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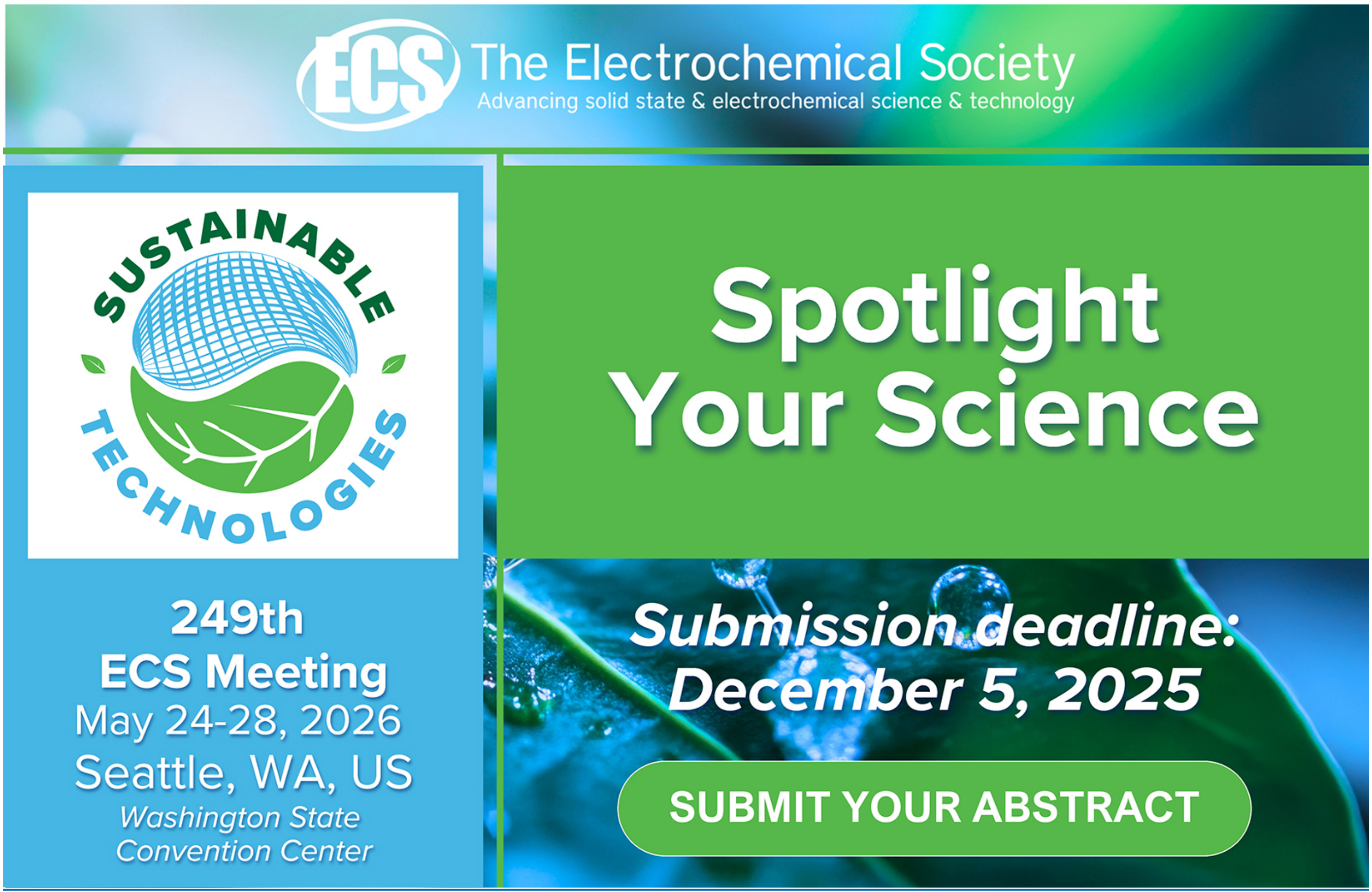

