RESONATE
Resilient Forests for Society

Deliverable 4.2

Presentation on modelling approaches in different case studies to other participants

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Version	Date	Author /Reviewers	Partner	Description
0.1	17/06/2022	Authors: Marco Patacca, Francisco Lloret, Thomas Cordonnier, Jette Bredahl Jacobsen, Gert-Jan Nabuurs	WR, CREAF, INRAE, UCPH, WR	Draft of common framework for case study modelling exercise in WP4.
0.2	01/07/2022	Reviewer: Jordi Martínez-Vilalta,	CREAF	Reviewer provided feedback on common ORF tables.
0.3	18/07/2022	Hlásny Tomáš; Peltoniemi Mikko; Aralisa Shedden; Dijana Vuletic; Masa Ostrogovic	CZUP; LUKE; BU; CFRI; CFRI	Reviewers provided comments, suggestion and general feedback on their CS in the common ORF tables.
0.4	11/10/2022	Juan Picos; Lukas Baumbach	UV; ALU	Reviewer provided comments, input and feedback on common ORF tables
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1.0	31/10/2022	Authors: Marco Patacca, Francisco Lloret, Thomas Cordonnier, Jordi Martínez-Vilalta, Hlásny Tomáš, Peltoniemi Mikko, Dijana Vuletic, Masa Ostrogovic, Juan Picos, Lukas Baumbach, Aralisa Shedden, Jette Bredahl Jacobsen, Gert-Jan Nabuurs	WR, CREAF, INRAE, CREAF, CZUP, LUKE, CFRI, CFRI, UV, ALU. UCPH, WR,	Revised deliverable for submission

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DISCLAIMER

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Executive Summery

This deliverable proposes a common framework to model resilience in WP4. It addresses the intrinsic logical differences of all the models that will be used in the 9 case studies to explore alternative forest management to enhance the resilience of the forest and the forest value-chain. To overcome these differences, we used the Operational Resilience Framework developed in WP1 to create a common narrative across case studies that will address the 4 Resilience Challenges of the project. The common narrative will help case study modellers to ask the same questions and design their model experiments in a coherent manner to enable comparing trends of the WP4 model projections.

Keywords

Operational Resilience Framework, Modelling, Case studies, Resilience challenges

1. Introduction

This deliverable provides the framework for the case study modelling approach in RESONATE Task 4.4. In this task, each Case Study (CS) will explore alternative management options for enhancing forest ecosystem and value-chain resilience of ecosystem services (resource provisioning, biodiversity and carbon storage) with respect to the *4 Resilience challenges* of RESONATE (Fig.1).

RESONATE 4 resilience challenges	
i) Changing **suitability of tree species** in response to climate change and extreme events	
ii) Increased risks of forests **disturbances**, e.g. wildfires, windstorms, insect pests	
iii) Changing **societal demand** on forest products and ecosystem services and their impacts on social-ecological resilience	
iv) **Biodiversity decline**, threatening ecosystem functioning	

Figure 1: RESONATE Resilience Challenges (RC).

CSs will address specific challenges (Fig.2), applying different modelling tools to explore the simulated effects of alternative forest management practices on the resilience of the forest-value-chain systems. Even CSs addressing the same challenge may use different models. This model specificity is one of the strengths of RESONATE, because regionally developed models are expected to better capture the characteristics and processes operating in a specific regional context. Indeed, CSs have different socio-ecological conditions, and forest types, and they suffer from different stressors or disturbances. Moreover, different models have different internal logics and structures, implying different assumptions in exploring alternative scenarios. Thus, the trade-off between comparability of models and high model specificity could make the comparison of results difficult. This deliverable makes use of the outcome of WP1 (Hurtado et al., 2022, D1.1) and builds on the past resilience pathways that will be assessed in WP2 (Shedden and Cantarello 2022, D2.3) to propose a common framework in order to address resilience in a coherent and comparable way across CSs when exploring the same resilience challenge. Further work in Task 4.4 will build on this deliverable to achieve Milestone MS 23 and Deliverable D4.8.

