Objectives and background

The annual losses due to conifer root and butt rot (RBR) caused by fungi in the Heterobasidion genus amount are widespred throughout Europe. Both Scots pine (Pinus sylvestris) and Norway spruce (Picea abies) are affected by Heterobasidion species but in Norway spruce the decay columns can in extreme cases rise up the stem to a height of 10-12 meters. This makes the disease particularly harmful in Norway spruce forests, as it destroys the most valuable part of the tree, reducing it from saw log quality (high value and high carbon substitution effect) to pulp or energy wood (low value and low carbon substitution effect).

Precision forestry has been defined as the planning and conducting of site-specific forest management activities and operations to improve wood product quality and utilization, reduce waste, increase profits, and maintain the quality of the environment. The fundamental idea behind PRECISION is that the information collected by harvesters, combined with remotely sensed and existing data, can form the backbone in developing a precision forestry framework aimed at reducing losses to RBR both in the short- and long-term. Hence, the overall objective of PRECISION is to develop a precision forestry framework for reducing the impact of root and but rot, improving resource utilization, and enhancing the economic robustness of the forest sector.

To operationalize the overall objective, six specific objectives were developed: (1)To develop an approach for automated collection of spatially-explicit RBR data and to generate a dataset of unprecedented scale; (2) To improve modelling of Heterobasidion spread and decay dynamics by taking into account the influences of local edaphic, climatic and demographic factors; (3) To make predictions of the severity of RBR in the standing forests; (4) To develop site-specific and spatiallyexplicit stand establishment strategies for reduction of RBR in the coming tree generation; (5) To develop a stand-level framework for optimizing the rotation age of the existing forest stands given the risk of RBR. (6) To assess the value-chain effects in terms of end products and value creation under different levels of RBR infestation.

Project results in the context of the project objectives

Overall our results show that a precision forestry approach that leverages data from harvesters, remote sensing and precision silviculture is operationally feasible and will lead to an overall better economic performance and health of Norway's spruce forests.

Key aspects of the project results as outlined according to specific objective is outlined below:

To develop an approach for automated collection of spatially-explicit RBR data and to generate a dataset of unprecedented scale: We demonstrated that collection of root information from harvesters is operationally feasible. The data was used to fulfil subsequent specific objectives. We collected three types of information here organized in categories: (1) very detailed information about the position of each tree (harvester with additional GNSS equipment and harvester operator registration of the rotten trees), (2) detailed information with approximate locations of each tree but with manual registration of RBR occurrence, and (3) standard harvester data.

To improve modelling of Heterobasidion spread and decay dynamics by taking into account the influences of local edaphic, climatic and demographic factors: We adapted the RBR spread model RotStand for Norwegian conditions and used data form harvesters to initialize the initial patterns of RBR within the stands.

To make predictions of the severity of RBR in the standing forests: We tested large scale prediction of RBR frequency on the stand level over large areas using all available geodata combined with the harvester-based data. We find that if we have a large local dataset, the possibility to predict root frequency is quite good but that there is still large uncertainty in the predictions. We also did much more detailed studies with drones and hyperspectral data and found some promising results to detect RBR but have to accept that if is very difficult to get very high accuracies for RBR even with very detailed remote sensing data.

To develop site-specific and spatiallyexplicit stand establishment strategies for reduction of RBR in the coming tree generation: We developed a decision forestry approach for regeneration strategies after harvesting. Using harvester data as input to develop RBR frequency maps we design optimal planting patterns. We show that in over 80% of the investigated stands there will be an economic gain in implementing precision forestry for reduced losses to RBR. It is especially in stands of intermediate productivity (SI: 10 – 18) that the precision forestry approach has a large potential.

To assess the value-chain effects in terms of end products and value creation under different levels of RBR infestation: Utilizing the large amount of harvester data we assessed the total value losses due to RBR. Our results suggest that RBR causes economic losses upwards of 7% of wood revenues, corresponding to €18.5 million annually in Norway.

