Transdisciplinary forest science and the rise of Nature-based Solutions

Based on the protection of natural capital, Nature-based Solutions (NbS) offer climate change mitigation and adaptation and are increasingly being embraced. However, methods for quantifying natural capital generally fail to offer effective values for comparison with social and economic capital. Professors Mitsuru Osaki and Hidenori Takahashi at Hokkaido University, Japan, Professors Tsuyoshi Kato and Nobuyuki Tsuji, and researcher Niken Andika Putri argue that the adoption of NbS approaches requires the development of transdisciplinary forest science.

Nature-based Solutions (NbS), offer a new approach to climate change mitigation and adaptation. However, while the NbS approach is increasingly embraced by the Global South, the Global North remains wedded to the use of industrial technology to address climate change. NbS are based on natural capital: natural assets including geology, soil, air, water, and all living things. In practice, however, NbS are largely supported by the function of forests ('forest function'), which includes timber production, as well as ecological and environmental stability (eg, soil erosion protection, flood, drought, temperature amelioration), climate economy (ie, carbon neutral/negative), and a forest's water budget. Forest function is overlooked by global warming theorists, lobbyists, and scientists, even forest scientists, but it is impossible to find alternatives to forests. An essential role of forests is the assimilation of carbon (CO_2 removal from air). However, forests also cool the air by removing latent heat (evapotranspiration, Figure 1). Forests reflect green spectrum light (thus dissipate heat). Industrial technologies cannot perform all these roles. Solar cells, for example, produce electric energy but cannot cool air (in fact, they may make it hotter), nor positively affect the water cycle (they may have a drying effect), and do not protect against erosion.

NATURE-BASED SOLUTIONS

The Paris Agreement requires all Parties to set out mitigation and adaptation plans in a Nationally Determined Contributions (NDCs) document submitted to the UN Framework Convention on Climate Change (UNFCCC) (NDCs are UN mandated plans to reduce national emissions and adapt to climate change impacts). In the 2021 NDC document, 105 out of 114 (92%) of enhanced NDCs included NbS: 96 in the context of mitigation measures, 91 in the context of adaptation plans, with an overlap of 82 in both mitigation and adaptation. The NbS are initiatives that protect, restore, and manage the sustainability of land and ocean ecosystems (eg, forests, peatlands, wetlands, savannahs, coral reefs and mangroves), while simultaneously addressing other societal challenges. More action is needed, however, as international frameworks (such as the UNFCCC) do not yet fully recognise the potential contributions of NbS. Moreover, guidance on the development of NDCs does not explicitly encourage use of NbS. The critical roles of oceans and coastal ecosystems in addressing climate change are particularly overlooked. Professors Mitsuru Osaki and Hidenori Takahashi at Hokkaido University, Japan, Professors Tsuyoshi Kato and Nobuyuki Tsuji, and researcher Niken Andika Putri, argue that the integrated function of forests is transdisciplinary, and that trees have many vital interrelated functions.

While frameworks do exist to evaluate natural capital, they generally fail to offer effective quantitative values for comparison with social and economic capital. As such, the natural world continues to be seen as less economically and politically important than other forms of infrastructure, such as the built environment. Osaki and colleagues address this issue by developing methods to calculate accurate equivalent monetary values for natural capital. For example, not just economic output based on logging, but the value stored within the forest owing to its varied functions: from timber production to soil conservation to landslide prevention to water storage.