Resilience Challenges	Case studies
i	Catalonia – Bauges – Upper Rhine Valley - Croatia
ii	Upper Rhine Valley – Bauges – Kostelec – Ireland – Galicia
iii	Upper Rhine Valley – Kostelec – New Forest – Galicia
iv	Finland – Bauges – Kostelec – Catalonia

Figure 2: Overview of Resilience Challenges addressed by RESONATE CSs

2. Resilience framing – towards a common narrative

To obtain a certain degree of comparability, **we agreed that the analysis of each challenge will adopt the same definition and general procedure to assess resilience** following the Operational Resilience Framework (ORF, Fig.3) produced in WP1. This means that case studies which address the same challenge should adopt such common definitions and procedures.

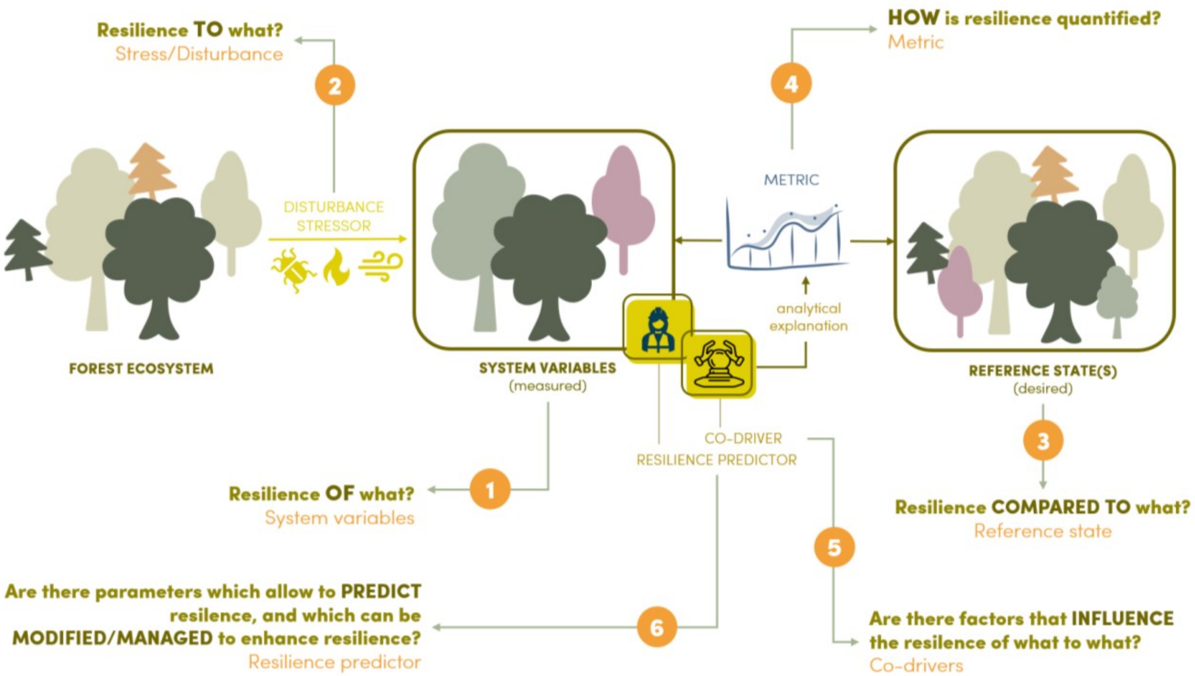

Figure 3: Key concepts of the Operational Resilience Framework (Hurtado et al., 2022, D1.1). Tree icons made by Gabriela Rueda. - The numbers will be referred to in the deliverable framework below.

