ANNEX II. TOOL METHODOLOGY

1. INTRODUCTION

Currently, *Eucalyptus* plantations in Spain and Portugal are threatened by a pest known as *Gonipterus platensis* (Eucalyptus snout beetle), a defoliator insect from Australia whose feeding is based on the consumption of Eucalyptus leaves. Affected trees, lose photosynthetic capacity so their growth is drastically reduced, and have more predisposition to suffer other pathogens attacks. Eucalyptus snout beetle has great expansion capacity, and has no natural enemies in Europe, so that its attacks, annually cause large losses in the volume of wood.

When a Eucalyptus tree is healthy, its leaves absorb, reflect and transmit incident sunlight, in a defined manner, describing a pattern known as spectral signature. In case the vegetation is suffering stress due to the attack of pests, or diseases the changes in the foliar structure cause that spectral signature to be altered. The study of these alterations is carried out by maps of vegetation indexes which are derived from multispectral images captured by specific cameras, such as the infrared (NIR) or the red border (RE) cameras. These vegetation indexes are images calculated from algebraic operations between different spectral bands where different properties of the vegetation (chlorophyll content, sanitary status, water stress ...) are graphically highlighted. For the capture of images in not very extensive areas, the use of UAVs has proved to be a very effective tool that allows to capture images in real time of Eucalyptus masses with a very high spatial resolution.

Having enough knowledge of the biology of the pest and the support of plots of field damage inventory, the level of affection in the areas of interest can be detected, determining the most precise vegetation indices for the detection of the damage, so that in the near future, these indices can be used as a first step to make decisions.

Harnessing the advantage of remote sensing tools to acquire high resolution images, the aim of this study was to assess defoliation caused by Eucalyptus snout beetle, using vegetation indexes derived from NIR (*Near Infrared*) and RE (*Red Edge*) multispectral cameras mounted on a fixed-wing UAV *(Unmanned Aerial Vehicle)*.

2. MATERIALS AND METHODS

Study Area

Data acquisition campaigns were conducted in four different areas planted with young Eucalyptus (5-6 years old) and different degrees of attack selected by the project partners: 3 them located in Spain (Galicia, Asturias and Cantabria) and the other one in Portugal (Figure 1).

Figure 1.Distribution of the study area

In each of them, a number of circular sampling plots were established trying to cover areas with different levels of damage and different orographic characteristics. The number of plots varied according to the area as shown in Table 1:

Table 1. Study plots

Zona	Número de parcelas
Asturias	6
Cantabria	1
Galicia	12
Portugal	8

Field damage inventory

Following the Field Manual proposed by the Portuguese partners, an inventory of damages was carried out within each plot. In addition to the values of the main dasometric variables (height and breast height diameter) other variables related to the health and phenological state of the tree were also registered:

- Status: general situation of the tree
- Health: health status.
- Shape: tree anatomical characteristics.
- Phenology
- Defoliation: Leaves surface status

In order to estimate defoliation degree, a scale of 7 levels was used, as shown in Table 2.

Tabla 2. Scale of defoliation levels

Defoliation level	Description
1	Absence of young leaves eaten by adults or larvae
2	Less than 25% of recent leaves gnawed
3	Between 25% and 50% of recent leaves gnawed
4	Between 50% and 75% of recent leaves gnawed
5	More than 75% of recent leaves eaten, but at least 1/4 of these leaves have more than 50% of their area intact
6	More than 75% of recent leaves eaten, and less 1/4 of these leaves have more than 50% of their area intact
7	Total consumption of recent sprouts, only traces of petioles remaining; peel of the branches very eaten

The way of measuring, each plot varied according to the partners criterion. In the case of Asturias and Cantabria, all trees within each plot were measured, while in Galicia and Portugal, only 12 trees were selected on both sides of the plot center following the plantation furrow.

Concurrent UAV image acquisition and field damage campaigns were scheduled from April to October depending on the area.

Trees geo-positioning

In two of the study areas (Asturias and Cantabria) all the trees contained in the plots were geo-positioned, in order to project them on a map and to test two approaches: the calculation of indices at individual tree level and stand level.

For the Eucalyptus geo-positioning, conventional topographic techniques were used, using a Trimble M3DR3 total station to measure distances and angles, and a prism to locate each point of the terrain (Figure 2). For the geo-referencing of the total station, a GPS model Leica Visa GS14 of centimetric accuracy precision was used.

Figura 2. Eucalyptus geo-positioning in the field using a total station

In the case of Galicia, the individual identification of the trees was done in the images captured by the UAV (photo-interpretation). In order to do that, cardboard arrows of sufficient size to be visible in aerial images and placed pointing one of the trees were used in each of the inventory plots. As a result in the aerial images, starting from that tree, the other eleven ones within the plot area were identified. In the center of each of the identified trees a circular geometry of 1 m diameter was drawn and the spectral data of the pixels included in it were extracted.

Finally, in the case of Portugal, no geo-positioning was carried out, so all the analysis were done at plot level.

Image collection and processing

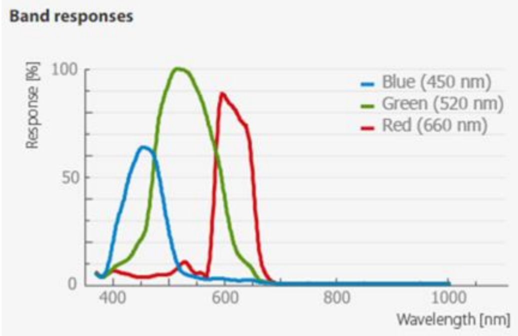
Multispectral images collection in the study areas was carried out with the UAV eBee RTK (Figure 3), a fixed wing model built in polypropylene foam that confers it great lightness.

