Integrated Biodiversity Conservation and Carbon Sequestration in the Changing Environment (IBC-CARBON)

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***WP5**: Economic and policy analysis and development of compensation mechanisms;*
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Executive summary

Policy context for project: Successful integration of biodiversity (BD) conservation with sustainable forest use under global changes is a major challenge for the Finnish society, and is the central theme for the proposed project. The Finnish National Energy and Climate Strategy (2016) outlines the actions enabling Finland to attain the targets specified in the Government Programme and adopted in the EU for 2030, and to set the course for achieving an 80−95% reduction in greenhouse gas (GHG) emissions by 2050. The Finnish Government Programme sets ambitious targets in the energy sector, including increasing the share of renewable energy to over 50 % of end consumption, increasing self-sufficiency to over 55 %, and bringing the share of renewable transport fuels up to 40 %, all this by 2030. Finland has large forest resources (owned to large extent by private forest owners) and highly developed forest industry; the goal is to increase the use of wood for different products and renewable energy up to about 80 million m^3 of stemwood annually. This is part of the general change towards a bio-based economy (Finnish Bioeconomy Strategy 2014). However, these aims need to be integrated and balanced with the second main policy context: the national strategy and action plan for the conservation and sustainable use of biodiversity approved in 2012. The main objective of the strategy ("Saving Nature for People") is to halt BD loss in Finland by 2020. It places ecological, economic and cultural values related to BD at the heart of decision-making on the use of natural resources. The strategy addresses measures on climate change impacts, halting the decline in forest species and habitats, enhancing the network of protected areas, and accounting for the BD and ecosystem services (ES) in land use planning. Furthermore, the EU Water Framework Directive (2000) aims at good ecological status of waters. These policy processes will be tackled in IBC-CARBON in an integrative way to identify feasible options, environmental risks and policies for sustainable forest use planning.

Scientific context: Climate change directly influences many ecosystem processes and indirectly affects the development of mitigation and adaptation strategies that are likely to have substantial impacts on BD. Approaches to maintain and enhance carbon (C) sequestration within forest ecosystems may have large impacts on BD. The planned increase in the use of forest bioenergy is considered as an important mitigation strategy against climate change, but it is a potentially conflicting driver. Drastic land use changes and/or increased biomass harvest will have far-reaching consequences for BD conservation, C-sequestration and soil quality, as

well as downstream water pollution. Optimal solutions can only be achieved when BD, C- and sustainability issues are incorporated within a joint spatial planning and optimization process, utilizing the opportunities of new technologies. Innovative monetary mechanisms for land owners have a special key role in such integrative planning to guarantee societal support for these processes. *The key aims of the IBC-CARBON project are:*

- Develop integrated model-based tools to determine spatially optimized land-use in forest ecosystems for the joint BD conservation and C-sequestration targets.
- Study integrated impacts of climate change, forest bioenergy policies and other drivers on BD indicators and C-sequestration/balances (also accounting for biophysical effects).
- Develop and test Earth Observation (EO) based variables for their capacity to provide cost effective tools to detect and quantify changes in forest BD and ES.
- Develop spatially explicit tools for evaluating and improving environmental sustainability of forest bioenergy and management policies.
- Develop voluntary monetary compensation mechanisms for forest owners together with environmentally responsible businesses to improve/optimize BD conservation and C-sequestration.
- Assess the economic feasibility and compatibility with the EU climate policy targeting of using increased forest C-sinks under such new compensation schemes for decreasing Finnish net emissions of GHGs.
- Evaluate vulnerability of current forest protection area network under changing conditions.
- Inform policy makers and stakeholders on adaptation options and sustainable policies and their ecological and economic boundary conditions, recognizing win-win situations.

We envisage that Finland could be a leading country in developing and implementing national schemes for simultaneously increasing C-sequestration of forested ecosystems, use of forest biomass in a sustainable way, and supporting integration of EU climate change and biodiversity policies. The project is carried out by a multidisciplinary team from the Finnish Environment Institute SYKE, and Universities of Helsinki and Eastern Finland. The team represents the top-level of science in these fields; the key researchers are affiliated with three current scientific Centres of Excellence and have access to core national research infrastructures and datasets.

1. Central idea of the research

Policy background and context for research:

The Finnish National Energy and Climate Strategy (2016) outlines actions that will enable Finland to attain the targets specified in the Government Programme and adopted in the EU for 2030, and set the course towards 80−95% reduction in greenhouse gas (GHG) emissions by 2050. Under the proposal issued by the Commission in July 2016, Finland's target (in the effort-sharing sector) is a 39 % reduction in GHG emissions by 2030 compared to 2005. Proposals were also issued for including the land use change and forestry sector (LULUCF) in the EU's climate targets for 2030. Consequently, the Finnish Government Programme sets ambitious targets, including increasing the share of renewable energy to over 50 % of end consumption, increasing self-sufficiency to over 55 %, and bringing the share of renewable transport fuels up to 40 %, all this by 2030. Finland has large forest resources (covering about 70% of the country; 60% of the forested area is owned by private forest owners) and highly developed forest industry. Based on these resources, the Finnish Bioeconomy Strategy (2014) aims at enhancing sustainable bioeconomy solutions. The goal is to increase the use of wood for different products and renewable energy to about 80 million m^3 of stemwood annually, up from about 66 million m^3 annually in 2013-2015. Such a wide-scale intensification of biomass removals from forests has raised concerns about harmful environmental side-effects and climate change mitigation potential of these activities (see Section 2 below). The European Renewable Energy Directive's

(2009) sustainability criteria for biofuels and bioliquids mandates that the raw material should not be obtained from land with high biodiversity (BD) value or high carbon (C) stock.

The national strategy and action plan for the conservation and sustainable use of biodiversity constitutes the other main policy context for the present proposal. This strategy, “Saving Nature for People”, was approved in 2012, and has a key objective to halt BD loss in Finland by 2020. It places economic and cultural values related to BD at the heart of decision-making on the use of natural resources. The strategy and its action plan implements the Convention on Biological Diversity and takes into account the objectives of the EU. The strategy includes measures on a range of topics including climate change impacts, halting the decline in forest species and habitats, enhancing the network of protected areas and taking into account the maintenance of biodiversity and ecosystem services (ES) in land use planning. Taken together, these policy processes call for integrative research and planning to identify feasible options, environmental risks and sustainable policies; these constitute the key topics of IBC-CARBON project.

How the application matches the programme’s objectives and questions:
A. Which change phenomenon of societal significance will the research address, and why are adaptation and resilience important factors here? Biodiversity and land-use processes in forested ecosystems are simultaneously affected by interacting factors of changing climate, deposition and intensified forest management, resulting from the societal transformation towards a bio-based economy. A balance needs to be reached between the use of forests, actual C-storage/sequestration in the ecosystem, BD conservation, and other environmental impacts. Integrated adaptive land use and conservation planning enhances sustainable forestry, and can lead to win-win situations. Mechanisms to enhance C-sinks in forest ecosystems have a high potential to cost-efficiently decrease Finnish net GHG-emissions.

B. What are the obstacles to adaptation and resilience, and why? The mitigation and adaptation strategies will themselves become major environmental drivers, as in the case of increasing use of forest biomass. The societal awareness that BD conservation and forestry are not necessarily mutually exclusive interests is only emerging. Moreover, the complex interactions between drivers, policies and different environmental processes are not thoroughly understood. New problem solving technologies (systematic spatial prioritization/optimisation and Earth Observation (EO) techniques), and monetary compensation mechanisms can aid tackling complex planning tasks, but they have been insufficiently utilized.

