Final project report
Funpotential

Project acronym	Funpotential
Project title	Potential of functional diversity for increasing the disturbance resiliency of forests and forest-based socio-ecological systems
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Project coordinator (Name)	Mikko Peltoniemi, research prof.
Project period (Start date – End date)	1.4.2021-31.3.2025
Project website, if applicable	https://projects.luke.fi/Funpotential/

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Period covered by this report:	1.4.2021-31.3.2025

List of partners involved in the project (company/organisation and principal investigator). Please use partner numbers to specify the tasks, work packages and inputs of each partner in the different sections of the report	P1:Natural Resources Institute Finland (Luke) P2:INRAE, France P3:Georg-August-Universität Göttingen, Germany (UGOE)

1. Public summary

Climate change and related extreme weather events pose a significant threat to forest ecosystems in Europe. This has detrimental effects on the provision of ecosystem services and, consequently, on human well-being. The Funpotential project demonstrated that increasing tree species diversity and enhancing forest structure are crucial for bolstering forest stability against disturbances and to minimize losses due to competition-driven background mortality. New ecological research conducted in Funpotential indicates that the efficiency and effectiveness of this nature-based solution depend heavily on species identity, traits, and the spatial scale considered. Landscape factors also play a role in shaping disturbance impacts, larger disturbance patches generally in landscapes with large canopy gaps. Increasing extreme events may still undermine the ability of species mixtures to buffer adverse climate effects, and new management solutions are required. Species diversity itself is not a panacea for forest adaptation: enhancing stability with less productive tree species will likely create trade-offs with the provision of wood and income. To mitigate such trade-offs, financial support for investment costs is essential, allowing for suitable mixtures that include more productive, albeit susceptible, conifers. Management guidelines and supporting policies should also account for larger spatial scales in terms of diversity in structures and species, accompanied by collective financial schemes to promote stronger joint action in adaptation strategies. Urgently, developing adaptation strategies and policies requires the maintenance, extension, and alignment of forest health monitoring within national and international

inventories. Based on the ecological research, model development and economic analysis, we arrived to the following key messages: It is important to i) monitor and maintain forest health, ii) openly share monitoring data, iii) develop and test relevant species mixture combinations for their resilience, iv) acknowledge that trade-offs of resilience and economic profitability are likely, and that financial incentives for maintaining appropriate tree species mixtures (e.g. conifer groups in mixtures) would be useful for maintaining stabile forest production, and that v) appropriate diversification should be ensured and incentives offered at all spatial scales.

Figure 1 Case study areas in Finland (boreal), Germany (temperate), and France (Atlantic)

2. Objectives of the research

The overall aim of Funpotential is to develop disturbance-resilient forest management strategies and policies that balance the provision of timber and climate services, and sustain biodiversity in a changing climate. To achieve this aim, we will:

1. **Create functional-diversity-sensitive models for forest mortality and disturbance effects, and associated climate change scenarios** (WP1);
2. **Analyse the role of functional diversity in forest recovery to disturbances,** and the feasibility of creating nature-based forest management solutions that foster recovery (WP2);
3. **Propose optimised nature-based** local **forest management solutions**, and evaluate the potential of functional diversity for improving risk-return balances under climate change-sensitive disturbances, via stand and enterprise-level economic analyses (WP3);
4. **Outline a policy incentivising** forest management leading to the **optimal** level of **functional diversity** for reducing disturbance risks at the landscape level, and analyse its application in alternative ecological and climatic contexts (WP4).

3. Project activities and achievements

3.1. General description of activities over the duration of the project

Funpotential derived new information about the ecological responses of trees to competition and severe disturbance events (wind, snow, fire, drought) based on forests inventory information from four countries, consisting of case study areas of Funpotential in boreal, temperature and Atlantic vegetation zone (Objective 1/WP1). Funpotential developed a new tool (IPM/MATREEX R Package), which integrates disturbance risk and recovery processes based on the Funpotential research. The model can be used to simulate resilience of forest developments under climate change (Objective 2/WP2). Funpotential also studied how management and structure of forests impacts the profitability of forestry of individual forest stands and enterprise forest holdings (WP3), and how policies could steer management (WP4). The economic calculations were done by utilizing a newly developed tool for wood valuation (WoodValuationDE), which incorporates valuation of salvage harvests. Ecological and economic models were integrated and used to estimate economically optimal management strategies that balance economic risks and returns of individual forests and a larger forest property (Objective 3).

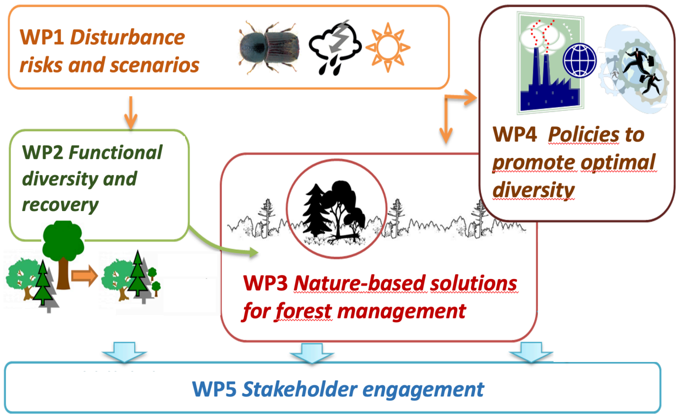

Figure 2 Funpotential work packages integrated ecological and economic research seamlessly.

Objective / WP 1

Luke and INRAE combined and harmonized new forest inventory data from case study countries (Finland, France, Germany), which was used in the mortality analyses of the project. Forest inventory dataset were also combined with data from collaborators in Spain (Miguel Zavala and Paloma Ruiz-Beneto).

The first forest inventory-based study investigated the impacts of catastrophic mortality of trees, and it was conducted in collaboration between INRAE and Luke. Use of remote sensing (RS) products with NFI-based disturbance data was also tested, but eventually discarded due to imprecise NFI plot location information in some countries.

The second joint (Luke, INRAE, GOE) manuscript of WP1 studied the effects of functional features and species identity on the background mortality of trees (Kulha et al., 2023). Lead author, PostDoc N. Kulha visited INRAE in Grenoble to progress the study.

It is commonly accepted that landscape surroundings and context can strongly influence how damage are manifested, but suitable spatially explicit data is rare. We identified a suitable dataset from Finland, where salvage loggings have been recorded over long period and span over several windstorms (2012-2024). Third manuscript of the WP1, thus, analysed the impacts of different types of landscape structures on wood losses in the area (Kulha et al., 2024). To conduct the analyses, each storms' impact region was divided up into subregions, for which several different spatial attributes were calculated (e.g. mean wind speed in storm(s), edge length, etc) for the statistical analyses.

Objective / WP 2

INRAE LESSEM Grenoble developed an R package wrapping the IPM model (**R package Matreex**) into a user-friendly format and updated several submodules based on the results of WP1 and new analysis, for use in WP2 simulations. The disturbance mortality model developed by Barrere et al. (2023) was implemented in the model, allowing tree species responses to key disturbances to be linked to their functional traits. A dedicated module was also developed to represent varying disturbance intensities, enabling connections with different external disturbance scenarios.

Since recruitment is a key process in post-disturbance recovery, a new recruitment module was developed. It includes a recruitment time lag (trees recruiting at 10 cm DBH), which depends on species growth rates. As recruitment is also a crucial stage where local diversity can shift after a disturbance or harvesting event, we also developed a module that accounts for dispersal from a regional species pool into the local stand. Dispersal distances were derived from species' functional traits.

We then used the **Matreex** R package to perform several simulations analyzing how functional diversity influences forest resilience to disturbances. In an initial analysis, we explored forest responses to a single storm disturbance across Europe. This work led to a joint publication in *Functional Ecology* (Barrere et al., 2024). We subsequently coupled the **Matreex** model with future disturbance scenarios developed by Rupert Seidl's group (University of Munich) within the H2020 RESONATE project. This allowed us to analyse how forest functional diversity may evolve under the combined effects of climate change and increasing disturbance regimes.
Finally, we developed two flexible and adaptive harvesting algorithms: one for even-aged and one for uneven-aged management, covering the main forest management strategies in France, Germany, and

Finland. This was done in close collaboration with Georg-August-Universität Göttingen, ensuring that the harvesting module could be easily integrated into economic analyses, the WoodValuation R package and subsequent Monte Carlo simulation, based on tree species and size classes.

Objective / WP 3

Georg-August-Universität Göttingen (UGOE) developed bioeconomic modelling approaches that account for disturbance risks at different spatial levels and investigate the economic adaptation potential of tree-species diversification.

For supporting joint studies, economic data from France and Finland were collected in close cooperation with all partners. At the beginning of the project, UGOE developed a detailed economic valuation model WoodValuationDE (code published OA, manuscript published (Fuchs et al. 2023) for Germany, which includes estimated disturbance coefficients from an econometric study of the consequences of disturbances (published in Fuchs et al. 2022a).

Results from WP1 and 2 were integrated into a bio-economic simulation-optimisation approach, linking the stand and forest enterprise level (published in Fuchs et al. 2024). The model, developed in close cooperation with WP4, investigates economically optimal tree species diversity levels that balance economic risks and returns. As a main innovation, the portfolio-based optimisation approach considers site heterogeneity, different spatial scales of forest planning, both compositional and configurational tree species diversity and the effects of extreme mortality events.

As a final output, WP3 currently leads a cross-country comparison of the influence of tree species and structural diversity on economic risks at the stand level using harmonised silvicultural approaches across the partner countries. As a main innovation, the model integrates stand productivity simulated by IPM (WP2) with biophysical disturbance (WP1) and market risks (WP3,4). The model integration has been achieved, and validation and publication are in progress.

Objective / WP 4

Luke developed bioeconomic models for environmental economic analysis of policies for guiding the forest management. The work was initiated by Luke recruiting a MSc thesis student to pursue a pre-study on the optimal rotation and tree species composition when facing a risk of stand-replacing disturbances. Thesis was finalized in April 2023.

Luke began with the analysis of adjacent stands. The analysis focused on externalities caused by forest management. In the specific case studied here, the adjacent stand provides shelter on the neighbouring stand until it is clear-felled, which triggers a border effect that increases the windthrow risk of the neighbour. Hence, there are positive and negative externalities. The non-cooperative Markov perfect equilibrium is involved with welfare loss compared to the case of cooperation. The non-cooperative management decisions can be made to internalize the externalities using policy instruments. The first paper (Lintunen et al., in revision) on adjacent stands focused on the magnitude of the phenomenon, its implication on the need for policy instruments, and demonstrates the negative impact of natural disturbances on the effectiveness of carbon sequestration subsidies. The second paper (Hyyrynen et al., in revision) focused on the tree-species diversity as a method of increasing the resilience and, hence, mitigating the problem.

