SAMFIX
SAving Mediterranean Forests from Invasions of Xylosandrus beetles and associated pathogenic fungi
www.lifesamfix.eu

# Deliverable: Report on best practices for the integration of remote sensing and GIS spatial analysis into invasive species control and monitoring tools

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## SUMMARY

In this Deliverable we report on the best practices based on the integration of remote sensing and GIS tools to monitor and control the *Xylosandrus* invasive species, according to the findings from the different study areas in the LIFE SAMFIX project. In this Deliverable we argue on what emerged from the previous milestones, we attempt the expansion of the risk maps already elaborated to the project replication areas, and we present the results obtained with the use of very high resolution imagery purchased in the study site. The findings allowed to derive useful indications also to plan future project activities.

In both Circeo and El Tello, the collected data suggest a decrease of *Xylosandrus* presence, according to trap and survey data. *X. crassiusculus* was mostly replaced by *X. germanus* in Italy. The *crassiusculus* species showed a decrease in Spain area too, where the invasion remain confined in a small portion of the study area. For France, this data were impossible to assess because of the considerable differences between 2019 and 2020 trapping seasons.

The field methods and protocols adopted in the different areas are well design and suited to monitor *Xylosandrus* detection. The comparison of 2019 and 2020 data indicate as important both the setup of traps in the same location each year, and to carry out surveys for additional data collection in large areas such as Circeo NP.

According to the data, no clear association of *Xylosandrus* with vegetation types was detected, but certain types, like coastal dunes, are avoided, possibly due to winds and less palatable vegetation species. In replication areas, the forests showed more occurrence of positive traps than other vegetation types, possibly indicating that this type might be the first entrance point for an invasion, that subsequently can expand in other land cover classes.

Overall the risk maps indicate a reduction in the risk of *Xylosandrus* expansion and presence. The methodology was successfully applied also in replication areas, where limited invasion presence was found. Special attention has to be devoted to islands, where the damages from invasion could imply additional issues.

Remote sensing analyses, as reported in previous reports, showed to be useful when the invasion reaches a high level, and the *Xylosandrus* species attack the upper canopy level. With moderate and low invasions, the *Xylosandrus* species might be present in lower canopy layer, where the satellite data cannot penetrate. The spatial resolution of

imagery can also have an impact, as free Sentinel 2 data are mostly useful in large areas, such as the French coast or the Circeo NP.

The use of very high resolution imagery, specifically purchased for the project, was not of help in Circeo NP or El Tello, again because of moderate-low invasion levels. The insect attacks mainly low branches leaving the upper crown level and the overall plant in healthy status. The vegetation resulted in health and not too much affected by *Xylosandrus* presence. However, in El Tello when entire trees are attacked and dried up, the very high resolution allow to detect other trees in similar conditions in the surroundings of the affected individuals, thus becoming a fast method to detect the spreading of the invasion. Furthermore, a difference in the vegetation indices computed from healthy and infected vegetation might emerge, allowing to use very high resolution imagery to detect new areas of *Xylosandrus* invasion. Overall, the very high resolution imagery acquisition is suggested when the area to be analyzed is limited, and analysis at single tree level cannot be performed.

## 1. MAIN AIM

We report here on the best practices based on the integration of remote sensing and GIS tool to monitor and control the *Xylosandrus* invasive species, according to the findings from the different study areas in the LIFE SAMFIX project. In this deliverable we argue on what emerged from the previous milestones, we attempt the expansion of the risk maps already elaborated to the project replication areas, and we present the results obtained with the use of very high resolution imagery purchased in the study sites. The findings allow to derive useful indications also to plan future project activities.



## 2. CONSIDERATIONS FROM PREVIOUS ANALYSIS

### Circeo National Park (Italy)

Compared to 2019, in 2020 the trapping effort increased consistently, moving from 36 to 125 records available in the latter year. The survey efforts (no trap data) were similar in both year. The rate of positive trap records at genus level was 78% in 2019 and 45% in 2020, showing a relevant decrease. Only 4 *X. crassiusculus* species were detected in 2020, suggesting minimal occurrence of this species in 2020. Most of the occurrence of *Xylosandrus* was recorded in forest and maquis vegetation types, with absence of positive records along the coastal dunes. According to traps and survey data, the *X. compactus* species showed numerical reduction, while an increase in *X. germanus* occurred.

The 2020 data collection was carried out in different locations from 2019, and this implies that it is not possible to compare the rate of change in *Xylosandrus* presence in land cover classes.

It is recommended to conduct the next traps and surveys in the same 2020 locations, to allow the evaluation of changes at vegetation type level. Considering the multiple vegetation types and the extent of this area, the survey data collection is considered a fundamental tool, in addition to traps that have the advantage of allowing the detection of single species. Both efforts resulted very important to derive useful indications.

### El Tello (Spain)

With respect to 2019, in El Tello a massive campaign with additional traps was carried out in 2020. To derive indications we consider data without these extra records, that were collected in same 2019 locations. The graph below, elaborated assigning a positive score independently from the number of times the trap was revisited indicates a strong reduction of the higher risk class in 2020, with an increase of no risk areas. 4

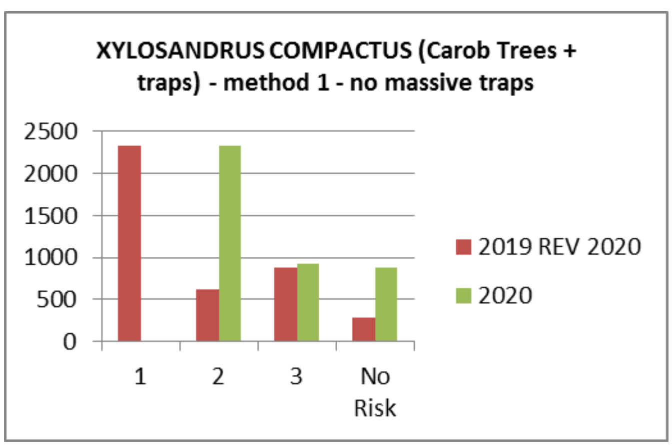



Figure 1: variation of the risk area not considering the number of times the traps were revised

Instead, if the revisits are considered, assigning a positive value every time the *Xylosandrus* is observed in the same trap, the reduction of areas at higher invasion risk is lower, but the increase in no risk areas is also present.

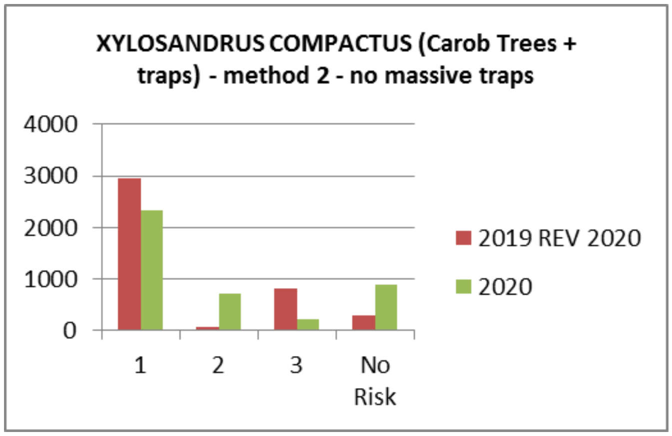



Figure 2: variation of the risk area observed considering the number of times the traps were revised

Overall, there are signs that indicate a reduction in the *X. compactus* presence in the study area, that are to be confirmed by next campaigns. The data also suggest that the invasion is prevalently occurring in the south-eastern portion of the study area, and in areas associated to old carob trees plantations. The methods adopted in this area seem appropriate to monitor *Xylosandrus* invasion and could be adopted for additional areas where the species has been recorded.



**Antibes, Ile Ste Marguerite and Nice Côte d'Azur (France)**

Due to the difficulty in comparing 2019 to 2020 data, caused by the strong Covid-related limitations in field work for France and the consequent absence of data from the 2020 *Xylosandrus* spp. flying season, it was impossible to derive any best practices on the appropriate methods to monitor *Xylosandrus* invasion.

In 2020 an increase in the number of land cover class type invaded by *Xylosandrus* spp. was registered, but this could be due to increased sampling effort, as other areas were sampled with respect to 2019. In fact, there is no evidence of an increase of *Xylosandrus* spp. presence along the coast from 2019 to 2020 if considering the rate of *Xylosandrus* presence (positive traps/all traps). Additional data from 2021 are needed to derive more indications for France, but it is recommended for next campaigns to replicate the same traps locations and surveys efforts carried out in 2020, to allow comparisons in invasion levels and in land cover classes impacted. In 2020, out of 52 traps *X. crassiusculus* was present in 27 traps (0.52%), *X. compactus* in 23 (0.44%), and *X. germanus* in 18 (0.35%), all rates very similar to those of the previous year. Due to the difference in the 2019 and 2020 trapping season, it was impossible to elaborate risk maps and related statistics as done for Italy and Spain, only the statistics above can be reported.

