universität freiburg

future forests

Excellence Cluster **Future Forests** –

Adapting complex social-ecological Forest Systems to Global Change

Project Summary

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1. Introduction and Rationale

Forests cover approximately 30% of the Earth‘s land area and are vital for providing renewable resources, mitigating climate change, supporting human health, and maintaining biodiversity. However, forests are facing unprecedented challenges due to rapid climate change, novel disturbances, species turnover, and shifts in societal demands and values. These changes are leading to the emergence of „novel forest social-ecological systems“ (SESs) with no histo-rical precedent (Figure 1), raising uncertainties about their ability to provide critical ecosystem services (ESs) and sustain biodiversity.

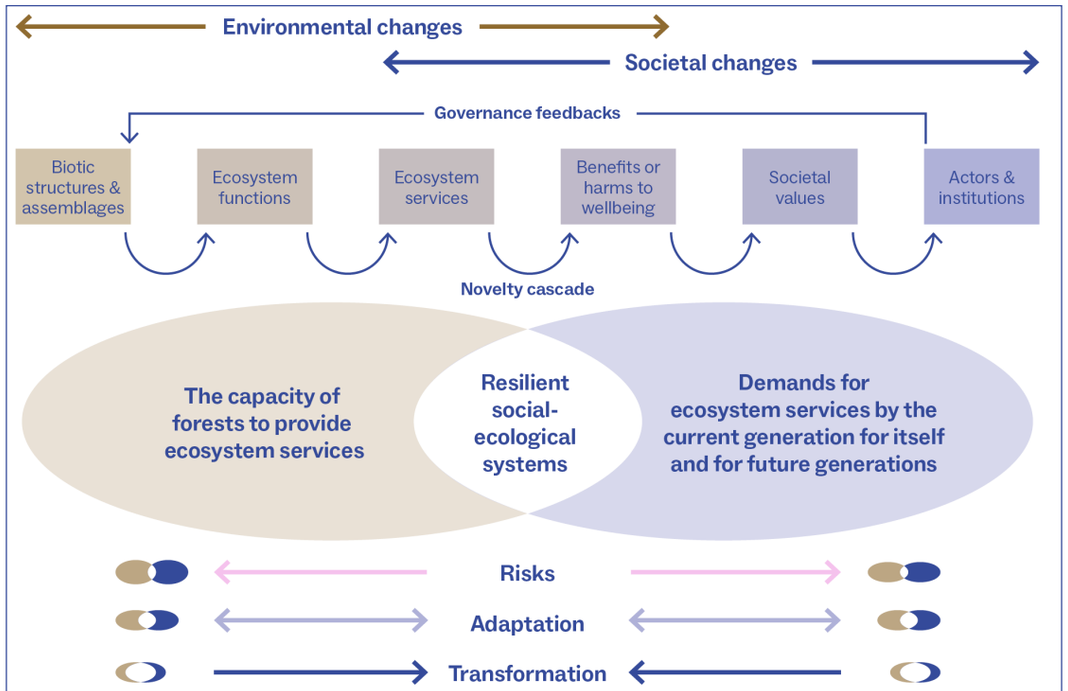


Figure 1 Conceptual understanding of resilient forest SESs and how they are shaped by environmental and societal changes, risks, and adaptation and transformation (A&T) approaches.

Parallel to ecological change, social dynamics—such as urbanisation, globalisation, shifting land use, and changing attitudes—are transforming how societies interact with and manage forests. These intertwined natural and social processes create complex, wicked problems that current forest science frameworks cannot adequately address. There is an urgent need for integrative approaches that combine social and natural sciences to co-produce new knowledge and options for action.

The Future Forests Cluster aims to become a leading centre for the science and governance of adapting and transforming forest social-ecological systems, with an initial focus on Germany‘s Black Forest and Upper Rhine Valley, and ambitions for knowledge and model transferability worldwide.

2. Vision and Objectives

2.1.Overarching Vision

Future Forests will develop into an internationally visible centre for interdisciplinary and transdisciplinary research on issues of adaptation and transformation of forests and forestry. Against the backdrop of rapid global change and profound uncertainties, it will provide robust adaptation options and decision-making bases for policy and practice based on social-ecological research approaches.

