Do pheromone traps help to reduce new attacks of *Ips typographus* at the local scale after a sanitary cut ? Supplements and detailed statistical analysis

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Contents

1 Introduction

Aim : test whether pheromone trapping could contribute to reduce *Ips typographus* attacks in combination with usual forest sanitation measures (cut and evacuate attacked trees).

- We selected patches of spruce that were attacked by *Ips typographus* during the preceding year and for which the attacked trees have been removed as much as possible.
- We selected 68 and 58 different sites in 2020 and 2021 respectively.
- The attacked patches were randomly assigned to 3 Trapping Treatments :
  - Control : no trapping device
  - Crosstraps : three cross traps / attacked patch
  - Treetrap : one tree trap / attacked patch (with pheromones + insecticide)
- The traps were placed in the spring and removed in the summer to avoid attracting the dispersing new generation of barkbeetles. Pheromones and insecticides were renewed when needed.
- The sites/patches were spread across 8 management districts ("Cantonnements"), 5 for each year (2 of them were used during both years : `Saint-Hubert` and `Bouillon`). Most sites were managed by public authorities. In 2021, 9 private sites (`Privé Jalhay`) were also used in the experiment (all within the `Verviers` public district).
- As much as possible the patches with the 3 different treatments were distributed equally within each management district in order to avoid factor confusion between the treatments and the management and environmental differences between regions.
- During the experiment year the newly attacked trees were cut and evacuated as much as possible as imposed legally in the area.

We measured both the volume (`V`) and Numbers of trees (`Nb`) in the patch in the previous year("initial" values) and again during the year of the experiment from April onward ("New values").

In 2021 we measured the new attacks only within 100m form the previous year patch center (`V_new_0_100m`) while in 2020 we measured the attacks at various distances from the patch center classified in 3 distance categories:

- 0 to 50 m from 2019 patch center (e.g. `V_new_0_50m` or `Nb_new_0_50m`)
- 50 to 100 m from 2019 patch center (e.g. `V_new_50_100m` or `Nb_new_50_100m`)
- beyond 100 m from 2019 patch center within the same administrative parcel that can be of various sizes and shapes (e.g. `V_new_bey_100m` or `Nb_new_bey_100m`)

We also considered the volume and number of trees attacked between 0 and 100m (as in 2021) (`V_new_0_100m = Nb_new_0_50m + Nb_new_50_100m`) and the total volume (`V_new_total = V_new_0_50m + V_new_50_100m + V_new_bey_100m`)

2 Exploratory and preliminary data analysis

2.1 Maps

Distribution of the sites

2.1.1 All sites per district (cantonnement)

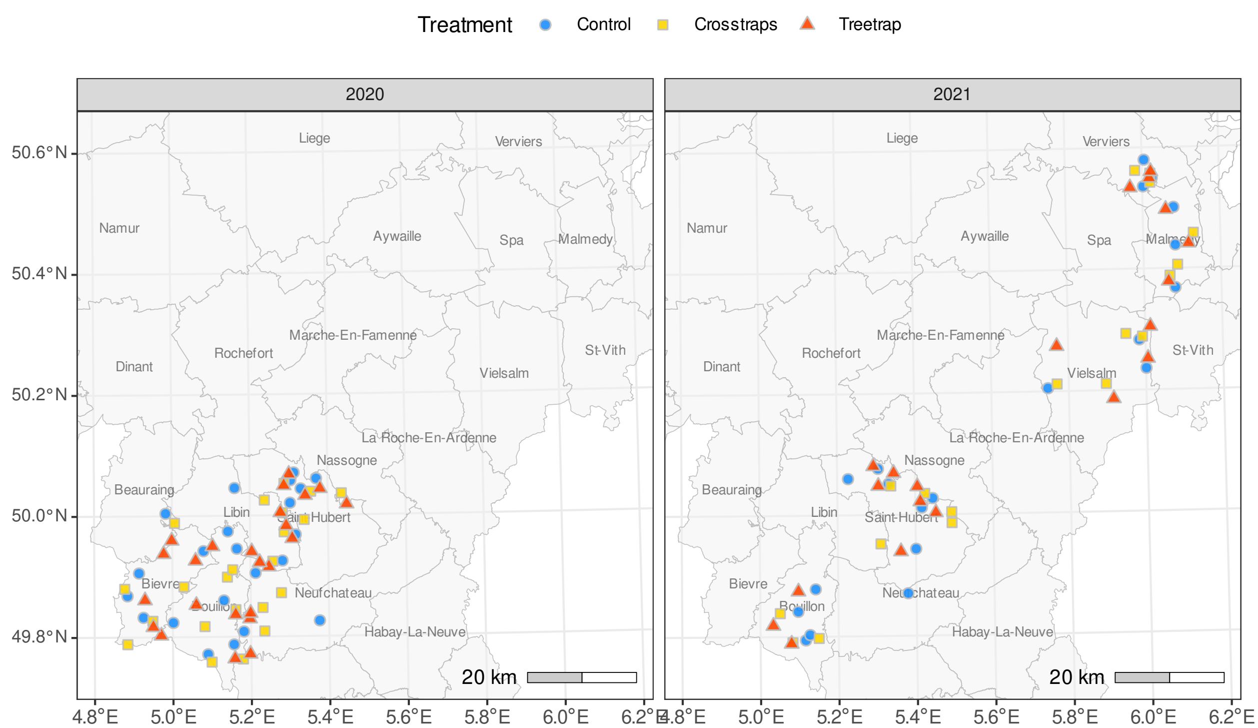

Figure 1:

The following table shows the distribution of the sites and the 3 treatments in the different districts

Year	District	Control	Crosstraps	Treetrap	Total
2020	Bièvre	5	5	6	16
2021	Bièvre	-	-	-	-
2020	Bouillon	6	6	6	18
2021	Bouillon	4	3	3	10
2020	Libin	3	4	4	11
2021	Libin	-	-	-	-
2020	Neufchâteau	3	3	3	9
2021	Neufchâteau	-	-	-	-
2020	Saint-Hubert	5	4	5	14
2021	Saint-Hubert	7	5	7	19
2020	Malmédy	-	-	-	-
2021	Malmédy	3	3	3	9
2020	Privé Jalhay	-	-	-	-
2021	Privé Jalhay	3	3	3	9
2020	Vielsalm	-	-	-	-
2021	Vielsalm	3	4	4	11

2.2 Are the sites homogeneous between treatments ?

The aim of his section is to compare the sites attributed to the 3 treatments to check if they were not different at the beginning of the study.

We used simple ANOVA to compare the quantitative descriptors and a chi squared test with simulated p-values for the qualitative sites descriptors.
The only descriptor which shows significant differences between treatments is the slope which tends to be weaker for Treetrap sites.

Description of the sites characteristics :

- **Quantitative sites descriptors**
  - **`Age`** : Average age of the Norway spruces in the stand (years)
  - **`Nb_init`** : Initial number of attacked trees in the infested patch the year preceding the year of the experiment
  - **`Patch_area_init`** : area (m^2) of the clear-cut (sanitary cut of the initial infested patch) at the beginning of the experiment (measured in the field)
  - **`Spruce_area_100m_new`** : Spruce (> 30 years) area (m^2) at the beginning the experiment within a 100 m radius around the center of the initial infestation in both public and private stands
  - **`Spruce_area_250m_init`** : Spruce (> 30 years) area (m^2) before the initial infestation within a 250 m radius around the center of the initial infestation in both public and private stands
  - **`V_init`** : Initial attacked wood volume (m^3) in the infested patch the year preceding the year of the experiment
- **Qualitative sites descriptors** :
  - **`Aptitude`** : Index resuming trophic and hydric suitability for the Norway spruce (*Picea abies*) in each experimental site. It ranges from 1 (exclusion) to 5 (optimum). Hydric and trophic data were obtained from the Species Ecological File
  - **`Orientation`** : Orientation of the experimental site. To reduce the number of values, orientations were grouped by sector (No_slope, S/SW, W/NW, N/NE, E/SE)
  - **`Slope`** : Slope of the experimental site (No_slope, Weak, Medium, Steep)
- **Meteorological descriptors** (for the Hibernation or Active period : see below) :
  - **`Irrad_sum`** : Global solar irradiance (kJ/m^2), summed by period.
  - **`Rain_sum`** : Precipitations (mm), summed by period
  - **`RH_avg`** : Relative humidity (%), averaged by period
  - **`Tmax_sum`** : Max temperatures (°C), summed by period
  - **`Tmin_sum`** : Min temperatures (°C), summed by period
  - **`Wind_avg`** : Wind speed at 10m (m/s), averaged by period

The meteorological descriptors have been computed as sum or average of daily values for to periods based on the activity of the bark beetles

- Hibernation: from November 1 to March 31 (before the experimentation = hibernation period influencing the subsequent year).
- Active: from April 1 to October 31.

2.2.1 Quantitative sites descriptors

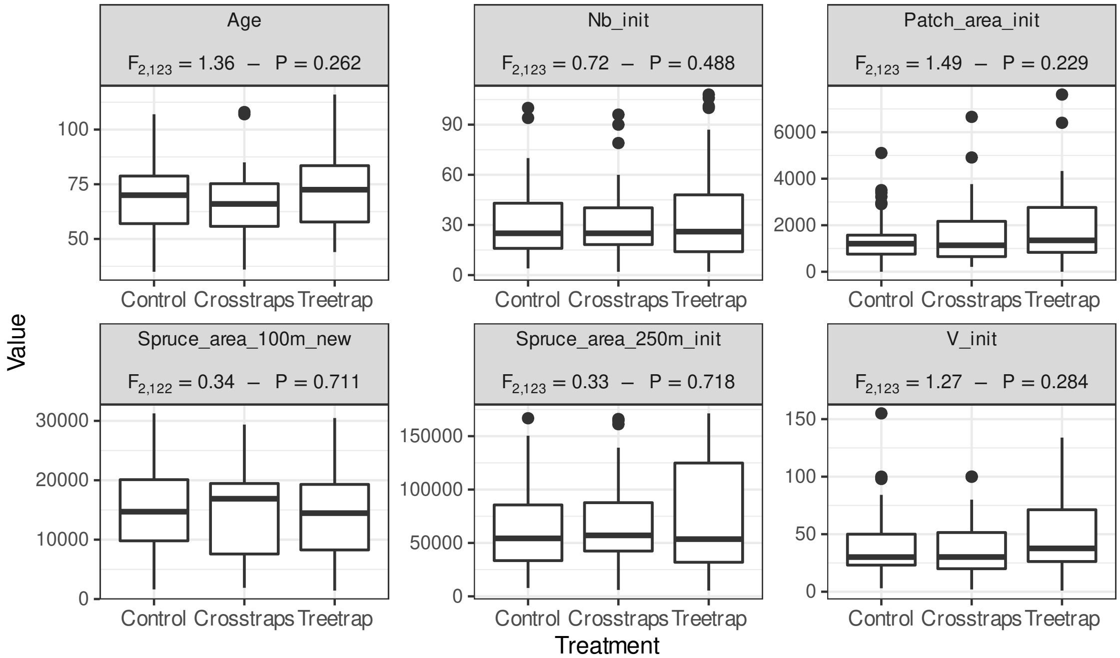

Figure 2:

2.2.2 Qualitative sites descriptors

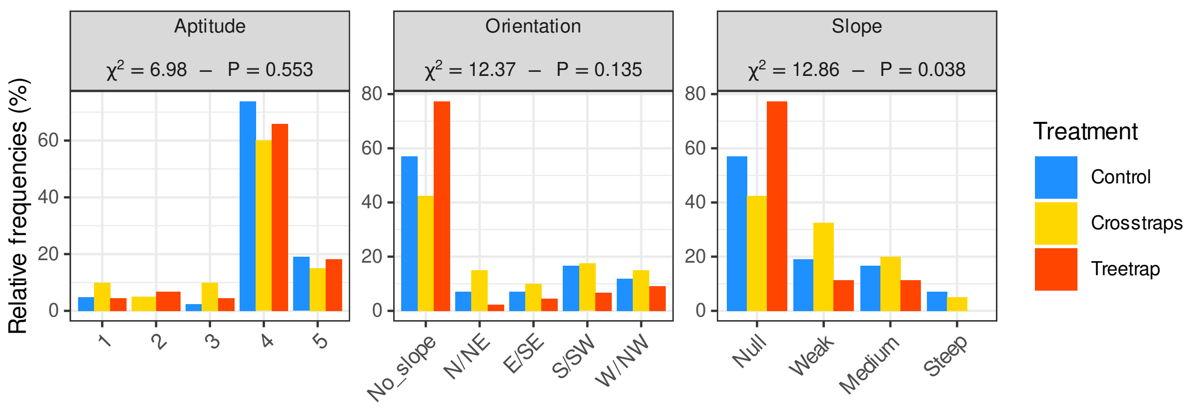

Figure 3:

