Global Change Biology

WILEY

Global Change Biology

EDITORIAL

Ecological and Evolutionary Dynamics of Invasive Species Under Global Change

Aibin Zhan[1,2] | Dan Bock[3] | Elizabeta Briski[4] | Robert Colautti[5] | Juntao Hu[6] | Hugh MacIsaac[7]

[1]Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing, China | [2]University of Chinese Academy of Sciences, Chinese Academy of Sciences, Beijing, China | [3]School of Environment and Science, Griffith University, Nathan, Queensland, Australia | [4]GEOMAR Helmholtz Centre for Ocean Research Kiel, Kiel, Germany | [5]Department of Biology, Queen's University, Kingston, Ontario, Canada | [6]Ministry of Education Key Laboratory for Biodiversity Science and Ecological Engineering, Institute of Biodiversity Science, Center for Evolutionary Biology, School of Life Sciences, Fudan University, Shanghai, China | [7]Great Lakes Institute for Environmental Research, University of Windsor, Windsor, Ontario, Canada

Correspondence: Aibin Zhan (zhanaibin@hotmail.com; azhan@rcees.ac.cn)

Received: 19 September 2025 | **Revised:** 19 September 2025 | **Accepted:** 19 September 2025

The Anthropocene is characterized by accelerating changes in climate, land use, pollution, and global connectivity, largely reshaping ecosystems across spatial and temporal scales (Keys et al. 2019; Willcock et al. 2023). These rapid transformations frequently outpace the adaptive capacity of native species, contributing to widespread biodiversity loss and, possibly, to a 6th mass extinction (Barnosky et al. 2011; Hoffmann and Sgrò 2011). In contrast, invasive species often thrive in disturbed environments, thereby further exacerbating ecological disruptions across diverse ecosystems (Gu et al. 2023). As such, biological invasions have emerged not only as a consequence of global change but also as a significant driver of further environmental degradation (Sage 2020). Increasingly, evidence indicates that the interactions between biological invasions and other global change drivers are complex, nonlinear, and can often produce unexpected economic, ecological, or evolutionary outcomes (Ricciardi et al. 2021; Hu et al. 2025). For example, global change-induced environmental extremes can result in rapid evolution in invasive species, which can enhance the probability of invasion success and alter species interactions and ecosystem functioning (Moran and Alexander 2014; Borden and Flory 2021). Thus, there exists an urgent need to deepen our understanding of the complex ecological and evolutionary dynamics underlying interactions between biological invasions and global change, and, more importantly, to develop effective management solutions.

Over the past decade, research has advanced from treating invasions as isolated phenomena to examining how multiple global change drivers shape the entire invasion process, spanning transport, introduction, establishment, spread, and impact. Recent studies increasingly investigate invasions across multiple levels, ranging from individuals and populations to species and communities, while integrating ecological and evolutionary principles to elucidate the dynamics and mechanisms underlying invasion success (e.g., Chapple et al. 2022; Hu et al. 2025; Zarri et al. 2025). Moreover, the integration of big data and artificial intelligence allows the development of climate-smart, adaptive management strategies that provide insights from diverse disciplines, including multi-omics and socioeconomics (e.g., Tuia et al. 2022; Thorogood et al. 2023).

As a reflection of the growing scientific interest in this topic, this *Global Change Biology* Special Issue titled "The ecology and evolution of invasive species under global change" attracted more than 120 submissions. The 17 published papers present both empirical and conceptual advances, shedding light on how invasive species interact with multiple dimensions of global change across scales, ranging from molecular to ecosystem levels. These studies highlight the importance of viewing invasive species not only as threats to be managed, but also as natural experiments that provide valuable insights into how life responds to environmental disruptions.

Collectively, the 17 articles published in this Special Issue span diverse taxa and ecosystems, encompassing field studies, laboratory experiments, meta-analyses, and methodological innovations. These papers also thoroughly cover research frontiers and compelling questions in biological invasions under global change, including the ways global change drivers reshape invasion pathways and risks, management frameworks and decision tools for climate-smart biosecurity, functional traits and adaptive strategies underlying invasion success, extreme events and stressors tipping the balance of invasion outcomes, effects of invasions on ecosystem processes such as soil dynamics and carbon cycling, as well as how pathogens, dispersal networks, and socioecological linkages mediate the cascading impacts of biological invasions. Together, these papers provide integrative evidence that advances invasion science and informs conservation practice and policy under accelerating global change.

