Swiss Re Foundation

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EY Shape the future with confidence

EY as a service provider to Swiss Re

Modelling **biodiversity and ecosystem services** loss scenarios

Awarded projects

Biodiversity and ecosystem service responses to land use change across global systems

Universität Zürich

Agro-biodiversity scenarios for Europe, focus on interactions between biodiversity, land-use, climate change

VU Vrije Universiteit Amsterdam · UNIL | Université de Lausanne

First national-scale assessment of future land use change and impact on BES for Peru (NASCENT)

ETH zürich · Wyss Academy for Nature · Université Grenoble Alpes · UNIL | Université de Lausanne

Development of a decision support framework to manage natural catastrophe risks for the state of Rio de Janeiro

IIS Instituto Internacional para Sustentabilidade · International Institute for Sustainability

Climate Crossroads: Futures for People and Nature in Central Belize

University of Belize · ERI Environmental Research Institute · CATIE

Content

Summary

This brief provides a summary of the projects' findings on Modelling Biodiversity and Ecosystem Services (BES) Loss Scenarios, awarded by the Swiss Re Foundation, the AXA Research Fund (now part of the AXA Foundation for Human Progress), WWF, and EY[1]. Research groups were invited, in an open call for submission process, to develop approaches that contribute (i) to a better understanding of the consequences of BES loss on different spatial and temporal levels, also from a societal and economic impact and dependency point of view, and (ii) to support the formation of biodiversity-respecting pathways towards resilience and sustainability with scenarios practically usable by governments and other stakeholders.

This brief elaborates how land-use change, climate change, and social vulnerability influence biodiversity and ecosystem services (BES) and community resilience across global, regional, and local contexts. It highlights results starting from the global modelling of mountain, island, and delta ecosystems (by University of Zurich), to a continental view on agricultural landscapes across Europe (by VU Amsterdam), to case studies on future-oriented conservation planning for Peru (by ETH Zurich), the role of Nature-based Solutions (NbS) for climate adaptation for the state of Rio de Janeiro (by IIS Brazil), and forest and watershed ecosystems risk assessment and modelling for Belize (by UB-ERI Belize).

[1] As a service provider to Swiss Re Foundation

The results show that:

- Conservation and regional planning must become more forward looking, because global warming alters the conditions for, and needs of, current habitats. Tomorrow's important areas for biodiversity and ecosystem services may not be the same areas as today.
- Intense land-use changes or fragmentation of natural habitats – like expansion of agriculture or of urban areas, especially in tropical areas – often leads to a decline of biodiversity.
- Nature-based Solutions (NbS) – like wetland or forest restoration – can reduce risks from flood or coastal hazards, for example.
- Local communities face increasing climate risks. Community knowledge with scenario modelling can support water and land management.
- The projects have demonstrated that modelling of BES loss is possible through scenarios at local, regional or global level, but assessing their social and economic impacts remains challenging. Combining BES modelling with assessing social and economic dependencies and impacts remains a frontier interdisciplinary research area. It continues to require significant attention and funding.

The scenario modelling mainly focuses on land-use change and climate change as two of the main drivers for biodiversity loss and ecosystem services degradation:

- Sustainable land-use pathways can reduce land-use pressure, improve ecosystem services (ES) provision, and mitigate climate impacts (in principle, all five projects).[2]
- Scenarios which represent continued negative pressures on biodiversity and ecosystem services (eg continued fragmentation or sealing of areas important for conservation) amplify risks to ecosystems and vulnerable communities (Peru, state of Rio de Janeiro, Belize case studies).[3]
- The comprehensive processes that were conducted in the Peru, state of Rio de Janeiro, Belize case studies highlight that
  - Stakeholders adhering to robust NbS approaches are able to retrieve optimal benefits.
  - A more forward-looking planning approach can enable better adaptation to future changes.
  - Pressures can be reduced when NbS, community-led planning, and future-aware conservation strategies are integrated into long-term governance frameworks (Peru, state of Rio de Janeiro, Belize case studies, and European agricultural landscapes study).
  - Conservation and development planning will more successfully manage risk and achieve resilience by considering the future challenges due to land-use change and climate change.

2 SSP1-type 'Sustainability scenarios', Nature Futures scenarios
3 SSP3-type 'Regional rivalry' – Business As Usual

Policy recommendations

1. Integrate land-use and conservation planning into cross-sectoral planning processes by applying forward looking, inter-temporal approaches

- Build and apply science-based land-use and climate change scenarios to inform conservation strategies.
- Integrate the consequences of global warming into zoning or conservation planning.
- Align food and water security with biodiversity conservation and climate adaptation.

2. Strengthen environmental governance

- Improve land tenure and local stewardship rights.
- Enforce anti-deforestation and watershed protection laws.

3. Scale up Nature-based Solutions where impact is expected to be highest

- Prioritize areas with overlapping ecological value, high exposure to relevant hazards, and social vulnerabilities.
- Incorporate NbS into urban planning, flood management, and coastal protection frameworks.

4. Empower local communities and knowledge systems

- Institutionalize participatory scenario-building, especially in indigenous and rural communities, and empower them to participate in such processes.
- Support local monitoring systems for floods, fires, water quality and quantity, soil, and biodiversity.

Synthesis

Issue and background

Human activities are having a global impact on biodiversity, increasingly threatening biodiversity and ecosystem services (BES), posing risks to global economies and societies.[4] The 2050 vision for biodiversity of the Kunming-Montreal Global Biodiversity Framework aims to protect and restore BES, by recognizing the essential role of ecosystems in providing clean water, food security, climate regulation, disease protection, and cultural values. When assessing future resilience of BES, scenario modelling is critically important because it enables stakeholders to anticipate, evaluate, and respond to environmental changes with informed strategies.

Ecosystem services encompass provisional (eg clean water), regulating (eg local air quality, natural hazards, invasive species), as well as cultural services (eg inspiration and a sense of place). Biodiversity – the diversity of genes, species, communities and ecosystems and their interactions – underpins ecosystem services and supports the achievement of the Sustainability Development Goals (SDGs).[5] The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) has highlighted the threats to nature. For example, since the 1970s, 75% of land surface has been significantly altered, 66% of ocean area has been impacted, and 85% of wetlands area has been lost.[6]

Ecosystem services are instrumental for the functioning of societies and economy at the global, regional, national, and local levels. More than half of global GDP is moderately or highly dependent on them. At the regional and national economy levels, dependency on BES is influenced by the sectoral contributions to economic value creation and by cross-border supplier relations.[7] Also at the local level, dependency on BES may vary significantly.

Public and private sectors need a granular picture of that risk. Scenarios can provide such a picture by analyzing BES loss drivers.

Across the globe, land-use and climate change are among the five most important drivers (with pollution, direct exploitation and invasive species being the other three), resulting in:[8]

- Loss and change of habitat and species
- Declines in regulating ecosystem services (eg pollination, regulation of local air quality, flood control)
- Increased disaster risks, changing patterns (eg evaporation, precipitation)
- Reduced resilience of social and ecological systems

Climate change increases the risk of extreme weather events, shifts species distributions, alters rainfall regimes, and amplifies hazards such as floods and droughts. Vulnerable social groups experience the comparatively largest burden.

The five projects cover cases at the global, regional, and national respectively local levels. Their respective geographical scopes and scenarios used are summarized on page 9.

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5 Obrecht A, Pham-Truffert M, Spehn E et al (2021): Achieving the SDGs with Biodiversity. Swiss Academies Factsheet 16 (1). https://doi.org/10.5281/zenodo.4457298

6 IPBES (2019): Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. S. Díaz, J. Settele, E. S. Brondízio, H. T. Ngo, M. Guèze, J. Agard, A. Arneth, P. Balvanera, K. A. Brauman, S. H. M. Butchart, K. M. A. Chan, L. A. Garibaldi, K. Ichii, J. Liu, S. M. Subramanian, G. F. Midgley, P. Miloslavich, Z. Molnár, D. Obura, A. Pfaff, S. Polasky, A. Purvis, J. Razzaque, B. Reyers, R. Roy Chowdhury, Y. J. Shin, I. J. Visseren-Hamakers, K. J. Willis, and C. N. Zayas (eds.). IPBES secretariat, Bonn, Germany. https://doi.org/10.5281/zenodo.3553579

7 Swiss Re Institute 2020. Biodiversity and Ecosystem Services – a business case for Re/insurance. Retsa A, Schelske O, Wilke B, Rutherford G, de Jong R, Zurich. Apart from the global view, authors also show for ca. 90 countries they looked at that the BES-dependency of the national economy can vary by factor 10 (pages 33–34, 52–53).
WEF/PwC 2020: Nature Risk Rising. Published by the World Economic Forum in collaboration with PwC, Geneva, Cologny 2020; updated in PwC 2023: Managing nature risk: From understanding to action. Evison W, Low L P, O'Brien D.
European Commission 2025. The EU economy's dependency on nature. Hirschbuehl D, Neuville A, Petracco M, Sanchez A I, Ispra, 2025, JRC140304. Authors found that between 19% and 36% of the EU economy's gross value is highly dependent on ecosystem services.

8 See footnote 6.

Key overview of the five projects

Global land-use and climate change scenarios for mountains, islands and deltas

University of Zurich

Agro-biodiversity scenarios for Europe, focus on interactions between biodiversity, land-use, climate change

VU Amsterdam

First national-scale assessment of future land-use change and impact on BES for Peru

ETH Zurich

Development of a decision support framework to manage environmental disaster risks for the state of Rio de Janeiro

IIS Brazil

Participatory visioning and climate and land-use scenarios for community resilience and landscape planning

UB-ERI, Belize

Key overview of the five projects

Title	Global land-use and climate change scenarios for mountains, islands and deltas	Agro-biodiversity scenarios for Europe, focus on interactions between biodiversity, land-use, climate change	First national-scale assessment of future land-use change and impact on BES for Peru	Development of a decision support framework to manage environmental disaster risks for the state of Rio de Janeiro	Climate Crossroads: Futures for People and Nature in Central Belize
Lead institution	**University of Zurich**	**VU Amsterdam**	**ETH Zurich**	**IIS Brazil**	**UB-ERI, Belize**
Geographic scope	Global, subset into biomes and mountain, island and delta systems	Europe-wide	National (Peru)	State-level (Rio de Janeiro, Brazil)	Central Belize (Sibun River & Belize River watersheds)
Primary objective	Identify consistent BES-land-use relationships	Model land-use & biodiversity futures under SSP1 vs SSP3	Co-develop nature-positive futures & assess BES impacts	Identify NbS priority areas for disaster risk reduction	Understand community risks and model water yield under scenarios
Main methods	Statistical modelling of BES vs LUH2 land-use data	CLUMondo land-system modelling & species distribution models (SDMs)	Participatory scenario creation & LULUCC modelling & ES & SDMs	Scenario modelling, InVEST® ES modelling & social vulnerability analysis	Participatory risk mapping & InVEST® SWY
Scenarios used[9]	SSP1, SSP2, SSP3, SSP5	SSP1-RCP2.6 & SSP3-RCP7	Nature for Nature, Nature for Society, Nature as Culture, BAU	SSP1, SSP2, SSP3	SSP5-RCP8.5
Main pressures	Agricultural & urban land-use change	Climate change & land-use change	Climate change & demographic change & land-use	Urban sprawl & land-use change & climate extremes	Climate change, land-use change & hydrology
Inclusion of social dimensions	Partially, via land-use and choices made	Partially, via land-use	Stakeholder participation	Fully integrated	Community-driven
Key findings	Declines for biodiversity and regulating ES; but provisioning ES rise with agriculture	Sustainable futures reduce land-use intensity; SSP3 intensifies agriculture & causes biodiversity loss	Nature-positive futures vary in trade-offs; BAU leads to most biodiversity/ES decline	Flood, heat & coastal protection improve substantially under optimistic scenario; worsen under pessimistic	Flooding and drought most damaging; land-use & climate jointly determine runoff & infiltration
Inputs for policy	Global hotspots for land-use policy, agricultural planning	Land-system planning, CAP reforms, EU biodiversity strategy	National conservation strategy	Urban planning, disaster risk management, climate adaptation	Community resilience, watershed planning
Conclusion	Manage agricultural expansion; avoid strong ES decrease	Promote de-intensification; integrate land-use planning for mitigation of biodiversity loss	Plan conservation using future ecological value; strengthen governance	Scale NbS in high-risk/ vulnerable areas; enforce environmental laws	Improve governance, address direct & indirect drivers of degradation

[9] SSP1 can be seen as 'optimistic', SSP2 as 'business as usual', SSP3 as 'pessimistic'.

Overarching main findings across the five projects

Applying different spatial perspectives, the five projects examine how land-use change, climate change, and social-ecological dynamics shape biodiversity and ecosystem services, social vulnerabilities, and Nature-based Solutions (NbS) planning.

1. Land-use as a dominant driver

All studies address land-use change as one of the key drivers of biodiversity decline and ecosystem service degradation.[10] Urbanization, deforestation, and agricultural intensification are associated with:

- Declines in biodiversity and regulating services.
- Increases in certain provisioning services (eg food, fuelwood) at the expense of other services.
- Regional thresholds beyond which recovery is difficult or costly.

2. Importance of future scenarios

Scenarios (SSP-RCP combinations, optimistic/BAU/pessimistic variants, Nature Futures scenarios) show that:

- 'Sustainable' futures (SSP1/optimistic/Nature-for-Nature) generally reduce land-use intensity, maintain and expand natural habitats, strengthen BES, and buffer climate impacts.
- More carbon-intensive futures (SSP3/pessimistic/BAU) increase land-use pressure, intensify agriculture, and exacerbate biodiversity loss, flood risk, and heat stress.