2.2.3 Meteorological descriptors during the hibernation period

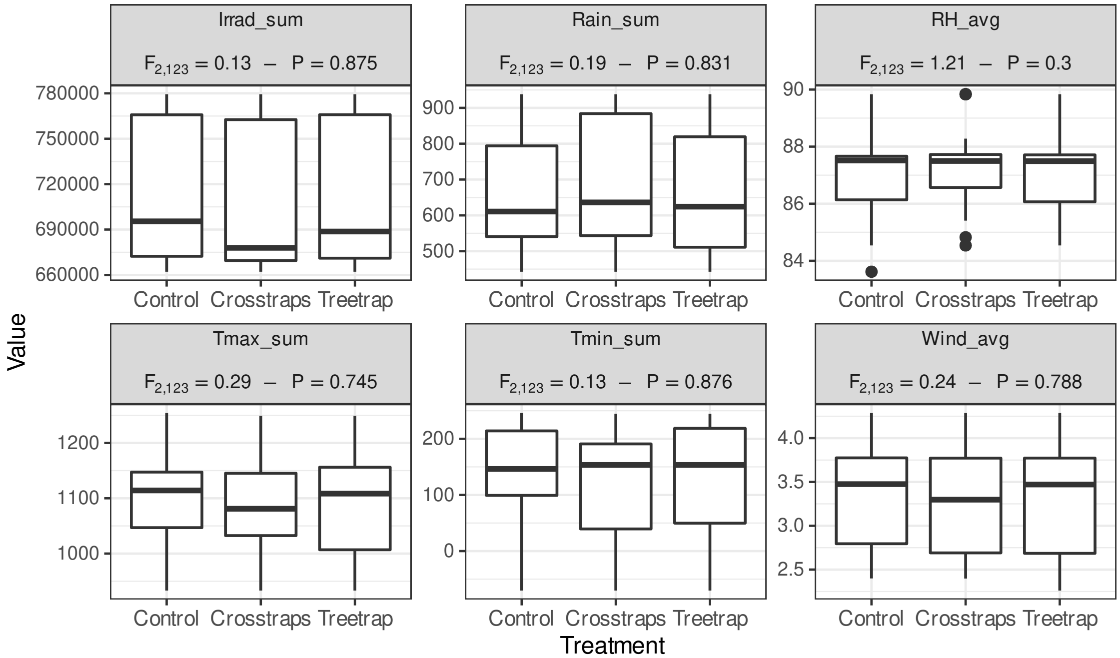

Figure 4:

2.2.4 Meteorological descriptors during the active period

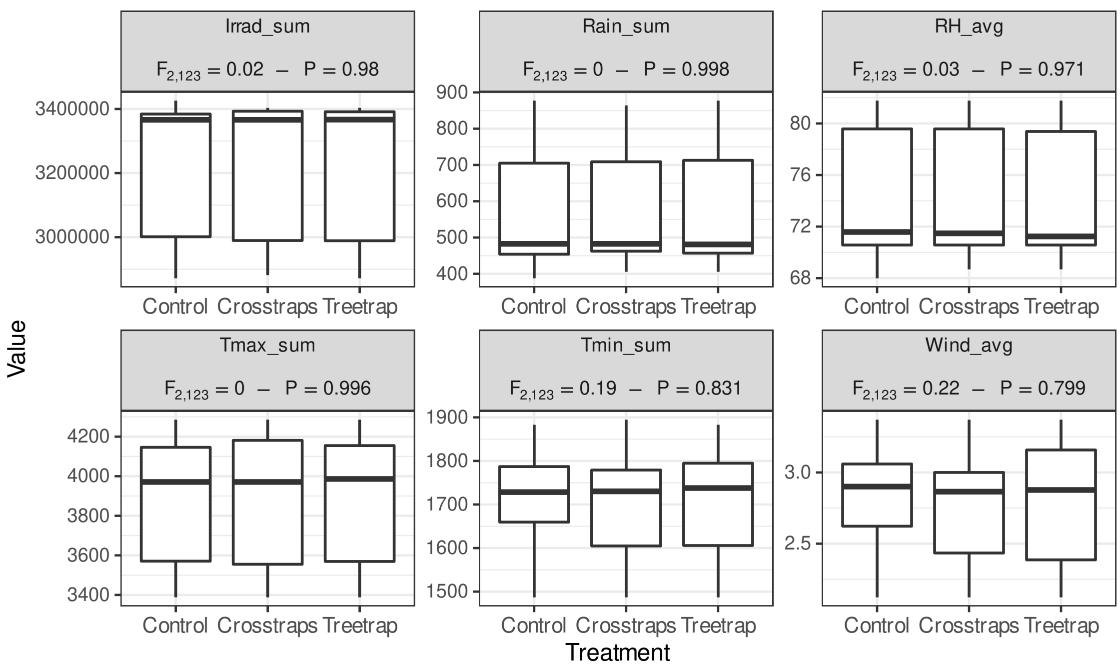

Figure 5:

2.2.5 Tables

Quantitative descriptors

Average ± standard deviation

Variable	Control	Crosstraps	Treetrap	Test
Age	71.4 ± 16	66.8 ± 14.7	72.5 ± 18.4	$F_{2,123}$=1.36 - P=0.262
Nb_init	31.7 ± 21.8	30.5 ± 21.5	36.7 ± 30.7	$F_{2,123}$=0.72 - P=0.488
Patch_area_init	1405.8 ± 1048.5	1576.5 ± 1351.4	1903.9 ± 1608.5	$F_{2,123}$=1.49 - P=0.229
Spruce_area_100m_new	15400 ± 7155.4	14767.4 ± 7872.9	14046.8 ± 7591.1	$F_{2,122}$=0.34 - P=0.711
Spruce_area_250m_init	65224.1 ± 39185.8	66281.5 ± 42541.9	72522.2 ± 51714.5	$F_{2,123}$=0.33 - P=0.718
V_init	40.3 ± 31.1	38.7 ± 26.2	48.5 ± 33.8	$F_{2,123}$=1.27 - P=0.284

Qualitative descriptors

Number of sites and % under parentheses

Variable	Value	Control	Crosstraps	Treetrap	Test
Aptitude	1	2 (4.8%)	4 (10%)	2 (4.5%)	χ^2=6.98 - P=0.553
Aptitude	2	0 (0%)	2 (5%)	3 (6.8%)	
Aptitude	3	1 (2.4%)	4 (10%)	2 (4.5%)	
Aptitude	4	31 (73.8%)	24 (60%)	29 (65.9%)	
Aptitude	5	8 (19%)	6 (15%)	8 (18.2%)	
Orientation	No_slope	24 (57.1%)	17 (42.5%)	34 (77.3%)	χ^2=12.37 - P=0.135
Orientation	N/NE	3 (7.1%)	6 (15%)	1 (2.3%)	
Orientation	E/SE	3 (7.1%)	4 (10%)	2 (4.5%)	
Orientation	S/SW	7 (16.7%)	7 (17.5%)	3 (6.8%)	
Orientation	W/NW	5 (11.9%)	6 (15%)	4 (9.1%)	
Slope	Null	24 (57.1%)	17 (42.5%)	34 (77.3%)	χ^2=12.86 - P=0.038
Slope	Weak	8 (19%)	13 (32.5%)	5 (11.4%)	
Slope	Medium	7 (16.7%)	8 (20%)	5 (11.4%)	
Slope	Steep	3 (7.1%)	2 (5%)	0 (0%)	

Meteorological descriptors

Average ± standard deviation

Period	Variable	Control	Crosstraps	Treetrap	Test
Active	Irrad_sum	3189067.9 ± 212439.5	3197986.8 ± 213511.6	3195909.3 ± 212318.7	$F_{2,123}$=0.02 - P=0.98
Active	Rain_sum	581.8 ± 149.2	579.8 ± 143.2	580.9 ± 149.2	$F_{2,123}$=0 - P=0.998
Active	RH_avg	74.8 ± 4.8	74.8 ± 4.7	74.6 ± 4.7	$F_{2,123}$=0.03 - P=0.971
Active	Tmax_sum	3884 ± 302.3	3879.7 ± 308.7	3885.5 ± 307.2	$F_{2,123}$=0 - P=0.996
Active	Tmin_sum	1711.6 ± 111.3	1699.2 ± 118.5	1713.1 ± 111.6	$F_{2,123}$=0.19 - P=0.831
Active	Wind_avg	2.8 ± 0.4	2.8 ± 0.4	2.8 ± 0.4	$F_{2,123}$=0.22 - P=0.799
Hibernation	Irrad_sum	718453 ± 46348	713145.1 ± 46269.8	715763.5 ± 46728.6	$F_{2,123}$=0.13 - P=0.875
Hibernation	Rain_sum	659.3 ± 160	681.4 ± 172.7	665.7 ± 174.1	$F_{2,123}$=0.19 - P=0.831
Hibernation	RH_avg	86.8 ± 1.4	87.2 ± 1.1	86.9 ± 1.2	$F_{2,123}$=1.21 - P=0.3
Hibernation	Tmax_sum	1097 ± 88	1082.8 ± 81.6	1092.3 ± 86.5	$F_{2,123}$=0.29 - P=0.745
Hibernation	Tmin_sum	130.6 ± 94.2	121.1 ± 98.3	130.5 ± 94.8	$F_{2,123}$=0.13 - P=0.876
Hibernation	Wind_avg	3.3 ± 0.6	3.3 ± 0.6	3.3 ± 0.6	$F_{2,123}$=0.24 - P=0.788

2.3 Number of insects captured in crosstraps

Bark beetles captured by the crosstraps were collected and their number was estimated based on their fresh volume using a conversion index. To build the conversion index (the average number of beetles per ml), 24 subsamples of trap captures with volumes ranging from 4 ml to 40 ml were counted entirely. The ratio between the number of beetles and the corresponding volume showed little variation and the average number of beetles per ml (± SD) is 38 (± 4.4). The volume of bark beetles captured in each collector after collection period (~7 to 10 days) was measured and samples were converted using this index. In 2020, bark beetles volumes could only be measured in Bièvre forest district over the whole trapping season.

The following table shows the total number of Ips captured in crosstraps for each site (sum of 2 traps).

The sites with largest number of Ips captured (> 30000) are spread across forest districts.