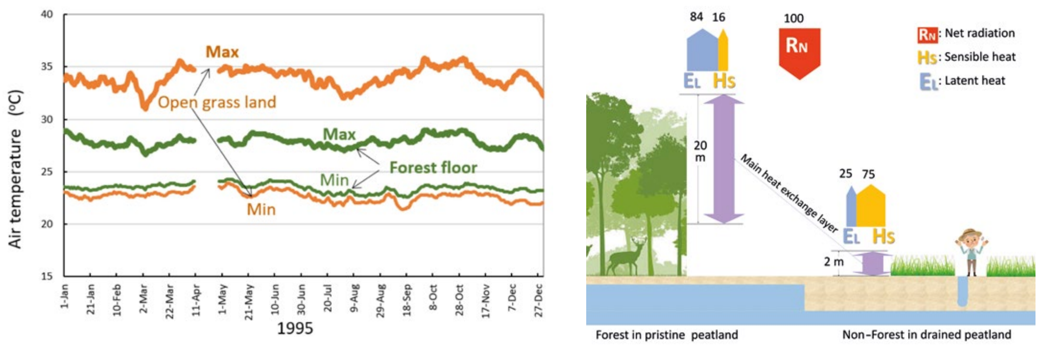

Figure 1. Heat balance in forest and non-forest. Left: Air temperature, Right: Relative intensity of net solar radiation, sensible heat, and latent heat.

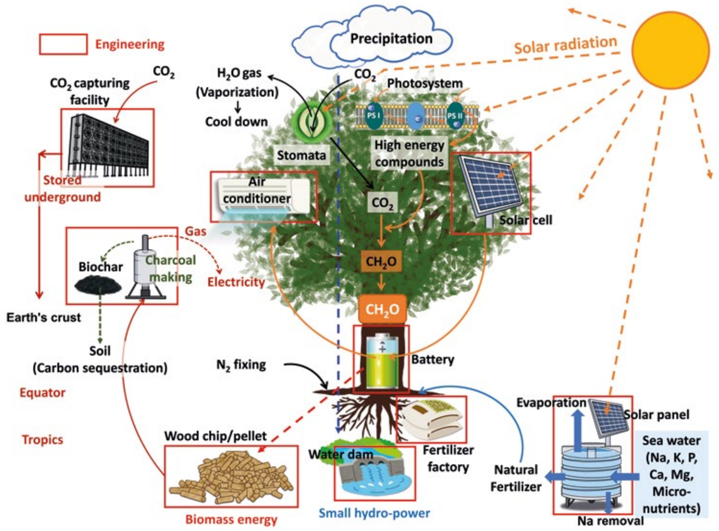

Figure 2. The multi-forest functions act as a bioapparatus.

Taking the mountainous village of Tudan (Sabah, Malaysia) as a case study, the researchers including Kazunobu Suzuki comprehensively monetised the town's natural resources, something that has never been done previously. The village lies in a buffer zone on the edge of a protected biosphere reserve, representing an area where human economic activity and environmental protection go side-by-side. With a population of just 315 (in 2014) and a total of 42 households, the estimated monetary value of the forest assets and agricultural capital of the village was a staggering 30 million US dollars. However, the study revealed the challenges of evaluating economic equivalents; some variables (such as biodiversity and the use of natural remedies) were not quantifiable owing to a lack of data.

Subsequently, Osaki and Tsuji performed natural capital accounting in Shimokawa (Hokkaido, Japan). Heavily forested, the town relies on economic output from forestry and agriculture. By further developing their method to include 19 variables related to agriculture and forests (including biodiversity protection) and assigning an economic value to each, Osaki showed that the town's natural capital value dwarfs its yearly gross production. Moreover, annual tree growth exceeds the annual tree harvest, so that the town is carbon negative (acting as a sink for 107,249 t-CO_2 per year).

Despite these successes, more methodological developments are needed. For example, challenges remain in quantifying biodiversity loss after an ecosystem is removed, and in evaluating the role of water-based ecosystems. With support from the JICA-JST SATREPS project, Osaki and colleagues, including Silsigia Sisva, address these issues via the development of transdisciplinary forest science.

BASIC FOREST FUNCTIONS

Forest (plants) have photosynthetic ability:

$CO_2 + H_2O \rightarrow CH_2O^* + O_2$ by Sun radiation energy (hv), where CH_2O^* is carbohydrate ($C_6H_{12}O_6$).