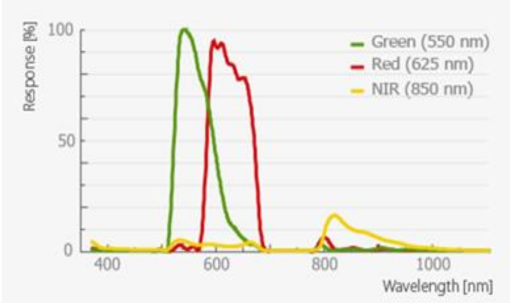
Figure 3. *Fixed-wing UAV used for image collection: eBee RTK.*

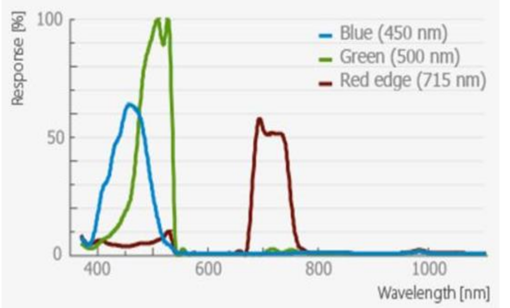
For data collection, different sensor were used: *RGB (CannonS110 y SODA), NIR, RE, Sequoia* y *ThermoMap.* Technical specifications of all of them are shown in Table.

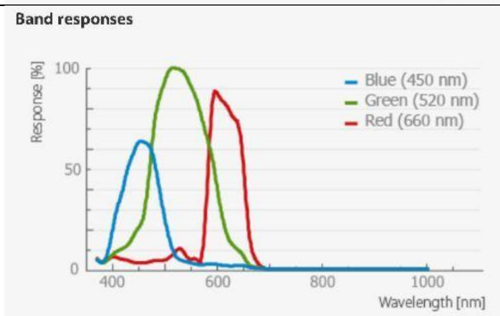
Table 3. *Technical specifications of the sensors involved in data collection*

<table>
<tr><th>Sensor</th><th>Characteristics</th><th>Spectral response</th></tr>
<tr><td>

RGB</td><td>Resolution: 12MP
Ground resolution (100m):
3.5 cm/px
Sensor size:
7.44 x 5.58 mm
Pixel size:
1.86 µm
Image format: JPEG/RAW</td><td>
</td></tr>
<tr><td>

NIR</td><td>Resolution: 12MP
Ground resolution (100m):
3.5 cm/px
Sensor size:
7.44 x 5.58 mm
Pixel size: 1.86 µm
Image format: JPEG/RAW</td><td>
</td></tr>
<tr><td>

RE</td><td>Resolution: 12MP
Ground resolution (100m):
3.5 cm/px
Sensor size:
7.44 x 5.58 mm
Pixel size: 1.86 µm
Image format: JPEG/RAW</td><td>
</td></tr>
<tr><td>SODA

</td><td>Resolution: 20MP
Ground resolution (100m):
2.3 cm/px
Sensor size:
12.75 x 8.5 mm
Pixel size: 2.33 µm
Image format: JPEG/DNG</td><td>
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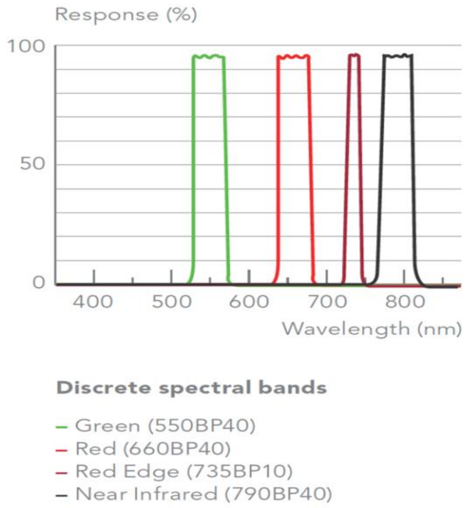
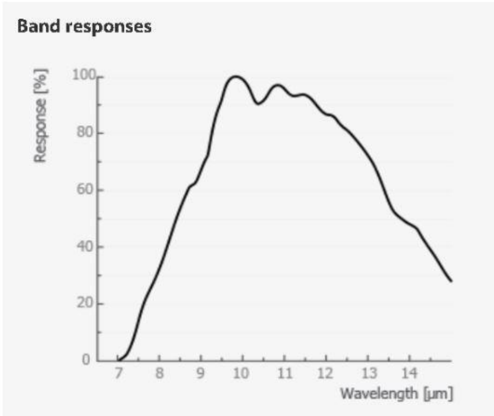
	**Resolution** : 4 spectral cameras of 1.2 MP Hasta 1 cuadro/seg RGB camera of 16 MP IMU & magnetometer	
ThermoMap 	**Image size:** 640 x 512 px **Ground resolution (100m)**: 14 cm/px **Scene temperature:**-10 to 160ºC **Temperature resolution:** 0.1ºC **Image format**: image TIFF + video mp4	

The number of flights and their date varies depending on the study area as it is shown in Table 4:

Table 4. Flights carried out in each study area

Zona	Número de vuelos	Fecha	Sensor
Asturias	27	April/May/June/October	RGB, NIR, RE
Cantabria	2	April/	RGB, NIR, RE
Galicia	3	July	RGB, Sequoia,thermoMAP
Portugal	2	April/June	RGB, NIR, RE, Sequoia

Flight planning was designed using eMotion software. The longitudinal overlap between images was 90%, while the lateral one was around 80%. The fact that these overlaps are very high, is explained because the study areas were very homogeneous.