2.2. Research Objectives

Future Forests will:

1. Generate generic knowledge and tools for analysing, developing, and assessing adaptation and transformation pathways (A&TPs) for resilient, biodiverse forest SESs.
2. Unravel the ecological and social mechanisms conferring resilience and adaptive capacity in novel SESs.
3. Understand the challenges in decision-making under uncertainty and normative ambiguity regarding forest management and governance.
4. Advance SES theory by developing a comprehensive and operational Forest SES framework.
5. Identify and test viable adaptation and transformation pathways using regionalised scenarios and multidimensional modelling.
6. Develop and assess innovative, adaptive governance approaches for transfer and scaling globally.

2.3.Structural Objectives

Future Forests will:

- Foster a productive, inclusive, inter- and transdisciplinary research environment supporting scientists at all career stages.
- Establish career development structures—especially for early career researchers (ECRs)—that encourage diversity, equity, and independent interdisciplinary work.
- Create new professorships, junior research groups, and international/national research hubs.
- Innovate science communication, stakeholder engagement, and teaching approaches.

3. Research Programme Structure

The programme is divided into three closely linked research areas (RA, Figure 2), each comprising several research themes. The research areas are supported by a number of central structures.

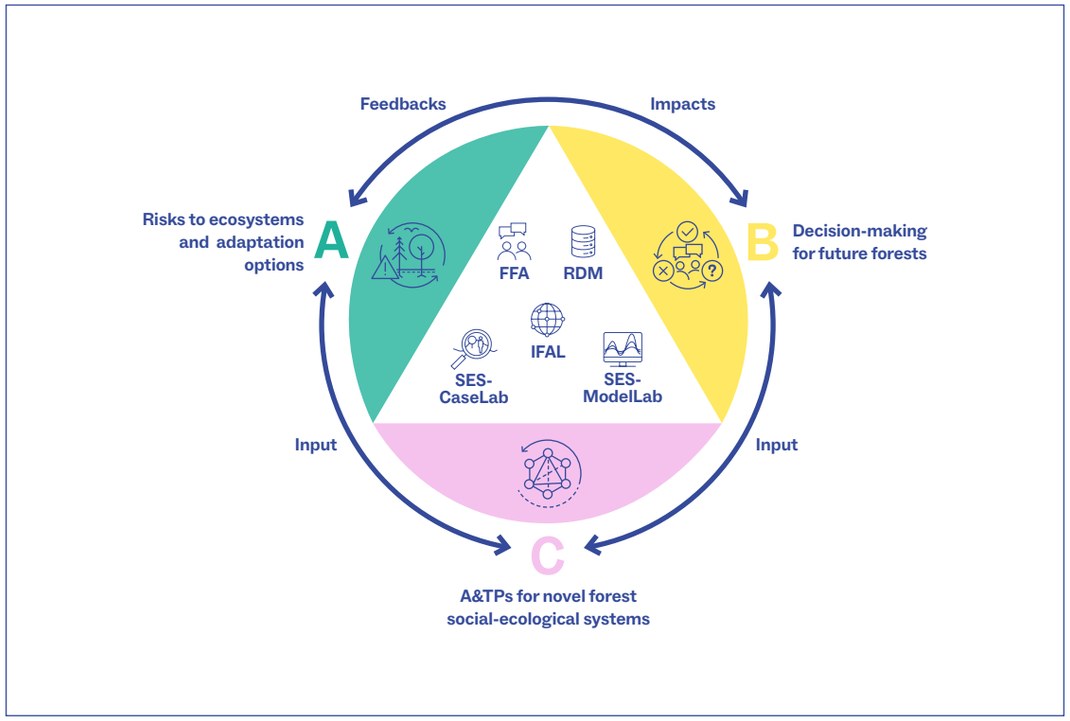


Figure 2 General project structure with Research Areas (RAs) and central structures of the Cluster. FFA = Future Forests; Academy; RDM = Research Data Management; IFAL= International Forest Adaptation Lab; SES-ModelLab = Social-Ecological Systems Modelling Lab; SES-CaseLab = Social-Ecological Systems Case Study Lab

