**LIFE 14ENV/IT/000414**
**Demonstrating Remote Sensing integration in sustainable forest management**
**FRESh Life**

**ACTION B3**

**Mapping SFM indicators**

**Report on the technical and economic viability of using very high spatial resolution optical data for mapping forest health and tree species related SFM indicators at the forest compartment level**

Viterbo, 30/04/2017

# Summary

## 1. Goals

University of Tuscia is the Beneficiary responsible for implementation of Action B3 - Mapping SFM indicators.

The goals of the Action B3 are to test and evaluate methods coupling remote sensed information collected from RPAS with plot-level data to derive:

- maps of Forest Europe SFM indicators: "Defoliation (# 2.3)", "Forest damage (# 2.4)", "Number of tree species (# 4.1)" and "Area covered by introduced tree species (# 4.4)"

This report examines the technical and economic findings on viability of very high spatial resolution optical imagery taken from the RGB camera equipped on eBee (SenseFly) drone, in the framework of B2 Action, for mapping SFM indicators (Defoliation, Forest damage, Number of tree species and Area covered by introduced tree species) in the pilot study areas of Caprarola, Pennataro and Rincine.

## 2. Milestones and Deliverables

The B3's Project Milestone is

| *Milestone name* | *Deadline* |
|---|---|
| Report on the technical and economic viability of coupling remote sensed information, collected from RPAS, with plot-level data to map selected Forest Europe SFM indicators at operational scale | 09/2017 |

The B3's Project Deliverable Products are

| *Deliverable name* | *Deadline* |
|---|---|
| Maps of European Forest Types for the pilot study areas | 12/2016 |
| Report on the technical and economic viability of using high spatial resolution optical data to stratify by European Forest Types (EFTs) medium- to large size forest management units | 2/2017 |
| Maps of SFM indicators "Defoliation (# 2.3)", "Forest damage (# 2.4)", "Number of tree species (# 4.1)" and "Area covered by introduced tree species (# 4.4)" for the pilot study areas | 3/2017 |
| Report on the technical and economic viability of using very high spatial resolution optical data for mapping forest health and tree species related SFM indicators at the forest compartment level | 4/2017 |
| Maps of SFM indicators: "Growing stock (# 1.3)" and "Above ground biomass (# 1.4)" for the pilot study areas | 6/2017 |
| Report on the technical and economic viability of using geostatistical methods and techniques for the spatial estimation of growing stock and above ground biomass, at the forest compartment level | 7/2017 |

## 3. Technical viability of mapping of forest health and tree species- related Forest Europe SFM indicators

### 3.1 Defoliation (indicator # 2.3)

Defoliation is an indicator of tree performance or health. Forest Europe definition of SFM indicator 2.3 is «Defoliation of one or more main tree species on forest and other wooded land in each of the defoliation classes "moderate", "severe" and "dead"». The indicator is a valuable early-warning sign for the response of forest trees to environmental pressures, which can be either anthropogenic or natural.

Individual tree defoliation is usually monitored by field visual assessment of crown condition. Fully foliated trees are rated with 0%, while a defoliation level of 100% indicates dead trees.

In the FREShLIFE Action B2 tree crown defoliation was one of the parameters collected during field sampling. The needle/leaf loss of a tree was compared to a reference (healthy) tree. Defoliation was assessed in 5% steps up to a maximum of 99% for all living trees. Dead trees (totally defoliated) were also inventoried. The relative frequency of defoliation classes observed in the study areas is shown in Figure 1. Based on field data, the number of dead trees per hectare for each forest compartment has been also calculated (Figure 2).

In order to map defoliation levels in the project test sites from drone imagery, we preliminarily verified whether what level of defoliation can be detected from the true color eBee orthomosaic. Crown defoliation was clearly detectable only on standing trees in the upper layer with over 70% of leaf or needle loss. Accordingly, the visual image interpretation of the RGB orthomosaic was targeted to mapping high levels of defoliation and standing dead trees. We digitized all polygons of partially (more than 70% of leaf and needle loss, defoliation class 1) and totally (100% of leaf and needle loss, defoliation class 2) defoliated crowns. The minimum mapping unit for defoliation classes was set $\geq 3\ m^2$. This threshold was selected according to the minimum surface of totally defoliated crown distinguishable on the orthomosaic.

Accordingly, maps of the defoliation were produced at the forest compartment level for the pilot study areas (Annex 1, figures 3-5). At this level, the highest class of defoliation density mapped is below 1 tree $ha^{-1}$ in Caprarola and Pennataro and can reach nearly 7 trees $ha^{-1}$ in Rincine.

Our findings show that the proportion of dead trees surveyed by field inventory is about 1-2% of the total forest trees in each study area a value significantly higher than defoliation levels mapped by remote sensing.

An explanation for this discrepancy is that the most of dead trees do not reach to the upper canopy layer: in fact the percentage of standing dead trees with height higher than average height of the stand is 3,5% in Pennataro, 7% in Caprarola and 9% in Rincine. This would explain why most of the dead trees are not detectable by visual image interpretation.

Fig. 1. Distribution of trees by defoliation classes in the three study areas, according to fied survey.