As an example, in Figure 4 the UAV trajectory along one of the study areas located in Asturias, is shown, each red point represents an image capture.

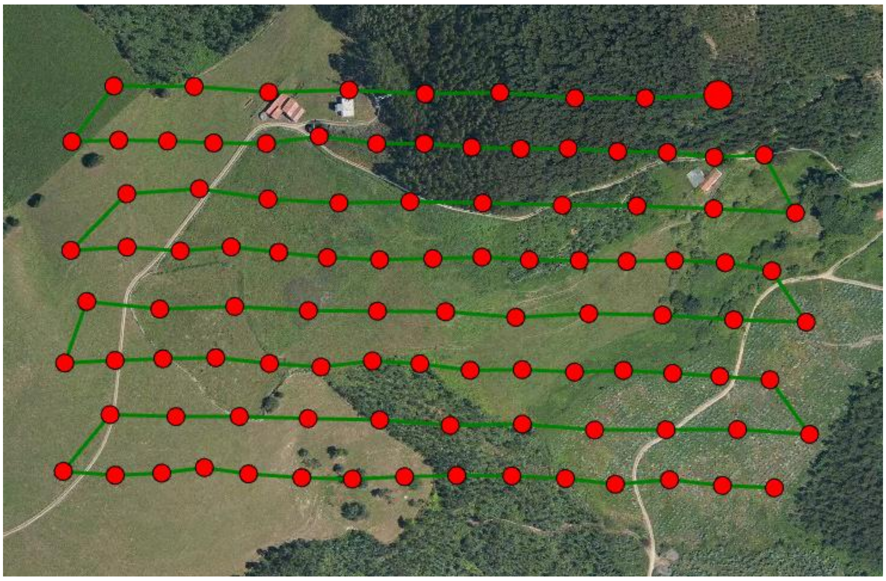


Figura 4. Flight plan of one of the study areas in ASturias

In the case of flights where images were collected with the modified cameras (NIR and RE) and the Sequoia, it was necessary to perform a radiometric calibration of the different bands captured, in order to minimize the effect of the atmosphere on the reflectance values obtained. For each flight, a calibration target (Figure 5) which allows comparing the values of the albedo in its central zone with the values obtained in the images was used.

Figura 5. Calibration target

All the images collected in the study areas were processed in Pix4D Mapper, a photogrammetry software that allows, among other things, the calculation of reflectance maps of the red, green, infrared and red border bands. These reflectance maps were used to calculate the 13 vegetation indexes evaluated in this study. These maps were generated with a resolution of 10 cm / pixel, a value a little higher than the minimum possible.

Vegetation indexes calculation

The evaluated indexes were obtained from various scientific articles related to the evaluation of vegetation damage. For this study, those related to plant vigor were chosen. The name of the indexes, as well as the formula used to calculate them, are shown in Tables 5.

All of them were calculated in Pix4D, which has an index calculator that allows combining the calibrated reflectance maps obtained for each band.

Tabla 5. Vegetation indexes evaluated

Index name	Formula	Reference
Normalized Difference Vegetation Index (NDVI)	$\frac{\rho_{NIR} - \rho_{red}}{\rho_{NIR} + \rho_{red}}$	(Kriegler, 1969, Rouse et al, 1973)
No linear index(NLI)	$\frac{\rho_{NIR}^2 - \rho_{red}}{\rho_{NIR}^2 + \rho_{red}}$	
Infrared Percentage Vegetation Index (IPVI)	$\frac{\rho_{NIR}}{\rho_{NIR} + \rho_{red}}$	
Green Normalized Difference Vegetation Index (GNDVI)	$\frac{\rho_{NIR} - \rho_{green}}{\rho_{NIR} + \rho_{green}}$	(Gitelson et al, 1996)
Normalized Red Green Difference Vegetation Index (NGRDI) o Green Red Vegetation Index (GRVI)	$\frac{\rho_{green} - \rho_{red}}{\rho_{green} + \rho_{red}}$	(Gitelson et al, 2002)
Green Chlorophyll Index (GCI)	$\frac{\rho_{NIR}}{\rho_{green}} - 1$	
SAVI (Soil Adjusted Vegetation Index)	$\frac{\rho_{NIR} - \rho_{red}}{\rho_{NIR} + \rho_{red} + L}(1 + L)$	(Huete, 1988)
***Normalized Difference Red Edge (NDRE)**	$\frac{\rho_{NIR} - \rho_{red\ edge}}{\rho_{NIR} + \rho_{red\ edge}}$	
***Red edge Chlorophyll Index (REGCI)**	$\frac{\rho_{NIR}}{\rho_{red\ edge}} - 1$	
Red_edge Green(REGNDVI)	$\frac{\rho_{rededge} - \rho_{green}}{\rho_{rededge} + \rho_{green}}$	
Red_edge NDVI (RENDVI)	$\frac{\rho_{rededge} - \rho_{red}}{\rho_{rededge} + \rho_{red}}$	
***Anthocyanin reflectance index 2 (ARI2)**	$NIR\left(\frac{1}{\rho_{green}} - \frac{1}{\rho_{red\ edge}}\right)$	(Gitelson et al, 2001)
Anthocyanin reflectance index (ARI)	$\frac{1}{\rho_{green}} - \frac{1}{\rho_{red\ edge}}$	(Gitelson et al, 2001)
***Normalized Difference Red Edge (NDRE)**	$\frac{\rho_{NIR} - \rho_{red\ edge}}{\rho_{NIR} + \rho_{red\ edge}}$	

In order to assess the indexes sensibility to defoliation, two different approaches were followed:

A. **Indexes calculation at individual tree level (Asturias, Cantabria and Galicia):** from the field geo-positioning data, a buffer of 0.25 m (Asturias-Cantabria) and 0.5 m (Galicia) width was generated around the center of each tree in order to establish the areas corresponding to the central part of the crowns. In this way the effect that the soil could have on the value of the indexes is attenuated since only the values corresponding to the crowns are considered. This buffer width value was selected according to the visual observations of the structure of the crowns made in the field.