The ORF is able to cope with different scales and levels of detail. Therefore, it allows variables not to be identical for all the CSs that address the same challenge (Fig.2), according to CS idiosyncrasies. The ORF represents a powerful tool to establish a **common narrative** for CS addressing the same challenge, making sure they frame resilience in the same way. We established the same narrative by discussing together with CSs modellers and representatives common **system variables and reference state** (point 1 and 3 of ORF) to assess for each resilience challenge. Each system variable will correspond to one ecosystem service provided by forests. In the Supplementary materials (S1) is available an overview of the possible ecosystem services that each model can simulate (produced in WP1 task 1.3). Also, disturbance/stressors (point 2 of the ORF) are expected to be common across CS addressing the same challenge. However, in some cases this will not be possible as different CS suffer from different stressors (e.g., for resilience challenge II). Disturbance data are made available by in WP2, and will already be used in T.2.1, giving further means of comparison among work packages. Resilience metrics, predictors and co-drivers (Points 4, 5 and 6 of the ORF) are more difficult to be defined in a homogenous way across CS. Resilience metric depends on the model's outputs, which differ across models. We discussed common metrics that could be used to assess resilience statistically, independently from the considered variable assessed (see examples in Tab.1-4). Co-drivers of resilience, which are those factors that influence resilience but cannot be modified (e.g., environmental factors), are different in different ecological conditions (therefore across CS). Resilience predictors, those factors that influence resilience and can be modified through management (e.g., stand structure, functional diversity, number of species, etc) are expected to vary in different contexts (i.e., CS). Resilience predictors are especially important in WP4 as here we aim to test alternative management strategies and assess their effects (as Task 4.4 objective). Therefore, we propose that CS will have quite some freedom in adopting metrics and testing resilience predictors and co-drivers, trying to adopt the same metrics where possible. Nevertheless, the use of a common frame will eventually enable comparisons between the results obtained in the different CSs by allowing CSs to pose the questions in the same way. Resilience is a difficult concept and can easily being studied from different perspective. Making sure CSs will ask the same questions will make possible to compare different answers.

3. Resilience challenge I - Changes in tree species suitability to climate change and extreme events

3.1 Description of the challenge

Climate change affects environmental conditions that determine forest ecosystem dynamics. At many sites, the currently dominating tree species will not be suitable to grow in a future climate, or only under high risk. Recent extreme weather events, including heat waves and extended droughts, have led to widespread tree mortality and forest decline even for several commercially important tree species which had not been regarded as particularly vulnerable.

RESONATE will study how to respond to the unprecedented intensity of drought and the associated challenges for forest management and the forest industry to deal with forest restoration and regeneration needs as well as impacts on forest productivity, wood quality, unpredictable wood flows, and a gradual change in timber species.

3.2 Addressing the challenge (as in the proposal)

i) Modelling impacts of recent changes in forest structure and composition (from NFI data, using MEDFATE process-based model package), as well as the impact of recent drought and heat wave episodes, disturbances and management systems (Catalonia), on the provision of key ecosystem services, including wood and timber but also climatic and hydrological regulation, erosion control and, potentially, recreational uses.

ii) We will use forest dynamics models (I-Maestro project, LandClim) which integrate climate change and forest management practice which allow computation of complexity metrics and resilience metrics. Multifunctional management (Bauges) promotes mixed stands to avoid large areas of pure spruce stands and identifying forest species adapted to the future climate.

iii) Data from several long-term growth and yield research plots (Upper Rhine Valley) will be used in the ILand model on the landscape aspects. The experiment dealing with tree species under climate change (“climate forest”) will be used together with results from many thinning trials used to assess the effectiveness of more intensive thinning to increase resistance and resilience to disturbance factors.

Table 1 represent the proposed common ORF for the Resilience challenge I, Changes in tree species suitability to climate change and extreme events.

Table 1: RC I draft of common ORF. Variables 1 to 3 are common across Case studies (orange background). Variables 4 to 6 can be different across CS (white background).

