

**Zamorano Pan-American Agricultural School
Department of Environment and Development
Environment and Development Engineering**



Graduation Special Project

**Classification of land use and land cover on three cattle farms within
the buffer zone of the Río Plátano Biosphere Reserve, Honduras**

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Abstract

In the last few decades changes in land use and land cover (LULC) have created pressure on natural ecosystems, altering their processes. This phenomenon is evident in the Rio Plátano Biosphere Reserve, where the expansion of the agricultural frontier within the buffer zone has created pressure on its natural resources, generating concern. This is why this descriptive, non-experimental study was done. The main objective of the study was to classify LULC on three cattle farms within the buffer zone of the reserve, to quantify them and establish a baseline for future monitoring. To achieve this, a photointerpretation analysis using multispectral and RGB images captured by an EbeeAg® drone was done. Subsequently, the Pix4D® software was used for the primary processing of the images. Furthermore, the classification process for LULC, the by-products, and the cartographic design of the maps were generated with the ArcGIS® and Surfer® software tools. Finally, a flight protocol and pre-processing images manual was made. As a result, a total of 12 land use and land cover classes were created and, an average of moderate to abundant vegetation cover and a slope range from 15-60% on the cattle farms were found. It is concluded that within the three farms the predominant land use was pasture and Nueva Esperanza was the farm with the most abundant tree cover (23.52%). Finally, those maps can be a valuable information for the generation of a land use capability classification of the cattle farms.

Key words: Land cover, land use, livestock, photointerpretation, protected area

Resumen

En las últimas décadas los cambios en el uso y cobertura del suelo han creado presión sobre los ecosistemas naturales, alterando sus procesos. Tal es el caso de la Biosfera del Río Plátano, donde la expansión de la frontera agrícola dentro de la zona de amortiguamiento ha creado presión a sus recursos naturales generado una gran preocupación. Es por ello que se realizó este estudio descriptivo, no experimental. Cuyo objetivo principal es clasificar los usos y coberturas en tres fincas ganaderas dentro de la zona de amortiguamiento de la reserva para cuantificarlas y establecer una línea base de monitoreo. Para ello, se realizó un análisis de fotointerpretación mediante imágenes multiespectrales y RGB captadas por un dron EbeeAg®. Posteriormente, se utilizó el “software Pix4D®” para el procesamiento primario de las imágenes. Además, el proceso de clasificación de los usos, los subproductos y el diseño cartográfico de los mapas fueron generados con el “software” de “ArcGIS®”. Finalmente, un manual de protocolo de vuelo y pre-procesamiento de imágenes fue realizado. Como resultado, 12 clases de uso y cobertura fueron creados, y se encontró un promedio de cobertura vegetal de moderado a abundante y un rango de pendiente de 15-60% en las fincas. Se concluyó que dentro de las tres fincas el uso del suelo predominante fue pastizales y Nueva Esperanza fue la finca con la cobertura arborea mas abundante (23.52%). Finalmente, se puede mencionar que estos mapas son de gran utilidad para determinar la capacidad de uso del suelo.

Palabras clave: Área protegida, cobertura del suelo, fotointerpretación, ganadería, uso del suelo

Introduction

Human activities have been dependent on the use of land. Land has been an important source of supplies such as food, fresh water, ecosystem services, and biodiversity. Moreover, land provides us with the basis for many other ecosystem functions and services, including cultural and regulation services (Intergovernmental Panel on Climate Change [IPCC], 2017). Land ecosystems are the basis for the maintenance of life systems on the planet. However, the rapid growth of cities, industries, and industrialized agriculture have created changes on the land surface. These changes range from clearing tropical forests to intensifying farmland production, to the expansion of urban centers (Foley et al., 2005). According to the report of land use statistic, about 4.8 billion ha, one-third of the global land area, were occupied by crops in 2019 and about two-thirds were permanent meadows and pastures that were used for livestock (Food and Agriculture Organization of the United Nations [FAO], 2022). The impact caused by Land use and Land Cover (LULC) will depend on the development of the economic activity, the type of crop implemented in the area, and whether the cropland reverts to something similar to the original vegetation, or if it is maintained or transformed into an urban landscape (Noblet-Ducoudré et al., 2012). The progressive growth of unsustainable agriculture and livestock can create negative modifications to forest areas, increasing susceptibility to erosion, loss of soil nutrients and thus generating low crop production (Orozco et al., 2004). Moreover, LULC can contribute to greenhouse gas emissions, habitat destruction, and hydrologic modifications. Furthermore, some studies mention that LULC not only negatively affects the patterns of climate, but also the socio-economic dynamics on a global and local scales (Reis, 2008).