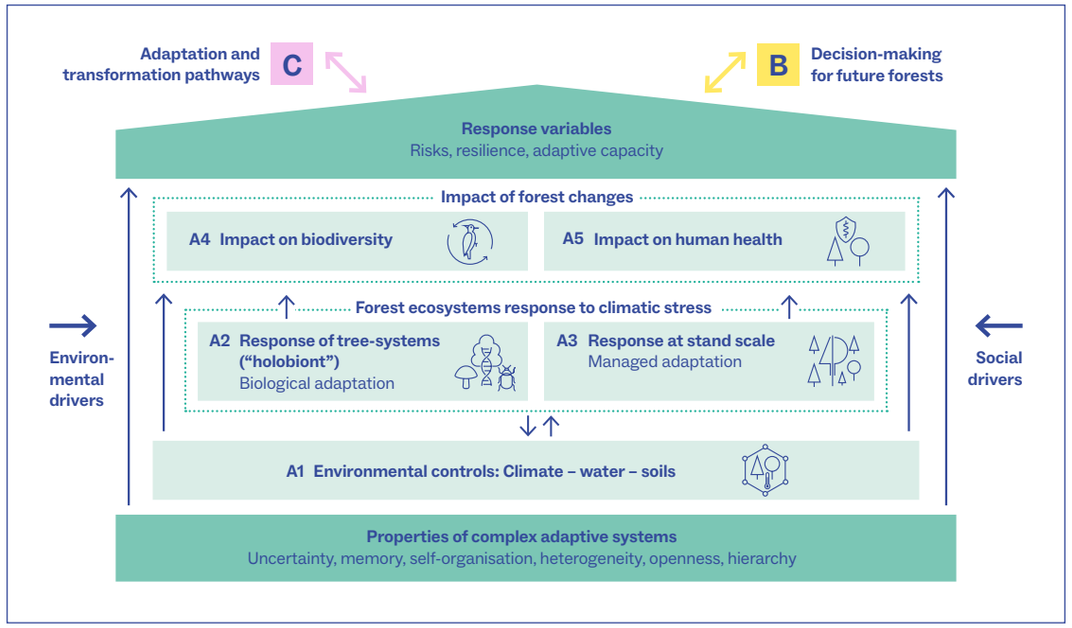


Figure 3 Conceptual organisation of RA A with Themes 1-5 and their interconnection (from environmental controls to responses to impacts) and integration into the Cluster. Individual Themes will address selected CAS properties.

3.1. RA A: Risks to Ecosystems and Adaptation Options

- Quantifies risks to forest ecosystem functioning and ES provision driven by environmental and social factors (Figure 3).
- Analyses resilience and adaptive capacity across different biological levels, via advanced monitoring networks, experiments, and modelling.
- Provides critical empirical data and understanding for other cluster research areas. innovations (C4).
- Integrates data, theory, and practical governance experiments to identify, test, and facilitate robust and adaptive future pathways.
- Supports the translation of research insights into actionable recommendations for policy and practice.