3. Biodiversity responses

Biodiversity models (global species distribution models (SDMs), European nested-species distribution models (N-SDMs), Peru's species distribution simulations) show:

- Strong geographic variation in climate vulnerability.
- Mountain, arid, and tropical regions experience the greatest losses.
- Some northern and higher-latitude regions may gain species.
- Land-use changes can either alleviate or worsen climate-driven biodiversity shifts depending on the adoption of sustainable pathways.

4. Ecosystem services responses

ES respond non-linearly. Provisioning and regulating ecosystem services are disturbed, with brief response time to adapt to changes:

- Provisioning ES (grazing, fuelwood, crop provision) often rise with agricultural use.[11]
- Regulating ES (pollination, flood mitigation, climate regulation) decline when land-use becomes more fragmented or intensively used.
- Time-lags exist between habitat loss and ecosystem services collapse.

Modelling in Brazil and Belize shows strong relevance of land-use change and climate change for:

- Flood control
- Thermal comfort
- Soil infiltration and water yield
- Coastal protection

[10] Note that the projects focus more on terrestrial and freshwater ecosystems. For aquatic systems, direct exploitation and pollution become more problematic.
[11] Note that this might be different if we look at provisioning services in marine ecosystems and aquaculture. However, such a view was beyond the projects' scope.

5. Social risk and vulnerability

The participatory processes in the Belize and Peru case studies reveal the following major findings for their regions:

- Both regions are exposed to major risks like flooding, drought, storms, fires, deforestation, and agrochemical pollution.
- Direct drivers (eg pollution, land clearing, extreme weather hazards) and indirect drivers (eg weak governance, land tenure issues, poverty) are active in parallel.
- There are strong links between environmental degradation and livelihood security.
- Spatial mapping shows hotspots where livelihoods overlap with multiple hazards – and future hazards may happen in different areas.

6. Nature-based Solutions

Frameworks developed in Brazil, Belize, and Peru emphasize what is beneficial for improving the state of BES:

- Integrating BES projections with climate hazards and social vulnerability.
- Spatially identifying priority areas for NbS investment.
- Considering future ecological value – not only present conditions – when expanding conservation areas.
- Assessing synergies/trade-offs between biodiversity, ecosystem services, and economic activities.

7. Policy- and research-oriented recommendations

Across studies, recommendations converge on:

- Expanding area-based conservation and restoration actions strategically, with future conditions in mind.
- Embedding NbS into climate adaptation and land-use planning.
- Strengthening governance, environmental enforcement, and community participation.
- Participation to ensure the benefits of conservation and NbS reach vulnerable communities.
- Using scenario modelling to inform decisions.
- Assessing social and economic dependencies and impacts in conjunction with BES loss on different spatial and temporal levels remains challenging and will need significant attention and funding in the future.

Project based findings summarized: from global to local scales

- **Global land-use and climate change scenarios for mountains, islands and deltas:** The analysis of 29 BES indicators shows that biodiversity and regulating services often decline sharply with land-use intensification, while provisioning services will increase with expansion of agricultural land-use (SSP2, SSP3).[12] Beyond certain conversion levels, declines accelerate. Future BES changes will be most pronounced in Central Africa, South-East Asia, and South America. At the global scale, agricultural land-use is still more influential than urban expansion on BES indicators. Land-use regulation, especially agricultural land in tropical regions, is the strongest lever policymakers have to protect biodiversity and maintain ecosystem services.

- **Agro-biodiversity scenarios for Europe, focus on interactions between biodiversity, land-use, climate change:** Land-use and biodiversity modeling for SSP1-RCP2.6 (sustainability) and SSP3-RCP7 (fragmentation) reveals that SSP1 leads to de-intensification, greater natural forest/wetland cover, and improved ecological resilience. SSP3 results in land-use intensification, losses in native habitats, and widespread biodiversity losses. Mountain, arid, and southern regions experience the largest declines. Northern Europe may gain species – but these changes might disrupt existing ecosystems (eg due to generalist species outcompeting specialist species in colder climates). EU strategies should integrate long-term land-system foresight to reduce agricultural intensity, restore ecosystems, and prepare for species and ecological communities restructuring.

- **National-scale assessment of future land-use change and impact on BES for Peru: Nature Futures Scenarios (NASCENT):** Through participatory scenario development and multi-model simulation, three nature-positive futures (Nature for Nature, Nature for Society, Nature as Culture) illustrate different paths toward sustainability. Business-as-usual leads to intensified biodiversity and ecosystem services decline. Future conservation areas differ significantly from today's optimal locations due to climate and land-use shifts. Impacts extend to agriculture, forestry, water, and energy sectors. Peru's conservation policies must plan for current and future ecological values.

- **Development of a decision support framework to manage environmental disaster risks for the state of Rio de Janeiro:** Using land-use scenarios, climate extremes, InVEST® models, and social vulnerability data, the analysis shows: Flood control: +5.9% (optimistic), +1.4% (BAU), –9.7% (pessimistic). Thermal comfort: +16.4%, +6.8%, –16.4%. Coastal protection declines under pessimistic futures. Priority areas overlap strongly with socially vulnerable populations. NbS can deliver major climate adaptation gains – when paired with strong environmental governance and aligned with social equity goals.

- **Current and future adaptive capacity of livelihoods in Central Belize:** Participatory workshops across the Belize River Valley and Sibun River Watershed highlight the threats communities face: Flooding (highest), drought, storms, fires, deforestation, agrochemical pollution. Direct drivers: environmental pollution, habitat loss, climate hazards. Indirect drivers: weak governance, land tenure conflicts, migration pressure, youth disengagement. Hydrological modelling (InVEST® SWY) shows: Climate and land-use change significantly influence runoff, infiltration, and water yield patterns. Flood and water scarcity hotspots emerge in populated and agricultural zones. Robust watershed planning requires integrating community knowledge with spatial modelling to guide equitable adaptation.

[12] In the long term, these provisioning services may then decline, eg due to erosion or other reasons, and depending on the circumstances.

Key messages

- Land-use change is the most current, immediate, and actionable driver of biodiversity loss and ecosystem service decline.
- Sustainable land-use pathways can also mitigate climate impacts.
- Future conditions matter. Conservation or Nature-based Solutions planning based on current biodiversity and ecosystem services patterns risk misallocating investments; forward-looking scenarios are essential.
- Vulnerable communities typically overlap with ecological pressure hotspots. Social vulnerabilities must be integrated into environmental planning to ensure equitable outcomes.
- NbS can offer several benefits. They work well under governance systems capable of enforcement, cross-sector coordination, and long-term investment.
- Participatory and inclusive scenario development enhances legitimacy and implementation, especially in diverse social-ecological landscapes.

Conclusion

The projects show that integrating regional planning and ecosystem services modelling approaches can provide valuable insights to decision-makers, because they improve the understanding of present challenges and support the adaptation to future challenges.

Land-use and climate change impacts species, ecosystems, and ecosystem services. The benefits provided by ecosystem services will change geographically. Measures with the greatest climate adaptation impact can guide local restoration and conservation policies.

The five projects suggest establishing nature restoration and associated infrastructures as a societal priority. Governments will need to secure land rights and enforce existing environmental laws. The integration of land-use planning, zoning, restoration and climate adaptation should be pursued. Governments that embed scenario-based methods, NbS and community participation into their policies may be better positioned to reduce risk, enhance the state of nature, and achieve development or economic goals.

Abbreviations

BAU	Business as usual
BES	Biodiversity and ecosystem services
CAP	European Union Common Agricultural Policy
CLUMondo	A model that is a spatially explicit and dynamics land system change model, developed by VU Amsterdam. Land systems are socio ecological systems that reflect land-use in a spatial unit in terms of land cover composition, spatial configuration, and the management activities employed.
EU	European Union
ES	Ecosystem Services
GDP	Gross Domestic Product
InVEST®	Integrated Valuation of Ecosystem Services and Tradeoffs; an open-source software suite used to map, quantify, and value ecosystem services to inform decisions, developed by the Natural Capital Alliance of Stanford University.
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
LUH2	Land-Use Harmonization, a set of land-use scenarios which are harmonized and connect historical land-use sets (or reconstructions of these sets) with future projections.
LULUCC	Land-Use and Land-Use Cover Change
NASCENT	NAture-positive SCenarios for ENvironmental Transitions
NbS	Nature-based Solutions
N-SDM	Nested-Species Distribution Models; whole range coarse-grain species distribution models combined with subrange fine-grain species distribution models.
RCP2.6	Representative Concentration Pathways, often called low-emissions scenario, corresponding to a stabilization of atmospheric greenhouse gas concentrations sufficient to limit warming below 2°C.
RCP7	Representative Concentration Pathways, a medium to high end emissions scenario, reflecting a "business as usual approach to greenhouse gas emissions", where emissions may stabilize but remain high.
RCP8.5	Representative Concentration Pathways, a high emissions climate scenario, assuming high population growth, slow income growth, persisting usage of fossil fuels especially coals, modest technology improvements, projecting highest greenhouse gas concentrations and a potential global temperature rise of around 4.3°C by 2100.
SDG	Sustainability Development Goals
SDM	Species distribution models, relate species observations to mapped variables of the environment to estimate the realized niche of species, and to predict their distribution.
SSP	Shared Socioeconomic Pathways represent a set of standardized future scenarios, which describe potential evolutions of society, demographics, economics, technology, and nature. Each SSP (eg, sustainability-focused, inequality-driven, fossil-fueled growth) represents a narrative that is used as an input in climate and land-use models to explore different development trajectories.
	SSP1 Shared socio-economic pathways; sustainability ("taking the green road")
	SSP2 Shared socio-economic pathways; ("middle of the road")
	SSP3 Shared socio-economic pathways; ("regional rivalry", "a rocky road")
	SSP4 Shared socio-economic pathways; inequality ("a road divided")
	SSP5 Shared socio-economic pathways; fossil-fueled development ("taking the highway")
SWY	Seasonal Water Yield

Appendix

> How we manage the land today, and the legacies we carry from the past, shapes the future sustainability of biodiversity, ecosystem services, and the societies that depend on them.

University of Zurich

Biodiversity and ecosystem service responses to land use change across global systems – University of Zurich

Authors:
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Maria J. Santos

Introduction

Global biodiversity and ecosystem services (BES) are increasingly threatened, with land-use change identified as the primary driver of this decline (IPBES, 2019). Land-use intensification to agricultural and urban land-uses, can damage BES through habitat replacement and associated pollution and fragmentation (Power, 2010). Understanding how BES responds to these changes is critical for their sustainable management – relationships can show lock-ins or thresholds beyond which recovery can be costly or irreversible (Santos & Dekker, 2020).

Several relationships have been theorised and established between land-use and BES in different regions and countries (de Groot et al., 2010; Maskell et al., 2013; Peng et al., 2017). Generally, provisioning services such as food and timber increase with agricultural land-use, but decline with urbanisation, while biodiversity and regulating services tend to decline with land-use intensification. These impacts may be delayed: an ecosystem service debt occurs when long-lived species temporarily maintain services after environmental degradation (Isbell et al., 2015; Kuussaari et al., 2009). However, it is unclear if these responses are consistent globally, and across different biomes and social ecological systems. We assess which consistent trajectories exist between land-use and BES, where they are, to what extent they are affected by past land-use change, and how future BES provision will be affected by different potential scenarios in the next century.

Key assumptions

- Land-use robustly relates to several biodiversity and ecosystem services (BES) indicators within different systems and biomes.
- Past land-use change influences current BES levels.
- Future relationships between land-use and BES will follow the same trajectories as those in the present day.

Key methods

- We quantified how 29 BES indicators respond to agricultural and urban land-use (0.25° data from the Land-Use Harmonization 2 models; Hurtt et al., 2020).
- Relationships were assessed globally, in mountains, islands and deltas (Reader et al., 2023), and across biomes and biogeographical realms (Dinerstein et al., 2017).
- To capture response trajectories, we fit linear, quadratic, and cubic models, selecting the best performing for each indicator.
- We then examined legacy effects by testing if adding historical land-use change (1975–2015) improved these models.
- We finally used the current models to predict BES changes based on projected land-use for 2030, 2040, 2050 and 2100.

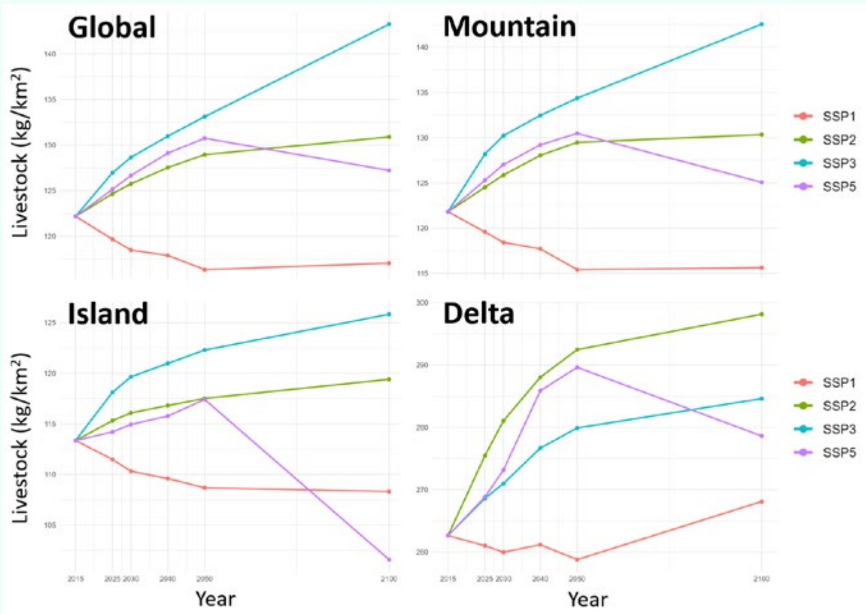
Scenarios

- We use four Shared Socioeconomic Pathway (SSPs) scenarios – potential development pathways with different assumptions about social, economic and political development:
  - SSP1 – a more sustainable future
  - SSP2 – business as usual
  - SSP3 – more regional division and lower economic development
  - SSP5 – more globalisation, higher economic development and consumption
- We use land-uses modeled from these scenarios from several integrated assessment models (IAMs) harmonised through the Land-Use Harmonization 2 (LUH2) datasets (Hurtt et al., 2020).

