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# Research to Identify the Key Scientific and Technological Innovation for Realization of Resilient Symbiotic Socio-Ecological System

## Initiative Report

July, 2021


Brainstorming Team "Socio-Ecological Symbiogenesis"

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## I. Concept

### 1. Proposed MS Goal

#### 1.1 Proposed MS Goal title

Realization of a resilient symbiotic socio-ecological system by 2050 in which natural ecosystems and social systems are harmoniously connected and synergistically flourish

#### 1.2 Vision for 2050 society

Japan's rich nature is connected to the society by the Internet of Nature (IoN), and is properly conserved and utilized by the innovative technology that monitor, comprehend and project the natural ecosystems using large-scale, high-resolution ecological information. The scientific and technological innovations that harmoniously connect the nature and society, the two large and complex systems that support humanity, lead to the paradigm shift that transforms the confrontational relationship between the economy and the environment into a win-win relationship (symbiotic socio-ecological system) in which the bounty of nature supports society and the society supports nature (**Fig. 1**). The proper utilization of natural ecosystem as natural capital leads to an improved living experience, good health, and mental fulfillment coincidentally and turns our society into a sustainable one with well-being. People recognize that nature supports society and strive to manage the natural capital more properly, and then this will lead to autonomous development toward a more stable and resilient society.

A sustainable society will be realized by appropriate land-use zoning and maximization of the potentials of natural ecosystem functions based on advanced social and ecological information. Natural capital is valuable as an asset for our society and as a driving force to enhance multifaceted local activities, including the revitalization of industries and collaboration among people. The ecological and social information on our diverse terroirs of Japan enable local communities to discover or rediscover their "regionalities" and establish regional branding and identity. Through these processes, people have their pride in and attachment to their home region and eventually it increases the diversity and attractiveness of the terroirs of whole Japan. Additionally, natural ecosystems serve as infrastructure to cope with the highly uncertain effects of extreme events caused by climate change and enhance the resilience of communities through adaptive management. Furthermore, the cost burden and beneficiaries of natural capital will be visualized to eliminate inequities in the distribution of natural capital. The innovative technology will expand globally and solve problems of inequities and increase the fairness of cost and burden allocation in natural capital across borders.


**Figure 1: Overview of the symbiotic socio-ecological system in 2050**

At first glance, the landscape of a society in which sustainability and well-being are simultaneously realized by an ecological-social system symbiosis may seem ordinary (a). However, there, large-scale ecological information is utilized, and scientific and technological innovations that harmoniously connect 'nature' and 'society,' which are massive complex systems, support the mutually beneficial 'symbiotic relationship' between nature and society **(b)**. If the symbiotic relationship fails, the concentration of metropolitan areas, population decline, global warming, and modification of ecosystems will proceed **(c)**.

## 2. Targets

### (1) By 2050, information on ecosystems obtained from advanced observations will be put to good use, and vibrant ecosystems will support a sustainable society with human well-being

In the symbiotic socio-ecological system, the monitoring network system of natural ecosystems is installed like "sensory organs/nerves" and provides the human society with the advanced information about the natural ecosystems. The information on nature obtained via the "Internet of Nature (IoN)" is integrated on the newly-developed information platform, which we call the Nature-based Solutions Platform (NbS-PF), together with information of regional societies and analyzed to provide, develop, and accumulate the tools to comprehend, evaluate and predict the natural ecosystems (**Fig. 2**). The NbS-PF serves as a digital ecosystem that enables local municipalities, companies, and research institutions effectively utilizing natural ecosystems and biodiversity and cooperatively solving the social problems. Analogous to the Urban Operating System (Urban OS), NbS-PF, a platform to integrate and utilize society's big data, can be viewed as the "Nature Operating System" (Nature OS) which allows efficient integration and utilization of ecological big data. Various digital applications to sustainably extract ecosystem services and avoid ecosystem disservice (Nature-based Solutions Applications; NbS-Apps) will be developed by local communities and/or civic-techs on the NbS-PF. These NbS-Apps will enable the collaborative governance of natural ecosystems by the local people. Multi-regional NbS-PFs will be interconnected to promote equitable, sustainable, and efficient use of magnificent natural ecosystems, to resolve conflicts of interest and foster cooperation among regions that share the natural ecosystems. We call the whole system to explore nature-based solutions for social issues using NbS-PF and NbS-Apps on the Nature-based Solutions System (NbS System). In the NbS System, local people play central roles to utilize and conserve the regional natural ecosystems and establish a sustainable society, in which regional environment, society, and industry healthily and autonomously flourish. The achievement of Socio-Ecological Symbiogenesis by 2050 will be confirmed by the fact that ecological information will become indispensable for human society. More specifically, (1) the use of ecosystem information leads to increased sustainable use of ecosystem services and reduced incidences of ecosystem disservice; (2) the benefits that the NbS System brings to society exceed the maintenance costs of the NbS-PF; and (3) the NbS-PF is installed, maintained, and expanded as an essential infrastructure in a society.

By 2030, monitoring systems over essential natural ecosystems to manage natural capital such as fishery resources, forest resources, biodiversity, and carbon fixation capacity will be installed or expanded to manage natural capital in several model regions; the NbS-PF and multiple NbS-Apps will be used for industries and in people's daily lives (**Fig. 3**). In these model regions, ecosystem information will be used in various aspects of daily life. Everyone will be able to access local ecosystem information through digital devices. It will also be used for eco-tourism activities, such as wildlife watching, including flower viewing, firefly hunting, and viewing the coloring leaves in the fall, and leisure activities, such as fishing. In addition, these experiences in the model region will be shared with people in distant places through NbS-Apps; thus, even in urban area, people can re-experience nature-based activities in the model region, and feelings of the attachment to nature will be also shared over the region. Ecosystem utilization based on scientific knowledge of ecosystem functions will increase the social productivity in general. For example, by proper assessment of carbon fixation in forests and seaweed beds, the carbon offset system can allocate the budgets to local areas and this enables local stakeholders to take measures to global warming and regional development. In coastal regions, predictions of the occurrence of harmful plankton that cause shellfish poisoning, can be useful for aquaculture, and a proper understanding of the status of fishery resources can increase profitability in the fishery industry. In the model regions, predictions of the impacts of climate change, anthroponotic usage and development will be implemented based on advanced ecosystem information and used in local decision-making options.

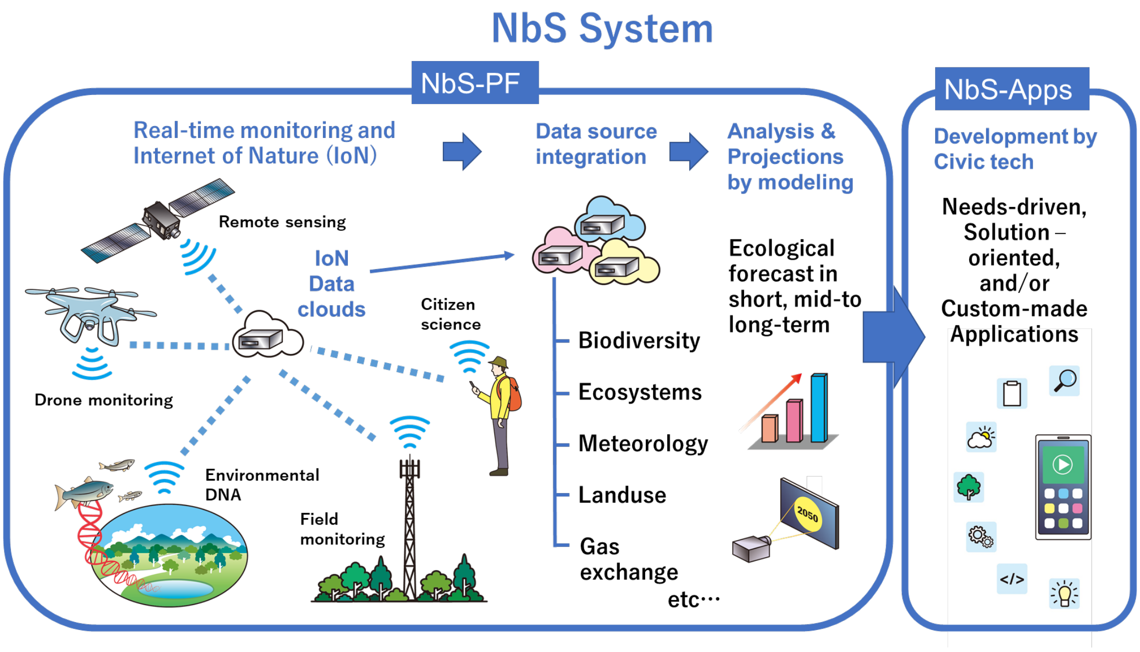


**Figure 2: The NbS System framework**

Information obtained from real-time observations of natural ecosystems is provided to human society by the IoN and stored in the data cloud as ecosystem big data. In the NbS-PF, these data will be integrated with other collected data sources. Advanced modeling using the accumulated ecosystem big data will enable short- to medium-term predictions of ecosystems. These products will be developed as individual applications (NbS-Apps) to solve local needs and issues with the help of civic tech.

**Figure 3. Ecological information utilized in people's daily lives** In a symbiotic society, various ecological information can be used on a daily basis. Through IoN, the nature is connected to the society, enriching our lives and enabling sustainable use of ecosystems.

**(2) By 2050, the natural ecosystems will be properly recognized as the foundation of human well-being, and human activities will support vibrant ecosystems.**

The NbS System enhances the proper use of natural ecosystems and promotes values and behavioral changes among people and businesses. The participation of residents in ecosystem observation and activities for social problem-solving promotes not only their understanding of their surrounding ecosystem, but also their attachment to the local nature and civic pride (their pride and responsibility as residents of the local community). The NbS System can also be used for environmental education and learning, thereby promoting value transformation among residents. Environmental education and learning will make use of local ecosystem information, and scientific knowledge about the origin and significance of local ecosystems. Through the education and learning, people understand that natural ecosystems are the foundation of their daily safety and well-being. Additionally, the impact and dependencies of various human activities (including corporate business activities) on the natural ecosystems will be visualized through the NbS System, which will enhance social responsibilities for environment and change purchasing and investment behavior and promote business and community activities that support vibrant ecosystems. The NbS System will promote collaboration among stakeholders to tackle environmental issues in which stakeholders share common goals to help solve the problems each other. In addition, the NbS-PF will promote coordination for more advanced and multi-social issues that require coordination of interests in terms of how best to use the ecosystems. As a result, various human socioeconomic activities will support vibrant ecosystems in a self-sustainable and decentralized manner. The achievement of this MS goal by 2050 can be confirmed by specific scenes; benefits from natural ecosystems and overloads on those become "visible" by scientific evaluation, and society and markets properly recognize and take those into their accounts and, and societies conserve and restore their natural ecosystems properly. Specifically, (1) NbS-PF for natural ecosystem observation, data acquisition, analysis, and prediction are implemented in a society, and the states of natural ecosystems and ecosystem services are "visible" and (2) by using NbS-Apps, policy-making and consensus-building are based on scientific evidence. Reaching a state of zero load (no net loss) or positive impact (net gain) by natural ecosystem recovery and increased ecosystem services, and minimization of reducing natural capital will be objectively quantified.

By 2030, in several model regions, NbS-PF is installed, and NbS-Apps are developed and residents will get an easy access to ecological information, for example, through information devices. People are able to easily learn about richness and benefits from the surrounding nature, its spatial distribution and temporal changes, and the impact of individual or social various activities on the natural ecosystem at any time As the connection between nature and people's lives being visualized, the value of natural ecosystems will be recognized by residents, the protection and fostering local nature will be encouraged in local communities, and residents will perform activities to understand and evaluate the value of local nature. For example, residents will conduct their own ecological observations of the local ecosystem and use that information to provide education and opportunities for learning and consensus-building on the use of the local ecosystem. Additionally, rules for the use and management of the ecosystem will be established to achieve the sustainable use of the ecosystem services in the local economy and industry. Coordination and collaboration among multiple communities will be promoted with the goal of nature restoration, thereby creating synergies among stakeholders intentionally.

**(3) By 2050, a resilient symbiotic socio-ecological system will be established, resulting in a high level of stable and steady sustainability of rich nature and human well-being.**

The NbS System promotes to increase the awareness and behavioral changes in businesses and community members, and hence a symbiotic socio-ecological system in which ecosystems and human society support each other will be realized. The ecosystem is resilient natural capital that can regenerate themselves even after being disturbed by typhoons and floods. Thus, we need to maximize their functions to support human well-being and safety as well as ensure life security. Ecosystem information can be essential in various social and industrial fields, including agriculture, forestry, fisheries, public health, greenhouse gas management, flood and landslide risk management, and insurance (Expert interview No.1, No.2, No.3). With the support of ESG investment, new industrial sectors using ecological Big Data will be lunched and ecosystem disservices will be minimized. On the other hand, human society will play a part of functional roles in promoting the conservation and restoration of ecosystems by quickly adjusting its socioeconomic activities and actions to impact on ecosystems, corresponding to large-scale ecosystem information acquired through ecosystem observation networks and IoN. The NbS System will integrate the socio-ecological system as a symbiotic entity that is resilient to ecological or social crisis, such as climate change, population decline and aging society. The achievement of this MS goal will be confirmed by following scenes; societies install the NbS System and successfully implement a Regional Circular and Ecological Sphere where resources, energy, and economies circulate autonomously based on their local natural capital basically, and the utilization and allocation of sustainable natural capital at the national and the global scale. In 2050, Japan's population is projected to reach approximately 101.92 million (National Institute of Population and Social Security Research 2017). To achieve high levels of happiness and wellbeing under the circumstances with a declining and aging population in the future, it is essential to establish a multipolar and decentralized society (Expert Interview No.6, Hiroi 2019). To do so, it is essential to build a social system that (1) in which local resource and energy used in local communities can independently circulate through effective utilization of natural resources, and (2) local people feel happy and fulfilled in their lives by the surrounding rich nature. At that time, through NbS-Apps, even people in urban areas can experience nature and culture in regions, which not only leads to increase personal happiness, but also leads to have an interest to Japan's diverse natural ecosystems and landscapes. This perceptive transformation on natural values in urban areas will leads to take natural capital into the economical account, facilitates telecoupling with urban livelihood and local natural ecosystems, and consequently changes the social system that return the urban economic affluence to the region. One of the criteria for determining the success or failure of this MS goal will be whether multipolar and Socio-Ecological Symbiogenesis local societies are established and are linked each other on NbS System. It should also be pointed out that if this MS goal is achieved, we can decelerate population decline and concentration of population in metropolitan cities in Japan because people migrate from highly-populated areas with lower birth rate to regional cities with higher birth rate.

By 2030, several model regions will install the NbS System and transform themselves into Socio-Ecological Symbiogenesis using ecosystem information in the local scale. Specifically, with the use of ecosystem information, the economic circulation in the region will be enhanced by attracting ESG investment, promoting regional industries, including the ecotourism industry, and improving labor productivity in primary industries. By taking advantage of the trend to incorporate ecosystems into investment decisions for ESG investment, which is expected to accelerate in the future, economic vitalization using ecosystem information will be realized. Furthermore, the value of natural capital will be visible, greatly advancing discussions on the imbalance and fairness of distribution of natural capital between large cities and rural areas.

## 3. Background

### 3.1 Why now?

Ever since the start of the Anthropocene era, resource utilization and technological innovations have led to convenient lifestyles and economic growth, especially in developed countries. However, as a result, the earth system has been degraded to a level where humanity cannot act safely regarding climate change, biodiversity, land-use change, and biogeochemical cycles. The environmental burden caused by human activities is considered to have exceeded the planetary boundaries (planet's limits) (Rockström et al. 2009, Steffen et al. 2015). If the degradation of the earth system continues, we cross the tipping points, which leads to irreversible changes, the destruction of our living infrastructure will be accelerated, and we can never be back to where we are now (Lenton et al. 2020). Currently, when the situation is already crucial, we must stop the current overload on the earth system and start taking actions to unexceed the planetary boundaries and transform our society into a sustainable one with well-being.

Climate change has become to be recognized as a crucial social risk. The transformation of society toward a decarbonized society is now proceeding rapidly, and related industries such as renewable energy and non-fossil fuel vehicles expand. The current rapid transformation toward a decarbonized society is owing to accumulated discussions over the years in the field of climate change science and the development of forecasting technologies (Expert interview No. 2). In field of natural capital, including biodiversity, it has just begun to be noticed by social leaders that we need to consider changes in natural ecosystems including water, forests, biodiversity, and oceans as socioeconomic risks although there have been significant delays in making these considerations comparing to the field of climate change (WWF 2020). Now that the Sustainable Development Goals (SDGs) have penetrated society and the motivation to change to an environment-centered society is growing among communities. We need to keep climate change, changes in biodiversity and land use, and biogeochemical cycles within sustainable limits and to transform into an environmental nation.

There is a strong social demand for a sustainable society that exists in harmony with nature. In the recent G7 Summit Statement, the G7 leaders have agreed to commit to global green transition to stop biodiversity loss and revert it as well as accelerate decarbonization (Ministry of Foreign Affairs, Japan 2021). The "Vision of Societies in Harmony with Nature" (CBD 2010, 2020), a vision of a society that realizes the conservation and sustainable use of biodiversity and ecosystems, has been set as a goal of the international community (Expert interview No. 1). Among feasible scenarios for recovery from the COVID-19 recovery, this vision highlights the multifaced benefits such as restoring biodiversity, reducing the risk of future pandemics, and providing benefit from natural ecosystems for human society (IPBES 2020). The society widely recognizes that natural ecosystems are an essential foundation of society and the economy (Millennium Ecosystem Assessment 2005). They are also included in the goals of the SDGs and the Paris Agreement. In fact, the World Economic Forum (WEF) has stated that biodiversity loss is an economic risk that cannot be ignored as more than 50% of the world's GDP, or USD $44 trillion, is moderately or highly dependent on nature (WEF 2020). There is a widespread demand for the participation of businesses in the private sector to help solve biodiversity issues (e.g., Nippon Keidanren 2018), and business practices such as biodiversity mainstreaming, ESG investment, and environmental finance (green economy) Taskforce on Nature-related Financial Disclosure (TNFD) are emerging in business communities (Expert interviews No. 4, No. 5).

There is also a significant scientific and technological demand to achieve the MS goal. In Japan's Fifth Science and Technology Basic Plan (2016-2020), Society 5.0 was proposed, and an environmentally harmonious and prosperous future society that makes full use of ICT and other technologies has been envisioned. In the vision of Society 5.0, the Internet of Things (IoT) will connect things through information networks. Smart cities, which refer to the societal implementation of Society 5.0 in cities, will be supported by platforms (i.e., Urban Operating Systems or Urban OS) for accumulating and analyzing urban Big Data and collaborating with other local governments, companies, and research institutions. However, humanity is not only dependent on human society and artifacts; all human life, society, and production activities are extensively reliant on a natural ecosystem (a large complex system comprising a diverse array of organisms). Considering that anthropogenic overload on the environment is threatening the sustainability of society and we need to deal with it, the realization of the Internet of Nature (IoN) or NbS-PF, which incorporates ecological information into information networks is the inevitable consequence of scientific and technological development.

The symbiotic socio-ecological system described in this MS goal is a vision of society in 2050 that incorporates a shift to a sustainable society with growing social urgency on the collapse of the global system and the development of ICT technology driven by Society 5.0. Due to the current growing social demands and technological development in related fields, this issue needs to be addressed with no delay.

### 3.2 Social significance (social significance of achieving the goals)

Ecosystem conservation is no longer just a movement to protect endangered plants and animals in extinction. The total value of the multifaceted functions and services generated by ecosystems is USD $125–140 trillion per year (more than 1.5 times the global GDP; OECD 2019). Ecosystem degradation that results in the loss of ecosystem services is a socioeconomic risk factor (financial risk for natural capital; World Economic Forum and PwC 2020), and the social importance of this risk is increasing every year (World Economic Forum 2018-2020). Global attention to the concept of **Nature-based Solutions** (**NbS**) is increasing because this mean offers the improvement of environmental, social, and economic development and resilience with reducing cost (IUCN 2020, Dasgupta 2021). This concept focuses on the impact of environmental modification on nature’s bounty and the development of the desired ecosystem services and functions to address social issues by suitably working with the ecosystems. Conventional concept of "nature conservation" tended to be an activity which aims to protect “pristine” nature and endangered species as individual volunteer activities and/or CSR activities in private companies. The concept of NbS, on the other hand, is based on the knowledge that natural ecosystems are the basis of human survival and activities and urgency on current ecosystem degradation and biodiversity loss cause social crises. This MS goal, Socio-Ecological Symbiogenesis, is based on the NbS concept; we consider natural ecosystems as “natural capital” that forms the basis of human living sphere and leads to the realization of a sustainable society with well-being through the appropriate usage of this natural capital.

The characteristics of social problem-solving based on NbS are a wide range of issues to be solved and their sustainability, both of which arise from the characteristics of the natural ecosystems. The first characteristic is multifunctionality. Natural ecosystems usually perform several different functions simultaneously. For example, forests fix carbon dioxide in the atmosphere, produce wood, store rainwater to mitigate flooding, purify water, and support local biodiversity. This multifaceted nature of their functions is in contrast with, for example, solar panels, which serve only to generate electricity. The second characteristic is self-healing/proliferation. Because ecosystems are composed of organisms that have features of self-propagating and self-organizing to environmental change, they can quickly recover from natural and human-derived disturbances. In fact, if the natural capital including biological resources are properly conserved, we will be able to extract permanently many services from it. The shift to renewable resources is essential for the sustainability of society, but the only resources that genuinely possess this property are those that can self-proliferate. Using these two characteristics, sustainable social development using various ecosystem functions will become feasible. These two characteristics of the ecosystems enables our society to establish an effective and resilient social system that responds flexibly and autonomously to the situation, especially under the uncertain and unpredictable environmental and social crises. In other words, in order to maintain these characteristics of ecosystems, it is necessary to monitor the ecosystems properly, implement the effective ecosystem management systems, and evaluate the multi-faced ecosystems functions in mid- to long-term.

The advancement of NbS System is also a major scientific and technological challenge. Ecosystems are complex systems that experience continuous and autonomous variation. They are self-organized systems in which millions of species and many chemical and physical factors interact, and understanding their dynamics is not a trivial challenge. The system is highly adaptive and resilient to change and disturbance, however, disturbance to a particular species oran environmental condition can have a ripple effect throughout the system, causing unexpected and significant changes. Furthermore, ecosystems are extremely large systems, as evidenced by the fact that organisms such as migratory fish and birds sometimes migrate thousands of kilometers, and the scope of such systems often exceeds the boundaries of administrative divisions and nations. Therefore, to implement high-level NbS

System that sustainably use ecosystems, it is essential to accurately grasp the overall condition of these large and complex ecosystems and adjust the utilization of the resources contained within them appropriately according to their current state. Additionally, mutual influence among the many and diverse stakeholders using the ecosystem can occur through changes in the state of the ecosystem, sometimes with a significant time delay (Tilman et al. 1994). Therefore, it is essential to establish a framework for promoting collaboration and coordination among these stakeholders.