Technological advances within agricultural systems are necessary to provide a rapid response for the creation of natural resource management and conservation systems. The applications of technologies such as remote sensing can help us to monitor changes in vegetation cover and land uses. Remote sensing involves collecting data from a distance, then analyzing and interpreting the collected data for specific purposes (Parece & Younos, 2015). The application of these technologies

becomes an important issue in the context of conservation, as it allows us to study the status of important coverages, such as forest, wetlands, and areas with a necessary degree of conservation. Likewise, it not only allows us to determine the type and quantity of cover of a place, but also allows us to determine the quality and development of the vegetation we are observing. Obtaining knowledge about land use and land cover gradually becomes important in the context of national and local planning, since this information can help us to overcome uncontrolled development, deteriorating environmental quality, loss of prime agriculture lands and destruction of important wildlife habitats (Anderson, 1976).

The classification of satellite images by remote sensing has been widely applied for land cover classification. However, the use of drones in the last few decades has become popular. This device provides us with an alternative to obtain high spatial and spectral resolution images. The advantage of using drones is that they can be flown when needed and do not depend on an already established temporal resolution as in the case of the use of satellites. Drones provide us with a fast and systematic way to observe images of different phenomena that occur on the earth's surface with a high temporal and spatial resolution (López & Mulero-Pázmány, 2019). On the other hand, drones have become a useful tool to assist monitoring activities within protected area (Bollard et al., 2022; Duffy et al., 2020). Protected areas can be grouped into different categories such as National park, Natural monument, Nature conservation reserve, Multiple use management area, World heritage site, etc (International Union for Conservation of Nature [IUCN], 2004). These areas can help to safeguard natural and cultural resources, protect human health and well-being, and support sustainable development. The Rio Plátano Biosphere Reserve is home to a variety of species and ecosystems and is considered as one of the most important protected areas in the Honduran biological corridor. Moreover, the Rio Plátano Biosphere Reserve is considered by the United Nations Educational, Scientific and Cultural Organization (UNESCO) as one of the World Heritage of Humanity sites. However, this reserve has been jeopardized mainly by agricultural frontier expansion and livestock, which are the primary source

of food for the inhabitants (Instituto Nacional de Conservación y Desarrollo Forestal Áreas Protegidas y Vida Silvestre [ICF], 2015). Illegal logging and commercialization of the forest in the core and buffer zones are major problems for the area's natural systems (ICF, 2019). To conserve the Rio Plátano Biosphere, its biodiversity and the ecosystem services it provides us, it is necessary to look for alternatives for the creation of management and sustainable production actions that can stop the advance of the agricultural frontier in this territory. An example of these actions is the MiBiosfera Project that Zamorano and other partners are implementing with the support of the European Union. Zamorano has proposed different technical studies of the cattle farms under intervention, one of which is the classification of uses and covers to quantify them and thus establish a baseline to monitor possible changes at the end of the intervention (2025). This study aims to achieve the following objectives: a) To classify the land use and land cover of three cattle farms in the buffer zone of the Río Plátano Biosphere through photointerpretation analysis applied to multispectral and RGB drone images. b) To characterize the relief of three cattle farms using a grid of elevation points produced by drone flights. And, c) To establish a flight protocol and image processing manual using multispectral and RGB drone imagery to be applied to the rest of the farms under the project intervention.