In the latter stage a conceptual model for market-level analysis of externalities and policy instruments was developed. The central idea is to link landscape-level forest properties with the probability of natural disturbances. Hence, creating an externality to other forest owners. Model has been developed in close cooperation with WP3. The modelling of market-level risk-linkages has proven difficult, and the publication is prepared from the expert view basis (Lintunen et al., in prep.)

3.2. Table of deliverables

Table: Milestones. P1: Luke, Finland; P2: INRAE, France; P3: UGOE, Germany

MILESTONES	WP	LEAD partner	ACCOMPLISHED	STATUS / COMMENT
M01 Kick-off meeting	WP.06	P1	5/18/2021	Kick-off was held on 2021-05-18 online
M02 Advisory Board meeting 1 (task 5.1)	WP.05	P1	2/11/2022	In the kick-off meeting, it was decided that AB meeting is postponed to December 2021, i.e. to month 8. Rationale for this was that it is beneficial to have some outcomes from the project for stakeholders to stimulate further thoughts.
M03 Dataset ready for analyses of WP1 and 2 (task 1.1)	WP.01	P1	10/1/2021	Finnish datasets ready 06/2022. ICP data acquired. French data set ready and German data set ready. FUNDIV dataset implements
M04 Meeting to develop simplified models with WP3 and 4 (task 2.2)	WP.02	P2	12/2/2021	Online meeting where plans and preliminary results were presented was held at 2021-12-02
M05 Backround mortality models for IPM (task 1.1)	WP.01	P1	9/1/2022	Multiple candidate models iterated, now final models for the manuscript ready. Manuscript published in Journal of Ecology
M06 IPM ready for WP3-4 (task 2.1)	WP.02	P2	4/1/2022	Full model developped and openly available on github.
M07 Data on management costs and wood prices compiled (task 3.1)	WP.03	P3	7/8/2022	Wood prices and management cost have been collected for all three countries, extended valuation model developed for Germany - manuscript Fuchs et al. (2023)
M08 Analytical results ready from stylized economic models regarding policies to promote socially optimal functional diversity (task 4.1)	WP.04	P1	4/1/2022	Analytical results used and presented in project meeting (Jussi L.). Manuscript under preparation, see also D10
M09 Draft version of simplified IPM ready for economic analyses (task 2.2)	WP.02	P2	4/1/2024	Full model and harvesting modules ready with speed of simulation requiring no simplifications. Simulations done, manuscript in preparation.
M10 Advisory Board meeting 2 (task 5.2)	WP.05	P1	6/10/2023	
M11 Preliminary coupling of IPM and portfolio optimization (task 3.1)	WP.03	P3	30/11/2024	Preliminary coupling accomplished used for simulating stylized forest management types across the countries
M12 Collaborative modelling activities (task 5.2)	WP.05	P3	6/10/2023	Project is in month 17. Stakeholders have been approached when WP3 manuscripts have been planned/done.
M13 Spatial correlations of severe disturbance based in NFI Spatial datasets	WP.01	P1	6/10/2023	Readjusted. A solution for considering neighbour stand damage correlations was introduced as a covariate in an economic WP4 optimization study, so that the correlation effects can be

ready for WP3 (task 1.2)			considered at least on the simplest case. This will also direct further work, i.e. how/if spatial correlatlions are included in WP3 context where economics of multiple stands are optimized at the same time
M14 Coordinated scenario set up with WP2 and WP4 (task 1.3)	WP.01 P1	In progress	Encapsulated in Barrere et al. manuscript "Transient response of forest composition to climate change and disturbances across Europe" which is in preparation. Results will be utlized in D14.
M15 Management scenarios for functional maintenance ready (task 2.4)	WP.02 P2	In progress	Project is at month 17. A set of practically feasible management scenarios / species mixtures has been chosen for WP3 manuscript based on local knowledge and models.
M16 Numerical models for WP4.2 and WP4.3 completed (task 4.1)	WP.04 P1	In progress	Publications on adjacent stands are in revision; market-level publication is in preparation
M17 Stand-level model extended to enterprise level with spatial damage correlation (task 3.2)	WP.03 P3	15/01/2024	Publication published
M18 Collaborative modelling activities (task 5.2)	WP.05 P3	26/11/2024	Shiny App develeped and used with German stakeholder, Master thesis published
M19 Enterprise-level model run for model enterprises at all three study sites (task 3.2)	WP.03 P3	"Expected 11/2025"	Coupling of models has been achieved, publication is pending, as we put a stronger focus on the stand-level analyses and the development of a more generic modelling approach (see M17), which resulted in a strong methodological advancement
M20 Results from numerical modelling ready (task 4.2)	WP.04 P1	26/11/2024	Publications on adjacent stands are in revision; market-level publication is in preparation
M21 Advisory Board meeting 3 (task 5.1)	WP.05 P1	Change of plan	Will be replaced by asking comments to a policy brief for comments
M22 Results from numerical modelling on optimal policies completed (task 4.3)	WP.04 P1	In progress	Manuscript in preparation
M23 Policy and price scenarios from WP4 included in analysis (task 3.3)	WP.03 P1	15/01/2024	See D09, which was a close collaboration including respective assumptions and methods
M24 Final meeting	WP.06 P1	Pending	Biodiversa event in June 2025

Table: Deliverables. P1: Luke, Finland; P2: INRAE, France; P3: UGOE, Germany

DELIVERABLES	WP	Lead partner	ACCOMPLISHED	STATUS / COMMENT
D01 - Project webpage	WP.06	P1	5/18/2021	Done, online 2021-05-18, Twitter account created

D02 - Scientific manuscript on the effects of functional and landscape diversity on background mortality and severe disturbance events (task 1.1)	WP.01	P1, P2	Accomplished	Split to two manuscript, which has slightly delayed progress. However, two manuscripts are in good shape. Disturbance mortality manuscript (Barrere et al.) published in December 2022 and background mortality manuscript (Kulha et al.) published in July 2023.
D03 - Management (functional-diversity) sensitive disturbance scenarios for study regions, which are consistent with AR6 equivalents of RCP and SSP. (task 1.3)	WP.01	P1	1/3/2025	A manuscript exploring how functional diversity change with the joint effect of climate change and future disturbances scenarios is ready to be submitted with IPM across Europe. This analysis is based on futur disturbance scenario developped by the group of Rupert Seidl in the H2020 project RESONATE.
D04 - Report documenting the structure of the forest model (IPM) (task 2.11)	WP.02	P2	Accomplished	IPM Package published (on github), Report description is part of the package (Vignette) see A website see https://gowachin.github.io/matreex/index.html and a paper is ready to be submitted to Journal of Open Source Software
D05- Scientific manuscript linking stand diversity and structure with economic risks and returns (task 3.1)	WP.03	P1, P2, P3	Accomplished	Neudam et al. (2023) and Knoke et al. (2022) developed the concept and methodological approach. Economic simulation based on Fuchs et al. (2024) has been coupled with IPM, simulation runs have been achieved (private model code on github to be published after publiction) and joint manuscript is in preperation
D06 - Report presenting the evaluation results of IPM against other existing growth models (task 2.2)	WP.02	P2	Accomplished	Rather than compare the IPM prediction with local model we compared the model prediction with PROFOUND data (not published) and with European NFI basal area data (in Guyennon et al. 2023 SI).
D07 - Scientific manuscript on the spatial covariance of stand-replacing disturbances (task 1.2)	WP.01	P1	Accomplished	Kulha et al. Manuscript on spatially explicit data on wind disturbances from Finland, published now in Landscape Ecology in May 2024
D08 - Scientific manuscript on functional diversity and recovery (IPM analysis) (task 2.3)	WP.02	P2	Accomplished	Barrere et al. (2024) Manuscript published in Functional Ecology
D09 - Scientific manuscript on	WP.03	P3	Accomplished	Fuchs et al. (2024) Manuscript published in Scientific Reports

economically desirable mix of species and stand types at the enterprise level to balance risks and returns under different disturbance scenarios (task 3.2)			
D10 - Scientific manuscript: A policy to promote socially optimal functional diversity for disturbance risk mitigation at the landscape level (task 4.1)	WP.04 P1	Accomplished	Manuscript about adjacent stand analysis in revision.
D11 - Policy Brief 1 (task 5.3)	WP.05 P1	Change of plan	Study plan forsaw one or two policy briefs, depending ont the results obtained for work. Decided to combine it with D15 to create one more impactful PB
D12 Scientific manuscript on how to manage and maintain the functional diversity and resilience (IPM) (task 2.4)	WP.02	Accomplished	Replaced by a manuscript analysing how climate change and disturbance will affect functional diversity by Barrere et al. Manuscript in preparation.
D13 - Summarizing Report on the key drivers affecting the suitability of NbS strategies (in terms of tree species and stand structure diversification) to balance biodiversity and carbon targets at the forest enterprise level (task 3.3)	WP.03 P3	Accomplished	Fuchs et al. (2024) Manuscript published in Scientific Reports outlining the driving factos and trade-offs, results will be included in Policy Brief and have been published in local (German) popular press.
D14 - Scientific manuscript: Optimizing functional diversity to mitigate disturbance risk when a forest stand is managed for timber and climate benefits (task 4.2-3)	WP.04	In progress	Market-level analysis based on D05 is under preparation.

D15 - Policy Brief 2 (task 5.3)	WP.05	In progress	One joint PB integrating D15 and D11

3.3. Scientific outcomes

Objective 1: Create functional-diversity-sensitive models for forest mortality and disturbance effects, and associated climate change scenarios

Funpotential demonstrated that functional traits explain tree species resistance to three major disturbance types in Europe. This analysis was made possible thanks to the international collaboration initiated through the Funpotential project, which enabled the merging of three European National Forest Inventories (NFIs) to assess the effects of disturbances on tree mortality.

While previous studies have analysed tree mortality using combined NFI data, this is the first to focus specifically on disturbance-related mortality by harmonizing the disturbance variables across the datasets. Using these synthesized data, we developed an innovative statistical framework to disentangle the effects of disturbance intensity from species-specific responses.

Our findings show that different combinations of functional traits drive species sensitivity to disturbances (Figure 3). Storm-sensitive species were characterized by a high height-to-diameter ratio, low wood density, and high maximum growth rate. Fire-sensitive species had low bark thickness and high P50 (i.e., low resistance to xylem cavitation). Species native to warmer and drier climates—where fires are more frequent—were generally more fire-resistant. Species rankings in disturbance sensitivity were largely consistent across disturbance types. Productive conifer species were among the most disturbance-sensitive, while Mediterranean oak species showed the highest resistance.