To achieve Socio-Ecological Symbiogenesis, the various sectors and regions that comprise the social system must cooperate and function in a coordinated manner so that the vast and complex ecosystem can be appropriately used. The essence of the concept of Socio-Ecological Symbiogenesis is to realize a self-sustainable and decentralized society that is cooperatively connected to natural ecosystems through the science and technology of the NbS System. Thus, by integrating and analyzing the varied ecosystem data acquired by individual regions and communities, we will understand them as a single enormous ecosystem. Then, based on the assessment of the impact and dependency of individual human activities on ecosystems, the dependence and mutual influence between regions and communities mediated by ecosystems will also be assessed. Additionally, based on this information, efficient cooperation, coordination, and payment for ecosystem use and conservation activities in each region and community will be implemented to realize sustainable and maximal utilization of ecosystems.

In a Socio-Ecological Symbiogenesis society, the multifaceted functions and services of ecosystems are evaluated and predicted based on ecosystem observation data and are appropriately valued and allocated to promote the maintenance and management of natural ecosystems. The social significance of this MS goal lies in the development of an autonomous cyclical flow that leads to the sustainable use of ecosystems (**Fig. 4**). Thus, this system will realize both (1) natural ecosystems, in which resilience and sustainability are ensured through appropriate conservation management, and (2) social systems, in which the ecosystems support resilience and sustainability and distribution is based on equity. The autonomous circulation flow of the NbS System will result in appropriate conservation of natural ecosystems, the resilience and sustainability of natural ecosystems and society, and the fair distribution of resources in the society. These actions will have a ripple effect, solving many of the social issues raised in the SDGs. The realization of a Socio-Ecological Symbiogenesis society will simultaneously achieve the future visions of existing sustainable societies, such as societies existing in harmony with nature, a Regional Circular and Ecological Sphere (Expert interview No.1), a decarbonized society (Expert interview No.2), a steady-state society, a decentralized society, and an era of life (Expert interview No. 6).

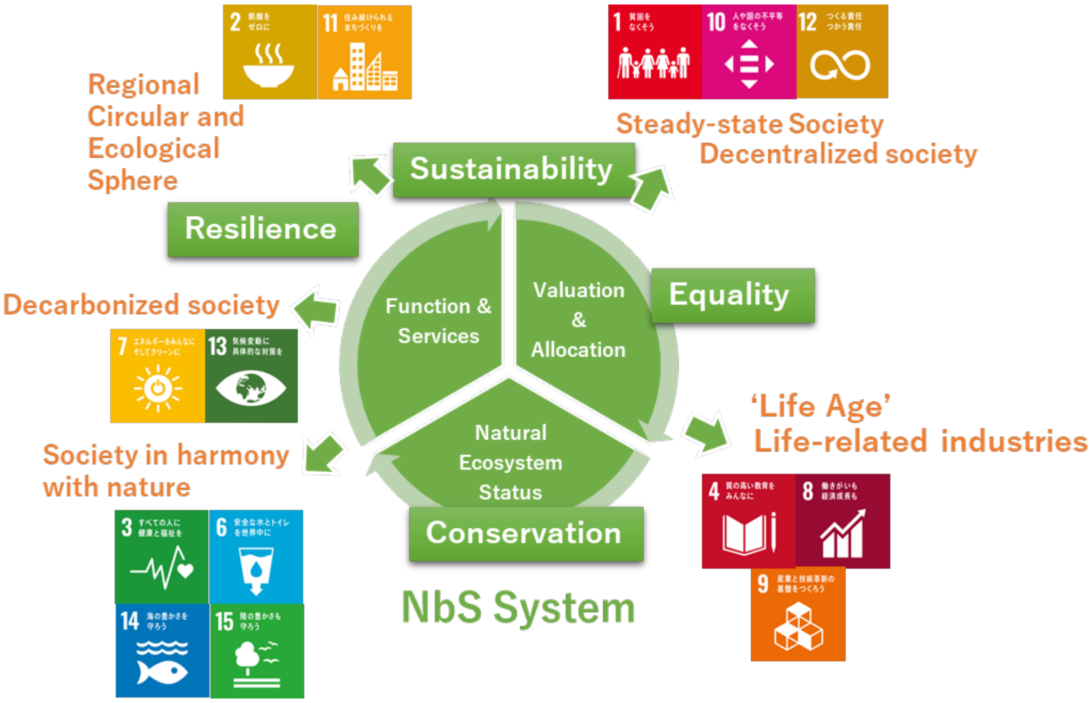


**Figure 4: Composition of the 2050 Socio-Ecological Symbiogenesis to be realized by the NbS System, and related visions of future society including SDGs**

Prediction of environmental risks will enable rapid response to risks by local governments, communities, individuals, and industries. In Japan, against the backdrop of a declining population, especially in rural areas, and increasing dependence on imports, the impact of the underutilization of nature on living organisms and ecosystems has become apparent. This is an issue in creating regions, constructing Regional Circular and Ecological Sphere (Fifth Environmental Basic Plan). The MS goal will contribute to realizing a sustainable society in the region while resolving the inequity between rural and urban areas and the international community.

### 3.3 Action outline

Socio-Ecological Symbiogenesis is a process in which ecosystems and social systems mutually influence each other and autonomously co-develop, leading to the transformation from an antagonistic relationship to a win-win one, under the guidance of science and technology, laws and regulations, and economic frameworks introduced at the right timing. In this section, we will present our hypothesis on this process, paying particular attention to the roles of the public sector (government and local administration), the private sector (corporations), and the nonprofit sector (community members) (**Fig. 5**).

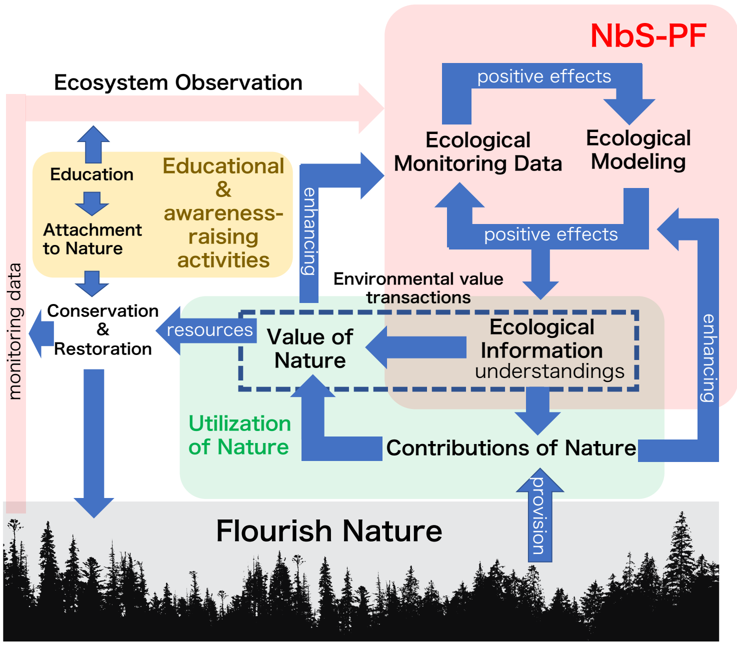


**Figure 5: Hypothesized process of the Socio-Ecological Symbiogenesis.** Mutual facilitation between the socio and ecological systems realized through the collaboration of public, private, and non-profit sectors. The existence of multiple positive feedbacks allows the entire system to develop autonomously. The NbS-PF contributes to all the positive feedbacks, proving its critical role in the process.

**STEP 1: Environmental improvement and triggers for Socio-Ecological Symbiogenesis (by 2030)**

Following two inputs from the field of science and technology will create an environment for the symbiosis of ecological and social systems in Japan. The first is the accumulation of large-scale, open ecological information in the NbS-PF and the provision of ecological information utilization technology, brought about by the development of advanced observation technology for ecosystems (technology to 'see' ecosystems) and predictive modeling technology for ecosystems (technology to 'understand' ecosystems). This will allow us to visualize biodiversity and ecosystem functions and their changes over time and space throughout Japan. The second is the visualization of the dependence and impact of business activities on ecosystems, which can be realized or sophisticated using socio-ecological system modeling technology. These two types of visualization make it possible to track the relationship between human activities (corporate businesses, nature restoration, etc.) and the state of the ecosystem and prepare for a harmonious connection between ecosystems and social systems.

The active involvement of the public sector will accelerate the symbiogenesis of ecological and social systems in this environment (e.g., ESG investment by GPIF, Expert interview No.4). In partnership with the private sector, the public sector will develop economic frameworks to internalize the impact and dependence of human activities on natural ecosystem. This includes legislation to facilitate environmental value transactions, such as ecosystem credit and payment for ecosystem services (PES), which will promote offsetting of significant environmental benefits. The combination of the environmental value-trading framework and visualized impact and dependence of human activities on natural ecosystems will ensure that the impacts of human activities on nature, which will appropriately compensate the ecosystem services. This also leads to fund flow into nature restoration projects, which are implemented by each sector. In addition to the development of laws and regulations to maintain a digital ecosystem that facilitates the expansion, sharing, and re-use of ecological information in the NbS System, the public sector should contribute to the provision of social security to help the society overcome changes in industrial structure and subside the efforts of businesses to promote Socio-Ecological Symbiogenesis.

In the situation that ecological information is available and environmental value transactions are properly conducted, three major forces affect the private sector. The first is the force to improve natural capital accounting. Because adverse effects on ecosystems harm the acquisition of funds from investments and loans through the deterioration of natural capital accounting, the private sector has an incentive to reduce the ecological burden of its operations and induce innovation to reduce the environmental burden. This also creates incentives for the private sector to promote nature restoration projects to acquire ecosystem credits. All these actions will help restore the richness of nature. The second is the creation of new businesses that utilize ecological information. The release of a large amount of ecosystem data through the NbS System will significantly reduce the marginal cost of launching an environment-related business using new ecosystem information utilization technologies (Rifkin 2014). In contrast, the value of ecosystem information itself will increase along with expanding utilization of the information and the development of the related technologies. Third, in case that industrial activities impact on the natural ecosystems negatively (or even positively), it is necessarily to quantify the impact scientifically. There will be an incentive to acquire ecological information for this calculation. This will speed up the accumulation of ecological information. Because acquired ecological information will become an essential resource for developing the whole society, the public sector can promote the enhancement of ecological information as infrastructure by, for example, institutionalizing the disclosure of information after a certain period has passed since its acquisition. The expansion of ecological information, and the visualization of impact and dependence of human activities on natural ecosystem, and the improvement of natural capital accounting that have occurred in this process will help the private sector attract nature-related ESG investments and boost its international competitiveness.

For the nonprofit sector such as local communities, the accumulation of ecological information and the visualization of benefit and cost burden to local biodiversity and natural ecosystems will promote the attachment to their local nature, and increase their civic pride, and change their behavior toward environmental ecosystem conservation. Local nature restoration and ecosystem observation efforts by residents using funds raised through ecosystem credit and other frameworks will become more active, significantly supporting the restoration of nature. Visualizing information on the environmental impact of companies, products, and services will influence individual investments and purchasing behavior and support businesses that take the natural environment into consideration. Civic technology initiatives to solve local social issues using the ecological information disclosed in NbS-PF will also flourish, and participation by residents will become more active. These changes in the values and behaviors of residents will accelerate the promotion of environmentally friendly business activities by the private sector and social transformation by the government. Additionally, the processes and mechanisms of the earth system and local natural ecosystems, which are the basis of the Socio-Ecological Symbiogenesis, are a basic knowledge that all community members should understand. In collaboration with the nonprofit sector, the public sector will provide opportunities for local people to learn and educate themselves about natural ecosystems and the benefits to people and culture. Opportunities to learn about socio-ecological systems will develop capacities who can survive in an era of diverse and uncertain change in the future by utilizing the local natural capital.

**STEP 2: The start of autonomous development toward Socio-Ecological Symbiogenesis (by 2040)**

By 2040, ecosystem degradation will be significantly deaccelerated through the vast use of environmental value transaction mechanisms, such as ecosystem credit and PES, and net gains in biodiversity will have been achieved in some regions. The development of ecosystem observation technologies has enabled the acquisition of large-scale, highly accurate ecosystem information at a low cost, and the accumulated ecological information and ecosystem information utilization technologies are disclosed in the NbS System, which has been developed as an open-source social infrastructure. As the accumulation of resources to promote ecosystem-based industries progresses and exceeds a certain level, the benefits gained from acquiring ecosystem information will exceed the cost of acquiring ecosystem information. As a result, the accumulation of ecosystem information, technological innovation, and creation of new industries will co-develop autonomously without the need for large-scale external financial input from this research and development project. Moreover, by this time, NbS-PF will be interconnected beyond administrative boundaries, and the relationships (loads and dependencies) between social systems and ecosystems beyond regional boundaries will become visible.

The next important issue in such a society is to promote collaboration and coordination among multiple stakeholders who use ecosystems for different purposes. Ecosystems with multiple functions can be used in various ways, but the optimal conditions for each usage may differ, resulting in conflicts among stakeholders regarding management methods and goals. The public sector will develop rules to promote cooperation among such stakeholders, amend the relevant laws and establish guidelines. The established rules will be implemented in the NbS System to promote consensus- building among various stakeholders and realize autonomous and decentralized ecosystem conservation. Technologies for harmoniously integrating ecosystems and social systems (technologies that “handle” ecosystems), which have been proposed as research topics to be implemented in this report, will play an important role in this.

In the private sector, the creation of new industries and innovation of industrial structures will be promoted through enhanced ecological information. This includes developing insurance products that reduce ecosystem-related risks, new forms of primary industry and tourism that significantly increase profits, and ecosystem information businesses that use ecological Big Data. The ecosystem information usage tools will be developed and released as NbS-Apps and widely shared. The digital ecosystem will be enriched, and innovation for the sustainable use of ecosystems will be accelerated by the spontaneous secondary use of NbS-PF and application development. As technologies to generate economic value from natural ecosystems develop and exceed a certain level, more economic value will be generated by increasing biodiversity and natural capital, and an autonomous Socio-Ecological Symbiogenesis in which ecosystems and social systems promote each other’s development will begin.

In the nonprofit sector, the movement toward autonomous management of ecosystems will be accelerated using highly developed ecosystem information technologies. Residents will observe their ecosystems and create economic value by using various ecosystem information and tools (NbS-Apps) made available in the NbS System. The proper payment for natural capital in local region through NbS-Apps enables local economy independent.

**STEP 3: Completion of the Socio-Ecological Symbiogenesis (2040-)**

As the process of Socio-Ecological Symbiogenesis reaches its final stage, we will commonly conserve and restore biodiversity effectively anywhere, and sustain Japan's rich nature. The multipolar and decentralized societies lead to have optimal size of population in each society and the Regional Circulation Ecological Spheres will be established through implementation of NbS System. Ecosystem-related tools will be customized to each region depending on the characteristics of each ecosystem for effective local management and usage of natural capital, and this will lead to realize to maintain Japan’s diverse ecosystems.

By that time, the autonomous management system will be established and the nonprofit sector this effectively manage the local natural ecosystems. The major role of the public sector will be to facilitate collaboration, coordination, and consensus-building among the various regions and stakeholders who maintain and update the NbS-PF. Residents surrounded by rich nature will have acquired extensive knowledge and skills on local nature and will effectively utilize the ecosystem services and minimize disservices. As rich ecosystems and societies support each other, the symbiotic socio-ecological system will be complete, in which both are stable and sustained at a high level.

Global population has been aging and a shift to a steady-state society becomes an imminent challenge, especially in Asia. Japan was the first country in Asia faced with an aging population, however, sustainable society with well-being is realized by shift to a decentralized and steady-state society owing to adopting the NbS System; Japan becomes a role model for the world. The NbS System will be exported to Asian and other countries by customization for each country and region. The further accumulation of global ecological data and visualization of on global beneficiaries and cost-bearers on the NbS System will lead to telecoupling between counties and/or local communities. The next phase aims to install NbS System on a global scale and achieve Socio-Ecological Symbiogenesis globally; this will lead to eliminate disparities in the Global South and other regions.

## 4. Benefits for industry and society

In a society that has achieved Socio-Ecological Symbiogenesis, the accuracy of understanding and predicting the state of ecosystems will be improved based on a large amount of ecosystem information, which will lead to significant changes in social and industrial structures. This section will provide an overview of the various changes that will be made possible using advanced ecosystem information, focusing on three areas: ”creation of a green economy and information industry of ecosystems,” “the maximization of nature’s bounty,” and ”the construction of a prosperous society in which no one is left behind.”

### A. The creation of a green economy and nature information industry

In the process of transition to a society of Socio-Ecological Symbiogenesis with the healthy global environment, the industrial structure and incorporate behavior shift toward environmental-friendly ones. In addition, nature-related risks will also reduce. These transitions will be driven by stricter environmental regulations, changes in the market environment, and changes in consumer behavior. Besides the primary industries that directly utilize ecosystems, in long-term, the secondary and tertiary industries that indirectly depend on ecosystems and almost all industries will be influenced. Additionally, the availability of large ecosystem dataset will create a new information industry based on it.

#### A1. Green economy using ESG investment

Recently, investment decisions have been increasing the consideration given to biodiversity at a rapid rate, especially among institutional investors (Appendix 1(1)).

In 2020, 26 financial institutions worldwide signed the “Financial for Biodiversity Pledge,” setting specific goals for contributing to biodiversity through investment and financing. In July, 2021, the international organization, TNFD has been launched, and a framework and guidelines for disclosing nature and biodiversity-related financial risks will be issued in 2023. With the expansion of these ESG investment frameworks related to biodiversity, the ability to adequately assess the impact and dependence on biodiversity will become a prerequisite for economic growth and industrial development. Japan can incorporate ESG investment regarding ecosystem into its growth strategy by proactively promoting Socio-Ecological Symbiogenesis. This is because in a society that has achieved Socio-Ecological Symbiogenesis, the conservation of ecosystems and social and economic development will mutually assist each other. Japan is also blessed with natural abundance that is unparalleled among developed countries. Keeping this in mind, by actively participating in establishing international rules, Japan can create a significant advantage for itself.

**A2. Biodiversity offsetting, credit, payment for ecosystem services, and market establishment**

Biodiversity offsetting is a framework in which developers compensate for their impact on the ecosystems by restoring or creating other ecosystems when their projects will inevitably harm the ecosystems. A credit system in which the results of ecosystem restoration and creation achieved by nature restoration projects implemented by third parties are purchased as credits for compensation is used as a framework to implement biodiversity offsetting efficiently. In a society that has achieved Socio-Ecological Symbiogenesis, detailed geographic information on local biodiversity and its changes can be acquired, making it possible to support important ecosystem conservation activities through credit trading systems and effectively reduce the net biodiversity loss to zero (i.e., achieve no net loss and net gain). A similar framework is the payment for ecosystem services (PES), in which beneficiaries pay for the ecosystem services provided. In a society that has achieved Socio-Ecological Symbiogenesis, ecosystem services and its fluctuations are evaluated, and activities to conserve natural ecosystems can be funded through PES. Thus, biodiversity offsetting and PES frameworks system make ecosystem information economic value. This will lead to increase the incentive for ecosystem observation, promote further accumulation of ecosystem information and support further Socio-Ecological Symbiogenesis in the society. The establishment of a biodiversity-credit establish the market to trade the credit. In the market, biodiversity credit is initially introduced to compensate the negative impact on the environment, however, in the future, trades for natural restoration and utilization will increase and it provide positive feedback to natural ecosystems. Then, biodiversity credit will be trade among individuals or small communities; for example, if marketplace applications for buying and selling biodiversity credits, it enhances local conservation and restoration activities among local people. For several types of ecosystem services which are unable to evaluate in monetary base, payment can be made through PES system. Under these systems, biodiversity itself will also develop economic value within these frameworks, encouraging technological innovations that reduce the direct and indirect impacts of human activities on the environment and promote ecosystem restoration.

**A3. Development of insurance products to reduce ecosystem-related risks**

The primary sector of industry and tourism are directly affected by changes in the ecosystems and are constantly exposed to ecosystem change risks. If a risk assessment of ecosystem changes can be performed through the accumulation of ecosystem information and the development of modeling methods, it will be possible to develop insurance products that mitigate ecosystem-related risks. By buying insurance for natural ecosystems that provide essential ecosystem services and possess high economic value, we can compensate for economic losses when ecosystems are destroyed and implement nature restoration projects. This will also create incentives for policyholders who want to keep insurance premiums low to reduce the degradation of ecosystems or effectively utilize the ecosystems. In a society that has achieved Socio-Ecological Symbiogenesis that understands ecosystem conditions and can predict ecosystem changes, insurance that reduces risks in ecosystem-related industries will be generated. The resilience of economies and communities that depend on ecosystems, such as agriculture, forestry, fisheries, and tourism, will be enhanced.

**A4. The rise of the nature information industry**

Despite the presence of rich natural ecosystems in our country, much of the ecological information remains to be acquired. Big data in human society have created an unexpected value and a vast information industry represented by IT companies such as GAFA (Google, Apple, Facebook, Amazon). For example, in the field of biology, big data, such as genome information, have led to revolutionary developments in the fields of life science and medicine. It is not difficult to imagine that the ecological big data provided in a society that has achieved Socio-Ecological Symbiogenesis will give rise to a "natural information industry," the likes of which have never been envisioned before. For example, in tourism industry (Appendix 1(2)) and real estate sector, the richness of nature and livability of the land, which are evaluated on the basis of detailed geographical information of each region, ecosystem information, may even affect land prices directly, and ecosystem information will thus become valuable. Additionally, as ecosystem data and social system data are accumulated and analyzed, the effects of various socioeconomic activities on ecosystems will become "visible" and services that use this information will emerge. Similar to gourmet food websites, services that rate the ecological impact of all products, services, and companies will emerge, and this may influence young generation's (such as Generation Z) purchasing behavior, which is highly concerned about social and environmental issues. Additionally, the observation of species that respond to diverse environments is equivalent to the indirect observation of diverse environments, and observing millions of species can be compared to obtaining millions of "biological sensors." The data of "biological sensors" which possess different features from conventional social and meteorological data, contains ecological and biodiversity monitoring sensors and therefore can be used to create new applications and values for new land management (Appendix 1(3)). For example, recent developments in ecological modeling have shown that when predicting the presence or absence of a particular organism or its fluctuations, the observation data of many other species besides the target organism can significantly improve the prediction accuracy (e.g., Ye & Sugihara 2016).

### B. Maximizing nature's bounty

Ecosystems are the social commons that form the basis of all human activities (industrial, economic, and cultural), survival, and security. Human society receives various services (such as the provision of biological resources and carbon fixation) as well as sometimes disservices (such as outbreaks of infectious diseases and pests) from ecosystems. In a society with a symbiotic socio-ecological system, benefits to the society from ecosystems can be expanded through an increase in quality and quantity of services and a decrease in those of disservices based on ecosystem information.