In the process of photosynthesis, water emitted from leaves (evapotranspiration) contributes to the water cycle and cools air by latent heat removal. The most basic functions of forests include energy fixation (from the Sun), CO_2 fixation (from the air), as well as water cycle, cooling, and green spectrum reflection (reduction of solar energy). We can therefore say that forests are a bioapparatus that store energy (a 'biotic-battery'), remove CO_2 from air (biotic-CO_2 capture and storage), contribute to the water cycle (biotic water-pump), cool air temperature (biotic air conditioner), and reduce solar energy (biotic spectrum reflector). Thus, forests have mulch-functions, simply via their leaves through photosynthesis.

MULTI-FOREST FUNCTIONS

The very high natural capital value of forests reflects their pivotal role in the flows of carbon, water, and nutrients (Figure 2). Osaki and colleagues suggest that trees offer a critical bioapparatus to mitigate and adapt to changing climate. They argue that the functions of common industrial technological solutions – solar panels, batteries, air conditioners, carbon sequestration, fertilizers, dams – can all be performed by trees in a way that achieves long-term sustainability.

This approach, known as the TREE model, highlights the role of the tree canopy in converting solar energy to energy stored in woody biomass (via photosynthesis), which can be used for subsequent production of electricity. In this way, trees are a renewable energy source, acting as solar panels and batteries, but without the need for the resource-intensive materials (eg, toxic rare metals), regular maintenance, and replacement costs associated with their man-made counterparts. As air conditioners, trees provide shade and cool the surrounding area via evapotranspiration (by absorbing latent heat and adding moisture to the air). Trees offer efficient carbon sequestration and provide a natural fertilizer function to soils (eg, through nitrogen fixation). Moreover, they can replace dams by storing water resources, moderating rainwater runoff to rivers, tapping into groundwater, and improving water quality.

It goes without question that forests have many functions. However, the functions of forests are also transdisciplinary: they assimilate thin CO_2 from the atmosphere using thin Sun energy; and via photosynthesis, can cool the air temperature (with water cycling) through evapotranspiration. In contrast, solar panels have only a single function: electric generation.

The natural world continues to be seen as less economically and politically important than other forms of infrastructure.

TRANSDISCIPLINARY FOREST SCIENCE

The widespread adoption of NbS both requires and will facilitate the development of transdisciplinary forest science. Both forest and water resources are critical components in Earth's climate. They are mostly studied as separate entities; however, 40% of precipitation comes from land-based

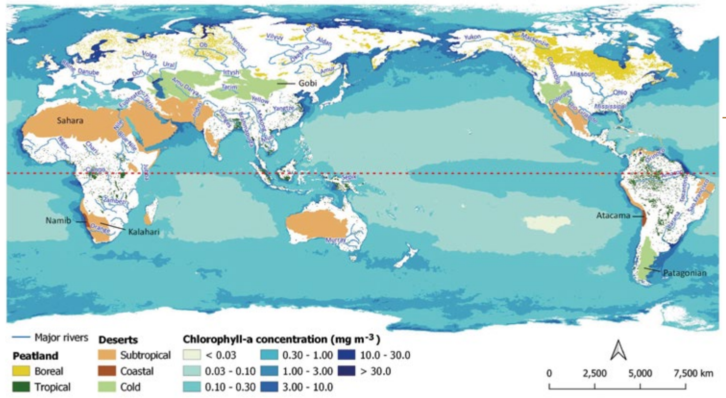

Figure 3. Map of mean monthly chlorophyll-a concentration overlay with global major rivers, deserts, and peatland.

evaporation, much of that from forest evapotranspiration. Currently, isolated examples of transdisciplinary forest science approaches are readily available.