Year	Cant	ID	Nb_Ips	Nb_days	Nb_Ips_per_80_days
2020	BIEVRE	08	117838	78	120859.5
2020	BIEVRE	11	116166	78	119144.6
2020	BIEVRE	17	102030	78	104646.2
2020	BIEVRE	02	66766	78	68477.9
2021	PRIV_JALHAY	79	33011	48	55018.3
2021	BOUILLON	43	40261	64	50326.2
2021	SAINT-HUBERT	73	49853	86	46374.9
2021	PRIV_JALHAY	76	27312	48	45520.0
2021	VIELSALM	02	44198	83	42600.5
2021	VIELSALM	06	44102	83	42508.0
2020	BIEVRE	14	39311	78	40319.0
2021	SAINT-HUBERT	61	39773	83	38335.4
2021	BOUILLON	42	28816	64	36020.0
2021	SAINT-HUBERT	51	31990	82	31209.8
2021	BOUILLON	36	27959	75	29822.9
2021	MALMEDY	26	23902	70	27316.6
2021	VIELSALM	05	28024	83	27011.1
2021	MALMEDY	23	22416	70	25618.3
2021	SAINT-HUBERT	66	23959	78	24573.3
2021	PRIV_JALHAY	77	12732	48	21220.0
2021	VIELSALM	12	18889	80	18889.0
2021	SAINT-HUBERT	58	16502	84	15716.2
2021	MALMEDY	21	7967	77	8277.4

2.3.1 Variation of captures between the three traps within each site.

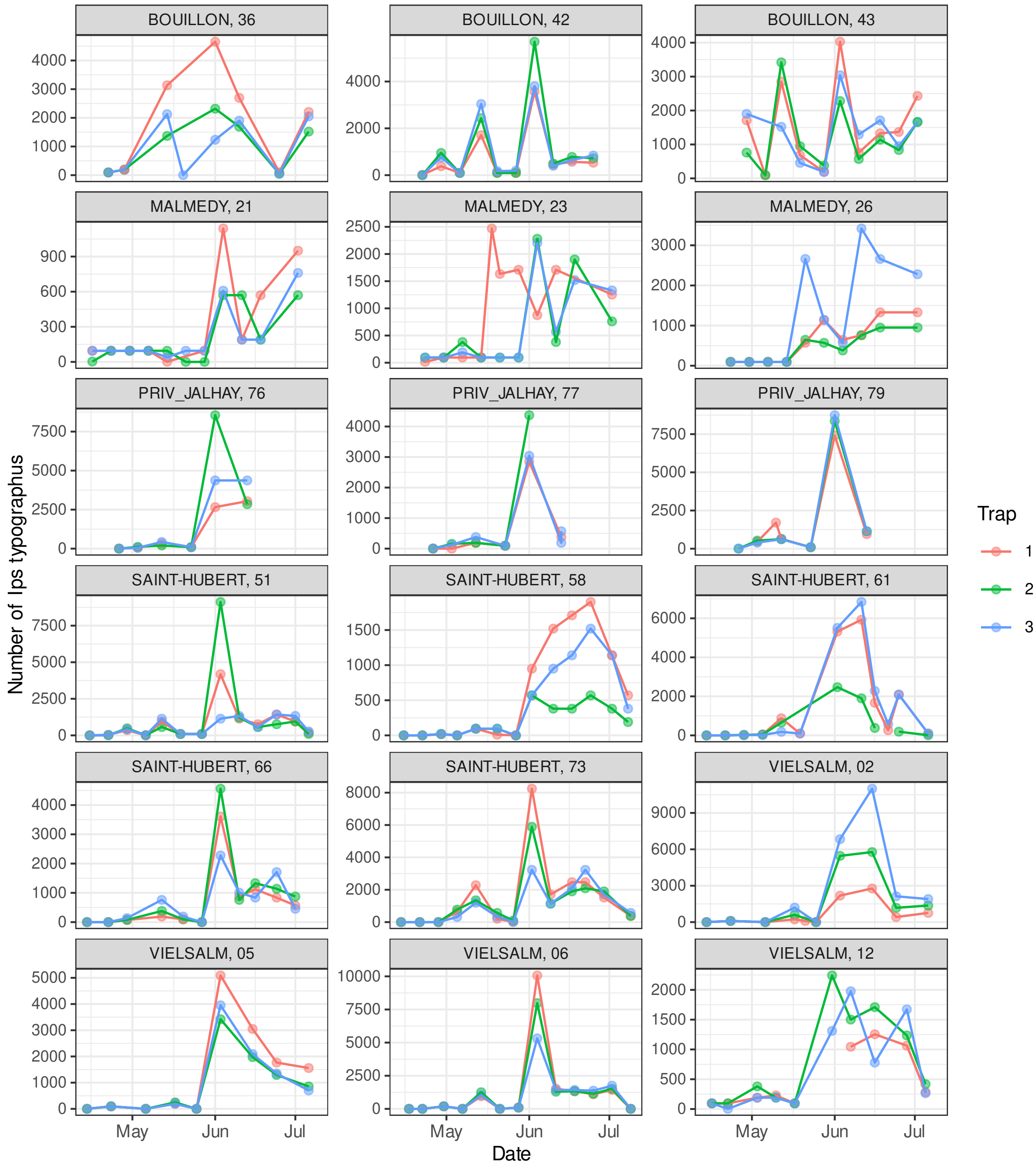

Figure 6:

There is a high variation between sites. While in most sites, captures are tightly correlated between traps, others show large differences (up to a factor 4), especially during peaks of captures.

2.3.2 Variation of captures between sites within each forest district

We can then investigate captures evolution at a larger scale, pooling trap captures by site

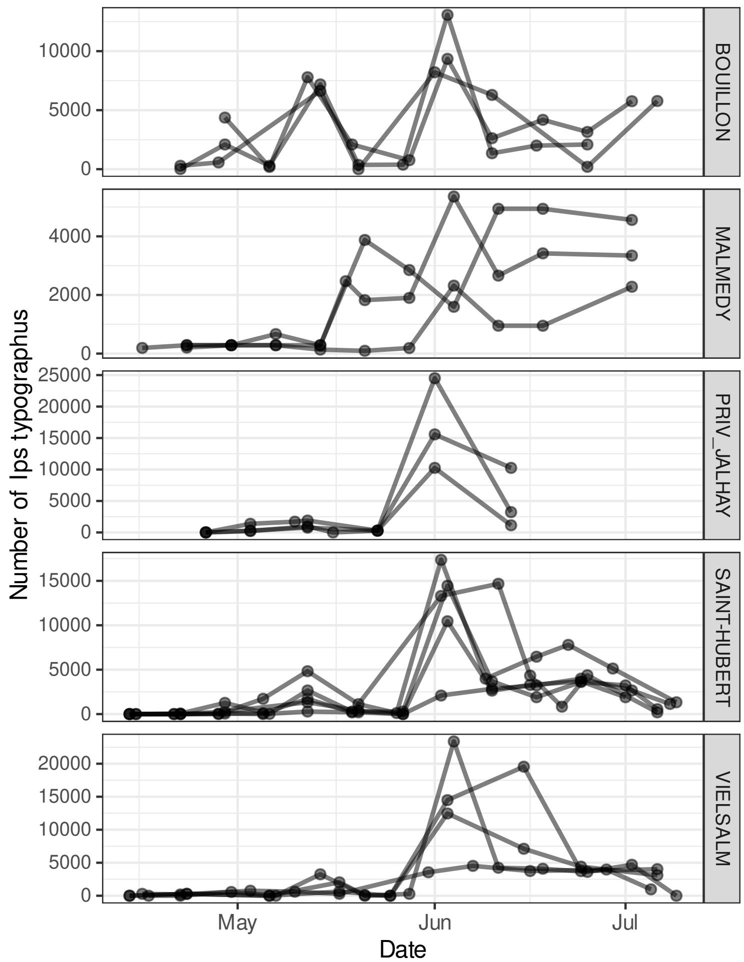

Figure 7:

There is a unique peak at the beginning of June shared by all forest districts except one site in Malmédy showing a reverse trend. In Bouillon, there is a smaller earlier peak in mid-May. Number and trend of captures are generally similar between sites within a forest district with the exception of Malmédy where sites show differences in trend and/or captures number.

2.3.3 Correlation between number of captures and volume of attacks

Explore the number of bark beetles captured by site and look for correlation with new attacks (data from 2020 and 2021 are pooled)

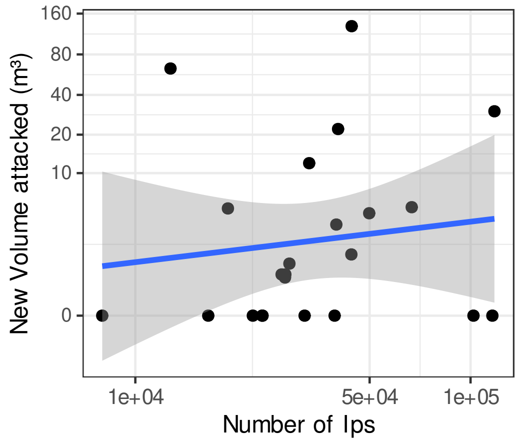

Figure 8:

```
##
## Call:
## lm(formula = log1p(vol_new_0_100m) ~ log1p(Number_Ips), data = df.m)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -1.6252 -1.1478 -0.5037  0.5394  3.5306
##
## Coefficients:
##                   Estimate Std. Error t value Pr(>|t|)
## (Intercept)        -1.8263     5.0477  -0.362    0.721
## log1p(Number_Ips)   0.2959     0.4831   0.613    0.547
##
## Residual standard error: 1.496 on 21 degrees of freedom
## Multiple R-squared:  0.01756,    Adjusted R-squared:  -0.02922
## F-statistic: 0.3753 on 1 and 21 DF,  p-value: 0.5467
```

2.4 Correlations

Pearson correlation matrix are displayed within scatterplot matrices.

2.4.1 Correlations between Volumes and Number of trees

We look here at the correlations between the volume (V) and number of trees attacked (Nb) in the initial year (`_init_`) and for the new attacks at different distances from the center of the attacked patch. All variables are log(x+1) transformed. The data from both years are displayed when available (only initial and 0-100m volumes and numbers for 2021).

Main observations :

- Volumes and numbers of trees attacked for the same site are highly correlated –> these descriptors are redundant and there is no need to analyze both. We chose to work with volume data because this metric is the most relevant in terms of economic impact.

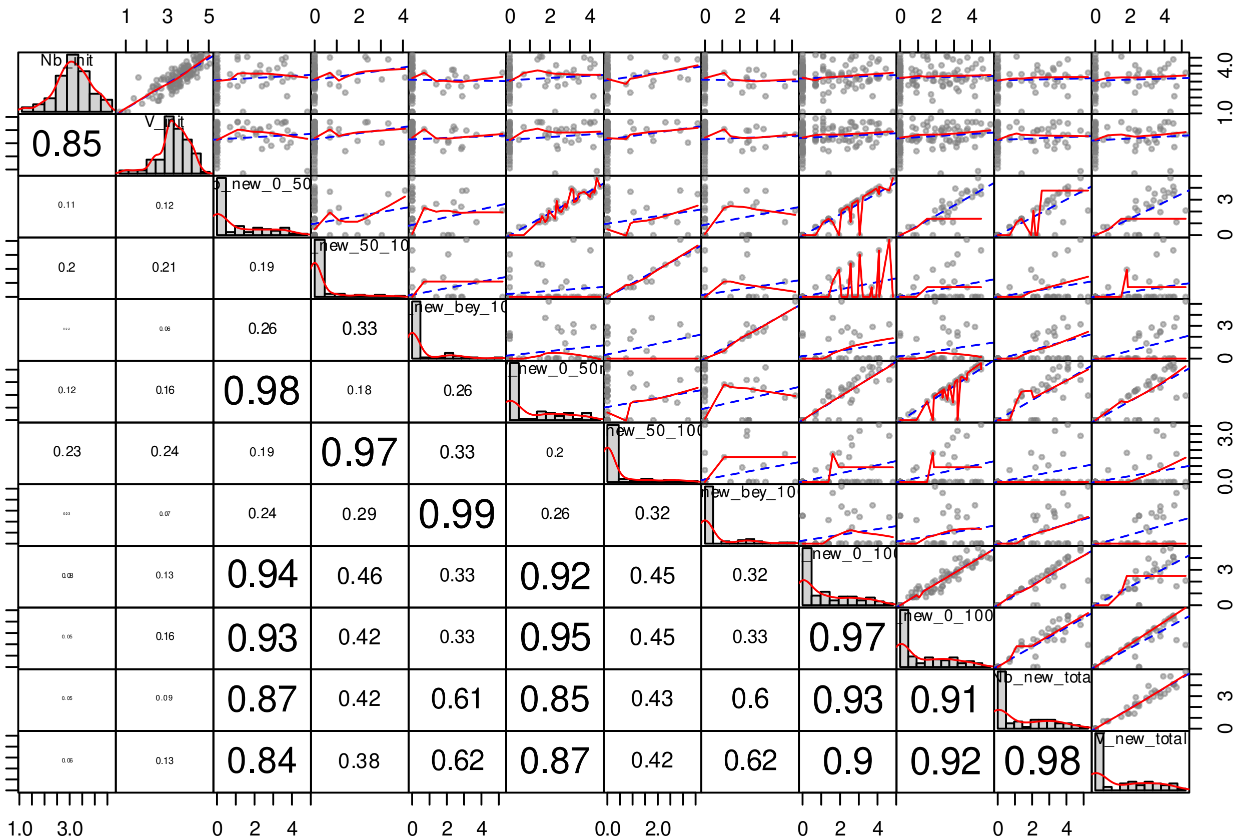

Figure 9:

Different visualization of the same data with a heatmap and clustering.