#### B1. Increasing production efficiency and sustainability in primary industries

Primary sectors of industry are directly dependent on the ecosystem services and are the biggest beneficiary of Socio-Ecological Symbiogenesis. For example, fisheries use resources in ocean ecosystems for aquaculture activities such as scallops and oyster farming, which also depend on plankton in natural ecosystems for food. The amount of fishery resources and plankton in these ecosystems fluctuates due to various environmental and artificial factors, including fishing, aquaculture methods, and land use. Based on the ecosystem information, biological resources can be effectively managed to realize a stable supply of resources and improve production. Similar improvements and stabilization of productivity can also be expected in agriculture and forestry, where soil microbes and pollinators play an essential role. Another example is that more than three-quarters of the world's major crops depend on pollinators, such as honeybees, which account for 5%–8% of global crop production, or USD $235–577 billion in market value per year (as of 2015) (IPBES 2017). Currently, opportunities for pollination services have been declining since the 1970s due to changes in climate, geographical features, and land use, threatening the sustainability of agriculture (Ministry of the Environment, Japan 2016). In a society that has achieved Socio-Ecological Symbiogenesis, large-scale information on a wide variety of organisms that directly or indirectly support agriculture, including pollinators, will be obtained, and a stable food supply will be realized through a more appropriate agroecosystem management.

#### B2. Suppression of emerging infectious disease epidemics

The outbreak and spread of emerging infectious diseases of wildlife origin, such as COVID-19, have been attributed to increased probability of exposure to pathogens and pathogenic viruses because nature destruction led to increase density of host organisms and decrease biodiversity (Allen et al. 2017). In the context of the post-COVID-19 pandemic, a shift to a biodiversity-inclusive approach to one health (a One Health approach) has been considered to prevent wildlife-borne infectious diseases while reaping benefits from biodiversity (IPBES 2020).

In a society that has achieved Socio-Ecological Symbiogenesis, the risk of infectious diseases will be visualized, and the social costs caused by infectious diseases will be minimized. Additionally, the achievement of the MS goal will promote the independence of local communities and promote a shift to a decentralized and multipolar society, thereby reducing spread risk of the disease. As a result, the risk of emerging infectious disease outbreaks in society in the future will be greatly reduced, and Japan becomes more resilient to infectious diseases.

**B3. Stabilization of $CO_2$ absorption through vegetation use**

Of greenhouse gases such as $CO_2$ released by humans due to the use of fossil fuels and land modification, 31% is absorbed by terrestrial ecosystems, 23% is absorbed by the oceans, and 46% remains in the atmosphere (Friedlingstein et al. 2020).

Although forests contribute to the absorption of $CO_2$, the amount of $CO_2$ absorbed by forests in Japan peaked at approximately 2004 and is currently on a downward trend (Ministry of the Environment, Japan 2021). Additionally, the amount of carbon removal by forests is not only affected by ecological characteristics such as tree species composition and forest age but also by year-to-year climate conditions, extreme weather, and climate change. Discussions on the realization of a decarbonized society focus on reducing emissions and renewable energy technologies, but it is also necessary to increase the amount of carbon removal by ecosystems. For this purpose, forest maintenance, including tree planting and thinning, must be promoted while considering the future impacts of climate change. In contrast to that in forests, in oceans, blue carbon and $CO_2$ sequestration are expected to increase due to anthropogenic interventions, such as seaweed bed maintenance, formation, and expand activities and seaweed cultivation (Kuwae et al. 2019). In a society that has achieved Socio-Ecological Symbiogenesis, based on real-time data monitoring of $CO_2$ absorption by forests and oceans and knowledge of carbon sequestration prediction models, information will be provided on when, where, and what kind of ecosystem management is necessary to increase the efficiency of greenhouse gas absorption, thereby reducing the risk of global warming.

**B4. Measures against abnormal outbreaks of wildlife such as damage by wild animals, locusts, and red tides**

The damage caused by wild birds and animals and the outbreak of pest diseases has been increasing in agriculture, forestry, and fisheries. Further, damage to fisheries and water pollution due to red tides remain unresolved issues, although their prevalence is decreasing (Ministry of the Environment, Japan 2021).

In particular, large mammals can cause severe damage to small-scale farming operations which are mainly managed by elderly people in mountainous regions. In these areas increasing number of deer has impacts on ecosystems by over-grazing of forest understory vegetation, leading to soil runoff and loss of biodiversity including the endangered plant species. The population dynamics of organisms are affected by climatic factors, surrounding land use, and other species. Therefore, predictions of changes in pest abundance must take these environmental factors into account (Bianchi et al. 2006). In a society that has achieved Socio-Ecological Symbiogenesis, appropriate management and control of pests can be conducted using predictions of changes in the populations of organisms.

**B5. Land use and zoning**

In local communities, land use zoning and the associated restructuring of existing industrial and social systems will be implemented to enhance the value and resilience of the community while achieving a sustainable system that maximizes the benefits of the community obtained from nature. By adopting "distributed energy systems", "environmentally friendly primary industrial systems," and "Nature-based disaster risk reduction" (Green infrastructure, Expert interview No. 3, Appendix 1(4)), the industrial and social structure will be transformed into one that has less environmental impact and more resilience to disasters. Maximizing sustainability within the target regions will require land-use design that reduces conflicts between local industries (e.g., solar panels vs. conservation zones) and proactively creates synergies and co-benefits (e.g., forest conservation areas vs. adjacent crops requiring pollinators). The optimized land-use zoning will be designed based on an assessment of the ecological characteristics of each site. Such local initiatives are expected to generate a clean image with zero environmental impact, increase the attractiveness of the region and enables to add value to the products produced through branding.

**C. Building a prosperous society where no one is left behind**

**C1. Correcting rural–urban inequities**

In a society that has achieved Socio-Ecological Symbiogenesis, inequities between rural and urban areas must be corrected. These inequities include disparities in employment opportunities, income, and learning opportunities (with these opportunities being more available in urban areas) as well as problems related to the mismatch between beneficiaries and cost-bearers of ecosystem services (e.g., renewable energy is generated in rural areas but consumed in urban areas). Burden-based payment systems (PES, water source tax, carbon pricing, etc.) will resolve this inequity. In a society with Socio-Ecological Symbiogenesis, the cost of environmental burden is calculated based on observed data. Additionally, information sharing between regions through NbS-PF will increase job opportunities in rural areas by promoting exchange and settlement between cities and villages and creating industries and innovations such as application development.

**C2. Correcting inequities in the international community**

Japan is highly dependent on foreign imports of food, resources, etc., and these imports have a significant impact on the biodiversity and environment of the local areas where they are imported (Hoang & Kanemoto 2021, Lenzen et al. 2012, Moran & Kanemoto 2017, Oita et al. 2016, Nakata 2003). The NbS System could provide a telecoupling system to visualize burden to natural the ecosystems, internalize and allocate the cost using the ecological footprint to counteract environmental impacts. Additionally, dependence on imports is directly related to the decline in domestic production and consumption of food and resources. Increasing domestic food self-sufficiency will also contribute to the promotion of a circulating society in the region.

**C3. Promotion of intra-regional, inter-regional, and international cooperation among community members**

Ecosystems are connected beyond regions and countries. Therefore, the realization of cooperative and collaborative systems that transcend regions and countries is indispensable for resolving issues on global inequality between beneficiaries and cost-bearers of ecosystem services (Global South). The NbS System, which connects all regions, will contribute to solving issues related to ecosystems by enhancing the inter-regional collaboration and enable a diverse range of people to build communities across distances to address common social issues. There are residents and communities in every region willing to take the initiative in solving local issues. By connecting these local communities, we can activate the power of open innovation and, simultaneously, enrich human connections (social capital). In addition, in case of the multi-tiered issues which multi-scale stakeholders from global to local get involved (e.g., issues of carbon storage: the beneficiaries are all the people on earth, but the cost-bearers are the local communities living near the deforested areas in tropical forests where hold high carbon storage), multi-tiered governance, probably led by international organizations, is a key for solution. The NbS System provides scientific evidence designed to deal with this type of spatially multi-scale issues for decision-making among multi-scale stakeholders by multi-tiered governance.

**C4. Well-being and self-realization brought about by the tolerance of diverse values at the individual level**

The acceptance of diverse values and concepts, including the “view of nature” and the “view of symbiosis,” directly impacts the individual behavior and the happiness. The NbS approach promotes sustainable behaviors at the individual level, such as reducing consumption and waste, choosing products that include sustainability, and justice in inequity and conservation. These behaviors will create a virtuous cycle in which individuals will feel more satisfied with their contributions to society and feel more connected to their communities and the world, thereby becoming more attached to their communities and nature. In other words, NbS concept enhance people to accept diverse thoughts and values and set to realize a society in which people can demonstrate their individuality and diverse talents and reach self-actualization.

## II. Analysis

### 1. Essential scientific/social components

**(Issues [scientific, technological, and social] and necessary measures to achieve the relevant MS goals)**

The scientific and social issues that need to be resolved to achieve the MS goal can be summarized into four points, as follows.

**(Scientific and technological issues)**

**I. Advanced technology for ecosystem observations**: Development of high-throughput ecosystem observation methods that cover a wide area where ecosystems function and enable rapid understanding of the various organisms driving the ecosystem at a high level of resolution (spatial, temporal, and taxonomic). Development and maintenance of the system infrastructure of NbS-PF and NbS-Apps to use the data from the advanced observations.

**II. Predictive modeling technology for ecosystems**: Development of modeling methods for understanding, predicting, and detecting changes and abnormalities in the state and function of targeted ecosystems from large-scale ecosystem information data.

**III. Socio-ecological system modeling technology**: Development of modeling methods to visualize how human activities and ecosystem elements relate to each other through integrated ecological and social information analysis. Development of modeling methods of future scenarios for environmental risk assessment, which is necessary for individual and community decision-making, visioning in policy, and ESG investment.

**IV. Methods to assess ecosystem value based on human well-being**: Development of methods for ecosystem-value assessment conducive to solving social issues such as inequity in the distribution of natural capital in human society by appropriately considering environmental and social sustainability and human well-being from a long-term perspective instead of short-term economic indicators such as GDP.

**(Social issues)**

**V. Appropriate environmental education and learning**: Community members' value and behavior change play an essential role in achieving sustainable ecosystem use. Environmental education and learning initiatives ensure that residents correctly understanding how biodiversity supports the sustainable development of human society.

**VI. Institutional design for ecosystem management**: Natural ecosystems are common social capital that can lead to disagreements among stakeholders on their optimal use and management methods. For proper management, social measures and institutional designs must facilitate collaboration among many stakeholders to resolve conflicts.

**VII. Financial frameworks**: As mentioned, the financial risk of natural capital is already recognized, and the promotion of international ESG investment has increased the need for disclosure of environmentally conscious corporate behavior and natural capital-related financial information [Environmental Reporting Guidelines 2018, Taskforce on Nature-related Financial Disclosure (TNFD)]. In particular, long-term risk assessment based on scientific evidence obtained from ecosystem observations is essential for ESG and impact investing. The establishment of a green economy is required through such efforts.

**VIII. Building a decentralized society and "Regional Circular and Ecological Sphere"**: Japan has entered an era of declining and aging populations ahead of the rest of the world. There is a need to establish a decentralized society and "Regional Circular and Ecological Sphere" in which cities, which depend on artificial capital, and regions, which possess and manage abundant natural capital, can coexist by taking advantage of their respective characteristics. Avoiding the concentration of population in large cities, where the population declining rapidly, will also curb population decline. To support this, a framework is needed to implement appropriate payments from cities, which are beneficiaries of services from local ecosystems, to local areas with ecological claims.

These eight scientific, technological, and social issues (I-VIII) can be classified into three tiers. The three tiers are issues related to ecological information (I and II), issues related to ecological-social complex (III, IV, and V), and issues related to economic activities (VI, VII, and VIII). These three tiers correspond to those in the "SDG Wedding Cake", which categorizes the 17 SDGs into three groups (**Fig. 6**): biosphere-related issues, society-related issues, and economy-related issues, and shows that issues at lower tiers are conditions for solving issues at higher tiers. Comparing the three-tiered structure of the issues we highlighted to the SDG Wedding Cake, it means that the solution of "issues related to ecological information" (biosphere) forms the basis for the solution of "issues related to the social-ecological complex" (society) and supports the solution of "issues related to economic activities" (economy), which is at a higher tier.


**Figure 6: SDGs Wedding Cake.** A model showing the dependency among the 17 goals of the SDGs by classifying them into three levels: 'economic challenges,' 'human society challenges,' and 'biosphere challenges.' Solving 'biosphere challenges' forms the basis for solving all other issues.

There is an explicit dependency among the three tiers of issues identified (ecological information, social-ecological complex, and economic activities). Without correctly understanding the state of biodiversity (solving ecosystem information issues), it is impossible to clarify the relationship between ecosystems and society (solving social-ecological complex issues). Furthermore, it will not be easy to realize economic activities that take ecosystems into account without changing values and behavior to recognize ecosystem values correctly.

To achieve the MS goal, a scenario emerges in which we work on the development of observation technology to acquire advanced ecosystem information, and modeling technology to analyze this information and use it as a foundation to develop efforts to link the knowledge obtained from the ecosystem information with social and economic issues. Based on this scenario, three areas of science and technology research have been highlighted as being most important for achieving the MS goal: two areas related to ecosystem information: (Area 1) Technology for advanced ecosystem monitoring, (Area 2) Technology for predictive ecological modeling, and an additional area: (Area 3) Technology for harmoniously integrating ecosystems and social systems, which will contribute to solving complex ecological and social issues and economic problems using ecosystem information.

In addition to international cooperation, collaboration across disciplines and sectors, it is required to address Ethical, Legal and Social Issues (ELSI) to achieve the MS goal. Ecosystems are large complex systems without any clear geographical boundaries. Organisms move across regions and countries, and ecosystem services are also consumed across regions and countries. It is widely recognized that the cause of the loss of biodiversity is the dependency of developed countries on the biodiversity of developing countries. Therefore, to realize sustainable use of ecosystems, ecosystem observation should not be limited to domestic use only but should be coordinated with international observation networks.

Collaboration across disciplines and sectors will also play an essential role in achieving the MS goal. To observe, understand, and control ecosystems, we must go beyond ecology and biology and collaborate with various disciplines, such as sociology and economics. For this purpose, we need to seek collaboration with various academic societies, which are groups of experts. We have already asked many relevant academic societies to collaborate on these MS goal, including the Ecological Society of Japan, the eDNA Society, the Japan Long Term Ecological Research Network (JaLTER), Japan Flux Research Network (JapanFlux), Japan Biodiversity Observation Network (J-BON), and Asia-Pacific Biodiversity Observation Network (APBON).

The role of ELSI cannot be ignored for realization of our MS Goal. The society recognize that conservation and utilization of natural ecosystems are essential for the sustainable development of humankind and the corresponding behavioral patterns must be widely accepted by society, and a "transformation" that includes a drastic revision of social structures, such as economic systems, financial systems, and legal systems, must occur. Economic development to date has been brought about based on the economic logic that the various benefits of nature are unlimited for society to enjoy. Because of our daily production and consumption activities, we are experiencing a global crisis of the natural environment, including depletion of natural capital, climate change, and biodiversity loss. Given the broad, diverse range of the impacts of human activities on the natural environment, these "transformations" must occur as soon as possible to address the social factors that underlie the diverse direct factors that impact the environment (IPBES 2019; Dasgupta 2021).

## 2. Science and technology map

From the previous section, two issues related to ecosystem information, **technology for advanced ecosystem monitoring** and **technology for predictive ecological modeling**, and one issue related to the connection of ecosystems and social systems, **technology for harmoniously integrating ecosystems and social systems**, were identified as science and technology research areas that are required to achieve the MS goal. In this section, these three issues are explained in detail.

### 2-1. Area 1 - Development of technology for advanced ecosystem monitoring: Technology to "see" ecosystems

To understand and predict the state of ecosystems, it is essential to observe the ecosystems according to the required accuracy. In particular, high-throughput and high-resolution observations are required for short-term prediction, anomaly detection, and highly accurate condition assessment. Additionally, because ecosystems cover broad areas and organisms move across borders of local governments or countries, obtaining broad -area information is essential for understanding their status. A technology to integrate various observation data collected at different points and times will play an important role. Additionally, these advanced observation data must be managed in an integrated manner to understand and evaluate the state of the ecosystem. In other words, progress in information processing and management technology, which will be the core of the NbS-PF, is required. Therefore, the technologies that require breakthroughs in ecosystem observation include (1) broad-area ecosystem observation technology, (2) high-resolution biological information acquisition technology, (3) automation of ecosystem observation, and (4) development and maintenance of the information system infrastructure for the NbS-PF.

**(1) Broad-area ecosystem observation technology**: Remote sensing using sound waves (sonar) and electromagnetic waves (visible light, infrared rays, microwaves, etc.) has contributed to the acquisition of ecosystem information over broad areas (**Fig. 7**). For example, remote sensing using earth observation satellites has made it possible to observe the distribution of terrestrial ecosystems, land-use change, coastal and marine environments, rainfall, and surface and ocean temperatures on a global scale. Recently, radar observations from aircraft (LiDAR) have been used to accumulate data on the three-dimensional structure of the environment in our living area, such as the structure of forests and the topography of rivers, in unprecedented detail. Underwater remote sensing using acoustics and narrow multibeam is also being developed. In the next few years, high-resolution observation satellites, such as ALOS-3 and ALOS-4, are planned to be launched from Japan. Additionally, LiDAR is scheduled to be installed in the Japanese Experiment Module (KIBO) on the International Space Station (ISS) (MOLI, https://www.satnavi.jaxa.jp/project/slats/news/2019/pdf/17_slatsMaterial-sakaisawa.pdf), which is expected to significantly advance remote sensing with lasers. In the next decade, the resolution and accuracy of ecosystem information obtained from broad-area observation will greatly improve. However, because most of the information obtained using these remote sensing techniques is in the form of physical values, the challenge is how to convert it into biological information, such as ecosystem functions and biodiversity, and how to obtain highly accurate and fast data that can be used in modeling to evaluate and predict ecosystem dynamics and natural capital conditions. For developing broad-area and detailed ecosystem observation technology and modeling using these remote-sensing technologies, it is essential to conduct cross-disciplinary research and development to comprehensively observe ecosystem elements at the ground observation sites of various climates and ecosystem types and verify their optical characteristics along with the effects of environmental changes (Muraoka and Koizumi 2009). In addition to clarifying the correlation between various ecosystem information obtained using different observation techniques, it is also essential to clarify the inter-relationships between the functions and services of the entire ecosystem, such as $CO_2$ absorption, carbon cycling, and primary production, and individual ecosystem elements (e.g., trees, soil microbes, and animals). To support this and provide ground realities, it is necessary to enhance the integrated ground-based observation infrastructure (Ecosystem Research Infrastructure; Chabbi and Loescher 2017) and develop an observation network that connects research, observation, and technology validation sites across the country (ecosystem observation network). (Muraoka et al. 2012; Ichii, Shibata, and Muraoka 2019).

**(2) Acquisition of high-resolution biological information**: Currently it is difficult to identify biological and physiological status at species or individual scales by remote sensing. For example, it is almost impossible to identify diverse aquatic and marine organisms using sound or electromagnetic waves. However, biological information with high taxonomic resolution is essential for assessing biodiversity. With the recent progress in technologies for molecular biological analysis, biological surveys using DNA from organisms in the environment (environmental DNA, eDNA) have quickly become popular in the past decade. This has made it possible to acquire information on the distribution and changes of organisms with high taxonomic resolution only from water and soil samples collected in their habitats. throughout Japan, ANEMONE and other projects to develop observation networks across the country are conducting advanced ecosystem observation through regular water sampling and analysis. Additionally, the development of instruments that automatically perform the entire process from water sampling to organism detection is also ongoing. The development of environmental RNA technology to understand physiological conditions and the use of biogenic volatile organic compounds (BVOC) in the atmosphere may also be a possibility for future development. Observations of fish and other organisms using eDNA are currently underway. However, future challenges include developing a more accurate species identification technology that covers many taxonomic groups inhabiting ecosystems and high taxonomic resolution for genetic diversity within species. Additionally, the development of a technology called environmental omics (Ge et al. 2013, Wang et al. 2020), which describes ecological surveys using biomolecules existing in the environment, such as RNA and proteins in addition to DNA, is expected to provide information at the individual level on topics such as the physiological state, individual size, and growth stage of organisms, which cannot be obtained by conventional technologies (**Fig. 7**).

**(3) Automation of ecosystem observations**: Automation of observations is an effective strategy for conducting multipoint, high-frequency ecosystem observations covering a broad area. Additionally, when observing ecosystems that are difficult to approach, such as mountainous areas, underwater areas, and forest canopy, automated observation systems using robotics can be a powerful option. There are several examples of automated observation systems. For example, in the "Argo" program (https://argo.ucsd.edu), many floating and mid-water buoys are drifted to observe the ocean, and automatic water sampling and analysis are conducted at fixed-point buoys in the ocean and land. Its extension to living organisms would enhance obtaining ecological data. Additionally, the Phenological Eyes Network (http://pen.envr.tsukuba.ac.jp/) uses automated cameras to continuously observe the unfolding, flowering, yellowing, and falling of leaves in forests and grasslands and stores the data. In addition to the use of unmanned aerial vehicles (UAVs) such as drones and remotely operated vehicles (ROVs) for robotic surveys, observation technology using acoustics is improving. Bio-logging and telemetry technologies using biosensors attached to living organisms are also advancing and are used to track the population dynamics of organisms. Few of these automated observation technologies have been socially implemented thus far. For biological observations (eDNA and biosensors), the technology itself has just been recently developed, and the development of automated observation has just begun. A micrometeorological observation method called eddy correlation is used to observe the $CO_2$ absorption in ecosystems. The eddy correlation method is a method to quantify the $CO_2$ transfer rate by continuously observing the atmospheric $CO_2$ concentration and wind direction and speed in the surrounding area from observation towers of approximately 30 meters in height set up in forests and grasslands. In recent years, the development of observation equipment has led to the automation of observations. However, in all these cases, major issues in observation control, remote maintenance, accuracy control of observation equipment, and data quality control remain to be solved. As a result, further sophistication and automation are expected.

For the development and function of the next generation of ecosystem observations described above, it is important to note that the enhancement and utilization of ecosystem and biodiversity observations conducted at various sites, such as forests, grasslands, farmlands, lakes, rivers, watersheds, coastal areas, and oceans, will play an important role. Over the past three decades, the international ecosystem and biodiversity observation system has grown steadily. International observation networks (the International Long-Term Ecological Research Network [ILTER]; the Global Biodiversity Information Facility [GBIF]; the Biodiversity Observation Network of GEO [GEO BON]; and an international flux research network-called FLUXNET) as well as information systems for collecting and releasing long-term observation data on ecosystems and biodiversity have been established and developed. Many Japanese researchers participate in these networks and information systems, and each of them has a Japanese branch (e.g., JaLTER, J-BON, and JapanFlux). Biodiversity observation in Japan has been conducted throughout the country via monitoring sites, such as Monitoring Sites 1000, which is promoted by the Ministry of the Environment Japan, and information on various ecosystems has been accumulated (http://www.biodic.go.jp/; Takeuchi et al. 2021). Furthermore, through the development and standardization of observation techniques and international joint data analysis, we can understand the state of ecosystems and biodiversity on a national, continental, and global scale and determine the factors that cause changes in these ecosystems as well as develop a set of essential observation indicators (such as Essential Biodiversity Variables) for biodiversity and ecosystem functions. The enhancement of these ground-based observation networks is not only essential for the development and validation of satellite observation technologies and modeling methods (Muraoka and Koizumi 2009; Muraoka et al. 2012) but can also play an essential role as a platform for social collaboration in the region. Moreover, monitoring networks using next-generation technologies that are to be developed in this MS, such as eDNA, will be discussed with the SSC Species Monitoring Specialist Group of the International Union for Conservation of Nature (IUCN) and other organizations.

