Results

Sasa expansion from 2012 to 2021

In 2012, the distribution area of Sasa covered $8,542\ m^2$, which expanded to $10,170\ m^2$ by 2021, representing an increase of $1,628\ m^2$ over nine years. This expansion corresponds to a 19% increase relative to the 2012 baseline. Alongside the expanded regions totaling $4,095\ m^2$, there were areas where Sasa distribution decreased by $2,467\ m^2$. However, most of these reduction areas are caused by the encroachment and growth of surrounding shrubs. In such cases, it is likely that Sasa persisted within the shrub understory or became intertwined with the shrubs, remaining undetected by the time-lapse cameras. Given these observations, it is appropriate to use the expanded Sasa area of $4,095\ m^2$ as the metric for quantifying Sasa expansion over the nine-year period. This metric represents a substantial 48% increase in Sasa area compared to 2012. Fig. Figure 1 shows the distribution of the expanded area. The observed 48% expansion of Sasa in nine years is consistent with trends reported in preceding studies from adjacent regions, where expansion reached up to 260% over 38 years (@Yoshida2016SasaTateyama).
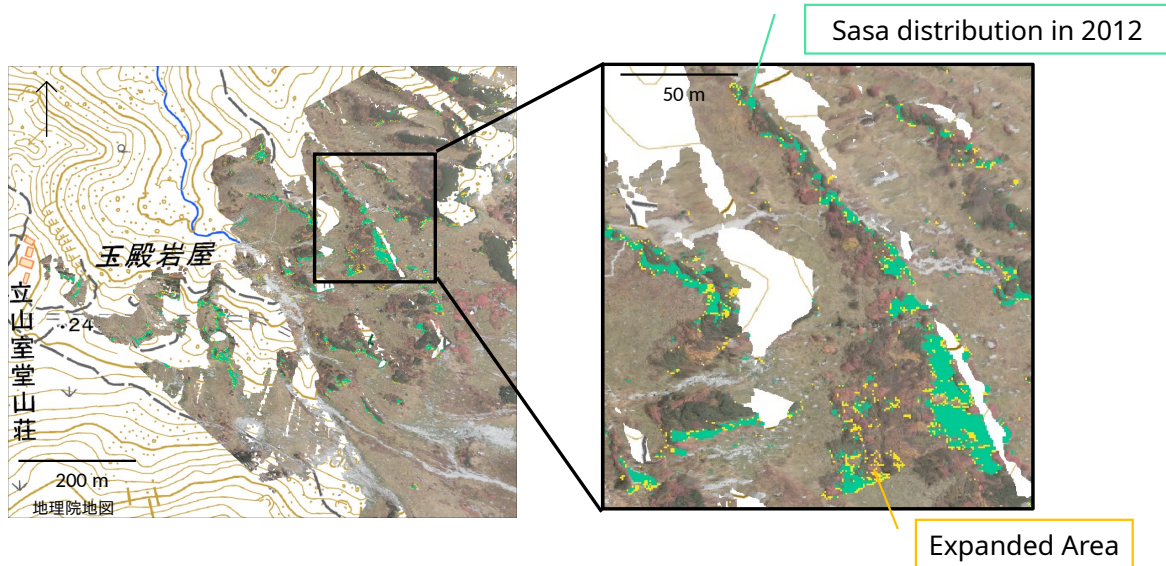

Figure 1: Distribution of Sasa Expansion from 2012 to 2021

HSM performance and feature importance

Figure **?@fig-hsm-performance** illustrates the performance metrics of each model derived from hyperparameter tuning during cross-validation. The TDM consistently exhibited higher TSS compared to the TBM. Within the TBM framework, the GBT and MaxEnt models demonstrated the highest performance metrics. Within the TDM framework, GBT, MaxEnt, and RF models outperformed GAM model.

Ensemble models were developed by combining the outputs of these high-performing individual models. The ensemble derived from the TBM achieved a TSS score of 0.55 on the testing dataset, while the TDM ensemble achieved a higher TSS score of 0.70. These results highlight the higher predictive capability of the TDM, due to the incorporation of distance measures alongside topographical features.