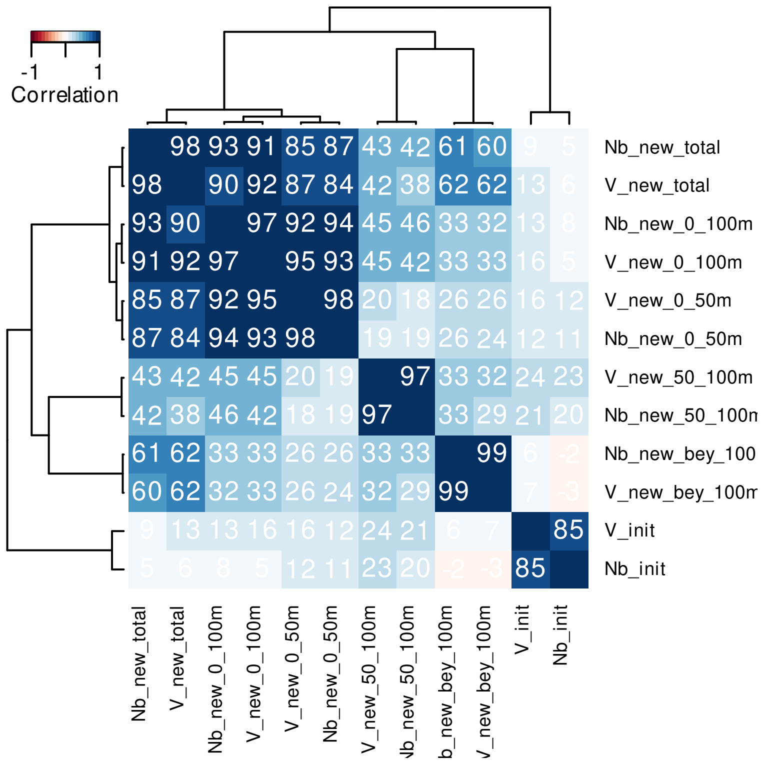

Figure 10:

2.4.2 Correlations between volume data at various distances

In the next graph/correlation matrix, we focus on the volume data only. NB we show the results for both years when available (only initial volume and new volumes between 0-100m for 2021). All volumes are log(x+1) transformed.

Main observations :

1) The volumes newly attacked between 0 and 50 m are poorly correlated with the volumes between 50-100m or beyond 100m
2) The volumes newly attacked between 0-100m are highly correlated with the volumes within 0-50m and much less correlated with the volumes between 50-100m. This means that most of the newly attacked trees are within the 0-50m range.
3) The correlations with the volume initially attacked (`V_init`) are weak
4) There are a lot of patches with no new attacks (lots of 0)
5) The correlation between the initial volumes and the new attacks beyond 100m are the lowest. The attacks beyond 100m form the patch center are probably mainly due to beetles coming from other patches.

Conclusion : based on these 2020 results we decided to work only with the new attacks between 0-100m in 2020 and 2021.

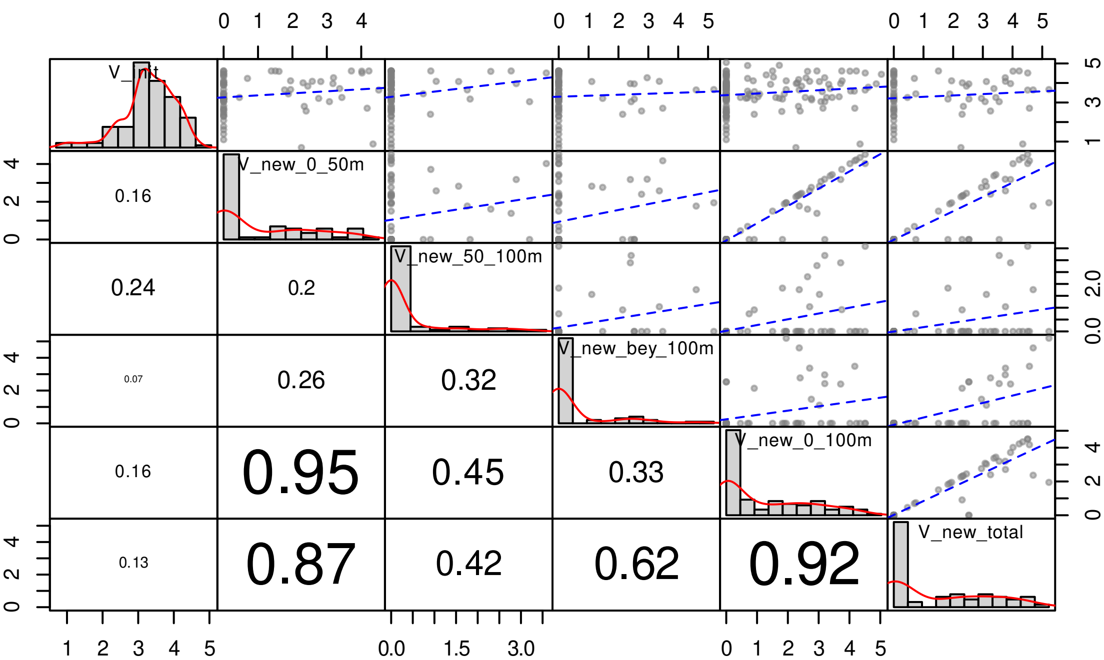

Figure 11:

2.5 Graphical representation of the attacks

2.5.1 Volumes of attacked trees

Each gray line represents the volume attacked in one site at different distances from the initial patch (`initial` = volume in the previous year). The red line represents the average value. (NB : for 2021 we only have the initial and 0-100m data).

Main observations :

- In most of the sites the volumes newly attacked are much lower than the initial volumes of the previous year.
- In 2020, most of the new attacks took place within 50m from the center of the patch.
- The attacks between 50 and 100m were particularly low. All sites with higher volumes within 50m in 2020 relative to 2019 have no attacks between 50 and 100m.
- Beyond 100m there are a few sites with important new attacks but these are not necessarily associated with high attacks <100m from the center. So, it is plausible that these attacks are independent from the patch attacked in 2019.

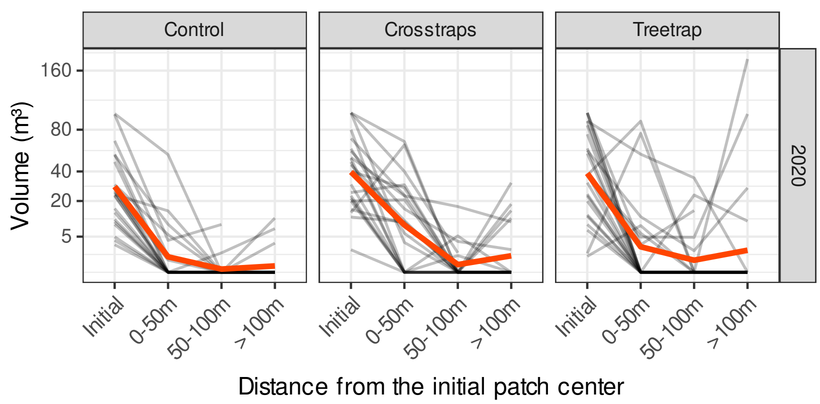

Figure 12:

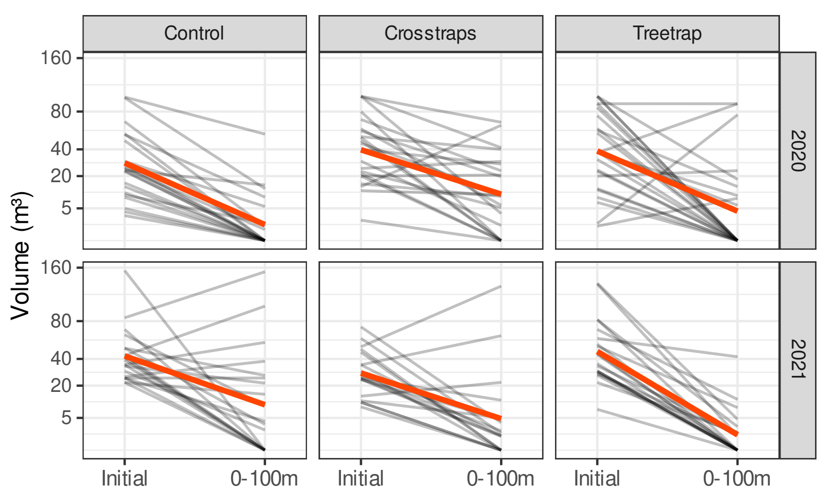

Figure 13:

2.5.2 % of sites with new attacks

Main observations :

- Most of the new attacks are concentrated within 50m from the patch center
- In 2020, we observed new attacks within 100m from the center in ~35-40% of the control and tree trap sites while in the cross traps sites we observed new attacks in > 75% of the sites.
- In 2021, the differences are less marked with ~60% of new attacks in the control sites, ~ 67% in the Crosstraps sites and 45% in the Treetrap sites

NB : one of for one of the treetrap sites, we have no information beyond 100m. –> This site is used for the computations between 0-100m but not beyond 100m and not for the total. This explains why, for the treetrap sites, the % corresponding to the total of the attacks is lower than the % between 0-100m.

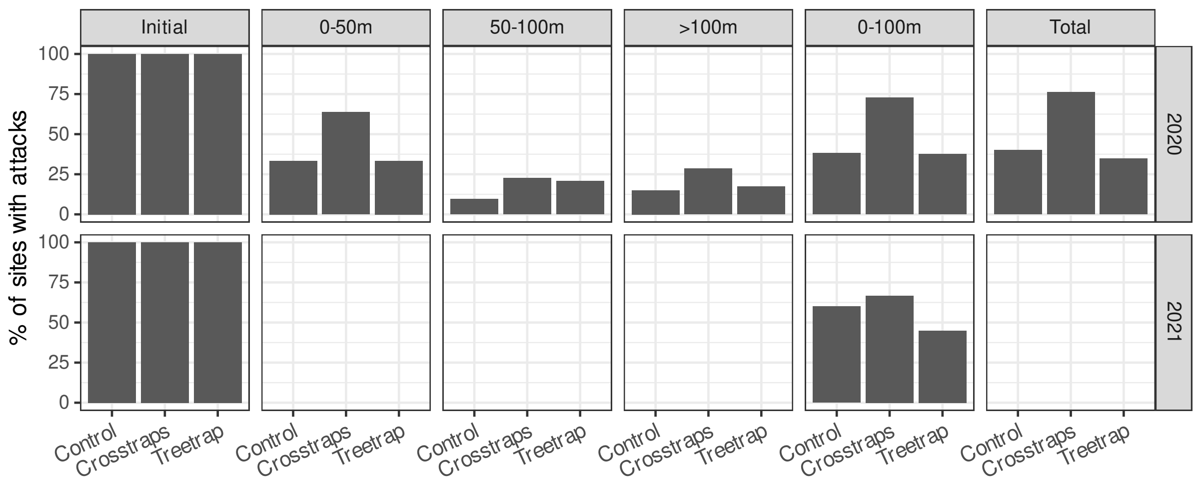

Figure 14:

table with the numbers used for the graph (% of sites with new attacks)

Year	Treatment	Initial	0-50m	50-100m	>100m	0-100m	Total
2020	Control	100	33.3	9.5	15.0	38.1	40.0
2020	Crosstraps	100	63.6	22.7	28.6	72.7	76.2
2020	Treetrap	100	33.3	20.8	17.4	37.5	34.8
2021	Control	100	NA	NA	NA	60.0	NA
2021	Crosstraps	100	NA	NA	NA	66.7	NA
2021	Treetrap	100	NA	NA	NA	45.0	NA

3 Statistical analysis of the effect of trapping treatments on new attacks in both years

3.1 Volume of new attacks

3.1.1 Methods

- Gaussian linear model (ANCOVA) :
- Response (Y) = Volume of attacked trees in 2020 (m^3) between 0-100m around the initial patch center. log(x+1) transformed (natural logarithm) to improve the distribution of residuals
- 4 Explanatory variables (all fixed effects) :
  - Treatment : qualitative variable with 3 levels –> main interest of the study
  - Year (as a factor) and its interaction with Treatment
  - V_init : initial volume attacked in the patch. Square root transformed (to obtain a better distribution and linear relationship with the response) and centered (remove the average) so that the intercept corresponds to a site with an average volume attacked in the previous year
  - Spruce_area_100m_new : Area (m^2) of spruce available in the parcel under study within 100m from the center. Also square root transformed and centered on the average. The aim of this covariate is to control for the fact that in some sites the number of trees available for new attacks is lower than in other sites.