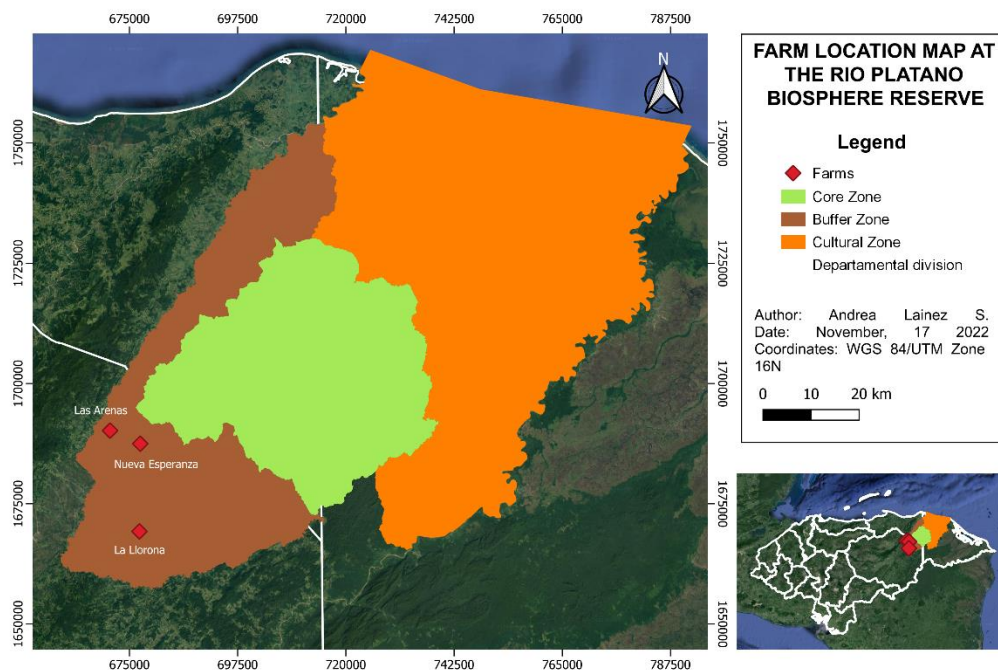
Methodology

Research Area

The Rio Plátano Biosphere is located in the northeast part of Honduras, at the intersection between the provinces of Gracias a Dios, Olancho, and Colón. This covers a total area of 832,344.10 ha and is composed of three zones: Core Zone with a total area of 210,733.19 ha, Buffer Zone with a total area of 197,441.99 ha, and Cultural Zone with a total area of 424,166.92 ha (ICF, 2013). The research area was focused on three cattle farms within the southern part of the buffer zone of the Rio Plátano Biosphere Reserve, in the province of Olancho in the municipality of Dulce Nombre de Culmí (Figure 1). The climate in this region is characterized as tropical-humid, with rainfall distributed mostly from May to January. The coordinates in UTM WGS 84 zone 16N of the three farms correspond to: i) $x = 677283$, $y = 1687677$ (Nueva Esperanza); ii) $x = 670983$, $y = 1690012$ (Las Arenas); iii) $x = 677226$, $y = 1669442$ (La Llorona).

Figure 1

Farm Location Map in The Rio Plátano Biosphere Reserve



Research Design

This is a descriptive, non-experimental study. It is a descriptive study because it aims to specify the characteristics of land use and land cover on three cattle farms within the buffer zone of Rio Plátano Biosphere Reserve. In addition, it is a non-experimental study because there is no manipulation of the study variables.

Data Collection

First, the delimitation of the farms was carried out in cadastral areas, with usufruct contracts (CUF) by the field technicians of the MiBiosfera Project. At the same time, the delimitation of each farm was validated with the farmers. The photogrammetric images were then taken from each plot of the cattle farms with the help of a fixed-wing EbeeAg[®] drone, by means of a previously planned flight. The images were taken by a sense fly Duet M with a Red, Green and Blue (RGB) color model and Multi-spectral camera with 4-band green (550 nm ± 40 nm), red (660 nm ± 40 nm), red edge (735 nm ± 10 nm) and near infrared (790 nm ± 40 nm). The multispectral resolution of this sensor was 1.2 Megapixel (MP), (1280 × 960 px). For the drone flight plan, the eMotion[®] software was used. With eMotion[®], the flight plan was designed using mission blocks and the area to be mapped was marked. Also, the main settings were defined, and the eMotion[®] software automatically generated the drone's flight plan. The parameters considered during the flight planning process encompassed altitude (set at 100 meters), overlap (with a value of 70%), resolution, wind speed and direction, as well as weather conditions.