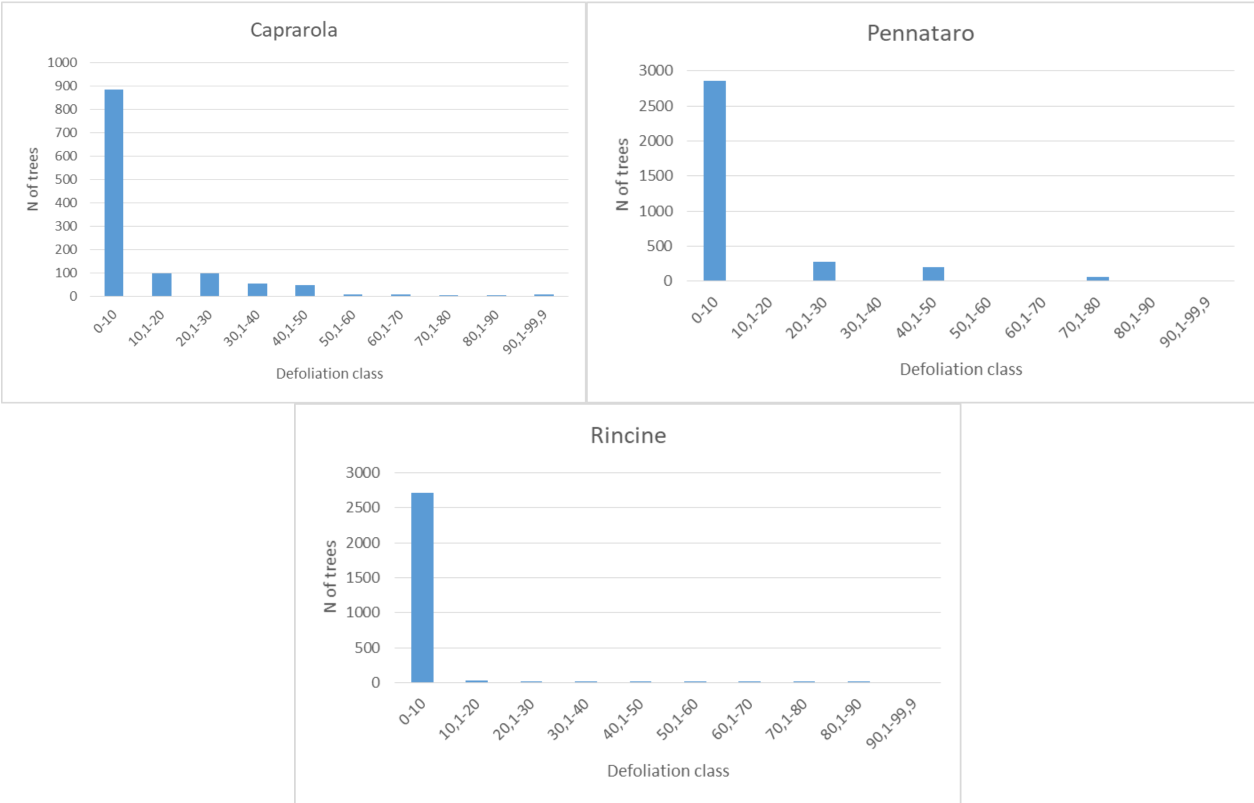
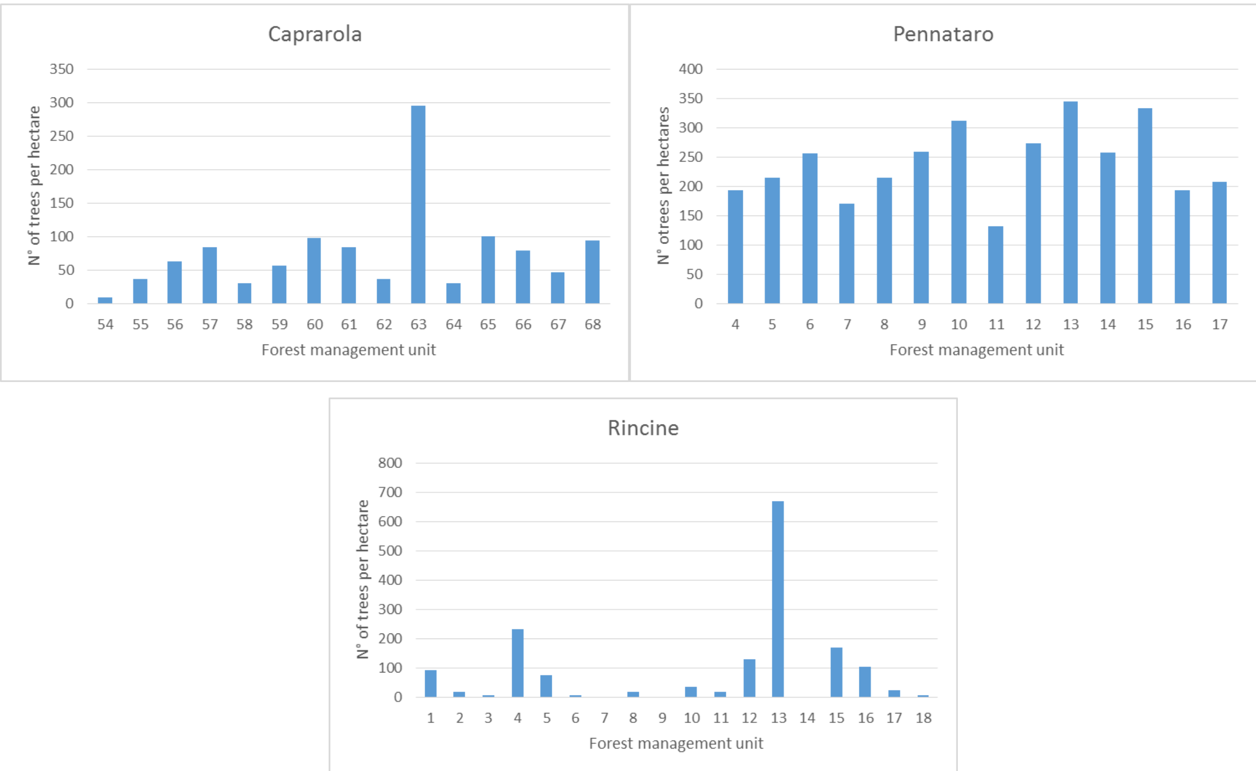



Fig. 2. Density (N/ha) of dead trees by forest management units of the three study areas.



## 3.2 Forest damage (indicator # 2.4)

Forest Europe definition of SFM indicator 2.4 is «Forest and other wooded land with damage, classified by primary damaging agent (abiotic, biotic and human induced) ». Indicator 2.4 refers to the forest area damaged by abiotic (wildfires, storms, avalanches, etc) or biotic disturbances (e.g. insects and diseases). In the project pilot study areas, forest damage occurred recently in Rincine case study only, due to a windstorm hiting the area in March 2015. The map of forest damage indicator for Rincine was derived by visual interpretation of true color orthomosaics (ground resolution 10 cm/pixel), with a minimum mapping unit 0,25 ha. The total forest area affected by wind damage in Rincine amounts to only 3 ha (Annex 1, Figure 7). This indicator was not surveyed on the field, as any of the randomly selected 50 plots in Rincine were established in damage-affected areas.

## 3.3 Tree species composition (indicator # 4.1)

Forest Europe definition of SFM indicator 4.1 is «Area of forest and other wooded land classified by number of tree species occurring». The indicator is intended to monitor the area of forest that consists of one tree species alone or several tree species. The number of tree species indicator has been quantified based on field plot dbh measurements, by calculating the number of tree species exceeding the 5% of total plot basal area.

There are of course some technical limitations to map the actual number of tree species in a given forest area from a classification of the eBee orthomosaic, due to the following reasons:

- some tree species are found only in the understory and do not reach the upper canopy layer;
- previous findings from the European Forest Types mapping activity (cf. Deliverable B3 Maps of European Forest Types) proved that the spectral and spatial resolution of the eBee orthomosaic allows to feasibly distinguish by visual interpretation only the dominant tree species covering a given tract of forest land. In this regard, the visual classification proved to be more accurate than semi-automatic classification for forest cover typing (cf. Report on the technical and economic viability of using high resolution optical data to stratify by European Forest Types (EFTs) medium-to large size forest compartments).

Considering these limitations, mapping the number of tree species occurring within a given forest compartment can be feasibly performed using the number of EFTs as a proxy (conservative estimate) of the number of tree species. Accordingly, the range of variability in the number of tree species occurring at the forest compartment level varies between 1 and 3 in Caprarola and Pennataro (Annex 1, Figures 8 and 9), and can reach 5 tree species in Rincine (Annex 1, Figure 10).