## 3. RISK MAPS EXTENDED TO REPLICATION AREAS

### Italy

The figure below illustrates the distribution of the replication areas, more than what initially planned for Italy:

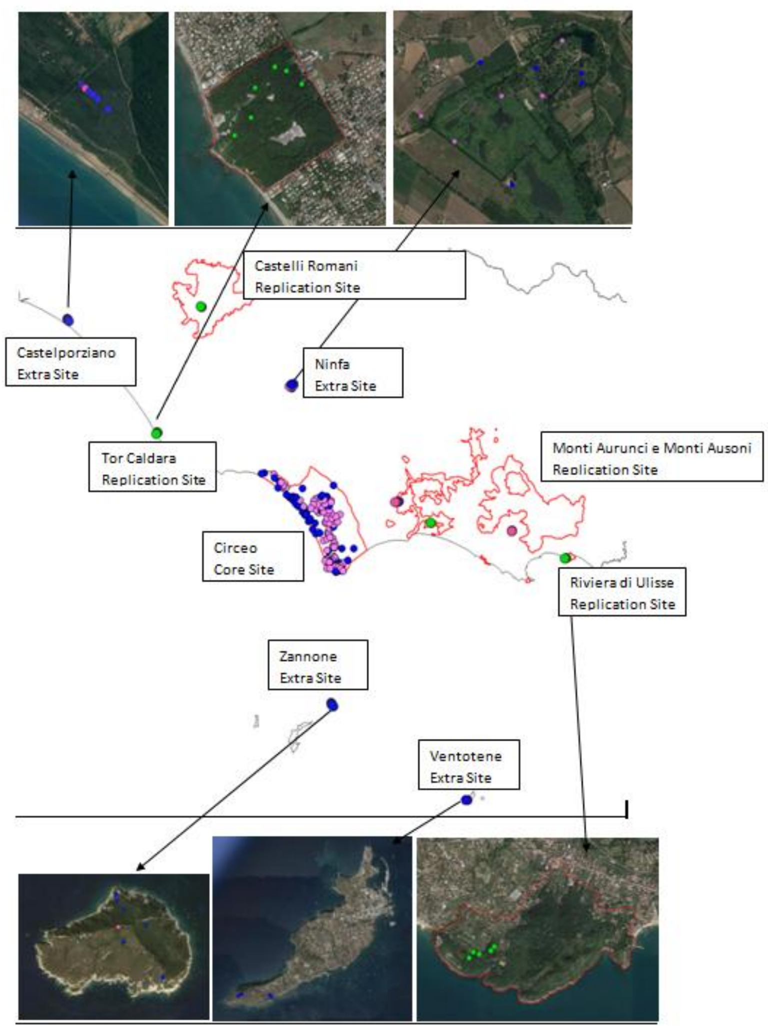



Figure 3: Replication areas in Lazio Region

However, due to COVID restrictions not in all areas it was possible to properly collect samples or analyse data from traps. Thus, in Castelli Romani, Tor Caldara, and Riviera di Ulisse, traps were installed but the samples were not properly collected/analysed. In the Ventotene island areas the traps were installed and controlled, and no *Xylosandrus* were detected. For all the above areas, the expansion of the risks maps was not possible. For the following areas, the risk maps and related statistics and images were elaborated: Aurunci e Ausoni (joined areas due to proximity), Castelporziano, Ninfa, Zannone.

Below, traps and rates of positive records are reported for the different replication areas:

**Table 1: positive traps and rate in Natural Parks of Monti Aurunci and Ausoni (joined data)**

| | # Traps Tot | # positive Traps | RATE |
|---|---|---|---|
| XYLOSANDRUS GENUS | 12 | 7 | 58.33% |
| XYLOSANDRUS COMPACTUS | 12 | 3 | 25.00% |
| XYLOSANDRUS CRASSIUSCULUS | 12 | 2 | 16.67% |
| XYLOSANDRUS GERMANUS | 12 | 6 | 50.00% |

**Table 2: positive traps and rate in Natural Park of Monti Aurunci**

| | # Traps Tot | # positive Traps | RATE |
|---|---|---|---|
| XYLOSANDRUS GENUS | 6 | 5 | 83.33% |
| XYLOSANDRUS COMPACTUS | 6 | 1 | 16.67% |
| XYLOSANDRUS CRASSIUSCULUS | 6 | 2 | 33.33% |
| XYLOSANDRUS GERMANUS | 6 | 4 | 66.67% |



**Table 3: positive traps and rate in Natural Park of Monti Ausoni**

| | # Traps Tot | # positive Traps | RATE |
|---|---|---|---|
| XYLOSANDRUS GENUS | 6 | 2 | 33.33% |
| XYLOSANDRUS COMPACTUS | 6 | 2 | 33.33% |
| XYLOSANDRUS CRASSIUSCULUS | 6 | 0 | 0.00% |
| XYLOSANDRUS GERMANUS | 6 | 2 | 33.33% |

**Table 4: positive traps and rate in State Reserve of Castelporziano**

| | # Traps Tot | # positive Traps | RATE |
|---|---|---|---|
| XYLOSANDRUS GENUS | 2 | 1 | 50.00% |
| XYLOSANDRUS COMPACTUS | 2 | 0 | 0.00% |
| XYLOSANDRUS CRASSIUSCULUS | 2 | 0 | 0.00% |
| XYLOSANDRUS GERMANUS | 2 | 1 | 50.00% |

Table 5: positive traps and rate in Ninfa Garden

| | # Traps Tot | # positive Traps | RATE |
|---|---|---|---|
| XYLOSANDRUS GENUS | 10 | 5 | 50.00% |
| XYLOSANDRUS COMPACTUS | 10 | 0 | 0.00% |
| XYLOSANDRUS CRASSIUSCULUS | 10 | 1 | 10.00% |
| XYLOSANDRUS GERMANUS | 10 | 5 | 50.00% |

Table 6: positive traps, survey and rate in Zannone Island (genus level)

| | # Traps Tot | # Survey Tot | # positive Traps | # positive survey | RATE |
|---|---|---|---|---|---|
| XYLOSANDRUS GENUS | 6 | 1 | 0 | 1 | 14.29% |

Table 7: positive traps, survey and rate in Ventotene Island (genus level)

| | # Traps Tot | # Survey Tot | # positive Traps | # positive survey | RATE |
|---|---|---|---|---|---|
| XYLOSANDRUS GENUS | 6 | 0 | 0 | 0 | 0.00% |

For the different areas, the vegetation types where positive traps were detected are also reported below, both at genus and species levels:

Table 8: positive traps per vegetation types in Natural Parks of Monti Aurunci and Ausoni (genus level)

| XYLOSANDRUS GENUS | | |
|---|---|---|
| COD CUS | Vegetation type | N. obs |
| N2111 | Agriculture areas | 5 |
| 311112 | Quercus ilex forest | 1 |
| 3222 | Maquis | 1 |
| | | **7** |

Table 8.1: positive traps per vegetation types in Natural Parks of Monti Aurunci and Ausoni (*X. compactus)*

| XYLOSANDRUS COMPACTUS | | |
|---|---|---|
| COD CUS | Vegetation type | N. obs |
| 2111 | Agriculture areas | 1 |
| 311112 | Quercus ilex forest | 1 |
| 3222 | Maquis | 1 |
| | | **3** |

Table 8.2: positive traps per vegetation types in Natural Parks of Monti Aurunci and Ausoni (*X. crassiusculus)*

| XYLOSANDRUS CRASSIUSCULUS | | |
|---|---|---|
| COD CUS | Vegetation type | N. obs |
| 2111 | Agriculture areas | 2 |

| | | |
|---|---|---|
| | | **2** |

**Table 8.3: positive traps per vegetation types in Natural Parks of Monti Aurunci and Ausoni (*X. germanus)***

| XYLOSANDRUS GERMANUS | | |
|---|---|---|
| **COD CUS** | **Vegetation type** | **N. obs** |
| 2111 | Agriculture areas | 4 |
| 311112 | Quercus ilex forest | 1 |
| 3222 | Maquis | 1 |
| | | **6** |

**Table 9: positive traps per vegetation type in Castelporziano (genus level)**

| XYLOSANDRUS GENUS | | |
|---|---|---|
| **INT** | **Vegetation type** | **N. obs** |
| 1_0_31211 | Pine forest | 1 |

