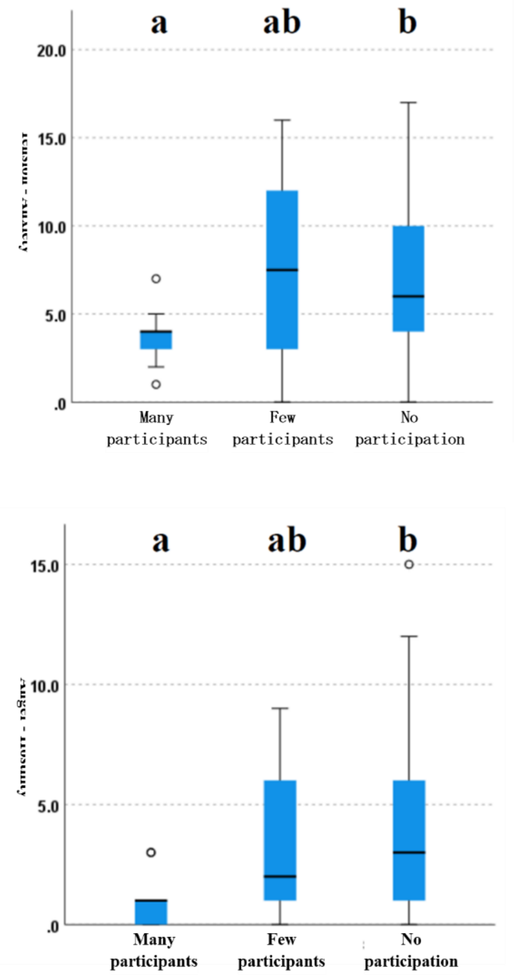


Fig. 12 Results of POMS
*No significant differences between the same letters of the alphabet

Photo 4 Artificial pond in SHI-RA-BE Forest

Table 3 Introduced submerged plants and their status of active and expanding

| Species | Planting time | Percentage of growth area in the pond as of September 2022 | Red Data Assessment |
|---|---|---|---|
| *Potamogeton dentatus* | 2019/10 | 81% | National-ⅠA |
| *Potamogeton crispus* | | 1%> | |
| *Vallisneria denseserrulata* | 2020/6 | 10%> | Chiba-B |
| *Vallisneria asiatica* | | 1%> | Chiba-C |
| *Potamogeton perfoliatus* | | 0% | Chiba-A |
| *Hydrilla verticillata* | | 43% | Chiba-C |
| *Potamogeton pusillus* | | 11% | Chiba-B |
| *Potamogeton malaianus* | 2020/8 | 1%> | Chiba-D |
| *Potamogeton anguillanus* | | 0% | |

research. Regular monitoring surveys conducted up to 2023 have revealed that there has been no unintentional introduction of invasive alien species or colonization by fish such as *Procambarus clarkii*, *Lithobates catesbeianus*, *Trachemys scripta elegans*, *Alternanthera philoxeroides*, and *Ludwigia grandiflora subsp grandiflora*. Leveraging the site's location within the security perimeter of the company premises has effectively prevented the ingress of organisms from outside. Moreover, the strategy of transplanting plants after the specified curing period to deter the incursion of such species has facilitated the preservation of valuable flora andfauna.

Photo 5 Growth of *Potamogeton dentatus*

## 7 Conclusion

Three years have elapsed since the inception of SHI-RA-BE, during which various research activities have facilitated an evaluation of its myriad functions as green infrastructure. These functions encompass rainwater storage, biodiversity conservation, and human utilization. Moving forward, our commitment remains to ongoing monitoring and the continued accumulation of knowledge in planning and maintenance. Concurrently, we will deploy diverse technologies and initiatives across various projects aimed at fostering harmony with local ecosystems and the coexistence of people with nature, thereby striving towards a society living in harmony with nature.

Moreover, in 2021, SHI-RA-BE was awarded Gold certification by the Sustainable Sites Initiative (SITES), an international green infrastructure certification akin to the Leadership in Energy and Environmental Design (LEED) program, which stands as the globally most recognized green building evaluation system. Operated by the American certification body Green Business Certification Inc. (GBCI), SITES evaluates the sustainability of outdoor environments comprehensively. Leveraging the accomplishments at SHI-RA-BE, we plan to propose a suite of unique technologies and initiatives pertaining to green infrastructure. Our goal is to adeptly assist our clients in addressing regional landscape issues and fulfilling their certification acquisition aspirations.

## Acknowledgments

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