# S2: Sensitivity Analysis of IPS-SPREADS

## 1 MATERIALS AND METHODS

As the location and amount of weakened spruce trees as well as the number of emerging beetles were proven to be the main drivers of the baseline model IPS-1.1 (Kautz et al., 2014, 2016; Pietzsch et al., 2018), four different study areas were used to account for variations within these characteristics (Table S1). These areas were randomly selected using the sampling function from R package *raster* (Hijmans, 2020) and imported into the IPS-SPREADS model (Figure S1).

**Table S1.** Characteristics of research areas used for the sensitivity analysis of IPS-SPREADS.

| Area<br>Code | Extent<br>$km^2$ | Spruce trees<br>n | Source trees<br>n | Begin of flight<br>Date | Simulated beetles<br>n |
|---|---|---|---|---|---|
| A | 2.25 | 33,338 | 95 | 04.04.2016 | 611,886 |
| B | 2.25 | 8,490 | 9 | 09.04.2016 | 70,242 |
| C | 2.25 | 48,305 | 34 | 06.04.2016 | 313,872 |
| D | 2.25 | 53,508 | 99 | 04.04.2016 | 945,870 |

The parameters under investigation during the sensitivity analysis of IPS-SPREADS were assigned a randomly chosen value from a uniform distribution for each model run (Table S2). As we were only interested in the parameter influence within the first beetle generation, *generations* was set to one. For each research area, 100 simulations were run resulting in a total of 400 model runs for the sensitivity analysis of IPS-SPREADS. To evaluate the importance of the parameters and their interactions on the model results, a mixed effect linear model with the research areas as random effect was calculated using the package *nlme* (Pinheiro et al., 2017) of the statistical environment R (RCoreTeam, 2020). The proportion of explained variance of these models was utilized as an indicator of parameter and interaction importance.

**Table S2.** Parameters investigated during the sensitivity analysis of IPS-SPREADS with minimum, maximum and standard values.

| Parameter | Unit | Minimum | Standard | Maximum |
|---|---|---|---|---|
| *moveangle* | $^\circ$ | 0.0 | 45.0 | 90.0 |
| *perceptdist* | m | 0.0 | 3.0 | 6.0 |
| *diffusionrate* | m | 0.0 | 12.0 | 24.0 |
| *swarming* | d | 7 | - | 56 |
| *winddirection* | $^\circ$ | 0.0 | - | 360.0 |
| *windspeed* | $\frac{m}{s}$ | 0.0 | - | 5.5 |
| *meanenergy* | - | 6.0 | 10.0 | 14.0 |