**(4) Development and maintenance of the information infrastructure for the NbS System:** To establish the NbS System, it is necessary to centrally manage the advanced observation data obtained by various methods, including the above mentioned methods, and exchange data with each other. Therefore, it is necessary to develop and maintain the information infrastructure for the NbS System. At present, the Darwin core (https://www.gbif.org/ja/darwin-core) proposed by GBIF (https://www.gbif.org/ja/) and the Biodiversity information standard (https://www.tdwg.org), a global standard format for recording biodiversity information, such as where organisms are distributed, has already been established. However, the standard format for ecosystems handled by the NbS System has not yet been established. Therefore, research and development are needed to identify the format items and to link the data. Additionally, because ecosystem observation data are more massive than conventional biodiversity data, research and development of data science technology is necessary, such as how to handle the data with an informatics approach, how to link different formats (e.g., satellite observation and environmental DNA), and how to manage and distribute the data.

### 2-2. Area 2 - Development of technology for predictive ecological modeling: Technology to "understand" ecosystems

Ecosystem modeling is essential for the detailed understanding and predicting of the state of ecosystems and for evaluating ecosystem services and disservices on the basis of observation data. IAs large-scale and detailed ecosystem observation data become available with the improvement of ecosystem observation technologies, it is necessary to develop modeling technologies to extract useful ecosystem information by making the most of large-scale ecosystem observation data. Presently, natural ecosystems on Earth are the only autonomous systems known to humanity. It is expected that a deeper understanding of their operating principles will lead to the development of core technologies required for the control and design of artificial ecosystems, such as agricultural ecosystems. The establishment of automated modeling technologies that enable local residents and other ecosystem service users to run ecosystem service models on their own may contribute to ongoing policy processes and decision-making at the national, regional, and local scales, as well as increase ownership of the final output (Willcock et al. 2018). Technologies that need breakthroughs for this task include statistical modeling, machine learning, AI, and ecosystem modeling.

**(1) Models for estimating and predicting the structure of ecosystems**: Ecosystems are complex systems in which diverse species interact with each other. Estimating the distribution and abundance of organisms plays a vital role in understanding their status. It is known that human society often receives services and disservices from specific species. For example, in the fishery industry, resource assessment for each species is required, and for infectious disease control, it is essential to identify species that serve as pathogen hosts. Therefore, there is a need to develop species distribution models for estimating the distribution and variation of species based on ecosystem observation data. In ecology, statistical modeling methods such as hierarchical Bayesian models, including state-space models and occupancy models, have been developed to handle various probability distributions, nonlinearities, uncertainties, and sparse data (Newman et al. 2014, Guisan et al. 2017, Kéry & Royle 2016). In particular, new modeling methods have been developed for ecological communities, such as joint species distribution modeling (Pollock et al. 2014), which can predict the distribution of species and their relationship with the environment based on ecological observation data at multiple locations. Many methods have been proposed to improve the accuracy of these statistical modeling methods, such as the incorporation of observation errors, model hierarchization, and causal inference. Still, no method has yet been proposed to comprehensively predict the structure of ecosystems, and a model incorporating these various methods and enabling highly accurate prediction of ecosystems is expected to be developed. Additionally, ecosystem prediction models require analysis of the inter-relationships among many organisms and environmental factors to estimate parameters, which require an enormous amount of computation time with current technology. The information provided by the NbS-PF may require modeling in extremely near-real-time computation time, and the challenge is to reduce the computation time by speeding up calculations such as parameter estimation and massively parallelizing the process.

**(2) Models for evaluating and predicting ecosystem functions**: Ecosystems perform multifaceted functions and provide a variety of ecosystem services. To use the multifaceted ecosystem functions sustainably and effectively, it is necessary to evaluate these functions and services quantitatively and accurately using empirical data and modeling. Examples of modeling for ecosystem functions related to global environmental regulation include process-based models that have been developed at a rapid pace since the 1990s and incorporate environmental response mechanisms of physiological processes, such as photosynthesis and respiration of plants and respiration by soil microorganisms, to evaluate and predict $CO_2$ absorption functions by terrestrial ecosystems (Ito and Oikawa 2002, Ito et al. 2015). Diagnostic models that introduce ecosystem data acquired by satellites (Sasai et al. 2005) and prediction models that assess environmental and climate change impacts on ecological processes (Ito et al. 2007) have also been developed. Recent models under development estimate and predict terrestrial ecosystem functions by fusing satellite observation data and ground-based $CO_2$ flux observation data using machine learning (Ichii et al. 2017). A dynamic model has also been developed and introduced the dynamics of forest plant populations and growth (Sato et al. 2007) . International model comparison studies are also underway to appropriately model the behavior of diverse and complex ecosystems and improve the accuracy of climate change impact prediction. However, these process-based models have been faced with issues in improving their accuracy. To model processes with high accuracy, it is necessary to describe many processes and phenomena in ecosystems. If the above high accuracy observations are made in the future, the models based on them may be developed at an outstanding pace. Additionally, the innovative development of information technology is also essential for developing models for ecosystems, which are highly complex systems, as the comprehensive analysis of climate change by the IPCC has been supported by the elucidation of the Earth system and the increasing processing speeds of computers. Machine learning algorithms for evaluating and predicting ecosystem services based on large-scale observation data have made significant progress recently (Hampton et al., 2013, Lokers et al., 2016, Richards & Tunçer 2018). They hold great promise in generating ecosystem information at various temporal and spatial scales (McKenzie et al. 2014, Scholes et al. 2013, Olsson et al. 2020). For example, in Japan, models have been proposed to predict forest ecosystem services based on forest flora, forest age, climate, and topography (Yamaura et al. 2021). Machine learning algorithms may be used to interpret big data to provide ecosystem and service information at various temporal and spatial scales needed by community members and decision-makers (McKenzie et al. 2014, Scholes et al. 2013, and Willcock et al. 2016). However, these machine-learning algorithms have not yet been socially implemented, and there are still unresolved issues in connecting them to systems, such as the NbS-PF, and reaching the high speeds that would enable us to use them effectively.

**(3) Modeling of socioecological systems**: To utilize ecosystem information for solving social problems, it is necessary to estimate the interaction between ecosystems and human society. For this, modeling is necessary to analyze observation data on ecosystems and social systems in an integrated manner. Studies have been conducted to determine the beneficiaries of ecosystem services and quantify the demand for access to utilize ecosystem services and their impact on human well-being (Bagstad et al. 2014, Poppy et al. 2014). Combining theories and data from social sciences seems to be an effective way to improve modeling in this area. However, social data are rarely used within ecosystem service models, with a few notable exceptions (Quintas-Soriano et al. 2018, Shi et al. 2020). In the future, there will be a need to develop a modeling process that integrates the use of ecosystem data and social science data. When the results of such modeling processes are used to improve the validity of policies and decisions or to search for solutions, efforts should be made to share the modeling approaches and results, including the associated uncertainties.

These models should be implemented in such a way that they can be automated so that users can utilize them with minimal support from scientists. This could contribute to ongoing policy processes, such as

IPBES and decision-making, at the national, regional, and local level and increase ownership of the final output (Willcock et al. 2018). The automation of such modeling processes also requires the provision of transparent data and procedures for computerized systems to select appropriate data and models depending on the situation.

### 2-3. Area 3 - Technology for harmoniously integrating ecosystems and social systems: Technology to "handle" ecosystems

An accurate understanding of ecosystems and predicting changes in ecosystems will be useful to enhance ecosystem services and reduce disservices. Achieving sustainable use of ecosystems is not an easy task. Not only do we need to understand the interactions between human activities and ecosystems, but we also need social devices to transform the way humans use and interact with nature. As previously described, this study has identified three areas related to the use of ecosystem information (**I. Technology for advanced ecosystem monitoring, II. Technology for predictive ecological modeling, and III. Technology for harmoniously integrating ecosystems and social systems**). These areas need to be developed to achieve the relevant MS goals. In addition to the above, we have identified five other issues: **IV. Ecosystem value assessment methods based on human well-being**, **V. Appropriate environmental education and learning, VI. Institutional design for ecosystem management**, **VII. Financial frameworks**, and **VIII. Building a decentralized society and a Regional Circular and Ecological Sphere**. Based on the ecosystem information, the NbS-PF needs to be introduced to solve these five issues and various other social problems as soon as possible. This section will focus on these five issues, examine ways to utilize ecosystem information to solve them, and provide examples of research and development that should be undertaken.

**(1) Development of ecosystem value assessment methods based on human well-being**: Ecosystems provide a variety of ecosystem services. To promote the use of ecosystems in a way that contributes to human well-being, it is necessary to clarify how ecosystems contribute to the richness of human society. However, the criteria for “richness” and “well-being” are influenced mainly by values and the environment and differ among sections of the society. It is a challenging but necessary task to develop alternative indicators to economic indicators, such as the GDP, to determine the direction that society should take. It is necessary to develop technologies to discover common values that can be widely agreed upon by the entire society, on the basis of appropriate socioecological system modeling using both data on social systems obtained from Urban OS and ecological observation data.

**(2) Development of appropriate environmental education and learning methods**: To implement the sustainable use of ecosystems as smoothly as possible, an essential social consideration is to create a framework for people to share the significance of sustainable ecosystem use. To achieve this, it is necessary for a society to widely share knowledge that nature's supports on human society, the multifaceted value of natural ecosystems, and the risks that unsustainable ecosystem use pose to human society. To achieve this, it will be adequate to offer pertinent education and awareness-raising activities based on scientific knowledge and cultivate facilitators in the society. While educational activities are a social issue, there are many science and technology issues that are closely related to the development of teaching and learning methods, such as the visualization of human impact on ecosystems and the use of VR to realize the richness of ecosystems. Additionally, the participation of local residents in ecosystem observation and social problem solving can serve as opportunities for educational and learning activities to learn about ecosystems and provide awareness that leads to value change and behavioral change. The development of a platform to facilitate this is also a significant scientific and technological challenge.

**(3) Institutional design for ecosystem management**: Ecosystems are spatially extensive, and their functions and services are multifaceted. Therefore, there are many, highly diverse stakeholders in ecosystem utilization. The design of institutions to appropriately resolve the disparity of interests among stakeholders regarding how ecosystems are utilized and managed is an important social issue. To solve this problem, research on science and technology must be conducted to develop methods to evaluate how different multiple ecosystem uses have changed the state of the ecosystems and how these changes have affected each stakeholder. To achieve sustainable use of ecosystems, it is necessary to consider the conflicts of interest among the present generation and conflicts of interest among future generations so as not to limit future possibilities. Promoting collaboration among different communities and individuals who share the same goals for ecosystem conservation is also an important social issue. Again, developing technologies to support this is a challenge in science and technology research.

**(4) Financial frameworks**: The movement toward ESG investment and financing that takes biodiversity into account is accelerating. In the recommendations by TNFD, which is scheduled for official release in 2023, the use of a “double materiality” structure that evaluates both the impact of nature on business and the impact of business activities on nature is being considered. If such biodiversity-conscious ESG investment becomes an international standard in the future, companies will be required to show how their activities affect and depend on ecosystems. The development of methods to evaluate the impact of corporate business activities on ecosystems and biodiversity based on ecosystem observation information is an important research topic that should be studied immediately.

**(5) Construction of a decentralized society and a Regional Circular and Ecological Sphere**: In Japan, one of the first countries to experience a declining and aging population, there is a need to build a sustainable new social system. To halt population decline and achieve both high sustainability and well-being, it is believed that a multipolar social system, rather than unipolar concentration in major cities, will be effective. For cities and regions to develop together, cities and regions must promote regional development that uses their respective artificial and natural capital (a Regional Circular and Ecological Sphere). The construction of a decentralized society and a Regional Circular and Ecological Sphere, is a social issue. Nevertheless, it includes many issues that should be resolved by science and technology. For example, the introduction of green infrastructures as more labor-saving social infrastructures and the improvement of productivity through the effective use of natural capital will be a major boost to the autonomous survival of rural areas. Additionally, estimating the extent to which cities depend on and influence local natural capital and assessing the appropriate compensation to be paid for it are scientific and technological tasks that should be conducted based on observational data of both ecosystems and social systems.

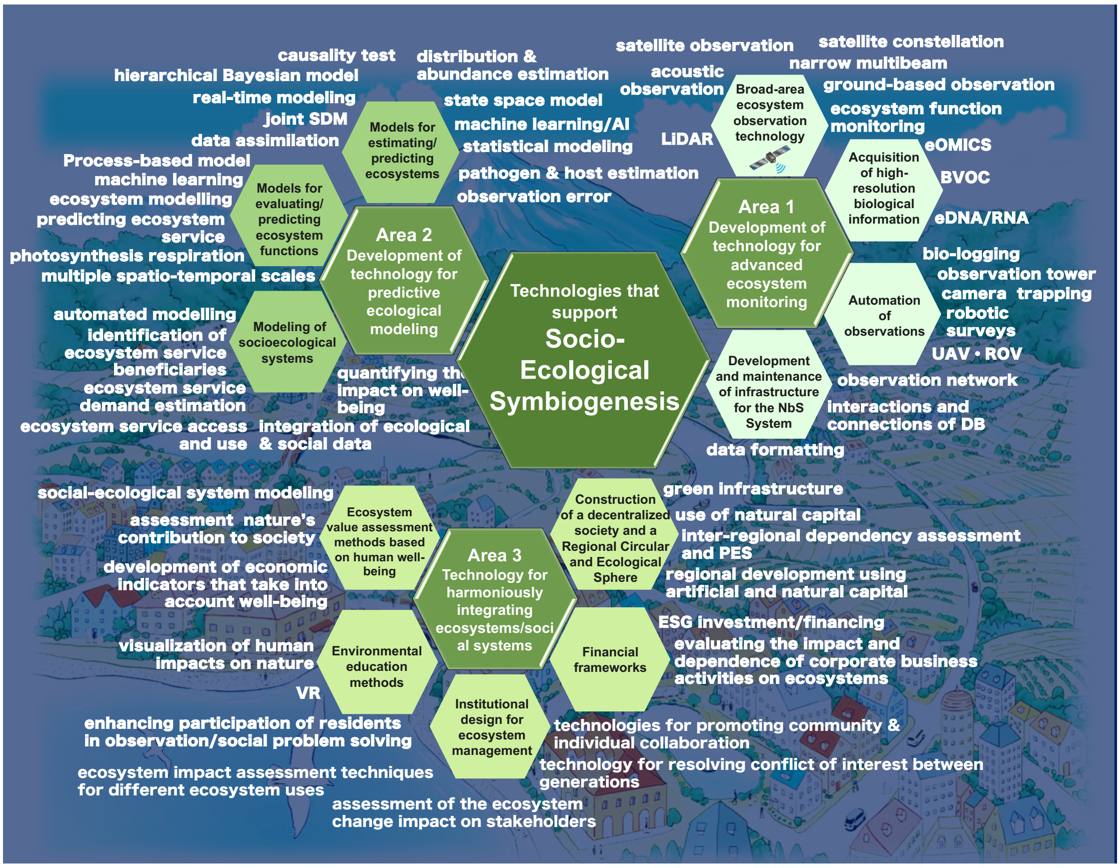


**Figure 7**: **Overhead view of issues to be overcome by science and technology to realize this MS target.**

### 3. Japan's position in overseas trends

### 3.1 Trends in research and development

The following is a summary of trends in research and development in the three areas: (Area 1) Technology for advanced ecosystem monitoring, (Area 2) Technology for predictive ecological modeling, and (Area 3) Technology for harmoniously integrating ecosystems and social systems related to the MS goals.

**(1) Trends in research and development on technology for advanced ecosystem monitoring (Area 1)**

Observation of the global environment using earth observation satellites is rapidly becoming more common. In recent years, the publication of satellite observation data has been increasingly promoted. As a representative example, data from the Landsat satellite (in operation since 1972) have been made available free of charge; quantitative evaluation of changes in global forests is now in progress. The Sentinel-2 satellite data have higher spatial resolution. These vast amounts of data are now being provided in cloud environments such as Google Earth Engine (https://earthengine.google.com). In Japan, the Ministry of Economy, Trade and Industry has launched Tellus (https://www.tellusxdp.com/). MODIS (Moderate Resolution Imaging Spectroradiometer), which uses visible and infrared radiation measurements, has also been in operation since 2001 (onboard Terra and Aqua satellites). DAICHI (Advanced Land Observing Satellite (ALOS))-2, launched in 2014, is being used for forest observation and disaster area monitoring. The Himawari-9 meteorological satellite, launched in 2016, and the SHIKISAI (Global Change Observation Mission - Climate (GCOM-C)), launched in 2017, are also used for ecological and phenological observations. Additionally, higher-resolution optical satellites, such as ALOS-3 and 4, are scheduled to become operational in the future (https://www.eorc.jaxa.jp/ALOS/a/jp/index_j.htm). Laser-based ecosystem observation (e.g., monitoring the condition of forests and rivers) using Laser Imaging Detection and Ranging (LiDAR) aircraft and drones are also in development.

Biological surveys using environmental DNA, which have been recently developed mainly in Japan, have led to the rapid popularization of such surveys over the past decade. In Japan, ANEMONE and other projects to develop observation networks throughout the country are already conducting advanced ecosystem observations by periodically collecting and analyzing water throughout the country (ANEMONE, https://sites.google.com/view/all-nippon-edna-monitoring-net/). Because environmental DNA can be analyzed simply by sampling water, the development of instruments that automatically perform the entire process from water sampling to organism detection is currently underway. Additionally, the International Barcode of Life (iBOL) project, which is constructing a DNA barcoding library, has been established. The big data infrastructure, which is the basis for the usage of genomic data, is now in place. The use of unmanned aircraft, biosensors, and unmanned aerial vehicles (UAVs), including drones, is also becoming widespread. In water, observation technologies using acoustics are improving, along with the use of remotely operated vehicles (ROVs). Bio-logging and telemetry technologies using biosensors, such as attaching sensors to organisms, are also becoming more advanced, and the population dynamics of organisms are being monitored.

Recently, databases that organize and integrate various information along the three axes of genes, phylogeny, and the environment have been developed, and integrated databases, such as MicrobeDB and FungiDB, are also in development. The Global Biodiversity Information Facility (GBIF, https://www.gbif.org/) is the world's largest database of information on organism distribution. It collects and publishes distribution data on nearly 1.7 billion organisms collected from across the world.

An observation system that uses $CO_2$, water, and heat balance data from meteorological observation towers has been in use internationally since 1990 to observe ecosystem functions such as carbon absorption (via the Eddy covariance method). It is used to quantify the transfer rate (flux) of $CO_2$ and water between the atmosphere and ecosystems as a result of photosynthesis, respiration, evapotranspiration, etc., and to elucidate the $CO_2$ absorption and water cycle functions of ecosystems. By combining observations of ecosystems in the vicinity of the observation plots, it is possible to elucidate the effects of changes in ecosystems and short-term changes in meteorological conditions on $CO_2$ absorption. There are several hundred observation plots in the world; an international observation network called FLUXNET has been established. In Japan, there are approximately 40 observation sites. The JapanFlux network (http://www.japanflux.org/) has been established and has greatly contributed to efforts to increase the capacity of researchers in Asia and the establishment of the AsiaFlux observation network. Some of these observation plots are also linked to the Japan Long-Term Ecological Research Network (JaLTER; http://www.jalter.org/), which consists of 58 observation plots mainly studying long-term changes in ecosystems and matter cycles. The interactive effects of climate change and ecosystem change on ecosystem functioning over the past 30 years are also being investigated by integrating long-term observation data. The observation of ecosystem function at a wide range of spatiotemporal scales is a technology that connects broad-area ecosystem information and detailed terrestrial biodiversity information in terms of phenomena and spatiotemporal scales; it also contributes to connecting ecosystem modeling and Earth system modeling.

The NbS-PF, as developed thus far, is based on existing databases or platforms for data management. However, to realize the establishment of the advanced NbS-PF proposed in this document, the observed data must be managed centrally and exchanged freely among organizations or stakeholders. International discussions on biodiversity information (i.e., the distribution of organisms) are already underway, and global standard formats for biodiversity information, such as the Darwin Core (https://www.gbif.org/ja/darwin-core) and the Biodiversity Information Standards (https://www.tdwg.org), have been established. At the same time, some standard formats for ecosystem information have been developed by ILTER and other organizations. Nevertheless, the data format corresponding to advanced observation has not yet been established.

**(2) Trends in research and development on technology for predictive ecological modeling (Area 2)**

In statistical modeling, which is the core of predictive modeling of ecosystems, methods such as state space models and hierarchical Bayesian models including occupancy models that incorporate advanced probability distributions, nonlinearities, uncertainties, and sparse data (data with many unobserved features) have been developed. In particular, the modeling methods that can consider the effects of other species and environments to a higher degree than before, such as joint species distribution models for biological communities (Pollock et al. 2014), have been recently proposed. Research on these statistical modeling methods is progressing rapidly, and immense progress is expected to be made in the future.

Additionally, machine learning algorithms, which have been used for various predictions and diagnostics in recent years, have undergone significant development; they now provide tools that can utilize big data to evaluate and predict ecosystem services (Hampton et al. 2013, Lokers et al. 2016, Richards and Tunçer 2018). For example, model algorithms for ecosystem functions, such as the carbon cycle, nitrogen cycle, and water cycle, have been developed by combining biogeochemical mathematical equations for the environmental response characteristics of organisms, such as photosynthesis, respiration, transpiration, and plant growth, with simplified ecosystem structures. In recent years, research and development have also been conducted to integrate ground-based multipoint observation data, satellite observation data, meteorological data, and model prediction data using machine learning algorithms. However, in parallel with the promotion of wide-area, detailed, and high-speed observation of ecosystem elements, if high-speed modeling that quantifies and predicts the complex interaction systems of diverse organisms and environmental elements becomes possible, it holds promise for the realization of short-term prediction (quasi-real-time, near-future change prediction) of ecosystems and their functions in the future. Because these ecosystem functions form the basis of ecosystem services, they will support evaluation and prediction technologies for various services, such as adjustments, supply, and culture.

**(3) Trends in research and development on technology for harmoniously integrating ecosystems and social systems (Area 3)**

Research on nature-based solutions (NbS) has progressed rapidly in recent years (https://helda.helsinki.fi/handle/10138/312390), with NbS having been mainly developed in Europe lately. The use of NbS in urban areas is mostly related to smart engineering, such as the design and management of urban ecosystems and small-scale ecological observation networks. The use of NbS in non-urban areas mainly focuses on agro-ecosystems, nature reserves and parks, river basins, and coastal zones. The ecosystem service valuation and NbS-PF are gradually beginning to be incorporated into urban planning in other countries. Innovative NbS visualization tools such as the Public Participation Geographic Information System (PPGIS) are used during planning for those projects. These tools significantly contribute to urban planning by visualizing the environment and benefits of NbS (Brown & Kyttä, 2014, Curran & Hamilton 2020).