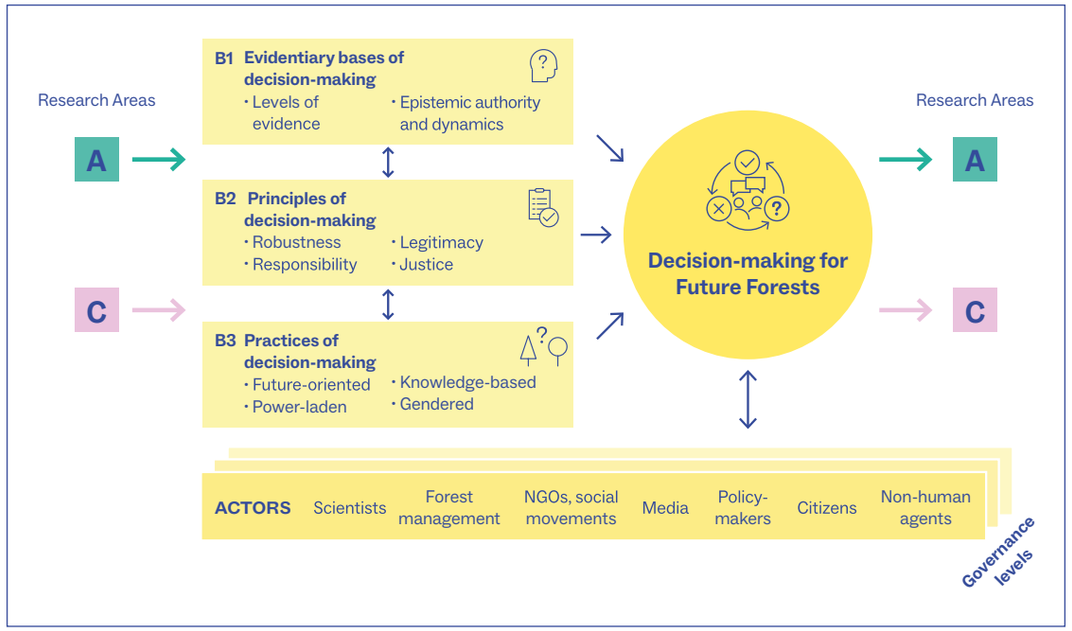


Figure 4 Conceptual organisation of RA B, Themes (B1-B3), actors involved and considered in research and integration into the Cluster.

Forest mortality in the Black Forest region as a result of natural disturbances. The impact of disturbances on future forest mortality will be one focus of Future Forests research. Photo: Teja Kattenborn

3.2. RA B: Decision-Making for Future Forests

- Examines how diverse actors (governments, owners, NGOs, citizens) make decisions under uncertainty and ambiguity (Figure 4).
- Investigates shifting knowledge bases (evidence), evolving normative principles (e.g., robustness, legitimacy, justice), and the practicalities of decision-making in real-world contexts.
- Employs qualitative and mixed-method social science approaches, integrated with natural science insights.

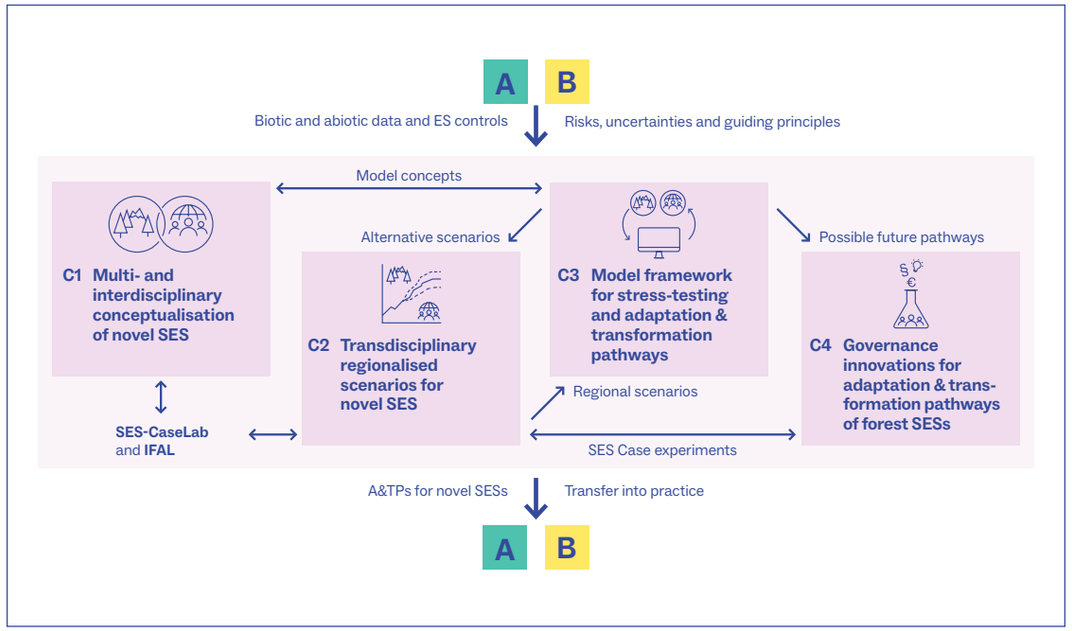


Figure 5 Conceptual organisation of C with Themes (C1-C4), their connections and integration into the Cluster.