Key results

- We found multiple robust relationships between BES and land-use – broadly positive for material ES and ES use, but with thresholds and decline for biodiversity and regulating indicators.
- Several indicators: fuelwood, grazing, access to nature and pollination had robust relationships with land-use globally, across mountains, islands and deltas, and across biomes.
- Most relationships were found with agricultural or total land-use, rather than urban land-use.
- Incorporating historical land-use improved 85% of models, representing a small but non-trivial increase in explained variance.
- Provisional ES and ES use are projected to increase across the scenarios, excepting post 2050 declines in SSP5 ('fossil-fueled development') (Figure 1). Highest ES use was projected in business-as-usual scenario (SSP2), with the largest differences found between SSP2 and SSP5. The most pronounced regional shifts are expected in Central Africa, Southeast Asia and South America (Figure 2).

Figure 1
Predicted changes in livestock density over time between SSP scenarios globally and across mountain, island and delta systems.



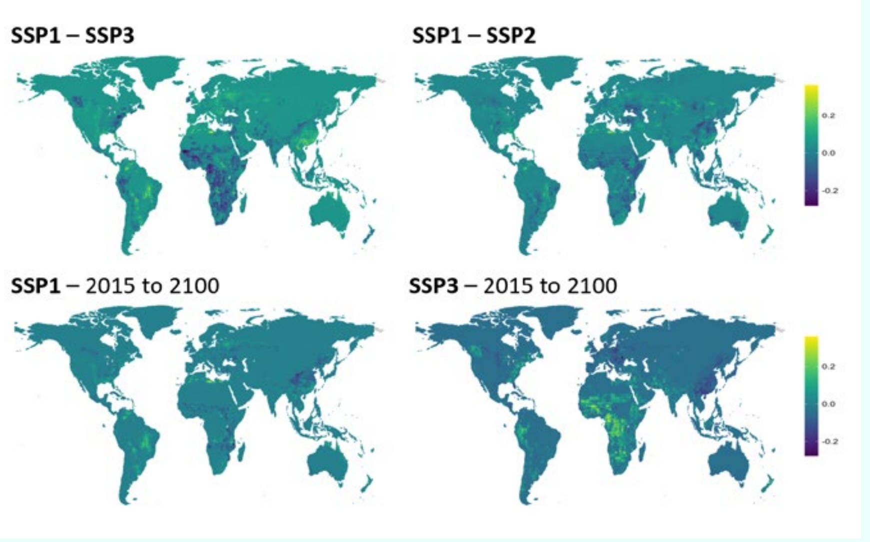


Figure 2
'Difference in grazing value (proportion) change predicted between scenarios from 2015 to 2100 (top row); change in grazing value between 2015 and 2100 for the most extreme scenarios (bottom row): SSP1 (sustainability) and SSP3 (regional rivalry)

Key recommendations

- Spatially explicit models enable us to identify areas of importance for planning and risk management – we show regions where different scenarios may result in the largest shifts in BES, and where future BES supply may be more stressed.
- Land-use – BES trajectories could indicate thresholds and in turn optimal land-use policy. Such thresholds could indicate land-use policy to optimize particular BES components, eg shared vs. spared approaches (Stott et al., 2015). Our findings, however, show relatively fewer clear thresholds than expected, potentially due to data limitations or scale dependent confounding factors.
- BES indicators are currently often limited spatially and temporally – more mechanistic indicators could provide better support for policy makers.

Key messages to stakeholders

Academics/data providers
- Current and past land-use can be used to predict ecosystem service futures – some ecosystem services have relatively consistent relationships, others differ in particular systems and biomes.
- High-resolution, frequent, global, mechanistic BES data is often lacking but will be vital for actionable predictions of global change impacts at larger scales.

Policy-makers, companies and the financial sector
- Sustainability, reputation, and regulations require the integration of BES and land-use impacts into decision making as soon as possible, and across governmental scales.
- Scenarios can help prioritise policy and investment by identifying plausible futures for BES in a given region, identifying where ecosystem services are more sustainable, or more at risk.

Who we are

The Earth System Science (ESS) group at the University of Zurich examines the co-evolution of social ecological systems in the Anthropocene. Since 2018, we have developed and applied multi- and inter-disciplinary approaches to observe, describe, and model the interactions and feedbacks between Earth System spheres and the human system. We combine field-based research, participatory approaches, archival analysis, remote sensing, GIS, and advanced modelling to uncover how land-use dynamics, resource decisions, and global change shape biodiversity, nature's contributions to people, and human well-being. Our research contributes towards the understanding necessary to tackle the key societal challenges expressed in the UN Sustainable Development Goals.

Meet the team

Martin Oliver Reader – Postdoctoral Researcher
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Linking climate, land-use, and biodiversity to foresee Europe's ecological future.

VU Amsterdam and University of Lausanne

Agro-biodiversity scenarios for Europe, focus on interactions between biodiversity, land-use, climate change – VU Amsterdam and University of Lausanne

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Background

We link climate change, land-use change, and biodiversity change to better understand how biodiversity and selected ecosystem services will shift across Europe, with a focus on agricultural landscapes. Our analytical pipeline begins by modeling land-use change under the assumption that global food trade and demand, as well as local environmental conditions, will determine the prevalence and distribution of different land system types across Europe (Van Asselen and Verburg, 2013). In our framework, land-use change represents the template upon which animals will adjust to ongoing climate change, resulting in a reorganization of ecological communities that depends not only on climatic forces, but also on how we choose to manage different landscapes across the continent (Guisan et al., 2025). In addition, for selected ecosystems services, estimates of ecosystem services demand and supply are then evaluated (eg pollination supply; Schulp et al., 2014). This is fundamental because most modeling exercises evaluating BES change fail to account for these two important drivers conjunctly, particularly at continental scales. Therefore, our analysis innovates in its integrative, quantitative approach.

We focused on two alternative futures based on SSP1-RCP2.6 and SSP3-RCP7 assumptions.

The first scenario (SSP1-RCP2.6) represents a future where environmental targets are met. The world gradually shifts towards sustainability, emphasizing inclusive development that respects environmental boundaries. The scenario assumes a significant improvement in the management of global resources, leading to better environmental outcomes. Increased investments in education and health accelerate demographic transitions, reducing inequalities both within and between countries. Economic growth is reoriented towards broader human well-being rather than solely focusing on GDP growth. The second scenario (SSP3-RCP7) depicts a fragmented world of resurgent nationalism in which international cooperation is weak, institutions are ineffective, and mitigation/adaptation face challenges. Technological change is hampered, with the energy system remaining fossil-fuel-dependent with higher energy and carbon intensity, and efficiency gains are modest. In land systems, these facts translate into greater pressure for agricultural expansion and higher land-use-dependent emissions, with reduced capacity to restrain deforestation relative to SSP1-RCP2.6.

Key methods, summary

For land-use scenarios, we use the CLUMondo modelling framework (Van Asselen and Verburg, 2013). CLUMondo is a spatially explicit land system change model that simulates how land systems (including land cover/land-use and management intensity) change over space and time. Model predictions consistent with SSP1-RCP2.6 and SSP3-RCP7 in the year 2050 are used in the analysis. Such models are based on an initial baseline map of land cover classes across Europe, from which suitability of different environmental conditions for different land system types is estimated. Next, simulations are run to predict plausible changes in land-use based on both climate change and regional demands. Climate predictions were based on the CHELSA dataset (Karger et al. 2017), whereas regional demands for agricultural commodities and wood where set to match the different SSP scenarios as simulated at global level by the GLOBIOM model (Tita et al., 2025).

For biodiversity scenarios, we used Species Distribution Models (SDMs) (Riva et al. 2024, Guisan et al., 2025). We applied a N-SDM (Nested Species Distribution Modelling) approach that integrates a global suitability model based solely on microclimatic variables when predicting local species distributions in response to land-use and local climatic conditions across Europe (Adde et al., 2023). Such models have been created for 1227 species of animals for which sufficient data is available across Europe [82 amphibians, 406 butterflies, 114 reptiles, 178 mammals, 447 birds, representing 78% (range: 67%–86%) of the species in these taxa]. Predictions of current and future species ranges was further refined based on expert-based range maps (Cazalis et al., 2022) and dispersal constraints based on animals' natural histories and body size (Moura et al., 2024).

Scenarios, summary

Our scenarios include both land-use and biodiversity change scenarios. Both approaches generate 1-km resolution maps across Europe for current conditions and for two comparable futures (SSP1-RCP2.6 and SSP3-RCP7). For analyses, we include counterfactual biodiversity scenarios where land-use is assumed to be constant, so that we can evaluate the relative contribution of climate change and land-use on biodiversity change in different regions.

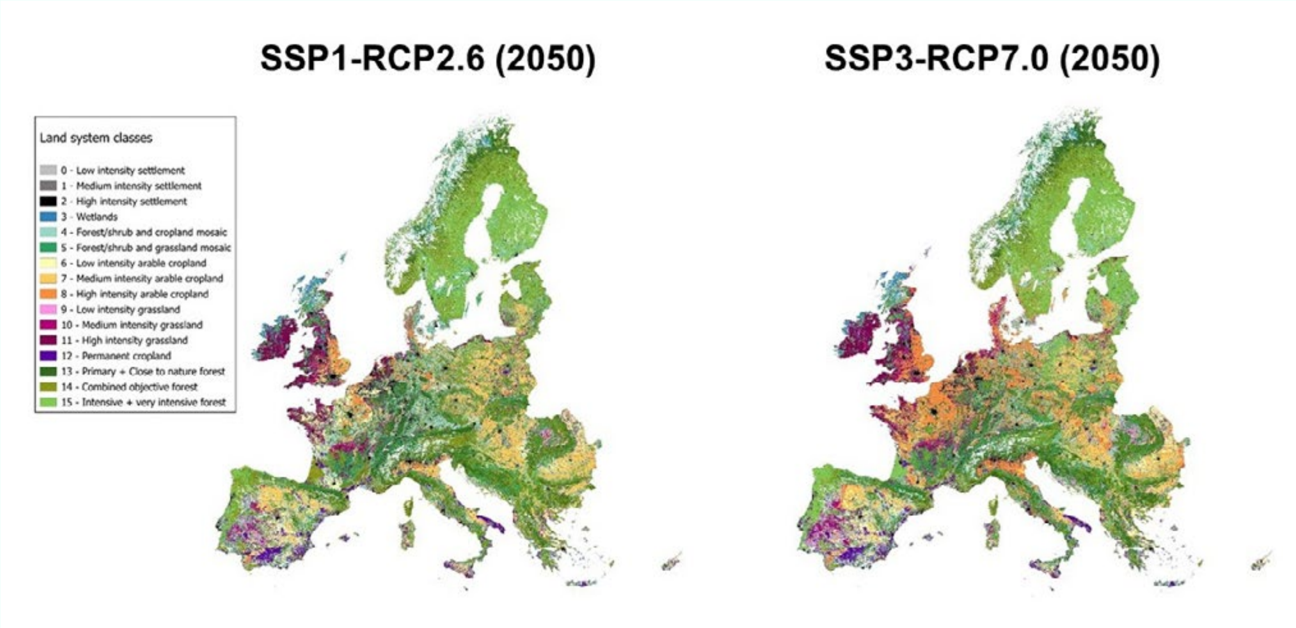
Land-use scenarios were parameterized to be consistent with SSP1-RCP2.6 (Green global transition scenario) and SSP3-RCP7 (Ignorant regress and Populism scenario) using the CLUMondo land systems model that simulates both changes in land cover and management intensity. Through time, probabilities of finding different land systems types at each locations are calculated and transitions maximize the tradeoff between allocating the necessary land system types, linked to provision of resources established in different scenarios, and where each land system type is most likely to occur based on local suitability values, transition rules and conversion costs.

Biodiversity models are calibrated for each of the 1227 species. Starting from climate scenarios and the CLUMondo land-use predictions we generated, we fitted statistical models building on hundreds of thousands of data points openly available across Europe. Such models are based not only on local suitability, but also on global suitability estimates from expert range maps; this allows controlling for species that are not restricted to Europe, and this improves the realism of our models. Furthermore, we restricted current predictions of species occupancy only within each species' range map, and constrained future dispersal to proximal suitable cells that are realistically available for colonization based on the dispersal capacity of each species, using body size and dispersal mode (eg flying vs. non-flying organisms) as variables to parameterize different dispersal ranges. Together, these steps ensured a more realistic picture of biodiversity change across Europe.

Results and discussion

Results of land-use scenarios
The model outcomes highlight alternative pathways for the continental Europe (Fig. 1). The SSP1 scenario projected to 2050 shows a pattern of clear deintensification of agricultural and forest use: high-intensity arable land strongly decreases in terms of area occupied across the continent, and so does high-intensity grassland management, while low arable and grasslands increases. Wetlands, forest-agriculture mosaics, and primary/close-to-nature forests all expand. This fits a sustainable world with strong policy and dominant land-use extensification rather than intensification. In contrast, SSP3 concentrates growth by intensifying agriculture (increases in high-intensity arable and grassland). These patterns are very noticeable yet more uneven and patchy, consistent with weak cooperation and fragmented governance.

Figure 1
Maps of land system predictions depending on different combination of RCP and SSP scenarios, for the year 2050.



Results of biodiversity models
Our models identify clear regional variation in biodiversity change across Europe (Fig. 2). Arid regions and mountains experience the most biodiversity loss, whereas northern regions will potentially receive expanding species. The signature of land-use appears particularly in regions that are experiencing transitions from high-intensity agriculture to more sustainable landscape mosaics. Thus, our exercise allows untangling the potential of land-use change to ameliorate the negative consequences of climate change on ecological communities.