Case study	**Catalonia**	**Bauges**	**Upper Rhine valley**	**Croatia**
Country code	ES	FR	DE	HR
Resilience challenge	I	I	I	I
Model	MEDFATE	LandClim	iLand	Biome-BGCMuSo
ORF				
1- System variable	Wood provisioning /carbon sequestration / water regulation (supply) / erosion control / potential recreation value [eventually NTFP]	Wood provisioning	Wood provisioning	Wood provisioning (carbon stocks and fluxes)
2- Stress or disturbances	Drought	Drought	Drought	Drought
3- Reference state	Same system variables under average climate conditions 1986-2000 (as WP2).	Same system variables under average climate conditions 1986-2000 (as WP2).	Same system variables under average climate conditions 1986-2000 (as WP2).	Same system variables under average climate conditions 1986-2000 (as WP2).
4- Resilience measuring	Log-ratio between system variable and reference state	Log-ratio between system variable and reference state	Log-ratio of system variable between a given year and reference state	Log-ratio between system variable and reference state
5- Co-drivers	Climate, soil attributes and topography as drivers of soil water content	Exposition	Climate, soil attributes, topography	Climate, soil attributes and topography
6- Resilience predictors	Alternative management options determining different structural attributes and functional diversity	Alternative stand structures	Alternative management options (e.g., different thinning intensities, specialization of supply chain – e.g. shift towards hardwood or different dbh ranges)	Alternative management options (different thinning intensities)

4. Resilience challenge II - Increased risks of forests disturbances, e.g. wildfires, windstorms, insect pests

4.1 Description of the challenge

Increased risks of natural disturbances (e.g., storms, insect outbreaks, wildfires, and their interactions) threaten ecological resilience, i.e. the ability of forests to recover their structure and functioning after stand-replacing disturbances.

RESONATE will study how post-disturbance management affects short- and long-term ecosystem resilience and how forest value chain resilience can be enhanced to cope with shocks from natural disturbances rippling through the forest-based sector; first creating a pulse of available timber from salvage harvesting as well as high costs for regeneration, and later resulting in a shortage of local timber supply. These challenges may also force private forest owners to abandon active forest management.

4.2 Addressing the challenge (as in the proposal)

Using nature-based solutions like promoting mixed stands (Upper Rhine Valley, Bauges) or transforming even-aged stands to continuous cover forests as an insurance service to deal with disturbances (Ireland), and the post-disturbance recovering process (Kostelec). Options for increasing resilience of forests at different levels of disturbance risk will be identified using forest landscape simulation models (LandClim, iLand) and links and trade-offs between diversity and production under a range of disturbance, management and climate scenarios will be analysed.

Table 2 represent the proposed common ORF for the Resilience challenge II.

Table 2: RC II draft of common ORF. Variables 1 and 3 are common across CS (orange background). Variable 2 represent disturbances characterizing the CS. Variables 4 to 6 can be different across CS (white background).

Case study	Kostelec	Bauges	Upper Rhine valley	Ireland	Galicia
Country code	CZ	FR	DE	IR	ES
Resilience challenge	II	II	II	II	II
Model	iLand	LandClim	iLand	Landis-II	Landis-II
ORF					
1- System variable	Wood provisioning, carbon sequestration, biodiversity	Wood provisioning	Wood provisioning, carbon sequestration	Wood provisioning	Wood provisioning