1 | Theme 1: Reshaped Invasion Pathways Under Global Change

Six studies (Biancolini et al. 2024; Cao Pinna et al. 2025; Deshpande et al. 2024; Marcolin et al. 2025; Rodrigues et al. 2024; Zhou et al. 2024) within this theme addressed a shared question: How does climate change determine where, when, and how invasions occur? These studies have moved from single-species, single-region forecasts to multispecies, multiscenario, and mechanistic appraisals of where and how invasions will spread under global change. Large-scale species distribution modelling (e.g., for 205 non-native mammals) identified new invasion hotspots when suitability was combined with dispersal constraints (Biancolini et al. 2024), while controlled experiments and scenario-based analyses revealed that invasion outcomes could change direction and magnitude depending on the climate scenario used (Rodrigues et al. 2024). Regionally focused, niche-dynamics studies showed frequent niche unfilling and expansion that were mediated by traits such as dispersal ability and trait variability (Cao Pinna et al. 2025). Simultaneously, empirical work documented how shifting animal movement patterns (e.g., bird migration changes) and socioeconomic urban gradients altered dispersal pathways and the provisioning of services that can facilitate spread (Deshpande et al. 2024; Marcolin et al. 2025). Finally, synthesis and mapping efforts highlighted that invasion-linked pathogen–vector systems can directly threaten major carbon sinks (Zhou et al. 2024). Together, these findings provide compelling cases for integrated invasion-risk assessments that explicitly combine climate projections, changing dispersal networks, species traits, and socioecological dynamics.

2 | Theme 2: Cutting-Edge Frameworks for Risk Assessment and Management

Four studies (Chen et al. 2024; Colberg et al. 2024; Dolan et al. 2025; Zhao et al. 2024) in this theme addressed the question: What conceptual and methodological tools allow managers and policymakers to anticipate future invasion threats and adapt interventions effectively under rapid global change? These studies approach invasion management not through static risk identification, but rather through actionable decision-support frameworks that explicitly incorporate climate uncertainty, pathways, and biological adaptation. Reviews and conceptual papers set out climate-smart principles and managerial priorities (Colberg et al. 2024), while mathematically explicit prioritization tools translate multidimensional risk (suitability × pathways × socioeconomics) into ranked actions for managers (Zhao et al. 2024). Other studies highlighted policy trade-offs; for example, Dolan et al. (2025) discussed how river-restoration via barrier removal may unintentionally accelerate aquatic invasions unless staged, monitored, and coupled with biosecurity measures. Importantly, integrating biological complexity, notably multi-omics measures of adaptive potential, improved the predictive accuracy of invasion-risk models and allowed managers to triage species or populations by predicted maladaptation (Chen et al. 2024). Overall, the field is converging on practical, evidence-based tools that can be embedded into policy and operational workflows under climate change.

3 | Theme 3: Functional Traits and Adaptive Capacity

Five studies (Chen et al. 2024; Fehlinger 2024; Mantoani et al. 2025; Nuhfer and Bradley 2025; Zhao et al. 2025) in this theme answered an interesting fundamental question: Which functional traits and adaptations determine invasion potential and guide species' responses to environmental change? Experimental comparisons and multifactor manipulations showed that invasiveness is not universally synonymous with stress tolerance and that invasive species can be more sensitive under compound, interacting stressors than native species (Zhao et al. 2025). Studies of extreme events have shown that invasion dynamics can be highly nonlinear and time-dependent, in ways that are not captured by models relying solely on long-term average climate conditions (Mantoani et al. 2025). Parallel syntheses on managed relocation and trait selection provided operational lists of high-risk traits (e.g., high reproductive output, long-distance dispersal) which can be used to balance assisted-migration decisions against invasion risk (Nuhfer and Bradley 2025). As well, a discussion of traits (e.g., ornamental appeal) and vectors/pathways (e.g., human-mediated release) highlighted sociocultural drivers that select for invasion-prone species, especially in urban and leisure contexts (Fehlinger 2024). Lastly, Chen et al. (2024) used an integrated genome–epigenome index framework to show that certain native populations of a widespread invasive species tracked environmental changes with minimal maladaptation. Thus, these populations may be particularly likely to seed new invasions under climate change (Chen et al. 2024). This finding calls for a management paradigm shift from reacting to established invaders to proactively monitoring and managing native-range populations that could become future invaders. Together, these papers contribute trait-informed toolkits for forecasting and mitigating invasion under both gradual and extreme environmental change.