Several problem-solving projects based on NbS are underway under the guidance of the IUCN. For example, there is an NbS for urban environmental sustainability that is similar to the Urban OS (GrowGreen, https://www.iucn.org/theme/nature-based-solutions/our-work), an NbS that is attempting to solve the problem of water scarcity, particularly in developing countries (Water and Nature, http://www.waterandnature.org), and an NbS that seeks to preserve mangrove forests to help protect against tsunami disasters and preserve the local climate (Global Mangrove Alliance, https://www.mangrovealliance.org). Many other NbS projects are introduced on the IUCN NbS website (https://www.iucn.org/theme/nature-based-solutions/our-work). As shown in **Table** 1, the functions that have been realized by these efforts, and the functions that can be utilized, are summarized. Comparing them with the NbS-PF to be developed in this MS target, it is suggested that many new developments and applications can be realized by this development. The results of this study are summarized below.

Table 1 Comparison between the functions and ability of NbS-PF in this MS target and the current NbS applications

| | Year | Link to observations | Ecosystem prediction | Understanding the whole ecosystem by local information | Searching for optimal solutions for local ecosystem–society coexistence | Provision of data | Provision of forecasts | Global development | Proposal of local control to achieve optimal solutions | Regional application | Application to national politics | Plan |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NbS-PF | ~2050 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | MS plan for 2050 |
| NbS-PF | ~2040 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | MS plan for 2040 |
| NbS-PF | ~2030 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | | MS plan for 2030 |
| GrowGreen | 2017 | ✓ | | | ✓ | | | | | | | |
| IUCN Water and Nature | 2018 | ✓ | ✓ | | | ✓ | | | | | | |
| Global Mangrove Alliance | | ✓ | ✓ | | | | | | | ✓ | | |
| INFOR FLR | | ✓ | | | | ✓ | | | | | | |

### 3.2 Technological elements in which Japan has strengths

Japan has been a global frontrunner in developing many of the core technologies for advanced ecosystem monitoring, such as satellite observation, environmental DNA, robotics, and LiDAR. For example, in using the satellite observation for ecosystems, Japanese researchers have been participating from various *in-situ* field sciences such as the international networks of flux research, long-term ecological research, and biodiversity observation since their inception and they have already played a central role in the world's observations.

In the area of eDNA, Japan was the first country to commence research and developed a comprehensive analysis method for fishes, which is now used worldwide (Miya et al. 2015, 2020). An ecosystem observation network is being developed using this comprehensive environmental DNA analysis method and eDNA collected throughout Japan (ANEMONE, https://sites.google.com/view/all-nippon-edna-monitoring-net/).

Japan has been a world leader in the development of observation robot technology. In particular, underwater exploration robots (ROVs and AUVs) are already being used for various applications, such as water quality observation and topographical surveys (https://www.jsme.or.jp/kaisi/1199-24/).

Japan is also a leader in LiDAR observation technology. Japan has the advantage of possessing airborne laser bathymetry (ALB), which can perform measurements underwater; Japan owns the largest share of three-dimensional data of rivers in the world. Japan is also the world leader in the use of this technology for the river environment conservation. As another advantage, Japan is the world leader in developing drones equipped with green lasers that can survey underwater topography from the air (Nakamura 2019). These drones are already being used in the field. Together with these LiDAR technologies, three-dimensional data has already been obtained for approximately 80% of Japan's land area, which means that the country already has a wide range of primary ecosystem observation data (Nakamura 2019).

In terms of technology for predictive ecological modeling, there is already a large amount of spatial data, such as topography and vegetation, which can be used as the basis for such modeling. Based on this, various ecosystem models have been proposed in Japan. Additionally, Japanese companies, including Preferred Networks, Inc., have already played a pioneering role in machine learning, and they are attracting attention worldwide.

Furthermore, Japan is rapidly developing 5G mobile communication networks ahead of the rest of the world for the core communication technology for building the IoN and the NbS-PF, which are essential for the harmonious integration of ecosystems and social systems. By utilizing the IoN from these cutting-edge observation technologies and communication infrastructure, areas in which Japan is already a forerunner, the construction of the foundation for developing the NbS-PF has already commenced.

### 3.3 Importance of Japan's efforts to achieve these goals

The importance of Japan's commitment to this research, which aims to harmoniously integrate the ecosystems with society, is also related to the backgrounds and current conditions of nature and society of Japan. Here is a list of points pertaining to the cultural background, social issues, and other factors that may make it possible to set goals that take advantage of these unique characteristics of Japan.

**(1) Nature in Japan and the "idea of symbiosis"**: Japan is known as one of the world's biodiversity hotspots (https://www.conservation.org/japan/biodiversity-hotspots), characterized by its rich forest and marine ecosystems. Japan's forest coverage is 68%, which is the second highest among OECD countries after Finland (73%). Japan is also home to a diverse range of organisms, with approximately 40% of land mammal and vascular plant species, 60% of reptile species, and 80% of amphibian species being endemic to Japan. As for ocean environments, Japan is blessed with 35,000 km of long, complex coastlines and various habitats, such as tidal flats, seaweed beds, and coral reefs. In addition to the Sanriku-Kinkasan coast, one of the world's three largest fishing grounds, the country is home to 50 of the world's 112 species of marine mammals and approximately 3,700 species of saltwater fish, or approximately 25% of the world's 15,000 species. Blessed with this rich natural environment, it is said that there exists a unique observation and awareness of nature in Japan that can be called "Japan-ness", as Kenji Miyazawa wrote "All mountains, rivers, plants, and trees have Buddhahood" in response to a phrase in a Buddhist scripture, the Nirvana Sutra, "All plants, trees, and lands are complete Buddhahood." This is the concept of "Tomo-Iki (literally meaning "Life Together")," in which all living things are respected on an equal footing with humans. The spread of this philosophy originated with the Buddhist scholar, politician, and educator Benkyo Shiio (1876–1971), who preached the importance of human beings living in harmony with all living things on an equal footing less than 100 years ago.

**(2) The concept of social common capital**: Hirofumi Uzawa (1928–2014) is an internationally acclaimed mathematical economist. Uzawa regarded the natural environment, social infrastructure, and institutional capital as "social common capital" and pointed out that this capital is a common asset to the society as a whole, and it is essential in building a prosperous society (Uzawa 2000). He then argued that social common capital should not be controlled by the market or bureaucratic standards but should be managed and utilized according to social standards. He explored the institutions of an economy that enables sustainable development 50 years before the UN advocated the SDGs. In Japan, many frameworks that followed Uzawa's proposal have sought to appropriately manage the natural environment based on solid observation data, science, and technology, a fact which may be of particular significance.

**(3) Countermeasures against population decline and concentration of population in cities:** In Japan, where the population is declining and aging remarkably ahead of the rest of the world, the concentration of population in cities and the shift to nuclear families has led to a decline in the health of social capital, even by global standards, and the reconstruction of local communities will become an important issue. There is increasing interest in green infrastructure that effectively utilizes the functions of natural ecosystems, and ecosystem-based disaster risk reduction (Eco-DRR), which uses the natural environment as a buffer zone against disasters, as a means of forming sustainable local communities (Renud et al. 2016). Technologies that enhance the utility of ecosystems in solving social issues based on advanced ecosystem information will help establish self-sustainable, locally symbiotic societies and halt the population decline by easing the concentration of populations in large cities.

**(4) Contribution to the international community**: Solving global environmental issues is not only a challenge for Japan but for all humankind. It is important to note that the degradation of ecosystems and biodiversity in the Asia–Pacific region, especially in developing countries, is strongly linked to the production of goods and food consumed in Japan. In addition to providing science, technology, and knowledge on environmental issues, Japan has a responsibility to help solve environmental problems in other countries. Only when we contribute to the recovery of biodiversity in other countries can Japan express its great pride in its bountiful nature. As an international framework for solving environmental problems, the Aichi Targets were adopted at COP10 of the United Nations Convention on Biological Diversity in Nagoya in 2010. In 2015, the Sendai Framework for Disaster Risk Reduction, the Paris Agreement on Climate Change, and the SDGs were also adopted. Japan has played a proactive role and worked to achieve the goals in all these international agendas. In 2016, the sixth Earth Observation Promotion Committee of the Council for Science, Technology, and Innovation compiled the “Japan’s Policy for the Implementation of Earth Observations for the Next 10 Years.” They discussed how to contribute to the international agenda by promoting problem-solving earth observation. It is strongly recognized that biodiversity, forest ecosystems, and marine resources are important aspects for realizing a sustainable society for humanity.

**(5) Problem-solving Earth system observation:** Japan formulated the “Earth Observation Promotion Strategy” (approved by the Cabinet in 2004) to utilize comprehensive Earth system observation for solving environmental problems toward the realization of a sustainable society. In parallel with this, the Japanese government played a central role in establishing the intergovernmental organization on Earth observations (Group on Earth Observations; GEO) in 2005. Thereafter, various systems for earth observations, such as satellites, aircraft, ships, various sensors, and field research, have been developed worldwide. During this period, Japanese researchers have already contributed to capacity building and human resource development for earth observation in Japan and overseas. In the “Japan’s Policy for the Implementation of Earth Observations for the Next 10 Years," compiled by the sixth Earth Observation Promotion Committee of the Council for Science and Technology in 2016, future policies were formulated to promote problem solving-oriented earth observation. Additionally, the follow-up report (https://www.mext.go.jp/b_menu/shingi/gijyutu/gijyutu2/097/houkoku/1422531_00003.htm) compiled by the eighth Earth Observation Promotion Committee in 2020 underlined the importance of the contribution of earth observation to the Convention on Biological Diversity (Aichi Targets and post-2020 targets), SDGs, the Paris Agreement, and the Sendai Framework for Disaster Risk Reduction. Furthermore, the importance of promoting science, technology, and capacity building and their dissemination to society through cooperation among research institutes, universities, industries, and community members has also been discussed.

## III. Plan for Realization

### 1. Area and field of challenging research and development, research subject for the realization of the goals

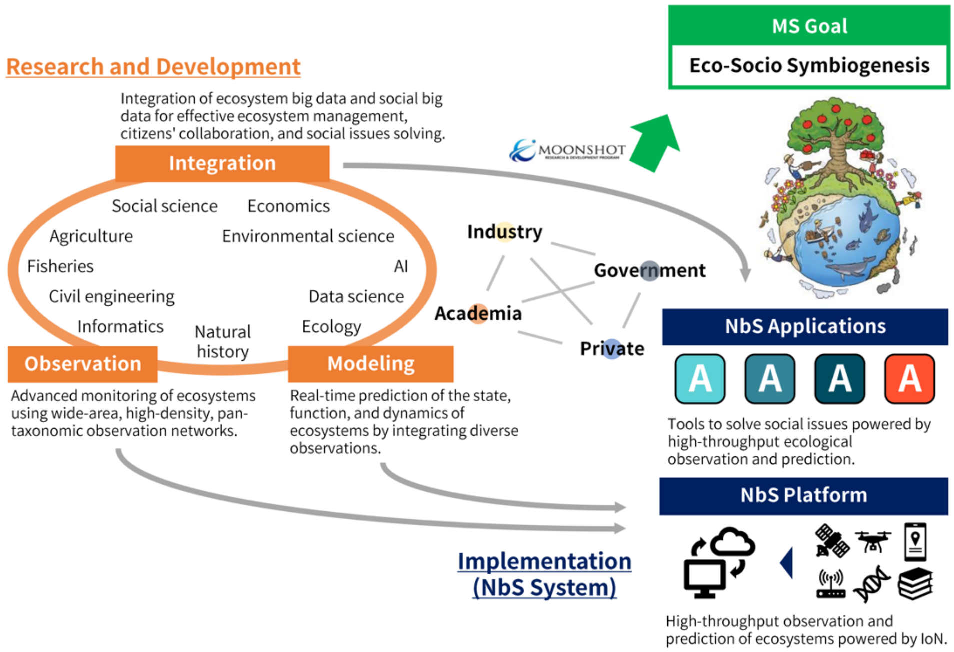


**Figure 8: Overhead view of the MS goal.**

**Socio-Ecological Symbiogenesis**, the goal of the MS R&D program, will be guided by developing the NbS System consisting of NbS platform (NbS-PF) and NbS applications (NbS-Apps) (**Fig. 8**). Therefore, the MS R&D program should promote the development of NbS-PF as a social infrastructure capable of generating and predicting large-scale, high-resolution biodiversity information and research to establish and utilize various NbS-Apps to solve diverse social issues using the output of NbS-PF.

Here, we propose three areas where challenging R&D should be promoted to realize these elements (**Area 1: technology for advanced ecosystem monitoring; Area 2: technology for predictive ecological modeling; and Area 3: technology for harmoniously integrating ecosystems and social systems**) and related research topics:

### (1) Area 1: Technology for advanced ecosystem monitoring

The NbS-PF realizes advanced ecological monitoring. It monitors the environment (physical, chemical, meteorological, atmospheric, water, etc.), organisms (species, biomass, physiology, morphology, behavior, genetic information, etc.), and ecosystem functions (primary production, matter cycles, pollination, water purification, water source recharge, disaster prevention, etc.) constantly over a wide area. Observation data are quickly shared via the IoN. The following are specific innovations and research issues that need to be addressed to achieve this goal.

#### Issue 1-1: High-throughput ecosystem observation technology

Technologies need to be developed to improve the quantity and quality of ecosystem monitoring data dramatically. The technologies developed must satisfy two high standards. First, to achieve rapid assessment and accurate prediction of the state of ecosystems, the observation must cover the vastness of the system and the diversity of its components. Therefore, improving the coverage and resolutions of observations is an important aspect. Three axes are particularly important: space, time, and biological hierarchy. In other words, the key focus of development will be how to make broad and detailed (space), long and frequent (time) observations of ecosystems, and how to assess the state and function of organisms over a wide range of biological hierarchy (e.g., genes, individuals, populations, communities, and ecosystems). In addition to the need to pioneer innovative observation approaches, it will be essential to upgrade, reduce cost, and simplify conventional methods such as remote sensing by satellites and UAVs/ROVs, automatic ecological observation by video and acoustic recording devices, biologging/telemetry, and environmental DNA analysis technology. Observation technology for ecosystem functions will also be an essential target. Second, the data generated in a high-throughput manner must be accurate enough for reliable assessment and prediction of the state of ecosystems. Sharing expert knowledge and skills essential for ecosystem observation will be a vital element for high-throughput ecosystem observation. For example, the fact that a certain (or even considerable) amount of expert knowledge and skills are required for species identification greatly restricts the accuracy and scale of ecosystem surveys. Artificial intelligence technology designed to assist and automate species identification will help solve this problem. Furthermore, enrichment of open databases that aggregate natural history information, such as species ecology, distribution, traits, and DNA sequences, will also underpin the accuracy of diverse ecosystem observations.

**Issue 1-2: Information technology for sharing and cross-sectional use of large-scale ecological data**

Technologies need to be developed for rapid aggregation and sharing of high-throughput ecological data and its integrated use. The components and functions of ecosystems are extremely diverse. Therefore, ecosystem monitoring via the NbS-PF will not be conducted through standardized observation protocols but by aggregating ecosystem observation data collected by various entities (researchers, governments, businesses, community members, etc.) in different formats. To achieve this, it is essential to develop IoN technology for automatically uploading data to the cloud from various origins and data description formats and databases that enable the centralization and cross-sectional use of various observation data.

**(2) Area 2: Technology for predictive ecological modeling**

Another critical component of the NbS-PF is an advanced modeling method that realizes the nowcasting and forecasting of ecosystems. Large-scale observation data are used to predict any given ecosystem's state, function, and services/disservices with high accuracy and resolution, automatically detecting any significant anomalies. In addition, a forecast of future dynamics of ecosystems will be provided. The following are specific innovations and research aspects essential to achieve this goal.

**Issue 2-1: Technology for real-time assessment and prediction of ecosystems based on advanced ecological observation data**

Technologies need to be developed for rapid inference and prediction of ecosystems based on the large-scale ecological observation data. The NbS-PF will enable high-throughput generation of large-scale data commensurate with the complexity of ecosystems, opening up new avenues for model-based assessment and prediction of the state of ecosystems. On the other hand, achieving such a real-time modeling approach will require resolving computational difficulties arising from the complexity of ecosystems. Ecosystems are complex systems in which diverse components interact under different or changing environmental conditions; therefore, predicting their state and dynamics requires identifying many unknown parameters and large-scale computation. To solve this problem, it is crucial to accelerate the numerical computations and data assimilation procedures required for model-based inference and prediction of ecosystems and reduce the uncertainty in predictive models by advancing the quantitative understanding of the processes of ecosystem dynamics.

**Issue 2-2 Integrated modeling of diverse ecosystem observation data**

Modeling methodologies need to be developed for integrating diverse datasets to predict the state and dynamics of ecosystems. In the NbS-PF, ecological observation data collected via various methods by different entities will be centrally aggregated and distributed in a standardized format. However, individual datasets will inevitably show significant differences in the target of observation, precision, bias, or spatiotemporal scale and resolution. Without methods to appropriately handle such heterogeneity among datasets, it is impossible to fully utilize the ecosystem big data to predict the state and dynamics of ecosystems. Therefore, it is necessary to develop a modeling framework to obtain the whole picture of ecosystems by appropriately calibrate the heterogeneity in the ecosystem big data delivered via the NbS-PF.

**(3) Area 3: Technology for harmoniously integrating ecosystems and social systems**

NbS-Apps promote the solution of various social problems by visualizing the connection between society and ecosystems and encouraging appropriate recognition of the value of ecosystems as natural capital. Big data on ecosystems generated by NbS-PF and big data on human society generated by Urban OS are input into an interdisciplinary model that integrates the environment, society, and economy to support policy making for a sustainable and prosperous society. NbS-Apps also facilitate collaboration among multiple stakeholders and resolve conflicts of interest to manage ecosystems that extend beyond regional and national boundaries properly. To achieve this goal, it is essential to promote interdisciplinary research and development to evaluate environmental risks and resource values based on ecosystem information generated from the NbS-PF and integrate the results appropriately into social and economic contexts. The following are specific innovations and research issues that need to be addressed.

**Issue 3-1 Technology for maximizing the conservation and utilization of ecosystems**

Scientific research and technological development need to be conducted to reveal the connection between ecosystems and social systems to facilitate human society to act as a functional part that promotes the conservation of ecosystems. The R&D should include assessing the impact of human activities on ecosystems, evaluating the dependence of various human activities on ecosystems, visualizing environmental risks based on ecosystem information, designing institutions that promote sustainable resource utilization, and developing environmental education programs. Another important research topic is the development of technologies that enable real-time evaluation of the value of natural capital and ecosystem services based on large-scale ecosystem information provided by the NbS-PF. The value of ecosystems visualized in detail will enable the assessment of the ecological wealth of a country or region and directly monitor the sustainability of society. Developing methods to encourage people to change their values and behaviors toward nature using scientific technologies such as virtual reality (VR) will be another research aspect.

**Issue 3-2: Technology for cooperation and coordination among stakeholders in ecosystem use**

Technologies need to be developed to implement collaborative ecosystem governance by diverse stakeholders. Ecosystems have no clear boundaries, and the functions and services they provide are multifaceted. As a result, many stakeholders are usually involved in the utilization, management, and conservation of ecosystems. For these stakeholders to utilize ecosystems sustainably and effectively, it is necessary to promote their cooperation and resolve their conflicting interests. Therefore, technologies need to be developed (1) to coordinate stakeholders with different approaches for inducing synergistic effects or (2) to promote cooperation among stakeholders with conflicting interests. The R&D should also include issues related to the payment based on claims and liabilities for natural capital.

## 2. Direction of research and development for the realization of the goals

In this section, we propose potential milestones, R&D themes to be addressed, and ripple effects on society for each target year (2030, 2040, and 2050) from the viewpoint of development and implementation of the NbS System (i.e., NbS-PF and NbS-Apps; **Fig. 9**). The development and implementation of the NbS System will begin with prototyping in model areas, where we will confirm whether the NbS System solves local social problems and encourages the transformation of values and behaviors of residents. Subsequently, the NbS System will be expanded to the whole country and the whole world. In this process, the NbS System will guide the transition to values, behaviors, and socio-economic systems that take the natural environment into account, thereby support realizing a symbiotic socio-ecological system type of society, the MS goal.

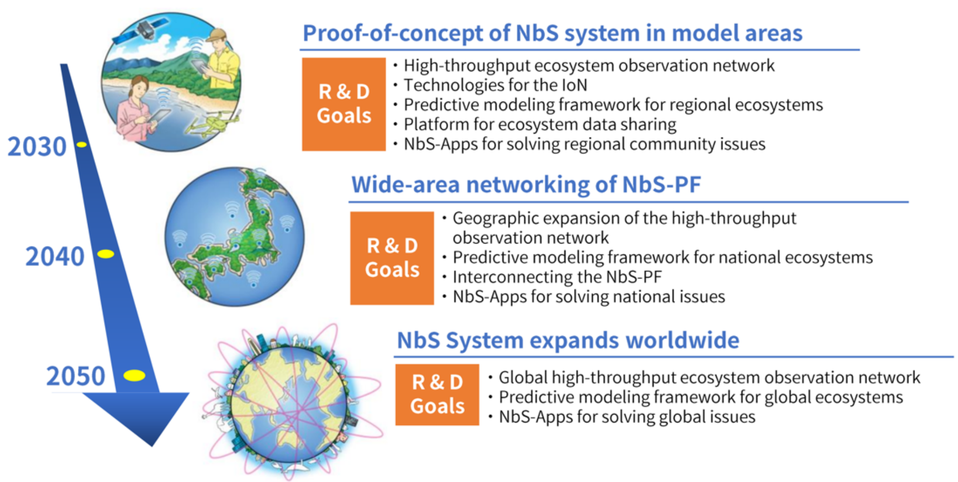


**Figure 9: Research and development scenarios for the MS goal.**

### (1) Targets for 2030, research and development to achieve them, and ripple effects

**Target (milestone): Proof-of-concept in model areas**

- A prototype of the NbS-PF, which enables high-resolution monitoring and prediction of regional ecosystems, is established in several model areas (e.g., local governments).

- Several NbS-Apps are developed and used as tools for solving social problems in the model areas based on the ecosystem information provided by the NbS-PF.