The 3 treatments are then compared with all pairwise post-hoc comparisons (Tukey test like) with p-value correction (single step method, R package `multcomp`).
Because the Treatment x Year interaction was significant these comparisons have been made within each year (in a single contrast matrix to correct the p-values of these 6 post-hoc comparisons)

3.1.2 ANCOVA table and summary (coefficients) of the model

Anova table

Table 7: Anova Table (Type II tests)

	Sum Sq	Df	F value	Pr(>F)
Treatment	11.928	2	2.738	0.069
factor(Year)	1.393	1	0.640	0.425
scale(sqrt(Spruce_area_100m_new), scale = F)	5.268	1	2.419	0.123
scale(sqrt(V_init), scale = F)	3.907	1	1.794	0.183
Treatment:factor(Year)	16.830	2	3.863	0.024
Residuals	252.655	116	NA	NA

Summary of the model

```
##
## Call:
## lm(formula = log1p(V_new_0_100m) ~ Treatment * factor(Year) +
##     scale(sqrt(Spruce_area_100m_new), scale = F) + scale(sqrt(V_init),
##     scale = F), data = d)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -2.5370 -1.0609 -0.4641  1.1310  3.5725
##
## Coefficients:
##                                               Estimate Std. Error t value Pr(>|t|)
## (Intercept)                                   0.859425   0.327149   2.627  0.00978 **
## TreatmentCrosstraps                           1.237995   0.456306   2.713  0.00768 **
## TreatmentTreetrap                             0.491866   0.455895   1.079  0.28287
## factor(Year)2021                              0.826771   0.472915   1.748  0.08307 .
## scale(sqrt(Spruce_area_100m_new), scale = F)  0.006772   0.004355   1.555  0.12263
## scale(sqrt(V_init), scale = F)                0.081905   0.061155   1.339  0.18309
## TreatmentCrosstraps:factor(Year)2021         -1.614213   0.672812  -2.399  0.01802 *
```

```
## TreatmentTreetrap:factor(Year)2021          -1.575898   0.649721  -2.426  0.01683 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 1.476 on 116 degrees of freedom
##   (2 observations effacées parce que manquantes)
## Multiple R-squared:  0.1423, Adjusted R-squared:  0.09054
## F-statistic: 2.749 on 7 and 116 DF,  p-value: 0.01117
```

3.1.3 Post-hoc tests, predicted values and graphical summary of the model

All pairwise comparisons between treatments within each year with p-value correction : (similar to a Tukey test).
NB : the Estimate is here on the log scale…

```
##
##   Simultaneous Tests for General Linear Hypotheses
##
## Fit: lm(formula = log1p(V_new_0_100m) ~ Treatment * factor(Year) +
##     scale(sqrt(Spruce_area_100m_new), scale = F) + scale(sqrt(V_init),
##     scale = F), data = d)
##
## Linear Hypotheses:
##                                  Estimate Std. Error t value Pr(>|t|)
## 2020 : Crosstraps - Control == 0    1.2380     0.4563   2.713   0.0411 *
## 2020 : Treetrap - Control == 0      0.4919     0.4559   1.079   0.7761
## 2020 : Treetrap - Crosstraps == 0  -0.7461     0.4417  -1.689   0.3797
## 2021 : Crosstraps - Control == 0   -0.3762     0.4847  -0.776   0.9196
## 2021 : Treetrap - Control == 0     -1.0840     0.4672  -2.320   0.1101
## 2021 : Treetrap - Crosstraps == 0  -0.7078     0.4879  -1.451   0.5331
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## (Adjusted p values reported -- single-step method)
```

The following table provides the average (`Avg`) and median (`Med`) volumes attacked for each treatment in the `Initial` patch and for `New` attacks without correction, and the values estimated by the model for new attacks (`PredNew`) after correction for the initial volume in the patch and the area of spruce available for new attacks. The predictions of the model are also based on log transformed values which will decrease the influence of very high values of volumes attacked in the average computation. `Lower` and `Upper` columns provide the 95% confidence interval bounds for these estimates. `cld` = Compact Letter Display : Treatments of the same year which do not share any of the letters are significantly different at 0.05 level.

Year	Treatment	AvgInit	AvgNew	MedInit	MedNew	PredNew	Lower	Upper	cld
2020	Control	35.15	4.76	24.40	0.00	1.36	0.24	3.48	a
2020	Crosstraps	44.90	17.29	42.74	9.71	7.15	3.37	14.18	b
2020	Treetrap	46.13	13.98	37.65	0.00	2.86	1.07	6.20	ab
2021	Control	45.92	22.67	37.10	3.61	4.40	1.80	9.42	a
2021	Crosstraps	31.09	13.65	25.50	1.20	2.71	0.85	6.43	a
2021	Treetrap	51.44	3.77	39.95	0.00	0.83	-0.05	2.53	a

Graphical representation of these predictions and 95% confidence intervals. NB : the letters are only valid within each year and cannot be used to compare the volumes attacked between years. In 2021, in treetrap sites, the lower bound of the confidence interval is slightly <0. It has been set to 0 just for the graphical representation to avoid problems with the logarithmic scale

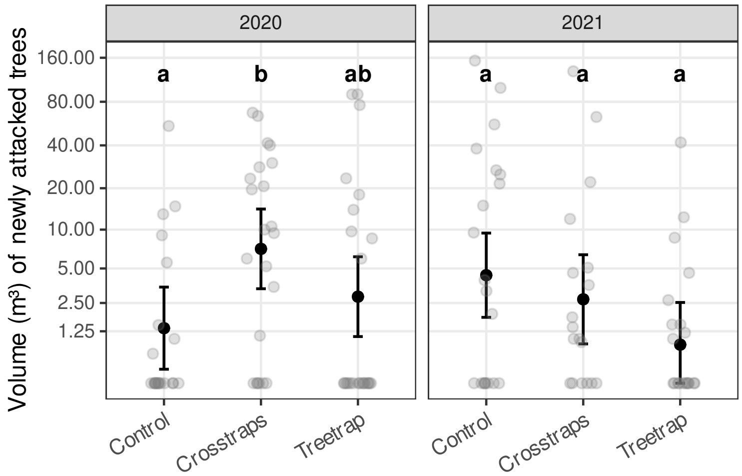

Figure 15:

3.1.4 Conclusions

There is a significant treatment x year interaction. This means that we observe differences between the treatments but that these differences are not the same for both years. When we compare the 3 treatments within each year, we observe a significant slightly higher new volume attacked on crosstraps sites (between 3.37 and 14.18 m^3) relative to the control sites (between 0.24 and 3.48 m^3) but only in 2020.

In 2021, the newly attacked volumes on Treetrap sites tended to be slightly lower than on Control sites but with a lot of variation between sites and some overlap between confidence intervals (2021 treetrap sites : between -0.05 and 2.53 m^3 vs 2021 Control sites : between 1.8 and 9.42 m^3)

3.1.5 Residuals plots to check the validity of the model (+ Spatial auto-correlation)

The distribution of the residuals is reasonably good even if slightly right skewed.

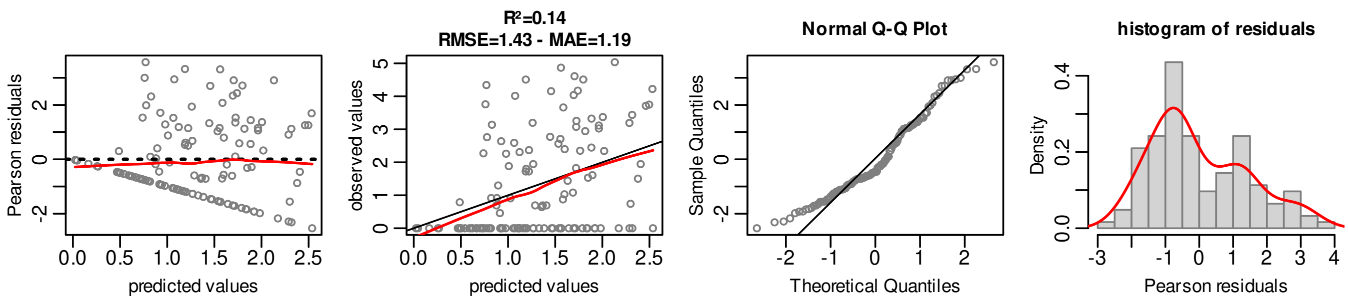

Figure 16:

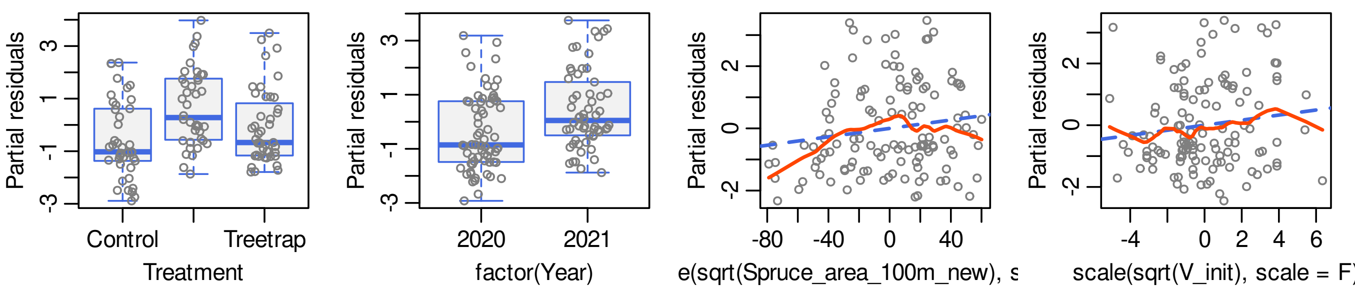

Figure 17:

There is no evidence of spatial correlation in the residuals of the model (spline spatial correlogram from package `ncf`)

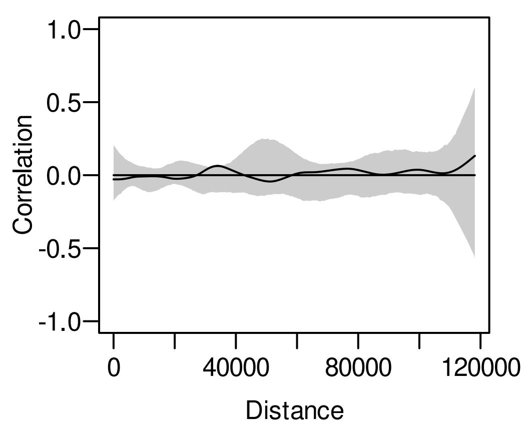

Figure 18:

3.2 Presence/Absence of new attacks

3.2.1 Methods

- Binomial Generalized Linear model (Logistic regression) :
- Response (Y) = Presence/absence of attacks 0-100m around the initial patch center.
- 3 Explanatory variables (all fixed effects) - identical to the Gaussian model for volume:
  - Treatment : qualitative variable with 3 levels –> main interest of the study
  - V_init : initial volume attacked in the patch (during the previous year). Square root transformed (to obtain a better distribution and linear relationship with the response) and centered (remove the average) so that the intercept corresponds to a site with an average volume attacked in 2019
  - Spruce_area_100m_new : Area (m^2) of spruce available in the parcel under study within 100m from the center. Also square root transformed and centered on the average. The aim of this covariate is to control for the fact that in some sites the number of trees available for new attacks is lower than in other sites.

The 3 treatments are then compared with all pairwise post-hoc comparisons (tukey test like) with p-value correction (single-step method, R package `multcomp`).