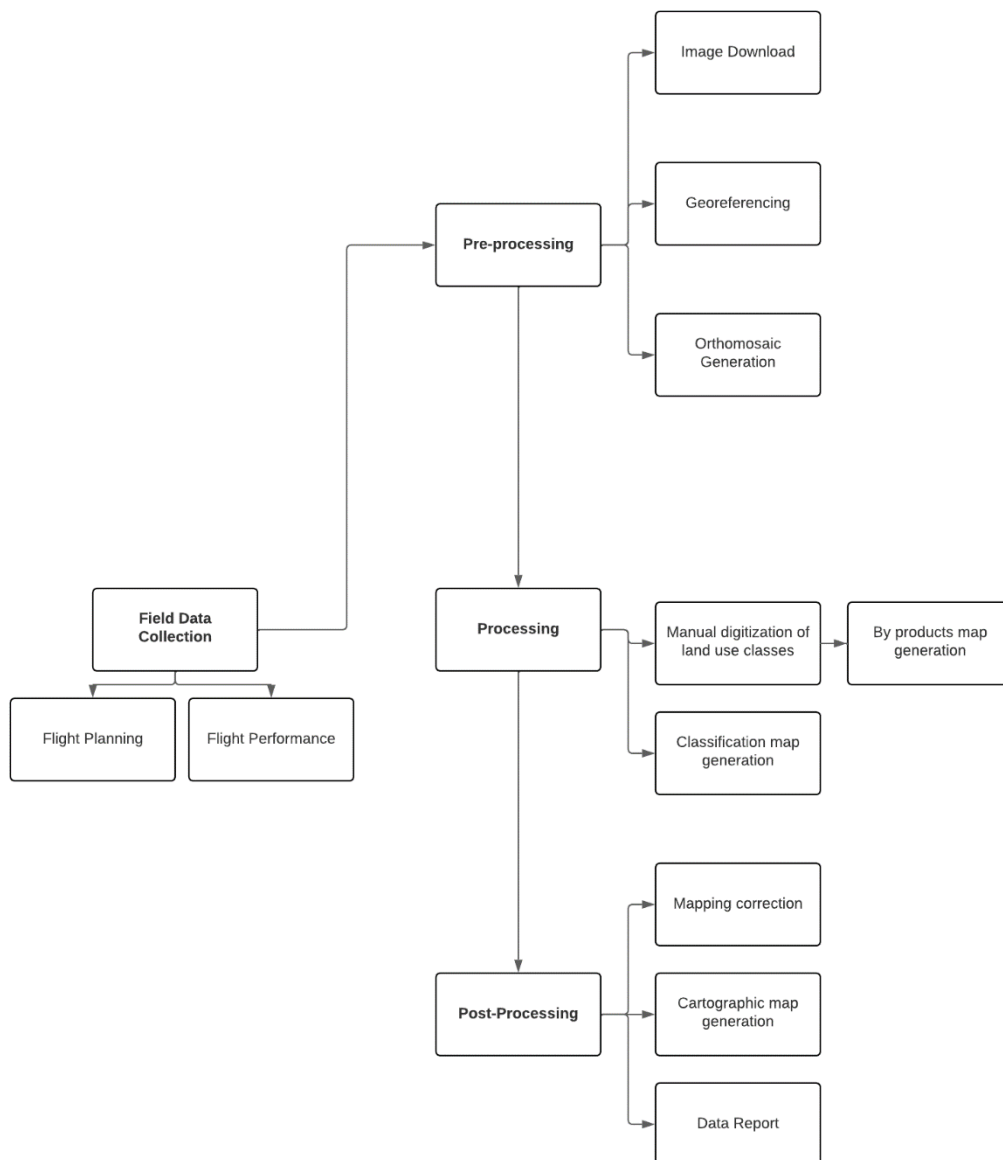
Image Processing

The images collected by the drone for the Land Use and Land Cover classification categories were subjected to a visual image interpretation. When analysing aerial images, some of the objects observed were easily identified while others were not. An image interpreter made a physical analysis of objects and phenomena on the images and the success of an accurate interpretation will depend on the understanding of the phenomena, knowledge of the geographical region studied and the