This study identifies key relationships between species functional traits and their sensitivity to disturbances, providing a foundation for more reliable predictions of how future changes in climate and disturbance regimes could shape forest structure and species composition across large spatial scales.

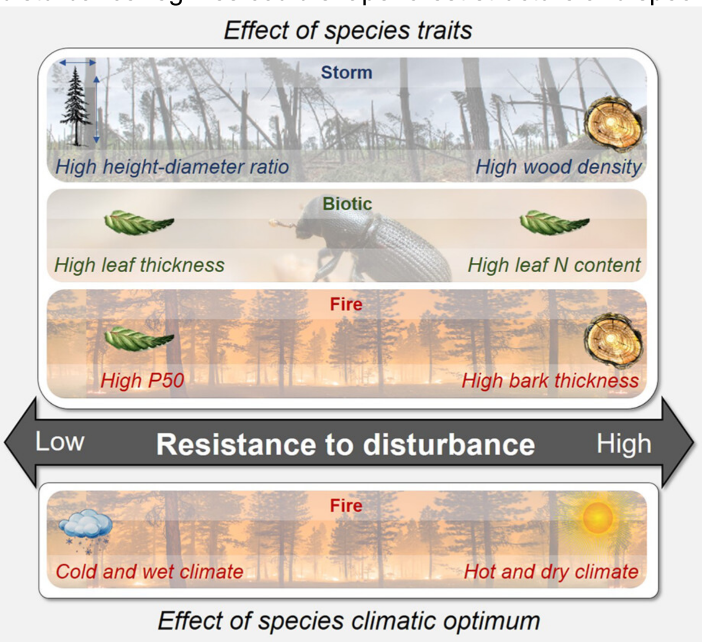

Figure 33 This figure summarises the main results of Barrere et al. (2023), which show that functional traits determine tree species resistance to three main disturbance storm disturbances, biotic disturbance, and Fire disturbances. Using forest inventory data from Spain, France, and Finland, we showed that resistance to most disturbance types was higher for conservative species (e.g., with high bark thickness and slow growth) and lower for productive species (e.g., high height to diameter ratio). Species resistance was also related to their mean climate, with species from arid and fire-prone environments being more resistant to fire.

Another important mortality process occurs due to competition-induced mortality, which is intensifying as forests are maturing and getting denser in Europe. Moreover, competition-induced mortality may exacerbate due to increasing droughts and biotic damage agents.

Funpotential analysed background mortality with inventory data covering a latitudinal gradient from the Mediterranean to the Arctic, and aimed to associate background mortality process to functional features of forests and tree species (Kulha et al., 2023). We devised generalized linear models to analyse these processes in a massive dataset consisting of repeated tree observations of nearly half a million trees and 50 000 plots. We found out that the basal area of larger trees (BAL) predicts the mortality of tree individuals most strongly, but that this effect is modulated by increasing proportion of conspecifics, and the target tree's and its competitor shade tolerance (Figure 4). Drought periods also increase mortality, especially among the most suppressed trees, These knowledge will improve our understanding of forest dynamics in a changing climate, helps to develop models further.

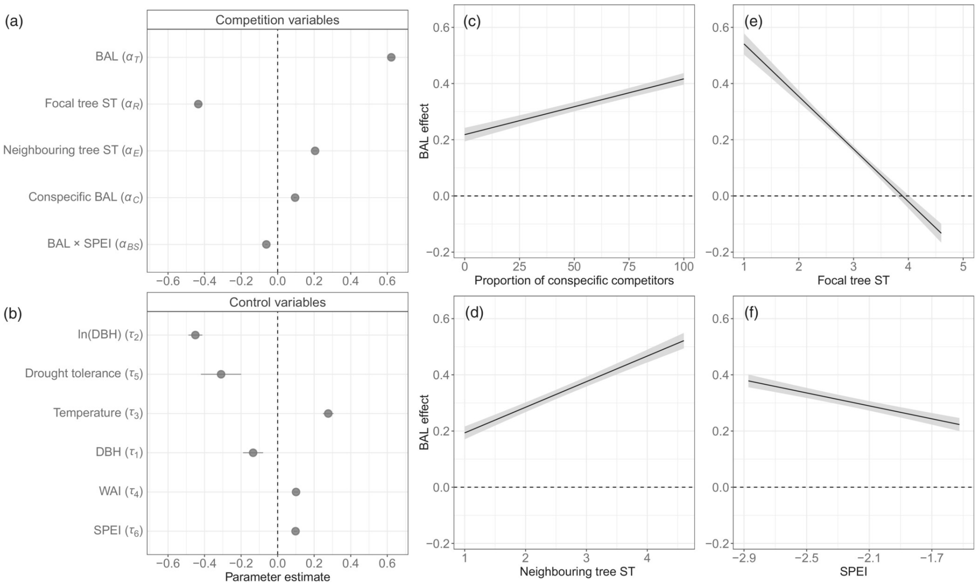

Figure 4 Factors affecting background mortality (Kulha et al., 2023). BAL: Basal area of larger trees (competition index), ST : shade tolerance. SPEI : a site-specific drought anomality index. DBH : diameter at breast height. WAI : water availability index (site specific)

Objective 2: Analyse the role of functional diversity in forest recovery to disturbances, and the feasibility of creating nature-based forest management solutions that foster recovery

The three main outcomes of this work package (WP) are:

- The development of a European-scale, open-source model—Matreex—based on integral projection models (IPMs) to simulate forest dynamics, accounting for climate, disturbances, and simplified management modules that allow connection to economic analysis.
- The use of this model to analyse how functional diversity influences storm resilience across European forests.
- The application of Matreex simulations to assess the joint effects of climate change and future disturbances on European forest functional diversity.

We first developed an open-source R package—Matreex—fitted to simulate the dynamics of European forests while accounting for climate, disturbances, and forest management. The key originality of this model lies in its use of integral projection models (IPMs), which are powerful tools for studying the temporal dynamics of size-structured populations, without the stochasticity of individual-based models commonly used in forest ecology. Understanding how forest size structure is affected by climate, disturbances, and management is crucial for assessing forest resilience and for designing nature-based management solutions such as continuous cover forestry or uneven-aged silviculture. The R package includes fitted functions to model the effects of climate on tree growth, survival, and recruitment; the impacts of disturbance on survival (allowing integration of various disturbance scenarios); and a novel recruitment module that incorporates dispersal from outside the local stand. A management module supports the implementation of various silvicultural strategies, particularly uneven-aged systems, and allows linkage to economic analyses. The open-source nature of the package has facilitated its adoption by research groups within and beyond the Funpotential project. Matreex is available at https://github.com/gowachin/matreex and a website documenting the model is available at https://gowachin.github.io/matreex/ . A manuscript presenting the model is ready to be submitted to [Journal of Open Source Software.]()

The second major outcome of this WP involved using Matreex to simulate how functional diversity influences forest resilience to storms across Europe's climatic gradient. This work was published in *Functional Ecology* (Barrere et al., 2024). While many studies have investigated the role of functional diversity in forest functioning, few have directly addressed its role in resilience to storm disturbances—despite storms being the most significant natural disturbance in European forests. Using simulations constrained by species assemblages observed in NFI data—thus capturing realistic diversity gradients nested within climate zones—we quantified forest resilience to storm for different functional composition. We estimated functional diversity and mean functional strategy at equilibrium along two key trait axes: (i) conservative vs. fast-growing strategies, and (ii) low vs. high recruitment potential. We found that, on average, species-rich assemblages had higher recovery and overall resilience to storm disturbance, while greater functional diversity enhanced both resistance and recovery. However, the influence of diversity varied with climate: it significantly increased resistance and resilience only at the climatic margins (Figure 5). Importantly, the mean position of species assemblages along the functional axes was also a strong predictor of resilience. In particular, the conservative–productive axis had an effect two to three times greater than functional diversity itself: forests dominated by conservative species were more resistant and resilient, but had lower recovery than stands dominated by fast-growing species (Figure 5, Barrere et al., 2024).

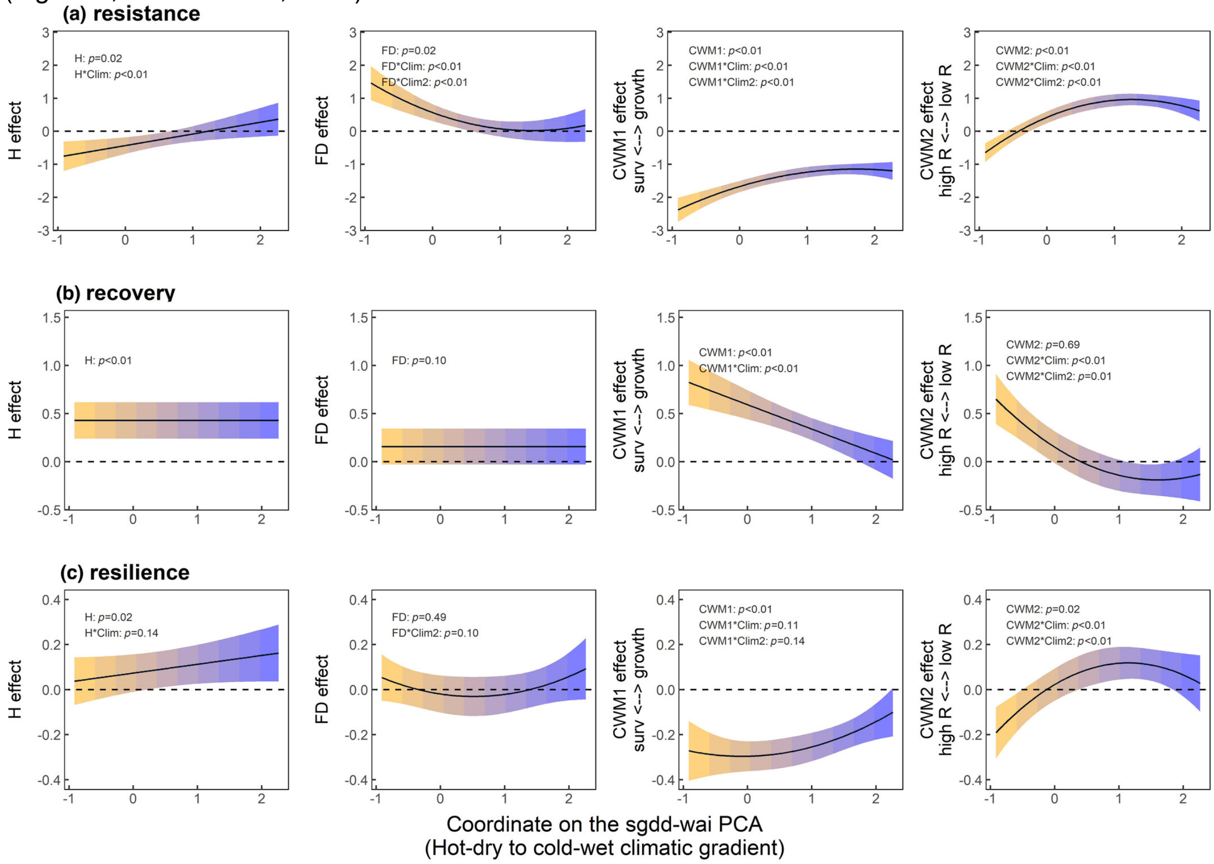

Figure 5 Effect of species composition metrics—Shannon diversity index (R), functional diversity (FD), and mean functional strategies (CWM1 and CWM2)—on forest (a) resistance, (b) recovery, and (c) resilience to storm events along Europe's main climatic gradient, ranging from hot and dry to cold and wet conditions. Results are based on simulations of storm resilience with Matreex for forest stands representative of the main functional diversity gradient across 10 climatic zones in Europe.