Results of ecosystem services
Models suggest that most of Europe will suffer from decreasing biodiversity and ecosystem services (Fig. 3). Nevertheless, we see clear positive implications of SSP1 as opposed to SSP3. Transitioning to more sustainable agroecosystems will benefit both pollination supply and pest control in Central and Northern Europe, and even more so when assuming that species will be able to track suitable climates. Such positive effects on ecosystem services in agricultural landscapes will be lost when considering the SSP3 scenarios. Even assuming that species will be able to track climatic changes, the SSP3 scenario results in severe losses of ecosystem services across most countries in Europe.

Figure 2
Predictions of biodiversity change based on climate and land-use scenarios, as well as different assumptions on the capacity of species to track climate change across Europe.

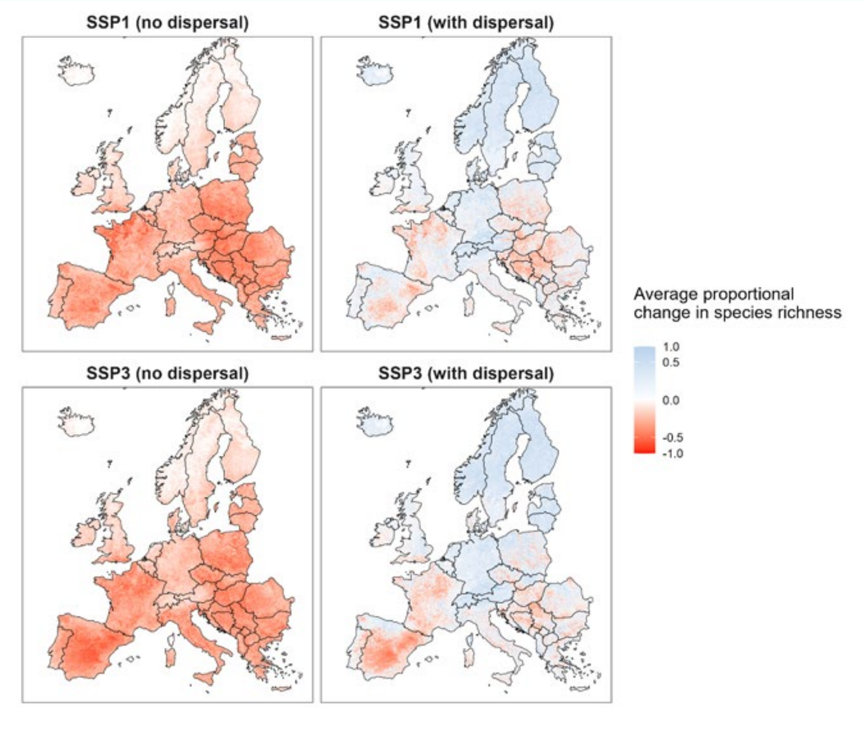
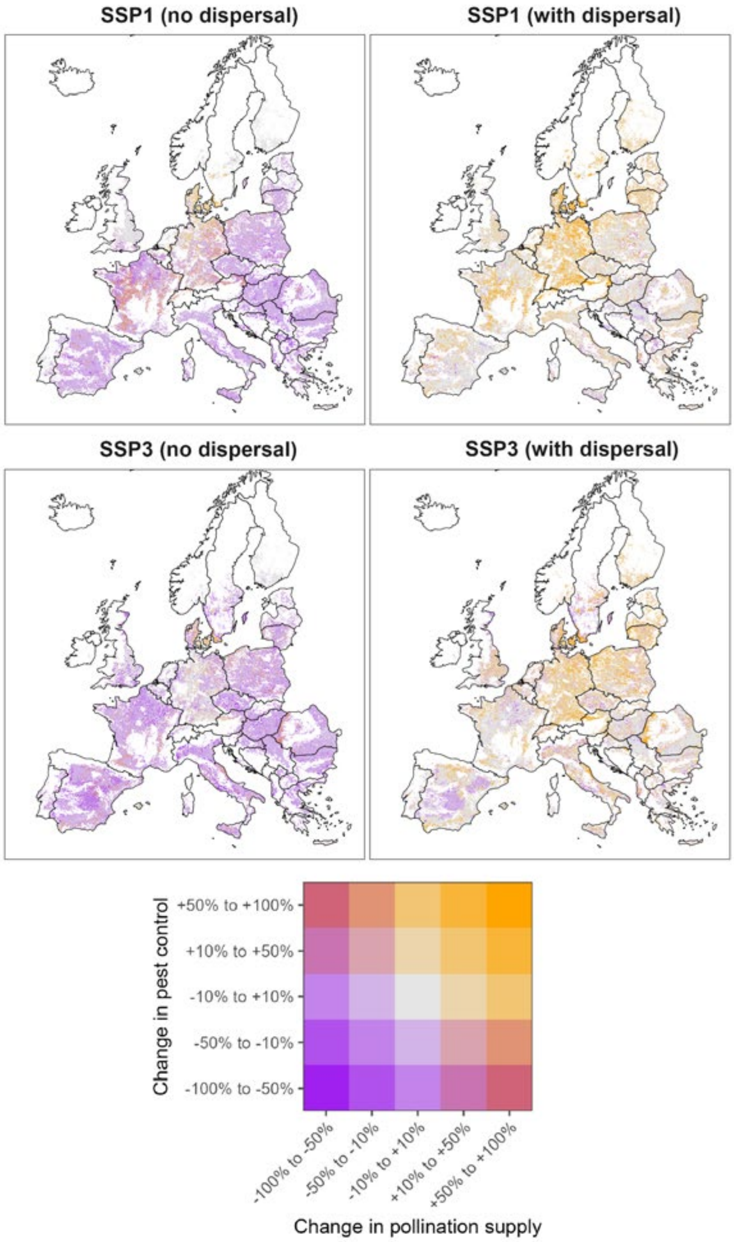
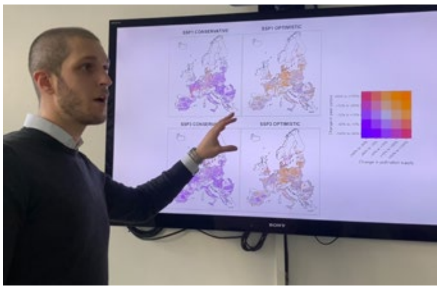


Figure 3
Changes in pollination supply and pest control as a function of land system and climate change across Europe. The subset of colored pixels indicates landscapes with agricultural land systems, where pollination and pest control are most relevant.



Who we are

IVM
The Institute for Environmental Studies (IVM) at VU Amsterdam is the oldest environmental research institute in The Netherlands, and one of the world's leading institutes in sustainability science. Research in the Department of Environmental Geography describes and explains the spatial aspects of interactions between humans and societies and their natural environment.



People
Federico Riva is assistant professor at Carleton University, Canada. He is a conservation biologist working at the interface of landscape ecology, biogeography, and macroecology. Federico coordinated the project and led biodiversity modeling.

Nuno Garcia is a geospatial and environmental data scientist, currently working with Floresta Bem Cuidada, Portugal. Nuno supported the project with data preparation and modeling of global range maps.

Wim Hordijk is an independent researcher with extensive experience in mathematical models and complexity science. Wim facilitated computation on the Snellius Dutch supercomputer.

Caroline Martin is a PhD student at the University of Lausanne, Switzerland. Caroline supported biodiversity data management and coding of the biodiversity modeling pipeline.

Antoine Guisan is professor at the University of Lausanne, Switzerland. He specialized in habitat suitability and distribution modeling, mainly at the level of species, but also of biodiversity, communities, ecosystems and their services. Antoine contributed to the species distribution modeling pipeline.

Peter Verburg is professor and leads the Environmental Geography Department. He has established a leading position in the field of land-use analysis and modelling, applying a wide range of methods to analyze spatial patterns of land-use at scales from local to global. Peter and his students led land-use modeling.

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> Peru's biodiversity is moving uphill – and conservation strategies must move with it.
>
> ETHZ NASCENT

First national-scale assessment of future land-use change and impact on BES for Peru – ETH Zurich

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Background:

As countries strive to meet the Kunming-Montreal Global Biodiversity Framework's (KM-GBF) target of conserving 30% of terrestrial and marine areas by 2030 (CBD 2022), there is growing recognition that current approaches to area-based conservation planning fall short in effectively accounting for key uncertainties (Maxwell et al. 2020; Pressey et al. 2021; Gurney et al. 2023). Specifically, they often overlook the diversity of social perspectives on what should be prioritized for conservation (Bhola et al. 2021; Pascual et al. 2023; Jung et al. 2024)., as well as how the future development of drivers such as climate change and land-use demand may impact the resources that conservation efforts aim to protect (Williams and Johnson 2013; Iwamura et al. 2018). The implication of this is that policy makers are not adequately informed of the societal trade-offs that conservation strategies may incur (Reside et al. 2018; Giakoumi et al. 2025), and whether strategies are robust to changing socio-environmental conditions (Tallis et al. 2021).

The NASCENT-Peru project addresses this gap by developing scenarios of landscape change for Peru between 2020 and 2060. Three of these, Nature for Nature, Nature for Society, and Nature as Culture, reflect pluralistic visions of desirable futures, each highlighting different conservation priorities and the boundary conditions needed to realize them. In contrast, the Business as Usual scenario provides a benchmark by projecting the continuation of current trends. The scenarios were co-developed through a participatory process with a diverse group of Peruvian stakeholders, guided by the IPBES Nature Futures Framework (Pereira et al. 2020). Their qualitative narratives are aligned with climate, demographic, and economic trajectories from the IPCC SSP-RCP framework and subsequently operationalized to quantify expected rates of future land-use change as well as alternative priority locations for the expansion of area-based conservation under each scenario. These quantitative scenario outputs can be applied through subsequent simulation modelling of land-use and land cover change, biodiversity, ecosystem service (ES) provision, to ultimately inform policy makers on the effects for Peru's major economic sectors. We demonstrate this potential with simulations of the projected shift in the spatial suitability of the landscape for 225 species, with further modelling to be completed.

Key scenario assumptions:

- Nature positive scenarios assume climate change and population growth according to SSP1-RCP2.6, with Business as Usual following SSP2-RCP4.5.
- Alternative expected rates of change for land-use activities under each scenario.
- Alternative realisations of conservation area expansion under each scenario to achieve KM-GBF 30x30 target.

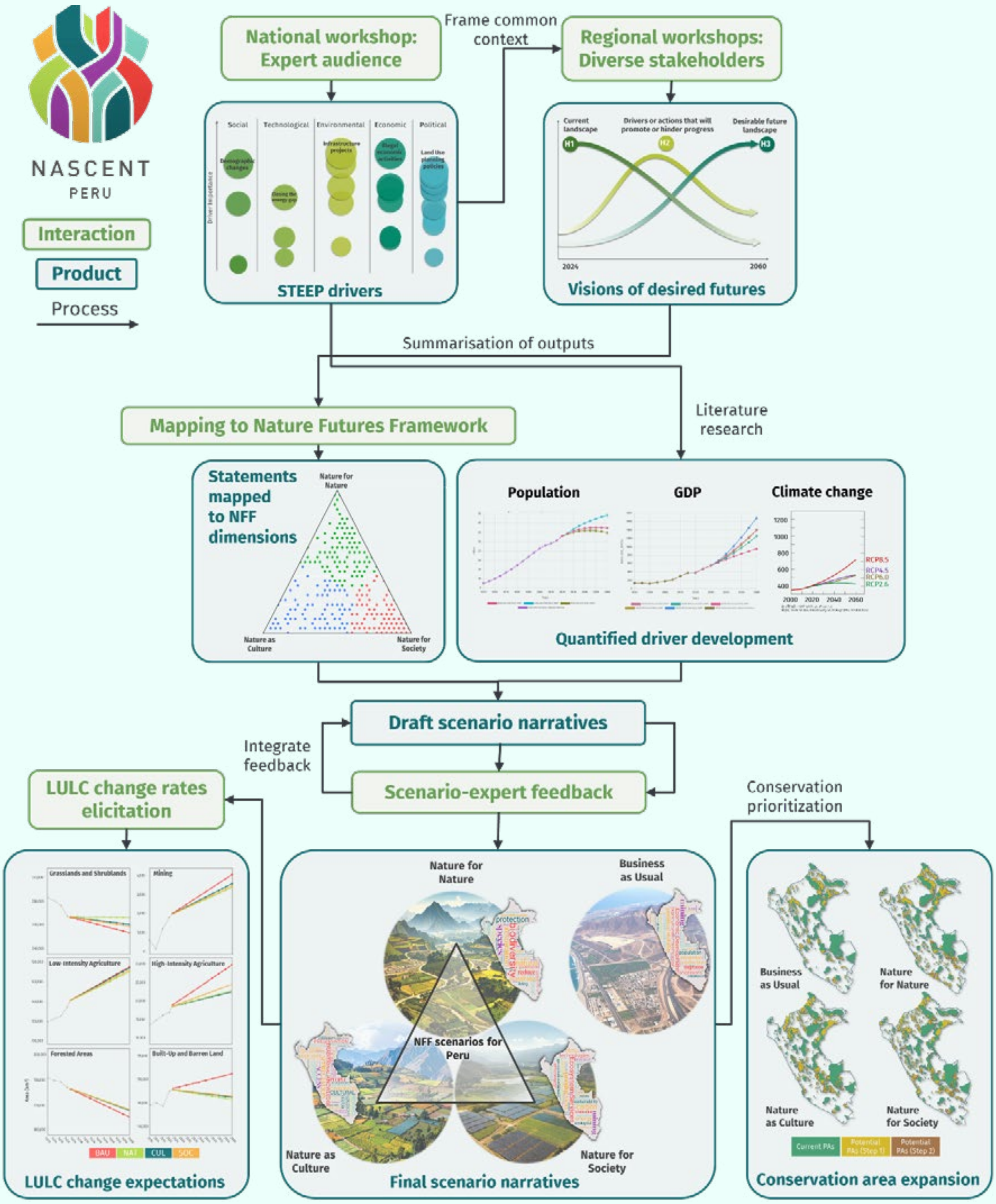
Key methods:

- Participatory scenario creation process involving 100+ stakeholders in Peru, using the IPBES Nature Futures Framework.
- Operationalization of scenario narratives into quantitative data for expected trends in climatic variables, GDP, population growth and land-use and land cover change.
- Utilization of scenario narratives within a Systematic Conservation Prioritization analysis to produce maps of priority locations for the expansion of area-based conservation under alternative social preferences.
- Species Distribution Modelling to simulate project shift in the spatial suitability of the landscape for 225 species under SSP1-RCP 2.6, SSP2-RCP4.5 and SSP5-RCP8.5

Project Overview

The project created three nature positive scenarios, Nature for Nature, Nature for Society, and Nature as Culture, that reflect pluralistic visions of desirable future landscape development in Peru, each highlighting different conservation priorities and the boundary conditions needed to realize them. A Business as Usual scenario that provides a benchmark for the comparison of BES impacts by projecting the continuation of current trends. These scenarios were created via a multi-step process (detailed in Figure 1) that combined participatory interactions in the form of national and regional workshops as well as web-based expert elicitation activities with data-driven analysis.