C. Which solutions can support adaptation to change and change management; how can adaptation facilitate sustainable growth? The biodiversity consequences of C-conservation strategies (and vice-versa) should be explicitly integrated into the land-use plans to maximize the co-benefits, targeting forest protection to locations that are important both for BD and the retention of C-stocks. A solution is to develop the current voluntary forest owner schemes for BD conservation (METSO, www.metsonpolku.fi/en-US/METSO_Programme) into a joint voluntary monetary compensation mechanism for promoting both BD conservation and C-sequestration (and where possible, also other ecosystem services, see WP3). Such a mechanism would importantly contribute to responsible land-use policies and provide enhanced understanding of the best practices for retaining ecosystem sustainability under intensified forest use. A key issue is the optimization planning at the landscape and regional level, whereby intensified commercial forestry could be allowed in locations less valuable in terms of integrated C-sequestration and BD, and BD-friendly management and local conservation actions applied in areas with notable ES and BD values. Also different mixes of approaches with varying intensity of forestry along with different protection and nature management actions could be applied, providing optimal solutions at the landscape level.

D. How the improved resilience affects society? The resilience of current protected area (PA) network can be increased by systematic land-use planning and targeting new conservation, nature management and BD-friendly forestry actions (incl. continuous cover forestry) to enhance connectivity of PAs and other green infrastructure. Development of efficient mechanisms to increase the areas with high BD and C-storage can increase system resilience to change. The development of spatially explicit dynamic assessment frameworks will enable incorporation of emerging process understanding. New EO based variables aid rapid and efficient detection of changes and monitoring the development in forested ecosystems, including the most valuable sites as regards to the proposed extended METSO-scheme.

<u>E. How can the harnessing of information in decisions by individuals, communities or society be promoted in order to improve the conditions for adaptation?</u> The vision of IBC-CARBON is that Finland would become a global fore-runner country in developing and implementing a national scheme for simultaneously increasing C-sequestration of forested ecosystems, and utilizing forest biomass in a sustainable way. Such a process would importantly support the integration of EU climate change and biodiversity policies. The envisaged framework would combine the decisions of individual forest owners, regional forest and land-use planners, and national-level decision makers. Participation of stakeholders in the design phase by co-creating the solutions will fundamentally improve the social acceptance of new mechanisms.

Generation of new knowledge, multi-/transdisciplinary collaboration, aspired societal impact: Successful integration of BD conservation with sustainable forest use under global climate change is a major challenge for the Finnish society. The consequences of the planned large shift towards bio-based economy are poorly known, and the sustainability of these policies needs to be evaluated. Land use changes and increased biomass withdrawal can have far-reaching consequences on BD conservation, C-sequestration and soil quality, as well as downstream waters. Optimal solutions can only be achieved when BD, carbon and sustainability issues are simultaneously incorporated in a spatial planning process, while also exploiting the opportunities of new technologies. Innovative financial compensation mechanisms for forest owners have a special key role in the process to guarantee societal support for these processes. The project will co-create such solutions in interaction with policy makers and stakeholders to develop feasible adaptation options and sustainable policies, considering ecological and economic boundary conditions, and recognizing win-win situations. Active engagement of administration, practical managers of forest, and potential buyers and sellers of offsets (SMEs) into the mechanism design is the key for reaching social acceptability.

Based on the comments of the Evaluation Panel on the Letter of Intent of IBC-CARBON, the policy relevance, social science and participatory approaches have been enhanced by (see Section 4): (i) Creating a new *WP5: Economic and policy analysis and development of compensation mechanisms*, to interact with other WPs*;* (ii) Engaging representatives responsible for implementing strategies of land-use, forestry and nature conservation to take part in the Stakeholder Board, workshops and practical demonstrations of the project; (iii) Engaging business networks and SMEs in the interaction activities (WP7); (iv) Including a professional facilitator in the project interaction team; (v) collaborating with *Future Earth Finland*.

2. Scientific objectives and their justifications as well as objectives for interaction

Scientific background and previous research around the topic by the consortium team: (publications involving members of the project team in bold)

Climate change represents a major threat to biodiversity (**Thomas** et al. 2013, **Heikkinen** et al. 2015, **Virkkala** et al. 2013) as well as to the sustainable management of the ecosystem services (ES) (**Forsius** et al. 2013, Fu and **Forsius** 2015). The societal response is to develop and implement mitigation strategies that minimize the speed and level of climate change, and to establish various adaptation strategies. These strategies will themselves become major environmental drivers (**Thomas** et al. 2013), including increased use of forest biomass for bioenergy and biofuel production (**Forsius** et al. 2016). Intensification of biomass removals from forests may invoke harmful impacts on forest productivity, biodiversity, soil quality, and climate change mitigation potential (**Aherne** et al. 2012, **Kotiaho** et al. 2015, **Forsius** et al. 2016,

Mäkelä et al. 2016, Soimakallio et al. 2016). Recent studies have suggested that increasing cuttings in forests, e.g., to increase biomass for bioenergy, will decrease the C-storage of forest vegetation and soil to an extent that cannot be fully compensated by the storage of C in forest products and product substitution (**Mäkipää** et al. 2015, Naudts et al. 2016, **Nikinmaa** et al. 2017). However, up to now these analyses have been largely based on "business as usual" regarding harvest intensities and spatial distributions of cuttings in different sites and regions. In addition, the effect of biophysical factors such as surface albedo and Volatile Organic Compounds (VOCs) emitted by different types of vegetation (Kulmala et al. 2013) have received little attention in forest policy planning (**Nikinmaa** et al. 2017).

Mechanisms to enhance C-sinks in forest ecosystems may importantly decrease European net GHG-emissions (**Nabuurs** et al. 2015), supporting the LULUCF and EU climate targets for 2030. Sustainable adaption and mitigation to climate change should be in synergy with other targets of the EU forest policy, such as developing the bio-economy and preserving biodiversity (**Nabuurs** et al. 2015) and accepted by the key stakeholders. The social welfare effects of biomass-based energy sources and their impact on both CO_2 emissions and biodiversity has been explored from citizens' and society's viewpoints (**Kosenius & Ollikainen** 2013; **Saikkonen** et al. 2014). Solely regarding BD conservation, a need for reconciling the interests of citizens, private non-industrial forest owners, and forest officials has been confirmed (Norden et al. 2017), as well as the obstacles for forest owners' participation in voluntary BD conservation (Paloniemi et al. 2017) but also their responsiveness for monetary incentives for preserving forest BD (**Juutinen & Ollikainen** 2010). To enhance C-sinks while preserving BD, a concrete option to be explored is an extension of the existing voluntary compensating scheme for BD conservation (METSO) in Finland, to allow the forest owner to get compensation also for C-storage/sequestration. This involves a need to develop economic mechanisms of joint ES provision (**Ollikainen** 2016; **Lankoski** et al. 2015; **Miettinen** et al. 2012, 2014) and the associated trading rules (**Larsen & Ollikainen** 2015), as well as to assess the coherence of various environmental policies and their acceptance among the key stakeholders.

Elevated nitrogen (N) deposition from human sources exerts various negative effects on ecosystem processes (e.g. **Forsius** et al. 2005), and forest BD (**Dirnböck** et al. 2014). Changing climate also affects decomposition processes in soils and impacts N availability to forests and ground vegetation, and can enhance N-leaching (**Vuorenmaa** et al. 2017). Importantly, BD, C-storage and land-use processes in forested ecosystems are affected by simultaneously interacting factors of changing climate and atmospheric deposition, and intensified forest management. A balance needs thus to be reached between the use of forests, actual C-storage/sequestration in the ecosystem, BD conservation, and other environmental impacts. A solution to this task, and examined in IBC-CARBON, is to apply integrated adaptive land use and conservation planning which can enhance sustainable forestry, and lead to win-win situations (**Thomas** et al. 2013, **Moilanen** 2013, **Moilanen** et al. 2014a).