3.2.2 Analysis of Deviance table and summary (coefficients) of the model

Anova table

Table 9: Analysis of Deviance Table (Type II tests)

	LR Chisq	Df	Pr(>Chisq)
Treatment	8.568	2	0.014
factor(Year)	0.094	1	0.759
scale(sqrt(Spruce_area_100m_new), scale = F)	7.952	1	0.005
scale(sqrt(V_init), scale = F)	1.576	1	0.209
Treatment:factor(Year)	1.321	2	0.517

Summary of the model

```
##
## Call:
## glm(formula = Attacks ~ Treatment * factor(Year) + scale(sqrt(Spruce_area_100m_new),
##     scale = F) + scale(sqrt(V_init), scale = F), family = binomial,
##     data = tmp)
##
## Deviance Residuals:
##     Min       1Q   Median       3Q      Max
## -2.2093  -1.0485   0.5222   1.0103   1.7315
##
## Coefficients:
##                                            Estimate Std. Error z value Pr(>|z|)
## (Intercept)                               -0.334637   0.472056  -0.709  0.47839
## TreatmentCrosstraps                        1.595852   0.706299   2.259  0.02385 *
## TreatmentTreetrap                          0.132114   0.665764   0.198  0.84270
## factor(Year)2021                           0.457459   0.673852   0.679  0.49722
## scale(sqrt(Spruce_area_100m_new), scale = F)  0.018547   0.006878   2.697  0.00701 **
## scale(sqrt(V_init), scale = F)             0.113270   0.091168   1.242  0.21408
## TreatmentCrosstraps:factor(Year)2021      -1.078123   1.004775  -1.073  0.28327
## TreatmentTreetrap:factor(Year)2021        -0.817701   0.941772  -0.868  0.38525
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## (Dispersion parameter for binomial family taken to be 1)
##
##     Null deviance: 171.38  on 123  degrees of freedom
## Residual deviance: 150.52  on 116  degrees of freedom
##   (2 observations effacées parce que manquantes)
## AIC: 166.52
##
## Number of Fisher Scoring iterations: 4
```

3.2.3 Post-hoc tests, predicted values and graphical summary of the model

All pairwise comparisons between treatments with p-value correction : (similar to a Tukey test).
NB : the Estimate is here on the logit scale (log(p/(1-p))...

```
##
##   Simultaneous Tests for General Linear Hypotheses
##
## Fit: glm(formula = Attacks ~ Treatment * factor(Year) + scale(sqrt(Spruce_area_100m_new),
##     scale = F) + scale(sqrt(V_init), scale = F), family = binomial,
##     data = tmp)
##
## Linear Hypotheses:
##                                Estimate Std. Error z value Pr(>|z|)
## 2020 : Crosstraps - Control == 0    1.5959     0.7063   2.259    0.119
## 2020 : Treetrap - Control == 0      0.1321     0.6658   0.198    1.000
## 2020 : Treetrap - Crosstraps == 0  -1.4637     0.6831  -2.143    0.156
## 2021 : Crosstraps - Control == 0    0.5177     0.7121   0.727    0.936
## 2021 : Treetrap - Control == 0     -0.6856     0.6701  -1.023    0.808
## 2021 : Treetrap - Crosstraps == 0  -1.2033     0.7255  -1.659    0.393
## (Adjusted p values reported -- single-step method)
```

The following table provides the proportion of sites attacked for each treatment in 2020 (initial) and 2021 (without correction), and the values estimated by the model for 2021 after correction for the initial volume in the patch in 2020 and the area of spruce available for new attacks. `Lower` and `Upper` columns provide the 95% confidence interval bounds for these estimates. `cld` = Compact Letter Display : Treatments which do not share any of the letters are significantly different at 0.05 level.

Year	Treatment	Initial	New	Predicted_New	Lower	Upper	cld
2020	Control	1	0.38	0.42	0.22	0.64	a
2020	Crosstraps	1	0.73	0.78	0.56	0.91	a
2020	Treetrap	1	0.38	0.45	0.25	0.67	a
2021	Control	1	0.60	0.53	0.31	0.74	a
2021	Crosstraps	1	0.67	0.65	0.40	0.84	a
2021	Treetrap	1	0.45	0.36	0.18	0.60	a

Graphical representation of these predictions and 95% confidence intervals

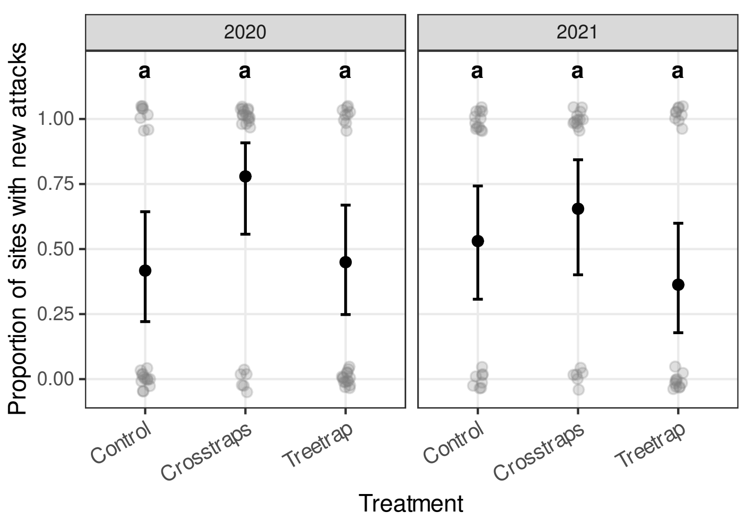

Figure 19:

Because the year x treatment interaction is clearly not significant, it would be more logical to make the comparisons of the average frequency of new attacks for both years

```
##
##   Simultaneous Tests for General Linear Hypotheses
##
## Fit: glm(formula = Attacks ~ Treatment * factor(Year) + scale(sqrt(Spruce_area_100m_new),
##     scale = F) + scale(sqrt(V_init), scale = F), family = binomial,
##     data = tmp)
##
## Linear Hypotheses:
##                                           Estimate Std. Error z value Pr(>|z|)
## Avg(2020,2021) : Crosstraps - Control == 0    1.0568     0.5006   2.111   0.0874 .
## Avg(2020,2021) : Treetrap - Control == 0     -0.2767     0.4737  -0.584   0.8285
## Avg(2020,2021) : Treetrap - Crosstraps == 0  -1.3335     0.5044  -2.644   0.0224 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## (Adjusted p values reported -- single-step method)
```

The following table provides the proportion of sites attacked for each treatment in 2020 (initial) and 2021 (without correction), and the values estimated by the model for 2021 after correction for the initial volume in the patch in 2020 and the area of spruce available for new attacks. `Lower` and `Upper` columns provide the 95% confidence interval bounds for these estimates. `cld` = Compact Letter Display : Treatments which do not share any of the letters are significantly different at 0.05 level.

Treatment	Initial	New	Predicted_New	Lower	Upper	cld
Control	1	0.49	0.47	0.32	0.63	ab
Crosstraps	1	0.70	0.72	0.56	0.84	a
Treetrap	1	0.41	0.41	0.26	0.57	b

Graphical representation of these predictions and 95% confidence intervals

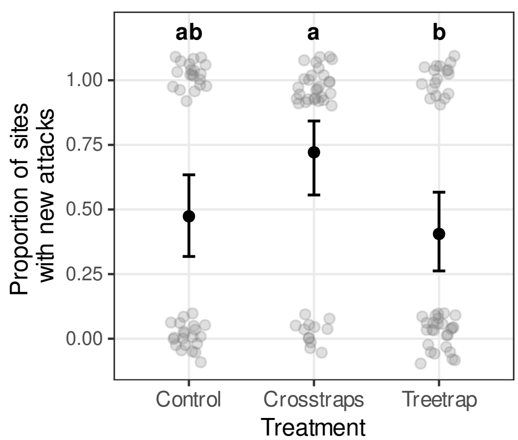

Figure 20:

3.2.4 Conclusions

In contrast with the volume data we found no significant year x treatment interaction. When the interaction is removed there is a significant Treatment effect related to a higher frequency of new attacks in crosstraps sites. However when we perform multiple comparisons within each year with p-value correction none of the comparisons is significant. However, because there is no interactions we could make the comparison for both years together (average of the frequency of new attacks). This decreases the number of comparisons and increases the statistical power. In this case the is a significantly higher frequency of attacks in crosstraps sites relative to treetrap sites (while the controls are in between)

3.2.5 Residuals plots to check the validity of the model (+ Spatial auto-correlation)

The distribution of the residuals is reasonably good with a few outliers in the cross traps treatment…

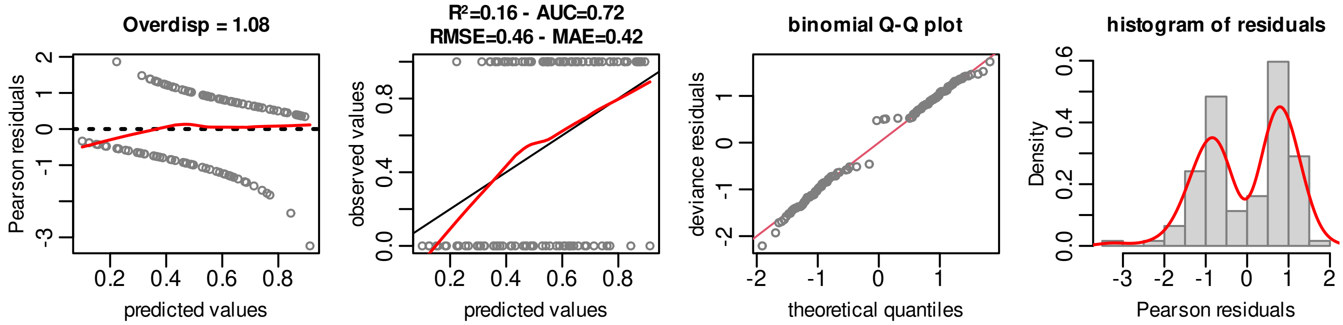

Figure 21:

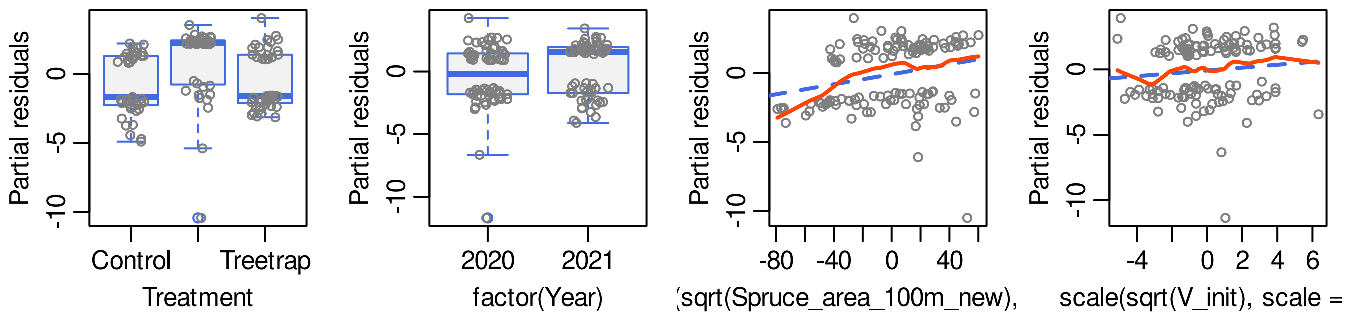

Figure 22:

There is no evidence of spatial correlation in the residuals of the model (spline spatial correlogram from package `ncf`)

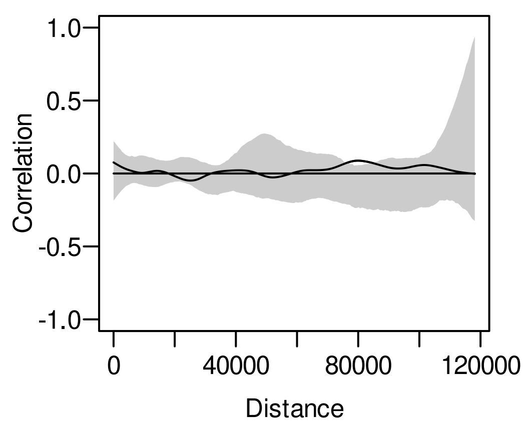

Figure 23:

4 Comparison with the Italian study of Faccoli & Stergulc (2008)

Faccoli, M., Stergulc, F., 2008. Damage reduction and performance of mass trapping devices for forest protection against the spruce bark beetle, Ips typographus (Coleoptera Curculionidae Scolytinae). Annals of Forest Science 65, 309. https://doi.org/10.1051/forest:2008010

Faccoli & Stergulc (2008) computed the % of volume reduction between the initial situation and the new attacks : `(V_init- V_new)*100/V_init`. They had almost only positive values ie their new volumes attacked where close the the initial volume or much lower.

We are in a quite different situation in Belgium with both 100% reduction values (no new attacks) and very high increase (negative %). Even when we filter out the few 2020 sites with $< 3m^3$ in the initial patch, the distribution we obtain with this approach is very scattered and very difficult to represent graphically and to analyse properly with any statistical tool.

4.1 Comparing trap densities

In the Italian study the number of traps was chosen to obtain 3 levels of trapping intensities relative to the initial volume attacked : 15, 30 or 40 m^3/trap. 15 m^3/ trap represents the highest trapping intensity.

In the Belgian study we chose to place 3 traps in all situations. The density of trapping was nevertheless changing between sites because the initial volume was not the same.

NB : the Treetrap in the Belgian study are probably not directly comparable with the other traps because one whole tree is probably more efficient than several logs.