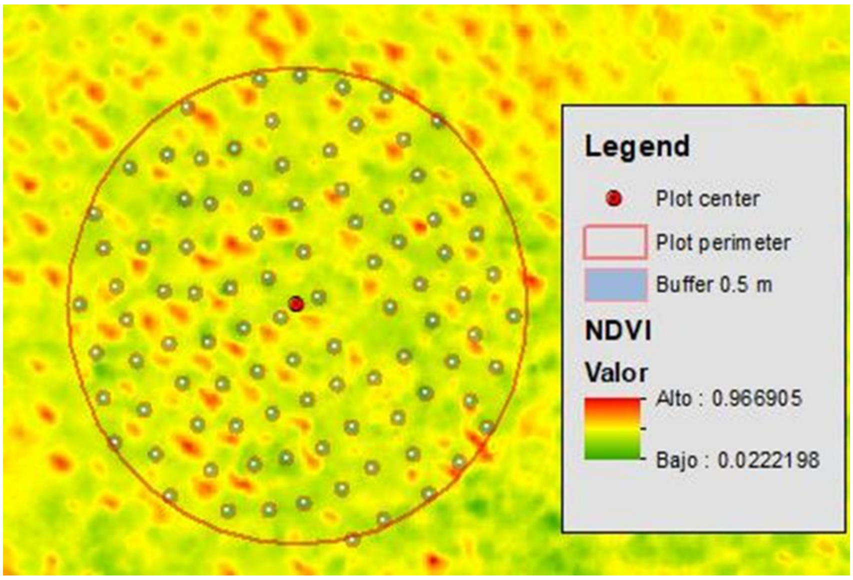


Figura 4. Delimitación de las copas de los árboles dentro de la parcela

After that, with the help of a GIS software, an average value of each index per tree was obtained. These values were merged with the field data in order to obtain a table where each single tree had an associated value for each of the 13 indexes and a percentage of defoliation measured in the field. The values obtained were exported to a spreadsheet for subsequent statistical analysis.

In a first step, the values of the vegetation and defoliation rates were evaluated through the SAS UNIVARIATE procedure (SAS Institute Inc., 2011) that performs the Shapiro-Wilk and Kolmogorov-Smirnov normality tests, in addition to calculating the main descriptive statistics of the variable.

By means of the construction of the box-plot diagrams, a bivariate detection of outliers was carried out by analyzing the values of the vegetation indexes against the defoliation at the individual tree level and at the plot level, depending on the study area.

To evaluate the efficiency of the vegetation indexes calculated for the defoliation detection caused by *Gonipterus*, a GLM (Generalized Linear Models) analysis was carried out. This type of analysis is similar to the analysis of variance ANOVA but allows to work with unbalanced data (different number of observations between groups).

The generalized linear models (GLM, Generalized Linear Models) allow to make comparisons between groups and to establish predictive equations.

However the results obtained by this method were not very good, so in a second step a Principal Component Analysis (PCA) was carried out. This technique has been widely used in remote sensing studies because of its capacity for removing or reducing the duplication or redundancy in multispectral images and for compressing all of the information that is contained in an original n-channel set of multispectral images into less than n channels or, more specifically, to their principal components (Ricotta et al., 1999)

B. **Indexes calculation at plot level (Portugal):** in this approach, an average value of the index per plot is obtained. Due to the Eucalyptus plantations are very young, the images captured show pixels of soil interspersed among the vegetation (Figure 6). To prevent the presence of these pixels from altering the average values of the index within the plot, it is necessary to remove them from the image by using a mask.

Figure 6. Detail of the plots situated in Portugal

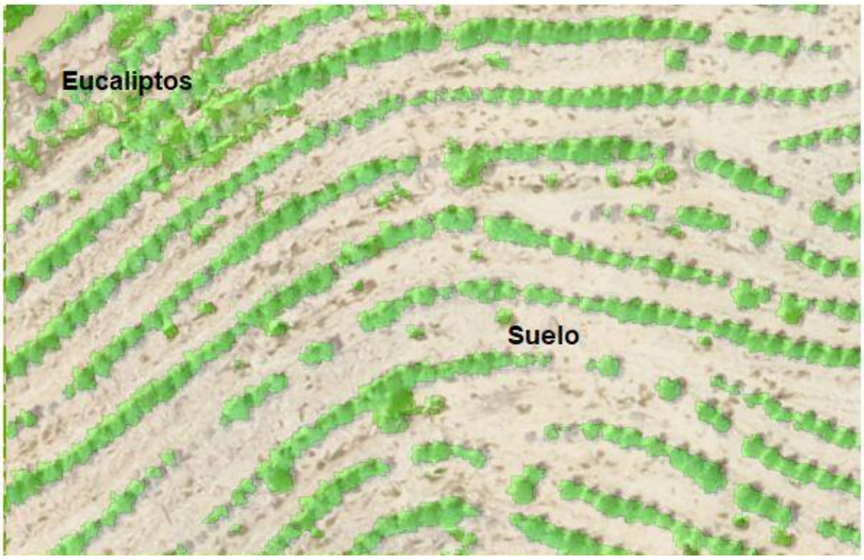


Figure 7. Vegetation mask applied to the study area

In this case, the mask was constructed using a supervised classification (ECognition Essentials) from the red, green, infrared and red edge bands that allowed separating the vegetation zones from the soil zones as shown in Figure 6.