Together, these findings highlight that while functional diversity contributes to resilience, the mean functional composition of species assemblages plays an even more critical role. This is an important result for the ecological studies on link between functional diversity and forests functioning. This has also strong implications for economic analysis, as it reveals a trade-off between species composition that promotes resilience versus fast-growing species typically favoured for economic return. In particular, a high proportion of fast-growing conifers reduces resilience, even in mixed-species stands.

The third key outcome stems from simulations exploring how climate change and future disturbance regimes will affect forest functional diversity in Europe (a manuscript is ready for submission). This analysis represents a deviation from the original plan, which aimed to assess how management could help maintain functional diversity. However, we shifted focus to seize the opportunity to use pan-European future disturbance scenarios developed by Rupert Seidl's group in another project, allowing us to explore the joint effects of climate change and disturbances at European scale. To address this issue, we simulated the trajectory of a sample of 10000 National Forest Inventory (NFI) plots distributed across Europe with a new version of Matreex which captures the effects of key processes of forest dynamics i.e. succession, regional dispersal, climate, competition, and disturbance. We compared shifts in tree species composition from 1990 to 2100 under different SSP scenarios, with and without disturbances. We found that shifts in forest composition followed a strong latitudinal gradient and were mostly driven by climate change rather than disturbance. Climate change favoured drought-tolerant species in Mediterranean forests and shade-tolerant species in boreal forests. Species and functional diversity declined across the European continent, but to a much greater extent at the drier sites. We also found that changes were much pronounced in early successional forest that in late successional forests. This is a novel aspect of this work is that we explicitly account for the initial forest structure, successional dynamics, and dispersal from surrounding landscapes. This is essential, as forests are slow-changing systems with strong legacy effects that influence their future trajectories and not only climate change.

We also complemented these simulations analysis with an analysis of field inventory data from NFIs to test how the size structure and the functional diversity influence forest responses to disturbances. We also analysed how disturbance modulate the stand structure and tree species diversity and how the disturbance sensitivity *changes* after disturbance, i.e. does the previous disturbance predispose the forest to subsequent same disturbance. This study integrated objectives from WP1 and WP2, and it was done in a close collaboration between Luke and INRAE (Kulha et al., in revision). Overall, we found weak effects of structural and species diversity on disturbance resistance, and other variables were more important (Figure 6). Together with earlier results (Barrere et al., 2023), this suggests that it is more important to selectively manage structure and species mixture rather than focus on increasing the diversities itself. We also observed that severe disturbances that killed more than half of the basal area tend to decrease the structural and species diversity irrespective of the disturbance type. But interestingly, some small scale disturbance (biotic and snow) that kill < 25% tend to increase these diversity metrics. The disturbance sensitivities decreased after a low severity fire, or low-moderate wind damage, but increased with moderate severity biotic and snow damage. While diversity variables generally have small role on the disturbance sensitivity, there seems to be a complex and selective relationship between the disturbance type, severity and its consequences.

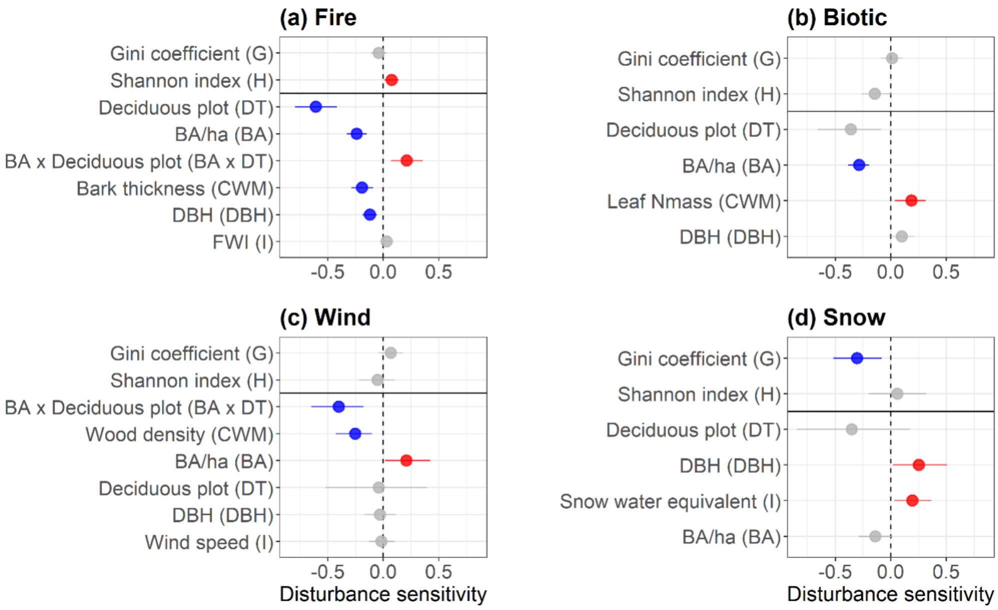

Figure 6 Parameter estimates for structural and species diversity and the control covariates in the agent-specific regression models with disturbance resistance, quantified as the plot-level ratio of basal area of trees that survived a disturbance (R) as a response variable. Estimates are from the models fitted with scaled and centered covariates. Points are model parameter estimates and the error bars are bootstrapped 95% confidence intervals for the estimates. Red dots indicate a significant increase and blue dots indicate a significant decrease to disturbance resistance at the 0.05 level. Light gray dots are non-significant covariates. FWI and SWE are fire weather index and snow water equivalent, respectively. The symbols in parentheses refer to those used in Equation 2. Numerical model parameter estimates are given in Table S3.

Objective 3: Propose optimised nature-based local forest management solutions, and evaluate the potential of functional diversity for improving risk-return balances under climate change-sensitive disturbances, via stand and enterprise-level economic analyses (WP3)

The main outcomes include two subobjectives:
(1) establishing the methodological foundation for testing the economic risk-return profiles of various silvicultural strategies.
(2) Comparing various management strategies towards tree-species diversification from stand to enterprise and regional level and under different disturbance scenarios.
The first methodological advancement is the development of a **consistent and generic framework for calculating stumpage values** (available as R-package and as EXCEL file). The framework combines

assortment tables, wood revenue and harvest costs models. The model was developed for the German case study region but has been built in a generic way to allow for consistent application in other countries. It is publicly available as R-package and EXCEL file (link). This step was crucial for deriving consistent indicators for comparing provisioning services between different silvicultural treatments and across countries. It was also important to technically improve the valuation to make it scalable and adjustable for larger-scale modelling. As a new component, the framework incorporates financial consequences of disturbances based on literature and own econometric analyses, which was necessary for distinguishing between small stand-level disturbances and large-scale disturbances with impacts on regional wood markets.

For this purpose, we developed, as a second component, an **econometric time series analysis of wood revenues**, using Structural Vector Autoregressive models and Impulse Response Functions. The model was applied to the accounting data of a large German public forest enterprise. The results revealed that the mechanisms behind the decrease in wood revenues, during past disturbances, differed between spruce (oversupply to wood markets) and beech (lower wood quality). This research provides quantitative estimates for disturbance-induced decreases in revenues, based on the characteristics of the disturbance event. The research has been published in scientific outlets (Fuchs et al. 2022*a*, Fuchs et al. 2022b, 2023).

As a third component, we coupled the Matreex model (developed in WP2, Jaunatre et al, in prep.) with biophysical and market risks (derived from WP2 and WP4) via Monte-Carlo simulation. This enabled us to **derive return distributions** from wood production under different silvicultural management and disturbance scenarios. The results can serve as input data for an optimisation model at the forest enterprise level, which allocates land area to forest types, defined by tree species and species mixtures. This already established portfolio-based model was extended by incorporating site heterogeneity, spatial correlations, differences between extreme events and stand-level disturbances, as well as an endogenous wood market simulation at larger spatial scales. This allows for scaling up the analysis to regional levels, including local and regional disturbance events, and considering tree-species diversity from the stand level (*alpha* diversity) to the enterprise and regional level (*beta* and *gamma* diversity). The enterprise-level model has been established for a first calibration for the German case study region (with local yield table data) (Fuchs et al. 2024), while a second cross-country study is underway but has not yet been published at the time of this report.

Using this novel modelling framework, we tested the effect of a regional top-down planning (i.e. having the opportunity to diversify across multiple landscapes which differ in their environmental conditions) and a bottom-up planning where diversification is restricted to one landscape. This approach is linked to the idea of *alpha*, *beta* and *gamma* diversity in ecology (see

Figure). In addition, we tested the effect of disturbances that occur locally at the stand-level and those which occur at the larger regional scale, which we termed “extreme events”. The approach allowed us to understand the effects on the economic adaptation potential. That is, we tested the magnitude by which the economic objective of a risk-averse decision-maker (here: Conditional Value at Risk) was reduced, assuming that the level of tree-species diversification was economically adapted to the respective disturbance scenario.

The main overall results can be summarized as follows:
Species diversification was a key strategy to buffer the economic consequences of stand-level disturbances. Local planning led to a higher degree of stand-type diversification within a landscape (*alpha* diversity), while regionally coordinated planning rather enhanced *beta* diversity between planning units.

However, with **increasing intensity and severity of extreme (regional) disturbance events, the positive effect of species diversity was partly undermined**: We observed a trend towards homogenisation of stand-type composition likely selected under a risk-sensitive economic objective and extreme disturbance events (**Error! Reference source not found.**). No diversification strategy fully buffered the adverse economic consequences. This led to “fatalistic” decisions: Stand types with low investment risks but also low resistance to disturbances were selected. For our study sites in Lower Saxony, this referred to spruce-dominated mixtures, which regenerate naturally but provide a relatively high return. Yet, the resulting forest structures indicate potential adverse consequences for other ecosystem services. This clearly underlines the trade-off between enhancing stability with less productive trees species with the provision of wood and income.