**Table 9.1: positive traps per vegetation type in Castelporziano (*X. germanus*)**

| XYLOSANDRUS GERMANUS | | |
|---|---|---|
| **INT** | **Vegetation type** | **N. obs** |
| 1_0_31211 | Pine forest | 1 |

**Table 10: positive traps per vegetation types in Giardino di Ninfa (genus level)**

| XYLOSANDRUS GENUS | | |
|---|---|---|
| **COD CUS** | **Vegetation type** | **N. obs** |
| 2121 | Agriculture areas | 2 |
| 243 | Agriculture and mixed natural areas | 1 |
| 31134 | Young forest | 2 |
| | | **5** |

**Table 10.1: positive traps per vegetation types in Giardino di Ninfa (*X. crassiusculus*)**

| XYLOSANDRUS CRASSIUSCULUS | | |
|---|---|---|
| **COD CUS** | **Vegetation type** | **N. obs** |
| 31134 | Young forest | 1 |
| | | **1** |

**Table 10.2: positive traps per vegetation types in Giardino di Ninfa (*X. germanus*)**

| XYLOSANDRUS GERMANUS | | |
|---|---|---|
| **COD CUS** | **Vegetation type** | **N. obs** |
| 2121 | Agriculture areas | 2 |
| 243 | Agriculture and mixed natural areas | 1 |
| 31134 | Young forest | 2 |
| | | **5** |

**Table 11: positive traps per vegetation types in Zannone (genus level)**

| XYLOSANDRUS GENUS | | |
|---|---|---|
| **COD CUS** | **Vegetation type** | **N. obs** |
| 32324 | Gariga | 1 |

Below the risk maps, computed with data at genus level, and all having a very low risk value.

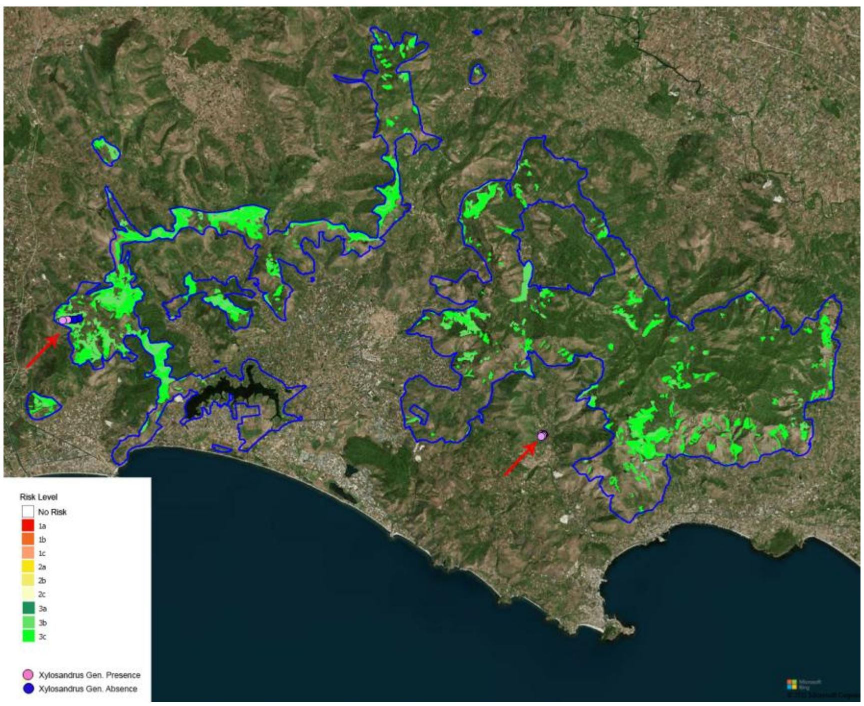



Figure 4: Aurunci and Ausoni risk map at genus level

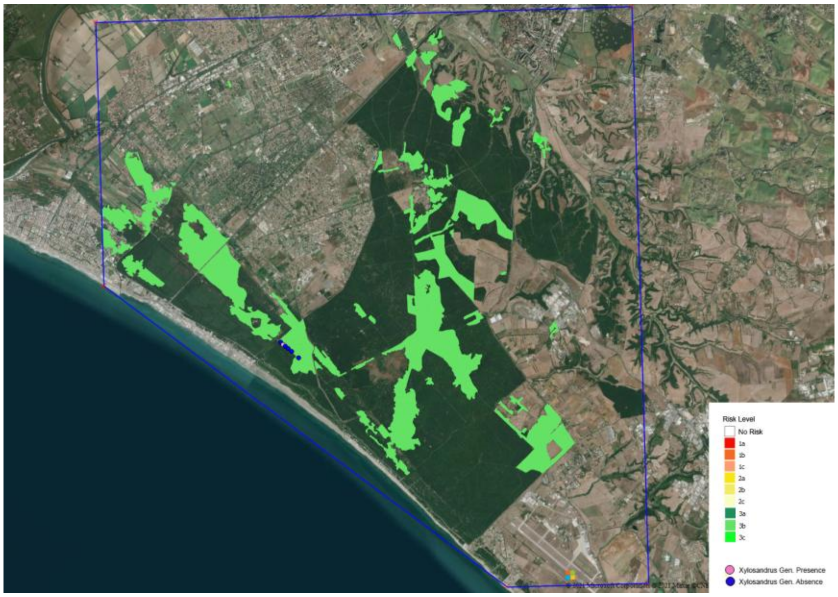



Figure 5: Castelporziano risk map at genus level


Figure 6: Ninfa risk map at genus level


Figure 7: Zannone risk map at genus level

## Spain

In the Muela de Cortes y el Caroche area the traps were installed and controlled, and no *Xylosandrus* were detected. Therefore, no risk map was produced. Instead, for the Sierras area the risk map and related statistics and image were elaborated.



Below, traps and rates of positive records are reported for the different replication areas:

**Table 12: positive traps, survey and rate in Muela de Cortes y el Caroche**

| | # Traps Tot | # Survey Tot | # positive Traps | # positive survey | RATE |
|---|---|---|---|---|---|
| XYLOSANDRUS GENUS | 12 | 0 | 0 | 0 | 0.00% |

**Table 13: positive traps, survey and rate in Sierras de Martés y el Ave**

| | # Traps Tot | # Survey Tot | # positive Traps | # positive survey | RATE |
|---|---|---|---|---|---|
| XYLOSANDRUS GENUS | 12 | | 1 | | 8.33% |
| XYLOSANDRUS CRASSIUSCULUS | 12 | | 1 | | 8.33% |

For the Sierras de Martés y el Ave area, the vegetation types were positive traps were detected are also reported below, both at genus and species levels:

**Table 14: positive traps per vegetation type in Sierras de Martés y el Ave (genus level)**

| XYLOSANDRUS GENUS | | |
|---|---|---|
| **INT** | **Vegetation type** | **N. obs** |
| 1_0_222 | Fruit crops | 1 |
| | | **1** |

**Table 14.1: positive traps per vegetation type in Sierras de Martés y el Ave (*X. crassiusculus*)**

| XYLOSANDRUS CRASSIUSCULUS | | |
|---|---|---|
| **INT** | **Vegetation type** | **N. obs** |
| 1_0_222 | Fruit crops | 1 |
| | | **1** |

Below, the risk map elaborated for the Sierra area is presented:

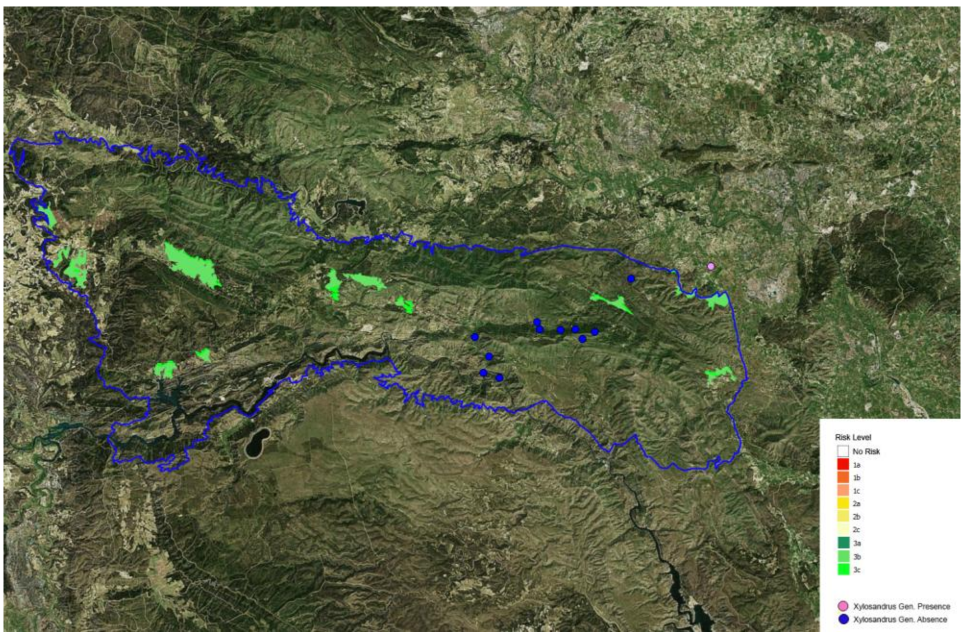



Figure 8: Sierras de Martés y el Ave risk map

## France

For France, Port-Cros National Park is the designated replication area, but the two traps that could be deployed only from early July on Porquerolles island, close to the borders of the Park area on this island, did not caught any *Xylosandrus*. Thus we could not elaborate risk maps and related figures and statistics.