The value of the index was extracted only for the pixels that were inside the mask, so finally an average value was obtained per plot. As in the previous case, these values were merged with the field data in order to obtain a table in which each plot had a value associated to each of the 13 indexes and a percentage of defoliation measured in the field. The values obtained were exported to a spreadsheet for subsequent statistical analysis.

A correlation analysis between mean indexes value and defoliation levels was carried out to check the sensitivity of the indexes to defoliation.

3. RESULTS

Damage inventory

From the analysis of the measurements of the level of damage in the field, it is clear that the degree of attack by Gonipterus platensis varies considerably depending on the territory to be considered. More specifically, Table 6 shows the percentage of trees measured on all flights carried out, which has been assigned to each level of defoliation in the 4 study areas. In view of the data, it can be seen that in Asturias, Cantabria and Galicia the attack has been weak or moderate.

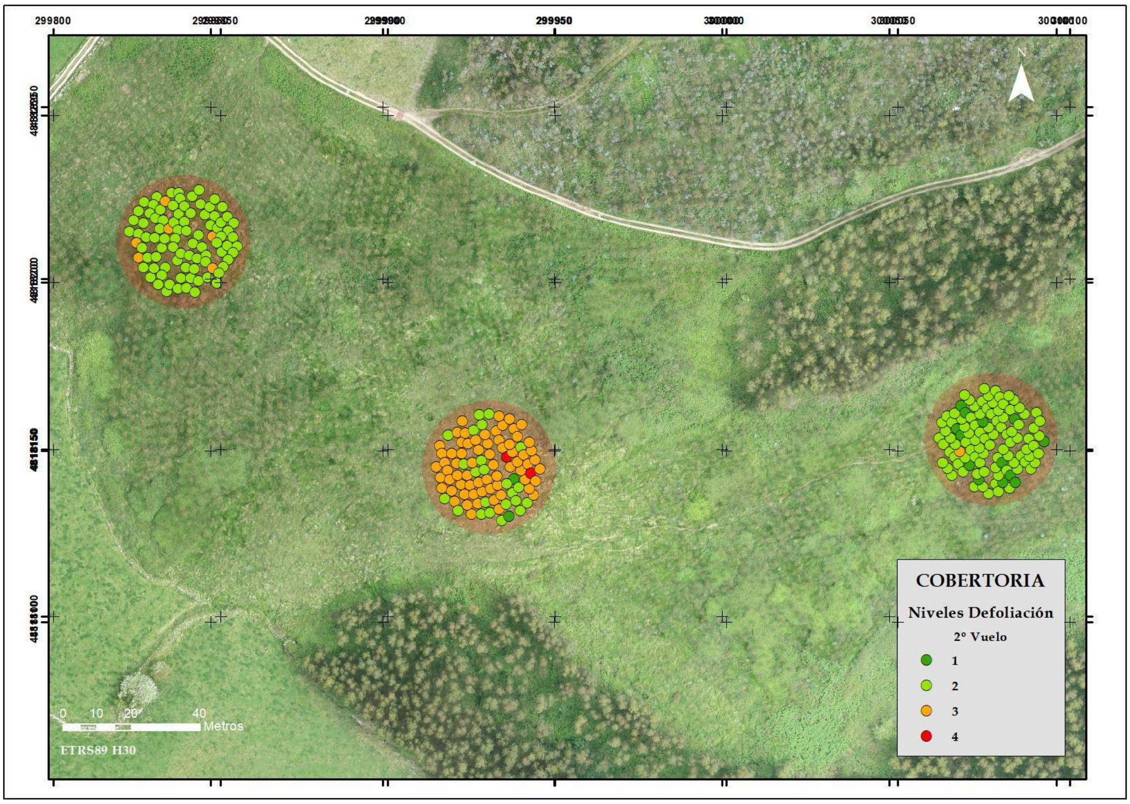


Figure 8. Detail of the plots situated in Cobertoria (Asturias)

In the case of Asturias (Figures 8 and 9), the first 2 levels of defoliation include 73.1% of the cases while in Cantabria they include 95.2% (Figure 10) In the case of Galicia, the situation is similar with 63.5% of the measurements in the first 3 levels. While it is true, that in this area there are more trees that belong to the higher categories of damage, which indicates a greater degree of attack.

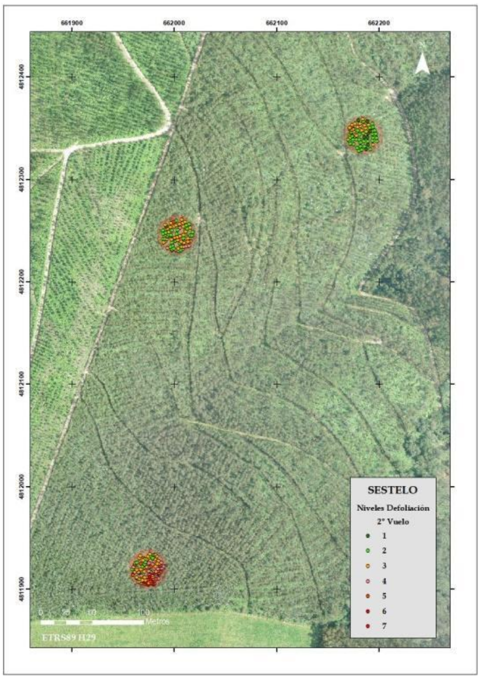


Figura 9. Detail of the plots situated in Cobertoria (Asturias)

Figura 10. Detail of the plot situated in Cantabria

Portugal is undoubtedly the most affected region, with practically half of the trees measured (49%) encompassed within the two highest categories of damage (6 and 7).

