Supplementary 5. Additional results

1. Management effect on storm damage and economic output

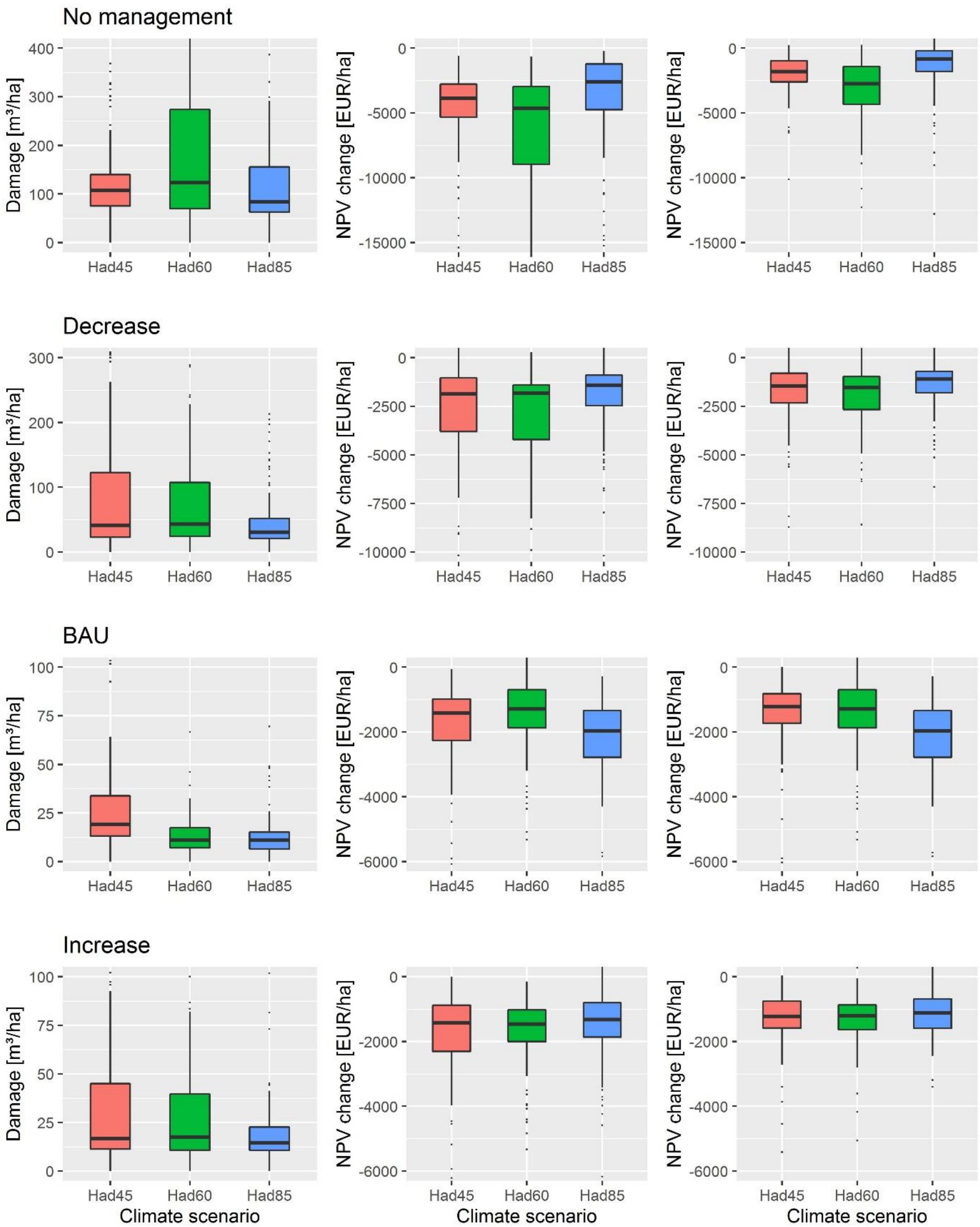

Figure S1. Storm damage (left column), economic impact without salvage logging (middle column) and with salvage logging (right column) across plots for each management strategy (rows) and climate scenario.

The thinning intensity applied was determinant to the amount of storm damage in the plots. A decrease in thinning intensity led to a higher damaged volume per storm event (152 and 76 m^3/ha on average) (Figure S1). Conversely, an increase in thinning intensity reduced the storm impacts (23 and 37 m^3/ha of damage, respectively). Although the BAU management showed lower damage levels, the economic loss under this management regime was larger than the one related to the increased utilization strategy, namely 1822 EUR/ha for the former and 1710 EUR/ha for the latter (middle column in Figure 2). The decreased utilization and no management strategies displayed average losses equal to 2706 and 5110 EUR/ha (for a 1% interest rate).

If salvage logging was conducted (Figure S1 – right column), the lying deadwood created by windstorms was removed from the stands and sold considering the net price of the lowest assortment for each species. Similar to the previous case, decreased in thinning intensity and no thinning showed the poorest economic outcomes. Salvage logging partly counterbalance storm impacts (additional 108 to 2803 EUR/ha), due to the extra income generated by the value of sold salvaged wood. We highlight that these figures do not consider salvage logging of dead trees created by natural mortality.