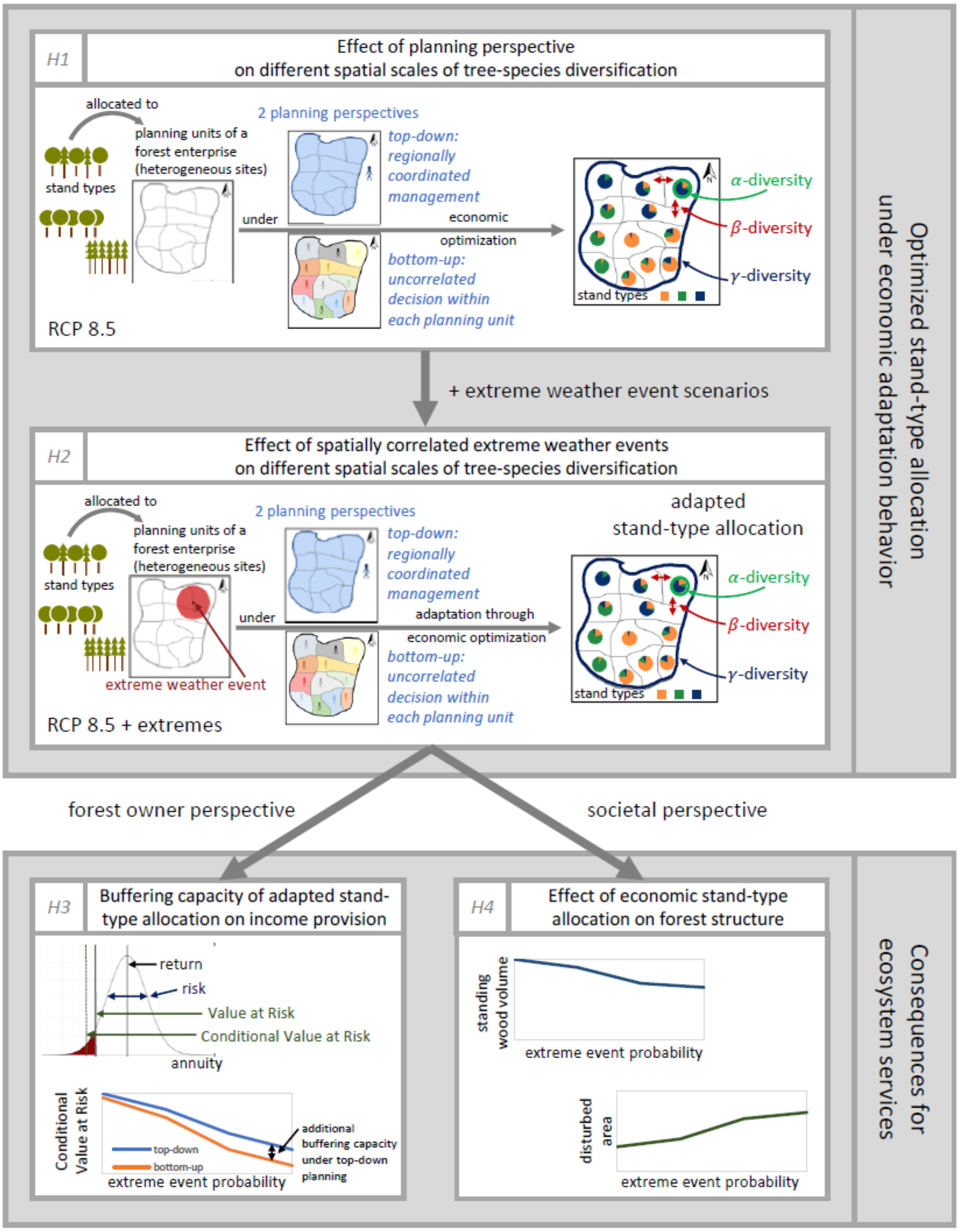

Figure 8: Study design of the integrative study in WP3 using the bioeconomic model, initially calibrated for Germany. Alpha-diversity refers to the number and evenness of stand types in local planning units, beta-diversity to the dissimilarity of the species composition across planning units, and gamma-diversity to the number and evenness of stand types in the entire forest enterprise. (Taken from Fuchs et al. 2024, see original publication for details).

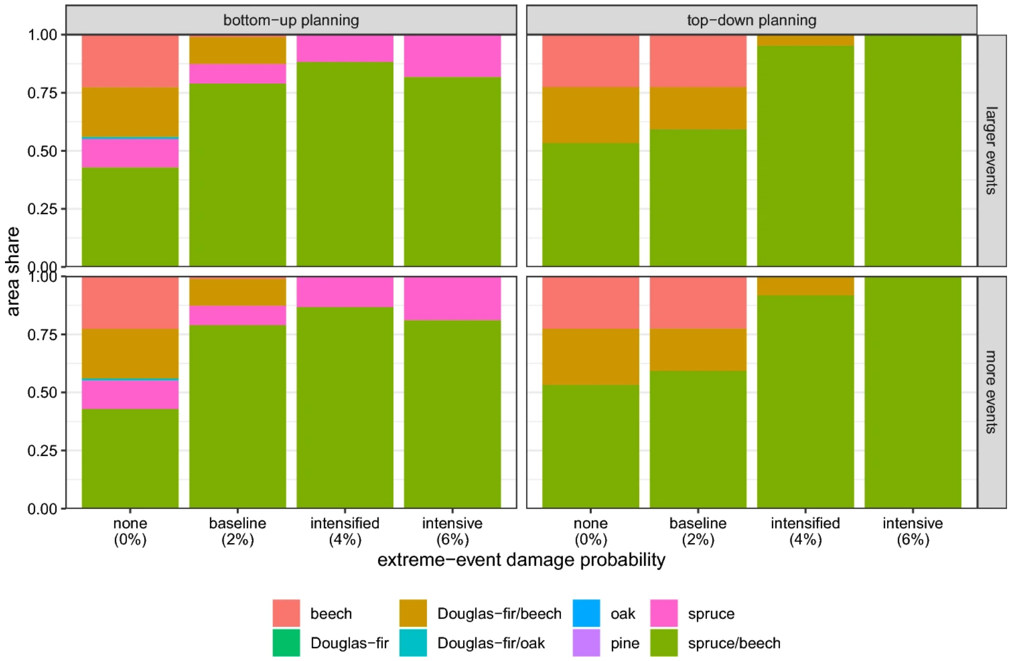

Figure 7 Optimised stand-type composition of the forest enterprise as sum of all planning units, reflecting gamma-diversity. Optimal compositions were derived under top-down and bottom-up planning (panel columns) and different extreme-event scenarios, defined by a probability of stand damage within 10 years (horizontal axis) and an increase in the size or number of events (panel rows). (Taken from Fuchs et al. 2024, see original publication for details).

This trade-off also became evident between the spatial level of forest management planning: **While regional-level planning of tree species allocation showed gains in the economic buffering capacity compared to local planning**, a more coordinated, top-down perspective led to a decrease in stand-type diversity (in terms of species and mixtures) compared to a bottom-up planning.
We conclude that high tree-species diversity may not necessarily buffer economic consequences of extreme weather events. Forest policies reducing forest owners' investment risks are needed to establish stable forests that provide multiple ecosystem services. Tree species diversification should also not be limited to stand-level diversification, as diversification at larger spatial scales may also be relevant from both an ecological and economic perspective.

Objective 4 4: Outline a policy incentivising forest management leading to the optimal level of functional diversity for reducing disturbance risks at the landscape level, and analyse its application in alternative ecological and climatic contexts

There are two main types of outcomes

1. Methodological foundation for analysing efficient cooperative and inefficient noncooperative forest management under stochastic natural disturbance risk when neighbouring stands are linked through disturbance probabilities
2. Numerical and analytical demonstrations and illustrations on forest management policies related to regulation of management externalities, forest carbon, and functional diversity.

The methodological advances are twofold. First, we developed a consistent optimization framework for adjacency externality in optimal rotation setup (Lintunen et al., in revision; Hyyrynen et al, in revision). The framework encompasses both the efficient cooperative and the inefficient noncooperative forest management regimes under stochastic natural disturbance risk when neighbouring stands are linked through disturbance probabilities. Efficient cooperative management regime was solved as a dynamic program and the non-cooperative regime as a Markov perfect equilibrium of a perpetual dynamic clear-felling game. Second, we further extended the adjacent stands setup to a market/landscape-level setting, where adjacency externality was abstracted in a spatially implicit setting. In this extended setup, externality effects can also emerge through longer-distance effects.

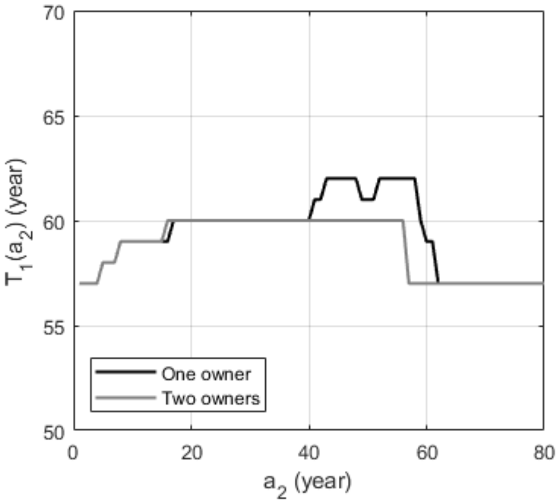

Figure 10: The optimal clear-felling policies for the efficient and inefficient cases of one (black) and two (gray) forest owners, respectively.

In the adjacent forest stand setting, we demonstrated both analytically and numerically the emergence of an externality. Since non-cooperative forest owners do not consider the impacts of their management on adjacent stand, the optimal clear-felling rule, i.e., a policy, differs from the efficient cooperative one (Figure 10). In the case of windthrow, this is observed as younger than efficient clear-felling ages when the neighbouring stand is mature as the forest owner is not incentivized to provide shelter. A policy instrument could be devices to correct this kind of management externalities, and we demonstrated how it could be constructed. However, in the calibration used in our analysis, the welfare loss of non-cooperation remained relatively low (Figure 11). In other calibrations and with other sets of natural disturbances and forest management options, the impacts could be greater. Nevertheless, the adjacency externality is a natural candidate for Coasian negotiation type of regulation, instead of government enforcing incentive mechanisms such as taxes and subsidies. The role of government could focus on the provision of information about the risk-induced externalities and their welfare costs, if the stand management is not done in cooperation.