Globally we had more cross traps in the Belgian study for a given amount of initial damage and we are covering most of the trapping intensities of the Italian study excepted the lowest trapping intensities (45 m^3/trap).

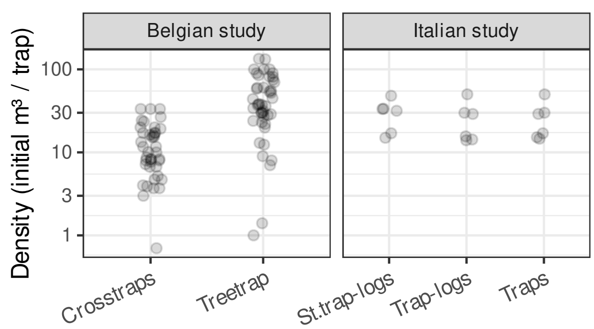

Figure 24:

4.2 Comparison of initial and new damage for both studies

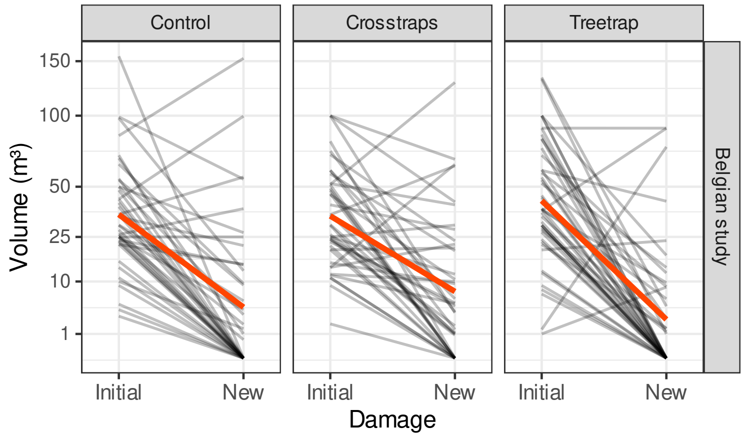

Figure 25:

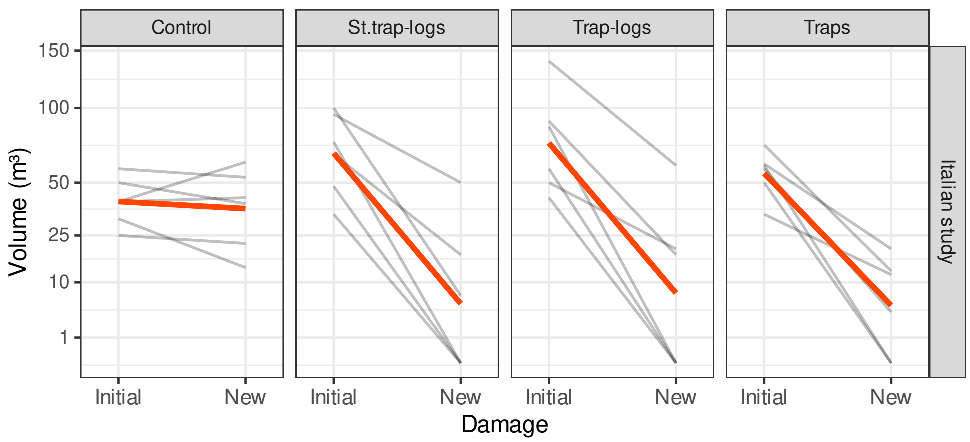

Figure 26:

4.3 Compare the % of damage reduction

Comparison of the % of damage reduction as computed in Faccoli & Stergulc (2008), eg see fig 1 in this paper.
The very large spread of Belgian values makes the graph difficult to read. The next graph is the same but with just the average value and an error bar representing a 95% bootstrap confidence interval.

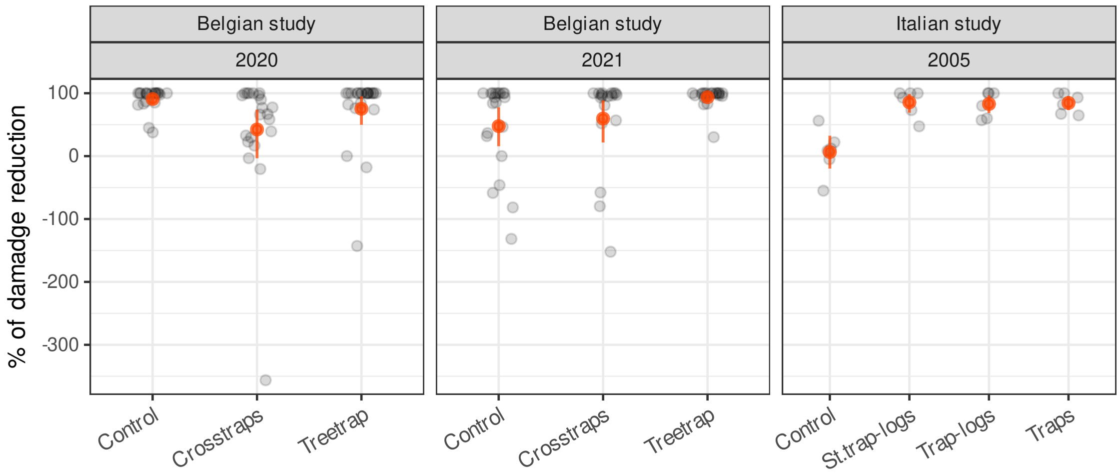

Figure 27:

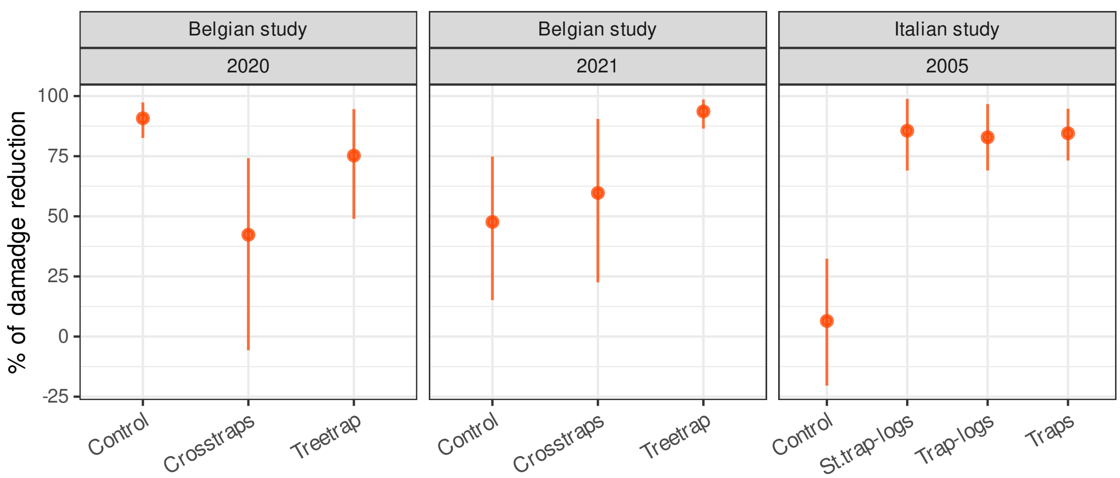

Figure 28:

5 Annexes

5.1 Table with the volumes attacked on all sites

All volumes are in m^3

- `Year` : Year of the study
- `ID` : Identification number for each site/patch (unique within Year)
- `Treatment` : Control (no traps) - Cross traps - Tree trap
- `District` : management district ("Cantonnement")
- `Tri` : "Triage" = Smaller management unit used by the forest administration (Tri ID are unique within district)
- `V_init` : Initial volume (m^3) attacked during the previous year in the patch
- `0-50m` : Newly attacked volume within 0-50m from the patch center
- `50-100m` : Newly attacked volume within 0-50m from the patch center
- `>100m` : Newly attacked volume beyond 100m from the patch center (but within the "parcel")
- `0-100m` : Newly attacked volume within 0-100m from the patch center (sum of columns 0-50m + 50-100m) –> this is the value used in most analyses and the only measure collected in 2021.
- `Total` : Newly attacked volume within the parcel (Sum of 0-50m + 50-100m + >100m)

Year	ID	Treatment	District	Tri	V_init	0-50m	50-100m	>100m	0-100m	Total
2020	1	Control	Bièvre	1	9.0	0.0	0.0	0.0	0.0	0.0
2020	2	Crosstraps	Bièvre	1	23.0	0.0	5.2	0.0	5.2	5.2
2020	3	Treetrap	Bièvre	1	85.0	0.0	0.0	0.0	0.0	0.0
2020	4	Control	Bièvre	2	3.0	0.0	0.0	0.0	0.0	0.0
2020	6	Treetrap	Bièvre	2	1.0	8.6	0.0	0.0	8.6	8.6
2020	8	Crosstraps	Bièvre	3	25.0	30.1	0.0	0.0	30.1	30.1
2020	9	Treetrap	Bièvre	4	75.0	0.0	0.0	0.0	0.0	0.0
2020	10	Control	Bièvre	6	16.0	0.0	0.0	0.0	0.0	0.0
2020	11	Crosstraps	Bièvre	6	2.0	0.0	0.0	0.0	0.0	0.0
2020	12	Treetrap	Bièvre	7	9.0	0.0	0.0	0.0	0.0	0.0
2020	13	Control	Bièvre	8	26.0	0.0	0.0	0.0	0.0	0.0
2020	14	Crosstraps	Bièvre	9	20.0	0.0	0.0	0.0	0.0	0.0
2020	15	Treetrap	Bièvre	10	13.0	0.0	0.0	0.0	0.0	0.0
2020	16	Control	Bièvre	10	4.0	0.0	0.0	0.0	0.0	0.0
2020	17	Crosstraps	Bièvre	11	80.0	0.0	0.0	0.0	0.0	0.0
2020	18	Treetrap	Bièvre	12	90.0	54.9	35.1	0.0	90.0	90.0
2020	19	Control	Bouillon	1	23.8	14.8	0.0	3.4	14.8	18.2
2020	20	Crosstraps	Bouillon	2	57.8	15.8	3.8	2.0	19.6	21.6
2020	21	Treetrap	Bouillon	2	23.0	0.0	0.0	0.0	0.0	0.0
2020	22	Control	Bouillon	2	48.0	0.0	0.0	0.0	0.0	0.0
2020	23	Crosstraps	Bouillon	2	15.5	9.4	0.0	0.0	9.4	9.4
2020	24	Treetrap	Bouillon	3	37.3	4.9	4.8	98.6	9.7	108.3
2020	25	Control	Bouillon	4	5.0	0.0	0.0	0.0	0.0	0.0
2020	26	Crosstraps	Bouillon	4	45.5	10.6	0.0	0.0	10.6	10.6
2020	27	Treetrap	Bouillon	4	12.4	0.0	0.0	0.0	0.0	0.0
2020	28	Treetrap	Bouillon	5	38.0	0.0	0.0	0.0	0.0	0.0
2020	29	Crosstraps	Bouillon	9	40.0	28.2	0.0	0.0	28.2	28.2
2020	30	Control	Bouillon	9	28.0	0.0	0.0	0.0	0.0	0.0
2020	31	Treetrap	Bouillon	10	1.4	75.9	0.0	0.0	75.9	75.9
2020	32	Crosstraps	Bouillon	10	21.5	0.0	0.0	0.0	0.0	0.0
2020	33	Control	Bouillon	10	14.0	0.0	0.0	0.0	0.0	0.0
2020	34	Treetrap	Bouillon	10	31.6	0.0	0.0	0.0	0.0	0.0
2020	35	Control	Bouillon	10	11.0	0.0	0.0	0.0	0.0	0.0
2020	36	Crosstraps	Bouillon	10	20.0	20.7	0.0	0.0	20.7	20.7
2020	37	Treetrap	Saint-Hubert	5	55.5	0.0	0.0	0.0	0.0	0.0
2020	38	Control	Saint-Hubert	5	23.5	0.0	0.0	0.0	0.0	0.0
2020	39	Crosstraps	Saint-Hubert	5	51.8	23.0	17.0	10.0	40.0	50.0
2020	40	Crosstraps	Saint-Hubert	6	51.1	0.0	0.0	11.5	0.0	11.5
2020	41	Control	Saint-Hubert	6	30.2	5.6	0.0	0.0	5.6	5.6
2020	42	Treetrap	Saint-Hubert	7	24.0	0.0	0.0	0.0	0.0	0.0
2020	43	Control	Saint-Hubert	7	54.8	0.0	0.0	0.0	0.0	0.0
2020	44	Treetrap	Saint-Hubert	8	19.9	0.0	23.5	10.3	23.5	33.8
2020	45	Crosstraps	Saint-Hubert	8	70.4	23.4	0.0	18.3	23.4	41.7
2020	46	Treetrap	Neufchâteau	11	100.0	3.0	15.0	-	18.0	-