3.3. RA C: Adaptation and Transformation Pathways for Novel Forest SESs

- The integrative core of the Cluster (Figure 5), advancing SES theory (C1), developing regionally-relevant scenarios (C2), constructing and applying comprehensive multi-scale models (C3), and piloting/assessing governance innovations (C4).
- Integrates data, theory, and practical governance experiments to identify, test, and facilitate robust and adaptive future pathways.
- Supports the translation of research insights into actionable recommendations for policy and practice.

Discussions between Future Forests researchers and Cem Özdemir (former German Federal Minister of Food and Agriculture). Future Forests will co-design forest research jointly with practitioners, foresters, forest owners and policy makers. Photo: BMEL

4. Methods and Innovations

- Complex Adaptive Systems (CAS) Thinking:
  - Theoretical foundation using CAS to guide research design, collaboration, and management within the cluster.

- Hierarchical and Nested Study Design (Figure 6):
  - Multi-scale empirical approach, from molecular and organismal processes to landscape and regional dynamics.

- Advanced Modelling and Data Science:
  - Linking physical, ecological, social, and economic models; leveraging machine learning, remote sensing, and agent-based modelling.

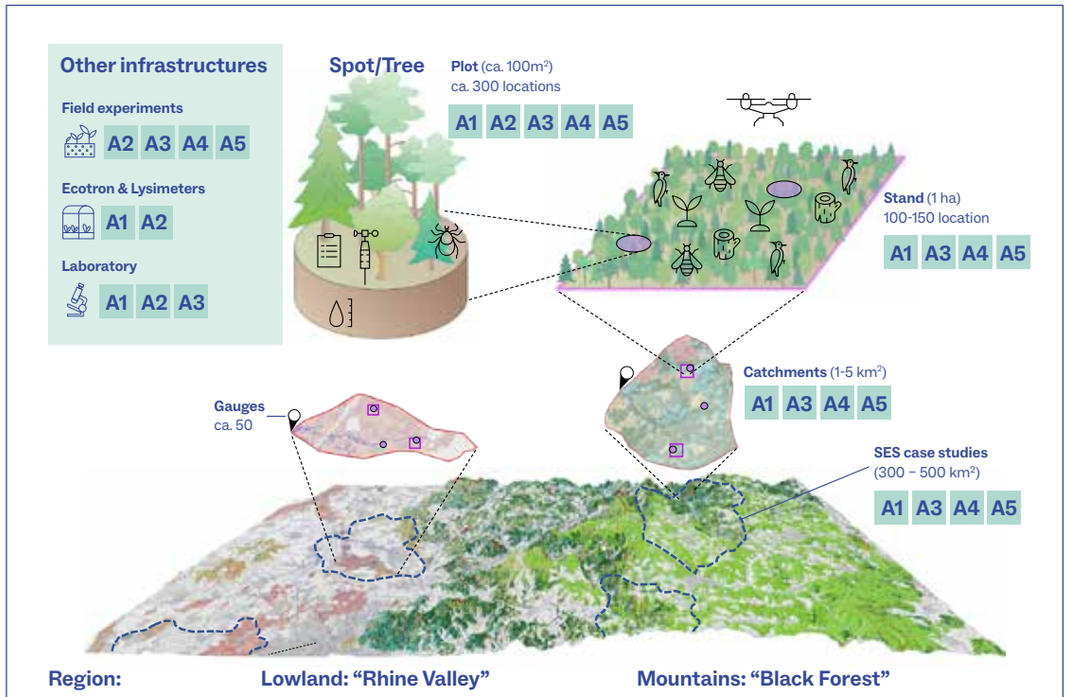
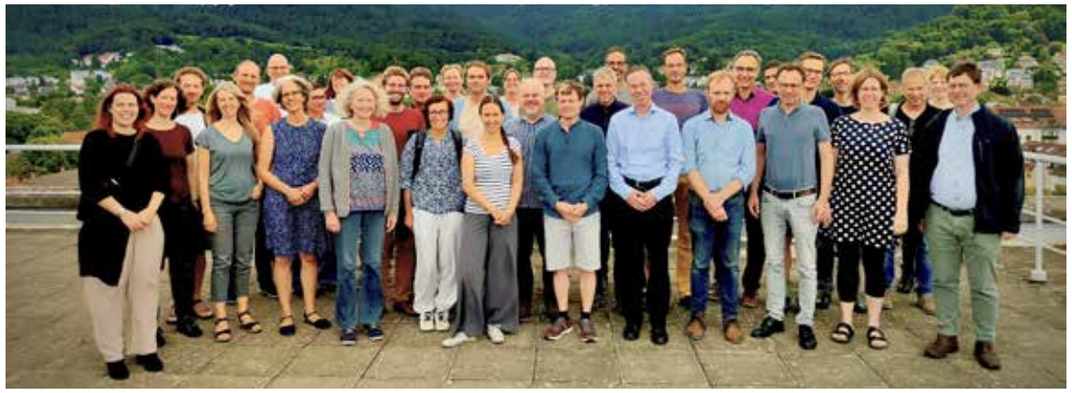