Table 6 .Porcentaje de árboles en cada nivel de defoliación

DEFOLIATION	DESCRIPTION	%PORT	% GAL	% CANT	%AST
1	No leaves eaten	7.5	51.6	12.6	9.1
2	<25% of leaves eaten recently	13.4	11.6	82.6	64
3	25% -50% of leaves eaten recently	8	5.3	4.7	21
4	50% -75% of leaves eaten recently	8.6	4.2		3.5
5	> 75% leaves and 1/4 of those leaves + 50% of their sup. Intact.	13.4	9.5	0.0	1.5
6	> 75% leaves eaten <1/4 of those leaves + 50% of their sup. Intact.	32.1	13.7	0.0	0.9
7	Total consumption of recent sprouting. Vestiges of petioles.	17.1	4.2	0.0	0.3

In the case of Asturias, which is the region where most flights have been made, in Figure 11 the evolution of the behaviour of the pest can be observed. In the months of April and May, the attack is slightly stronger, reaching 74 of the 281 trees in level 3 of defoliation. However, as of June the trees are able to re-sprout and reverse the damage to a certain extent, so that the number of trees in class 3 decreases considerably (from 74 to 2). Between June and October the trees that were in class 2 also decrease slightly (276 to 271), increasing the number of individuals in class 1 (3 to 8).

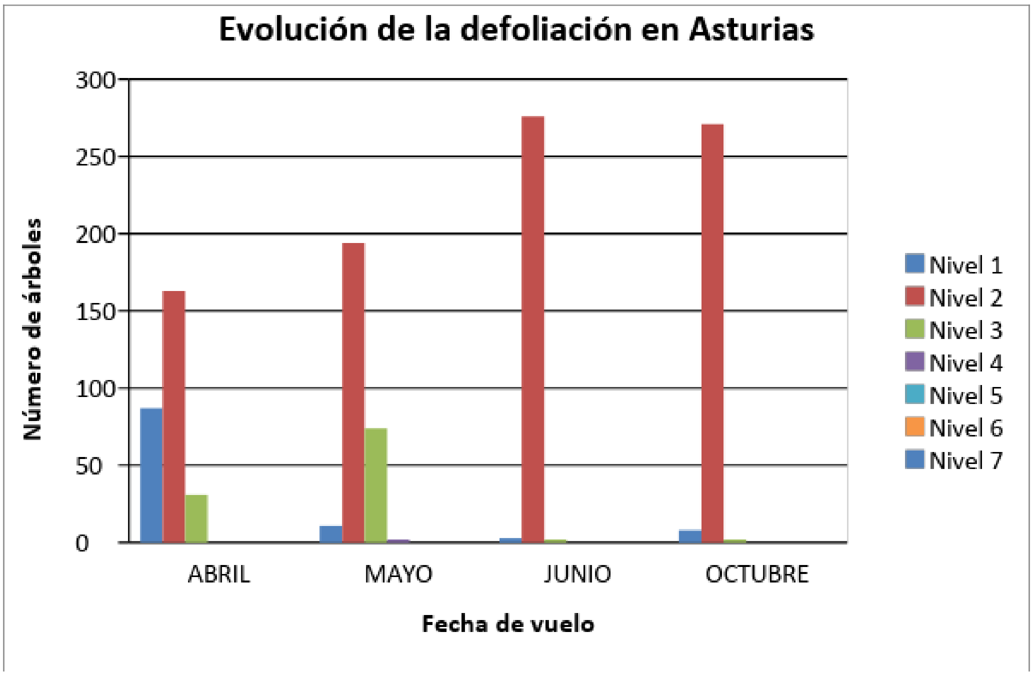


Figure 11. Defoliation levels evolution in Asturias (Cobertoria)

Statististical analysis

Indexes calculation at individual tree level (Asturias, Cantabria and Galicia):

The Spectral vegetation indices were subjected to principal component analysis (PCA). Their eigenvalues were used as assessment criteria. Only PCs with eigenvalues greater than 1 were chosen for the next step in this study.

In this study the front 3 principal component (PCI) spectra derived from the vegetation indexes, explained over 91% of defoliation variation as shown in Table 7.

Table 7. Global PCA analysis. Components matrix 1,2,3

	EIGENVALUES		
COMPONENT (PC)	TOTAL	% VARIANCE	% ACCUMULATED
1	9.851	70.367	70.367
2	1.801	12.867	83.234
3	1.109	7.920	91.155

Within the ranges of green, red-edge (RE) and NIR, the first three PCs showed an eigenvalue greater than 1. In the Green/Nir region, the first PC (PC1) was able to synthesize the major part of the total variance and the general behaviour of this spectral interval, as its component loadings were all equally weighted. The second component (PC2), which however explained only a low percentage of the total variance, was instead more related to the wavelengths of RE. The first two components explained respectively 70,3 % and 12,7% of the total variance.

As most of the variability of defoliation is explained in the 2 first principal components, an analysis of the vegetation indexes components is shown in table 8. The first component was more correlated to the index using wavelengths in the central part of the spectral interval. The second component was instead characterised by positive loadings using RE spectra.