## 4. VERY HIGH RESOLUTION IMAGERY

### Circeo National Park (Italy)

- **Source data:**

SPOT7 very high resolution image acquired on 17/09/2020 over Circeo Nation Park area (Italy). SPOT7 has 4-bands (VIS-NIR) plus panchromatic spectral range, and a spatial resolution equal to 1.5 m.

Traps surveys 2020 (fixed traps and surveys)

- **Methods and comments:**

The SPOT7 orthorectified image (Figure 9) was acquired, pansharpened, and computation of vegetation indices: NDVI and Simple Ratio (SR).

Figure 9: SPOT7 very high resolution imagery of Circeo NP

We explored the possibility to detect a difference between healthy and infected vegetation (where *Xylosandrus* was present) in different vegetation classes.

First we explored the *Quercus cerrus* both in wet and dry areas inside the foresta demaniale, where 23 validation points (including 17 positive and 6 negative) with data from traps or field surveys were available. The points number is lower than the total number available, as we had to select only those data collected before the acquisition date of the imagery.

Around each point a buffer of 10 m was established, extracting and averaging the reflectance values and the Simple Ratio (SR) and Normalized Difference Vegetation Index (NDVI) indices. The values were extracted both from the 6 m resolution image (non pansharpened) and the 1.5 spatial resolution image (pansharpening applied). Results for NDVI and SR are presented as follows:

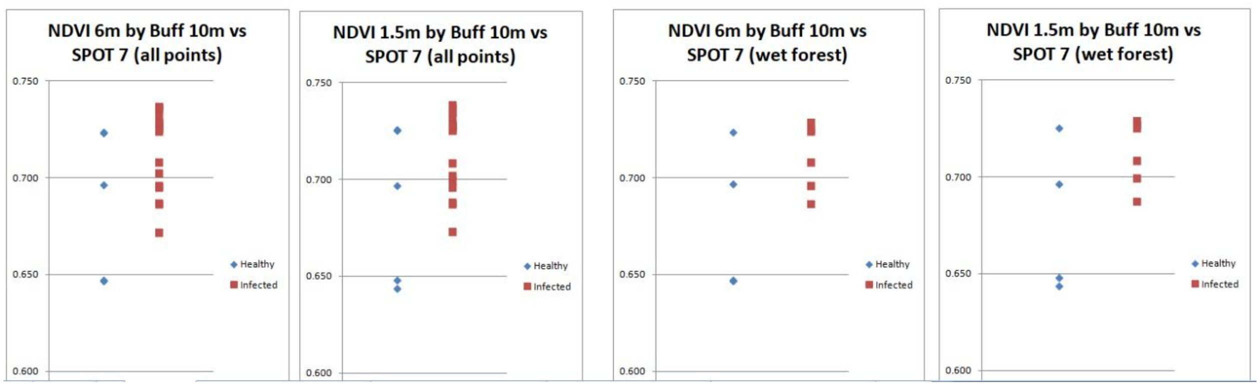



Figure 10: NDVI and SR ratio values for 23 validation points with and without *Xylosandrus* presence, extracted in the Foresta Demaniale area.

Results indicate no substantial difference between infected and non-infected vegetation, according to indices and reflectance values from SPOT7 at both spatial resolutions.

This confirms what previously presented in the Dec. 2020 Deliverable, and suggests that in a multilayered forest the *Xylosandrus* spp. presence is mostly in lower layers and therefore not easily detectable at early stages of infection by remote sensing. Only when the infection progresses, such as in 2016, the insects reach the upper canopy layers and therefore the signs of infection can be detected by optical remote sensing.

The same approach was adopted for the Quarto Freddo area, in the *Quercus ilex* coastal forest, where a total of 25 points from surveys and traps were analyzed. The results (Figure 11) for the total amount of points are similar to those presented in Figure10, leading to the same consideration above mentioned.

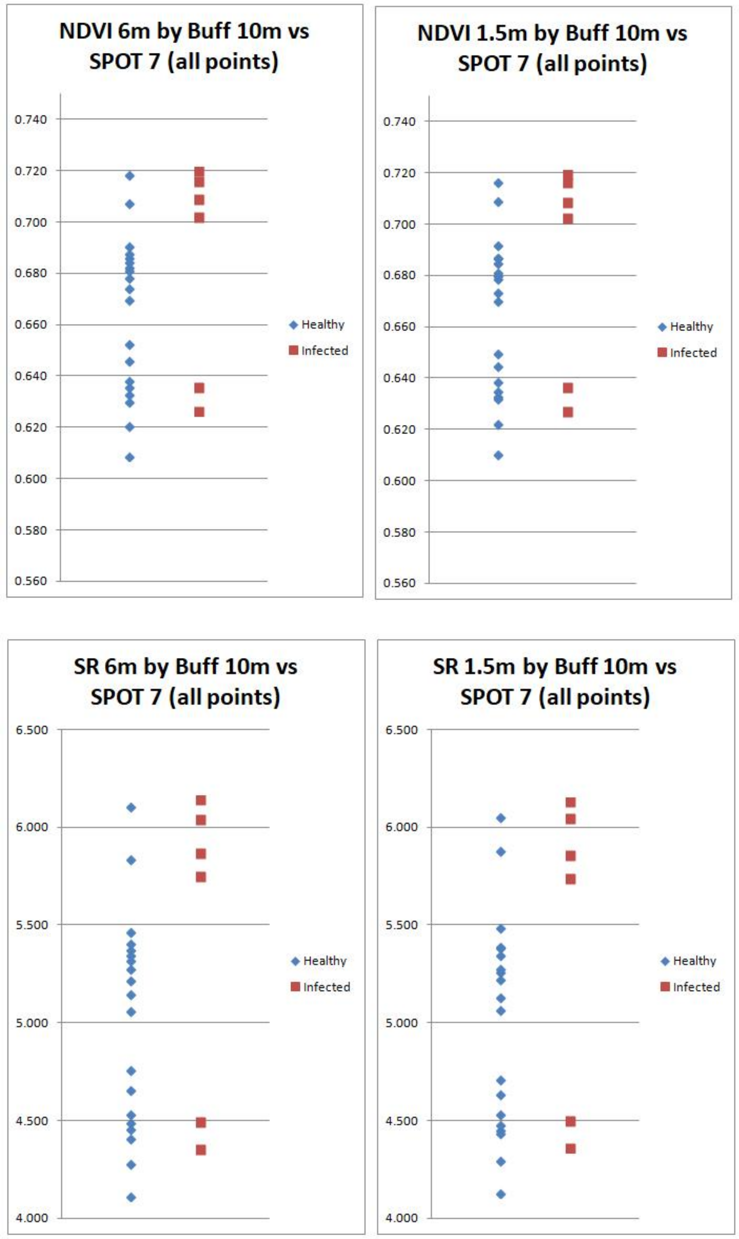



Figure 11: NDVI and SR ratio values for 25 validation points with and without *Xylosandrus* presence, extracted in the Quarto Freddo area



The analysis of these field validation data was repeated for a subset of points included in an area called 'early warning', again with *Quercus ilex* vegetation type, where intense trapping activity and additional field sampling was performed by the entomologists of Tuscia University. The graphs are as follows:

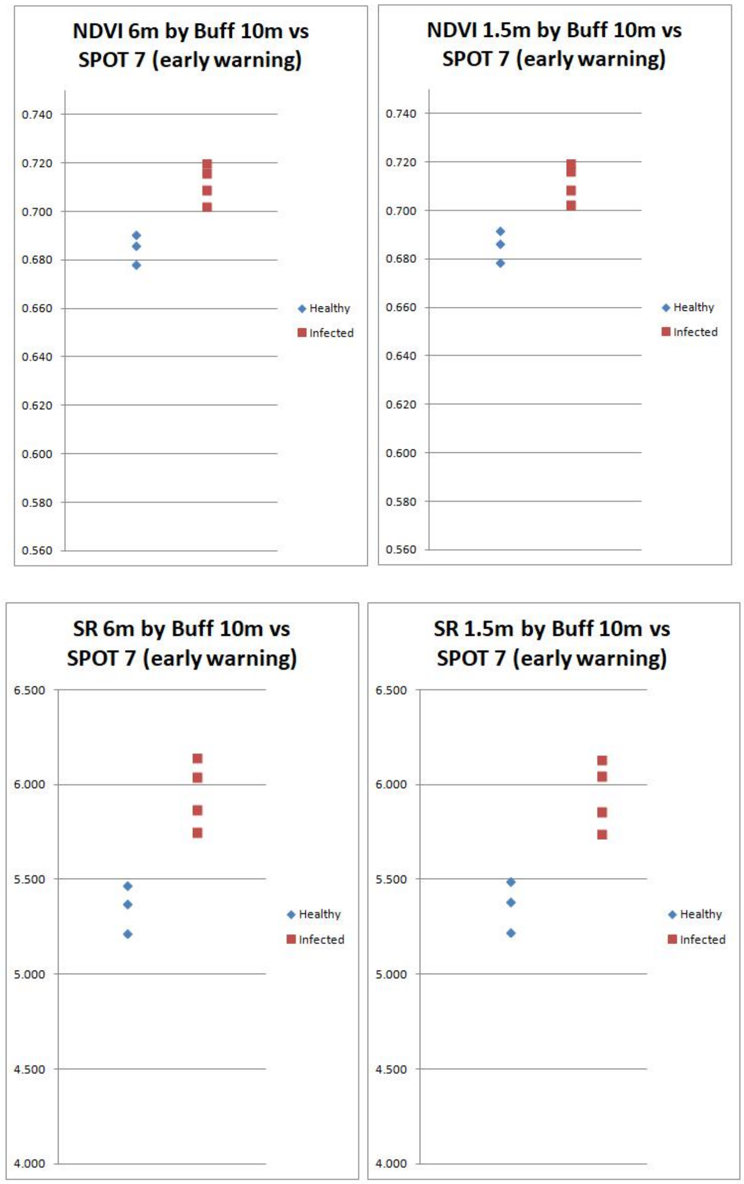



Figure 12: NDVI and SR ratio values for 25 validation points with and without Xylosandrus presence, extracted in the Quarto Freddo area

Here the results show a minimal difference, with no overlap in SR and NDVI from values of healthy and infected vegetation. It could be a positive result, but the lower values of vegetation indices in healthy vegetation were not expected: usually non healthy vegetation shows lower reflectance due to reduced photosynthetic activities and drier conditions. Additional tests in the field will be carried out to understand the leaves status in those areas, to try to explain this unexpected reflectance behavior.

Finally, the same field traps used for the analysis presented in the deliverable 'Report on Remote Sensing data collection, analysis and integration procedures' (December 2020) were used for a last test, for comparison purposes with 2020 results. Again, points belong to *Quercus ilex* (quarto freddo) and *Quercus cerrus* in wet area (foresta demaniale) vegetation classes. The same procedure with a buffer of 10 m radius applied around to each point prior to reflectance values extraction applies.

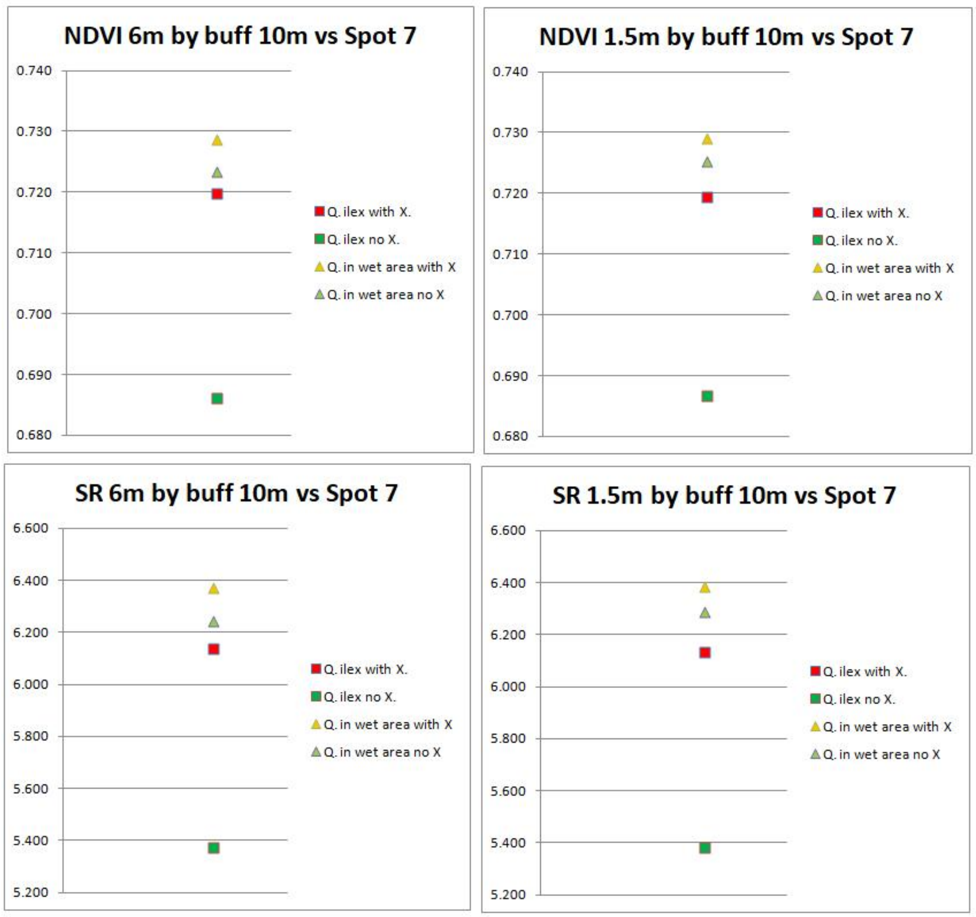



Figure 13: NDVI and SR ratio values for points with and without Xylosandrus presence, analyzed in the Dec. 2020 deliverable

Again, we observe a difference in values for the Quarto Freddo area only, similar to what found above. Additional research is needed to justify this result.

**El Tello (Spain)**

- **Source data:**

GeoEye-1, 3/10/2020, 2m multispectral , 50 cm panchromatic, 4 bands (VIS-NIR)

Traps surveys 2020 (massive and normal)

- **Methods and comments:**

The GeoEye-1 image (Figure 14) was acquired and processed, through orthorectification and computation of vegetation indices: NDVI and Simple Ratio (SR). Due to data availability, the western portion of El Tello area is missing from the imagery.

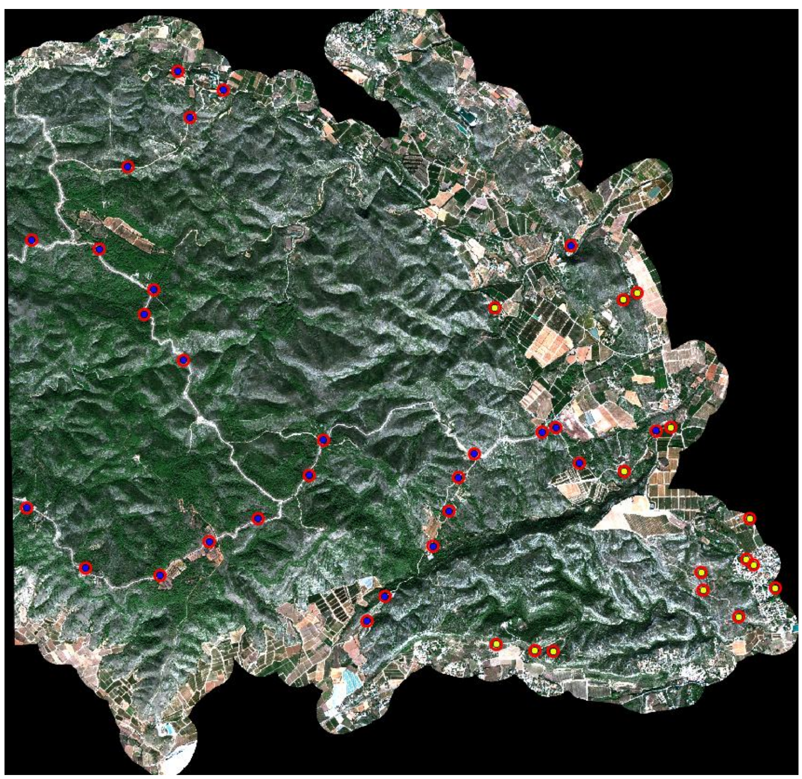


Figure 14: GeoEye 1 very high resolution imagery of El Tello area, Spain

A preliminary analysis of reflectance values in the area did not show sites with significant differences with the surroundings, with all the area characterized by vegetation in healthy status and absence of evidences of dry zones.