Figure 1
Infographic detailing the main steps with the NASCENT-Peru scenario creation process.



Key results:

- While all three nature-positive scenarios projected smaller declines in forests and grasslands and reduced agricultural expansion compared to business-as-usual, mining area was nonetheless expected to grow under every scenario through 2060, albeit at a slower rate.
- Across multiple conservation scenarios with varying priorities, a core set of spatial areas consistently emerged as high priority for conservation in Peru, suggesting these locations can satisfy competing objectives and build social consensus for expanding protected areas.
- Climate change will increasingly shift habitat suitability for Peru's biodiversity toward higher elevations along the Andes and away from the Amazonian lowlands, with the severity of this pattern escalating under higher emissions scenarios, underscoring the importance of integrating these projections with conservation priority mapping to ensure protected area expansion is both climatically resilient and socially robust.

Key recommendations:

- Prioritize the consensus conservation areas immediately. Core spatial areas that emerged across multiple scenarios represent politically feasible, multi-objective solutions that can accelerate protected area expansion while building stakeholder support.
- Design climate-adaptive conservation networks with elevation connectivity. Given projected upward habitat shifts along the Andes, prioritize establishing or strengthening protected area corridors that span elevation gradients, particularly connecting lowland Amazonian areas to montane regions.
- Integrate mining development into conservation planning rather than treating it as external. Since mining expansion is projected across all scenarios, develop spatial planning frameworks that identify where mining and conservation priorities overlap, enabling proactive negotiation and offsetting strategies.
- Participatory scenario creation is a crucial tool to stimulate dialogue between conservation policymakers and relevant stakeholders, to develop effective and socially feasible conservation strategies.

Key messages for stakeholders:

- The NASCENT-Peru scenarios of future landscape change should not be viewed as concrete forecasts of 'what will happen', rather they should be taken as examples of 'what might happen' to prompt further discussions about how society might promote or respond to the trends they present.
- If we select conservation areas based on their current value for Biodiversity in the present, this will likely miss the areas that will be most important in the future. Simulations of alternative conservation priorities can help us incorporate future changes in our planning.

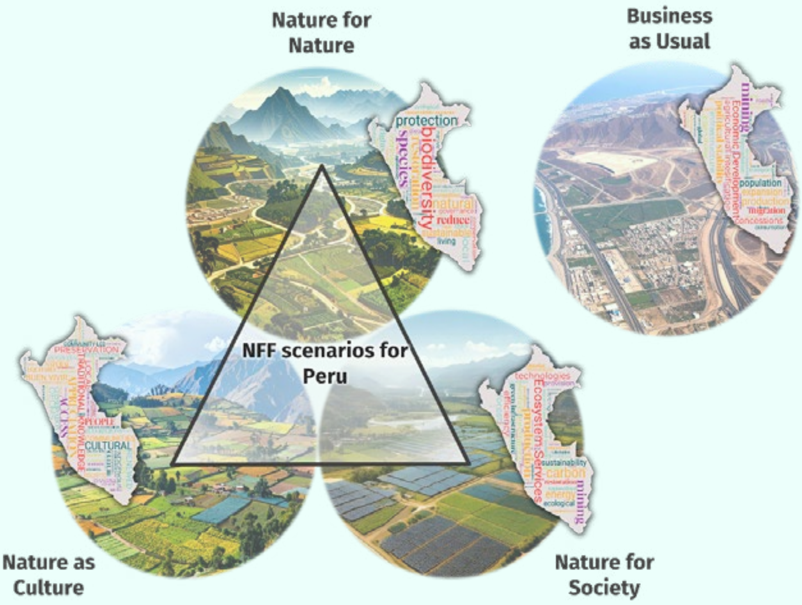
Results

1. Summaries of scenarios

The Nature for Nature scenario envisions a Peru in 2060 where landscapes are shaped by a commitment to minimizing human impacts and recognizing the intrinsic rights of nature. Strong rural-to-urban migration supports the growth of dense, sustainable urban settlements, reducing pressure on natural areas. Dietary shifts away from livestock contribute to declining levels of animal farming, though extensification of production leads to moderate agricultural expansion. No new mining concessions are granted, and existing operations continue only under strict regulations. Conservation efforts focus on areas with high biodiversity value, carefully selected to represent Peru's diverse eco-regions, ensuring that ecological integrity takes precedence over economic considerations.

In the Nature for Society scenario, landscapes in 2060 are optimized to sustain the provision of key ESs through strong cross-sectoral planning and the adoption of green technologies. Governance remains largely top-down for efficiency, though some authority is devolved to regional experts. Economic development is decentralized, with major cities beyond Lima emerging as regional hubs of service-sector growth. Agriculture intensifies through the widespread use of digital technologies, boosting productivity. However, high levels of personal consumption and large per capita living space sustain significant urban sprawl. Conservation priorities are directed toward safeguarding essential services such as water regulation and carbon sequestration, with new areas strategically selected to strengthen the connectivity of the national conservation estate.

Figure 2
Illustrative representation of the key themes of the four NASCENT-Peru scenarios.



The Nature as Culture scenario portrays a Peru in 2060 where sustainability, cultural preservation, and social equity are advanced through community-led governance inspired by the principles of Buen Vivir. Urbanization proceeds only modestly, with lower-density settlements reflecting a preference for dwelling close to nature. Individuals pursue self-sufficiency by reducing consumption and embracing sustainable lifestyles. Agriculture is characterized by holistic agro-ecological practices such as agroforestry and the cultivation of endemic medicinal and botanical plants, leading to moderate expansion of agricultural land but with relatively low intensity of use. Land management emphasizes equitable access and ecological stewardship, supported by effective zoning and strict pollution controls. Peru also fulfills its KM-GBF Target 11 commitment, expanding protected areas and OECMs to 30% of national territory by 2030, with many designated on Indigenous lands to preserve both cultural heritage and ecological diversity under community management.

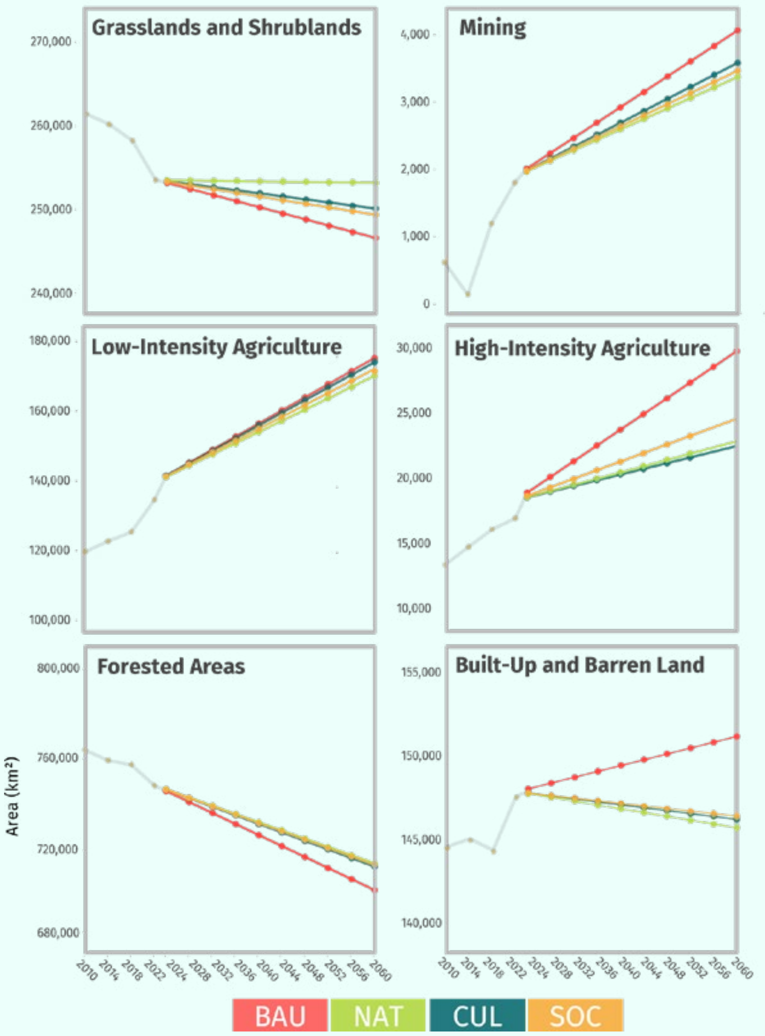
Under the Business as Usual scenario, the landscape of Peru in 2060 reflects a continued prioritization of economic development over environmental sustainability. Agriculture and extractive industries expand to dominate much of the territory, driving deforestation and urban sprawl, while climate change pressures on water and food security intensify migration from the highlands toward coastal and Amazonian regions. Although all departments complete Ecological and Economic Zoning plans, planning remains reactive and vulnerable to economic capture, permitting development in ecologically sensitive areas. Environmental awareness among the population remains limited, while rising living standards support moderate population growth to 39.81 million by 2060. Combined with high per capita living space and moderate rural-to-urban migration-leading to 86.88% of the population residing in urban areas-settlement expansion is substantial. Within this trajectory, two alternatives emerge: one in which Peru fails to meet its commitment to protect 30% of national territory by 2030, and another where the target is reached, but only through the designation of low-value marginal lands.

2. Future Trends in Land-use and Land Cover

Figure 3 below shows the variations in the expected trends in the areas of major land-use and land cover (LULC) types in Peru between 2020 and 2060 under the different NASCENT-Peru scenarios. These results were derived through an iterative process of historical data extrapolation and expert elicitation wherein experts estimated the impacts of key developments described in the scenario narratives on LULC using an interactive web-based application.

Given the 'nature positive' framing of the scenarios it is unsurprising that the Nature for Nature, Nature for Society and Nature as Culture scenarios all exhibited smaller declines in Forested Areas as well as Grassland and Shrublands as compared to the BAU scenario. Similarly, they exhibited substantially smaller increases in the area of land utilized for High Intensity Agricultural production as well as a decline in the area of Built Up and Barren land. By contrast, a rather unexpected, but likely realistic, result was that the area of land-used for Mining was projected to continue to increase until 2060 under all scenarios albeit with smaller increases under the nature positive scenarios.

Figure 3
Charts showing expected trends in the areas of major Land-use and Land Cover categories between 202 and 2060 under each NASCENT-Peru Scenario.



3. Spatial priorities for conservation

Figure 4 shows maps of the priority areas for expanding conservation areas in Peru under the different preferences encapsulated in the NASCENT-Peru scenarios. These maps were produced using a Systematic Conservation Prioritization methodology which is a spatial optimization approach that varies the weighting of a range of factors including Biodiversity, Ecosystem Services Constraint of human activities, the representation of Ecoregions and the inclusion of Indigenous titled lands (Deléglise et al. 2024). A key finding from this analysis is that there are clear spatial overlaps in the locations identified as being priority areas for conservation across the scenarios. This is policy relevant because these areas are those for which protection can satisfy multiple competing conservation objectives and hence they can help build social consensus for further conservation area expansion in accordance with international targets.

Figure 5 shows maps of the projected change in habitat suitability for 225 species across Peru between 2020 and 2060 under three SSP-RCP climate scenarios of increasing severity: SSP1-RCP2.6, SSP2-RCP4.5, and SSP5-RCP8.5. These results were derived from Species Distribution Models run at 100m spatial resolution, with the colour scale representing the magnitude of change from loss (brown, ≤ −0.2) through stable (white) to gain (teal, ≥ +0.2). These three climate scenarios are directly aligned with the NASCENT-Peru scenarios: SSP1-RCP2.6 reflects the lower emissions trajectory consistent with the Nature for Nature, Nature for Society and Nature as Culture scenarios, SSP2-RCP4.5 reflects the Business as Usual scenario, and SSP5-RCP8.5 reflects a Business as Usual trajectory under high-impact climate change. Under SSP1-RCP2.6, projected changes are relatively modest, with most of Peru remaining close to stable and only minor gains visible in the southern Andean region. As emissions intensity increases, however, the spatial patterns of change become considerably more pronounced.