Year	ID	Treatment	District	Tri	V_init	0-50m	50-100m	>100m	0-100m	Total
2020	47	Control	Neufchâteau	11	98.0	4.0	9.0	-	13.0	-
2020	48	Crosstraps	Neufchâteau	10	100.0	67.3	0.0	0.0	67.3	67.3
2020	49	Treetrap	Neufchâteau	10	100.0	0.0	0.0	0.0	0.0	0.0
2020	50	Crosstraps	Neufchâteau	13	47.9	0.0	0.0	0.0	0.0	0.0
2020	51	Control	Neufchâteau	13	100.0	-	-	-	-	-
2020	52	Crosstraps	Neufchâteau	12	100.0	40.0	1.5	-	41.5	-
2020	53	Treetrap	Neufchâteau	14	37.0	89.9	0.0	0.0	89.9	89.9
2020	54	Control	Neufchâteau	14	99.0	54.5	0.0	0.0	54.5	54.5
2020	55	Control	Saint-Hubert	4	23.0	0.0	0.0	11.6	0.0	11.6
2020	56	Control	Saint-Hubert	4	10.0	0.0	1.5	7.5	1.5	9.0
2020	58	Treetrap	Saint-Hubert	4	58.4	12.2	1.8	28.0	14.0	42.0
2020	59	Treetrap	Libin	8	100.0	0.0	0.0	0.0	0.0	0.0
2020	60	Crosstraps	Libin	8	100.0	3.5	0.0	0.0	3.5	3.5
2020	62	Treetrap	Saint-Hubert	7	60.4	0.0	0.0	0.0	0.0	0.0
2020	63	Crosstraps	Saint-Hubert	7	30.3	0.0	1.1	0.0	1.1	1.1
2020	64	Control	Libin	13	25.0	0.6	0.0	0.0	0.6	0.6
2020	65	Control	Libin	10	68.0	1.0	0.0	0.0	1.0	1.0
2020	66	Crosstraps	Libin	10	12.0	10.0	0.0	15.0	10.0	25.0
2020	67	Treetrap	Libin	10	38.0	6.0	0.0	179.0	6.0	185.0
2020	68	Crosstraps	Libin	11	14.0	63.9	0.0	31.5	63.9	95.4
2020	69	Treetrap	Libin	11	7.0	0.0	0.0	0.0	0.0	0.0
2020	70	Treetrap	Libin	12	90.0	0.0	0.0	0.0	0.0	0.0
2020	71	Crosstraps	Libin	12	60.0	6.0	0.0	0.0	6.0	6.0
2020	72	Control	Libin	7	54.0	9.1	0.0	0.0	9.1	9.1
2021	1	Treetrap	Vielsalm	1	43.9	-	-	-	0.0	-
2021	2	Crosstraps	Vielsalm	4	51.3	-	-	-	129.3	-
2021	3	Control	Vielsalm	4	35.2	-	-	-	55.8	-
2021	4	Treetrap	Vielsalm	4	82.0	-	-	-	0.0	-
2021	5	Crosstraps	Vielsalm	4	24.6	-	-	-	1.0	-
2021	6	Crosstraps	Vielsalm	8	26.0	-	-	-	1.8	-
2021	7	Control	Vielsalm	8	35.0	-	-	-	0.0	-
2021	10	Treetrap	Vielsalm	10	133.9	-	-	-	4.6	-
2021	12	Crosstraps	Vielsalm	10	11.7	-	-	-	5.1	-
2021	15	Control	Vielsalm	11	39.0	-	-	-	0.0	-
2021	16	Treetrap	Vielsalm	11	34.1	-	-	-	1.5	-
2021	18	Control	Malmédy	1	155.0	-	-	-	0.0	-
2021	19	Treetrap	Malmédy	1	27.0	-	-	-	0.0	-
2021	20	Treetrap	Malmédy	6	54.0	-	-	-	0.0	-
2021	21	Crosstraps	Malmédy	6	46.0	-	-	-	0.0	-
2021	22	Control	Malmédy	6	34.0	-	-	-	21.6	-
2021	23	Crosstraps	Malmédy	6	11.0	-	-	-	0.0	-
2021	24	Control	Malmédy	6	22.0	-	-	-	15.0	-
2021	25	Treetrap	Malmédy	6	8.0	-	-	-	0.0	-
2021	26	Crosstraps	Malmédy	6	9.0	-	-	-	0.0	-
2021	27	Treetrap	Bouillon	3	28.9	-	-	-	0.0	-
2021	28	Control	Bouillon	3	84.2	-	-	-	152.9	-
2021	36	Crosstraps	Bouillon	5	24.0	-	-	-	0.9	-
2021	37	Control	Bouillon	5	50.0	-	-	-	3.2	-
2021	40	Control	Bouillon	6	50.0	-	-	-	26.8	-
2021	41	Treetrap	Bouillon	6	70.0	-	-	-	12.3	-
2021	42	Crosstraps	Bouillon	6	60.0	-	-	-	1.4	-
2021	43	Crosstraps	Bouillon	7	14.0	-	-	-	22.1	-
2021	44	Control	Bouillon	7	26.0	-	-	-	38.0	-
2021	45	Treetrap	Bouillon	8	81.5	-	-	-	2.7	-
2021	47	Treetrap	Saint-Hubert	7	132.4	-	-	-	1.0	-
2021	48	Control	Saint-Hubert	7	64.0	-	-	-	9.5	-
2021	50	Control	Saint-Hubert	3	25.0	-	-	-	4.0	-
2021	51	Crosstraps	Saint-Hubert	9	49.0	-	-	-	0.0	-
2021	52	Treetrap	Saint-Hubert	9	45.0	-	-	-	0.0	-
2021	54	Control	Saint-Hubert	9	41.0	-	-	-	0.0	-
2021	55	Treetrap	Saint-Hubert	5	22.0	-	-	-	1.5	-
2021	56	Control	Saint-Hubert	4	43.0	-	-	-	0.0	-
2021	58	Crosstraps	Saint-Hubert	4	30.0	-	-	-	0.0	-
2021	60	Treetrap	Saint-Hubert	4	30.0	-	-	-	0.0	-
2021	61	Crosstraps	Saint-Hubert	10	73.0	-	-	-	3.6	-
2021	65	Control	Saint-Hubert	8	22.0	-	-	-	0.0	-
2021	66	Crosstraps	Saint-Hubert	8	11.0	-	-	-	0.0	-
2021	67	Treetrap	Saint-Hubert	8	36.0	-	-	-	0.0	-
2021	68	Treetrap	Saint-Hubert	8	28.0	-	-	-	1.2	-
2021	70	Treetrap	Saint-Hubert	12	52.0	-	-	-	8.7	-
2021	72	Control	Saint-Hubert	12	43.0	-	-	-	99.6	-

Year	ID	Treatment	District	Tri	V_init	0-50m	50-100m	>100m	0-100m	Total
2021	73	Crosstraps	Saint-Hubert	12	24.0	-	-	-	4.6	-
2021	75	Control	Saint-Hubert	11	30.0	-	-	-	2.0	-
2021	76	Crosstraps	Privé Jalhay	1	35.0	-	-	-	1.0	-
2021	77	Crosstraps	Privé Jalhay	1	35.0	-	-	-	62.9	-
2021	78	Control	Privé Jalhay	1	70.0	-	-	-	0.0	-
2021	79	Crosstraps	Privé Jalhay	1	25.0	-	-	-	12.0	-
2021	80	Treetrap	Privé Jalhay	1	30.0	-	-	-	0.0	-
2021	81	Control	Privé Jalhay	1	25.0	-	-	-	0.0	-
2021	82	Treetrap	Privé Jalhay	1	60.0	-	-	-	41.9	-
2021	83	Control	Privé Jalhay	1	25.0	-	-	-	25.0	-
2021	84	Treetrap	Privé Jalhay	1	30.0	-	-	-	0.0	-

5.2 Session Info

```
## R version 4.2.1 (2022-06-23)
## Platform: x86_64-pc-linux-gnu (64-bit)
## Running under: Ubuntu 22.04 LTS
##
## Matrix products: default
## BLAS:   /usr/lib/x86_64-linux-gnu/openblas-pthread/libblas.so.3
## LAPACK: /usr/lib/x86_64-linux-gnu/openblas-pthread/libopenblasp-r0.3.20.so
##
## locale:
##  [1] LC_CTYPE=en_GB.UTF-8       LC_NUMERIC=C               LC_TIME=en_GB.UTF-8
##  [4] LC_COLLATE=en_GB.UTF-8     LC_MONETARY=en_GB.UTF-8    LC_MESSAGES=fr_BE.UTF-8
##  [7] LC_PAPER=fr_BE.UTF-8       LC_NAME=C                  LC_ADDRESS=C
## [10] LC_TELEPHONE=C             LC_MEASUREMENT=fr_BE.UTF-8 LC_IDENTIFICATION=C
##
## attached base packages:
## [1] stats     graphics  grDevices utils     datasets  methods   base
##
## other attached packages:
##  [1] mgcv_1.8-40      nlme_3.1-157     gplots_3.1.3     vegan_2.6-2      lattice_0.20-45
##  [6] permute_0.9-7    dplyr_1.0.9      tidyr_1.2.0      ggspatial_1.1.5  sf_1.0-7
## [11] ncf_1.3-2        ggrepel_0.9.1    multcomp_1.4-19  TH.data_1.1-1    MASS_7.3-57
## [16] survival_3.3-1   mvtnorm_1.1-3    car_3.0-13       carData_3.0-5    ggplot2_3.3.6
## [21] kableExtra_1.3.4 pander_0.6.5     knitr_1.39
##
## loaded via a namespace (and not attached):
##  [1] bitops_1.0-7        webshot_0.5.3       RColorBrewer_1.1-3  httr_1.4.3
##  [5] backports_1.4.1     tools_4.2.1         utf8_1.2.2          R6_2.5.1
##  [9] rpart_4.1.16        KernSmooth_2.23-20  Hmisc_4.7-0         DBI_1.1.3
## [13] colorspace_2.0-3    nnet_7.3-17         withr_2.5.0         gridExtra_2.3
## [17] tidyselect_1.1.2    compiler_4.2.1      cli_3.3.0           rvest_1.0.2
## [21] htmlTable_2.4.0     xml2_1.3.3          sandwich_3.0-1      labeling_0.4.2
## [25] bookdown_0.26       checkmate_2.1.0     caTools_1.18.2      scales_1.2.0
## [29] classInt_0.4-7      proxy_0.4-27        systemfonts_1.0.4   stringr_1.4.0
## [33] digest_0.6.29       foreign_0.8-82      rmarkdown_2.14      svglite_2.1.0
## [37] jpeg_0.1-9          base64enc_0.1-3     pkgconfig_2.0.3     htmltools_0.5.2
## [41] fastmap_1.1.0       highr_0.9           htmlwidgets_1.5.4   rlang_1.0.2
## [45] rstudioapi_0.13     generics_0.1.2      farver_2.1.0        zoo_1.8-10
## [49] gtools_3.9.2.1      magrittr_2.0.3      Formula_1.2-4       Matrix_1.4-1
## [53] Rcpp_1.0.8.3        munsell_0.5.0       fansi_1.0.3         abind_1.4-5
## [57] lifecycle_1.0.1     stringi_1.7.6       yaml_2.3.5          grid_4.2.1
## [61] parallel_4.2.1      crayon_1.5.1        splines_4.2.1       pillar_1.7.0
## [65] codetools_0.2-18    glue_1.6.2          evaluate_0.15       latticeExtra_0.6-29
## [69] data.table_1.14.2   png_0.1-7           vctrs_0.4.1         gtable_0.3.0
## [73] purrr_0.3.4         assertthat_0.2.1    xfun_0.31           e1071_1.7-11
## [77] class_7.3-20        viridisLite_0.4.0   tibble_3.1.7        units_0.8-0
## [81] cluster_2.1.3       ellipsis_0.3.2
```

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