For example, Osaki and colleagues highlight the concept of 'flying rivers'. Via the so-called biotic pump, evapotranspiration from forests maintains low atmospheric pressure on land, causing the suction of moist air from oceans to the land. When forests are sufficiently extensive, stable hydrological cycles protect land areas from climate-based disasters, such as floods, droughts, and hurricanes. A single tree can transfer hundreds of litres of water into the atmosphere a day. In the Amazon, more than half of all rainfall originates from forest transpiration. These mechanisms operate over continental scales. Trans-Siberian flying rivers cross Europe and Asia and supply 80% of China's water resources, while most rainfall in the Congo basin comprises water evaporated over East Africa. Of 29 global megacities, 19 get more than a third of their water supply from land-based evaporation, mostly from transpiration. In this way, land-use change and deforestation in Europe could have devastating long-term consequences for Shanghai. Deforestation is widely recognised as contributing to rising atmospheric CO_2; however, as demonstrated by the biotic pump, the implications of forest loss are incredibly complex and more far-reaching than generally acknowledged.

The ecological link between forests and biodiversity is another transdisciplinary area of study. Rising in Siberia and Mongolia, the Amur River flows east, tracing the border between Russia and China. More than 4,400 km long, the river drains an area of more than 2.1 million km^2, much of it forested. The Amur-Okhotsk Project, led by Hokkaido University researchers, shows that the river is a critical conduit for transportation of dissolved iron chelates with humic compounds originating from natural peatlands and wetlands in the middle and lower reaches. This iron flows into the Sea of Okhotsk, where it is critical for primary marine production. The river basin can be considered as a 'giant-fish breeding forest', a new environmental concept that links upstream forests with coastal ecosystems. Land-use change along the river course has accelerated in recent decades, and while no appreciable changes in dissolved iron chelates have been identified in the main channel to date, numerical simulations suggests that future changes in land use (eg, peatland and wetland reclamation and deforestation) could reduce the dissolved iron chelates supply to the oceans, with potentially significant consequences for fish stocks.

There is a secret web of natural interconnections, invisible to the naked eye.

The link between inland forests and coastal ecosystems was also demonstrated in a study of 22 major Japanese estuaries. Among global ecosystems, estuaries are one of those most vulnerable to the impacts of climate change; moreover, localised activities also pose a huge threat, with 31% of the global population living within 100km of a coastline. DNA analysis shows that the greater the forest cover, the greater the species richness. This link could reflect a number of factors, including the positive role of forests in supplying bioavailable iron to support estuarine and coastal primary production and also protecting against flooding and erosion that disrupts aquatic ecosystems via elevated sediment and pollutant runoff into the watercourse. In short, the study clearly highlights the importance of effective and wise forest management in the stewardship of aquatic biodiversity, including endangered fish species.

BLUE CARBON

The oceans represent our largest carbon sink, with phytoplankton primary production accounting for around half of global CO_2 fixation. During photosynthesis, phytoplankton take up CO_2 from surface waters; when they die, their carbon-rich bodies settle in the deep ocean. Despite its importance, few studies have considered the role of forests and land function in the global distribution of this process. By harnessing satellite-derived ocean colour data and distribution of chlorophyll-a (the pigment that makes plants green) on a monthly scale, Osaki and colleagues have used chlorophyll-a concentrations as a proxy for phytoplankton abundance and biomass in coastal waters. They found that high concentrations are found in waters near major river mouths (eg, the Amazon, Yangtze, Mississippi–Missouri, Yukon, Brahmaputra), deserts (eg, Sahara, Kalahari, Atacama). This effect is more pronounced in the Atlantic than in the Pacific, and shorelines connected to peatland or wetland (Figure 3). This reveals the critical role of forests and land in mediating nutrient supply to oceans, and in turn the sequestration of CO_2.