4 | Theme 4: Responses to Stress and Extreme Events

Within this theme, three studies (Buttimer et al. 2025; Mantoani et al. 2025; Zhao et al. 2025) investigated how climate extremes and environmental stressors influence invasion performance, resilience, and ecological outcomes. These studies symmetrically revealed that climatic extremes and abiotic stressors could reconfigure invasion performance, sometimes in counterintuitive ways. Warming extremes often affect native and non-native species differently, with evidence that the former can sometimes display greater resistance to escalating stressors, complicating the expectation that warming universally favors invaders (Zhao et al. 2025). Conversely, extreme cold episodes create dynamic, transient windows that can either set back invaders or remove native competitors depending on timing and life history (Mantoani et al. 2025). Experimental drought work on amphibian–pathogen systems showed a striking trade-off; drought suppressed pathogen abundance, but increased transmission and disrupted hosts' protective skin microbiomes, counterintuitively amplifying disease risk despite lower pathogen load (Buttimer et al. 2025). These findings stress that extremes can alter not just establishment and spread, but also epidemiological dynamics and community resilience. Therefore, monitoring and management must explicitly account for extreme event contexts and non-linear responses.

5 | Theme 5: Feedback and Ecosystem Processes

Two complementary studies (Sun et al. 2025; He et al. 2025) in this theme investigated how invasions reshape ecological feedback and ecosystem functions. By linking invasion dynamics to belowground feedback and carbon-cycle consequences, these studies showed that invasions can generate self-reinforcing ecosystem change. Integrating eco-evolutionary dynamics and plant–soil feedback demonstrated how warming and biocontrol herbivory interact with soil community shifts to modify an invader's spread potential—feedback that can either accelerate or dampen expansion depending on microbial and herbivore responses (Sun et al. 2025). Combining meta-analysis and empirical work showed that plant invasions commonly elevate soil microbial biomass carbon, with implications for soil carbon storage, nutrient cycling, and long-term ecosystem function (He et al. 2025). Both studies illuminated mechanistic pathways through which invasions alter ecosystem processes and generate feedbacks that in turn reshape invasion trajectories and carbon budgets—a critical link for scaling local invasions to global biogeochemical consequences.

6 | Theme 6: Pathogens and Biosecurity Risks

Two papers (Buttimer et al. 2025; Zhou et al. 2024) in this theme explored the ways pathogens, vectors, and biosecurity risks interact with environmental change to amplify invasion impacts. Complex drought×disease interactions in amphibians can suppress pathogen prevalence while simultaneously increasing host susceptibility and transmission potential through microbiome disruption, complicating straightforward mitigation (Buttimer et al. 2025). In an invasive pathogen–vector system, climate-driven expansion of the vector and increased host vulnerability can shift productive forests from carbon sinks to carbon sources (Zhou et al. 2024). Both studies highlight that accurate invasion-risk assessment must explicitly account for host–pathogen–vector ecology and biosecurity pathways, as ignoring these interactions risks underestimating biodiversity loss and carbon-cycle consequences under changing climates.

7 | Future Remarks

In the rapidly changing Anthropocene, biological invasions are both drivers and consequences of global change, posing significant threats to ecosystems, economies, and human well-being. Emerging research highlights that invasions have been shaped by a complex interplay of multiple global change stressors and anthropogenic impacts, including climate change, land-use alteration, and global trade, which not only facilitate the spread of invasive species but also modulate the vulnerability of native communities (Early et al. 2016; Ortiz et al. 2023; Gallardo et al. 2024). Evidence increasingly shows that the causes and consequences of global change-driven invasions are far more complex than previously understood (Ortiz et al. 2023; Gallardo et al. 2024). Therefore, concurrent research on multiple stressors, with the integration of knowledge from multiple disciplines, is needed to improve predictions. Integrative research is a particularly powerful means to advance our understanding of invasion science and ecosystem resilience to invasions and other global change-driven impacts. Furthermore, advancing theoretical frameworks, such as multiscenario integrative models spanning from molecular to ecosystem levels, while incorporating ecology, evolution, and social sciences, offers comprehensive insights into invasion dynamics. Simultaneously, technical innovations, including environmental DNA/RNA (eDNA/eRNA) monitoring, remote sensing, and big data-driven artificial intelligence approaches, enable large-scale detection and tracking of invasions. Integrating these theoretical and technical approaches supports global, interdisciplinary strategies for scenario-based planning, proactive management, and informed development of policies to mitigate, anticipate, and manage biological invasions under global change.