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EDITORIAL

Advancing nature-based solutions toward sustainability

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1. Introduction

As global warming and environmental challenges escalate, nature-based solutions (NbSs) have emerged as a critical strategy to combat climate change, biodiversity loss, and ecosystem degradation while also providing co-benefits to human well-being and economic resilience (Seddon 2022). These solutions influence key earth system processes, such as carbon, water, and energy cycles, while in turn, their effectiveness is shaped by complex interactions among climate change, societal dynamics, and technological progress (Griscom *et al* 2017). Although NbS hold great promise, especially through practices like conservation, restoration, and sustainable land management, their implementation must be context-specific and guided by principles that ensure social equity, biodiversity protection, and alignment with urgent climate targets (Seddon *et al* 2021).

This special issue of *Environmental Research Letters*, titled 'Focus on NbSs Toward Sustainability', presents 28 studies contributing to the growing body of research on NbS. These papers span diverse geographical regions, from global assessments to specific areas such as China, South Africa, U.S., and Europe, and cover diverse ecosystems, including agricultural lands, forests, grasslands, coastal wetlands, and urban areas (figure 1). They offer valuable insights into ecosystem-based climate mitigation, terrestrial ecosystem resilience, blue-green infrastructure (BGI), and the socio-ecological aspects of sustainable land management. This editorial classifies these contributions into four key perspectives and synthesizes their findings to highlight pathways for implementing NbS at multiple scales.

2. NbSs for climate change mitigation and adaptation

Forests are widely regarded as one of the most effective NbS for carbon sequestration and climate resilience. Wu *et al* (2024) evaluate the combined global warming impacts of carbon dioxide, methane, and albedo in an island forest nature reserve, illustrating how these biophysical factors interact to sustain forests as net carbon sinks. Similarly, Ampah *et al* (2024) assess the potential of land-based carbon removal strategies in Africa, including afforestation/reforestation (AR), bioenergy with carbon capture and storage (BECCS), and biochar, to achieve net-zero emissions by 2050. Their findings indicate that while AR alone can sequester substantial amounts of carbon, integrating it with BECCS and biochar provides a more balanced approach, reducing trade-offs related to food security and land use.

However, afforestation-based carbon sequestration should be implemented with caution due to potential trade-offs. Zhao *et al* (2024) evaluate the impact of afforestation on the regional carbon sink in the Yangtze River Delta, demonstrating that while

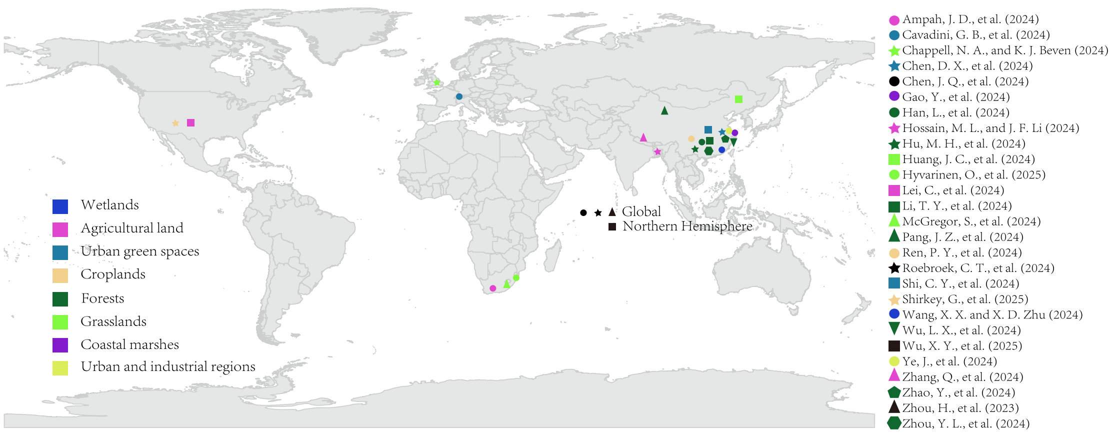

Figure 1. Research domain and land cover types featured in the studies of this special issue on NbS. One study not shown focused on the oceanic carbon sink (Chen *et al* 2024c).