The location (points )of field traps collected in the 2020 year were overlapped to the image (massive trapping and normal trapping). Around each trap point a buffer of 50 m radius was set up and in that area the vegetation health status was visually explored, when possible by prevalent vegetation class (land use map from Spain partner).

The reflectance analysis of the buffered plot area is not suggested in case of very high resolution imagery, as inside the area multiple target object might be present, including bare ground, vegetation, shadows etc., each with its own response. Furthermore, the buffer was considered necessary to compensate potential geolocation inaccuracies from GPS instruments that record the exact trap location. To avoid the mixed signature issue, we preferred to perform a visual interpretation of the imagery and the vegetation indices.

A total of 42 buffered points were visually checked. For all the points the imagery was explored as true color (321 bands), false color (432 bands) compositions, NDVI and SR indices. The Table 2 below illustrates the buffered points, including positive (*Xylosandrus* presence, with date) and negative (no associated date) ones.

| AREA | Nome | TIPO | N_O | X Con | X Cra | X Ger | X.GE | BOLEA | FirstDate | Classe CUS |
|---|---|---|---|---|---|---|---|---|---|---|
| Tello | trap 10 | Trap | 9 | | 0 | | 0 | 0 | | Uncultivated |
| Tello | trap 12 | Trap | 9 | | 0 | | 0 | 0 | | Pine forests with carob trees |
| Tello | trap 13 | Trap | 10 | | 0 | | 0 | 0 | | Bushes with dispersed carob trees |
| Tello | trap 14 | Trap | 9 | | 0 | | 0 | 0 | | Bushes with dispersed trees |
| Tello | trap 15 | Trap | 9 | | 0 | | 0 | 0 | | Bushes with dispersed trees |
| Tello | trap 16 | Trap | 10 | | 0 | | 0 | 0 | | Bushes with dispersed carob trees |
| Tello | trap 17 | Trap | 10 | | 0 | | 0 | 0 | | Bushes with dispersed trees |
| Tello | trap 18 | Trap | 9 | | 0 | | 0 | 0 | | Pine forests with carob trees vicino a Bushes with dispersed carob trees |
| Tello | trap 24 | Trap | 10 | | 0 | | 0 | 0 | | Bushes with dispersed trees |
| Tello | trap 26 | Trap | 9 | | 0 | | 0 | 0 | | Rainfed arable crops |
| Tello | trap 27 | Trap | 9 | | 0 | | 0 | 0 | | Pine forests with carob trees |
| Tello | trap 28 | Trap | 8 | | 0 | | 0 | 0 | | Bushes with dispersed trees |
| Tello | trap 29 | Trap | 9 | | 0 | | 0 | 0 | | Pine forests |
| Tello | trap 3 | Trap | 9 | | 0 | | 0 | 0 | | Pine forests |
| Tello | trap 30 | Trap | 9 | | 0 | | 0 | 0 | | Bushes with dispersed trees |
| Tello | trap 31 | Trap | 9 | | 0 | | 0 | 0 | | Pine forests |
| Tello | trap 32 | Trap | 9 | | 0 | | 0 | 0 | | Bushes with dispersed trees |
| Tello | trap 33 | Trap | 9 | | 0 | | 0 | 0 | | Pine forests |
| Tello | trap 34 | Trap | 9 | | 0 | | 0 | 0 | | Bushes with dispersed trees |
| Tello | trap 4 | Trap | 9 | | 0 | | 0 | 0 | | Pine forests with carob trees |
| Tello | trap 5 | Trap | 9 | | 0 | | 0 | 0 | | Pine forests with carob trees |
| Tello | trap 6 | Trap | 9 | | 0 | | 0 | 0 | | Olive crops |
| Tello | trap 7 | Trap | 9 | | 0 | | 0 | 0 | | Pine forests |
| Tello | trap 8 | Trap | 9 | | 0 | | 0 | 0 | | Bushes with dispersed carob trees |
| Tello | trap 9 | Trap | 9 | | 0 | | 0 | 0 | | Pine forests with carob trees |
| Tello | Mass 9 | Trap Mass | 6 | | 0 | | 0 | 0 | | Bushes with dispersed carob trees |
| Tello | trap 11 | Trap | 9 | | 1 | | 1 | 1 | 14/12/2020 | Bushes with dispersed carob trees |
| Tello | trap 19 | Trap | 9 | | 15 | | 15 | 1 | 05/06/2020 | Bushes with dispersed trees vicino a Bushes with dispersed carob trees |
| Tello | trap 20 | Trap | 10 | | 13 | | 13 | 1 | 06/09/2020 | Bushes with dispersed carob trees |
| Tello | trap 21 | Trap | 10 | | 9 | | 9 | 1 | 05/06/2020 | Bushes with dispersed trees |
| Tello | trap 22 | Trap | 10 | | 1 | | 1 | 1 | 19/09/2020 | Bushes with dispersed trees |
| Tello | trap 23 | Trap | 10 | | 10 | | 10 | 1 | 03/07/2020 | Pine forests with carob trees |
| Tello | trap 35 | Trap | 9 | | 2 | | 2 | 1 | 19/09/2020 | Bushes with dispersed carob trees |
| Tello | trap 37 | Trap | 10 | | 21 | | 21 | 1 | 19/05/2020 | Pine forests |
| Tello | trap 38 | Trap | 10 | | 11 | | 11 | 1 | 19/05/2020 | Pine forests |
| Tello | trap 39 | Trap | 10 | | 1 | | 1 | 1 | 19/09/2020 | Bushes with dispersed carob trees |
| Tello | trap 40 | Trap | 9 | | 22 | | 22 | 1 | 05/06/2020 | Bushes with dispersed carob trees |
| Tello | Mass 3 | Trap Mass | 6 | | 77 | | 77 | 1 | 27/07/2020 | Irrigated tree crops |
| Tello | Mass 5 | Trap Mass | 6 | | 54 | | 54 | 1 | 27/07/2020 | Pine forests with carob trees |
| Tello | Mass 7 | Trap Mass | 6 | | 1 | | 1 | 1 | 19/09/2020 | Bushes with dispersed trees |
| Tello | Mass 8 | Trap Mass | 6 | | 7 | | 7 | 1 | 27/07/2020 | Bushes with dispersed trees |
| Tello | Mass 10 | Trap Mass | 6 | | 3 | | 3 | 1 | 19/09/2020 | Bushes with dispersed trees |

Table 15: buffered traps areas in which vegetation status was checked by means of visual interpretation of GeoEye 1 very high resolution imagery.

*Case A: Bushes with dispersed Carob trees*

In EL Tello area, *Xylosandrus* was initially mainly found in Carob trees and old plantations of those species. The trapping effort surveyed a total of 9 traps in this class, in 5 cases the *Xylosandrus* presence was recorded.

Here we present some examples for this class.