Global change, including biological invasions, is a major driver of biodiversity loss and ecosystem transformation worldwide. This Special Issue addresses this urgent challenge by presenting research that advances understanding of invasion processes and their ecological consequences, while offering insights to support ecosystem protection, restoration, and adaptive management. As global change continues to reshape the biosphere, invasion science provides essential tools for predicting biodiversity responses, informing conservation strategies, and guiding sustainable management practices. We anticipate that this collection will stimulate further interdisciplinary and international collaboration, further fostering deeper integration of invasion biology and conservation science to address the pressing challenges of a rapidly changing world.

Author Contributions

Aibin Zhan: conceptualization, writing – review and editing, writing – original draft, project administration. **Dan Bock:** writing – original draft, writing – review and editing. **Elizabeta Briski:** writing – original draft, writing – review and editing. **Robert Colautti:** writing – original draft, writing – review and editing. **Juntao Hu:** writing – original draft, writing – review and editing. **Hugh MacIsaac:** writing – original draft, writing – review and editing.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

References

Barnosky, A. D., N. Matzke, S. Tomiya, et al. 2011. "Has the Earth's Sixth Mass Extinction Already Arrived?" *Nature* 471, no. 7336: 51–57.

Biancolini, D., M. Pacifici, M. Falaschi, et al. 2024. "Global Distribution of Alien Mammals Under Climate Change." *Global Change Biology* 30, no. 11: e17560.

Borden, J. B., and S. L. Flory. 2021. "Urban Evolution of Invasive Species." *Frontiers in Ecology and the Environment* 19, no. 3: 184–191.

Buttimer, S., D. Medina, R. A. Martins, et al. 2025. "Experimental Drought Suppresses Amphibian Pathogen Yet Intensifies Transmission and Disrupts Protective Skin Microbiome." *Global Change Biology* 31, no. 6: e70275.

Cao Pinna, L., L. Gallien, T. Jucker, et al. 2025. "Niche Dynamics of Alien Plant Species in Mediterranean Europe." *Global Change Biology* 31, no. 8: e70379.

Chapple, D. G., A. C. Naimo, J. A. Brand, et al. 2022. "Biological Invasions as a Selective Filter Driving Behavioral Divergence." *Nature Communications* 13, no. 1: 5996.

Chen, Y., Y. Gao, Z. Zhang, and A. Zhan. 2024. "Multi-Omics Inform Invasion Risks Under Global Climate Change." *Global Change Biology* 30, no. 11: e17588.

Colberg, E. M., B. A. Bradley, T. L. Morelli, and C. J. Brown-Lima. 2024. "Climate-Smart Invasive Species Management for 21st Century Global Change Challenges." *Global Change Biology* 30, no. 10: e17531.

Deshpande, P., N. Johansson, E. Kluen, A. Lehikoinen, and R. Thorogood. 2024. "Changing Bird Migration Patterns Have Potential to Enhance Dispersal of Alien Plants From Urban Centres." *Global Change Biology* 30, no. 11: e17572.

Dolan, E. J., I. Soto, J. T. Dick, F. He, and R. N. Cuthbert. 2025. "Riverine Barrier Removals Could Proliferate Biological Invasions." *Global Change Biology* 31, no. 3: e70093.

Early, R., B. A. Bradley, J. S. Dukes, et al. 2016. "Global Threats From Invasive Alien Species in the Twenty-First Century and National Response Capacities." *Nature Communications* 7, no. 1: 12485.

Fehlinger, L. 2024. "Beautiful Killers—The Goldfish Effect." *Global Change Biology* 30, no. 11: e17582.

Gallardo, B., S. Bacher, A. M. Barbosa, et al. 2024. "Risks Posed by Invasive Species to the Provision of Ecosystem Services in Europe." *Nature Communications* 15, no. 1: 2631.

Gu, S., T. Qi, J. R. Rohr, and X. Liu. 2023. "Meta-Analysis Reveals Less Sensitivity of Non-Native Animals Than Natives to Extreme Weather Worldwide." *Nature Ecology & Evolution* 7, no. 12: 2004–2027.

He, Y., J. Li, E. Siemann, B. Li, Y. Xu, and Y. Wang. 2025. "Plant Invasion Increases Soil Microbial Biomass Carbon: Meta-Analysis and Empirical Tests." *Global Change Biology* 31, no. 3: e70109.