Under the two higher emissions scenarios, a clear and consistent spatial pattern emerges: habitat suitability gains are concentrated along the Andean mountain range running north to south through Peru, as well as in the southern portions of the country, while losses become increasingly prevalent across the Amazonian lowlands to the north and east. This pattern intensifies markedly under SSP5-RCP8.5, where substantial gains along the Andes are accompanied by widespread habitat suitability losses across much of the Amazon basin. Notably, the intermediate SSP2-RCP4.5 scenario already exhibits a meaningful deterioration relative to the lower emissions pathway, reinforcing the biodiversity co-benefits of the nature-positive scenarios. These results are consistent with the well-documented tendency of species to shift their ranges to higher elevations and latitudes under climate warming (Chen et al., 2011; Rubenstein et al., 2023),and highlight the Andean region as a potential climate refugia, while signalling significant biodiversity risk in the lowland Amazon under high emissions trajectories. This pattern of upslope displacement has been specifically documented for Andean species, with modelling studies projecting substantial losses in climatic niche space for birds and vascular plants across the Tropical Andes under future climate scenarios (Ramirez-Villegas et al., 2014).

These projections of future habitat suitability change should be considered alongside the conservation priority area maps presented in Figure 4 when planning conservation area expansion in Peru. Specifically, areas identified as consistent conservation priorities across the NASCENT-Peru scenarios that also overlap with projected habitat suitability gains — particularly along the Andes — may represent especially high-value targets for protection, as they can simultaneously satisfy multiple conservation objectives while also serving as climate refugia for a broad range of species. Conversely, the projected habitat suitability losses across the Amazonian lowlands reinforce the urgency of protecting areas in this region before further degradation occurs, even where future climatic suitability may decline. Integrating these two lines of evidence into conservation planning would therefore help ensure that newly protected areas are both socially robust and climatically resilient over the longer term.

Figure 4
Maps of priority areas for conservation expansion to meet the KM-GBF 30x30 target under each NASCENT-Peru scenario.

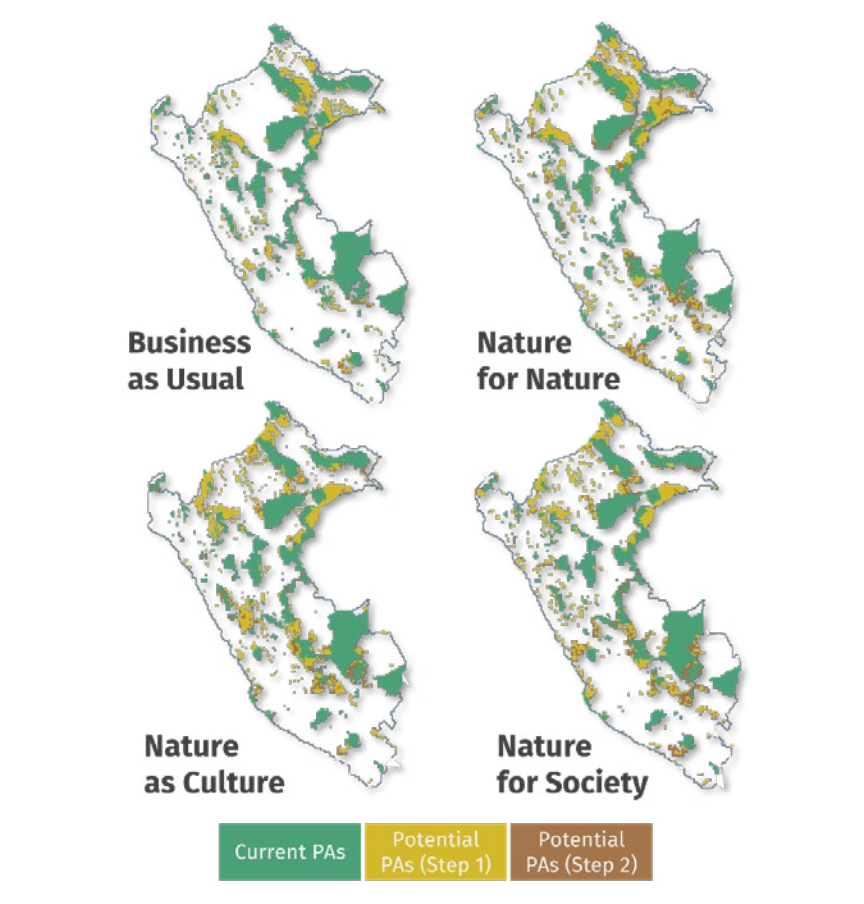
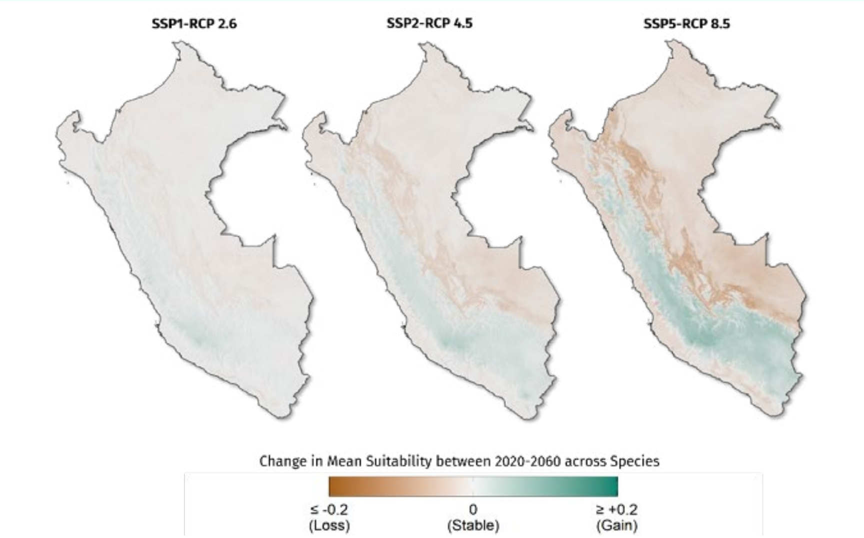


Figure 5
5 Maps of the change in mean suitability of the landscape for 225 species in Peru under the different SSP-RCP pathways aligned with the NASCENT-Peru scenarios. Note: Change refers to the difference in suitability between 2020 and 2060 based on predictions made using Species Distribution Models.



Who We Are:

The NASCENT-Peru project was primarily conducted by The Chair of Planning Landscape and Urban Systems (PLUS) at ETH Zurich. PLUS aims at advancing knowledge on how the interactions of humans with their environments shape landscapes and vice versa. We strive to identify principles of sustainable landscape development by synthesizing empirical evidence across different temporal and spatial scales. We focus on advancing innovative approaches using land-use decision models in forecasting and backcasting models to inform and guide the sustainable transformation of urban, peri-urban, and rural areas. Building on decision-making theories, we develop new approaches and decision support platforms to help negotiate short- and long-term landscape development and land management goals that transcend sectors and scales.

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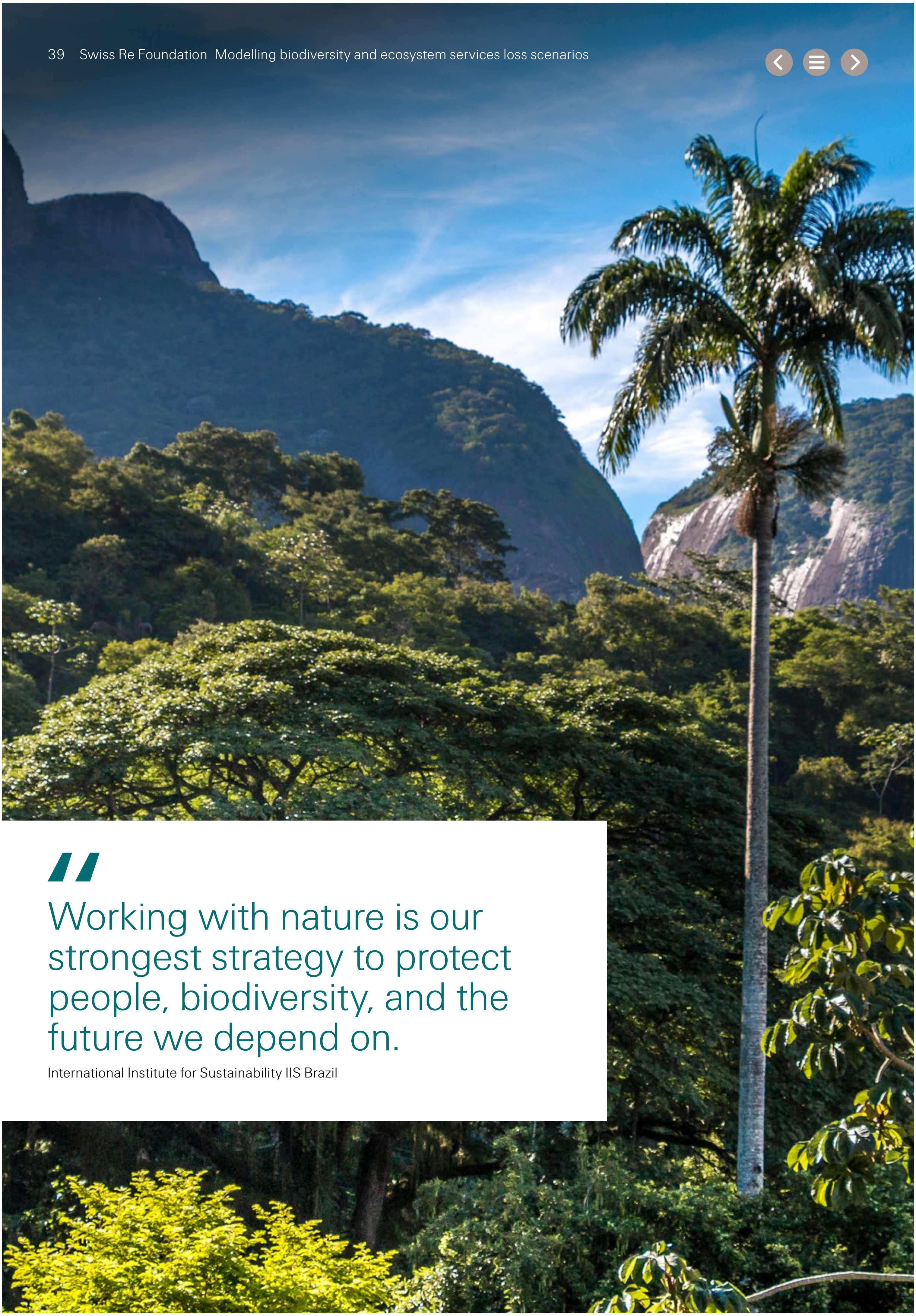

> Working with nature is our strongest strategy to protect people, biodiversity, and the future we depend on.

International Institute for Sustainability IIS Brazil

Development of a decision support framework to manage natural catastrophe risks for the state of Rio de Janeiro – International Institute for Sustainability IIS Brazil

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Introduction

Global climate and land-use changes are driving profound losses in biodiversity, ecosystem services, and human well-being, with impacts expected to intensify as extreme climatic events become more frequent and severe (IPCC, 2021; Prado et al., 2024). In this context, strategies focused solely on mitigation are no longer sufficient. Adaptation actions that strengthen societal resilience to climate-related hazards are urgently needed to sustain people ecosystem services (ES) provision and reduce disaster risks (Pörtner et al., 2022).

Nature-based Solutions (NbS) have emerged as a promising pathway to address this challenge. When strategically implemented, NbS can function as a no-regrets solution, simultaneously reducing climate risks, conserving biodiversity, and generating social co-benefits (IUCN, 2020, Lavorel et al., 2019). Identifying priority areas for NbS implementation is essential to maximize multiple benefits, improve cost-effectiveness, and advance climate justice through the reduction of long-standing socio-environmental inequalities (Holifield, 2001).

Here, we propose a spatial intelligence-based decision-support framework to guide the prioritization of areas for NbS implementation aimed at environmental disaster risk reduction. By translating complex ecological and socioeconomic data into spatially explicit and actionable information, the framework helps bridge the gap between science and policy, supporting informed investment in NbS. Applied to the state of Rio de Janeiro, Brazil, this approach demonstrates how data-driven planning can align global environmental commitments with local action, strengthening resilience while advancing biodiversity conservation and ecosystem restoration goals.

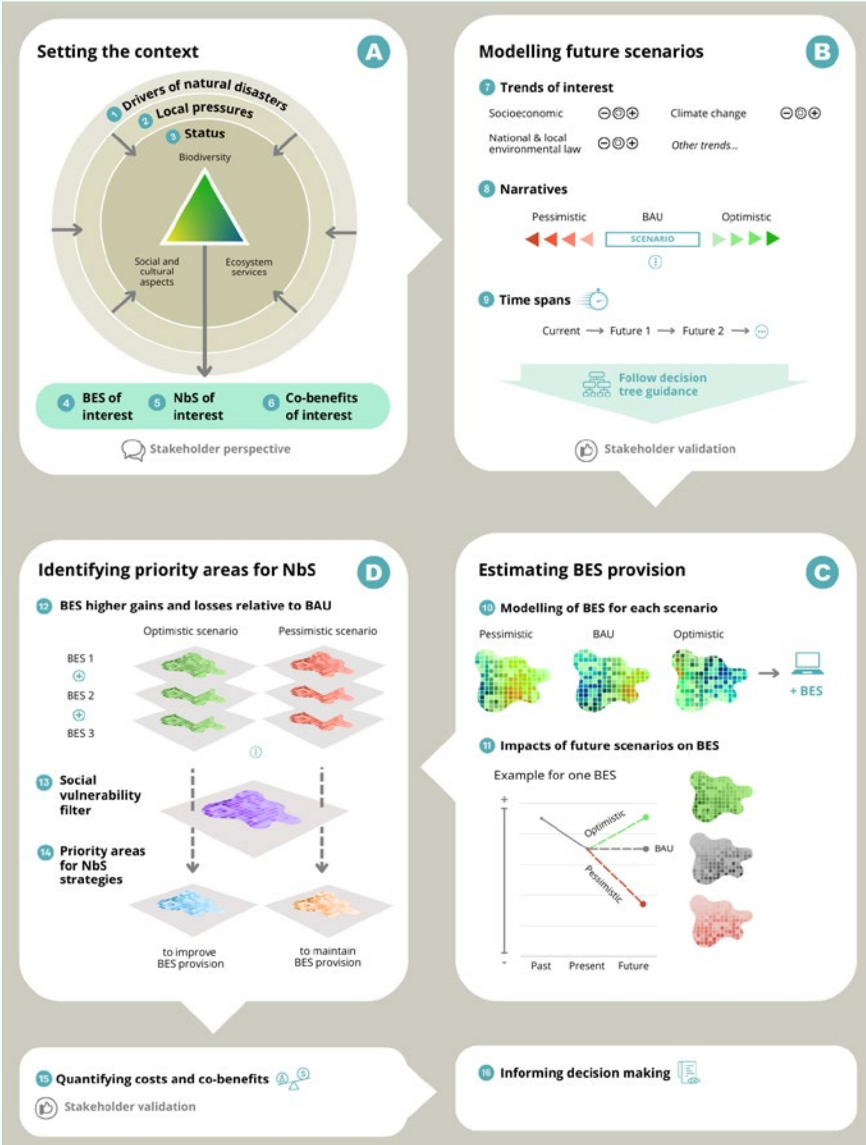
General Information:

1. Key assumptions:
Ecosystems provide essential services that help reduce disaster risks. However, land-use changes, and climate extremes are intensifying these risks. When strategically planned and spatially optimized, targeted Nature-based Solutions (NbS) can simultaneously strengthen environmental resilience, enhance ecosystem service (ES) provision, conserve biodiversity, and reduce social vulnerability.