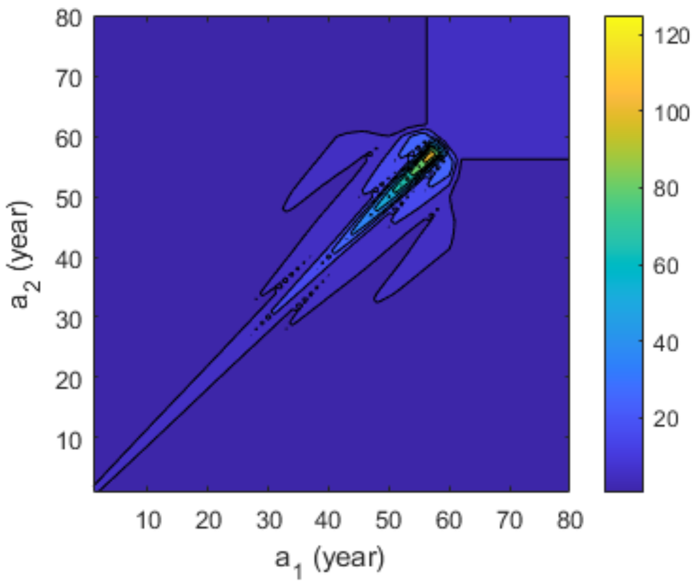

Figure 11: The gain in the joint value of the two stands from co-operation.

The policy analyses made with the adjacent stand model provided several policy findings. The main findings are related to forest carbon sequestration policy. Figure 12 shows that taking the disturbance risks into account reduces the effectiveness of forest carbon sequestration subsidies. While risk-ignorant forest owner ("Faustmann") extends their clear-felling ages strongly as the carbon sequestration incentives become stronger (i.e., the higher social cost of carbon, SCC), a forest owner who reacts to disturbance risks ("Efficient") increases the clear-felling age more conservatively. The effect is amplified by the fact that windthrow risk increases as the trees grow older and, hence, taller. Importantly, the carbon sequestration subsidy is still efficient climate policy even though disturbance risks do make it less effective. The findings also suggest that mixed-species forestry is economically profitable in forest management settings to mitigate losses from natural disturbances, and it could become more profitable with higher carbon prices in the future (Figure 13) suggesting that there is a synergy between the mitigation and adaptation goals.

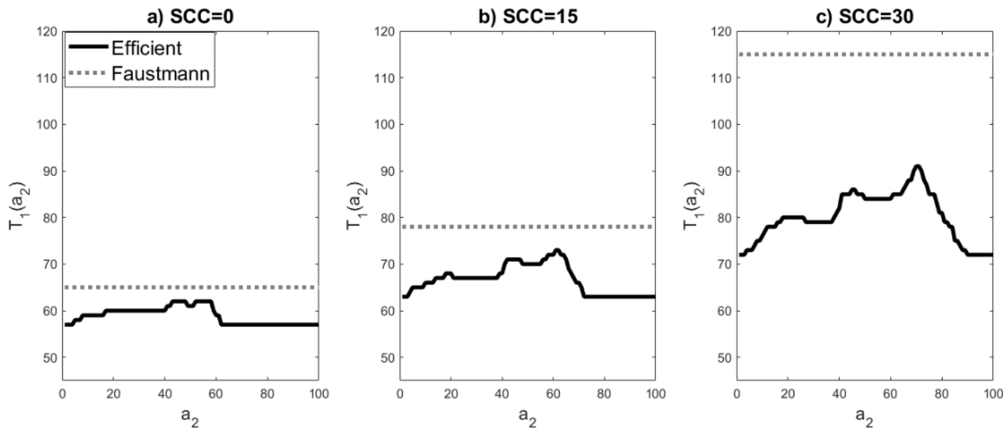

Figure 12. Effect of the social cost of carbon (SCC) on the no-risk rotation (dotted line) and the optimal harvest age under disturbance risks (solid line)

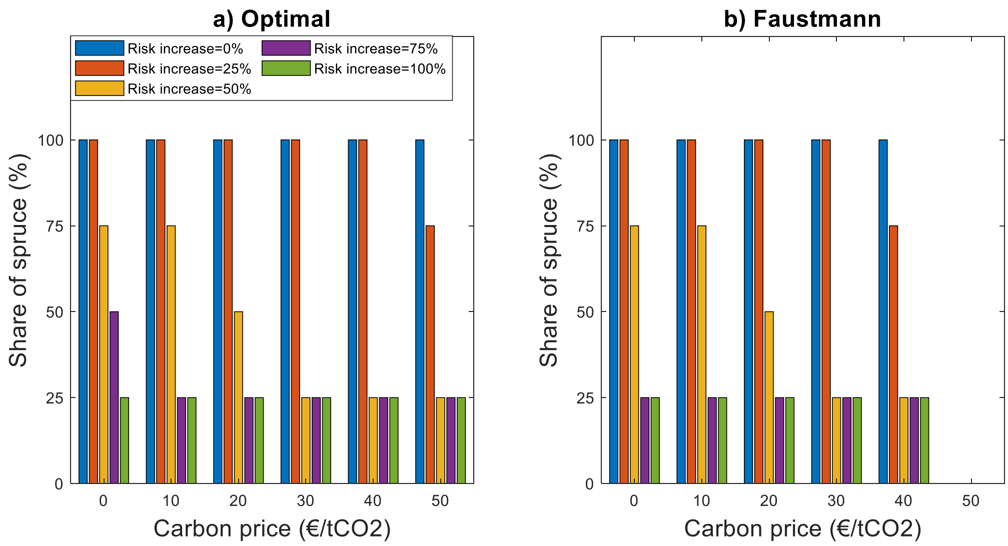

Figure 13. Optimal share of spruce for different carbon prices (25, 50, 75, or 100%) and for different spruce risk levels in Optimal a) and Faustmann b) harvest policies. With carbon price of 50€ tCO$_2$-eqv the Faustmann rotation exceeded 200 years could not be assessed.

The market/landscape-level findings stem from the same mechanisms as the adjacency externality, but the mechanisms are augmented by longer-range externalities. A need for policy instruments stems mostly from the climate and biodiversity externalities and targets related to them. In comparison, the management externality avenue seems to have more of a supporting role. But again, different forest management condition and practices may have different needs for policy instruments.

3.4. Outcomes for the consortium / added value

	Rating (3=major outcome, 2=moderate outcome, 1=minor outcome, n/a= not applicable)
1. Increased research capacity	2 (Three trained postdocs and a PhD)
2. Improved scientific evidence base	2 (New knowledge of stand border effects)
3. New method, data or technology	3 (Implemented new algorithms and developed codes;)
4. New / improved product or service	3 (Two new tools published)
5. New technical process	3 (Portfolio optimization in forest enterprise level diversification integrating tools developed by two teams, game-theoretical algorithm)

6. New organisational process	1 (Established fruitful cross-disciplinary collaboration)
7. Better access to international networks / markets	2 (Networked with other projects)
8. Better understanding of other European cultures / issues	n/a
9. Enhanced research network to compete for future European project funding	3 (Created an extended consortium for a new Biodiversa proposal)
10. Better understanding of stakeholder needs	1 (Advisory board meetings and experiences gained during the project)
11. Other(s) (specify):	n/a

The following fundamentally important aspects and results of Funpotential would not have been possible without the consortium

- Integrating data from different countries to joint analyses,
- Integrating ecological and economic expertise together, which resulted in fruitful and important research results,
- Understanding the wide range of different forest management practices put in place in the three countries and the climate challenges foresters faces in each country through both the field visit during the annual meeting and the work on the development of the harvesting modules of Matreex.
- Integrating models of ecological processes and economic valuation for large scale simulations large spatial scales, which was needed for economic optimizations of forest management.

3.5. Follow up activities and plans for further exploitation of the results

a) Did your project achievements lead to additional funding during or after the completion of the BiodivERsA project?	1. Yes (please specify) - New proposal to Biodiversa - Research outputs benefit accepted Horizon Europe projects ForestPaths and SafeNet. - Link with a new French project on forest regeneration within the PEPR FORESTT Project in the REGE-ADAPT project - Link with a new German consortium (REGULUS call, project REHA on reforestation dynamics in the Harz mountains, where Matreex could be applied - New proposal to Swiss SFOE (2nd round in prep.) based on the generic wood valuation framework and bioeconomic models.
b) If yes, does the follow-up project involve…	1. Further research YES 2. Implementation of results obtained YES 3. Commercialisation of outcomes NO 4. Other (please specify) YES, further development of open-source code and tools
c) Follow up activities and plans for further exploitation of the results: Full implementation and testing of created models in each case study region would be beneficial for increasing the plausibility of model predictions, and optimizations of forest management. Further research can build on the integration of Matreex model and economic analyses, which will be used in more detailed analysis and planning of nature-based management. Translation of optimization software (Rshiny) for different countries would benefit take up in companies.	

4. Stakeholder engagement before, during and after project's life

4.1 General Stakeholder engagement reporting

1. *Stakeholders' participation to project framing (including before the application)*

a. Advisors were approached before the submission of proposal, by contacting them directly. UPM AB member emphasized importance of practical applicability of results. FSC AB member was interested in pan-European applicability of results.

2. *Provision of data or knowledge by stakeholders; use of field / experiments allowed by stakeholders*
    a. Fuchs et al. (2022a,b) is based on harvest and sales records of the public forest service of Hesse, Germany (HessenForst).
    b. French on wood price and sales records were provided by the French National services (ONF)
    c. Advisory board member Wolf Kleinschmit (public forest service of Lower Saxony, Germany; Niedersächische Landesforsten) gave advise that helped to frame the research questions and model setup of the enterprise level study of WP3 (online meeting, Oct. 2021).
    d. Representatives of two public forest services in Germany co-authored the WP3 manuscripts Fuchs et al. (2022a,b, 2023) (a: v. Bodelschwingh, HessenForst 2022b/2023: v. Bodelschwingh and Offer, HessenForst as well as Koster BaySF). They contributed, among others, to the model development and practical interpretation.
    e. Fuchs et al. (2022b, 2023) are based on assortment tables and sales records of the public forest service of Hesse, Germany (HessenForst).
    f. The public forest service of Lower-Saxony, Germany contributed GIS data for the stylized forest management units and for the derivation of growth assumptions for the WP3 study at the enterprise level.