To capture the dynamics of forest ecosystems and planning, new cost-effective technologies are needed to detect and monitor the changes. EO has tremendous potential for providing large-scale, standardized, spatially complete, as well as economically feasible information that enables rapid detecting, quantifying and forecasting of BD, C-sinks and their changes, as well as other ES (Lausch et al. 2016, **Vihervaara** et al. 2016). Launching of new concepts such as Essential Biodiversity Variables (EBVs) has stimulated progress to unify BD and ES monitoring globally (Pereira et al. 2013, **Pettorelli** et al. 2016). EO techniques are also in the core in EU policy processes for mapping land-use changes. However, EO data has not been fully utilized in BD conservation and other ecological research (Geller et al. 2016; **Pettorelli** et al. 2016).

Main research questions and hypotheses, objectives and expected scientific results:

1. Climate mitigation strategies in Finland rely on increased use of bioenergy and other forest-biomass based products which will increase the annual cuttings and decrease the C-storage of forest ecosystems. Recent studies suggest that this decrease may not be compensated

by the related increase in C-storage in forest products and by product substitution. However, to date the assessment of forest management effects has been based on current management practices without considering possible changes in land use and silvicultural systems. Moreover, the studies have been mainly based on C-budgets only, without including related biophysical effects on radiative forcing.

→ We will carry out a thorough analysis of allocating forest land to different purposes and different management regimes that could help reconcile the objectives of reduced radiative forcing, bioenergy production, and maintenance of biodiversity.

→ We will develop tools to estimate and predict the development of forest vegetation and C content, albedo and resulting radiative forcing using models that are both environment and management sensitive. This will allow quantification of the actual impact of forestry measures on the climate mitigation potential in Finland, and evaluation of uncertainties in future forest growth patters as a function of changes in main drivers.

2. The integration of BD safe-guarding into sustainable forestry is hampered by the difficulties in measuring the multifaceted aspects of forest BD over large, differently human-impacted areas. Achieving environmentally sustainable use of forest resources under dynamic circumstances and changing climate depends on integrative approach of multiple forest data sources, robust modelling tools tailored to data gap filling, and rapidly updated and ecologically meaningful EO-based BD proxies. Such multi-source information enables successful detection of sites of maximal potential for forest BD conservation as well as areas where intensified forest use will cause minimal harm (WP2).

   →We will develop multi-factorial analyses of different forest habitats, coupled with upgraded models, to assess current and future hotspots for maintaining valuable forest BD and populations of sensitive forest species, particularly with respect to the potential new forest owner–based conservation actions (WP5) to complement current reserve network.

   →We will develop cost-effective EO-based tools which allow systematic updating of forest BD retention potential across extensive areas and rapid updating of the BD values into the optimized land use planning (WP6) for accounting the dynamically changing forest use.
3. Intensification of biomass removals from forests will increase environmental impacts on BD, soil and water quality, forest productivity, and climate change mitigation potential. Biophysical estimates of ES provision need to be coupled to an economic valuation.

   →We will develop a quantitative modelling framework for evaluating integrated impacts of forest biomass removal and land-use change scenarios on different key environmental sustainability/ES indicators. This information is used for economic valuation (in WP5).
4. Environmental change detection can significantly improve our ability to monitor and understand land cover changes and its impacts on BD and C carbon stocks in the boreal forests. EO has tremendous potential for providing large-scale, standardized, spatially complete, continuous as well as economically feasible information that is urgently needed for the detecting, quantifying and forecasting of BD and ES.

   → We will develop and test EO-based variables for their capacity to provide cost-effective ways to quantify changes in BD and biogeochemical patterns.
5. Sustainable adaptation and mitigation of climate change need to be mainstreamed in forest policy and management, with specific attention paid to local circumstances, opportunities and challenges, and to synergies with bio-economy development and biodiversity preservation targets. These measures should be maximally on line with other policy targets for the EU forest sector, such as developing the bio-economy and preserving biodiversity.

   →We will develop monetary compensation mechanisms for forest owners' voluntary participation to jointly improve/optimize BD conservation and C-sequestration.

   →We will assess the economic feasibility as well as compatibility with the EU climate policy targeting LULUCF of using increased forest C-sinks under such new compensation schemes for decreasing Finnish net emissions of GHG.
6. BD and processes in forested ecosystems are affected by simultaneously interacting factors of changing climate, deposition and intensified forest management. A balance needs to be

reached between the use of forests, actual C-storage/sequestration in the ecosystem, and biodiversity conservation (**Thomas** et al. 2013, **Moilanen** et al. 2014a ,b).

→ We will develop integrated model-based tools to determine spatially optimised land-use in forest ecosystems for joint BD conservation and C-sequestration targets.

→ We will study integrated impacts of climate change, forest bioenergy policies and other drivers on BD indicators and C-storage/sequestration, and their joint spatial optimization.

Positioning of consortium in the scientific field and potential for breakthroughs:
The researchers involved in this application represent the top level of research in these fields of science in Finland, being affiliated to three current Centres of Excellence: '*Metapopulation Research'* and '*Atmospheric Science'* (Academy of Finland), and '*An integrating nexus of land and water management for a sustainable Nordic bioeconomy*' (NordForsk). See Section 5 and CVs for details. The consortium therefore has proven capacity for making scientific breakthroughs. The project is implemented by a truly multidisciplinary team composed of experts in forest modelling, forest/biosphere feedback mechanisms, BD conservation and systematic spatial planning, biogeochemistry, catchment-scale ES modelling, environmental economics and policy, and science/policy and stakeholder interactions (Fig. 1). The consortium team has experience on previous collaboration as well as on various international and domestic multidisciplinary project consortia, access to top-quality data from research stations and national data bases, as well as excellent international contacts (see Sections 3 and 6). This will enable new innovative scientific understanding and integrative solutions.

Objectives for consortium's interaction activities, publication plan:
Objectives and implementation of interaction activities are described in Sections 1 and 4. Results of the project will be published in high-class scientific journals, reports and policy-briefs/fact-sheets (containing results of relevance for stakeholders), and as part of national (e.g. Finnish Climate Change Panel) and international assessment activities and products (e.g. IPBES, AMAP, CLRTAP/WGE). Electronic channels will also be utilized (details in Section 4).