In Caprarola, at the forest compartment level, the results when using the number of EFTs as a proxy of the number of tree species are similar to those obtained by field surveys (Figure 8).

In Pennataro, the number of tree species occuring at the forest compartment level assessed by EFTs is underestimated, except for the management unit n. 4 (Figure 9).

In Rincine, the classification derived by eBee images, compared with field data, underestimates the indicator in almost the 50% of the forest compartment. On the other hand, overestimation is observed in only two forest management units (the more heterogeneous in terms of mapped EFTs).

### 3.4 Area covered by introduced tree species (indicator # 4.4)

Forest Europe definition of SFM indicator 4.4 is «Area of forest and other wooded land dominated by introduced tree species». Introduced tree species are tree species occurring outside their natural vegetation zone, area or regions (also known as exotic or alien species). These areas are mapped under the class *14 Introduced tree species forest* of the EFTs. In our case studies, forest areas covered by introduced tree species are found in Rincine case study only (Figures 11-12). These areas cover about the 25% of the pilot study area (70 ha ca) and are represented by reforestations with Douglas fir (*Pseudotsuga menziesii*) or other introduced conifers (e.g. *Chamaecyparis lawsoniana*). The minimum mapping unit for this indicator is the same as for EFTs maps (0,5 ha). The map of the indicator obtained by visual interpretation was compared with the ground data surveyed in the sample plots. The EFT was assigned to each of the 50 plots identifying the dominant species based on the relative basal area proportion out of total plot. The User and Producer accuracy for the EFT #14 is 95% (Table 1).

Table 1. User and Producer accuracy for the EFT classification by visual interpretation in the study area of Rincine.

| | Producer accuracy | User accuracy |
|---|---|---|
| 7.3 Apennine Corsican mountainous beech forest | 1,00 | 1,00 |
| 8.2 Turkey oak, Hungarian oak and Sessile oak forest | 1,00 | 1,00 |
| 8.7 Chestnut forest | 1,00 | 1,00 |
| 8.8 Other termophilous deciduous forest | 0,60 | 1,00 |
| 10.2 Mediterranean and Anatolian Black pine forest | 1,00 | 0,85 |
| 14 Introduced tree species forest | 0,95 | 0,95 |

## 4. Final technical remarks on viability of mapping tree-related SFM indicators

- "Defoliation" is not a frequent phenomenon in the FREShLIFE pilot study areas. Moreover, defoliation is only detectable on standing dead trees or trees with severe crown defoliation (over 70% foliage loss) that are part of the dominant layer. The latter represents only a small part of the standing dead trees within our study areas, since most of them are found in the dominated layer.
- "Forest damage" and "Area covered by introduced tree species" indicators were mapped in Rincine only, because were absent in the other two study areas. Reliable maps were obtained by visual interpretation. This technique is much faster than mapping the indicators using field surveys.
- "Number of species" is an indicator beyond semi-automatic classification capabilities, due to serious difficulty in distinguishing species at single tree level, as a consequence of flaws of the images (shadows, balance of colours) and the large intraspecific variability of the colour tone.

## 5. Economic viability considerations: time and costs to process indicators maps vs field survey data collection

A quantification of the time required to produce the maps of Forest Europe SFM indicators: "Defoliation (# 2.3)", "Forest damage (# 2.4)", "Number of tree species (# 4.1)" and "Area covered by introduced tree species (# 4.4)" is reported in Table 2. This time is compared to the time spent for field data collection in the 50 sample plots for the same indicators, as recorded in the specific data collection sheet.

Table 2. A quantification of the time required to produce the maps of Forest Europe SFM indicators in the pilot study areas.

| | *Time required for visual interpretation of drone imagery* | *Time spent by field data acquisition* |
|---|---|---|
| Defoliation (# 2.3) | 5-15h | 135-289h |
| Forest damage (# 2.4) | 2h | - |
| Tree species composition (# 4.1) | 8-10 h | 135-289h |
| Area covered by introduced tree species (# 4.4) | 5h | 135h |

An evaluation of costs of eBee derived maps is shown in Tables 3-5, based on the steps (Ebee data acquisition, Orthomosaic, Mapping) required to accomplish the mapping of these four SFM indicators (Defoliation, Forest damage, Number of tree species and Area covered by introduced tree species). The total cost of mapping SFM indicators is the sum of the costs of these three steps (Table 6).

The hourly rate of a Technician for Ebee data processing and Junior technician for mapping SFM indicators are based on market prices (60 €/hour, 40 €/hour, respectively).

Based on cost analysis in the three test sites, the total cost of SFM indicators maps at the forest compartment level by remote sensing is largely influenced by the cost of Ebee data acquisition rather than the labour cost of visual interpretation of drone images.

Overall, the economic feasibility of using eBee images to map SFM indicators is demonstrated by a total cost for mapping these SFM indicators much lower (4770-5250 €) than costs for field surveys (Table 7). These costs are calculated using the same sampling intensity used in the project (1 plot of 529 $m^2$ every 5 ha) and the hourly rate of an experienced professional as result of market prices (40 €/hour).

More importantly, it must be noticed that these two approaches cannot be compared as plot-level information on these SFM indicators is provided only for a very small fraction of the test areas (about 1% of 250 ha).

Table 3. Costs of EBee data acquisition, in the three test sites.

| *Test site* | *EBee data acquisition* | | | | | | |
|---|---|---|---|---|---|---|---|
| | *Ground control point (12) Technician cost* | *Time* | *Total 1* | *RGB data* | *Area* | *Total 2* | *TOTAL (1+2)* |
| | €/hour | hours | € | €/hour | ha | € | € |
| Rincine | 40 | 8 | 320 | 13 | 250 | 3250 | 3570 |
| Caprarola | 40 | 8 | 320 | 13 | 250 | 3250 | 3570 |
| Bosco Pennataro | 40 | 8 | 320 | 13 | 250 | 3250 | 3570 |

Table 4. Costs of Orthomosaic, in the three test sites.

| *Test site* | *Orthomosaic* | | |
|---|---|---|---|
| | *Technician cost* | *Time* | *TOTAL* |
| | €/hour | hours | € |
| Rincine | 60 | 10 | 600 |
| Caprarola | 60 | 10 | 600 |
| Bosco Pennataro | 60 | 10 | 600 |

Table 5. Costs of mapping Forest Europe SFM indicators.

| | *Test site* | *Mapping* | | |
|---|---|---|---|---|
| | | *Technician cost* | *Time* | *TOTAL* |
| | | €/hour | hours | € |
| *Number of tree species (# 4.1), Area covered by introduced tree species (# 4.4)* | Rincine | 40 | 10 | 400 |
| | Caprarola | 40 | 8 | 320 |
| | Bosco Pennataro | 40 | 8 | 320 |
| *Defoliation (# 2.3)* | | 40 | 5-15 | 200-600 |
| *Forest damage (# 2.4)* | Rincine | 40 | 2 | 80 |

Table 6. Total costs of eBee derived Forest Europe SFM indicators maps (for SFM # 2.3 the highest cost value was used).