2- Stress or disturbances	Bark beetles, wind, drought, browsing	Windstorm	Wind, drought, bark beetles	Windstorm	Fire
3- Reference state	Present structure / spp comp., reference level of wood provision, C sequestration and climate (1985-2010)	Present structure / spp comp., reference level of wood provision, C sequestration and climate (1985-2010)	Present structure / spp comp., reference level of wood provision, C sequestration and climate (1985-2010)	Present structure / spp comp., reference level of wood provision, C sequestration and climate (1985-2010)	Present structure / spp comp., reference level of wood provision, C sequestration and climate (1985-2010)
4- Resilience measuring	Counterfactual approach: position in a 2D space of 'recovery time-impact' (as in Ingrish and Bahn 2018)	Counterfactual approach: position in a 2D space of 'recovery time-impact' (as in Ingrish and Bahn 2018)	Counterfactual approach: position in a 2D space of 'recovery time-impact' (as in Ingrish and Bahn 2018)	Counterfactual approach: position in a 2D space of 'recovery time-impact' (as in Ingrish and Bahn 2018)	Counterfactual approach: position in a 2D space of 'recovery time-impact' (as in Ingrish and Bahn 2018)
5- Co-drivers	Climate, ownership	Slope/aspect	Climate, soil attributes, topography, [maybe ownership]	Soil water content?	Fire weather, slope, road access
6- Resilience predictors	Species planting, modified rotation length, sanitation removal of wind-felled trees	Structural diversity (Gini?)	Thinning intensities, species mix	Silvicultural framework (even age vs CCF)	management fragmentation

5. Resilience challenge III - Changing societal demand on forest products and ecosystem services and their impacts on social-ecological resilience

5.1 Description of the challenge

Society's demand regarding goods and services from forests is changing continuously. At the same time, changes in climate, disturbances and land use may decrease the ability of ecosystems to provide such services.

RESONATE will study which goods and services are expected to be changed in the foreseeable future under different socio-economic scenarios (e.g. increases in biomass demand for material and energy use, carbon sequestration, recreational use, others), how forest system management can be adapted to increase resilience to such changes with consideration of diverse interests of forest owners and society (including the European Green Deal policy and responses to economic impacts of COVID19), and what trade-offs may result from these.

5.2 Addressing the challenge (as in the proposal)

This contains three aspects:

i) Investigate how long-term species composition changes affect forest value chain by identifying key drivers of wood supply to construct scenarios (e.g. assortment prices, owner category, forest management system, non-forest income, presence of damaged wood from salvage cutting;

ii) Analysing trade-offs with other services requirements (e.g. carbon storage, water services, recreation);

iii) Account for foreseen forest expansions.

Table 3 represent the proposed common ORF for the Resilience challenge III.

Table 3: RC III draft of common ORF. Variables 1 to 3 are common across CS (orange background). Variables 4 to 6 can be different across CS (white background).

Case study	**Kostelec**	**Upper Rhine valley**	**New Forest**	**Galicia**
Country code	CZ	DE	UK	ES
Resilience challenge	III	III	III	III
Model	iLand	iLand	Landis-II	Landis-II
ORF				
1- System variable	Wood provisioning/C storage/ recreation	Wood provisioning /C storage/ recreation	Wood provisioning /C storage/ recreation	Wood provisioning
2- Stress or disturbances	Societal changes (e.g., Spp. Comp. Changes/ interests for alternative timber assortments (e.g. fuelwood) / recreation	Societal changes (e.g., demand for fuel wood, recreation, higher biodiversity, protected/hands-off areas)	Societal changes (e.g., Spp. Comp. Changes/ C storage / water regulation/ recreation	Societal changes (e.g., Spp. Comp. Changes/interests for alternative timber assortments
3- Reference state	Timber production and C dynamics under current forest structure, spp. Composition, past climate and management (1985-2010)	Timber production and C dynamics under current forest structure, spp. Composition, past climate and management (1985-2010)	Timber production and C dynamics under current forest structure, spp. Composition, past climate and management (1985-2010)	Timber production under current forest structure, spp. Composition, past climate and management, ownership (1985-2010)
4- Resilience measuring	Change trajectories in a multidimensional space; recovery time; position in a 2D space of	Change trajectories in a multidimensional space; recovery time; position in a 2D space of 'recovery time-	Statistical modelling	Statistical modelling

	'recovery time-impact' (as in Ingrish and Bahn 2018)	impact' (as in Ingrish and Bahn 2018)		
5- Co-drivers	Climate, increased disturbed areas	Climate, ownership	forest expansion, climate	slope, road access
6- Resilience predictors	Management scenarios	Management scenarios	Management scenarios	Change in ownership management (e.g. from single to cooperative management)

6. Resilience challenge IV - Biodiversity decline, threatening ecosystem functioning

6.1 Description of the challenge

Forests play a vital role in safeguarding Europe's biodiversity, but climate change threatens their integrity as suitable habitats of native species, which may get lost. Adaptive targeted management actions (e.g., tree species diversification in managed forests, assisted migration, creating stepping stones or corridors to connect protected areas, protecting climate refuge areas) can mitigate biodiversity loss and enhance resilience.