3. *Involvement of stakeholders considered as research objects (e.g., Participatory meetings use to assess biodiversity and service values by them)*
    a. An onsite forest owner workshop was co-organized in collaboration with ForestPaths project in Finland, where two presentations relating to climate change impacts and risks (Peltoniemi, Honkaniemi) and management alternatives were explored by visiting forest experiments (Bark beetle, root-rot, carbon, extended rotation. 35 forest owner participants.
    b. Inrae organised a one-day meeting with Zone Atelier and Alpine Sentinels on Mountain Forests to bring together scientist, forest managers from public and private forest and manager of protected areas to discuss the adaptation of mountain forest management to climate change while preserving biodiversity. INRAE participated in a joint session between scientists and forest managers focused on adapting mountain forest management to climate change (with ONF and CNPF). Presentation by Georges Kunstler on the results of simulations using the Matreex model.
    c. A separate meeting was held with industrial stakeholder (H. Viiri, UPM) where she described information needs and concerns of industry related to forest damage and resilience. In this meeting, preliminary project results and AB meeting materials were presented to her. Discussions steer helped project to select practically feasible management alternatives for Finnish case, and stimulated ideas how to present results of the economic analyses.
    d. Private forest owners from the German case study region have been involved in a WP3 participatory modelling workshop. An R-Shiny app has been successfully developed for the bio-economic modelling approach. One private and one public forest owner have been involved in a co-learning process. We compared the economically optimized tree-species compositions with the actual long-term objective of the forest management plan and the adjusted personal strategic objective. We found that forest owners acted risk-averse, but also economically efficient (in the sense of a mean-variance portfolio). It also served as plausibility test for the modelling results, which seemed to give realistic values for economic decision-making, whereas the experiment showed that forest managers tend to also give a strong focus on further objectives, such as maintaining forest stability. One of the forest enterprises was intensively involved in applying our planning tool on its own forest management data. The goal was to jointly develop strategies on target forest composition and diversity, accounting for current policies and financial incentives. Results have been summarized in the Master's thesis (UGOE) of Felix Thiel.

4. *Other meetings and activities (to be specified)*

a. Statement about Finland's position (EU/516/2024-MMM-2) on new EU legislation development. Funpotential coordinator (M. Peltoniemi) prepared and coordinated the writing of an official statement to the Ministry of Agriculture and Forestry and policy makers on behalf of Natural Resources Institute Finland on the topic of managing climate risks in the natural resources sector in Finland ("Ilmastoriskien hallinta ihmisten ja hyvinvoinnin suojelemiseksi") in response to new legislation developments of EU (COM(2024) 91 final, 12.3.2024).

5. Follow-up activities with stakeholders

FSC participated in Funpotential Advisory Board was involved as a partner in new Horizon Europe project SafeNet (https://www.safenet-project.eu, co-coordinated by M. Peltoniemi). Project deals with conservation and management of forests and biodiversity, and is partially relying on Funpotential results.

Sitra that participated in Funpotential Advisory Board funds a new project about the policy instruments for Finland to obtain its climate and biodiversity targets set for its forests. Jussi Lintunen, WP4 leader, leads this new project. The results and conceptual models developed in Funpotential are utilized in the project, especially, related to the climate policies and the impacts of functional diversity on resilience of the forests.

4.2 Detailed stakeholder engagement reporting

See tab SH_Engament in the Excel.

4.3 Project products for stakeholders

Please use the dedicated excel sheet, section "SH_Products"

5. Dissemination of results

5.1 List of scientific publications

See accompanying excel sheet.

5.2. Dissemination of results to scientists and scientific organisations (0.5 page max)

BiodivERsA has been acknowledged in almost every time we have disseminated our results. For partner contributions (in any of the scientific steps, although not always necessarily mentioned among authors), see at the end of each presentation.

5.2.1 Presentations and Poster: Please describe the dissemination of results to scientists/scientific organisations, in particular listing all relevant (i) oral presentations, and then (ii) posters resulting from the project.

Oral presentations in conferences

- Barrere, J. et al. including Kunstler, G. (2022). How do tree size, functional traits and climate drive disturbance-induced tree mortality across European forests?. Forest disturbances and ecosystem dynamics in a changing world – Berchtesgaden National Park, Germany. 19-22 Septembre. P2.
- Kunstler, G. (2022). Beyond mean fitness: demographic stochasticity, species interactions and resilience to disturbance matter at tree species climatic edges. SFE2 GFO EEF Joint meeting, International Conference on Ecological Sciences, Metz – France. 21-25 Nov. P2.
- Barrere, J. et al. including Kunstler, G. (2022). How do tree size, functional traits and climate drive disturbance-induced tree mortality across European forests?. SFE2 GFO EEF Joint meeting, International Conference on Ecological Sciences, Metz – France. 21-25 Nov. P2.

- Julien Barrere, Maxime Jaunatre, Björn Reineking, Georges Kunstler. Forest resilience to storm disturbances depends on interplay between functional composition and climate. British Ecological Society Annual Meeting 2023, British Ecological Society, Dec 2023, Belfast, Ireland. P2
- Peltoniemi, Mikko & Niko Kulha (2024). Do stand structural and species diversities increase forest disturbance resistance? IUFRO meeting, Stockholm, 25.6.2024. P1
- Kulha, Niko (2023), How do functional traits, species properties and climate influence tree mortality across Europe? IBFRA, Helsinki, Finland, 28-31.8.2023. P1.
- Fuchs, Jasper (2023): Climate change and extreme events – modeling economic adaptation of forest enterprises through tree species selection at different spatial scales, IBFRA, Helsinki, Finland, 28-31.8.2023. P3
- Niko Kulha; Juha Honkaniemi; Julien Barrere; Georges Kunstler; Thomas Cordonnier; Björn Reineking; Carola Paul; Mikko Peltoniemi (2022). How do tree functional traits influence the rate of background mortality in Europe? Forest disturbances and ecosystem dynamics in a changing world – Berchtesgaden National Park, Germany. 19-22 September. P1, P2, P3.
- Juha Honkaniemi; Niko Kulha; Clara Antón Fernández; Sören Wulff; Kari T. Korhonen; Cornelius Senf; Mikko Peltoniemi (2022). The effect of disturbances on forest dynamics in Fennoscandia. Forest disturbances and ecosystem dynamics in a changing world – Berchtesgaden National Park, Germany. 19-22 September. P1.
- Fuchs, J., Husmann, K., Paul, C. (2024): Diversification of the tree species selection at different spatial scales to adapt forest enterprises to climate change and extreme weather events, IUFRO conference, Stockholm Sweden 23-29 June. P3
- Fuchs et al. (2022). Optimierung eines betrieblichen Baumartenportfolios unter heterogenen Standortsbedingungen und räumlich korrelierten Extremwetterereignissen [Optimization of a tree species portfolio at the enterprise level under of heterogeneous site conditions and spatially correlated extreme weather events]. Risikoworkshop, Lohr a.M. 28.06.2022 (Meeting of forest risk modelers from universities and research institutions of the public forest services in Germany). P3
- Fuchs J., Husmann, K., Schick, J., Albert, M., Lintunen, J., Paul, C. (2023): Diversifikation der Baumartenwahl auf verschiedenen räumlichen Skalen als forstbetriebliche Anpassungsstrategie an den Klimawandel und Extremwetterereignisse. [Diversification of tree-species selection at different spatial scales as a forest adaptation strategy to climate change and extreme weather events] Forstökonomisches Kolloquium, Dresden Germany 13-15 September (meeting of German, Austrian, and Swiss forest economists). P3, P1.

5.2.2: Scientific events: Please describe any scientific events your consortium organised. Please give a short explanation and report tasks of respective project partner.

- IBFRA-meeting, Helsinki, Finland, 28-31.8.2023. Funpotential PI (Peltoniemi, Luke) was co-organizing the meeting, and designed the scientific program of the meeting. P1.
- An IBFRA meeting session "Managing for diversity: A call for a better understanding of linkages between forest structure, biodiversity and carbon cycle" was themed with topics related Funpotential and co-organized by N. Kulha, Luke, IBFRA, Helsinki, Finland, 28-31.8.2023. P1.

5.2.3 Interactions with other BiodivERsA projects

- Funpotential significantly differed from other projects funded in the same BiodivERsA call, and there were few options for collaboration. However, Funpotential coordinator and INRAE lead and MixForChange coordinator and INRAE explored possible collaborations at the beginning of the project. Based on these discussions, the collaboration was limited to exchanging information about the definition and metrics used for functional diversity/traits.

5.3 List of dissemination activities towards stakeholders

Dissemination of results to stakeholders (except general public)

- The scientific IBFRA meeting was also open for stakeholders. There are no records of stakeholder participants, but also several stakeholders were present in the meeting. P1, P3.
- WP3 studies (see publications) were presented and co-authored with German AB members. P3
- C. Paul presented results of the project in a workshop organised by the "Dachverbandes wissenschaftlicher Gesellschaften der Agrar-, Forst-, Ernährungs, Veterinär-, und Umweltforschung e.V. (DAF). 12.10.2023, Berlin. This workshop was directly targeted at political decision-makers. P3.

Information / technology transfer

- Wood valuation tools developed by UGOE have been published openly online in platforms that are widely used by the society, including the source codes (R, Github, Zenodo). See Publications list for links. P3.

Outreach to the general public

- Kunstler, G. (2022). Changements climatiques et dynamique des forêts de montagnes. CYCLE DE CONFERENCE « Dérèglement climatique dans les Alpes de notre région, comprendre pour agir » Muséum de Grenoble. 4 Mai 2022. P2
- Kunstler, G. (2023). Changements climatiques et dynamique des forêts de montagnes. CREA Centre de Recherche sur les Ecosystemes d'altitude. Chamonix. 2 Fev. P2.
- Kunstler G. 24 May 2024. Presentation on the impact of climate change on mountain forest responses to climate change, delivered to the General Prosecutor's Office of Grenoble (Parquet Général, Cour d'appel de Grenoble). This talk was part of a seminar series aimed at raising awareness of environmental issues. P2.
- N. Kulha (Luke) participated in the organization of the annual event of Finnish Forest Biological club of the Finnish forest society (Suomen metsätieteellisen seuran Metsäbiologian kerho), which was associated with forest certification and diversity. No Funpotential project results were yet ready to be presented. Relevant AB members were invited to meeting. P1.
- An article in "The Guardian" presented the key results of Barrere et al. (2024) Functional Ecology to the general public see https://www.theguardian.com/environment/2024/jan/25/diverse-forests-of-slow-growing-trees-more-resilient-to-storms-study-finds-aoe. P2.
- A press release was published on the publication Fuchs et al. (2024) by UGOE and taken up by the media, including one journal of private forest harvesting companies (see list of stakeholder products) (see SH dissemination list for details). P3
- A blog post to Journal of Ecology based on Kulha et al., 2023 paper: https://jecologyblog.com/2023/09/05/great-expectations-hard-times-a-tale-of-competition-induced-tree-mortality-across-europe/. P1

Education projects

- *NA*

6. Global Impact assessment indicators

6.1 Impact statement

Project contributed well to the call objectives by studying ecological processes affecting forests (disturbances, climate change), and possibilities to affect that with nature-based forest management. The project made several scientific advancements regarding to ecological process knowledge, and how it affects management of forests. New openings were also made methodologically, as the impacts of tree species diversity had not properly been dealt at large scale economic optimizations, and game-theoretically justified solutions to forest management under disturbances had been lacking.