| *Number of tree species (# 4.1), Area covered by introduced tree* | *Test site* | *EBee data acquisition* | *Orthomosaic* | *Mapping* | ***TOTAL COST*** | |
|---|---|---|---|---|---|---|
| | | € | € | € | € | €/ha |

| | | | | | | |
|---|---|---|---|---|---|---|
| *species (# 4.4)*<br>*Defoliation (# 2.3)*<br>*Forest damage (# 2.4)* | Rincine | 3570 | 600 | 400+600+80 | 5250 | 21 |
| | Caprarola | 3570 | 600 | 320+600 | 4770 | 19 |
| | Bosco Pennataro | 3570 | 600 | 320+600 | 4770 | 19 |

Table 7. Total cost of field data collection in forest inventory plots.

| *Plots* | *Time Plot* | *Cost* | *Total cost* |
|---|---|---|---|
| Number | Hours | €/hours | € |
| 50 | 9 | 40 | 18000 |

**Annex 1 – SFM Indicators Maps**

Figure 3. Maps of density of defoliated trees within each forest compartment in the study area of Caprarola. Threshold values were determined according to quantiles.

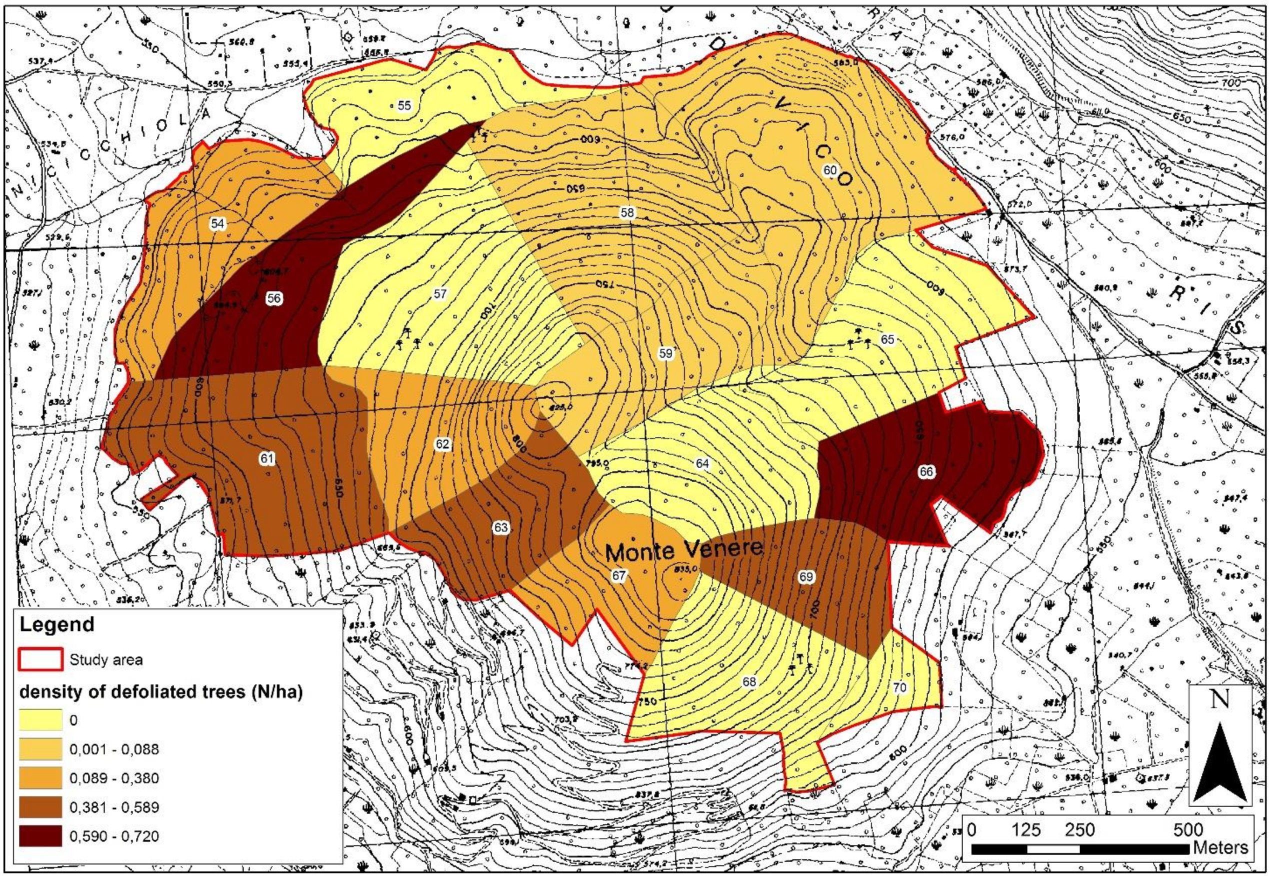


Figure 4. Maps of density of defoliated trees within each forest compartment in the study area of Pennataro. Threshold values were determined according to quantiles.