RESONATE investigates integral solutions for biodiversity management across landscapes that consider a mix of conservation measures (from strict protection to limited or no management restrictions) to safeguard / enhance biodiversity in a dynamically changing environment.

6.2 Addressing the challenge (as in the proposal)

i) We will analyse the trade-offs between timber supply under high wood demand and biodiversity and climate change mitigation aims in a region (Finland) using a predefined set of wood demand, climate, and disturbance scenarios;

ii) Using data from observation of 300 small plots we will investigate how to limit the impact of droughts, wind throws and bark beetle attacks in mountainous areas (Bauges), while keeping the delivery of ecosystem services and biodiversity at a high level, balancing protection functions against gravitational hazards in protected areas;

iii) Knowledge from long-term silviculture experiments (Kostelec) will be combined with a modelling approach to investigate options to increase the resilience of forests under different levels of risk from bark beetles, and to increase the resilience of a new forest cohort emerging at large disturbed sites;

iv) By combining data from NFIs with long-term silviculture experiments and available surveys of drought impacts (Catalonia) we will analyse how overstocked forests threaten biodiversity conservation, as they are more prone to forest dieback and fires.

Table 4 represent the proposed common ORF for the Resilience challenge IV.

Table 4: RC IV draft of common ORF. Variables 1 and 3 are common across CS (orange background). Variable 2 represent disturbances characterizing the CS. Variables 4 to 6 can be different across CS (white background).

Case study	**Kostelec**	**Finland**	**Catalonia**	**Bauges**
Country code	CZ	FI	ES	FR
Resilience challenge	Iv	Iv	Iv	Iv
Model	iLand	PREBAS	MEDFATE	LandClim
ORF				
1- System variable	Biodiversity indicators (forest structure, deadwood)	Biodiversity indicators (forest structure, deadwood)	Biodiversity indicators (forest structure, deadwood)	Biodiversity indicators (forest structure, deadwood)
2- Stress or disturbances	Bark beetles, wind, drought, browsing	Wind	Drought	Drought/wind/ bark beetles
3- Reference state	Same system variables under average climate conditions for the corresponding time period (1985-2010)	Same system variables under average climate conditions for the corresponding time period (1985-2010)	Same system variables under average climate conditions for the corresponding time period (1985-2010)	Same system variables under average climate conditions for the corresponding time period (1985-2010)
4- Resilience measuring	Change trajectories in a multidimensional space; recovery time	Log-ratio between system variable and reference state	Log-ratio between system variable and reference state	Log-ratio between system variable and reference state
5- Co-drivers	Climate	Temperature and rainfall changes	Climate, soil attributes and topography as drivers of soil water content	Slope/aspect, Gravitational Hazard
6- Resilience predictors	Management scenarios controlling different aspect of stand and landscape structure and species composition	Mgmt. intensities; forest age and species structure	Alternative management options determining different structural attributes (and functional diversity?)	Spp. selection through management.

7. Conclusion and steps forward

This deliverable sets the foundation for further work planned in T 4.4. The established common narrative enables case studies to look at resilience in a coherent and comparable perspective. Building on the common framework, the next step of T 4.4 will be to specifically define the different options to increase resilience each CS will explore (MS 23, due Month 24). This work will consist in describing in detail the alternative resilience predictors that will be modelled to explore how to increase resilience in the different CS's contexts. This next further step (MS23) will be instrumental to finally model those options in the future and investigate ways to enhance resilience (D4.8, due M36).

8. References

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