forest expansion enhances carbon storage, associated land use changes (e.g., the reduction of shrubland) can partially offset its benefits. Furthermore, Roebroek *et al* (2024) caution against over-reliance on forest carbon sinks, emphasizing the uncertainties in carbon storage potential under future climate scenarios. They argue that while forests play a crucial role in climate mitigation, their capacity to act as carbon sinks may be nearing its peak, necessitating additional decarbonization efforts.

Moreover, the value of other ecosystems, such as grasslands, savannas, and agricultural systems, for NbS may be severely underestimated. Unlike forests, grasslands and croplands provide a distinct mitigation pathway by enhancing surface reflectivity through their high albedo. Chen *et al* (2024b) emphasize the underappreciated role of albedo in terrestrial ecosystems, demonstrating how surface reflectivity influences radiative forcing and contributes to climate mitigation. Their study underscores the necessity of integrating albedo effects into land management decisions to maximize cooling benefits. Building on this perspective, Lei *et al* (2024) and McGregor *et al* (2024) explore albedo dynamics in agricultural systems and grassland ecosystems, respectively, illustrating how crop selection, land-use strategies, and vegetation management influence localized cooling effects. Similarly, Hyvarinen *et al* (2025) investigate the cascading effects of megagrazer loss in savannas on albedo and carbon dynamics, emphasizing the role of large herbivores in modulating ecosystem-climate feedbacks and the importance of biodiversity conservation as a key NbS.

3. Terrestrial ecosystems and carbon dynamics

Terrestrial ecosystems play a vital role in carbon sequestration, water supply, wildlife habitats, and other ecosystem services, but their efficiency is influenced by environmental factors such as land cover changes, climate variability, and biogeochemical responses to anthropogenic disturbances. For example, Chen *et al* (2024a) analyze the combined effects of urbanization and climate variability on carbon and water balances in a rice paddy-dominated basin in China. Their findings emphasize that the expansion of impervious surfaces is the primary factor driving reductions in evapotranspiration and gross primary productivity (GPP), thereby elevating storm runoff and exacerbating degradations of watershed ecosystem health in an urbanizing environment.

Extreme climate events have profound impacts on the terrestrial carbon cycle. Li *et al* (2024) document the widespread reduction in GPP caused by the 2022 heat and drought event in the Yangtze River Basin. However, Han *et al* (2024) show divergent responses of subtropical evergreen and deciduous forest carbon cycles to the same drought event, revealing that while evergreen forests exhibited resilience with increased net ecosystem productivity, deciduous forests experienced a delayed and more substantial decline, emphasizing the role of vegetation types in ecosystem adaptation to climate extremes. Wu *et al* (2025) explore the declining resilience of forest carbon sinks in the Northern Hemisphere, linking increased atmospheric water deficit to reduced ecosystem recovery from droughts.

The interplay between solar radiation, diffuse light, and ecosystem productivity is a critical yet overlooked factor in carbon dynamics. Zhou *et al* (2023) provide a global perspective on climatic drivers of GPP variability using FLUXNET data, identifying diffuse radiation as a key factor at sub-daily timescales, while air temperature dominates longer-term trends. Huang *et al* (2024) reveal how diffuse radiation enhances grassland carbon and water use efficiency, a finding with implications for ecosystem responses to changes in atmospheric aerosols and cloud cover. Zhou *et al* (2024) further explore the weakening effect of solar radiation variability on GPP gains from vegetation restoration in China's forestry engineering areas, emphasizing the need to account for climate factors in NbS planning.