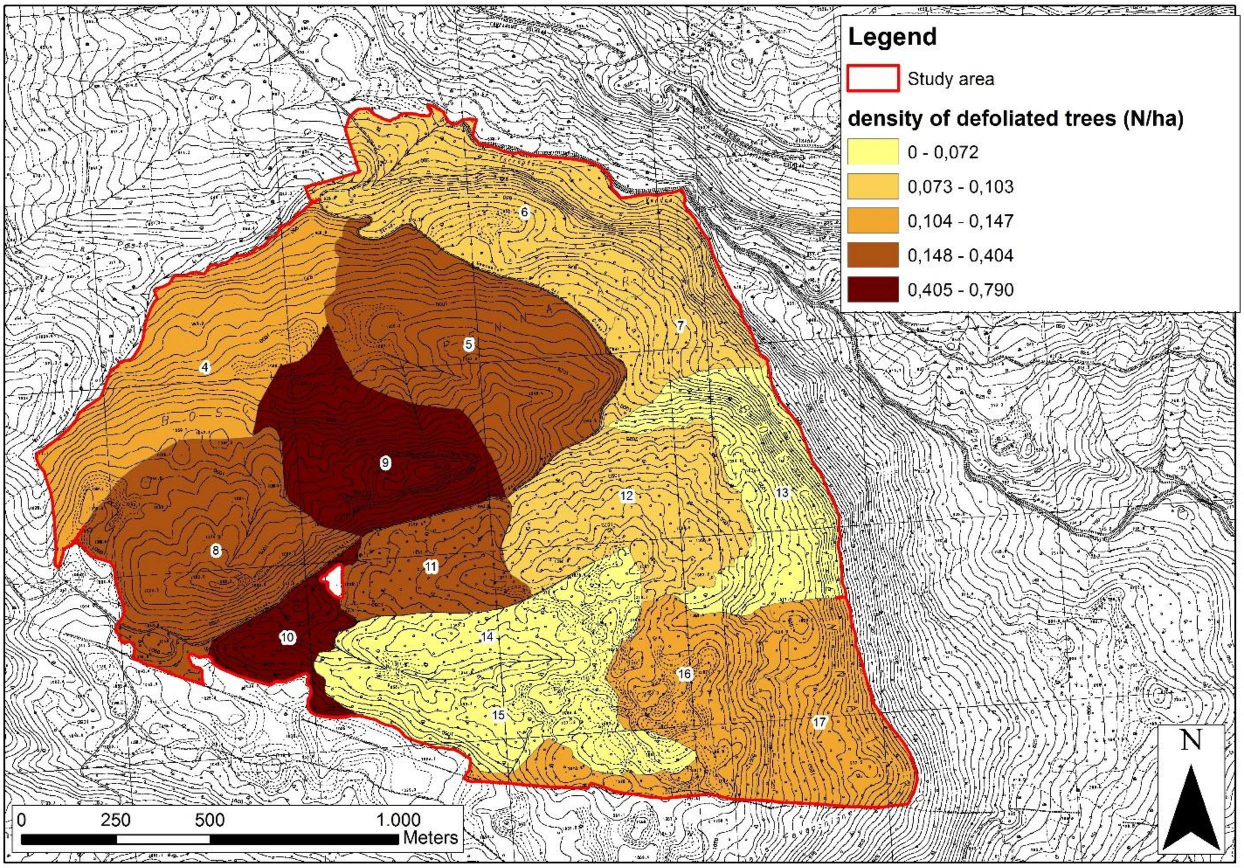


Figure 5. Maps of density of defoliated trees within each forest compartment in the study area of Rincine. Threshold values were determined according to quantiles.

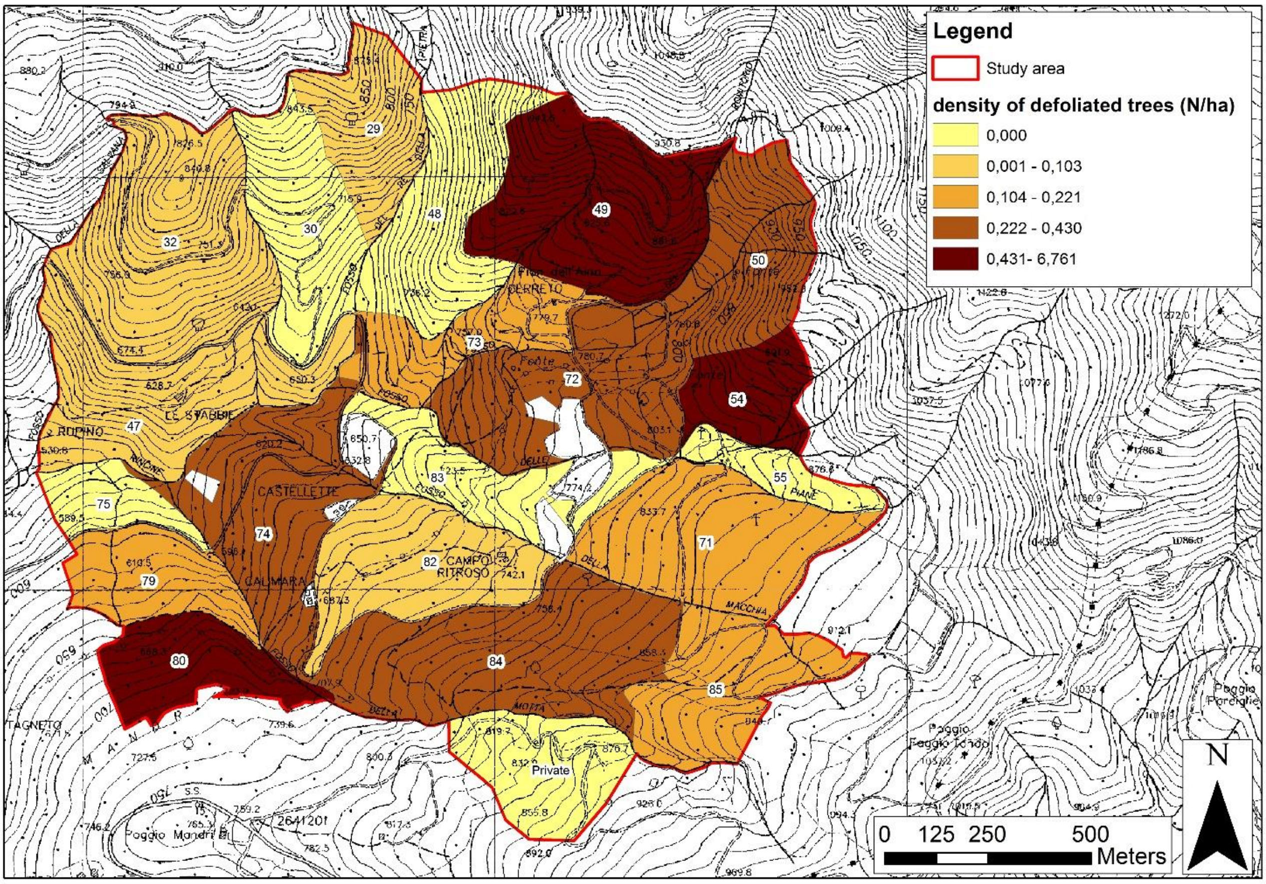


Figure 6. Map of forest damage in the study area of Rincine displayed on high-resolution image acquired by eBEE.