Did the project demonstrate transnational added value?

Project integrated ecological and economic expertise and tools developed by different research groups, offering great additional value over national project. Regarding to data, the project was able to combine large dataset for the analyses, which originated from different countries and would have been difficult to access and interpret without transnational character of the project. Moreover, consideration of management systems and case area specific forest management problems provided a wider frame for model development, and applicability of the results.

How have the results been exploited (valorisation)?
Project results will be valorised in new projects that have been received partially based on the experiences in Funpotential. Several research articles have been published, and tools are published allowing others to apply our findings and methods. Tools will be used also in the subsequent projects by the Funpotential team members.

6.2. Other scientific valorisation factors

	Number, years and comments (Actual or likely valorisations)
International patents obtained	NA
International patents pending	NA
National patents obtained	NA
National patents pending	NA
Operating licences (obtained / transferred)	NA, tools are open-source
Software and any other prototype	Matreex R package; woodValuationDE R package and Excel tool
Company creations or spin-offs	NA
New collaborative projects	Proposal BIOFORCE to BiodivClim 2024 call. SafeNet HE project 2025 (with FSC stakeholder). Project on policy instruments on forestry funded by Sitra 2024-2025 (Stakeholder involved).
Scientific symposiums	IBFRA 2024 (contributed to organizations)
Other(s) (specify)	

6.3. Assessment and follow-up of personnel recruited on fixed-term contracts (excluding interns)

Identification			Before recruitment for the project			Recruitment for the project				After the project			
Surname and first name	Sex M/F	E-mail address	Last diploma obtained at time of recruitment	Country of studies	Prior professional experience, including post-docs (years)	Partner who hired the person (Organisation and Country)	Position in the project (1)	Duration of missions (months) (2)	End date of mission on project	Professional future (3)	Type of employer (4)	Type of employment (5)	Promotion of professional experience (6)
Kulha Niko	M	Niko.kulha@bio.au.dk	PhD	Finland	PostDoc 1 year	Luke, Finland	PostDoc	30	31.7.2024	*fixed-term contract*	teaching and public research	researcher	yes
Matti Hyyrynne	M	Matti.hyyrynen@luke.fi	PhD	Finland	PostDoc 1 year	Luke, Finland	PostDoc	24 (partially funded by Funpotential)	31.3.2025	*still working on the project*	EPIC	researcher	
Julien Barrere	M	Julien.barrere@inrae.fr	PhD	France	PhD student	INRAE LESSEM, France	Postdoc	34	31/07/2024	*Open-ended contract* :Permanent Researcher at INRAE Aix en Provence	EPIC	researcher	yes
Jasper Fuchs	M	Jasper.fuchs@usys.ethz.cz	MSc	Germany	NA	UGOE, Germany	PhD student	30	30.03.2024	*fixed-term contract* PostDoc in ETH Zurich	*teaching and public research*	researcher	yes

6.7. Data Management and timeline for open access

In day to day work the project uses online folders set in Microsoft Teams, and for scientific computation environment at CSC (www.csc.fi) and github for code collaboration. The project does not generate new data, except simulation data and model program code, which will be documented in scientific publications, and shared online in established arena when they have use value for others.

Project cannot share openly all original data used in the studies. The Finnish NFI data belongs to the forest inventories who granted the access to data on the condition that it will not be shared further. The French and German data are public and code to format these public data have been made open on github (see https://github.com/kunstler/laselva and https://github.com/jbarrere3/GermanNFI.

The project has generated code and software tools (see publications excel), which are shared openly in internet (R Cran, Github, Zenodo), where it can be downloaded and used, and modified by any individual. See the replies regarding to this tool in the enumerated list below:

1. *Agreed standards to be used for data and metadata format and content (where existing standards are absent or deemed inadequate, this should be documented along with any proposed solutions or remedies);*
    a. Publication follows metadata formats of R Cran and Zenodo
2. *Policies for broad access and sharing including provisions for appropriate protection of privacy, confidentiality, security, intellectual property, or other rights or requirements;*
    a. Tool are published open access. The Matreex model is available at https://gowachin.github.io/matreex/
3. *Policies and provisions for mining, reuse, re-distribution, and the production of derivatives;*
    a. Requirement for citing the original tools, CC BY
4. *Contact information for the person(s) that is responsible for updating the data management plan for your project;*
    a. mikko.peltoniemi@luke.fi
5. *A list of anticipated trustworthy, long-term repositories or data centres that will be used to ensure preservation of access to data and digital outputs following completion of the project.*
    a. Zenodo
    b. Github
    c. R Cran

7. Comments

Please note that the following section is not mandatory and will not be evaluated by the Call Steering Committee. We would be very grateful if you could nonetheless provide the requested information if relevant.

7.1. Success stories

Funding offered an exceptional possibility for integrating research of three research groups and focusing on a specified but transdisciplinary research topic.

Thanks to his paper in Functional Ecology arising from FUNPOTENTIAL, Julien Barrere was short-listed for the Haldane prize of the British Ecological Society of 2024 see https://functionalecologists.com/2025/03/25/julien-barrere-diverse-forests-are-more-resilient-to-storm-disturbances-across-europe/

Jasper Fuchs successfully obtained his Phd in the course of the project and won the Gerhard Speidel Award 2024 (PhD thesis) for outstanding scientific achievements in forest economics and social sciences

7.2. General comments

Funding offered an exceptional possibility for integrating research of three research groups and focusing on a specified but transdisciplinary research topic.
The project offered a key opportunity to understand how forest ecology and forest economic approach the role of diversity for forest resilience with different methods and perspectives.
The project stimulated independent collaboration between postdoc from the three research groups

8. Access and Benefit Sharing

Please give an up-to-date information about the impact of regulations for Access and Benefit Sharing (ABS) of the CBD on your research project and about the steps, which you have taken to accord with ABS regulations.

Please note: Please note that BiodivERsA unfortunately can neither offer guidance to identify the respective steps required in your project, nor does BiodivERsA intend to control whether the project fulfils EU and national requirements.
General information on ABS is available at https://www.cbd.int/abs/
Country specific information including national contacts can be checked at https://www.cbd.int/countries/?country=de.

8.1. Have members of your consortium used Genetic Resources from provider countries which are members to the Nagoya Protocol and have their respective ABS regulations in force?

… Yes …X. No

If yes, *please answer the following questions 8.2 – 8.5.*

8.2. Which was/were the provider country/ies? ……………………………………………………

8.3. Was there an impact of the provider country's operation of the ABS regulations on your project?

… Yes …X. No

If yes, *which kind of impact?*

- High time investment?

….Yes …..No

- Administrative burden (e.g. bureaucratic fuzziness in getting PIC and MAT)?

….. Yes….No

If yes, please specify: ....

- Conflict with national policy on Genetic Resources?

….. Yes ….No

8.4. What kind of benefit sharing you agreed to?

…………………Monetary ……………Non-monetary (please specify)

8.5. Was it the first time that you had an ABS relevant project in this provider country or could you benefit from earlier experiences or contacts?

First project in the provider country …………..

9. Ethics self-assessment1

Please indicate below if you yes or no you face ethics issues within your project, and if yes, please indicate how you plan to deal with it.

1. HUMAN EMBRYOS/FOETUSES	**Y / N**	**If yes, please detail and indicate how you plan to deal with this ethic issue.**
Does your research involve Human Embryonic Stem Cells (hESCs)?	N	
Does your research involve the use of human embryos?	N	
Does your research involve the use of human foetal tissues / cells?	N	
2. HUMANS		
Does your research involve human participants?	N	
Does your research involve physical interventions on the study participants?	N	
3. HUMAN CELLS / TISSUES		
Does your research involve human cells or tissues (other than from Human Embryos/Foetuses, i.e. section 1)?	N	
4. PERSONAL DATA		
Does your research involve personal data collection and/or processing?	N	
Does it involve the collection and/or processing of sensitive personal data (e.g.: health, sexual lifestyle, ethnicity, political opinion, religious or philosophical conviction)?	N	
Does it involve processing of genetic information?	N	
Does it involve tracking or observation of participants?	N	
Does your research involve further processing of previously collected personal data (secondary use)?	N	
5. ANIMALS		
Does your research involve animals?	N	
6. THIRD COUNTRIES		
In case non-EU countries are involved, do the research related activities undertaken in these countries raise potential ethics issues?	N	

[1] For more information, please consult the Horizon 2020 Programme Guidance "How to complete your ethics self-assessment": http://ec.europa.eu/research/participants/data/ref/h2020/grants_manual/hi/ethics/h2020_hi_ethics-self-assess_en.pdf

Do you plan to use local resources (e.g. animal and/or human tissue samples, genetic material, live animals, human remains, materials of historical value, endangered fauna or flora samples, etc.)?[2]	N	
Do you plan to import any material - including personal data - from non-EU countries into the EU?	N	
Do you plan to export any material - including personal data - from the EU to non-EU countries?	N	
In case your research involves low and/or lower middle-income countries, are any benefits-sharing actions planned?	N	
Could the situation in the country put the individuals taking part in the research at risk?	N	
7. ENVIRONMENT & HEALTH and SAFETY		
Does your research involve the use of elements that may cause harm to the environment, to animals or plants?	N	
Does your research deal with endangered fauna and/or flora and/or protected areas?	N	
Does your research involve the use of elements that may cause harm to humans, including research staff?	N	
8. DUAL USE		
Does your research involve dual-use items in the sense of Regulation 428/2009, or other items for which an authorisation is required?	N	
9. EXCLUSIVE FOCUS ON CIVIL APPLICATIONS		
Could your research raise concerns regarding the exclusive focus on civil applications?	N	
10. MISUSE		
Does your research have the potential for misuse of research results?	N	
11. OTHER ETHICS ISSUES		
Are there any other ethics issues that should be taken into consideration?	N	

[2] Please note that for access to genetic resources, you must comply with the Nagoya Protocol on Access and Benefit Sharing and EU Regulation (EU) No 511/2014 which implements this Protocol. You will also have to ascertain towards the competent authorities and focal point that these used genetic resources and traditional knowledge associated with genetic resources have been accessed in accordance with applicable access and benefit-sharing legislation or regulatory requirements, and that benefits are fairly and equitably shared upon mutually agreed terms, in accordance with any applicable legislation or regulatory requirements.

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