Tabla 8. PCA analysis by index. Components matrix 1,2

VEGETATION INDEX	PC1	PC2	Group of indexes
NDVI_MEAN	0.979	0.124	Contain NIR band
GNDVI_MEAN	0.969	0.178	
IPVI_MEAN	0.979	0.124	
GCI_MEAN	0.947	0.160	
NLI_MEAN	0.929	0.142	
ARI2_MEAN	0.957	0.060 TB RE	
REGNDVI_MEAN	0.818	0.182	Contain RE band
NDRE_MEAN	0.774	-0.508	
ARI_MEAN	0.765	0.312	
REGCI_MEAN	0.787	0.514	
RENDVI_MEAN	0.725	0.634	
SAVI_MEAN	0.453	0.557	Do not contain either the NIR or the RE band
NGRDI_MEAN	0.270	-0.391	

According to the results exposed in Table 8, on the one hand those indexes containing NIR band have a very high correlation with defoliation values in the first component (PC1). On the other hand, those indexes containing RE band have reasonably high correlations with defoliation in the first and the second components (PC1 and PC2). However the indexes which don´t contain either the NIR or the RE band have a very low correlation with defoliation levels in both components. For that reason they are not sensitive at all to defoliation and must be removed in the next steps.

Indexes calculation at plot level (Portugal):

Results from correlation analysis between indexes values and defoliation at a level plot are shown in Table 9. Correlations values are low for all the indexes evaluated, the highest values were achieved by NDRE and REGCI indexes describing only around 30-35% of the variable defoliation. Both indexes contain a combination of NIR and RE bands.

Table 9. Correlation analysis results (Vegetation indexes-defoliation level)

VEGETATION INDEX	CORRELATION
NDVI_MEAN	0.178(**)
GNDVI_MEAN	0.154(**)
IPVI_MEAN	0.241(**)
GCI_MEAN	0.189(**)
NLI_MEAN	0.221(**)

NGRDI_MEAN	0.091(**)
NDRE_MEAN	0.344(**)
REGCI_MEAN	0.302(**)
RENDVI_MEAN	0.057(*)
SAVI_MEAN	0.119(**)
REGNDVI_MEAN	0.197(**)
ARI_MEAN	0.147(**)
ARI2_MEAN	0.206(**)

**Significant at level 0.01 (bilateral).

4. CONCLUSIONS

- In areas where the insect attack is weak, the capacity of the indexes to explain the variability of the defoliation is low. However, in areas where the attack of the insect is strong (4, 5, 6 and 7), the capacity of the indexes to explain the variability of the defoliation variable increases.
- The results obtained from this study show that Principal Components of vegetation indexes can extract valuable and compressed defoliation information by creating a new variable set with eliminated interband correlation and reduced dimensionality of the data.
- In the next step, Principal components which were highly loaded with the spectral information of defoliation will be considered as a feature component to create an "Improved index" specially designed for defoliation estimation.
- The images captured by multispectral cameras mounted on a UAV have proved to be a promising tool for the evaluation of damages by Gonipterus platensis, that in the near future will be able to serve as a support in both, the early detection and the management and control of the pest in Eucalyptus plantations

Some of future work approach that can be highlighted:

- Application of this methodologies in an integrated spatial platform for forest management
- Ability to use these methodologies to calibrate and validate models for calculations of variables, such as LAI (Leaf Area Index)
- Possibility of real-time integration of defoliation damages, LAI etc., in models to evaluate the effect on productivity at plot scale, or spatial scale.

TOOL FOR DEFOLIATION ASSESSMENT IN *EUCALYPTUS GLOBULUS* PLANTATIONS THROUGH THE USE OF MULTISPECTRAL CAMERAS MOUNTED ON A *UAV*

Tool description

The tool will be based on the use vegetation indexes of the interest area to assign a defoliation level to each classified into categories that allow assigning a level of damage to Gonipterus for each part of the study area. The final aim will be to develop an “improved vegetation index” with high sensitivity to changes in defoliation levels.

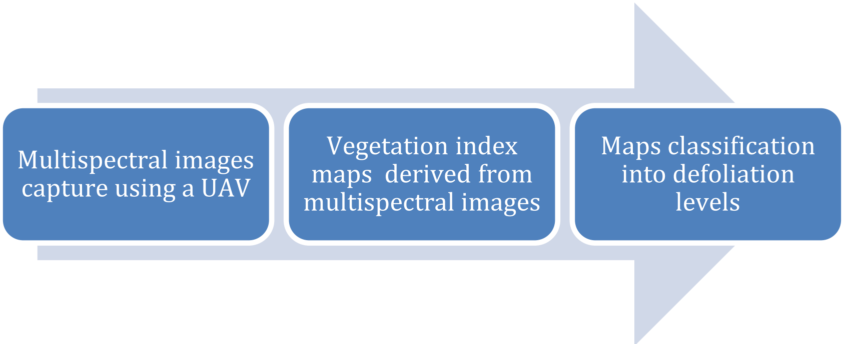


Figura 12. Workflow to assess defoliation with the tool

<u>Multispectral images capture using a UAV</u>

Guidelines

- **<u>Platform characteristics</u>**

For data collection the recommended platform is a UAV (Unmanned Aerial Vehicle) that can be fixed or rotary wing. Fixed wings, as they are gliders, have higher autonomy and allow data capture on large surfaces. Due to this fact, their use is recommended when the surface to monitor is extensive. However, rotating wings can also be suitable for data collection as long as they have sufficient autonomy to fly the area of interest.

It is recommended the use of a UAV that can work with an RTK positioning system (Real Time Kinematic) to avoid the need to do post-processing work in the office and topographic support in the field, although it is not an essential condition.

- **<u>Sensor type</u>**

Light reflectance in the plants, is a complex phenomenon that depends on multiple biophysical and biochemical interactions. The visible range (VIS 400 to 700 nm) is mainly influenced by the content of foliar pigments. The reflectance of the near infrared (NIR 700 at 1,100 nm) depends on the structure of the leaves, the processes of internal dispersion and the leaves water absorption. The short-wave infrared (1,100 to 2,500 nm) is influenced by the chemical composition of the leaves and water. Red edge captures a critical part of the plant light spectrum (712-722 nm), called the red border band. In this region of the spectrum is where the first signs of stress begin to appear.