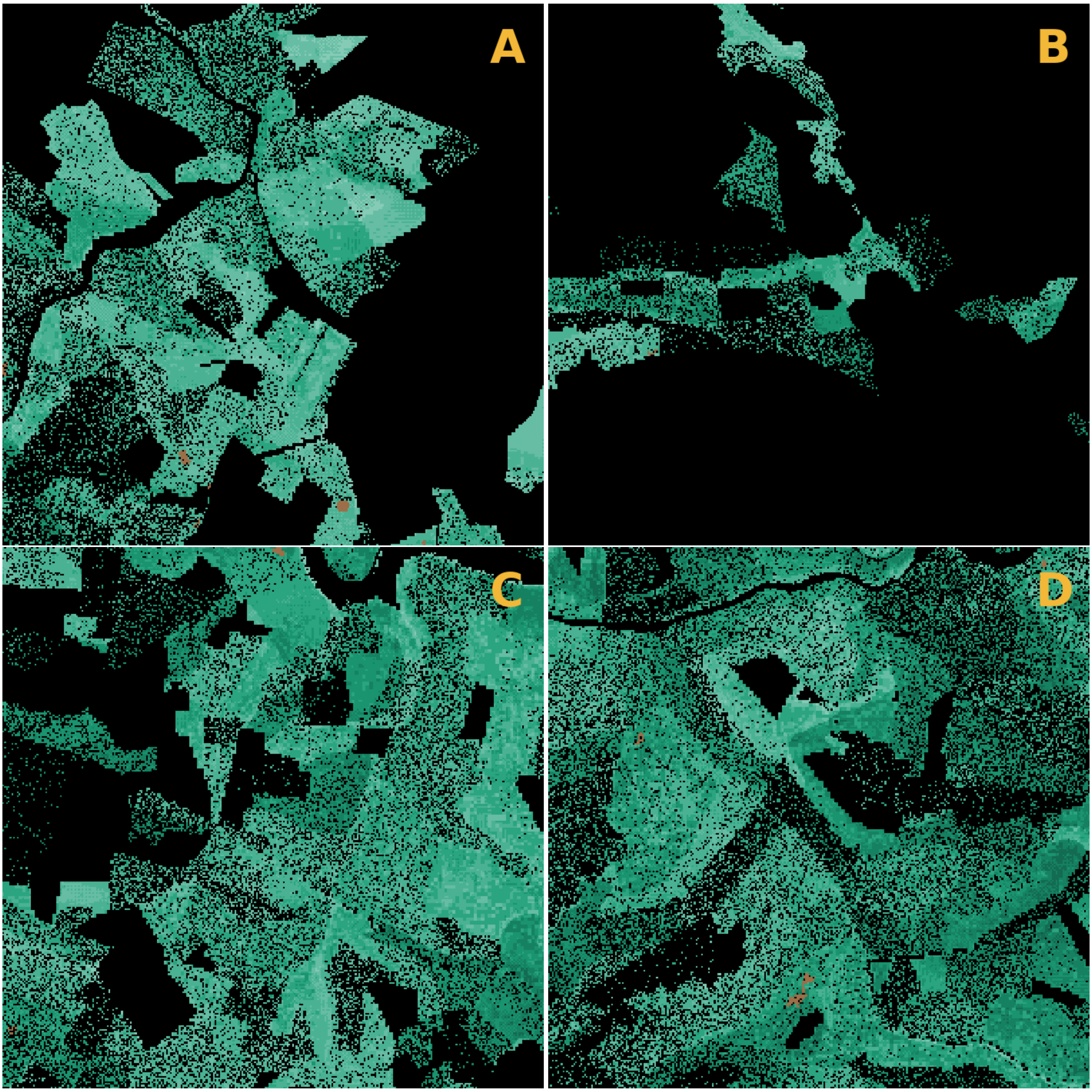


**Figure S1.** Depiction of the sites investigated during the sensitivity analysis of IPS-SPREADS. Spruces a resembled by greenish fields, while beetle sources are colored brown. Black parts of the model world refer to anything that is neither a spruce nor a beetle source (e.g. other tree species, infrastructure or meadow). The extent of each simulation area is 2.25 $km^2$ with each side reaching 1.5 km length.

## 2 RESULTS AND DISCUSSION

The sensitivity analysis reveals an exceedingly high influence of mean beetle energy supply (*energy*) on all investigated model outputs (Table S3). Further noteworthy influences are exerted by the number of days beetles are swarming (*swarming*) and the wind speed (*windspeed*). On the other side, the directional angle during the beetle dispersal flight (*moveangle*), the beetle perception distance (*perceptdist*), the wind direction (*winddirection*) and the maximum distance volatiles can travel (*diffusionrate*) have a negligible influence or none at all.

**Table S3.** Proportion of explained model variance by parameter for the investigated model outputs. Only parameters and interactions scoring one percent or more are shown.

| **output**<br>chr | **unit**<br>chr | **parameter**<br>chr | **proportion**<br>% |
|---|---|---|---|
| infestation distance | m | energy | 25.97 |
| | | swarming | 8.62 |
| | | swarming:windspeed:energy | 6.04 |
| beetle success | % | energy | 51.75 |
| | | swarming | 26.14 |
| | | moveangle | 7.75 |
| infestation amount | n | energy | 72.26 |
| | | swarming | 5.61 |

Due to the beetle willingness for infestation attempts increasing with lower energy levels, higher mean energy levels result in trees infested farther away and in higher flight distances of infesting beetles. Furthermore, the farther away and therefore later beginning of beetle attacks results in lower probabilities for sufficient amounts of beetles attacking the same tree in a given amount of time and with this in less infested trees in general. Longer periods of beetle swarming further decrease these probabilities as the beetle density is even lower due to fewer beetles starting from the beetle source trees each day. Higher wind speeds cause more distant tree infestations while not influencing the amount of infested trees or the beetle success. While the wind direction did not achieve a variance proportion of one or more percent during the sensitivity analysis, it is still of importance for the model as it controls the direction of effect the factor *windspeed* is exerting. If the analysis would have investigated the parameter effects for each research area separately, the wind direction would have had a big impact (compare results and discussion of the model calibration of IPS-SPREADS). In contrast to findings of previously published studies of the base line model IPS (Kautz et al., 2014, 2016; Pietzsch et al., 2018), the directional angle during dispersal flight (*moveangle*) exerts only a marginal influence on one of the outputs of IPS-SPREADS. The reason for this is the introduced wind, which attenuates the impact of *moveangle* as it exerts a higher impact on the direction and distance the beetles are drifted during each time step. The missing influence of beetle perception distance (*perceptdist*) and maximum volatile dispersal distance (*diffusionrate*) is due to their time of action: Both parameters regulate how beetles find already infested trees and do not a play a role for the initial beetle attack attempts and infestations.

## REFERENCES

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