Hoffmann, A. A., and C. M. Sgrò. 2011. "Climate Change and Evolutionary Adaptation." *Nature* 470, no. 7335: 479–485.

Hu, J., M. Barbier, G. Bunin, and J. Gore. 2025. "Collective Dynamical Regimes Predict Invasion Success and Impacts in Microbial Communities." *Nature Ecology & Evolution* 9, no. 3: 406–416.

Keys, P. W., V. Galaz, M. Dyer, et al. 2019. "Anthropocene Risk." *Nature Sustainability* 2, no. 8: 667–673.

Mantoani, M. C., C. Sweeney, and B. A. Osborne. 2025. "Complex and Dynamic Effects of an Extreme Low Temperature Weather Event on Invasive Plant Populations and Resident Communities." *Global Change Biology* 31, no. 3: e70113.

Marcolin, F., S. Mammola, R. Alba, P. Segurado, L. Reino, and D. Chamberlain. 2025. "Socio-Economic Status and Non-Native Species Drive Bird Ecosystem Service Provision in Urban Areas." *Global Change Biology* 31, no. 7: e70311.

Moran, E. V., and J. M. Alexander. 2014. "Evolutionary Responses to Global Change: Lessons From Invasive Species." *Ecology Letters* 17, no. 5: 637–649.

Nuhfer, T. W., and B. A. Bradley. 2025. "Balancing Risk and Resilience: Which Plant Traits Should Inform Managed Relocation Species Selection?" *Global Change Biology* 31, no. 3: e70145.

Ortiz, A. M. D., M. L. Jamero, S. J. Crespin, et al. 2023. "The Land and Sea Routes to 2030: A Call for Greater Attention on All Small Islands in Global Environmental Policy." *npj Biodiversity* 2, no. 1: 18.

Ricciardi, A., J. C. Iacarella, D. C. Aldridge, et al. 2021. "Four Priority Areas to Advance Invasion Science in the Face of Rapid Environmental Change." *Environmental Reviews* 29, no. 2: 119–141.

Rodrigues, T., P. Kratina, R. B. Setubal, et al. 2024. "Interaction Between Climate Change Scenarios and Biological Invasion Reveals Complex Cascading Effects in Freshwater Ecosystems." *Global Change Biology* 30, no. 10: e17540.

Sage, R. F. 2020. "Global Change Biology: A Primer." *Global Change Biology* 26, no. 1: 3–30.

Sun, Y., D. Silvestro, G. H. Mathes, M. G. van Der Heijden, and H. Müller-Schärer. 2025. "Eco-Evolutionary Dynamics of Plant–Soil Feedbacks Explain the Spread Potential of a Plant Invader Under Climate Warming and Biocontrol Herbivory." *Global Change Biology* 31, no. 3: e70110.

Thorogood, R., V. Mustonen, A. Aleixo, et al. 2023. "Understanding and Applying Biological Resilience, From Genes to Ecosystems." *npj Biodiversity* 2, no. 1: 16.

Tuia, D., B. Kellenberger, S. Beery, et al. 2022. "Perspectives in Machine Learning for Wildlife Conservation." *Nature Communications* 13, no. 1: 792.

Willcock, S., G. S. Cooper, J. Addy, and J. A. Dearing. 2023. "Earlier Collapse of Anthropocene Ecosystems Driven by Multiple Faster and Noisier Drivers." *Nature Sustainability* 6, no. 11: 1331–1342.

Zarri, L. J., C. E. Kraft, P. B. McIntyre, et al. 2025. "Eradication Efforts Catalyze Rapid Evolution in an Invasive Predatory Fish." *Proceedings of the National Academy of Sciences of the United States of America* 122, no. 24: e2424067122.

Zhao, H., X. Xian, N. Yang, et al. 2024. "A Proposed Coupling Framework of Biological Invasions: Quantifying the Management Prioritization in Mealybugs Invasion." *Global Change Biology* 30, no. 11: e17583.

Zhao, Y., Y. H. Xu, K. Guo, W. Y. Guo, and Y. J. Wang. 2025. "Native Plant Species Are More Resistant Than Invasive Aliens to Escalating Environmental Change Factors." *Global Change Biology* 31, no. 6: e70282.

Zhou, J., J. Du, L. Bonifácio, et al. 2024. "Vulnerability of Global Pine Forestry's Carbon Sink to an Invasive Pathogen–Vector System." *Global Change Biology* 30, no. 12: e17614.