The role of soil microbial processes in ecosystem recovery is highlighted by Hu *et al* (2024), who find that forest restoration in degraded tropical lands gradually alleviates microbial carbon limitation but intensifies phosphorus limitation, underscoring the need for nutrient management strategies in reforested landscapes. Gao *et al* (2024) examine carbon and nitrogen fluxes in a Yangtze coastal marsh, demonstrating how reciprocal lateral nutrient flows influence meta-ecosystem connectivity and resilience.

4. Watershed management and urban resilience

Urban watershed environments are increasingly threatened by climate change and over population, necessitating innovative and effective ecosystem management strategies that must consider the ecosystem tradeoffs of NbS measures. Chappell and Beven (2024) propose key design criteria for nature-based flood mitigation solutions, emphasizing the importance of understanding hydrological processes and their interactions with landscape features to enhance flood resilience. In agricultural landscapes, Wang and Zhu (2024) explore how salinity stress and atmospheric dryness co-limit evapotranspiration in subtropical mangroves, with implications for future wetland management under climate change. Hossain and Li (2024) assess adaptive strategies for salinization-affected coastal agriculture in Bangladesh, highlighting the effectiveness of rainwater harvesting and vermicomposting in mitigating soil and water degradation.

BGI and other NbS are being deployed to enhance urban resilience to extreme weather events and improve water quality. Cavadini *et al* (2024) examine the potential of BGI in mitigating combined sewer overflows (CSOs) in Swiss urban catchments under future climate scenarios. They find that integrating bioretention cells and porous pavements can effectively reduce CSO frequency and volume, though cost-effectiveness remains a challenge. Shi *et al* (2024) propose an ecological compensation framework for China's sponge cities, addressing financial sustainability and governance barriers to urban NbS implementation.

5. Socio-ecological interactions and sustainable land management

Effective implementation of NbS requires an integrated understanding of ecological, social, and economic dimensions. Several studies in this issue highlight the complex interactions between human activities, land use changes, and ecosystem services. Ren *et al* (2024) highlight the increasing harvested carbon in China's croplands, demonstrating the substantial role of agricultural productivity in the national carbon budget. Their findings emphasize the need to integrate cropland carbon management into broader sustainability strategies to enhance food security while maintaining ecological balance.

Zhang *et al* (2024) investigate cropland abandonment as an unintended consequence of wildlife conservation policies in China and Nepal, showing that crop-raiding by wildlife increases the likelihood of land abandonment, with implications for food security and rural livelihoods. Shirkey *et al* (2025) advocate for geospatialized life cycle assessments and fine-scale socio-ecological data integration to optimize NbS implementation in agroecosystems, demonstrating how different management intensities influence greenhouse gas emissions.

Pang *et al* (2024) focus on forest water use efficiency in China's Three-North Shelterbelt Program, identifying soil moisture and stand characteristics as key regulators of forest carbon-water trade-offs. Their findings provide crucial guidance for optimizing afforestation strategies in arid and semi-arid regions. Ye *et al* (2024) analyze shifting pollutant transport patterns in East China, revealing how atmospheric circulation changes influence air quality and carbon fluxes, with implications for NbS in urban planning.

6. Conclusion

The studies featured in this special issue highlight the diverse potential of NbS to address climate change, water resilience, and biodiversity conservation while delivering socio-economic co-benefits. However, their effective implementation requires an in-depth understanding of ecosystem processes, land-use trade-offs, and governance mechanisms. Ecosystem monitoring and remote sensing techniques, including albedo measurements and eddy covariance flux data, play a crucial role in understanding ecosystem processes, such as the cooling potential of agricultural systems (Lei *et al* 2024) and the impact of climate stresses on mangrove wetlands (Wang and Zhu 2024). Modeling approaches are widely used to assess carbon sequestration and emission reduction strategies, such as integrated assessment models for carbon removal solutions in Africa (Ampah *et al* 2024) and high-resolution vegetation models to study carbon dynamics in China (Zhao *et al* 2024). Life cycle assessments and socio-ecological data integration are also used to evaluate the broader impacts of land management practices, as demonstrated by Shirkey *et al* (2025) in assessing global warming potential in agroecosystems. Future research should focus on integrating NbS across various spatial and temporal scales, taking advantage of technological advancements in remote sensing and machine learning to improve decision-making. By advancing interdisciplinary collaboration and policy engagement, the global community can harness the full potential of NbS to build a more resilient and sustainable future.