2. Key methods:
This study presents a decision-support framework designed to identify priority areas for NbS implementation to manage environmental disaster risks (Figure 1). The framework integrates biodiversity and ecosystem services (BES) modelling with social vulnerability indicators under multiple land-use and climate scenarios. It is structured into four stages: (A) Setting the Context, which defines the socio-environmental conditions, key drivers, pressures, priority ES, and NbS of interest; (B) Modelling Future Scenarios, which projects alternative land-use and climate pathways; (C) Estimating BES Provision, which quantifies changes in ES provision across scenarios; and (D) Identifying Priority Areas, which integrates BES gains and losses with social vulnerability to select priority areas for NbS implementation, followed by cost (eg restoration implementation costs) and co-

benefit analysis (e.g biodiversity conservation). The framework is flexible and applicable across diverse contexts, supporting decision-making from local to regional scales.

Figure 1
Graphic representation of the framework for managing environmental disaster risks.



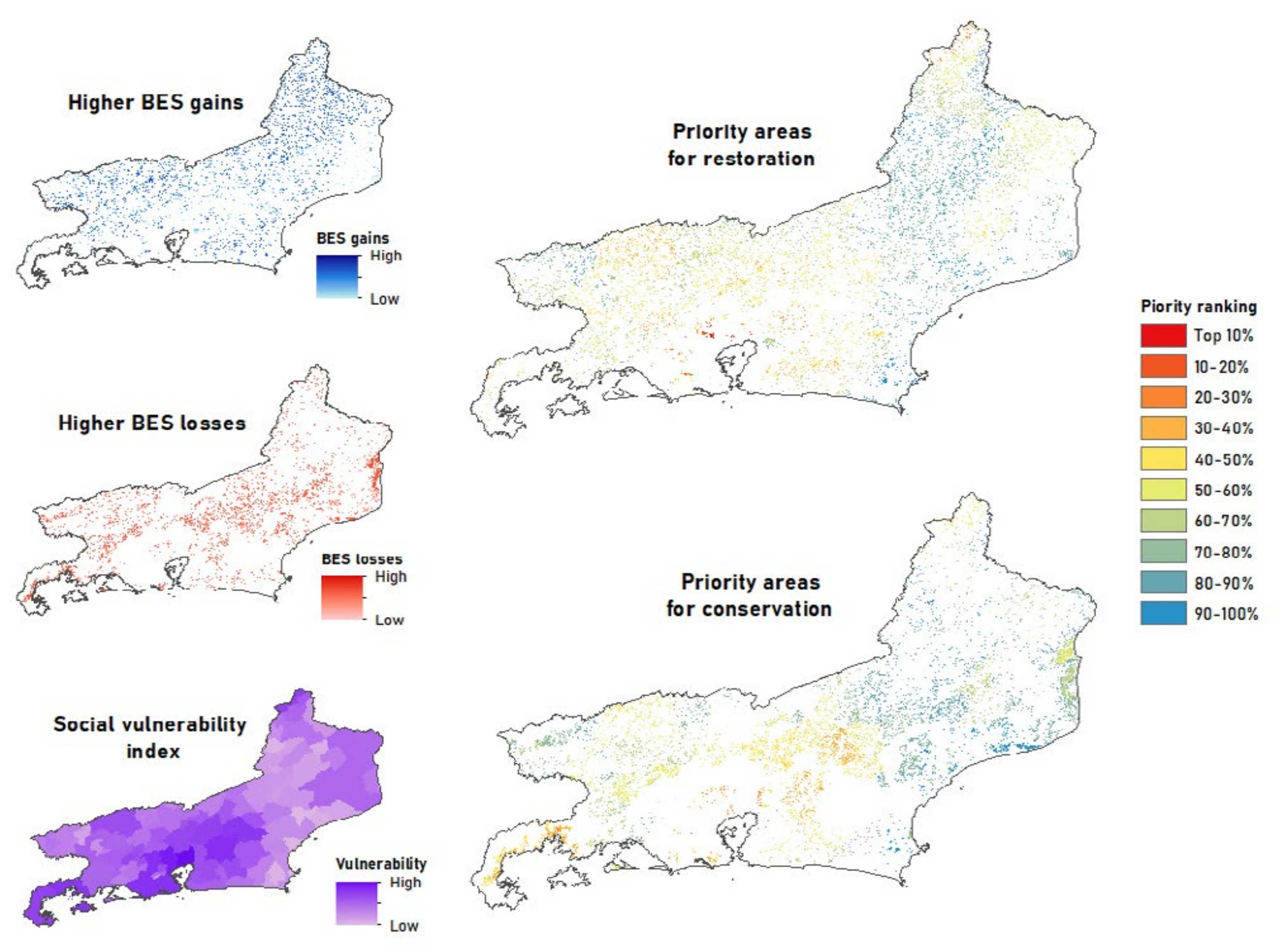
3. About future scenarios:

a. What are they: Three policy-relevant Land-use scenarios for 2050 were developed: (1) Optimistic: moderate urban sprawl (IPCC-SSP1), full compliance with Brazil's Native Vegetation Protection Law, and state restoration targets (+10% native vegetation cover); (2) BAU: Continuation of current trends (IPCC-SSP2) (+3% native vegetation cover); and (3) Pessimistic: urban sprawl (IPCC-SSP3), weak environmental policies, and loss of non-protected vegetation (–10% native vegetation).

b. How were they run/calculated: Land-use maps were modeled using MapBiomas data in combination with the IPCC Shared Socioeconomic Pathways. Extreme events were integrated into the analysis, including a 50 mm/h rainfall event to represent flood risk, a +5 °C urban heat island effect for cooling assessment, and high sea-level rise for coastal risk. InVEST models were then applied to quantify changes in flood regulation, heat mitigation, and coastal protection across scenarios.

4. Key results of scenarios – scientific findings:
Flood-risk reduction improved by +5.9% under the optimistic scenario, slightly under BAU (+1.4%), but fell sharply under pessimistic scenario (–9.7%). Thermal comfort rose +16.4% in optimistic, +6.8% in BAU, and dropped –16.4% in pessimistic scenario. Coastal protection remained stable in optimistic and BAU but worsened by +3.3% high-risk areas in pessimistic scenario. Priority areas overlapped regions of high social vulnerability, where NbS can deliver the greatest socio-environmental benefits (Figure 2). Co-benefit analysis showed significant carbon sequestration potential and avoided carbon losses, as well as biodiversity benefits for thousands of species through habitat gains.

Figure 2
Identification of priority areas for restoration and conservation in Rio de Janeiro, Brazil. Priority areas are identified by multiplying the higher BES gains (restoration) and BES losses (conservation) by the social vulnerability index.



5. From findings to recommendations – bridge:
Our approach optimizes NbS investments by identifying areas of both high impact and high need. Although data limitations and governance constraints remain challenges, the methodology provides a replicable and adaptable pathway for incorporating NbS into disaster risk management. Ongoing stakeholder engagement is crucial to ensure real-world applicability and equitable outcomes. By combining ecological modelling, climate projections, and social vulnerability mapping, this framework provides decision-makers with a robust tool to plan and prioritize NbS, building resilient, sustainable, and just societies.

6. Key recommendations (by scenario):
- Optimistic: Enforce vegetation laws; scale restoration to meet local/regional goals; target high-vulnerability zones.
- BAU: Integrate NbS into urban planning; maintain vegetation recovery trends; enhance green infrastructure.
- Pessimistic: Strengthen conservation of remaining native cover; prevent further degradation; prepare for higher disaster losses.

Across all: mainstream NbS into climate adaptation policy, link to carbon and biodiversity markets, and ensure social inclusion.

7. Key Messages to Stakeholders:
a. Scientists/Academia: "Advance science for real-world impact: replicate and test this approach across contexts to strengthen its policy relevance, co-produce knowledge with policymakers and practitioners, translate findings into actionable insights, and leverage research networks to amplify societal benefits."
b. Representatives from local/regional/national governments: "Turn science into stronger policy: use these findings to enhance disaster risk management and NbS implementation at all levels, evaluate what works, adjust regulations for greater impact, and collaborate with scientists to turn evidence into action. Lead with credibility through policies grounded in solid, transparent science."
c. Banking and insurance sector: "Reduce risk and seize opportunity: use our framework to identify and finance NbS that lower climate-related financial risks while generating returns, integrate climate science into investment, and lending strategies to meet and exceed ESG goals. Translate complex data into actionable risk indicators and position institutions of the sector as a market leader in sustainable finance and climate resilience."

Who We Are:

For over 15 years, the International Institute for Sustainability (IIS) has been a leading voice in advancing science-based solutions for land-use planning, ecosystem restoration, and climate adaptation. As a non-profit research organization from Brazil, IIS combines cutting-edge modelling, policy engagement, and field implementation to transform sustainability science into action. Our mission is to generate solutions that reconcile nature conservation with social and economic development, ensuring that people and ecosystems thrive together. IIS operates nationally and globally through a broad network of partners, including governments, universities, businesses, and multilateral organizations. We are guided by the principles of excellence, collaboration, commitment, independence, and flexibility, producing open-access, science-based tools and strategies that strengthen decision-making and public policy.

"Decision-Making in Environmental Disaster Management through Nature-based Solutions" is a pioneering IIS project developed under the biodiversity and ecosystem services scenarios modelling initiative, led by the Swiss Re Foundation, in partnership with the AXA Research Fund (now part of the AXA Foundation for Human Progress), WWF, and EY. The project was selected as one of the five global winners, recognizing its innovative approach to integrating Nature-based Solutions (NbS) into climate adaptation and disaster risk management. The project designed a decision-support framework to identify priority areas for NbS implementation under future climate and land-use scenarios, using the

Rio de Janeiro state (Brazil) — one of the country's most climate-vulnerable regions — as a study case. The framework connects ecosystem service modelling, social vulnerability analysis, and economic valuation to guide investments where nature can most effectively reduce disaster risks such as floods, heatwaves, and coastal erosion.

Main Achievements:

- Developed a four-stage operational framework to integrate NbS into disaster risk management.
- Modelled three land-use and climate scenarios for 2050 (optimistic, BAU and pessimistic) using InVEST tools to assess impacts on flood-risk reduction, thermal comfort, and coastal protection.
- Mapped priority NbS areas in Rio de Janeiro state, where ecological gains overlap with high social vulnerability.
- Estimated costs, carbon sequestration potential, and biodiversity co-benefits to guide restoration and conservation investments.
- Received the 2025 MapBiomas Award (Climate Emergency Category), recognizing its innovative use of national land-use data to address climate resilience challenges.

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Project outputs and publications:

Available on IIS's institutional page under 'Project' → 'Framework to guide the mitigation of environmental disasters through Nature-based Solution'.

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> Nature sustains our lives. As climate change alters natural systems, understanding impacts on livelihoods is essential for crafting adaptation strategies that are locally-owned and relevant.

University of Belize Environmental Research Institute UB-ERI and CATIE

Forest cover change in Belize intensifies projected climate driven decreases in soil water availability and exacerbates local surface runoff – University of Belize Environmental Research Institute (UB-ERI) and CATIE

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Introduction

Futures for People & Nature in Central Belize is a project developed by UB-ERI. The project was selected as one of five global winners under the Biodiversity and Ecosystem Services (BES) Scenarios Modelling Initiative, led by the Swiss Re Foundation, in partnership with AXA Research Fund (now part of the AXA Foundation for Human Progress), WWF, and EY.

Nature underpins society's health and prosperity, and inspires and connects us to the world around us (Diaz et al., 2015). Changing climate patterns will alter the state of nature and therefore affect our livelihoods, well-being, and quality of life (Pörtner et al. 2022). Understanding what impacts will occur and where can help in charting strategies for adapting to these changes. Through a participatory process, the UB-ERI supported 21 local communities in Central Belize to chart local actions towards climate resilience that safeguards their way of life. This was done by cooperatively identifying with them climate impacts on local livelihoods, sharing modelled scenarios of future soil water availability and surface runoff, and engaging them in visioning. The approach is the first of its kind to be implemented nationally in Belize and can provide a toolkit for replication across various landscapes and contexts. The communities that collaborated in generating the findings of this project include: La Democracia, Mahogany Heights, Cotton Tree, St Matthews, Frank's Eddy, Harmonyville, More Tomorrow, Gracie Rock, Hattieville, Armenia, St. Margaret, Freetown Sibun, Isabella Bank, Flowers Bank, Willows Bank, Scotland Half Moon, Rancho Dolores, Bermudan Landing, Lemonal, St. Paul's Bank, Double Head Cabbage.