PROTECTING NATURAL INTERCONNECTIONS FOR THE FUTURE

Courtesy of technological innovation, we increasingly live in an interconnected world; few corners of the planet are not connected via internet and telephone cables, mobile phone signals, or satellite communications. However, alongside there is a secret web of natural interconnections, invisible to the naked eye. These environmental cables and wires maintain our complex climate system, not least the carbon–water balance upon which natural capital, and by extension human survival, rely. With forests at its centre, the transdisciplinary science of forests is vital for seeking out and exposing these connections, allowing us to protect them for generations to come. Osaki and colleagues argue that this approach needs to enter the mainstream. Given the unprecedented threat posed by climate change to our planet and to our way of life, maximising our arsenal of tools to fight back offers the best chance of success.

Behind the Research





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Research Objectives

Through the development of transdisciplinary forest science, the researchers develop methods to evaluate natural capital, which contribute to forest eco-management systems, to help preserve, restore, and protect these environments with NbS in mind.

Detail

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Bio

Mitsuru Osaki was professor at the Research Faculty of Agriculture and the Graduate School of Agriculture, Hokkaido University, 2006–2017. Currently, he is Professor Emeritus at Hokkaido University, and President of the Japan Peatland Society. He trained as a plant physiologist and soil scientist and obtained his doctorate degree from the Faculty of Agriculture, Hokkaido University in 1981.

Hidenori Takahashi was born in Hokkaido, Japan in 1940. He received BAgr from Hokkaido University in 1965, and DrAgr in 1973. From 1965–2004, he was a researcher/lecuturer, Faculty of Agriculture and Graduate School of Environmental Earth Science, Hokkaido University. He is currently Director of NPO Hokkaido Institute of Hydro-climate, established in 2006 in Sapporo, Japan. His expertise is climatology and biosphere hydrology.

Tsuyoshi Kato is Deputy Divisional Manager, Environment and Resource Division, Sumitomo Forestry Co Ltd, Japan. He studied forest ecology at Kyoto University, conducting a five-year field research project to understand the recovery process of a tropical forest after commercial logging, in Jambi district of Sumatra, Indonesia. From 2010–2022 he managed two forest plantations on peatlands, and conducts field studies in W Kalimantan, Indonesia.

Nobuyuki Tsuji graduated from Saga University, Japan, where he then worked before moving to Sasebo College of Technology, Japan, National Institute of Environment Studies, Tsukuba, and Center for Sustainability Science, Hokkaido University. In 2016, he moved to the Institute of Tropical Biology and Conservation, and Small Island Research Centre, University Malaysia Sabah, Sabah, Malaysia. He obtained his doctorate degree from Kyusyu University, Japan in 1990.

Niken Andika Putri graduated from the Department of Forest Management, IPB University, Indonesia, where she then worked in PT Mayangkara Tanaman Industri/PT Wana Subur Lestari, Indonesia. She obtained her MSc from Shizuoka University, Japan, in 2018. In 2022, she moved to Sumitomo Forestry Co Ltd, Japan.

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Collaborators Miss Silsigia Sisva, PT. Wana Subur Lestari, Indonesia and Dr Kazunobu Suzuki, Collage of International Relations, Nihon University, Japan.

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Personal Response

What steps need to be taken to get organisations such as the UN to officially encourage the use of NbS?

" NbS is still misunderstood because some Global North countries include industrial technology (such as solar panel and wind power) into NbS. We believe that including industrial renewable energy technology confuses the concept of NbS. It is preferable to separate NbS into nature management and industrial technology.

Forest function is also misunderstood. Forest (plants) are just one CO_2-concentration bioapparatus, and not merely an energy sink for the Sun's energy. Individual tree planting is important, however, forests as a whole have many functions and are interconnected with other ecosystems. It's therefore important that we develop a more effective and human-friendly forest system; or 'foresting' (that is, cultivate the mulch-functional forest system), rather than plant individual trees. Forests have important carbon negative potential. If a forest is enclosed, conserved, and protected, it can be carbon neutral. Wise use and management of forests are critical for stabilising the global ecosystem.

The Global North's strategies for climate change are largely focused on industrial technology. The Global North should respect the NbS proposed by the Global South. "

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