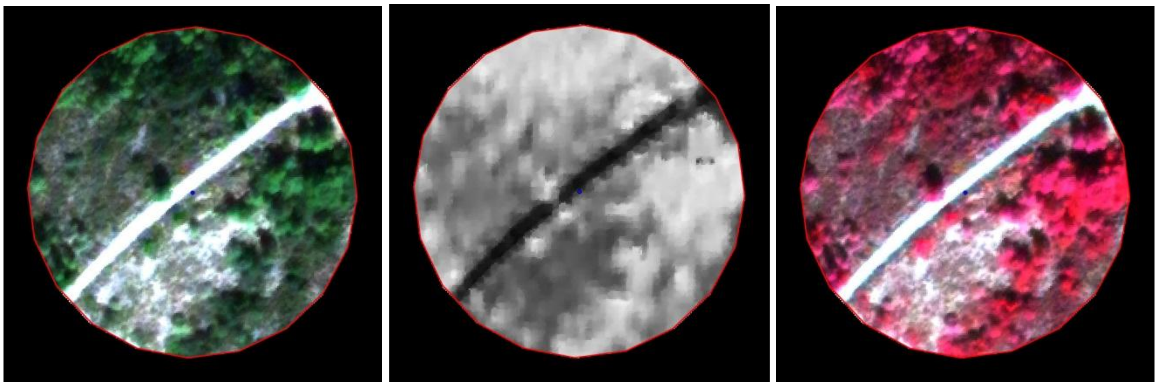


Figure 15: Trap 11 (positive) - true color composition, NDVI, false color composition

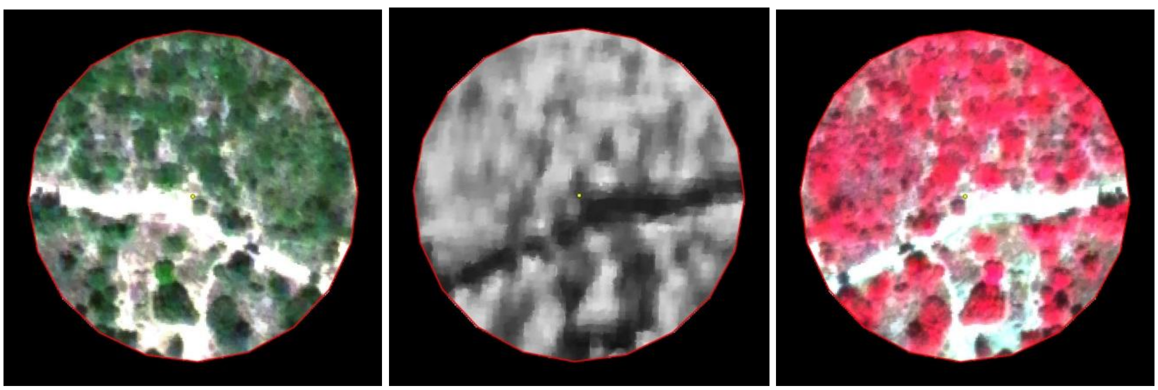


Figure 16: Trap 40 (positive) - true color composition, NDVI, false color composition



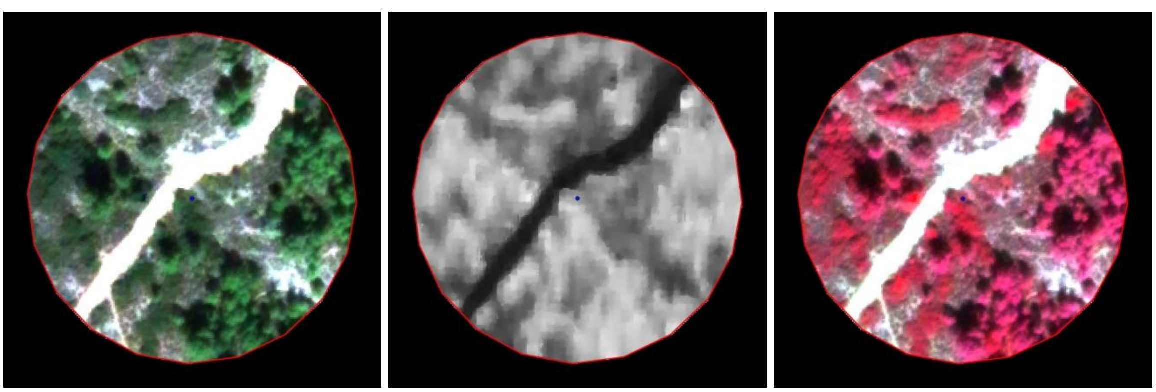


Figure 17: Trap 13 (negative) - true color composition, NDVI, false color composition

From the 9 examples explored for this class, also including those not shown here and also considering the inspection of the reflectance values in the trap point, no significant difference emerged between the vegetation status of the positive and negative areas.

This fact might be explained by the low level of *Xylosandrus* invasion recorded in 2020 compared to previous year, both in terms of number of infected sites and intensity of the attack. Most of the attacked plants parts are lower branches, covered by the canopy, and not visible from the remote sensing imagery.

*Case B: Bushes with dispersed trees*

This class is very similar to the previous one except for the absence of Carob trees. The total number of traps set up in this land cover class are 14, of which 6 resulted positive and 8 negative.

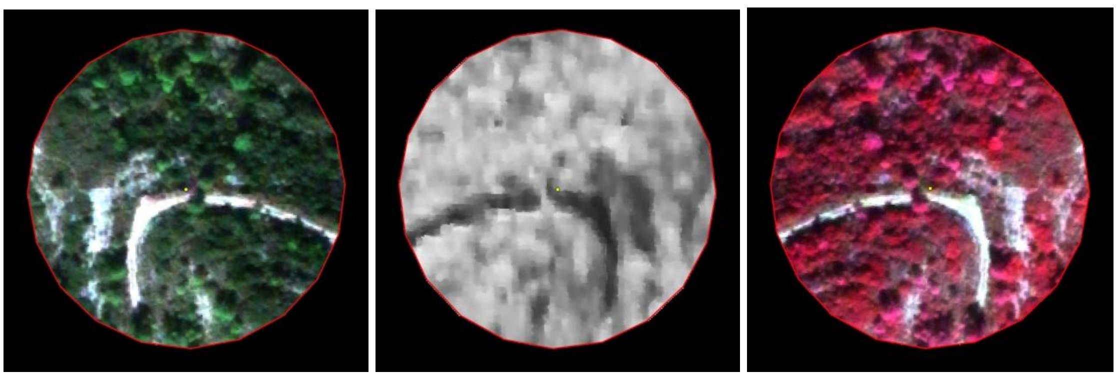


Figure 18: Trap 10 (positive) - true color composition, NDVI, false color composition

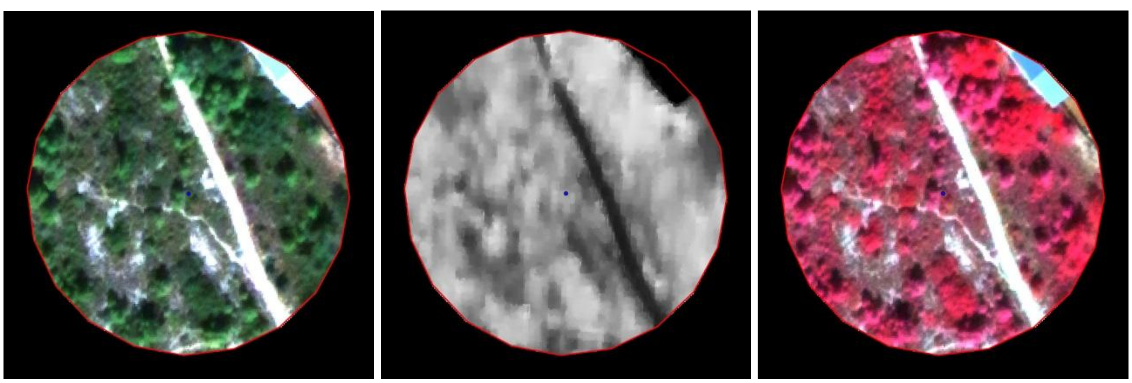


Figure 19: Trap 17 (negative) - true color composition, NDVI, false color composition

From the various examples explored for this class, also including those not shown here and also considering the inspection of the reflectance values in the trap point, no significant difference emerged between the vegetation status of the positive and negative areas.

<u>*Case C: Pine forest*</u>

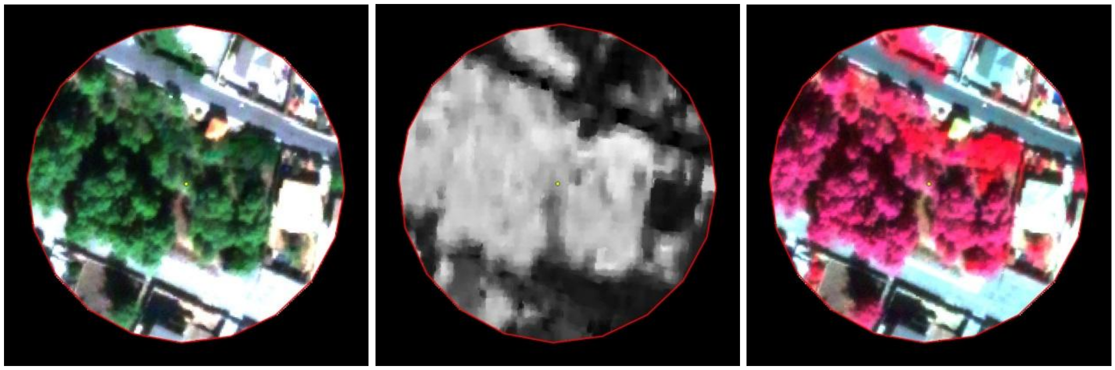


Figure 20: Trap 37 (positive) - true color composition, NDVI, false color composition

In this class, 2 traps were set up of which only 2 resulted positive. In the positive case shown above (trap 37), in exact correspondence of the trap location a lower value in reflectance was observed. Even if the difference with surrounding did not result significant, the plant possibly has part of the crown in dry and unhealthy status, due to *Xylosandrus* attack.