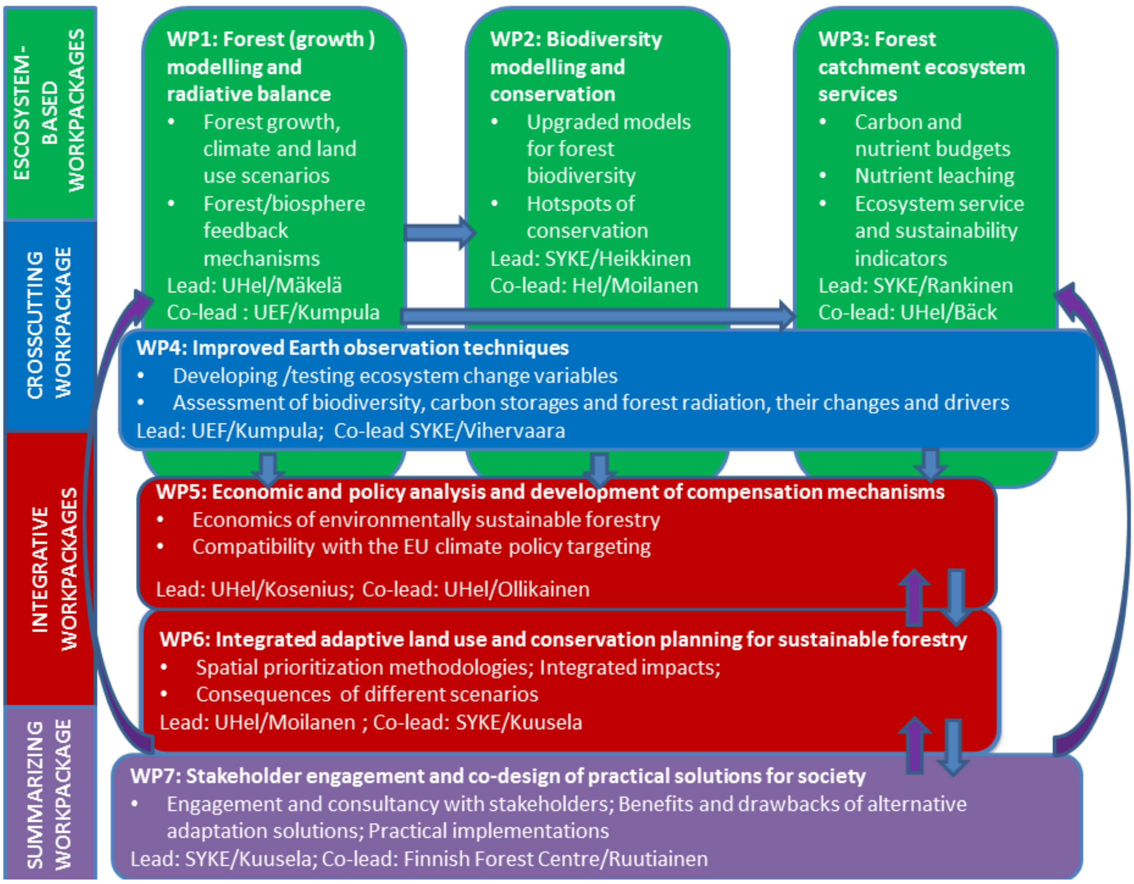

Figure 1: Work package structure, organization of work and information flow in project.

3. Research implementation, methods and data, breakdown by work package

WP1: Forest (growth) modelling and radiative balance (Lead: UHel/Mäkelä, Co-lead: UEF/Kumpula)

In WP1, we propose that a more thorough analysis of allocating forest land to different purposes and different management regimes could help reconcile the objectives of reduced radiative forcing, bioenergy production, and maintenance of BD. Measures affecting all of these at the same time could include (i) increasing the area of protected and / or unmanaged forest in appropriate locations, (ii), lengthening stand rotation in selected managed sites, and (iii) increasing the proportion of mixed species and continuous cover management in forests.

In order to assess the utility of the proposed actions we need tools that are both climate and management sensitive and can be reliably utilised over large regions with input data that is feasibly available. In recent EU-funded projects (FORMIT, North State, MONIMET) we have developed and applied a novel process-based model system (PREBAS) for estimating forest C fluxes and growth on the basis of gridded climate, vegetation and land-surface data (**Peltoniemi** et al. 2015, **Minunno** et al. 2016, **Härkönen** et al. 2010, 2011, **Mäkelä** et al. 2016, **Mäkelä** et al. in prep.). The submodels of PREBAS have been defined with the objective of representing the biological processes as faithfully but at the same time as simply as possible, and to ascertain realism in predictions they have been calibrated with Bayesian techniques against large data sets, e.g., from flux towers and permanent forest management trials. PREBAS is currently applicable to even-aged stands of all Finnish commercial tree species. Here, we will (1) further develop PREBAS to cover old-growth and uneven-aged stands, (2) incorporate BD indicators as defined by WP2, (3) incorporate biophysical indicators of albedo and VOCs to allow us to estimate the full radiative forcing due to forestry, and (4) apply the model across Finland under selected climate change and management scenarios in interaction with WP2-WP6.

Model development will focus on factors that are crucial for determining the C sequestration potential of old growth and uneven-aged forests when compared with even-aged managed forests. Key factors include changes in photosynthetic capacity due to more heterogeneous canopy structures, changes in C allocation due to different local environments (**Mäkelä & Valentine** 2006) and aging (Genet et al. 2010), and changes in mortality and deadwood accumulation (Hedwall and Mikusinski 2015). For the modelling, we will utilise relevant literature (e.g. Valentine et al. 2014) and data collected in recent (CONBIO) and on-going projects as well as country-wide multisource national forest inventory (MS-NFI) data. *Biodiversity indicators* will be defined in terms of model variables in order to connect the model with the biodiversity analysis in WP2. They include, e.g., deadwood volume, species composition, canopy openness and age structure. Biophysical indicators will be treated following Nikinmaa et al. (2017) but with quantitative refinements based on specific datasets obtained from the SMEAR II/LTER station Hyytiälä (VOCs) and new information from satellite data in WP4 (albedo).

The model will be applied to a grid covering the whole of Finland. The inputs required by PREBAS are the initial state of forests, represented as grid cell means of forest mensuration variables. The input data are available from open MS-NFI from Luke (resolution ≥16 m ×16 m). The climate variables needed for model projections will be obtained from the Finnish Meteorological Institute as bias-corrected multi-model mean projections of selected representative concentration pathway (RCP) scenarios. The resolution of the climate data is ≥1 km^2. Forest management scenarios will be constructed in collaboration with stakeholders (WP7) as prescribed decision chains yielding the silvicultural system (unmanaged, continuous cover or even-aged forestry), species selection at regeneration, and the timing and intensity of harvests. We will also produce order-of-magnitude estimates of C stocks in forest products using literature-based mean residence times for different product assortments.

Model outputs will cover C fluxes and stocks, stem volume and volume growth, the BD indicators and changes in total radiative forcing, all subject to different climate scenarios and management options. The results of WP1 will be used for model development in WPs 2 and 3, and economic and policy assessments in WP5. The results will also be input to the optimization in WP6, where the modelling allows for considering the effects of land use changes such as afforestation of agricultural land and transfer of managed to protected forest, in addition to changes of silvicultural systems and management.

WP2: Biodiversity modelling and conservation (Lead: SYKE/Heikkinen, Co-lead: UHel/Moilanen)
WP2 will produce a multifaceted evaluation of the key elements in forest BD, covering a major part of Finland at fine spatial resolution directly applicable to forest management and conservation planning. For this task, WP2 will extract information from several sources, with a focus on ecologically essential forest characteristics, the environment and forest species, available from the data sets governed by the consortium partners, open access sources, or via established research collaboration. Where required, detailed spatial data on sensitive forest species and key BD elements (for model validation) will be obtained as outsourced services.

The research builds upon the METSO programme (link in section 1), particularly the Zonation decision-making conservation planning in METSO where SYKE has a key role. Crucial information employed in earlier METSO analysis includes the data developed by the Finnish Forest Centre (FFC; forest resource data), Metsähallitus and private owned nature conservation areas (forest stand and nature type inventory data) and in the MS-NFI of Finland (**Lehtomäki** et al. 2009, 2015, **Mikkonen** et al. 2017 unpublished). These data contain nation-wide information on stand volume, tree species, stand age and site fertility; MS-NFI data is open access data, others are available via negotiations. The MS-NFI data covers systematically the whole country, providing a baseline proxy for each forest stand of their potential to support forest BD. In addition, we aim to utilize more detailed stand-based inventory data (FFC and Metsähallitus) which provides key proxies for forest biodiversity (e.g. the amount of dead wood; **Lehtomäki** et al. 2009). These data cover only limited areas in Finland. Thus, this WP will develop best practices for extrapolating the BD proxies to insufficiently known areas using state-of-the-art modelling approaches, i.e. model ensembles (**Marmion** et al. 2009; Thuiller et al. 2009) and novel machine learning models (Crisci et al. 2012). In these models, data on forest features and BD proxies will be related to different environmental variables, such as soil type and local climate, to produce projections of dead wood accumulations and sites with high naturalness. In collaboration with WP4, the potential of deriving useful cost-effective forest BD proxies from EO-data such as airborne laser scanning data will be assessed (**Vihervaara** et al. 2015). Here, the focus is in techniques capable of detecting the vertical heterogeneity of forests, a key feature supporting and maintaining forest BD (Kuuluvainen 2009; Guo et al. 2017).