**R&D goals to achieve the milestone**

- Establishment of a high-throughput ecosystem observation network
- Development of technologies for realizing the IoN
- Development of predictive modeling technologies for regional ecosystems
- Constructing a platform for sharing of ecosystem data
- Establishment of technologies to develop NbS-Apps for solving regional social problems

**Ripple effects of achieving milestones on society**

- By realizing automatic data collection through IoN, the state of biodiversity and ecosystems in the model areas will be monitored in real-time. The NbS System will promote the autonomous management of ecosystems by local residents by providing detailed visualization of ecosystem services and functions. For example, a potentially large number of stakeholders will be able to act to conserve or restore ecosystems by quickly detecting ecosystem degradation based on the high-throughput ecosystem monitoring and sharing this information. Furthermore, the multifaceted functions and services of regional ecosystems will be delivered at a high level by utilizing the information on ecosystems to coordinate interests and make decisions among residents regarding the use of ecosystems, thereby supporting the economy, well-being, and safety of the regional community.
- The visualization of ecosystems through the NbS System will also enhance the regional financing base. Specifically, efforts to conserve, restore, and utilize the natural capital in the region will be evaluated with greater accuracy, leading local companies and governments to have more opportunities to raise funds through ESG investments and offset credits.
- Environmental education and learning will be implemented using mapped biodiversity information. Educational materials will become available that overlay a map of the region with the geographic distribution of diverse organisms as well as the functions and services of the regional ecosystems. This will engage local residents, including children, leaders of future generations, to be proactive in learning the origins and significance of their unique ecosystems. The reaffirmation of the regional natural environment's multifaceted value will accelerate the movement toward achieving both decarbonization and biodiversity conservation.

**(2) Targets for 2040, research and development to achieve them, and ripple effects**

**Target (milestone): Interconnection and networking of the NbS-PF**

- The NbS-PF is established in many regions, and they will be interconnected to form a network for sharing ecosystem information on a nationwide scale.
- NbS-Apps are used to solve social problems in a wide area across multiple administrative districts.

**R&D goals to achieve the milestone**

- Development of technologies for establishing the high-throughput ecosystem observation over a wide area
- Development of modeling technologies for wide-area prediction of ecosystems
- Development of technologies for interconnection of NbS-PF
- Establishment of technologies to develop NbS-Apps for solving social problems in a wide area

**Ripple effects of achieving milestones on society**

- The broadened NbS System will transform people's value toward sustainable use of natural capital and correction of the inequitable allocation of welfare and well-being derived from nature. It will enable detailed visualization of regional differences in the supply of ecosystem services due to differences in natural and social conditions as well as the degree of impact on the natural environment in remote areas through the linkage of socioeconomic activities among regions. This will foster a sense of understanding that payments for the various benefits derived from ecosystems should be made across administrative districts based on sufficient data and evidence. Such a value transformation will support the establishment of the Regional Circular and Ecological Sphere based on resource utilization and mutual cooperation according to regional characteristics.
- The development of the NbS System will serve as a seed to create new industries and demands. For example, by recording ecosystem changes over a long period and a wide area, the risk of ecosystem change can be quantified with high accuracy, which will enable the commercialization of insurance for industries and individuals that depend on ecosystems, including agriculture, forestry, fisheries, and tourism. Localized natural information will be utilized in the real estate sector. Furthermore, similar to weather forecasting, "ecosystem forecasting," which predicts and provides information on the future changes in ecosystems based on large-scale observation information, will become possible. This will allow various activities in the society to be flexibly adjusted to changes in the ecosystems, thereby increasing labor productivity and reducing environmental risks.

**(3) Targets for 2050, research and development to achieve them, and ripple effects**

**Target (milestone): Expanding the NbS System globally**

- The NbS-PF is expanded to the Asia-Pacific region and other countries, thereby establishing a network to realize the accumulation of ecosystem information and its utilization on a global scale.
- NbS-Apps are used to solve social problems on a global scale.

**R&D goals to achieve the milestone**

- Establishment of a high-throughput ecosystem observation network on a global scale
- Development of modeling technologies for ecosystem prediction on a global scale
- Establishment of technologies to develop NbS-Apps for solving social problems on a global scale

**Ripple effects of achieving milestones on society**

- Ecosystems and human society will be transformed into a symbiotic entity that support each other. The change in people's values and behaviors promoted by the NbS System will encourage them to pay appropriate compensation for ecosystem utilization. As a result, activities related to the conservation and management of ecosystems will be established as a new industry, and economic activities that enhance the richness of nature will be realized. On the other hand, the ecosystem information provided by the NbS System will enable people to live a rich life by making the most of the multifaceted functions of ecosystems. As the economic value of natural capital and ecosystem services visualized by the NbS System function as a monitoring index for a steady-state society, natural capital will not be depleted; thereby, our society, economy, and culture will sustainably develop.
- Inequities in the use of ecosystems among countries and regions will be corrected, and a regional circular and the Regional Circular and Ecological Sphere will be established. The NbS System will visualize the burden on ecosystems and optimize payments for ecosystem use. The costs of maintaining and restoring natural capital will thus be shared fairly between cities and rural areas or between developed and developing countries. At the same time, in each country and region, the NbS System will encourage productive activities that make the most of ecosystems as local resources. The dependence on domestic and foreign imports will be minimized, and the transition to a sustainable decentralized society in which distinctive countries and regions support each other will be promoted.

**3. International cooperation**

The following international efforts are required to achieve the MS goal.

### (1) Building/strengthening the international observation network

In high-throughput ecosystem observation, the basis of the NbS System, advanced measurement technologies such as AI-based remote sensing will be greatly utilized. However, due to the high spatio-temporal heterogeneity of biological and ecological systems, large-scale data based on such automated observations are likely to contain significant error components. Citizen observation data will also play an essential role in the NbS System, but the data collected by many citizens with various survey techniques and areas of activity may contain significant bias and heterogeneity. Therefore, to effectively assess the ecosystem in a wide area using these large-scale data, it will be crucial to perform calibration based on high-precision field observation data (ground verification measurement). The observation networks of field research sites (e.g., APBON, ILTER, AsiaFlux; Muraoka et al. 2012, Haase et al. 2018, Takeuchi et al. 2021), where research institutes conduct high-precision measurements, and the ground-based observation infrastructure (Ecosystem Research Infrastructure; Chabbi & Loescher 2017) will play an essential role as a calibration base for the high-throughput ecological observation networks in the NbS-PF. Therefore, it is essential to foster the engagement and networking of international observation networks for collaboration in promoting research and development of the NbS System.

### (2) Initiatives toward the achievement of international goals

NbS refers to a cross-sectional approach to solving social issues, such as climate change, food and water security, natural disasters, human health, and biodiversity loss (Cohen-Shacham et al. 2016, 2019). International frameworks, such as the Sustainable Development Goals (SDGs), the Sendai Framework for Disaster Reduction, the Paris Agreement, and the Aichi Targets (and their successors), have been established to address these social issues common to all humankind. Strengthening the commitment to these international goals through the development and dissemination of NbS Systems that support the achievement of NbS in countries and regions is vital as a way of international cooperation for the realization of the targeted social vision.

## 4. Interdisciplinary cooperation

The achievement of the MS goal requires collaboration among all sectors of industry, government, academia, and the private sector and participation in research by a wide range of academic disciplines regardless of the humanities and sciences (**Fig. 8**). In particular, the following types of collaboration are required to develop and disseminate the NbS System: (1) research and development to implement the system, (2) construction of a high-throughput observation system for ecosystems, and (3) social implementation of the NbS System.

### (1) Research and development for system implementation

Industry–academia collaboration between research institutes and companies is required for the rapid development and social implementation of fundamental technologies, such as the IoN and NbS-PF, which are to be realized for the MS goal. For example, the development, high functionality, and affordability of various ecological observation instruments will be promoted by combining creative concepts established by research institutes with the powerful development and production capabilities of companies. The research and development of the NbS System require the participation of diverse fields, including basic research fields of ecosystems such as ecology and natural history, the applied research fields such as fishery science and agriculture, in addition to data science, information science, civil engineering, ICT, AI, sociology, and economics (**Fig. 8**).

### (2) Establishment of a high-throughput observation system for ecosystems

Ecosystem observation in the NbS-PF will be implemented by aggregating observation data collected by various entities in different ways. Therefore, observations of ecosystems by research institutes, municipalities, governments, organizations, and citizens are mutually linked under the NbS-PF. To establish a wide-area and high-density observation system, it is essential to strengthen this cooperative relationship between the different entities. Specific approaches include, for example, the establishment of a knowledge hub to collect, share, and exchange expertise, case studies, and related literature on regional ecosystem observations among the entities.

### (3) Social implementation of the NbS System

We proposed prototyping in model areas as a possible development scenario of the NbS System (see Section III.2). In this context, collaboration between research institutes and local communities (e.g., local governments and residents) is required. Tasks that need to be addressed in the prototyping of the NbS System include the construction of an observation network for regional ecosystems, the development of an information-sharing platform, and the solution of local issues using the shared ecosystem information. To steadily advance these tasks, it is necessary to promote research, development, and verification based on partnerships between academia and local communities. The local community is a major stakeholder in the NbS System and thus should play an essential role in the subsequent expansion phase of the NbS System.

## 5. Ethical, legal, and social issues (ELSI)

The ethical, legal, and social issues for achieving the MS goal include the following.

**(1) The need for the transformative changes**

For the actual realization of the vision of society envisioned in the MS goal, "transformative changes" that include a transformation of people's values and behaviors toward conservation and utilization of ecosystems for the sustainable development of humankind and a significant overhaul of social structures, such as economic systems, financial systems, and legal systems must occur. As a result of humanity's industrial development to date, our daily production and consumption activities have created a significant environmental burden, leading to a global crisis of the natural environment, including depletion of natural capital, climate change, and loss of biological resources and biodiversity. Given the broad, diverse range of the impacts of human activities on the natural environment, these "transformative changes" must occur quickly to address the social factors that underlie the various direct factors that impact the environment (IPBES 2019, Dasgupta 2021, Ministry of the Environment, Japan 2021).

Nevertheless, the fact that such a large-scale social transformation is required does not necessarily mean realizing the MS goal is unrealistic. The movement toward "transformative changes" is making steady progress internationally. For example, in 2020, 74 financial institutions, regulators, and corporations launched an international initiative to establish the TNFD, which will deliver a framework for corporations and financial institutions to assess, manage, and report their dependence on and impact on nature. The TNFD is expected to be launched in 2021, with plans to issue a framework and guidelines for nature- and biodiversity-related disclosures by 2023 (https://tnfd.info/). Additionally, in 2016, the Natural Capital Protocol, a standard framework for companies to assess their impact and dependence on natural capital and use it to make business decisions, was developed (Natural Capital Coalition 2016). These international trends will drive financial change, a key driver of the "transformative changes", by directing financial flows towards conserving natural capital through ESG investments related to biodiversity (Dasgupta 2021).

Efforts are also underway to incorporate the value of natural capital into national accounts. The Aichi Biodiversity Targets from the Convention on Biological Diversity include a related goal (Strategic Goal A, Target 2), and as of 2020, the value of biodiversity has already been incorporated into national accounts in nearly 100 countries (Secretariat of the Convention on Biological Diversity 2020). The background to these trends is the development of global standards for integrating environmental and economic information. In March 2021, the System of Environmental-Economic Accounting Ecosystem Accounting (SEEA-EA) was formally adopted by the United Nations as a statistical standard for ecosystem accounting (https://seea.un.org/ecosystem-accounting). Such a shift to inclusive national accounts will be crucial in adequately internalizing the value of natural capital into the economic system and achieving sustainable development (Managi & Kumar 2018).

Another essential aspect is to promote the "transformative changes" through the introduction of appropriate policies. Effective measures include, for example, revising laws and regulations as well as establishing systems and frameworks related to incentives (such as taxation, exemptions, penalties, and rewards) and certification for ecosystem conservation, introducing PES, developing guidelines, establishing infrastructure to support appropriate disclosure of information to the investment market, and supporting technological innovation (Ministry of the Environment, Japan 2021). Measures are needed to induce a virtuous cycle between the economy and the conservation and utilization of ecosystems and promote education and values that support this cycle. Government initiatives should also include setting ambitious goals for building a society in harmony with nature to encourage action by diverse sectors, providing social security to overcome changes in industrial structure, and promoting legislation for ecosystem-based land use.

Finally, it is important to note that the NbS System, which we aim to realize in this MS R&D program, will serve as a device to facilitate the necessary "transformative changes." The visualization of the state and value of nature brought about by the NbS System will enable environmental education and learning, the resolution of social issues through the participation of local residents, and the design of institutions for ecosystem management, thereby promoting the transformation of the values and behaviors of people, the change of industrial structures, and the internalization of natural capital, which has been an external diseconomy, for the realization of a resilient symbiotic relationship between natural ecosystems and human society.

**(2) Establishing ethics and governance in the use of ecosystem big data**

As we can see from the history of the development of computers and the Internet, as well as the rise of big data such as genome information, the development of new information has been a major driving force that has enriched our society, but it has also raised a variety of new problems. The large-scale ecological information provided by the NbS System is also expected to attract unconventional social and economic risks and ethical issues. Therefore, to achieve the MS goal, it is necessary to identify the social, economic, and ethical issues related to acquiring and utilizing ecosystem big data and promote efforts to resolve these issues.

A specific example is the issue of the safe and appropriate operation of ecosystem information. Various stakeholders should openly use ecosystem information provided by the NbS System for the sustainable and effective utilization of ecosystems. At the same time, however, there is a risk that making detailed information on ecosystems accessible to everyone may encourage exploitative use of ecosystems, such as overfishing of aquatic resources and poaching of rare species (Lindenmayer & Scheele 2017, Tulloch et al. 2018). It is also possible that the increasing sophistication of ecosystem monitoring may lead to situations where the dignity, rights, and safety of individuals and groups are unintentionally violated (Handsley-Davis et al. 2020, Sandbrook et al. 2021). Therefore, in parallel with the development of the NbS System, studies are required to show how information management and ecosystem governance should be in a society where advanced ecosystem information is provided in addition to establish our "ecosystem information literacy" (i.e., social responsibility in the use of ecosystem information).

## IV. Conclusion

Team "Socio-Ecological Symbiogenesis" conducted research to identify the society of 2050 that we should aim for in the post-corona/after-corona era, the issues that we should tackle to realize that society, and the scenarios and milestones that will lead us to achieve the goals. Our working hypothesis was that "sustainability and well-being can be realized simultaneously by harmoniously connecting two large, complex systems on which humanity depend heavily, namely the ecosystem and the social system." Based on this hypothesis, we conducted literature surveys, interviews with experts from various fields and observation networks, pol.is questionnaires, and public symposium. By carefully examining, analyzing, and utilizing the vast amount of information and knowledge we obtained, we conducted a thorough examination and discussion of the social significance and feasibility of this hypothesis from a multifaceted perspective, taking into account not only science and technology but also social and economic systems, legislation, and international situations.

As a result of this research, it was found that by focusing on the collaborative governance of ecosystems, which is realized through the cooperation of residents, it will be possible to shift to a completely new kind of social system in which rich nature supports society and society supports nature (Socio-Ecological Symbiogenesis). This will not only create a green economy and a natural information industry, but will also enable the construction of a prosperous society where no one is left behind and where individual happiness and self-realization are realized. In the process of achieving this goal, the Internet of Nature (IoN), which visualizes the state of the ecosystem and its relationship with the social system, and social devices for the transformation of the ecosystem-society relationship, such as environmental value trading based on the IoN, were identified as potentially playing an important role.

Contributions that should be made from the field of science and technology were also discussed. In addition to proposing a frame for the NbS System as an ecological information infrastructure that will play a central role in the process of Socio-Ecological Symbiogenesis, we identified three important research topics that are required for its realization: (1) development of technology for advanced ecosystem monitoring, (2) development of technology for predictive ecological modeling, and (3) technology for harmoniously integrating ecosystems and social systems. In addition, as a milestone for 2030, prototypes of the NbS System that enable high-resolution monitoring and prediction of ecosystems will be built in several model regions, and will be used to solve local social issues based on ecosystem information (promotion of ecosystem autonomy management, upgrading of ecosystem functions and services, financing through ESG investment and offset credits, promotion of environmental education and learning, etc.).

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Expert Interview No. 2: Dr. Nobuko Saigusa, Director, Earth System Division, National Institute for Environmental Studies (NIES)

Expert Interview No. 3: Prof. Takehito Yoshida, Associate Professor, Research Institute for Humanity and Nature / Associate Professor, Graduate School of Arts and Sciences, The University of Tokyo

Expert Interview No. 4: Prof. Ayumi Onuma, Professor, Faculty of Economics, Keio University

Expert Interview No. 5: Mr. Teppei Dohke, Executive Director, The Nature Conservation Society of Japan (NACS-J) and the Japan Committee of the International Union for Conservation of Nature (IUCN)

Expert Interview No. 6: Prof. Yoshinori Hiroi, Professor, Research Center for the Future of Humanity, Kyoto University

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## Appendix 1. Economic, market and industrial sectors related to the implementation of the NbS System

### (1) Impact on ESG investment

Globally the Environmental, Social, and Corporate Governance (ESG) investments is expanding among investors with long-term perspectives; the ESG investments accounted for $31 trillion in 2018, which was about one-third of the total investment market (Global Sustainable Investment Alliance 2019). In Japan, 97.9% of investment organizations say that they use the ESG information for their investment decisions, and ESG investment is expected to expand more and more among corporate pension funds (nearly 100 trillion JPY in the assets) (Ministry of Economy, Trade and Industry 2019). Climate change-related indexes have recently been used in EGS management. Next target would be "biodiversity," (e.g., UN PRI 2020, TNFD and this trend will expand rapidly in next few years.

The NbS System analyzes and predicts impacts on natural ecosystems including both direct and indirect factors, and identifies beneficiaries and cost-bearers of ecosystem services at the same time. This enables us to quantify benefits and disadvantages for each stakeholder and trace the impacts in our social systems. The NbS System is expected to have a high impact on future ESG investments, as it provides information on "the impact of industrial activities on natural ecosystems and biodiversity, and ultimate impact on our whole society," which is required by the TNFD.

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### (2) Tourism industry

The tourism sector has been continuously growing globally and regionally in recent years before COVID19. In 2019, international tourist arrivals exceeded 1.5 billion people (more than the world's total population) in the world; the tourism industry contributed $8.9 trillion (10.3% of the total GDP), and Japan contributed $357.7 billion, which was the third largest in the world (WTTC 2020). The industrial growth rate of tourism sector was 3.5% year-on-year, which was higher than the global average of 2.5% (above 2.5% for the ninth consecutive year), and was the third highest after the information services and financial services industries. Before COVID-19, the tourism industry was expected to expand into 11.3% of GDP by 2030 (WTCC 2020). Among OECD countries, this sector directly contributed to 4.4% of GDP, 6.9% of employment and 21.5% of service exports.

In Japan, the tourism industry is recognized as the main engine of economic growth in recent years (Tourism GDP (2012-2016) was 23.0% growth rate; the tourism industry had about 5% (about 2 trillion JPY) among the nominal GDP increased by about 40 trillion JPY; the share of GDP was 2.6 times the growth comparing to about 1.7% (2012))(Tourism White Paper 2018). As of 2018, the number of foreign tourists visiting Japan reached a record high of more than 30 million people (8.7% up year-on-year, the number of foreign travelers accepted: 11th largest in the world, the third largest in Asia), and the consumption of foreign travelers is estimated to be 4.5 trillion JPY (Japan Tourism Agency 2019). The positive effect of these foreign tourists visiting Japan is not only on consumption during their stay, but also on export industries of cross-border e-commerce after returning to their home.

Tourism contributes not only for the economical market, but for enrichment of human’s life. As tourists experience the nature and culture in the visiting places, these experiences promote mutual understanding across areas and attachment to nature, which are essential factor for the transformation to a sustainable society. Foreign tourists visiting Japan are interested in "experience in nature" (cf. "nature and scenic spots tourism": 3rd place overall, " nature experience tour and agriculture and fishing village experience" 14th place overall), thus Japan's rich nature is a major tourist resource (Japan Tourism Agency 2019). The NbS System support regional tourism industry by developing regional tourism industry tools, exploring new regional tourism resources, and creating tourism-related applications. The NbS System not only contributes to regional revitalization by maximizing the attractiveness of the region and natural ecosystem, but also boost competitiveness regionally and internationally by innovating tools in the tourism industry. These NbS tourism system will lead to increase the share among the international tourism industry, especially the eco-tourism market.

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**(3) Next-generation industries related to natural capital**

In order to realize symbiotic socio-ecological system, scientific and technological innovation to visualize the value of natural capital and positive and negative impact to natural ecosystems using big data of ecosystems is essential. Currently, transformation into a society for decarbonization is accelerating, and technological development on "cleantech" is rapidly progressing such as AI and big data analysis, low prices of renewable energy, storage batteries. The number of cleantech startups aiming to develop environmentally friendly technologies are re-lunching supported by global trend of ESG investments for those companies. For example, global venture capital investments in clean energy startups doubled to $6.9 billion in 2018 (International Energy Agency 2019). This trend has led to recent aggressive investments by managers of large IT global companies (Amazon, Microsoft) for cleantech companies (e.g., Microsoft launched Climate Innovation Fund in 2020 and invested $1 billion over the next four years for $CO_2$ reduction and removal related companies). As after TCFD TNFD will be on track in the near future, societal demand for information on ecosystems, technologies to visualize the status and impact on ecosystems and biodiversity, and systems that bring them into the market and account, will be increased rapidly.

The NbS System that supports symbiotic socio-ecological system provides fundamental information on ecosystems, which can be utilized by startup companies that create new industries related to natural capital. In addition, through the collaboration with startup companies, the NbS System itself will be improved and strengthened and more resilient.

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**(4) Industries related to disaster prevention and mitigation**

In recent years, natural disasters have become more severe and frequent due to the effects of climate change, and it is a critical risk to people's lives, property, and industries (Cabinet Office 2018). Thus, comprehensive strategies for disaster prevention and mitigation is recognized as urgent issues in Japan. To make the feasible and effective strategies, not only public initiatives such as the national government and local governments, but also all the people in society including corporations and citizens should participate for the strategic plan. The Japan Cabinet Office (2020) has announced to bring the projects to accelerate disaster prevention and mitigation and national resilience for five years (Cabinet Office 2020) with an additional fund of 15 trillion JPY, Moreover, the market of national resilience business in private sector is estimated about 11.9 trillion JPY as of 2013 and about 11.8 to 13.5 trillion JPY by 2020. Thus, growing attention has been paid to this sector as a fast-growing business (Cabinet Office 2016). Green infrastructure (or Eco-DRR) aims to "create a society that is strongly resilient to the natural disasters and in harmony with nature" based on predictions of future population decline and severe climate disasters. Moreover, demand for green infrastructure will grow because of multiple functions and merits of this system; this system can 1) mitigate the natural disaster by "avoiding exposure" and "reducing vulnerability" and 2) extract multifaceted ecosystem functions such as biodiversity and other ecosystem services, and 3) make local people to conduct adaptive management, which can be implemented even in rural areas (Natural Affairs Bureau, Ministry of the Environment 2016). For example, the "Disaster-Resilient Forest" project conducted by Hyogo prefecture (funding was based on prefectural green tax, project cost 8.8 billion JPY) is evaluated as a total of 44.5 billion JPY including benefits such as water source recharge and environmental conservation, as well as disaster prevention and mitigation effects, and 12.2 billion JPY as an economic spillover effect, and contribute to 1,437 people employment (Hyogo Prefecture 2020). The proper management of natural ecosystems contributes not only for disaster prevention and mitigation in the region, but also produces multifaceted benefits and the local economy.