For all above, it is recommended to use a sensor whose bands are between the green, red and near infrared ranges, including the red edge (where the vegetation presents its greater response of absorbance and reflectance). The ideal situation is to use a sensor with discrete bands spectral bands instead of non discrete ones (Figure 13) so there is no overlap between the spectral information which can cause problems of noise when calculating the vegetation indexes. The treatment of these images not only requires geometrical correction, but also requires radiometric calibration operations and atmospheric corrections (necessary for obtaining validated reflectance data). Thus, the selected sensor must have a system for making such corrections, such as a target with known albedo values.

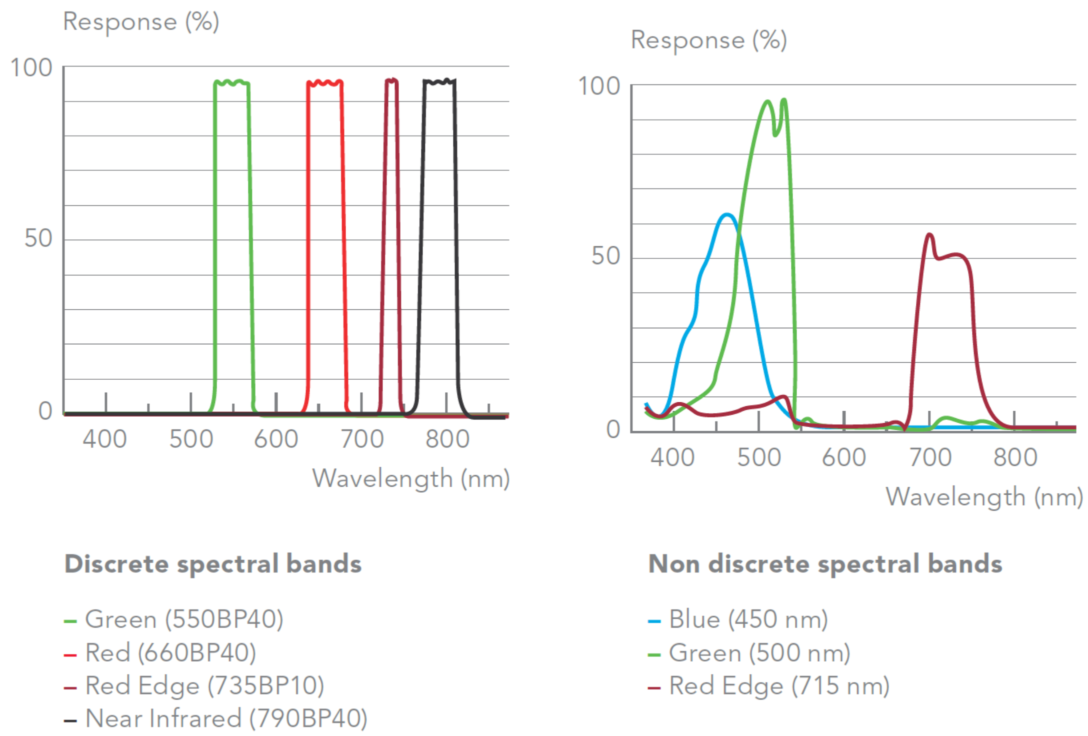


Figure 13. Differences between discrete and non discrete spectral bands

- **<u>Flight planning</u>**

Planning is a crucial aspect when making a flight with a UAV, on the one hand to collect data with sufficient quality, and on the other hand, to ensure all the activities are done safely for people and for the environment.

Regarding to data quality, it is essential that image capture is done in a planned manner, following pairs of parallel lines and guaranteeing a minimum overlap between images. For this reason, the use of a flight planning software that facilitates the design tasks is fundamental.

There are three aspects that are key when it comes to photogrammetry with drones:

1. The flight trajectory
2. Images overlap

3. Camera position

These three elements are determined by a common need: for a detail to be faithfully reconstructed, it is necessary to appear in a minimum number of photographs. The more varied and numerous the points of view, the more abundance of useful information when processing.

The trajectory to follow must be always a grid, with minimum theoretical overlaps of 75% (frontal) and at least 60% (lateral). However, in difficult areas where vegetation is highly homogeneous (as Eucalyptus plantations), it may be necessary to increase the frontal overlap to 80-90% and the lateral to 70-80%. The position of the camera will be completely perpendicular pointing to the ground (zenithal plane).

Flight height cannot exceed 120 m due to current legislation, so this is the reference value for taking photographs. The higher the UAV flies, the more surface it can cover in a flight but also the less resolution in the obtained images. For the calculation of vegetation indices with a spatial resolution of approximately 10 cm, 120 meters is a reasonable height.

- **<u>Flight conditions</u>**

Climatic conditions when taking pictures, must be taking into account, to minimize the effect of shadows. Images should always be taken in RAW format.

In relation to safety, in addition to planning the entire bureaucratic and operational part, the technical specifications and limitations specified by the manufacturer in the manual of the selected UAV must always be taken into account in order to stay within the margins of maximum mass, wind limits, outside temperature etc. The pilots in command have to be informed about the environmental phenomena that will take place at the date and place foreseen for the operation. The flight preparation therefore requires:

• Study of updated weather forecasts.

• Planning of alternative measures in case the flight cannot be completed as planned due to weather conditions.

• Thorough analysis of the terrain, obstacles, and the possibility of interfering with other aircrafts.