At the species level, we will construct spatial data layers for the distribution of sensitive forest taxa and indicator species of BD, and data on breeding sites of important forest-dwelling bird species such as goshawk (Björklund et al. 2015), three-toed woodpecker (Pakkala et al. 2002; Fayt 2006) and capercaillie (**Sirkiä** et al. 2012). We will use ensemble models and machine-learning models in two ways to produce projections to accomplish the data: (1) where realistic, by downscaling the coarse-scale occurrence patterns to local forest stand level (McPherson et al. 2006; Rempel & Hornseth 2017), and (2) filling in the spatial data gaps with the models based on known local occurrences and breeding sites and their environmental characteristics (Zellweger et al. 2013). We will also predict the probable sites of species occurrence over large areas by using EO data. For particularly important species, we will run spatially explicit dynamic population models (**Bocedi** et al. 2014; **Heikkinen** et al. 2015) to assess their persistence under different forest use and protection level scenarios.

Climate change impacts will be assessed in two ways. First, scenarios developed in WP1 will describe future changes in key forest features and can be used in WP2 to forecast associated changes in forest BD values. Second, bioclimatic envelope models (**Heikkinen** et al. 2006) can be used to assess broad-scale range shifts of forest species, to detect locations where key species might retreat northwards (**Virkkala** et al. 2013). The EO techniques tested in WP4 will provide tools for cost-effective monitoring of the changes in forest structure and composition. As an outcome, WP2 will deliver (1) data layers and maps for multiple forest BD proxies, directly useful to the stakeholders and transferred into the WP6 together with data from WP1 and WP3 for joint optimization analyses, (2) increased understanding for the predictability of key BD elements in boreal forests, and (3) projections of how climate change might change the features and spatial distributions of BD hotspots in forest ecosystems in Finland.

WP3: Forest catchment ecosystem services and sustainability indicators (Lead: SYKE/Rankinen, Co-lead: UHel/Bäck)

Land-use planning takes place at regional and municipal scales and its effects are manifested from decades to hundreds of years. Therefore landscape-scale integrative approaches are needed to evaluate impacts on multiple indicators such as C and soil nutrient balances (base cations and N), nutrient and C-leaching to surface waters, and proxy indicators for species diversity. WP3 will continue the development of our catchment-based quantitative modelling framework for evaluating the integrated impacts of forest management and land-use change scenarios on different key indicators (**Holmberg** et al. 2015, **Forsius** et al. 2016). The framework will be extended to include the spatial and temporal variation of fluxes and budgets of water, C and nutrients to answer to the question of ecosystem sustainability under multiple pressures. High-resolution maps of these indicators will be produced by coupling simulated estimates of them with detailed land cover and forest data (CORINE, multisource NFI).

Our framework will include advanced modelling tools and databases to calculate C and nutrient fluxes in catchments (Wade et al. 2002, Futter et al. 2011, Pumpanen et al. 2014). They will be quantified using empirical, statistical and process-based methods (Tuomi et al. 2011, **Rankinen** et al. 2016, **Akujärvi** et al. 2016). We will explore the possible implications for water resources, environmental pollution and ESs at the catchment level for well-studied catchments, using spatially extensive databases on land use, water quality, biodiversity and climate. Models will first be developed and calibrated for small-scale, well-monitored catchments and then up-scaled to higher order river basins. The approach will be developed and tested using data from the intensively studied LTER research sites (see below).

WP3 will provide combined information on the provisioning of ESs to support sustainable land-use planning at catchment and landscape scales, covering the mosaic of forests and croplands. Current forest management practices will be analysed according to their impacts on climate relevant gas fluxes, BD and forest productivity. Scenarios on climate change, land use and forest management will be obtained from WP1 and stakeholder engagement, while results on BD responses will be provided by WP2. The biophysical estimates of ES provision resulting from WP3 will be coupled to an economic valuation and sustainability analysis in WP5. ESs will be prioritized and indicators selected through stakeholder interaction (WP7).

WP4: Improved Earth Observation techniques (Lead: UEF/Kumpula, Co-lead: SYKE/ Vihervaara)

The key aims of WP4 are to: (i) collect cutting-edge EO data at various spatial and temporal scales for IBC-CARBON studies; (ii) develop and produce novel remotely sensed indicators of BD variables and variables for C-sequestration and forest radiation studies. Different variables describing biodiversity and ecosystem properties are produced using a multi-sensor approach. We will utilize 1) optical satellite images (e.g. Sentinel, Landsat), 2) airborne laser scanning data, and 3) unmanned aircraft systems (UAS).

Optical remote sensing covers large geographical areas at 10-30 m spatial resolution and temporal span of several decades (**Kivinen & Kumpula** 2014). Laser scanning is a superb method to capture the 3D structure of forested ecosystems with sub-meter accuracy (Maltamo et al. 2014), and has been used in growing numbers to study wildlife habitats and BD (Davies &

Asner 2014). Integrating multisource and multiscale remote sensing (RS) data and methods allows studying forest BD and C-sequestration related questions in great detail. Furthermore, such data are freely available for the whole Finland from the National Land Survey. Novel UAS methods contribute for bridging the gap in EO between field and airborne measurements and providing ultra-high spatial and temporal resolution imagery for detailed assessment of different ecosystems properties. Because of the potential for rapid deployment, spatially explicit data from UASs can be acquired irrespective of many of the costs, scheduling, logistic and weather limitations to satellite or piloted aircraft missions. Field data (e.g. species diversity) will be collected especially from the UAS-data acquisition sites, but also to tackle the research questions of ICB-CARBON in co-operation with other WPs. The other RS datasets (satellite images and lidar) are freely available via USGS/NASA and National Land Survey of Finland.

WP4 will develop further on the concept of spectral traits (ST) (Lausch et al. 2016) in boreal environments. Biotic traits, especially functional traits, are becoming increasingly important concept in ecology, conservation biology and sustainable resource management (Mason & de Bello 2013; Jetz et al. 2016). They can be biochemical, physiological, morphological, structural, phenological or functional characteristics of plants, populations or communities. Spectral traits are traits that can be directly or indirectly recorded using RS. Deriving spectral traits from various RS data can provide detailed valuable information for BD research. In addition, the planned use of lidar data allows studying traits related to forest and vegetation structure in 3D. Thus, as forest and vegetation structure is a primary determinant of habitat quality and species diversity (cf. seminal work of MacArthur & MacArthur 1961), it is imperative to assess this kind of structure in 3D, using e.g. airborne laser scanning (ALS) (Vierling et al. 2008). Multi-temporal EO data also enable detection of changes in spectral traits, i.e. spectral trait variations (STV) which can be related to physiology and phenology as well as stress and disturbances. Calculating the spatial composition and configuration of ST's also plays a crucial role in distinguishing different biotopes, communities and species, and linking BD variables with ecosystem functioning and biogeochemical processes.

WP 4 will develop and produce remotely sensed indicators of BD variables and variables for C sequestration and forest radiation studies. These variables will be available in multiple spatial resolutions (~ few cm to 30 m) and temporal resolutions (years to decades) depending on the boundaries of the examined area. Indicators and proxies are based on spectral features of the targets (satellite images, UAS) and 3D structural variables (laser scanning data). A wide range of different variables can be produced for various needs. For example, laser scanning data is analyzed and processed with tailored geospatial algorithms, which enables calculation of variables that are considered the most topical and important ones in specific studies.WP4 also produces a practical, hands-on guide about utilization of optical remote sensing, 3D laser scanning and UAS data in ecosystem research and management. This guide can be distributed to environmental management bureaus and forest management organizations. WP4 will provide EO based indices and proxies for assessment of BD (WP2), C sequestration (WP1, WP3, WP5, WP6), and forest radiation (WP1). Planning of data collection in specific sites and development of suitable variables will be carried out in a close collaboration with other WPs.