2. Out-of- sample performance of the robust solutions

To test the robustness of our solutions, we have conducted an out-of-the-sample validation in selected plots. To this end, we randomly selected 9 plots and randomly sampled 3 groups of 5, 6, 7 and 8 plots, and a scenario including all 9 plots. We solved the Risk Mitigation preference scenario (B) for these groups using the same data applied in our analysis. We simulated 900 independent NPV values for these plots (out-of-sample). We then compared the VaR obtained in the optimization solution with the empirical distribution of the independent NPV calculations (Figure S2).

The out-of- sample results show that the framework applied was capable to identify safe management portfolios in the face of climate change, windstorm and economic uncertainty. For all scenarios tested, the VaR computed in the optimization model provided a safe bound for the empirical distribution, considering a same confidence level applied, namely 5%. We found that, in fact, the optimized solutions achieved a higher confidence level when compared against the out-of-sample distribution, ranging from 0.4 to 4.7%. On average, the confidence level of the 13 scenarios tested was 2.7 %, meaning that in 97.3% of the cases the profitability of the portfolio was higher than the VaR computed.

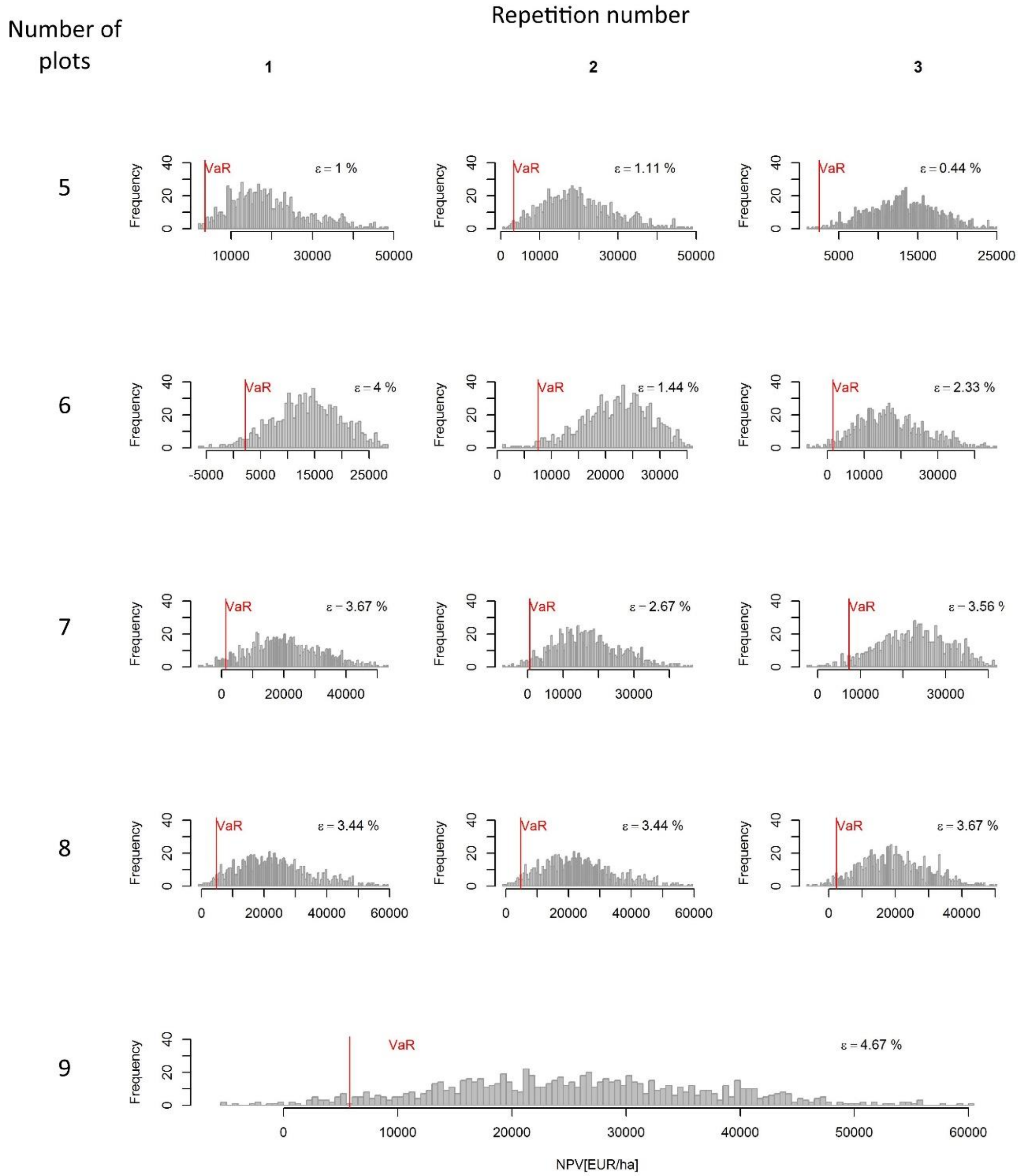

Figure S2. Out-of-sample net present value (NPV) distribution and the value-at-risk (VaR) of the optimal portfolios derived using the optimization model of preference scenario B (risk mitigation) for selected plots. The red vertical lines indicate the VaR and ε indicates the out-of-the-sample confidence level of each portfolio, i.e. the proportion of values below the VaR. The rows indicate the number of plots used in the optimization model and the columns indicate the repetition number (random draw from the selected plot list). The last row included all plots.