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References

Ampah J D, Afrane S, Adun H, Dioha M O, Agyekum E B, Yusuf A A, Naseer M and Bamisile O 2024 Carbon dioxide removal and net zero emissions in Africa: an integrated assessment modelling based on three different land-based negative emission solutions *Environ. Res. Lett.* **19** 084021

Cavadini G B, Rodriguez M, Nguyen T and Cook L M 2024 Can blue-green infrastructure counteract the effects of climate change on combined sewer overflows? Study of a swiss catchment *Environ. Res. Lett.* **19** 094025

Chappell N A and Beven K J 2024 Nature-based solutions for effective flood mitigation: potential design criteria *Environ. Res. Lett.* **19** 074006

Chen D X, Liu N, Gan G J, Liu Y B, Qin M S, Zheng Q Z, Sun G and Hao L 2024a Combined effects of urbanization and climate variability on water and carbon balances in a rice paddy-dominated basin in southern China *Environ. Res. Lett.* **19** 124042

Chen J Q, Lei C Y, Chu H S, Li X L, Torn M, Wang Y P, Sciusco P and Robertson G P 2024b Overlooked cooling effects of albedo in terrestrial ecosystems *Environ. Res. Lett.* **19** 093001

Chen T Y, Chen J J and Chou W C 2024c Rethinking blue carbon: unlocking invisible carbon sinks *Environ. Res. Lett.* **19** 101001

Gao Y *et al* 2024 Rooting meta-ecosystems with reciprocal lateral carbon and nitrogen flows in a Yangtze coastal marsh *Environ. Res. Lett.* **19** 104056

Griscom B W *et al* 2017 Natural climate solutions *Proc. Natl Acad. Sci. USA* **114** 11645–50

Han L, Chen Y N, Wang Y, Sun Y, Ding Z, Zhang H S and Tang X G 2024 Divergent responses of subtropical evergreen and deciduous forest carbon cycles to the summer 2022 drought *Environ. Res. Lett.* **19** 054043

Hossain M L and Li J F 2024 Salinity challenges and adaptive strategies in salinization-affected coastal Bangladesh: implications for agricultural sustainability and water resource management *Environ. Res. Lett.* **19** 114048

Hu M H, Zhu Y R, Li J L, Yao X Y, Hu Y L, Huang X L, Li Y H, Zhang D Q and Deng Q 2024 Changes in soil microbial metabolic limitations after half-century forest restoration in degraded tropical lands *Environ. Res. Lett.* **19** 074060

Huang J C, Yue X, Wang B, Lu X F and Dong G 2024 Impact of diffuse radiation on the coupling of carbon and water fluxes in the grassland of northeastern China *Environ. Res. Lett.* **19** 084020

Hyvarinen O, te Beest M, le Roux E, Kerley G I H, Buitenwerf R, Druce D J, Chen J, Rapp L, Fernandes J and Cromsigt J P G M 2025 Megagrazer loss drives complex landscape-scale biophysical cascades *Environ. Res. Lett.* **20** 024028

Lei C, Chen J Q, Ibanez I, Sciusco P, Shirkey G, Lei M, Reich P and Robertson G P 2024 Albedo of crops as a nature-based climate solution to global warming *Environ. Res. Lett.* **19** 084032