Main R&D tasks and roles of partners

Main research partners:

NIBIO and NMBU were the main research partners in the projects and lead and collaborated on all the key aspects of the project.

NIBIO lead the project was the main responsible for harvester data collection, large scale mapping of RBR risk, modelling of RBR spread, and precision forestry concept.

NMBU**:** was responsible for detailed studies of RBR with remote sensing, for detailed harvester measurements, for studies related to economics and rotation ages.

Evaluation of the economic effects of RBR was carried out as a close collaboration between NIBIO and NMBU.

The Forestry Extension Institute was responsible for communications and dissemination. They focused much effort on educating and instruction machine operators about the registration procedure for RBR.

International partners:

The international partners played a central role in the project:

There was a very close collaboration with Dr. Timo Pukkala (Finland) (also active coauthor on papers) on the adaptation of RotStand to Norwegian conditions.

Dr. Michele Dalponte (Italy) (also active coauthor on papers) was a very important collaborator in the analysis of the hyperspectral data and also co-supervised a phd students in this area.

Dr. Ola Ringdahl (Sweden) (also active coauthor on papers) was instrumental in collaboration of machine learning approaches for RBR from proximal sensors.

With Tomas Lundmark (Sweden) and Marc Hanewinkel (Germany) the collaboration and involvement was not as close as envisioned and was limited to participation in meetings and workshops.

Industrial partners:

The six forest owner associations (Glommen Skog AS, Viken Skog SA, Norskog, Mjøsen Skog BA, Allskog BA, and AT Skog SA) provided harvester data for the project and participated in the evaluation of the results.

TerraTec AS collected hyperspectral data for studies of remote sensing data and RBR infection in standing forest.

Gundersen and Løken AS provided positioning equipment for two harvesters that enables submeter accuracy of the positions of the harvested trees.

Norges Skogeierforbund supported the dissemination of the results (e.g. organized sessions at Skog and Tre) and administrated the funding for industrial partners.

A description of the plans for disseminating and utilising the results

Due to the involvement of the industrial partners in the project, the operational forest managers of Norway are to a large extend aware of the results. Further, the collaboiration and results from Precison was instrumental in establishing SFI SmartForest and the most promising results from Precision are being further developed in SmartForest.

For scientific dissemination, we consider the scientific output from the project as good, and even more papers will come within the next year.

Research stays

A Ostovar (Swden) vistied NIBIO for 6 month as part of WP1 to work on machine learning and RBR. Michele Dalponte vistied Norway for 4 month throughout the project. Several NIBIO employees have had several visits to Finalnd and Timo Pukkala.

A description of the anticipated significance/benefits of the results

We believe that the results have really increased the awareness of the effect of RGR in the Norwegian forest sector. We also believe that the project results will lead to a change in management practices and also to the implementation of precision forestry in Norway.

A brief assessment of the project's implementation and use of resources.

Overall the project implementation was good and the project functioned well and worked towards the intended objectives in an efficient manner with a proper use of resources.

Some challenges was faced: (1) there was large challenges in rights to harvester data and this caused a loss of time and many discussions between partners, (2) The pandemic came in the middle of the project and did

A description of the results that are expected to be finalised after the completion of the project

As always there are several studies that still are waiting for publication during 2023.

Hansen K. et al. (in perp). Time consumption for tree planting with high accuracy

Horvath C. et al. (in prep) Real-time positioning for accurate manual planting

Lara W. et al. (in prep) Biophysical Factors Influencing the Spatial Occurrence of Butt Rot in Norway Spruce Stands

Hansen, E., Wold, J., Dalponte M., Gobakken, T., Noordermeer, L. & Ørka, H.O. 2023. Large-area estimation of rot occurrence, severity, and volume using airborne laser scanning and optical satellite data

Allen, B., Dalponte, M., Ørka, H. O., Næsset, E., & Gobakken, T. 2023 Data Fusion of Aerial Imagery and Airborne Laser Scanning for the Detection of Root, Butt, and Stem Rot in Norway Spruce.