Figure 6: Study design of Research Area A, organised along abiotic and management gradients and nested spatial scales with their social and natural subsystems. The two regions harbour a) lowland forests with Pinus sylvestris on poor sand or gravel substrate and heterogeneous alluvial mixed oak forests in the Rhine Valley, and b) near-natural montane coniferous-broadleaved mixed forest, dominated by Picea abies, Abies alba, and Fagus sylvatica in the Black Forest. Each region will have several case studies. Here, we focus on scales relevant to Themes A1-A5. They will interact with RA C at all spatial scales and with RA B mostly at the SES case study scale.

- Real-World Case Studies and Stakeholder Co-creation:
  - Intensive research in two climate-change hotspot regions in Germany (Figure 6), with plans for expansion and knowledge transfer through the International Forest Adaptation Lab (IFAL).

- Transdisciplinary Science Communication and Outreach:
  - Innovative strategies to engage policy, practitioners, and the public; co-production of knowledge and mutual learning.

5. People and Environment



Future Forests research team. Photo: Ronny Rotbarth

5.1. Team

- A diverse, internationally recognised set of experts from forest ecology, management, economics, law, policy, modelling, medical sciences, social sciences, and more.

5.2. Environment

- Hosted by the University of Freiburg, a leading institution in forest sciences, with access to state-of-the-art labs, extensive experimental forest infrastructure, and long-term regional partnerships.

5.3. Partnerships

- Strong collaborations with German and international research centres, governmental agencies, NGOs, regional stakeholders, and global research networks (Figure 7).

6. Support, Structures, and Networking

- Early Career Researchers (ECR) support via the Future Forests Academy (FFA), incorporating mentoring, training, independence budgets, and innovative career development opportunities.
- Equality, diversity, and inclusion (EDI) embedded as a guiding principle in recruitment, management, and training.
- Research Data Management (RDM) ensuring FAIR principles, high interoperability, and open access.
- Central facilities:
  - **Social-Ecological Systems Case Study Lab** (SES-CaseLab) for coordinating case studies and stakeholder engagement.
  - **SES-Model Lab** for technical and conceptual leadership on modelling.
  - **International Forest Adaptation Lab** (IFAL) for global collaboration and knowledge transfer.

Figure 7 Partners and collaborators of Future Forests.