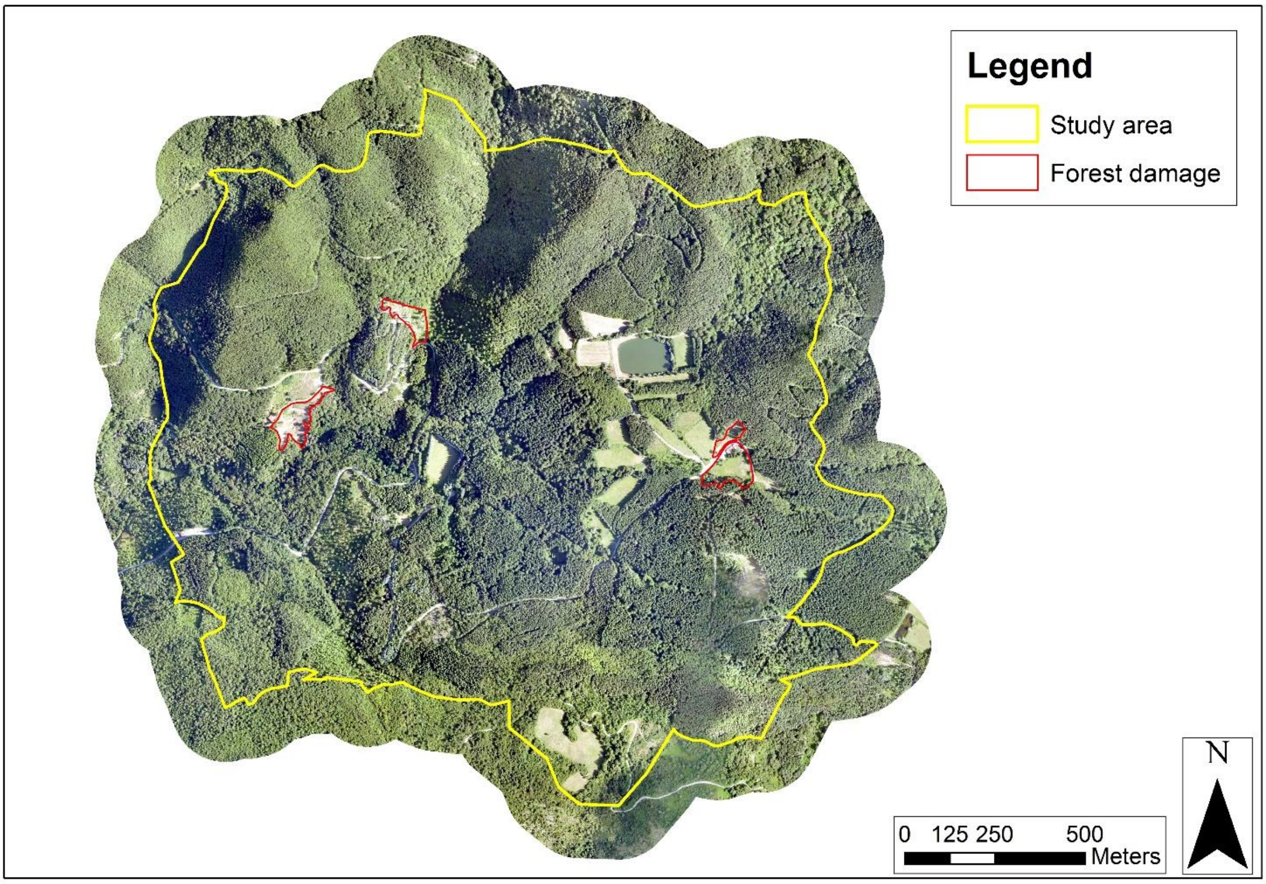


Figure 7. Map of forest damage in the study area of Rincine.

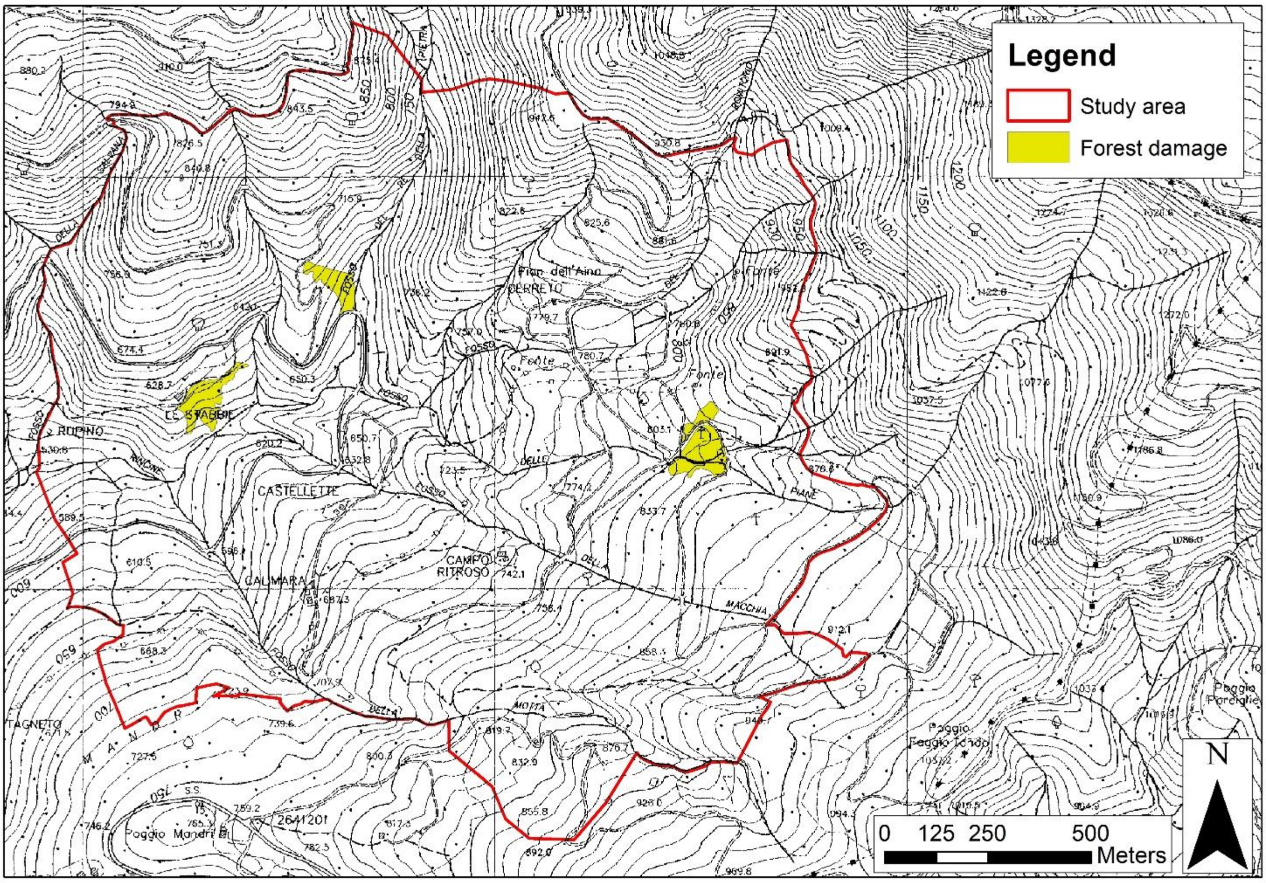


Figure 8. Map of the indicator “Tree species composition” (# 4.1) measured in the field plots and expressed in terms of number of EFTs within each forest compartment in the study area of Caprarola.