WP5: Economic and policy analysis and development of compensation mechanisms
(Lead: UHel/Kosenius, Co-lead: UHel/Ollikainen)

For successful maintenance of BD and to enhance C-sinks, forest owners' voluntary participation in conservation is necessary. Previous research experience in Finland shows that forest owners accept economic incentives for voluntary BD conservation (e.g. Horne 2006, **Juutinen & Ollikainen** 2010). Incentives for BD conservation should not be developed in isolation but in synergy with other policy targets for forest sector, such as promoting the bio-economy-based growth and climate smart forestry (Nabuurs et al. 2015). Moreover, to promote social acceptance of the compensation mechanism, it is important to co-create a system suitable for Finnish conditions through participatory approach, for the outcome to be incentive and well-received among all relevant stakeholders. WP 5 will develop an improved voluntary monetary compensation mechanism, representing an extension of the existing METSO compensation scheme for BD conservation by allowing the forest owners to get compensation also for C-storage/sequestration. This expands the scope of METSO and attracts new funding. The microeconomic simulation work is complemented with experimental economics lab, stakeholder survey, econometric analysis and active work with stakeholders (as part of WP7).

First, WP5 develops an integrated compensation model for BD and C. As the type and size of compensation affects both forest owners' willingness to supply offsets and the need for funding, be it public or private, the well-planned compensation mechanism should be subject to economic scrutiny in order to be effective. In comparison to a compensation model for forest BD (**Kangas & Ollikainen** 2017), an integrated model involves two specific features: stacking, that is, producing several environmental benefits at the same time, and the bundling of targets, that is, the possibility of conserving BD jointly in adjacent forest areas instead of enrolling single forest areas (Lankoski et al. 2015, Wissel and Wätzold 2010). The effect of these features on efficiency of conservation, type of payment (uniform or differentiated), size and type of compensation, and the best mechanism to promote both BD and C goals is examined in detail with an economic simulation model.

Second, WP5 analyses stakeholder preferences for joint compensation of BD and C. Preferences for the supply of environmental benefits from forests differ between stakeholder groups (Norden et al. 2017) and depend on the use of forest resources for energy production and the current forest management (**Kosenius & Ollikainen** 2013, Vedel et al. 2015). A structured stakeholder survey questionnaire will be implemented to examine the factors (from WPs 1-4, 6, 7) affecting the social acceptability of compensation mechanism and assess the adaptation of forest owners to BD and climate policies (Hensher et al. 2015), using advanced econometric methods. Another stakeholder survey will be targeted to administration and regional forest authorities to determine their opinions on the new compensation mechanism and its suitability to current institutional setting. Finally, companies will be interviewed to explore their willingness to voluntarily use compensation, and the ideas of mechanisms will be jointly reworked in stakeholder workshops focusing on the totality of the compensation system from administration up to practical managers of forests (in WP7).

Third, WP5 examines alternative trading rules needed for the efficiency of compensation market and explores the potential risks. The specific features related to BD offsetting and the joint compensation for BD and C place the need for modified trading rules (**Larsen & Ollikainen** 2015). The environmental benefit indices, developed using the natural science models (WPs1-4 and 6), will be combined with information on stakeholder benefits (WP5) (Iho et al. 2014, Wang et al. 2012), and the details of the compensation mechanism are tested using experimental economics laboratory (Latacz-Lohmann & van der Hamsvoort 1997). By analyzing the actions chosen by participants for BD and C-sequestration under alternative compensation schemes, the results indicate which schemes work best.

Moreover, the potential of the mechanism for improving BD conservation and helping to reduce GHG emissions in Finland as well as its compatibility with the EU climate policy targeting LULUCF will be assessed. The work in WP5 (supported by stakeholder activities in WP7) provides a well-developed, ecologically sound and economically efficient compensation mechanism, reasonable also from the administration angle, complements current conservation means and boosts forest BD protection. Outputs include scientific articles and policy papers providing concrete suggestions for the compensation scheme that is ecologically and economically feasible as well as socially accepted in Finland, and for adapting the mechanism to the Finnish forestry framework.

WP6: Integrated adaptive conservation and land-use planning for sustainable forestry (Lead: UHel/Moilanen, Co-lead: SYKE/Kuusela)
This WP will integrate the findings from and data developed by WPs 1-5 into spatial prioritization. There will be three major WP6 tasks: (i) First, areas will be identified and land use optimized simultaneously for both BD conservation and C-sequestration. While BD is generally positively associated with ecosystem C, this association is geographically variable (**Thomas** et al. 2013). In IBC-CARBON, options will therefore be developed for including forest growth and C-processes into Zonation analyses (from WPs 1 and 3) to provide operational analytical solutions. As a byproduct, areas suitable for ecological impact avoidance will be identified. (ii) Further, these analyses will be fine-tuned and interpreted from the perspective of identifying areas that are suitable as ecological compensations (for WP 5). (iii) The third and most complex task is to find optimal “win-win” solutions, also accounting for factors such as expected climate change, land-use change, land cost, area size, ecological connectivity, ESs, and willingness of land owners to participate in conservation schemes (see also Paloniemi et al. 2017). This task requires development of advanced spatial analyses with significant underlying data (WPs 1-4).

Task 1. Simultaneous planning for biodiversity conservation and C-sequestration. This task is about a new generation of analyses on the distributions of BD and C in Finnish forest landscapes. It utilizes data presently available from national forest inventories, species distributions modeled in WP 2, and additional data developed by WPs 1 and 4 about forest growth, dead wood, etc. Analyses required here will be implemented using the Zonation approach and software for ecologically based land use planning (**Moilanen** et al. 2005, **Lehtomäki & Moilanen** 2013, **Moilanen** et al. 2014a, b), which is able to integrate large amounts of grid-based data about the environment. Products of this task include spatial priority rankings and associated quantitative information, which can be interpreted for the purposes of forest conservation or ecological impact avoidance in sustainable bioeconomy.

Task 2. Identifying areas that are suitable as ecological compensations. This task is about spatial analyses that support impact avoidance (Kareksela et al. 2013) and BD offsetting (WP 5; **Moilanen** 2013). It builds on the analyses of task 1, with additional modeled information needed about the long-term difference (conservation) action makes at any given forest location (WPs 1, 2 & 5). These analyses will again be implemented as Zonation setups. Products of this task include spatial locations of and net benefits produced by areas that would be priority as ecological compensations (BD offsets). This information is co-designed together with environmentally responsible businesses in co-operation with FIBS ry. (see Section 4) and can be utilized in offsetting business, e.g. by our stakeholders.

Task 3. Advanced analyses for biodiversity conservation, C-sequestration, ecological compensations and spatial ecological impact avoidance. This task expands from tasks 1 and 2 by inclusion of several non-trivial considerations. It utilizes further data from WP 3 about ecosystem services (for methods see **Kukkala & Moilanen** 2017), from WP 1 about climate change (see **Kujala** et al. 2013) and land use change (see **Pouzols** et al. 2014), and from WP 5 about willingness of land owners to participate in conservation. In terms of analysis methods (Zonation) and interpretation this task is similar to the two previous ones, but the complexity of data and analysis implies that this task completes late in the project. These analyses will be extremely useful for administrative uses such as zoning, conservation planning, or impact avoidance in development.

WP7: Stakeholder engagement and co-design of practical solutions for society (Lead: SYKE/Kuusela, Co-lead: The Finnish Forest Centre/Ruutiainen). See Section 4.

Ethical and data issues:
The project partners are committed to open science and will develop together compliant, open data systems for research, education and stakeholder use (see Data Management Plan). No

ethical issues are foreseen. The project will use data from highly instrumented research stations of the Finnish LTER-network (Long-Term Ecosystem Research), especially Hyytiälä and Lammi stations (www.helsinki.fi/hyytiala/english/eng_tutkimus.htm; www.helsinki.fi/lammi/english). These stations are part of LTER-Europe (www.lter-europe.net), providing a link to European datasets and research infrastructures.

4. Implementation of interaction (WP7)

The planned stakeholder engagement will ensure the relevancy of our interdisciplinary research and the usability of the results for society. We have a priori identified important stakeholders through a stakeholder analysis, in which actors were mapped in relation to their ability to influence and to their interests (Durham et al. 2014). Most of the original group of stakeholders invited to the project's Stakeholder Board agreed to join, representing a wide range of organizations and actors from several different fields of the society.