Li T Y *et al* 2024 Widespread reduction in gross primary productivity caused by the compound heat and drought in Yangtze River Basin in 2022 *Environ. Res. Lett.* **19** 034048

McGregor S, Jpgm C, te Beest M, Chen J, Roy D P, Hawkins H J and Kerley G I H 2024 Grassland albedo as a nature-based climate prospect: the role of growth form and grazing *Environ. Res. Lett.* **19** 124004

Pang J Z, Xu H, Zhang Q, Zhang Y F and Zhang Z Q 2024 Stand characteristics regulate forest water use efficiency in the Three-North Shelterbelt Forest Program region of China *Environ. Res. Lett.* **19** 114028

Ren P Y, Wang D J, Xia X S, Chen X Z, Qin Z C, Wei J, Liu S G, O'Sullivan M and Yuan W P 2024 Increased harvested carbon of cropland in China *Environ. Res. Lett.* **19** 054036

Roebroek C T, Caporaso L, Alkama R, Duveiller G, Davin E L, Seneviratne S I and Cescatti A 2024 Climate policies for carbon neutrality should not rely on the uncertain increase of carbon stocks in existing forests *Environ. Res. Lett.* **19** 044050

Seddon N 2022 Harnessing the potential of nature-based solutions for mitigating and adapting to climate change *Science* **376** 1410–6

Seddon N, Smith A, Smith P, Key I, Chausson A, Girardin C, House J, Srivastava S and Turner B 2021 Getting the message right on nature-based solutions to climate change *Glob. Change Biol.* **27** 1518–46

Shi C Y, Li Y, Li H J, Qiu H and Xu T Y 2024 Towards sustainable urban water management: an ecological compensation framework for sponge cities *Environ. Res. Lett.* **19** 123002

Shirkey G, Anctil A, John R, Kolluru V, Mungai L, Kashongwe H, Cooper L T, Celik I, Fisher J B and Chen J 2025 Identifying opportunities for nature-based solutions with geospatialized life cycle assessments and fine-scale socioecological data *Environ. Res. Lett.* **20** 014023

Wang X X and Zhu X D 2024 Salinity stress and atmospheric dryness co-limit evapotranspiration in a subtropical monsoonal estuarine mangrove wetland *Environ. Res. Lett.* **19** 114067

Wu L X *et al* 2024 Global warming impacts of carbon dioxide, methane, and albedo in an island forest nature reserve *Environ. Res. Lett.* **19** 114085

Wu X Y, Xu H, Pang J Z and Zhang Z Q 2025 Declining resilience of forest carbon sinks linked to increased atmospheric water deficit during droughts in the Northern Hemisphere *Environ. Res. Lett.* **20** 014055

Ye J *et al* 2024 Significant shift of footprint patterns and pollutant source contributions: insights from observations at Shanghuang observatory, East China *Environ. Res. Lett.* **19** 124026

Zhang Q, Hu J, Graybill S A, Moody A, Bista R, Bilsborrow R E and Song C H 2024 Crop-raiding by wildlife and cropland abandonment as feedback from nature-based solutions:

lessons from case studies in China and Nepal *Environ. Res. Lett.* **19** 124029
Zhao Y, Yue X, Zhou H, Yu Z and Yuan W P 2024 The effect of afforestation on a regional carbon sink: a case study in the Yangtze River Delta, China *Environ. Res. Lett.* **19** 104064
Zhou H, Yue X, Wang B, Tian C G, Lu X F, Zhu J and Cao Y 2023 Distinguishing the main climatic drivers to the variability of gross primary productivity at global FLUXNET sites *Environ. Res. Lett.* **18** 124007
Zhou Y L, Wei X N, Wang Y Y, He W, Dong Z T, Zhang X Y, Liu Y B, Nguyen N T and Ju W M 2024 Solar radiation variation weakened the boost of gross primary production by vegetation restoration in China's most forestry engineering areas during 2001–2020 *Environ. Res. Lett.* **19** 014082