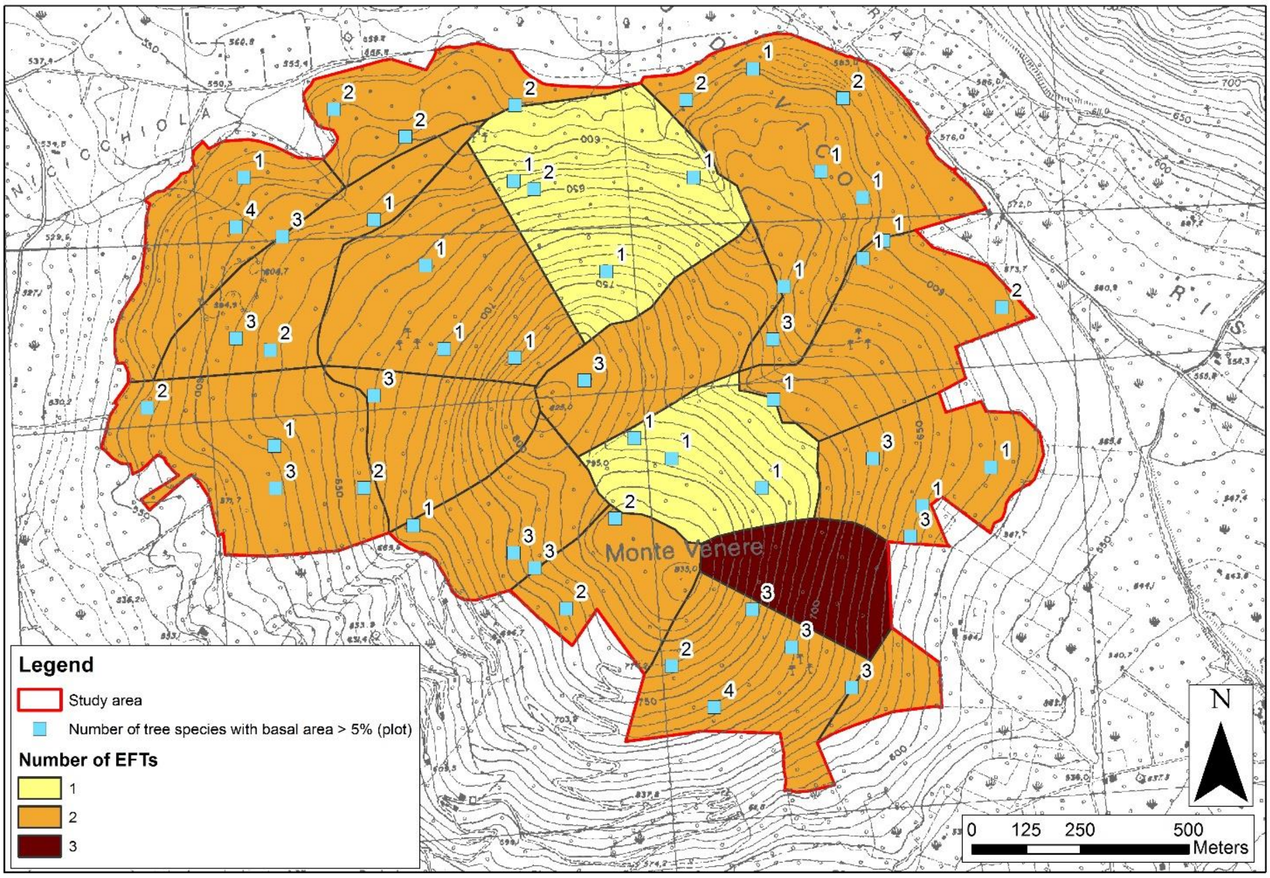


Figure 9. Map of the indicator "Tree species composition" (# 4.1) measured in the field plots and expressed in terms of number of EFTs within each forest compartment in the study area of Pennataro.

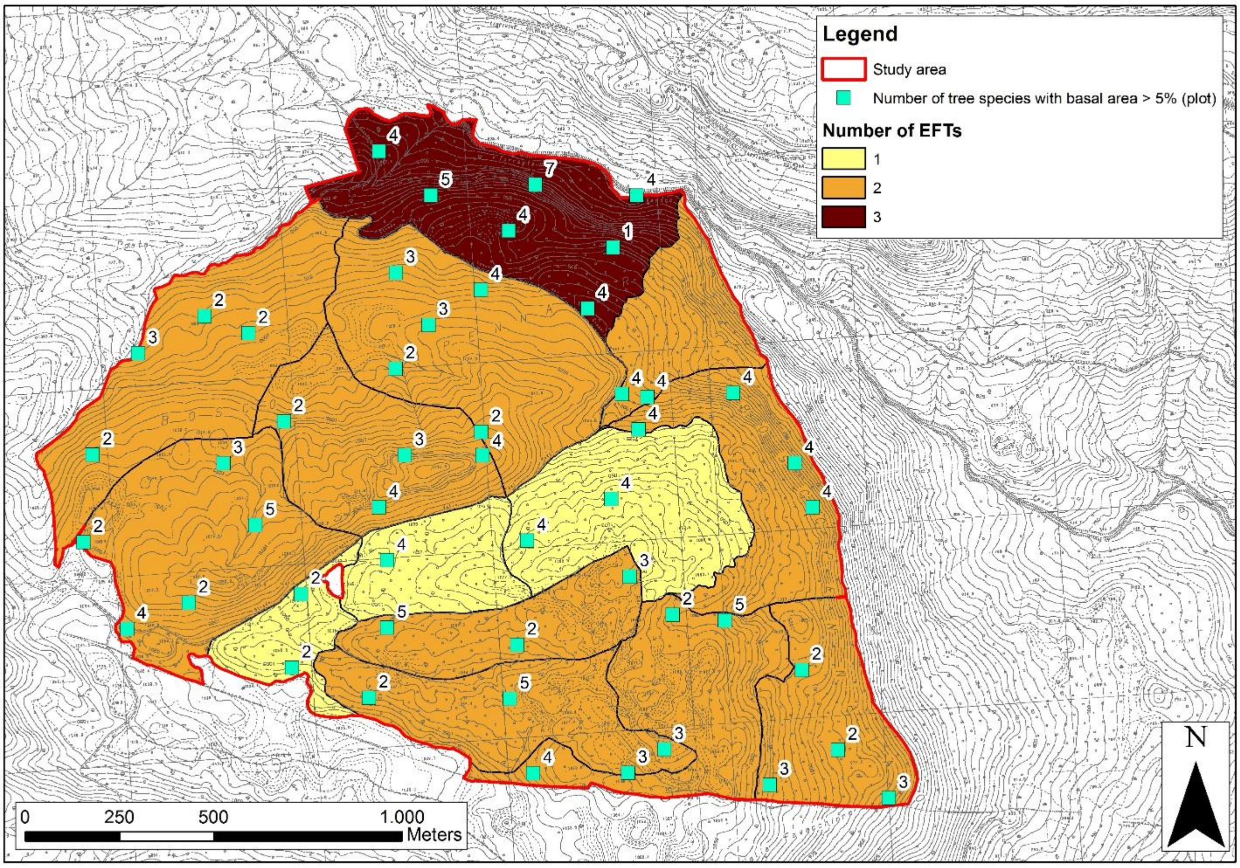


Figure 10. Map of the indicator "Tree species composition" (# 4.1) measured in the field plots and expressed in terms of number of EFTs within each forest compartment in the study area of Rincine.