The NbS System provide an advanced tool for designing and implementing green infrastructure in regions because the system is equipped the prediction tools of natural ecosystem dynamics. Moreover, combining with social data, it provide scientific evidence to enhance the resilience and sustainability of local society and natural ecosystems in terms of medium- to long-term perspectives. By visualizing the multifaceted functions of natural ecosystems, we can evaluate the co-benefits of green infrastructure and impact on the society (Expert Interview No. 3). The proper evaluation of economic and social effects of green infrastructure will lead to autonomous economic cycle in the region.

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Expert Interview No. 3: Prof. Takehito Yoshida, Associate Professor, Research Institute for Humanity and Nature / Associate Professor, Graduate School of Arts and Sciences, The University of Tokyo https://sites.google.com/view/eco-socio-symbiogenesis/専門家インタビュー (in Japanese)

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## Appendix 2. A survey on Attitudes toward Natural Coexistence using a consensus-building tool, pol.is

### 1. Survey Objective

In order to make use of social opinion in designing the MS goals, we explored the common values of those who are interested in the fields of ecology and environmental sciences regarding the ideal vision of society in harmony with nature, the challenges in realizing it, and the ways to devise and solve them.

The survey was conducted using pol.is (https://pol.is), an open-source tool developed to explore the distribution of participants' opinions and the common values and to promote "dialogue" that leads to a rough consensus among participants. Participants can post their own opinions at any time, and at the same time, they can anonymously vote for or against the opinions that other participants posted. The obtained information is analyzed using principal component analysis, for example, to find similarities among participants.

### 2. Survey Method

We started the survey using pol.is on March 17, 2021. The website used by the survey is shown in **Document 1**. In addition to the research team's website, the survey was publicized on jeconet, a mailing list for ecologists, the Ecological Society of Japan Public Symposium, the Japan Long-Term Ecological Research Network, the Japan Flux Research Network, the Japan Society of Civil Engineers, and other natural environment-related academic societies. After being publicized, the survey was conducted under the condition that everyone can participate. New comment submissions were closed on May 3, and as of July 7, only voting was ongoing.

### 3. Results

By July 7, 2021, 614 people had participated in the survey; 177 opinions and 33,610 approval/denial votes had been submitted. **Document 2** shows a summary report of the survey results automatically generated by pol.is. The latest summary report of survey results is available at https://pol.is/report/r5wbpnvkmhujvmacrmatm.

Of the participants, 570 provided basic information about themselves (**"Metadata", Document 2**). According to **Metadata**, most of the participants are in the group that thinks "0. Our country should aim for a society in harmony with nature". Most of the participants were between 30 and 60 years old (68%), followed by those under 30 (24%) and those over 60 (6%). The largest percentage of respondents (43%) live in cities with a population of 500,000 or more, roughly equal numbers live in cities and towns with a population of 50,000-200,000 (27%) and cities and towns with a population of 200,000-500,000 (29%). The smallest percentage (13%) live in rural areas.

There were opinions that more than 90% of the participants voted similarly for or against, while there were some opinions that were very divided (see **"How divisive was the conversation?", Document 2**). These can be used to infer the common values of the participants. The common opinion that received the most votes in favor (see **"Majority", Document 2**) was "Ref. 9. Observation of ecosystems plays an important role in building a society in harmony with nature" (92% agree, 2% disagree, 5% pass), " Ref. 11. Ecology can contribute to building a society in harmony with nature" (93% agree, 2% disagree, 3% pass), " Ref. 16. To realize a society in harmony with nature, ecosystems and biodiversity must be explained in an easy-to-understand manner to non-specialists" (92% agree, 3% disagree, 3% pass). On the other hand, " Ref. 20. We should humbly acknowledge the value of nature even if the mechanisms of natural ecosystems can never be fully understood or predicted" (93% agree, 2% disagree, 3% pass).

The opinion that divided the vote the most (see **"How divisive was the conversation?", Document 2**) was "Ref. 12. Realizing a sustainable society in harmony with nature and increasing GDP are incompatible" (27% agree, 52% disagree, 19% pass), "In order to achieve a society in harmony with nature, Japan's population should be reduced" (23% agreed, 47% disagreed, 28% passed), and "Ref. 8. The value of ecosystems and biodiversity can be evaluated with money" (25% agree, 50% disagree, 23% pass).

The 571 participants were divided into two groups (A and B) based on their votes for and against (**"Opinion Group", Document 2**). 129 participants belonged to Group A and 442 to Group B. Compared to Group B, Group A voted less in favor of "Ref. 22. The value of natural ecosystems can be evaluated economically in some areas and not in others," while Group B voted less in favor of "Ref. 117. In the past, a society in harmony with nature was realized even if the value of biodiversity in the fields of economy and health was not clearly shown to everyone," "Ref. 121. In discussing a society in harmony with nature, each individual must have a blueprint of an ideal symbiotic society". The majority of respondents voted against "An ideal society in harmony with nature is a world in which all living things in the world are able to care for each other by being deeply aware of the fact that all living things on earth were born from a single cell". Group B voted for "Ref. 32. Communicating the appeal of nature is the role that ecology should play in realizing a society in harmony with nature". Group B voted for "Ref. 50. In order to realize the autonomous management of local ecosystems by local residents, a mechanism to support local residents, who do not have as much power as large corporations, is necessary", "Ref. 11. Ecology can contribute to the construction of a society in harmony with nature" and "Ref. 55. Respect for others (disadvantaged people, organisms, and their future generations) will realize symbiosis with nature".

There were some questions that received particularly contrasting approval and disapproval votes between Groups A and B. The opinion that characterizes Group A by the large number of affirmative votes is "Ref. 42. I feel uncomfortable with the idea that a society in harmony with nature is wonderful because it is baseless and imposes values," "Ref. 70. There is no scientific proof that traditional satoyama management methods are sustainable" (**Graph 2, Document 2**). The opinions that strongly characterize Group B are: "Ref. 41. A society in harmony with nature begins with each person loving nature, including humans," "Ref. 117. In the past, a society in harmony with nature was realized even if the value of biodiversity in the fields of economics and health was not presented in a way that was easily understood by everyone," "Ref. 32. Communicating the appeal of nature is the role that ecology should play in realizing a society in harmony with nature," and "Ref. 99. It may be important to define "wildlife well-being" as well as "human well-being"".

## 4. Discussion

There are high expectations for ecology and ecosystem observation to realize a society in harmony with nature. Highly condensed opinions that more than 90% of the participants voted include the ones that emphasized the role of ecology for realizing a society in harmony with nature (9, 11) and that pointed out the importance of non-specialists having access to ecological knowledge (16). The MS goal proposes a symbiotic socio-ecological system that makes maximum use of information in ecology and dataset obtained from ecosystem observation, and this indicates that this basic concept will be widely accepted among the ecological community. Although there is a high expectation that ecology will play an important role in the establishment of a society in harmony with nature, not a few participants believed that the value of nature should be recognized even if ecosystems is not fully understood scientifically. Therefore, In order for the MS goal to be widely accepted, it is necessary to take into account the fact that people perceive ecosystem values that do not necessarily derive from scientific understanding.

In relation to the establishment of a society in harmony with nature, the two opinions that split the vote the most among the participants were those related to the economic valuation of ecosystems (8, 12). While about a quarter of the voters thought that the realization of a sustainable, nature-friendly society and an increase in GDP are incompatible, roughly half of the voters thought that both are compatible. Also, about a quarter of the participants think that the value of ecosystems and biodiversity can be evaluated in terms of money, while about half of the participants think that it cannot be evaluated in terms of money. These results show that while there are studies that value the contribution of ecosystem services and biodiversity to industry, there are not a few who believe that the value of ecosystems cannot be translated into economic value. These relative distributions of opinions indicate that it is still not easy to reach a consensus on the economic valuation of ecosystem services and biodiversity values. In this study, we propose a vision of a society in which the economic value of ecosystems can be assessed by "visualizing" the impact of ecosystems on human society and incorporating appropriate environmental value transactions into the social system through the combined analysis of advanced ecosystem observations and data on social systems. It can be inferred from this survey that this proposal will be perceived as a major scientific challenge, and not as something that everyone thinks is possible.

By comparing the two opinion groups identified from this survey, we can see that there are two very different ways of thinking about what a society in harmony with nature should be. In Group B, which includes about 70% of the total participants, it can be seen that natural ecosystems are viewed as entities with their own inherent value. The members of this group tend to believe that the root of a society in harmony with nature lies in compassion for others (169), consideration for the well-being of wildlife (99), and love of nature (41). As a result, the members of this group believe that it is important to widely communicate the "attractiveness of nature" (32) and to "educate" (50) people about the significance of biodiversity conservation in order to realize a society in harmony with nature. In contrast, Group A does not consider nature's inherent lovable qualities and its own value as a prerequisite for the realization of a society in harmony with nature. Rather, this group seems to strongly recognize that natural ecosystems have a value that can be evaluated by their functions. For example, we can see this from the members who believe that the value of natural ecosystems can be evaluated economically (22), and from the opinion that the evaluation of the value of biodiversity in the economic and health fields (117) will be the basis for a society in harmony with nature. In fact, in this group, there was a member with the characteristic opinion that "I feel uncomfortable with the idea that a society in harmony with nature is wonderful because it has no basis and is an imposition of values," which suggests that they believe that the value of ecosystems and nature is not emotional, but is only evaluated by its utility. It can be inferred that they believe that the value of ecosystems and nature is not emotional, but rather evaluated by their utility.

In both of Groups A and B a majority believe that we should aim for a society in harmony with nature, but the percentage is considerably higher in Group B (94%) than in Group A (77%). By focusing on this difference in orientation toward a society in harmony with natur, we can identify what should be done in the future toward its establishment. It can be suggested that the low level of orientation toward a society in harmony with nature in Group A is related to the value system that the value of natural ecosystems is not inherent, but should be evaluated based on their functions. While Group B may find value in the existence of all nature itself, Group A, which focuses on the function of nature, may have the concept of nature without value, and these two views of nature may even conflict with each other in the social movement toward the establishment of a society in harmony with nature. It seems that these two views of nature may even conflict with each other. This MS goal proposal, "Socio-Ecological Symbiogenesis," aims to realize a society in harmony with nature by "visualizing" the socioeconomic value of natural ecosystems through the use of advanced ecosystem observation and modeling and environmental value trading mechanisms. This approach is expected to appeal strongly to those belonging to Group A who seek an objective and scientific basis for the value of nature. This will have a positive effect on people's value transformation toward the realization of a society in harmony with nature. At the same time, however, " Socio-Ecological Symbiogenesis " proposes to promote attachment to nature by familiarizing local residents with nature, and its approach includes promoting symbiosis by increasing the number of those who hold Group B values.

Document 1: The pol.is website used for the survey

# 理想的な自然共生型の社会に向けて

生態系に過剰な負荷を与える人間活動やライフスタイルが生物多様性や自然の恵みの劣化を引き起こす一方、食料や健康、教育などの基本的ニーズも満たされない人々が多数存在しています。すべての人類がより「よく生きる（human well-being）」ことのできる世界を実現するには、不足と過負荷を同時に解決する自然共生型の社会システムをつくっていく必要があるでしょう。

このアンケートは、理想的な自然共生の姿と、それを実現する上で課題となっていること、さらにはその工夫や解決の方法について、広く意見を求めることを目的としています。投稿された意見は、今後、シンポジウム等の場で共有・議論され、ムーンショット目標検討のために活用させていただきます。本事業については以下のウェブサイトをご覧ください：

https://sites.google.com/view/eco-socio-symbiogenesis

ご協力よろしくお願いします。

＜問い＞

自然と共生する社会とはどのようなものでしょうか？あなたが思い描く理想の社会像を教えてください。

理想の自然共生社会を実現するにはどのような取り組みが必要でしょうか？インフラ整備、社会システム、教育や文化、法整備など多様な側面から教えてください。

自然との共生実現に向けて科学・技術はどんな貢献ができるでしょうか？特に、生態学や応用生態学、生態工学等のマクロ生物学の果たすべき役割について考えをお聞かせください。

＜本システムの使い方＞

１）すでに提起されている意見について、あなたの考えを

① agree（賛成）

② disagree（反対）

③ unsure（スキップ/不確定）

のいずれかで回答してください。

２）すでに提起された意見とは別の意見やアイデアをお持ちの方は「Share your perspective…」にご自身の意見を投稿（Submit）してください。

＊誰かの意見に返事をする必要はありません。新しい視点や経験、または問題を記入してください。

＊いくつかの意見・アイデアがあるときは、一つにまとめないで分けて投稿してください。質問形式での記載はしないでください。

＊意見はわかりやすく簡潔にまとめてください（140字以内）。

＊「Share your perspective…」は個別の意見に対して感想を述べたり、反論するためのものではありません。皆さんご自身の意見をわかりやすく説明してください。参加者はここで投稿された意見に対して賛成/反対の票を投じます。

（このアンケートは多数決をするためのものではありません。意見の分布を知り、多様な意見の背後に隠された共通価値を探るためのものです。多くの方が同じ意見を出された場合は単一の意見として表示されます。みなさんがご自身の意見を出してくださることをお待ちしています。）

Document 2: Summary report automatically generated by pol.is



# Report

pol.is/8tsapcm2am

auto-refresh

color blind mode

## Overview

Pol.is is a real-time survey system that helps identify the different ways a large group of people think about a divisive or complicated topic. Here's a basic breakdown of some terms you'll need to know in order to understand this report.

**Participants:** These are the people who participated in the conversation by voting and writing statements. Based on how they voted, each participant is sorted into an opinion group.

**Statements:** Participants may submit statements for other participants to vote on. Statements are assigned a number in the order they're submitted.

**Opinion groups:** Groups are made of participants who voted similarly to each other, and differently from the other groups.

This pol.is conversation was run by Kondoh Michio. The topic was '理想的な自然共生型の社会に向けて'.

| 614 | 570 | 33,610 | 177 | 54.74 | 3.03 |
|---|---|---|---|---|---|
| people voted | people grouped | votes were cast | statements were submitted | votes per voter on average | statements per author on average |

## How divisive was the conversation?

Statements (here as little circles) to the left were voted on the same way—either everyone agreed or everyone disagreed. Statements to the right were divisive—participants were split between agreement and disagreement.

**How to use this:** Hover to see the statement text. Start on the far right to find out what the most divisive statement was.

Consensus statements | Divisive statements

| | STATEMENT | OVERALL | A 129 | B 441 |
|---|---|---|---|---|
| 30 | 自然共生社会を目指す為には、日本の人口は減らすべきである。 | 23% 47% 28% (446) | 30% 44% 25% (112) | 21% 49% 29% (334) |

# Majority

Here's what most people agreed with.

60% or more of all participants voted one way or the other, regardless of whether large amounts of certain minority opinion groups voted the other way.

% Agreed | % Disagreed | % Passed | % Didn't vote

| | STATEMENT | OVERALL 570 | A 129 | B 441 |
|---|---|---|---|---|
| 9 | 自然共生社会の構築には生態系の観測が重要な役割を果たす。 | 92% 2% 5% (468) | 78% 8% 13% (120) | 97% 0% 2% (348) |
| 11 | 生態学は自然共生社会の構築に貢献できる。 | 93% 2% 3% (466) | 79% 8% 12% (121) | 98% 0% 0% (345) |
| 16 | 自然共生社会を実現するには、生態系・生物多様性について非専門家にもわかりやすく説明されなくてはいけない。 | 92% 3% 3% (478) | 77% 14% 7% (118) | 97% 0% 2% (360) |
| 20 | 自然生態系の仕組みが完全に解明、予測されることがなくとも、自然の価値を謙虚に認めるべきだ。 | 91% 2% 5% (468) | 80% 6% 12% (120) | 95% 0% 3% (348) |
| 28 | 労働時間を半分にしても、自家消費分の農産物は自給自足すべきである。 | 9% 66% 24% (416) | 8% 72% 18% (111) | 10% 63% 25% (305) |
| 35 | 自然共生社会では、誰も「楽」はできない。 | 17% 53% 28% (428) | 18% 52% 28% (108) | 17% 54% 28% (320) |
| 42 | 自然共生社会が素晴らしいとする考えには根拠がなく、価値観の押し付けであるため不快に感じる。 | 13% 59% 27% (392) | 26% 32% 40% (101) | 8% 68% 22% (291) |
| 45 | 理想の自然共生社会を実現するためには、自然環境の高度な情報収集・利活用と同時に、自然環境の維持や再生に携わる人の情報収集やネットワークが必要である。 | 92% 2% 5% (409) | 80% 6% 12% (108) | 96% 0% 2% (301) |
| 163 | 自然を守るために自然を作る事業を行うことは、人工物であるため、環境保護の観点から行うべきではない。 | 11% 67% 20% (34) | 20% 50% 30% (10) | 8% 75% 16% (24) |

# Opinion Groups

Across 570 total participants, opinion groups emerged. There are two factors that define an opinion group. First, each opinion group is made up of a number of participants who tended to vote similarly on multiple statements. Second, each group of participants who voted similarly will have also voted distinctly differently from other groups.

# Metadata

The demographic breakdown of each group, as self reported by agreeing and disagreeing on statements marked 'metadata' by moderators.

| | STATEMENT | OVERALL 570 | A 129 | B 441 |
|---|---|---|---|---|
| 0 | 我が国は自然共生社会を目指すべきである。 | 90% 1% 7% (566) | 77% 5% 17% (129) | 94% 0% 4% (437) |
| 1 | 私は30歳未満（0〜29歳）である。 | 24% 73% 1% (565) | 17% 77% 5% (129) | 26% 72% 0% (436) |
| 2 | 私は30歳以上60歳未満（30〜59歳）である。 | 68% 29% 1% (565) | 72% 23% 3% (129) | 67% 31% 0% (436) |
| 3 | 私は60歳以上である。 | 6% 90% 2% (563) | 6% 88% 5% (129) | 7% 91% 1% (434) |
| 4 | 私は人口5万人〜20万人程度の市町村で生活している。 | 27% 66% 6% (565) | 27% 62% 10% (129) | 27% 67% 4% (436) |
| 5 | 私は人口20万人〜50万人程度の市町村で生活している。 | 29% 63% 6% (564) | 31% 59% 9% (129) | 29% 64% 5% (435) |
| 6 | 私は人口50万人以上の都市で生活している。 | 43% 51% 5% (565) | 39% 51% 8% (129) | 44% 51% 4% (436) |
| 7 | 私の住む地域は農山漁村である。 | 13% 82% 4% (565) | 8% 80% 10% (129) | 14% 82% 2% (436) |

## Group A: 129 participants

Statements which make this group unique, by their votes:

| | STATEMENT | OVERALL 570 | A 129 | B 441 |
|---|---|---|---|---|
| 22 | 自然生態系の価値は経済学的に評価できる部分とできない部分がある | 89% 5% 5% (460) | 86% 5% 7% (118) | 90% 4% 4% (342) |
| 117 | かつては、生物多様性の経済や健康分野での価値が誰の目にもわかりやすい形で示されていなくても、自然共生社会は実現していた。 | 29% 43% 26% (315) | 14% 65% 20% (84) | 35% 35% 29% (231) |
| 121 | 自然共生社会について議論する上で、個々人は理想とする共生社会の青写真を持たねばならない。 | 41% 31% 27% (311) | 17% 58% 24% (81) | 49% 22% 28% (230) |
| 28 | 労働時間を半分にしても、自家消費分の農産物は自給自足すべきである。 | 9% 66% 24% (416) | 8% 72% 18% (111) | 10% 63% 25% (305) |
| 169 | 理想の自然共生型社会とは、地球上の生き物がたった一つ細胞から生まれたという事実を深く自覚することで、世界中の生き物がお互いを慈しみあえる世界 | 13% 50% 36% (30) | 0% 77% 22% (9) | 19% 38% 42% (21) |

## Group B: 441 participants

Statements which make this group unique, by their votes:

| | STATEMENT | OVERALL 570 | A 129 | B 441 |
|---|---|---|---|---|
| 32 | 自然の魅力を伝えることが、自然共生社会の実現に向けて生態学が果たすべき役割である。 | 66% 18% 14% (472) | 27% 48% 23% (118) | 79% 8% 11% (354) |
| 50 | 自然共生社会の実現には、生態学者が生物多様性保全の意義を啓蒙することが求められる。 | 77% 9% 12% (420) | 47% 25% 27% (106) | 87% 4% 7% (314) |
| 111 | 地域住民による地域生態系の自治管理を実現するためには、大企業などに比べると強い力を持たない地域住民を援助する仕組みが必要である。 | 82% 5% 11% (326) | 54% 17% 27% (84) | 92% 1% 5% (242) |
| 11 | 生態学は自然共生社会の構築に貢献できる。 | 93% 2% 3% (466) | 79% 8% 12% (121) | 98% 0% 0% (345) |
| 55 | 他者（不利益を被る人や生物、その将来世代）の尊重が自然共生を実現する。 | 84% 5% 10% (410) | 60% 17% 21% (105) | 92% 0% 6% (305) |

# Areas of uncertainty

Across all 570 participants, there was uncertainty about the following statements. Greater than 30% of participants who saw these statements 'passed'.

Areas of uncertainty can provide avenues to educate and open dialogue with your community.

| | STATEMENT | OVERALL 570 | A 129 | B 441 |
|---|---|---|---|---|
| 125 | 高度な社会分業によって持続可能な社会が実現する。 | 18% 31% 50% (299) | 13% 40% 45% (79) | 19% 28% 52% (220) |
| 34 | 高度な社会分業は、サステイナブルではない。 | 23% 34% 41% (426) | 21% 37% 41% (112) | 24% 33% 42% (314) |
| 26 | 自然共生社会では生態系のディスサービスが低減されているはずだ。 | 37% 22% 40% (456) | 20% 30% 49% (116) | 42% 19% 37% (340) |
| 126 | 農作業の集約化による国内の農産物の自給率は、自然共生社会の構築に貢献する。 | 35% 21% 42% (301) | 27% 22% 49% (79) | 38% 21% 39% (222) |
| 38 | 自然共生社会はそれを強制する法制度の整備に合意が得られず実現しないだろう。 | 17% 45% 37% (396) | 23% 30% 46% (104) | 15% 50% 33% (292) |

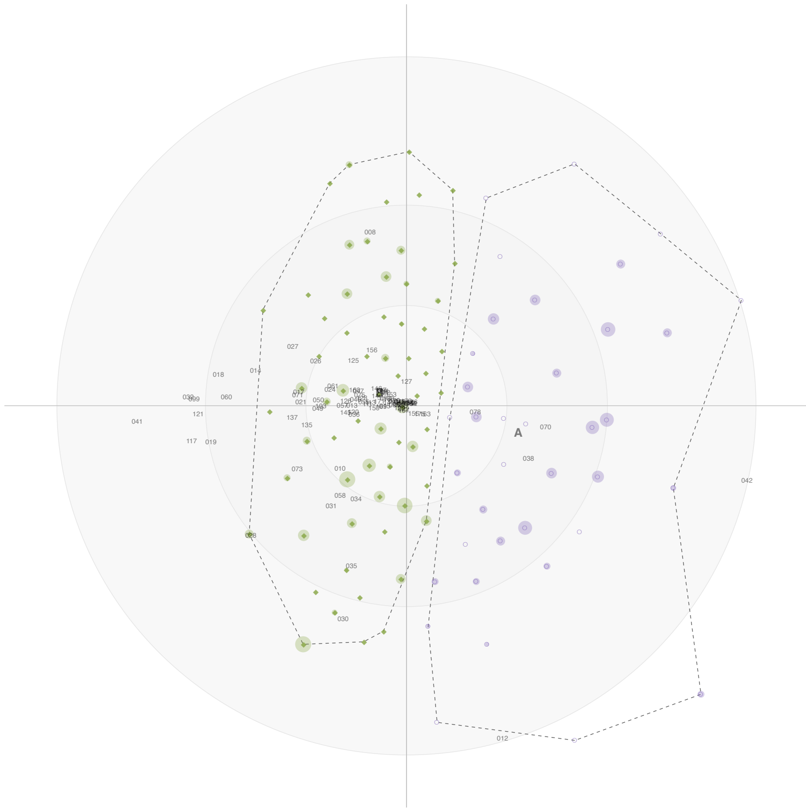
# Graph

Which statements were voted on similarly? How do participants relate to each other?