IBC-CARBON will significantly support the governmental strategy formation leading to sustainable, climate-wise land-use decisions, especially related to forestry. We will **collaborate** with the *Ministry of Agriculture and Forestry* and the *Ministry of the Environment* in designing a well-functioning, relevant and applicable compensation mechanism. By engagement in stakeholder forums, workshops and practical demonstrations, the following actors will be **involved** in the co-creation activities of the project. The *Central Union of Agricultural Producers and Forest Owners (MTK)* and *Finnish Forest Industries Federation (Metry)* are key actors for the processes and actions affecting sustainable forestry as well as social acceptability of the monetary compensation mechanisms developed during this project. Incorporating the viewpoints of both the sellers of offsets as well as the buyers', the *Business network FIBS ry*. has direct contacts to companies that are potentially interested in compensation of land-use activities with biodiversity or climate impacts. This setting serves as a contact platform for the co-design of a feasible compensation mechanism. SME representative *Arbonaut Oy* has a particular interest in co-operating in remote sensing research activities.

Further stakeholders will be frequently **consulted** to ensure that our results will be conveyed as practical and user-friendly: *Metsähallitus Parks & Wildlife Finland*, *ELY Centre Pirkanmaa* and *The Finnish Forest Centre* which are responsible for practical implementation of the METSO programme (i.e. negotiating compensation contracts with the forest owners and managing protected areas). These stakeholders thus provide a practical framework for the development of the compensation mechanism. Additionally, these stakeholders will play an important role in co-production of guidance to forest owners on climate-wise decisions securing forest biodiversity. Finally, we will **inform** the scientific community, media and the public about interaction, progress and outcomes. Since the envisaged new national compensation scheme will be of high international relevance, our results will be disseminated also to an international audience of scientific and practical background, in collaboration with the *European Forest Institute*.

The stakeholder engagement and interaction activities are undertaken in WP7, and partly in WP5. To guarantee the utility of our work to the society, interaction will be co-designed with key stakeholders and specified in an interaction and communication plan. We start by a kick-off event to define stakeholder roles and interests, and identify key dates and decision-making processes that may benefit from our mid- and end-products. Messages from the stakeholders will be considered in the internal project meetings, and stakeholders will be informed about the implementation of the project, ensuring an iterative, interactive process of stakeholder engagement (see e.g. Bautista et al. 2017).

Furthermore, stakeholders will be invited to co-design activities related to different project elements. Key opportunities for stakeholder engagement will be to i) influence the final selection of the climate-change and land-use scenarios (WP1), ii) address data requirements (WP2), iii) take part in the selection of ecosystem service indicators and iv) evaluate future changes in the demand of important ecosystem services (both in WP3), v) plan business co-operation and end-products, such as hands-on guide about utilization of optical remote sensing, 3D laser scanning and UAS data in ecosystem research (WP4), vi) contribute to planning of a forest owner survey, vii) participate in specifying the characteristics of compensation mechanisms to be tested in experimental laboratory setting, viii) provide perceptions and information on stakeholder's adaptation to biodiversity and climate policies and ix) find out which elements of mechanism are important for environmentally responsible companies (all in WP5) and x) recognize bottlenecks in the adoption of decision-supporting tools and aggregated spatial information (WP6). More specifically, WP5 will develop all aspects of compensation mechanisms in close collaboration with forest owners, administration and other stakeholders, especially companies. Details of the mechanism will be tested in experimental laboratory which allows for choosing actions for biodiversity and carbon sequestration under alternative compensation schemes. With the aid of FIBS ry., the aspects of mechanism (e.g. type of compensation) will be explored from the point of environmental responsibility for selected companies involved in the FIBS network. Sustainability of the results will be ensured by surveying forest owners' opinions about factors impacting social acceptability and popularity of compensation mechanisms. The usefulness and suitability of the theoretically best mechanisms as regards the current administrative framework will be evaluated based on the questionnaires targeted to the ministries and regional forest authorities. Furthermore, the ideas will be jointly reworked in stakeholder workshops focusing on the ensemble of the compensation system from administration to forest managers.

Towards the end of the project, results of the different WPs will be visualized and verified against independent data with the stakeholders. They will participate in the evaluation of results, co-designing of communications material and reviewing project success. In total, 2–5 workshops, stakeholder forums and practical demonstration events will be organized each year, focusing on the beginning (framing of the project goals) and the end (concretizing the results). Yearly, 2 Steering Group meetings will be organized, as well as 3–5 internal project meetings per year to promote collaboration between WPs. Workshops and meetings will be guided by a professional facilitator and supervisor (Pia Rotko, Psychodrama director, MSc (Tech), Supervisor). She uses action methods to make abstract things visible enabling a shared vision between participants, including enquiry techniques that help participants to detect relevant issues and find sustainable solutions. Moreover, *Future Earth Finland*, a project partner enhancing societal impact and global networking, will be organizing 3–6 seminars, stakeholder forums or workshops. The reception of a new policy instrument is influenced by constraints and mechanisms related to the institutions involved, as well as to how the actors perceive the trade-off between the use of forest resources and the conservation of biodiversity (Primmer et al. 2013). The workshops will facilitate increased awareness, and promote successful implementation. To ensure successful links between the biodiversity conservation actions of the environmental administration to the objectives and practices of other policy sectors (Sarkki et al. 2016), the project will provide a forum for dialogue between different sectors promoting forest management, conservation, sustainable land-use and climate mitigation.

Stakeholders, scientists and the public will be informed about the project goals, progress and overall results by: a project brochure, press releases, field trips, web pages, posts in social media, newsletters, blogs (guest authoring blogs, e.g. www.biotalous.fi, www.syke.fi/ratkaisuja-blogi) and layman's reports. Timing of the communication activities and their target audiences will be specified in the interaction and communication plan at the beginning of the project, together with the stakeholders. We allocate separate funding for tailored events and products designed and implemented by the stakeholders. As an example, together with FIBS ry. and its clients (companies willing to use compensation) we will produce guidelines on biodiversity-friendly, climate-wise entrepreneurship. Compensation mechanisms will be disseminated together with the stakeholders, and presentations will be given in stakeholders' events to effectively reach end-users, e.g. land-use planners and forest owners. In addition to national events, international meetings will be attended, and all communication material will be produced both in Finnish and English (key results also in Swedish).

Interaction is coordinated and facilitated by SYKE, based on its current core role in METSO and its professional Communications Unit. The WP7 Co-lead J. Ruutiainen represents the Finnish Forest Centre, ensuring that stakeholders have low threshold in the engagement, that forest owners are effectively reached (Korhonen et al. 2013) and that the interaction will have practical and understandable outcomes.

5. Consortium's responsibilities and competence as regards scientific and societal impact

SYKE is the main centre for environmental expertise and data in Finland. SYKE is assessing environmental problems from a multi-disciplinary perspective integrating socio-economic considerations into science. The Consortium PI Research prof. *Martin Forsius* has conducted research on biogeochemical processes and sustainability concepts in forested ecosystems (H-index 33, > 4 700 citations, Google Scholar) , and has directed several Finnish, Nordic and EU funded research and demonstration projects. He is also Vice-Chair of LTER-Europe. As current Chair of AMAP (Arctic Monitoring and Assessment Programme, Arctic Council), Extended Bureau member of the Working Group on Effects (WGE) and Head of Programme Centre of ICP IM programme (UN/ECE LRTAP Convention on air pollution), he has large experience regarding science-policy interactions at the international level (see CV). Dr. *Risto Heikkinen* has a pronounced publication profile and in-depth expertise on spatial modelling for BD. Adjunct prof. *Katri Rankinen* is an expert on catchment modelling of biogeochemical processes. Adjunct prof. *Maria Holmberg* is an expert on systems analysis. Adjunct prof. *Petteri Vihervaara* has expertise in developing biodiversity and ES indicators using EO observations. Adjunct prof. *Raimo Virkkala* is on expert on forest biodiversity and climate change impacts. Dr. *Saija Kuusela* is project manager in the METSO-programme and thus has a strong background in interaction with stakeholders and science communication in general. Forsius and Rankinen are affiliated to the Nordic Centre of Excellence (NordForsk): *An integrating nexus of land and water management for a sustainable Nordic bioeconomy (BIOWATER)*.