To determine the contribution of each explanatory variable in the TBM and TDM, I assessed variable importance using permutation loss. This method measures how much the model's performance decreases when a variable is randomly shuffled, indicating its impact on predictive accuracy. We used TSS as the performance metric. The results, shown in Fig. Figure 2, indicate that the snowmelt DOY was the most important variable in the TBM. In the TDM, the distance from the 2012 Sasa distribution was the most important and the snowmelt DOY was the second.
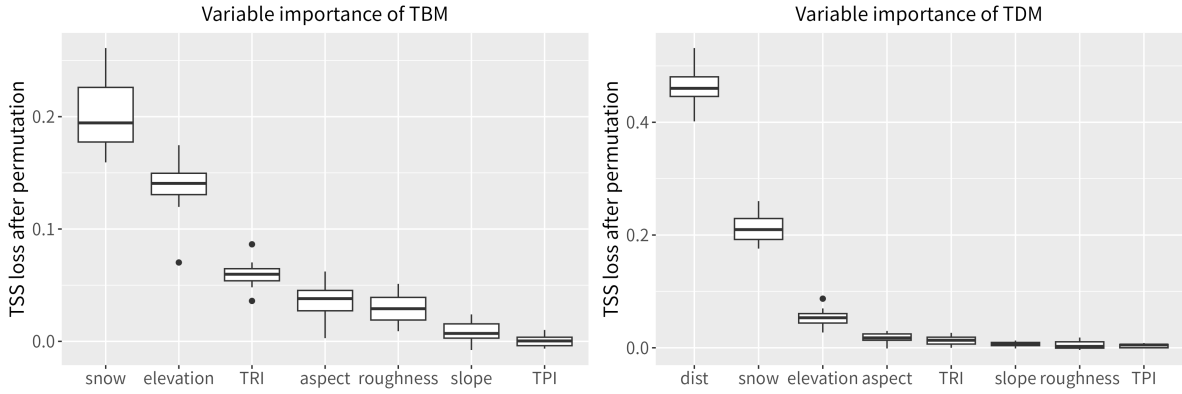

Figure 2: Variable importance based of TBM and TDM

Figure Figure 3 shows the Habitat Suitability (HS) maps for 2021 generated by the TBM and TDM. The TBM predicted $47,253\ m^2$ as suitable for Sasa habitation ($HS > 0.5$), significantly overestimating the actual distribution area of $10,170\ m^2$. In contrast, the TDM predicted $12,766.04\ m^2$ as suitable, which is much closer to the observed distribution.
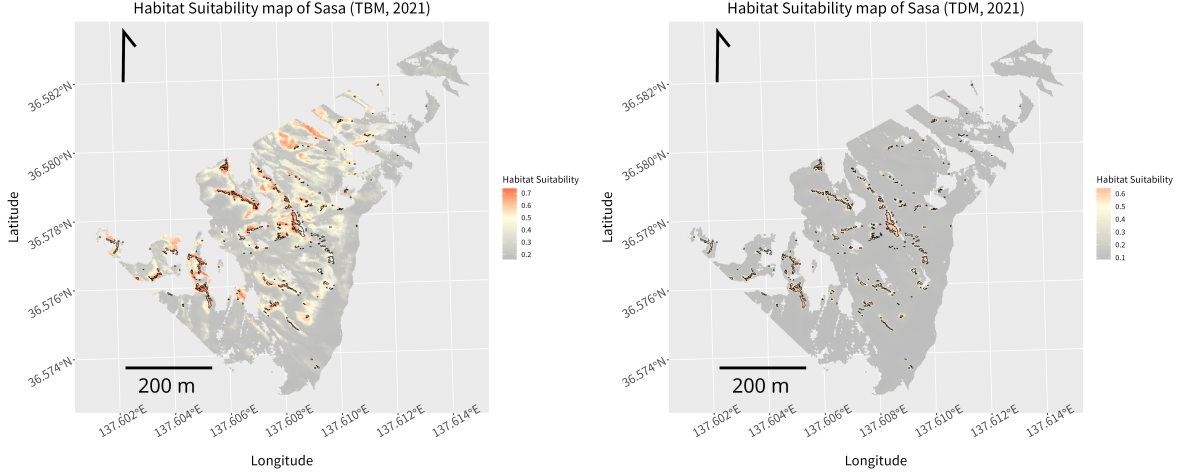
Figure 3: Predicted habitat suitability of Sasa in 2021

Future prediction and estimated risky area

Figure Figure 4 shows the HS maps for 2030 (top) and the differences from the 2021 HS maps (bottom). The TBM predicted $27,049$ m^2 (57% of the 2021 predicted suitable area) as newly suitable for Sasa habitation in 2030, while the TDM predicted $4,387$ m^2 (34%). These projections indicate a potential for Sasa distribution expansion similar to the observed growth over the past nine years.