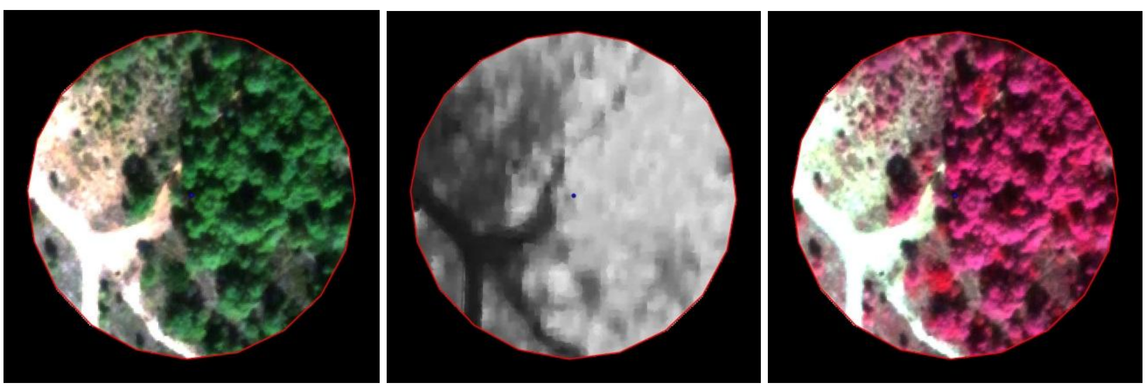


Figure 21: Trap 31 (negative) - true color composition, NDVI, false color composition

Case C: Irrigated tree crops

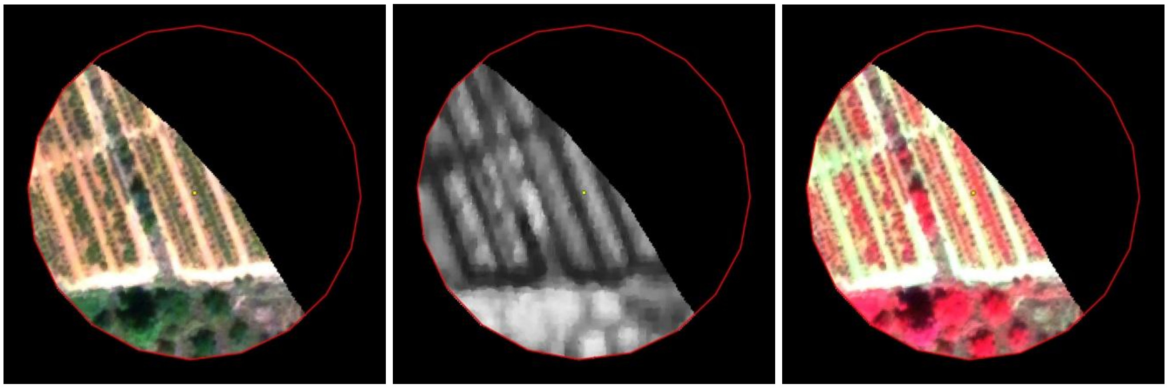


Figure 22: Trap 3 (positive) - true color composition, NDVI, false color composition

In this class only 1 trap was set up, with *Xylosandrus* presence recorded. No differences in vegetation inside and outside the buffer was detected.

Case C: other classes

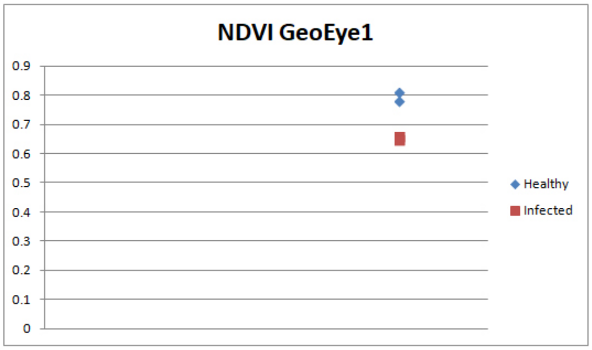
Among other classes, only in one case *Xylosandrus* resulted present: Pine forest with Carob trees, here not shown because no difference with respect to previous examples was present (total of 8 traps of which 2 resulted positive).



Other sampled classes where traps were set up and no *Xylosandrus* presence was recorded include: sparsed vegetation, rainfed arable crops, and olive crops.

NDVI and SR analysis from selected trees/shrubs

In the previous RS Deliverable (Dec. 2020), the trends in indices extracted from Sentinel 2 data were computed for infected and healthy vegetation from different classes, using pixels included in the 50 m buffer set up around each trap. With GeoEye, that allows the identification of single features in the image, we repeated the procedure using visual interpretation to select only vegetation pixels (trees and shrubs) and thus exclude shadows, bare soil and other non-vegetated targets. It is a test that could provide information on the opportunity to perform segmentation of the very high resolution imagery, prior to analysis, to select only targets of interest.



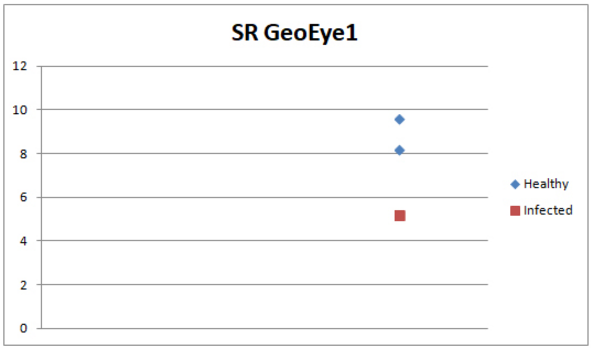




Figure 23: NDVI and SR GeoEye1 test only selecting vegetation pixels

The result indicate that when single trees and shrubs are selected, there is a difference in the computed vegetation indices for El Tello area.

## 5. CONCLUSIONS

In both Circeo and El Tello, the collected data suggest a decrease of *Xylosandrus* presence, according to trap and survey data. *X. compactus* was mostly replaced by *X. germanus* in Italy. The *compactus* species showed a decrease in Spain area too, where the invasion remain confined in a small portion of the study area. In France, due to the considerable differences in 2019 and 2020 trapping campaigns, it was impossible to elaborate risk maps and related statistics. No further data have been collected in replication areas.

The field methods and protocols adopted in the different areas are well design and suited to monitor *Xylosandrus* detection. The comparison of 2019 and 2020 data indicate as important both the setup of traps in the same location each year, and to carry out surveys for additional data collection in large areas such as Circeo NP.

According to the data, no clear association of *Xylosandrus* with vegetation types was detected, but certain types, like coastal dunes, are avoided, possibly due to winds and less palatable vegetation species. In replication areas, the forests showed more occurrence of positive traps than other vegetation types, possibly indicating that this type might be the first entrance point for an invasion, that subsequently can expand in other land cover classes.

Overall the risk maps indicate a reduction in the risk of *Xylosandrus* expansion and presence. The methodology was successfully applied also in replication areas, where limited invasion presence was found. Special attention has to be devoted to islands, where the damages from invasion could imply additional issues.

Remote sensing analyses, as reported in previous reports, showed to be useful when the invasion reaches a high level, and the *Xylosandrus* species attack the upper canopy level. With moderate and low invasions, the *Xylosandrus* species might be present in lower canopy layer, where the satellite data cannot penetrate. The spatial resolution of imagery can also have an impact, as free Sentinel 2 data are mostly useful in large areas, such as the French coast or the Circeo NP.

The use of very high resolution imagery, specifically purchased for the project, was not of help in Circeo NP or El Tello, again because of moderate-low invasion levels. The insect attacks mainly low branches leaving the upper crown level and the overall plant in healthy status. The vegetation resulted in health and not too much affected by *Xylosandrus* presence. However, in El Tello when entire trees are attacked and dried up, the very high resolution allow to detect other trees in similar conditions in the surroundings of the affected individuals, thus becoming a fast method to detect the spreading of the invasion. Furthermore, a difference in the vegetation indices computed from healthy and infected vegetation might emerge, allowing to use very high resolution imagery to detect new areas of *Xylosandrus* invasion. Overall, the very high resolution imagery acquisition is suggested when the area to be analyzed is limited, and analysis at single tree level cannot be performed.