UHel: Consortium Deputy PI, Research Director *Atte Moilanen*. With ~120 publications, Moilanen is in the ISI Web-of-Science ranked among World-leading researchers in spatial conservation prioritization, in conservation planning, and in biodiversity offsetting (of relevance for WP5). He has an H-index of 55 (Google Scholar) and >10 700 citations to work, and has, e.g., been recipient of an ERC grant. Having three university degrees that facilitate multidisciplinary work, Moilanen is scientifically well positioned to co-lead this project. Moilanen's work in ecologically based land use planning and spatial prioritization has covered development of concepts, methods, and software (incl. Zonation). Applications of this work have ranged from local to global. He is currently affiliated to the Finnish Academy Centre of Excellence '*Metapopulation Research'.*

The Department of Forest Sciences (DFS) conducts research on all aspects of forest sciences. The researchers involved in this application are affiliated to the Finnish Academy *Centre of Excellence in Atmospheric Sciences*, focusing on the eco-physiology of forest-climate interactions and forest growth. *Annikki Mäkelä* is Professor in silviculture at DFS. Her work has focused on the development of process-based forest growth models and their applications to stand-level management questions and large-scale estimation of productivity and C balances (see CV). *Jaana Bäck* is Professor in Forest-atmosphere interactions and leader of the Ecosystem processes group at DFS. She has studied the impacts of forest management options on climate change mitigation. She is PI in the Centre of Excellence in Atmospheric Sciences, and WP leader in several EU Research Infrastructure projects.

Dr. *Anna-Kaisa Kosenius* (Department of Economics and Management) has experience in economic valuation of environmental benefits, including applications to renewable energy, climate effects, BD, and forest management practices. She is an expert in survey methods and econometric modelling of choices. Her recent work focuses on farmers' participation in development of practices for reducing nutrient leaching, in close co-operation with farmers and other stakeholders (see CV). *Markku Ollikainen* is Professor of Environmental and Resource Economics. He has extensive scientific experience in designing economic instruments and policies to improve the state of the environment and use of natural resources. His studies on forestry cover a wide range of issues from forest taxation and timber markets to BD conservation, water protection and climate mitigation in forestry, and bioenergy policies. He is the Chair of the *Finnish Climate Change Panel* since 2014. Dr. *Liisa Saikkonen* is a specialist in microeconomic studies with simulation models and a recent focus on climate change and bioenergy. Dr. *Jenni Miettinen* has expertise in forest economics and diffuse load management in forestry. Doctoral student *Karen Larsen* is experienced in behavioral economics and conducting laboratory experiments to design environmental contracts.

UEF: *Timo Kumpula* is Associate Professor in geography at The Department of Geography and history at UEF. Kumpula has extensive experience in studying the northern environments, ecosystem services and social-ecological systems utilizing remote sensing and geoinformatics (GIS, remote sensing) methods (see CV). His current research focuses on land use and land cover changes in the Arctic, subarctic and boreal zone. He is co-PI in NASA's project: Yamal LCLUC Synthesis (2014-2017).

Management, distribution of work and ensuring collaboration between work packages:
IBC-CARBON will be managed by a coordination team at SYKE and the project *Steering Group*, formed of the Consortium, Deputy PIs, the WP-leaders and the key stakeholders. The Steering Group is the main decision making body of the project and will be in charge of the management of individual WPs as well as coordination of distribution of work within the project. A tight and logical flow of information between the WPs is already planned (Section 3). As part of the interaction activities (Section 4) a broader *Stakeholder Board* will be established, formed of representatives responsible for implementing strategies of land-use, forestry and nature conservation. The Board will have a major role in the co-design of the project and its WP aims and products, as well as selection of the policy relevant input scenarios.

Critical points for success, alternative implementation strategies:
Successful design and implementation of the new voluntary compensation mechanisms (WP5/WP7), likely forms the most challenging part of the project. Another demanding task is the spatial optimization and integrated planning of WP6. Successful implementation of this WP requires use and integration of data from all other WPs of the project, as well as successful interaction with the stakeholders (WP7). Great flexibility by the project team and the interaction activities will be required to meet problems and find alternative solutions with respect to the above issues, or any other problem not yet foreseen. It is planned to have close contacts with the Stakeholder Board members, as well as utilizing advice from external colleagues and networks. It is also likely that the rapidly advancing national and international policy processes will demand redefinition/redesign of some of the project activities, so that the project can deliver useful results and products.

6. International collaboration and researcher mobility

International connections and cooperation:
The project team has excellent international connections based on participation in numerous EU- and other international research projects, as well as international assessment activities and expert work. Letters of Commitment from a wide range of collaborators are included in the project application. Additional information can be found in the submitted CVs.

Plan for researcher mobility that will support project implementation:
Detailed information is provided in the individual applications of the project partners. Plans include visits to the International Institute for Applied Systems Analysis (IIASA, Austria), Norwegian Institute of Bioeconomy Research (NIBIO), Helmholtz Centre for Environmental Research – UFZ and University of Copenhagen.

7. Schedule

Schedule for research and interaction activities:

	2018				2019				2020				2021				2022				2023			
Main focus	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
WP1																								
Model adjustment and calibration for old growth and continuous cover forest	x	x	x	x	x	x																		
Geographical model testing and growth simulation with MS-NFI input			x	x	x	x	x	x	x	x						x	x	x	x					
Construction of management and climate scenarios							x	x	x	x	x	x												
BD and biophysical indicators									x	x	x	x	x	x	x									
Results and assessment											x	x	x	x	x	x	x	x	x	x	x	x		
WP2																								
Collection of forest, BD and environmental data	x	x	x	x	x	x	x																	
Data completing by modelling				x	x	x	x	x	x	x	x													
Empirical verification of BD models						x	x	x	x	x	x	x												
Applying EO tools to BD models									x	x	x	x	x	x	x	x								
Assessing future changes in forest BD												x	x	x	x	x	x	x	x	x	x			
WP3																								
Model development	x	x	x	x	x	x	x	x																
Collection of field and model input data			x	x	x	x	x	x	x	x														
Definition of indicators and scenarios				x	x	x	x	x	x	x	x	x	x	x	x									
Scenario assessment									x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
WP4																								
EO and GIS database collection	x	x	x	x	x		x			x				x			x							
Collection of UAS-data from field sites			x				x				x				x									
EO data analysis			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x				
EO indicators of BD, C and forest radiation					x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
WP5																								
Development of compensation model			x	x	x	x	x	x	x															
Analysis of stakeholder preferences	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x				
Examination of trading rules						x	x	x	x	x														
Synthesis and proposal on suitability of compensation model									x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
WP6																								
Collation and formatting of data					x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		
Spatial planning for biodiversity and C							x	x	x	x	x	x												
Identification of areas suitable as ecological compensations										x	x	x	x	x	x	x								
Advanced spatial prioritization analyses															x	x	x	x	x	x	x	x	x	x
WP7																								
Workshops, seminars, other events	x		x		x	x		x	x		x		x			x		x	x			x		x
Co-designing research elements	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Internal meetings + Steering Group	x	x	x	x	x		x	x	x		x	x	x		x	x	x			x	x	x	x	x
Communication activities	x	x		x		x	x	x	x	x		x	x		x	x	x	x		x		x	x	x
Publications and other materials		x		x			x			x		x			x			x		x		x	x	x

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