Main Achievements:

- Mapping of livelihood and related climate impacts across 21 communities in Central Belize.
- Modelled outputs of soil water availability and surface runoff across all of Belize for 2021–2040 under SSP5-8.5 scenario (fossil-fueled development) and BAU land-use scenario, using InVEST tool.
- Publicly accessible community "Storymaps" of all local livelihood, climate impact data and community visions.
- Development of a Landscape Management Plan for the Sibun River watershed using this approach.

Key Assumptions

Ecosystems and the services they provide are under increasing pressure from changes in land use, climate variability and extreme events. Local and regional planning decisions currently lack sufficient integration of future scenarios of climate and land use change, and how they impact local communities. Engaging communities to integrate their knowledge and values, coupled with spatially-explicit modelling of ecosystem services can help steer more locally-relevant adaptation pathways, thereby reducing social and ecological risk.

Key Methods

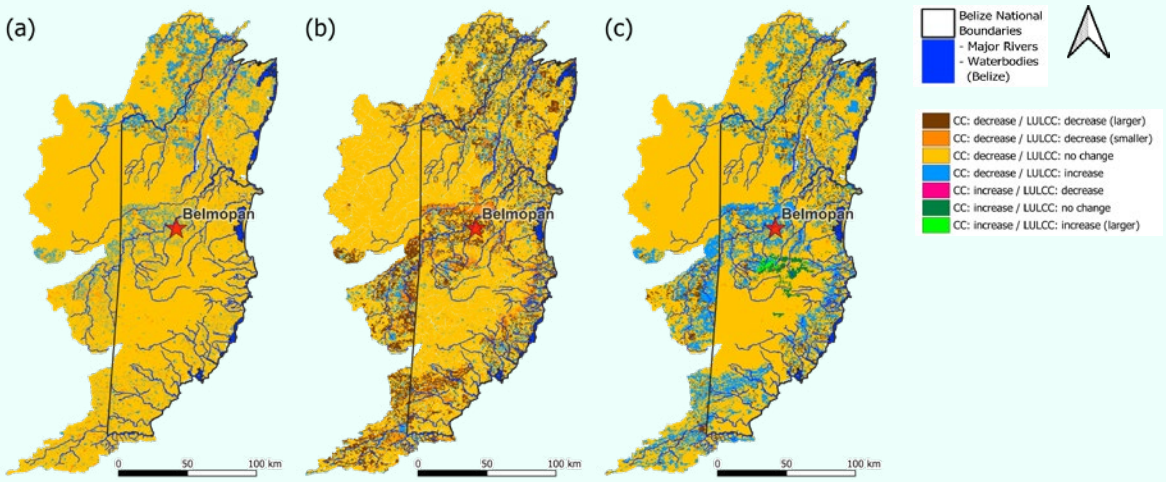
- Ecosystem Service Scenario Modelling:
  The project uses the InVEST tool (Natural Capital Project 2025) to model how different climate and land use futures may affect water ecosystem services critical to livelihoods in central Belize. The project models soil water availability (baseflow) and surface runoff (quickflow) under IPCC-Shared Socioeconomic Pathway SSP5-8.5, and under a Business as Usual deforestation rate. The modeled results are compared to historical climate and land use conditions.As recommended by model developers (Natural Capital Project, 2025), we sourced all climatic data required by InVEST from the public online database WorldClim v.2.1 (Fick and Hijmans, 2017) at a spatial resolution of 30 arc-seconds.
- Participatory Mapping:
  Engagement with 21 communities through mapping workshops documented local ecosystem-livelihood dependencies, climate impact knowledge, and community priorities tied to the surrounding landscapes.
- Visioning with the Three Horizons Approach (Sharpe et al., 2016):
  A futures-thinking framework was applied to support communities in envisioning preferred pathways for resilience and identifying practical actions to achieve them.

Scenarios used:
The project models soil water availability and surface runoff under IPCC SSP5-8.5: Fossil-fueled Development for the period 2021-2040. We selected SSP5-8.5 for all our simulations to incorporate a high level of greenhouse gas emissions and to ensure comparability with previous research due to the widespread use of this SSP (Briley et al., 2021; Sarofim et al., 2024). The land-use/land cover change (LULCC) scenario we utilized translates to a business as usual (BAU) deforestation rate of 0.6%, as derived by Martin-Arias et al. (2022) for the baseline period of 2008-2018. The modeled results are compared to historical climate conditions from 1970-2000 and historical land use conditions in 2001.

Key findings of scenarios (scientific findings):
Simulated climate change (CC) and land-use/land cover change (LULCC) impacts reinforce or counteract each other in a spatially variable way across Belize (Figure 1). Generally, LULCC tends to intensify CC-driven reductions in the case of soil water availability (baseflow) and mitigate them in the case of surface runoff (quickflow). However, LULCC reinforced or counterbalanced the precipitation-driven reductions in surface runoff (quickflow) depending on the area and the assessed flow component. Accordingly, despite the drying effects of CC, the conversion of forest to agricultural land will likely result in locally increased surface runoff volumes across Belize. Summing baseflow and quickflow into a Total Flow parameter shows that these contrasting effects offset each other in the south of Belize, implying no net change in Total Flow in this southern region. In the north, the magnitude of the quickflow trend is higher, resulting in positive Total Flow values there, implying net increase in Total Flow.

Figure 1

Direction and qualitative magnitude of change in annual **(a)** Total Flow, **(b)** Baseflow, and **(c)** Quickflow, from comparing the CC scenario, and the LULCC scenario, with historical conditions, respectively. Of special significance are areas in brown and bright orange in **(b)** where CC and LULCC effects reinforce each other and project a reduction in soil water availability (Baseflow). Areas in bright green in **(c)** indicate areas where CC and LULCC effects also reinforce each other and project an increase in surface runoff (Quickflow). In **(c)** areas in blue show areas where the effects of CC and LULCC compensate each other but the overall projection is still an increase in surface runoff.



Recommendations for policy and planning

Our holistic community-driven approach assists local communities to engage in future thinking by compiling and visualizing climate impacts on local livelihoods, and presenting them with critical future scenarios of soil water availability and surface runoff. Based on this information, communities collectively outlined local actions towards climate resilience. These actions represent practical, grassroots measures that local and national decision-makers as well as civil society and the private sector might support and scale up to further climate change adaptation at the landscape level.

Key recommendations

As the BAU scenario in this study highlights, the overall decrease in soil water availability and increase in surface runoff, particularly linked to changes from forest to agriculture, point to the need for forest/vegetation conservation and restoration to future-proof the effects of such expected changes, particularly surrounding urban and rural communities. As articulated by communities during this process, solutions include (i) restoring critical vegetation linkages including riparian zones, (ii) investing and scaling agricultural practices that conserve water such as silvopastoral and agroforestry systems, and (iii) promoting native climate-smart crops.

Key Messages to Stakeholders

1. Banks; Funders (IFIs, Climate Finance Sector); Insurance: Mobilize investments across scales for landscapes/ecosystems supporting the various economic sectors to prioritise areas with the highest risk or loss potential.

2. Representatives from local/regional/national governments & NGOs: Mainstream our approach into on-going national efforts through national agencies to influence decision-making eg Adaptation Planning. Co-create and empower: engage communities early and find ways to empower their self-advocacy eg through making information accessible; capacity-building; co-creating locally useful data tools and/or plans for livelihoods, sustainability, disaster management, climate resilience/ adaptation.

3. Academia: Replicate and scale-up the community-driven approach across socio-cultural and economic contexts to understand generalities/specificities and co-produce sustainable pathways across diverse landscapes and communities.

Who We Are:

Established in 2010, the University of Belize Environmental Research Institute (UB-ERI) is a semi-autonomous unit of Belize's national university. UB-ERI helps the University fulfil its education and research mandate through nationally relevant training, research, and strategic communication and outreach. The mission of the UB-ERI is to advance environmental science and support a culture of evidence-based decision-making relevant to sustainable development in Belize, under the vision "Environmental Science for the prosperity of Belize's Ecosystems and Society." UB-ERI's work spans both terrestrial and marine ecosystems and includes fundamental biodiversity research and monitoring, ecosystem services, climate risk assessments, data management, and analysis to support decision-making.

The UB-ERI has three main work areas: Research and Monitoring, Training and Fellowships, and Communication and Outreach, organised under its Sustainable Landscapes and Coastal Resilience programmes. Over the past decade, the UB-ERI has expanded its scope beyond conservation science to include work that integrates livelihoods, business planning, and market-based approaches to sustainability, with a strong commitment to locally led development and strengthening the capacity of rural communities. UB-ERI's stakeholder engagement and outreach activities across private, public, not-for-profit, and civil society sectors are a critical part of the Institute's work and a central pillar of its communication and dissemination strategy.

The UB-ERI has a wealth of experience in stakeholder engagement through the development of conservation action plans, area management plans, and sustainable development plans, including the Central Belize Corridor Conservation Plan, Sibun River Watershed Landscape Management Plan, and the Sustainable Development Plan for the Chiquibul Mountain Pine Ridge-Caracol Complex. These initiatives required wide stakeholder consultation with over ten communities within the project area, non-governmental and government partners, as well as the private sector. In addition, the UB-ERI has a track record of successfully working with community-based groups, more recently with the Maya Nut and Farmers' Association in Harmonyville to support the development of a micro-business focused on products from Maya Nut *(Brosimun alicastrum)* seeds. Previous work with Mayan villages of Santa Cruz and Santa Elena focused on governance strengthening with the Rio Blanco Mayan Association, and governance work with the Belize Federation of Fishers. These experiences have not only deepened UB-ERI's expertise in community-based natural resource governance but also in enterprise development, business skills training, and identifying viable livelihood opportunities for local communities, with an emphasis on equitable participation and culturally grounded engagement.

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Meet the Team

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Project outputs and publications

Available on UB-ERI's institutional page under 'Projects' → 'Climate Crossroads: Futures for People & Nature in Central Belize'.

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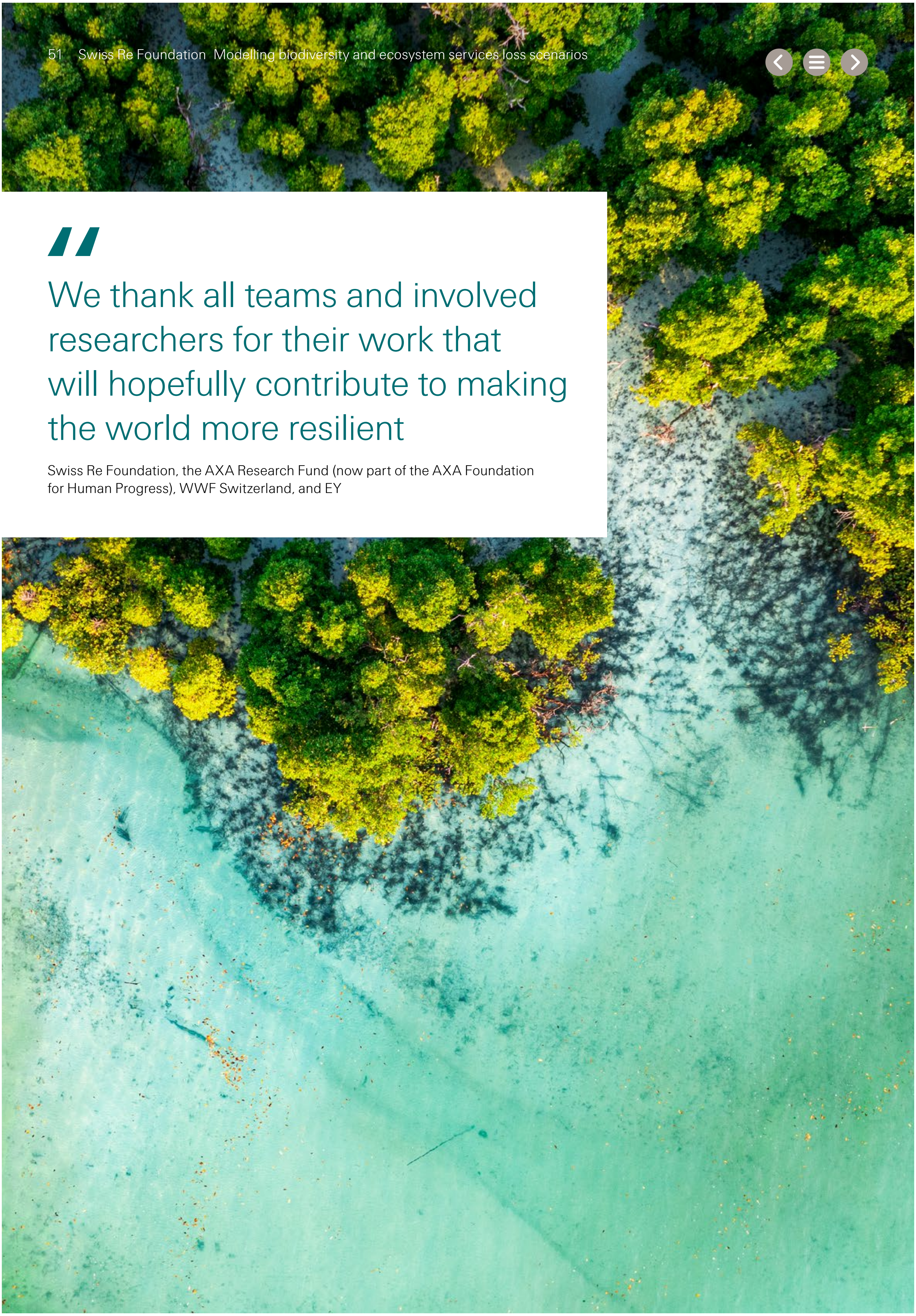

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