Even in areas where Sasa was present in 2021, some regions are expected to become unsuitable by 2030. The TBM identified $2,257$ m^2 (21% of the 2021 distribution area) as unsuitable, while the TDM identified 717 m^2 (7%) as unsuitable. These reductions indicate changes in habitat suitability and potential shifts in Sasa distribution due to earlier snowmelt timing.

Additionally, to contribute to future conservation planning, we extracted potential habitats for Sasa from the TBM predictions. Sasa expansion tends to occur in vegetation shorter than Sasa, such as snow meadows, while invasion into shrubs is unlikely. In this study, all vegetation other than shrubs and Sasa was categorized as "Other Vegetation." Therefore, I defined the areas where the 2021 vegetation classification was "Other Vegetation" and the 2030 HS was high (HS > 0.5) as "risky areas" (Fig. Figure 5).
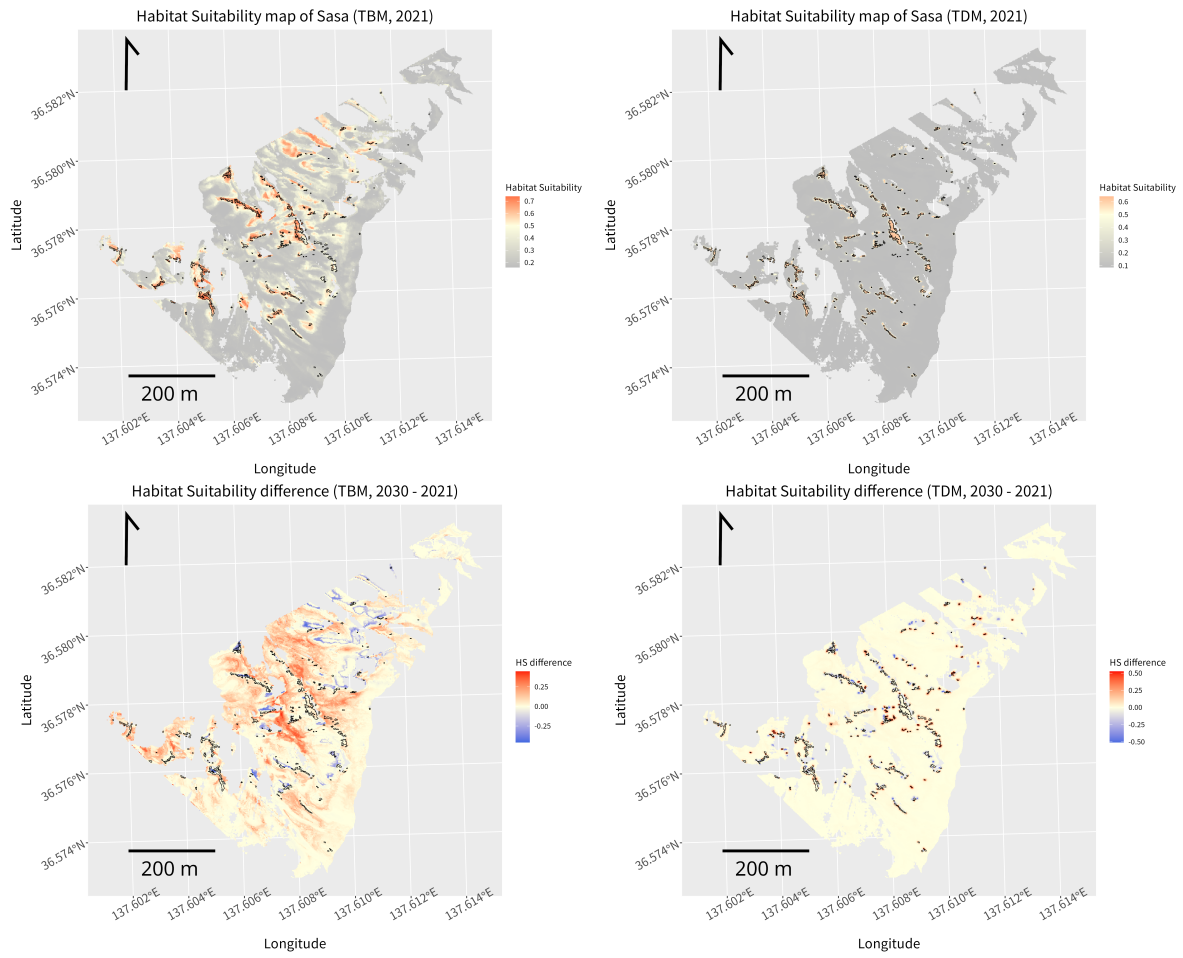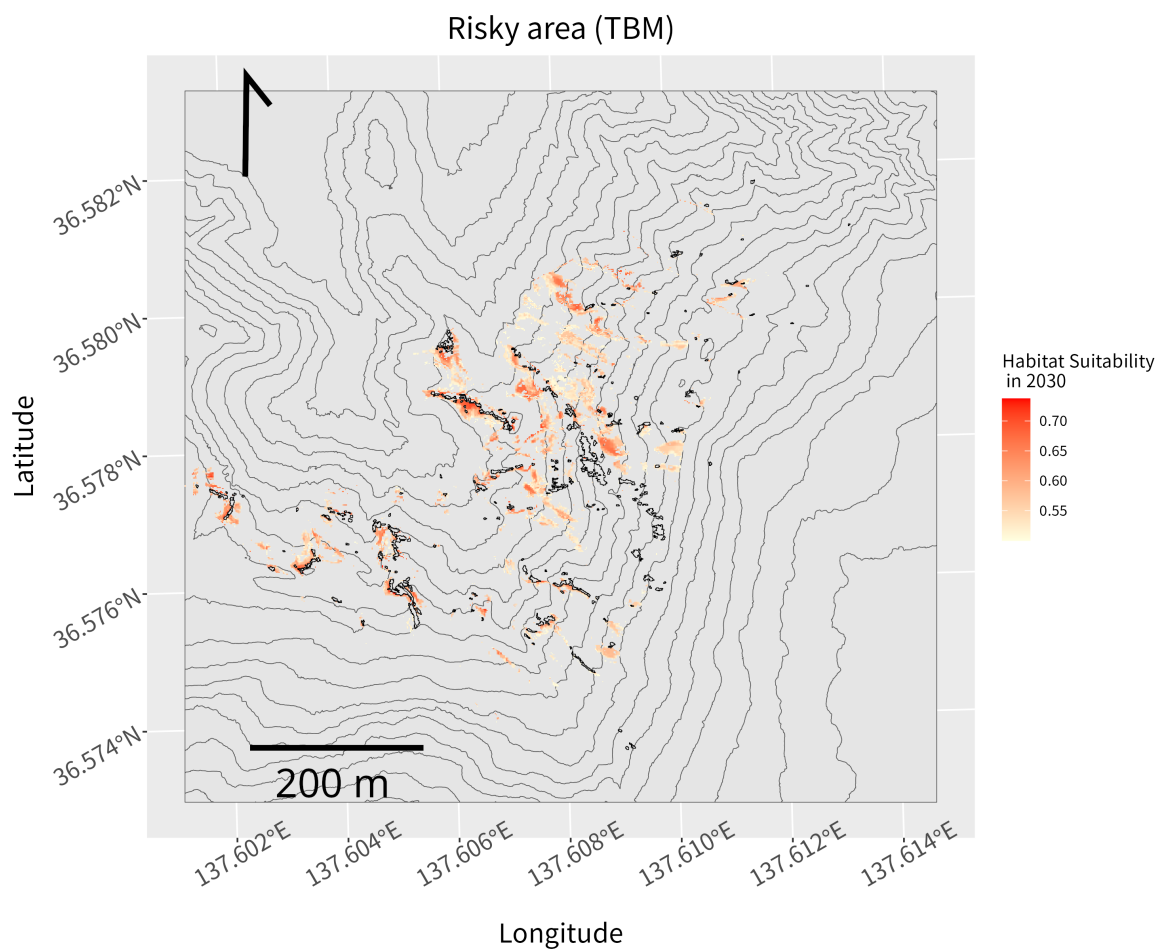
Figure 4: Predicted habitat suitability of Sasa in 2030

Figure 5: Predicted potential habitats for Sasa (risky area)