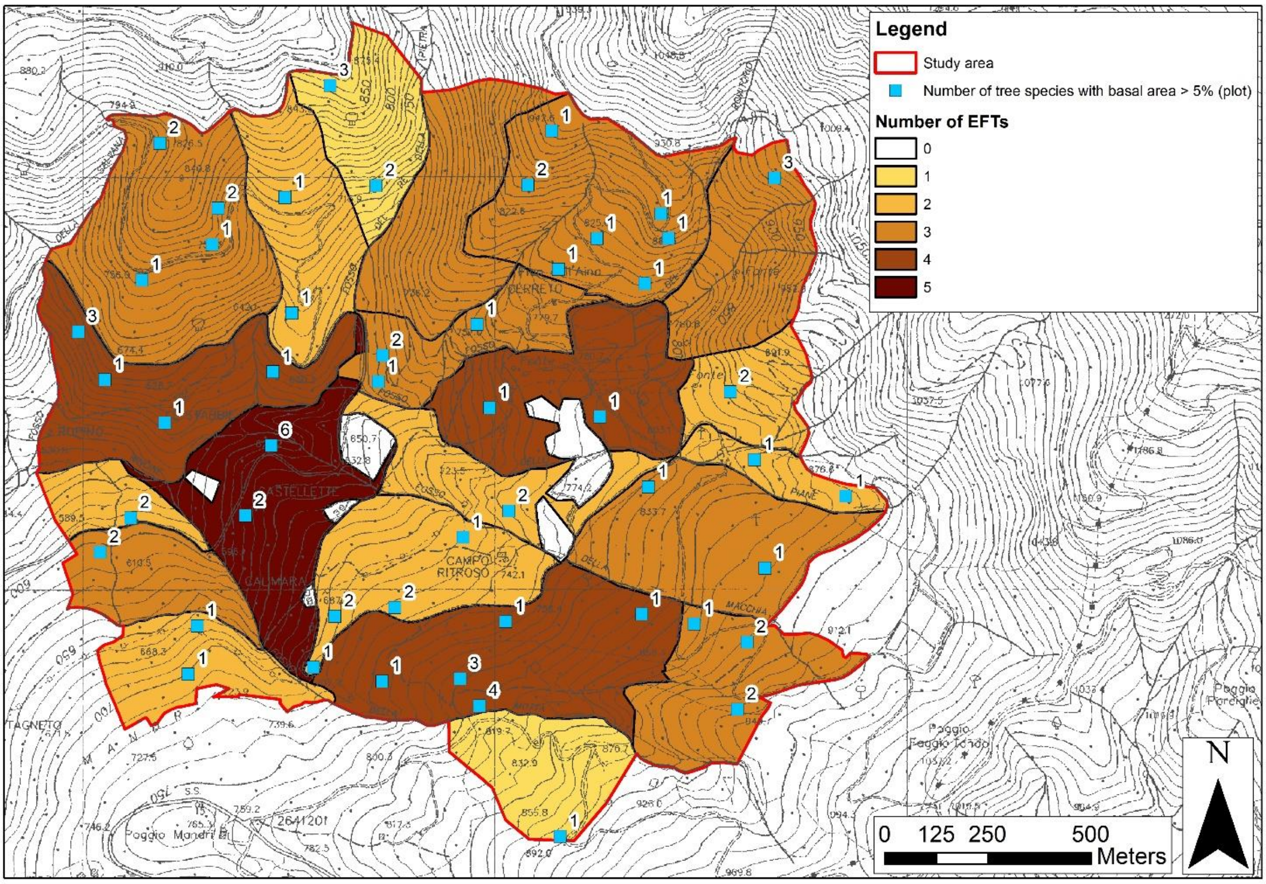


Figure 11. Map of "introduced tree species" in the study area of Rincine displayed on high-resolution image acquired by eBEE.

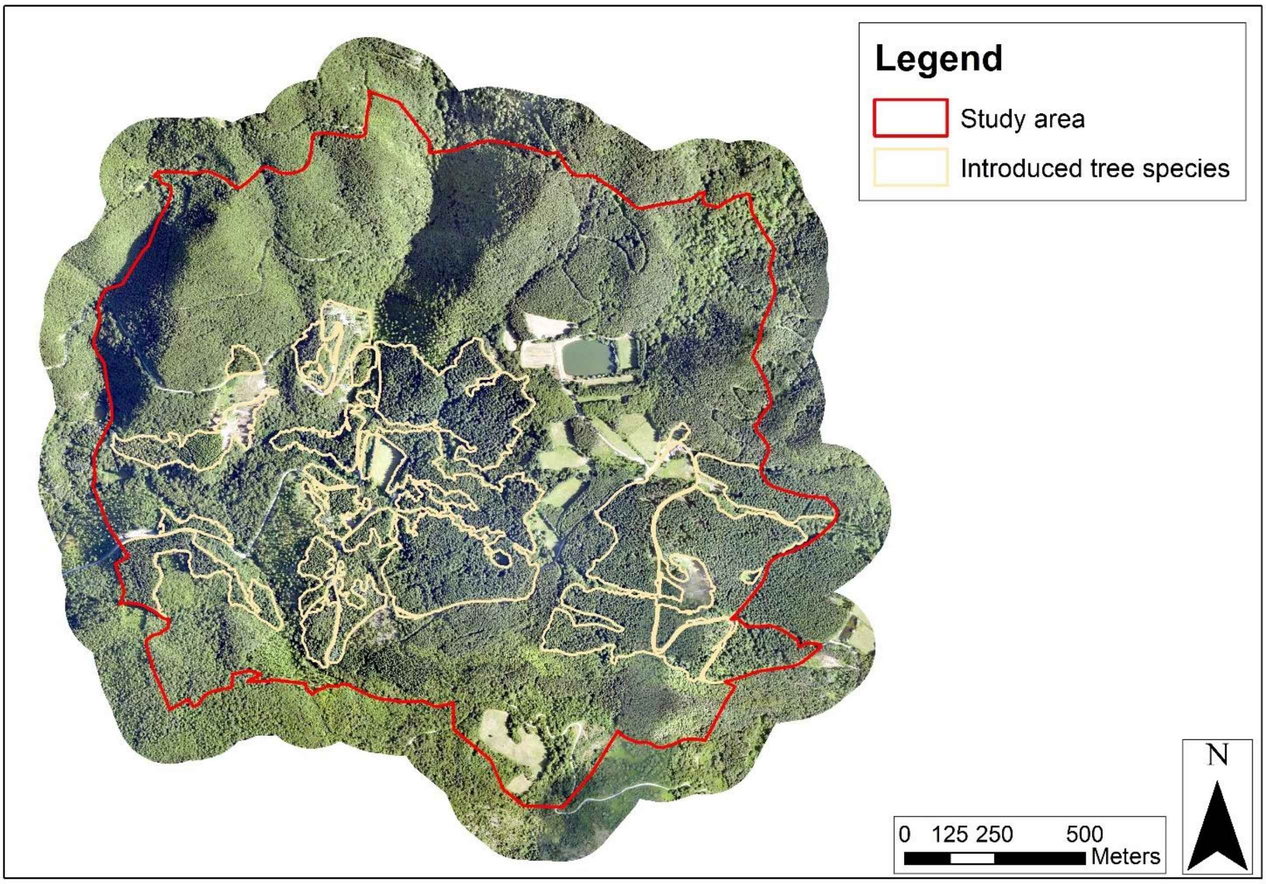


Figure 12. Map of “introduced tree species” in the study area of Rincine.