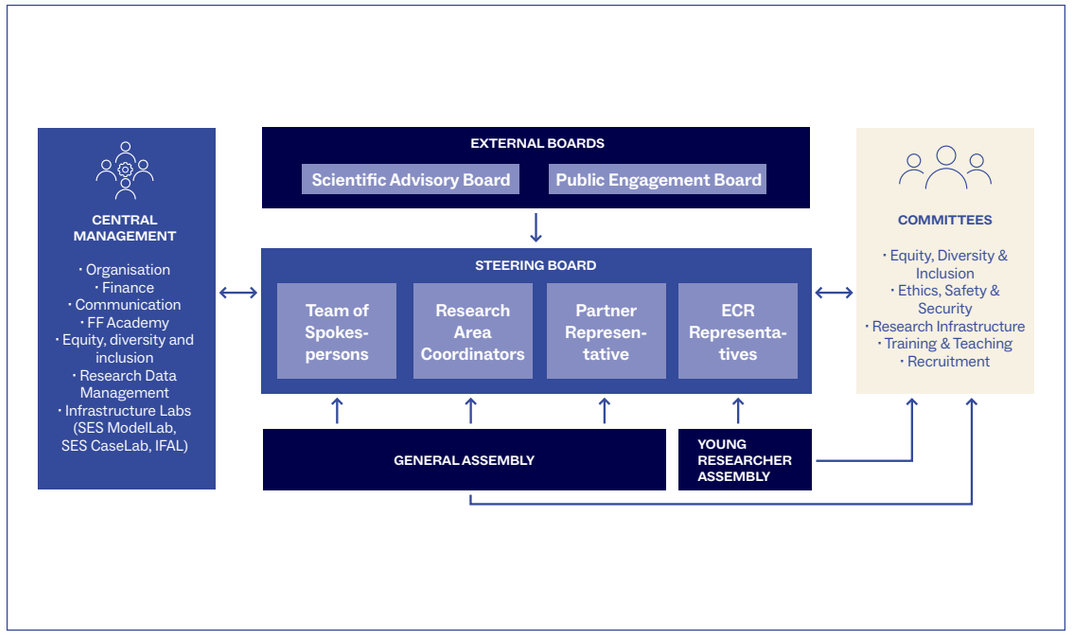


Figure 8 Management Structure of the Future Forests Cluster. ECR = Early Career Researchers.

7. Governance and Quality Assurance

- Transparent, dynamic management with steering and advisory boards, strong stakeholder and public engagement through dedicated boards (Figure 8).
- Annual reviews, quality control protocols, integrated feedback, and flexible funding for innovation and high-risk proposals.
- Commitment to open science, ethical conduct, responsible data stewardship, and robust EDI processes.

8. Science Communication and Teaching

- Actionable, transparent, and reflexive science communication for policy, practitioners, and society.
- Digital 'Knowledge Hub' and events, immersive virtual and real-world experiences, and targeted education for students and professionals.
- Integration of research with teaching from high school to graduate level, fostering new generations of transdisciplinary forest SES scientists.

9. Expected Impact

9.1. Scientific

- Innovative forest adaptation solutions that consider ecosystem capacity and integrity as well as societal values and demands.
- Establishment of new standards for integrated forest SES research and modelling; advancements in theory, empirical understanding, and application.

9.2. Societal

- Direct support for forest management, policy, and governance aimed at adapting forests to global change to ensure future provision of ecosystem services; contribution to biodiversity conservation, climate mitigation, human health, and sustainable resource use.
- Contribution to the conservation of biodiversity, climate protection, human health and the sustainable use of resources.

9.3. Global

- Transferability and scalability of frameworks, tools, and governance innovations to diverse social-ecological contexts worldwide.
- Establishment of a network of living labs that focus on the adaptation of forests as social-ecological systems

10. Conclusion

The Future Forests Cluster of Excellence offers a novel, comprehensive, and actionable approach to the adaptation and transformation of forests in an era of rapid environmental and societal change. Combining outstanding interdisciplinary expertise, advanced research infrastructure, innovative methods, and strong partnerships, the Cluster is poised to become a global leader in forest SES science and sustainability solutions.

Collaborations and participation inquiries are welcome. For more information, visit our website https://uni-freiburg.de/futureforests-en/ or contact the coordination team.

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Imprint

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Stefan-Meier-Str. 76
79104 Freiburg
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Design and layout by
Tamara Klaas
Marketing & Events