In this graph, statements are positioned more closely to statements which were voted on similarly. Participants, in turn, are positioned more closely to statements on which they agreed, and further from statements on which they disagreed. This means participants who voted similarly are closer together.

Axes | Radial axes | Statements | Participants (bucketized) | Group outline | Group labels

Click a statement, identified by its number, to explore regions of the graph.



# All statements

Group votes across all statements, excluding those statements which were moderated out.

Sort by: Statement Id

| | STATEMENT | OVERALL 570 | A 129 | B 441 |
|---|---|---|---|---|
| 0 | 我が国は自然共生社会を目指すべきである。 | 90% 1% 7% (566) | 77% 5% 17% (129) | 94% 0% 4% (437) |
| 1 | 私は30歳未満（0〜29歳）である。 | 24% 73% 1% (565) | 17% 77% 5% (129) | 26% 72% 0% (436) |
| 2 | 私は30歳以上60歳未満（30〜59歳）である。 | 68% 29% 1% (565) | 72% 23% 3% (129) | 67% 31% 0% (436) |
| 3 | 私は60歳以上である。 | 6% 90% 2% (563) | 6% 88% 5% (129) | 7% 91% 1% (434) |
| 4 | 私は人口5万人〜20万人程度の市町村で生活している。 | 27% 66% 6% (565) | 27% 62% 10% (129) | 27% 67% 4% (436) |
| 5 | 私は人口20万人〜50万人程度の市町村で生活している。 | 29% 63% 6% (564) | 31% 59% 9% (129) | 29% 64% 5% (435) |
| 6 | 私は人口50万人以上の都市で生活している。 | 43% 51% 5% (565) | 39% 51% 8% (129) | 44% 51% 4% (436) |
| 7 | 私の住む地域は農山漁村である。 | 13% 82% 4% (565) | 8% 80% 10% (129) | 14% 82% 2% (436) |
| 8 | 生態系や生物多様性の価値はお金で評価できる。 | 25% 50% 23% (487) | 19% 59% 21% (121) | 27% 48% 24% (366) |
| 9 | 自然共生社会の構築には生態系の観測が重要な役割を果たす。 | 92% 2% 5% (468) | 78% 8% 13% (120) | 97% 0% 2% (348) |
| 10 | 生物多様性・生態系保全を実現するために、人間活動は制限される必要がある。 | 69% 15% 14% (494) | 59% 20% 19% (122) | 73% 14% 12% (372) |
| 11 | 生態学は自然共生社会の構築に貢献できる。 | 93% 2% 3% (466) | 79% 8% 12% (121) | 98% 0% 0% (345) |
| 12 | 持続可能な自然共生社会の実現とGDPの増大は両立しない。 | 27% 52% 19% (501) | 35% 36% 28% (125) | 25% 57% 16% (376) |
| 13 | 産業・社会・住民は自然の恵みを与えてくれる生態系（自然資本）の利用に対して相応の対価を支払うべきだ。 | 79% 7% 13% (469) | 58% 15% 25% (119) | 86% 4% 9% (350) |
| 14 | 生物多様性の経済や健康分野での価値が誰の目にもわかりやすい形で示されないと、自然共生社会は実現しない。 | 65% 20% 14% (506) | 38% 43% 18% (125) | 73% 13% 13% (381) |
| 15 | 脱炭素社会の実現には、エネルギー関連技術イノベーションの他にも、生態系機能の保全が不可欠である。 | 89% 4% 6% (474) | 72% 10% 16% (121) | 94% 2% 2% (353) |
| 16 | 自然共生社会を実現するには、生態系・生物多様性について非専門家にもわかりやすく説明されなくてはいけない。 | 92% 3% 3% (478) | 77% 14% 7% (118) | 97% 0% 2% (360) |
| 17 | 地域の特徴や文化に応じて、自然の恵みが公平に行き届き、特定の地域社会に不利益が集中しない状態を目指すべきだ。 | 74% 14% 11% (478) | 47% 31% 20% (120) | 82% 8% 8% (358) |
| 18 | 自然共生の実現には、「人間の幸福」の定義が重要な役割を果たす。 | 64% 16% 19% (496) | 31% 44% 23% (123) | 74% 7% 17% (373) |
| 19 | 自然共生社会を実現するには自然に対する畏敬の念が必要である。 | 63% 20% 16% (498) | 34% 39% 25% (124) | 72% 13% 13% (374) |
| 20 | 自然生態系の仕組みが完全に解明、予測されることがなくとも、自然の価値を謙虚に認めるべきだ。 | 91% 2% 5% (468) | 80% 6% 12% (120) | 95% 0% 3% (348) |
| 21 | 生態系管理はトップダウンではなく、地域住民が地域生態系を自治管理するのが望ましい。 | 55% 15% 28% (463) | 41% 26% 31% (119) | 60% 11% 27% (344) |
| 22 | 自然生態系の価値は経済学的に評価できる部分とできない部分がある | 89% 5% 5% (460) | 86% 5% 7% (118) | 90% 4% 4% (342) |
| 24 | 自然共生社会の実現とは、それを人が意識しなくなることである。 | 31% 40% 27% (446) | 26% 43% 30% (116) | 33% 39% 26% (330) |
| 26 | 自然共生社会では生態系のディスサービスが低減されているはずだ。 | 37% 22% 40% (456) | 20% 30% 49% (116) | 42% 19% 37% (340) |

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| 27 | 自然共生社会と平等性は両立できる | 54% 16% 29% (438) | 37% 27% 34% (115) | 60% 12% 27% (323) |
| 28 | 労働時間を半分にしても、自家消費分の農産物は自給自足すべきである。 | 9% 66% 24% (416) | 8% 72% 18% (111) | 10% 63% 25% (305) |
| 30 | 自然共生社会を目指す為には、日本の人口は減らすべきである。 | 23% 47% 28% (446) | 30% 44% 25% (112) | 21% 49% 29% (334) |
| 31 | 自然共生社会を実現するためには、社会が一定の損害を受忍することが不可欠である。 | 56% 22% 20% (463) | 53% 25% 20% (117) | 57% 21% 20% (346) |
| 32 | 自然の魅力を伝えることが、自然共生社会の実現に向けて生態学が果たすべき役割である。 | 66% 18% 14% (472) | 27% 48% 23% (118) | 79% 8% 11% (354) |
| 34 | 高度な社会分業は、サステイナブルではない。 | 23% 34% 41% (426) | 21% 37% 41% (112) | 24% 33% 42% (314) |
| 35 | 自然共生社会では、誰も「楽」はできない。 | 17% 53% 28% (428) | 18% 52% 28% (108) | 17% 54% 28% (320) |
| 36 | 自然共生社会を実現するためには、「自然との共存のためにコストを払ってもよい」という社会全体の意識改革が必要である。 | 82% 8% 9% (440) | 63% 18% 18% (114) | 88% 4% 6% (326) |
| 38 | 自然共生社会はそれを強制する法制度の整備に合意が得られず実現しないだろう。 | 17% 45% 37% (396) | 23% 30% 46% (104) | 15% 50% 33% (292) |
| 41 | 自然共生社会は各自が人間も含めた自然を愛することから始まる。 | 54% 23% 21% (441) | 23% 54% 22% (112) | 65% 13% 20% (329) |
| 42 | 自然共生社会が素晴らしいとする考えには根拠がなく、価値観の押し付けであるため不快に感じる。 | 13% 59% 27% (392) | 26% 32% 40% (101) | 8% 68% 22% (291) |
| 45 | 理想の自然共生社会を実現するためには、自然環境の高度な情報収集・利活用と同時に、自然環境の維持や再生に携わる人の情報収集やネットワークが必要である。 | 92% 2% 5% (409) | 80% 6% 12% (108) | 96% 0% 2% (301) |
| 46 | 自然共生社会は正しい知識で推進するべきで、その過程での困難は仕方がない。 | 74% 8% 17% (412) | 56% 15% 28% (107) | 80% 5% 13% (305) |
| 47 | 自然共生社会には何かしらのコストや犠牲が伴うので、これに見合う「すばらしいもの」が何かがわからなければ、大部分の市民は自然共生社会の実現に向けて動かない。 | 73% 13% 12% (423) | 58% 25% 16% (108) | 79% 9% 11% (315) |
| 49 | 自然共生社会の実現には、生態学者が水産資源との付き合い方を消費者に啓蒙することが求められる。 | 73% 10% 15% (425) | 51% 24% 23% (110) | 81% 6% 12% (315) |
| 50 | 自然共生社会の実現には、生態学者が生物多様性保全の意義を啓蒙することが求められる。 | 77% 9% 12% (420) | 47% 25% 27% (106) | 87% 4% 7% (314) |
| 54 | 人間は行動経済学的に従って利得よりも損を避けるものである。 | 55% 10% 34% (390) | 56% 12% 31% (103) | 55% 9% 35% (287) |
| 55 | 他者（不利益を被る人や生物、その将来世代）の尊重が自然共生を実現する。 | 84% 5% 10% (410) | 60% 17% 21% (105) | 92% 0% 6% (305) |
| 57 | 生態系は生態学的な価値（効用）がなくても、文化的な価値を持つものとして尊重されるべきである。 | 73% 8% 17% (414) | 53% 19% 26% (108) | 81% 4% 14% (306) |
| 58 | GDPを増大させるべきという前提は存在しない。 | 61% 18% 20% (426) | 57% 19% 23% (107) | 62% 17% 20% (319) |
| 60 | 「人間の幸福」とは何であるかの理解が自然共生社会の実現を左右する。 | 59% 17% 23% (417) | 31% 42% 25% (110) | 69% 8% 22% (307) |
| 61 | 自然の恵みが公平に行き届くことはないので、それを所与として、特定の地域社会に不利益が集中しない状態を目指すべき | 72% 10% 16% (395) | 57% 25% 16% (102) | 78% 5% 16% (293) |

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| 70 | 伝統的な里山管理手法にはサステイナブルであるという科学的証明がない。 | 35% 27% 37% (353) | 52% 13% 34% (90) | 29% 32% 38% (263) |
| 71 | 伝統的な里山管理手法の利用は、自然共生社会実現の手段としての有効な選択肢である。 | 66% 13% 19% (363) | 33% 34% 31% (92) | 78% 6% 15% (271) |
| 73 | 自然共生社会の実現に向けて、GDPの成長を前提としない革新的なアプローチを考慮に入れるべきだ。 | 66% 14% 18% (384) | 49% 24% 26% (95) | 72% 11% 15% (289) |
| 75 | 不在地主・不在山主は、適切な山林・農耕地管理の実現を阻害する。 | 65% 10% 23% (351) | 52% 13% 34% (90) | 69% 9% 20% (261) |
| 78 | 自然共生社会の実現に向けた啓蒙活動は生態学者が実施しなくとも良い。 | 40% 40% 20% (350) | 42% 32% 25% (90) | 39% 42% 18% (260) |
| 92 | 自然共生社会の実現のためには，エネルギー技術などによる環境保全と人間の社会・経済活動との相互作用に関わる革新が発展することが必要であり，その革新の方向性が重要である。 | 83% 4% 11% (353) | 68% 10% 20% (91) | 88% 2% 8% (262) |
| 95 | 自然共生の実現には、哲学、生態学、経済学といった広い異なる学術分野を同時に考慮できる人材が求められる。 | 89% 4% 5% (339) | 77% 11% 11% (87) | 94% 1% 3% (252) |
| 99 | 「人間」だけでなく、「野生生物の幸福」の定義も重要かもしれない。 | 52% 25% 21% (331) | 26% 46% 27% (88) | 62% 18% 19% (243) |
| 103 | 自然共生社会の実現は、これまでの社会からの大転換であり、これまで損害と考えていたものが損害ではなくなる可能性がある。 | 66% 9% 24% (318) | 37% 21% 40% (82) | 76% 4% 18% (236) |
| 111 | 地域住民による地域生態系の自治管理を実現するためには、大企業などに比べると強い力を持たない地域住民を援助する仕組みが必要である。 | 82% 5% 11% (326) | 54% 17% 27% (84) | 92% 1% 5% (242) |
| 113 | 自然共生社会の実現には、生態学者が水産資源との付き合い方を漁業者に対しても啓発することが求められる。 | 83% 6% 10% (332) | 61% 15% 22% (84) | 91% 2% 6% (248) |
| 117 | かつては、生物多様性の経済や健康分野での価値が誰の目にもわかりやすい形で示されていなくても、自然共生社会は実現していた。 | 29% 43% 26% (315) | 14% 65% 20% (84) | 35% 35% 29% (231) |
| 119 | 再生可能エネルギーの導入やリサイクルの具体的な技術開発など、社会および自然環境への影響力を持つ工学系の人材との意見交換や共有が、自然共生社会の実現には必要だ。 | 95% 0% 4% (324) | 89% 1% 9% (84) | 97% 0% 2% (240) |
| 120 | 土地の所有権および国土管理について、早急に新しいコンセンサスを作るべきであろう。 | 63% 8% 27% (311) | 45% 13% 40% (81) | 70% 6% 23% (230) |
| 121 | 自然共生社会について議論する上で、個々人は理想とする共生社会の青写真を持たねばならない。 | 41% 31% 27% (311) | 17% 58% 24% (81) | 49% 22% 28% (230) |
| 122 | 自然共生社会というのが、江戸時代のようにすべて手作業の労働を強いられるものであったら誰も「楽」はできないが、テクノロジーをどのように使うか熟考することで「楽」をすることが可能になる。 | 78% 5% 15% (314) | 65% 10% 25% (80) | 83% 3% 12% (234) |
| 125 | 高度な社会分業によって持続可能な社会が実現する。 | 18% 31% 50% (299) | 13% 40% 45% (79) | 19% 28% 52% (220) |
| 126 | 農作業の集約化による国内の農産物の自給率は、自然共生社会の構築に貢献する。 | 35% 21% 42% (301) | 27% 22% 49% (79) | 38% 21% 39% (222) |

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| 127 | 自然共生社会の実現のためには、環境や生物の保全だけでなく、人間の利益・快適性に繋がることを謳う、ある意味「人間中心」の観点からアプローチすることも必要だ。 | 82% 9% 8% (325) | 76% 10% 12% (82) | 83% 9% 6% (243) |
| 128 | 地域の草の根的な活動・コミュニティ同士を横に繋ぐ取り組みが、自然共生社会の実現や幸福度の増進に有効だ。 | 79% 5% 14% (316) | 51% 16% 32% (81) | 89% 1% 8% (235) |
| 129 | 自然共生の実現にイノベーションは一定の役割を果たしうるが、もっぱらイノベーションにのみ頼るのは危険である。 | 85% 3% 11% (300) | 80% 6% 12% (78) | 87% 2% 10% (222) |
| 134 | 「理想の自然共生社会」は人によって異なるが、違いを緩やかに許容できることが前に進んでいくために必要である | 94% 1% 4% (293) | 86% 2% 10% (74) | 96% 0% 2% (219) |
| 135 | 自然共生型社会を目指す具体的な手段の一つとして、伝統的農業によって生息場所が維持されている環境や生物を守るために、画一的な圃場整備はやめるべきだ。 | 52% 16% 31% (293) | 32% 29% 38% (71) | 59% 11% 28% (222) |
| 137 | 自然共生社会の構築には、過疎と人口都市集中を緩和することが必要不可欠である | 57% 18% 24% (280) | 35% 35% 28% (67) | 63% 13% 23% (213) |
| 140 | 自然共生社会を実現するには、多くの人が自然に関する知識を高めるモチベーションを持つことが必要である。 | 77% 8% 13% (227) | 58% 13% 27% (51) | 83% 7% 9% (176) |
| 141 | 自然共生社会の実現には地域の社会教育拠点（生涯学習センター、博物館）の機能が有効である。 | 81% 3% 15% (232) | 59% 9% 30% (52) | 87% 1% 11% (180) |
| 142 | 自然共生社会の実現には義務教育へのアプローチが不可欠だ。 | 87% 5% 7% (235) | 73% 16% 10% (56) | 92% 1% 6% (179) |
| 143 | 食料、物品、エネルギーなど、何を対象としても、じゃぶじゃぶ大量に使うのではなく賢く丁寧に利用して、その上で経済性が担保できる形の社会にするべきだ。 | 89% 2% 8% (223) | 75% 3% 20% (53) | 94% 1% 4% (170) |
| 145 | 自然共生社会を実現していくには、食料や木材、人件費などの過度なグローバルスケールの貿易を抑えて、地域や国スケールで持続可能な社会の形にする必要がある。 | 66% 14% 19% (212) | 44% 26% 30% (50) | 72% 10% 16% (162) |
| 146 | 自然共生社会の実現には、DX（デジタルトランスフォーメーション：データやデジタル技術を利用した変革）など、デジタルな部分の技術開発・環境整備・制度設計が必要不可欠である。 | 66% 6% 26% (217) | 46% 18% 36% (50) | 72% 3% 23% (167) |
| 147 | 輸入を前提とした上で、国内消費を調整することで、国内の自然共生型社会の実現が可能である。 | 25% 29% 44% (197) | 17% 36% 45% (46) | 27% 27% 44% (151) |
| 150 | 循環型、分散型、人やコミュニティのネットワークが強くしなやかな社会を目指す、というようような概念が、共通意識の醸造に役立つと思います。 | 70% 5% 24% (199) | 48% 11% 39% (43) | 76% 3% 20% (156) |
| 152 | 自然共生型の社会を目指すためには、教育の対象となる子どもたちだけでなく、その教育に携わる保護者や各学校教諭などにもわかりやすい情報の提供が必要である。 | 97% 0% 2% (199) | 90% 0% 9% (43) | 99% 0% 0% (156) |
| 153 | 自然共生社会の実現のためには、経済的・非経済的に一定のコストが発生するが、それより大きなリターンがあることを分かりやすく示さなければならない。 | 79% 7% 13% (192) | 65% 16% 18% (43) | 83% 4% 11% (149) |

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| 155 | 自然共生型社会を実現したいと考えるのは、先進国に住む、余裕のある裕福な人々であり、自然共生型社会の実現を阻んでいる張本人であるとの自覚が必要だ。 | 50% 17% 31% (179) | 60% 10% 30% (40) | 48% 20% 31% (139) |
| 156 | 済成長を止めることなく社会的弱者の生活レベルを引き上げつつ、自然共生型社会の実現を図る方法を考えるべきだ。 | 60% 19% 20% (194) | 37% 37% 24% (45) | 67% 13% 18% (149) |
| 158 | 自然資本を持続的に活用していける自然・社会システムの構築が必要。そのためには、その状態・トレンド（過去から、近未来の両方）を可視化できるようなツール、モニタリングシステムが必要。 | 91% 1% 6% (187) | 82% 4% 12% (41) | 93% 0% 5% (146) |
| 159 | SDGは、小学生から高齢者まで予想以上に浸透しました（言葉だけかもしれませんが）。どのようにしたら、浸透するか、主流化できるか、を研究し、これからの自然生態系の保全につなげる必要があると思います。 | 76% 7% 15% (189) | 57% 27% 15% (40) | 81% 2% 16% (149) |
| 160 | GDPという単一の指標ではなく、価格のつかない多様なもの・ことに価値を見出す人間の幸福（well-beings）を考慮に入れた経済指標を採択することで、「経済成長」と自然共生は高いレベルで両立する。 | 66% 7% 26% (176) | 34% 26% 39% (41) | 76% 1% 22% (135) |
| 163 | 自然を守るために自然を作る事業を行うことは、人工物であるため、環境保護の観点から行うべきではない。 | 11% 67% 20% (34) | 20% 50% 30% (10) | 8% 75% 16% (24) |
| 164 | 生態学者に頼るだけでは自然共生社会は実現しない | 97% 2% 0% (41) | 92% 7% 0% (14) | 100% 0% 0% (27) |
| 165 | 一般的な自然共生論は、2050までに人口・居住地域が3割近く減少することが予想されることの影響を過小評価している。 | 20% 5% 73% (34) | 30% 10% 60% (10) | 16% 4% 79% (24) |
| 167 | 現代の柴刈りとは？というように昔の生き方を現代版にアレンジして考えると自然共生のヒントが得られるかもしれない。 | 58% 11% 29% (34) | 63% 18% 18% (11) | 56% 8% 34% (23) |
| 168 | かつての里地・里山は生物と人間がバランス良く生活していたが、これに地産地消の再生エネルギーを組み合わせると良いと思う。 | 60% 17% 22% (35) | 30% 60% 10% (10) | 72% 0% 28% (25) |
| 169 | 理想の自然共生型社会とは、地球上の生き物がたった一つ細胞から生まれたという事実を深く自覚することで、世界中の生き物がお互いを慈しみあえる世界 | 13% 50% 36% (30) | 0% 77% 22% (9) | 19% 38% 42% (21) |
| 170 | 全てを無尽蔵に増殖可能な貨幣価値に置き換える現代の資本主義を、限りある地球を資本とする新たなな資本主義に置き換える事で、自然共生型社会も自律的に生まれる。 | 28% 25% 46% (32) | 20% 40% 40% (10) | 31% 18% 50% (22) |
| 171 | スマートシティとか、DXとかによる大人数の人工的インフラベースの人間だけの密集生態系ではなく、少なくとも人間はもっとスモールな集団で自然の溶け込んだ社会。 | 34% 21% 43% (32) | 20% 50% 30% (10) | 40% 9% 50% (22) |
| 173 | 自然共生社会は人にとっても住みやすいものであろう。 | 52% 11% 35% (17) | 40% 40% 20% (5) | 58% 0% 41% (12) |
| 175 | 平等という考え方はダイバーシティの考え方と矛盾するため、社会構築について議論する際には考えない方が良い。 | 15% 57% 26% (19) | 50% 33% 16% (6) | 0% 69% 30% (13) |

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| 176 | 多様な価値観を許容する社会を築くべきであって、自然共生型社会か否かという二元論は意味がない。 | 59% 22% 18% (22) | 80% 20% 0% (5) | 52% 23% 23% (17) |