experience of the interpreter (Lillesand et al., 2015). On the other hand, a supervised classification of the by-product maps such as Slope and Normalized Difference Vegetation Index (NDVI) was carried out. Supervised classification creates rules that allow new objects with known measurements to be classified using samples of existing items (J. Hand et al., 2001). For the mapping generation process, it was divided into three parts: Pre-processing, processing, and post-processing (Figure 2). These phases were carried out using Pix4D® and ArcGis® software.

Figure 2

Description of the process of Land Use and Land Cover Classification



Pre-processing

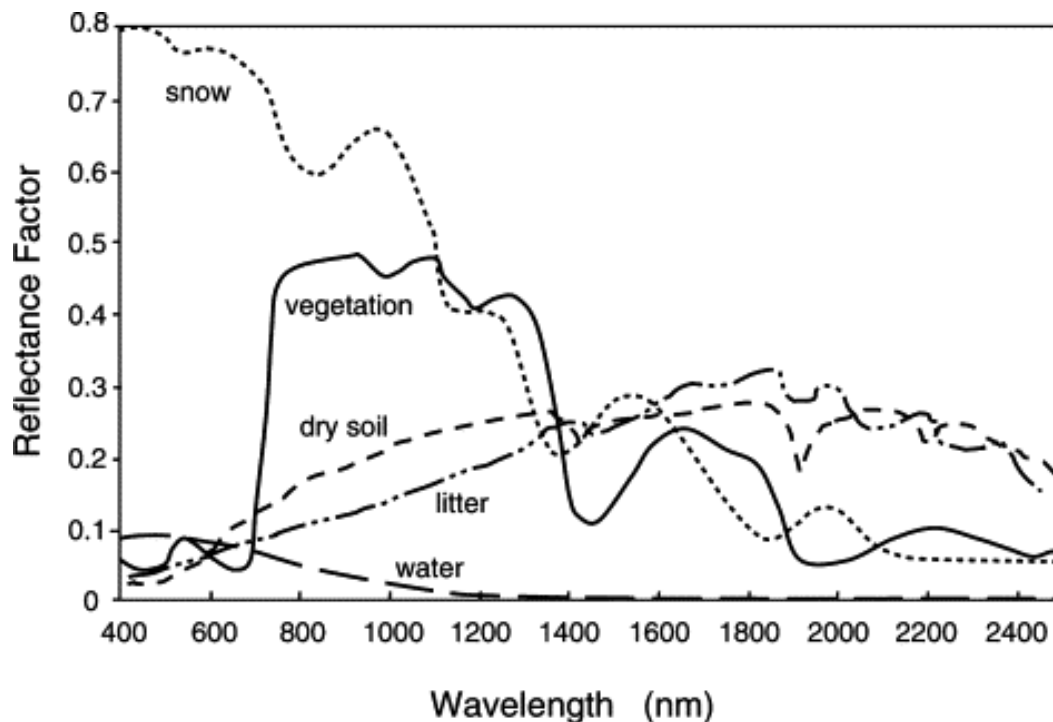
The images were transferred from the drone to the computer. Second, the georeferencing of the images and the generation of the orthomosaic and extra products like contour lines were created from the drone images using the Pix4D® software. An orthomosaic is the composition of multiple images captured by the drone and grouped together to form a single image. An orthomosaic gives us a comprehensive perspective of an area and helps the human operator to identify areas of interest. Aerial photos are corrected for perspective and camera distortion using the camera location information, resulting in an orthomosaic image that is true to scale and has a map projection throughout (Hinzmann et al., 2018). One important parameter to consider when generating an orthomosaic is the overlap of the images taken by the drone. Multiple studies have found a correlation between the overlap and the quality of the orthomosaic generation (Dandois et al., 2015; Flores-de-Santiago et al., 2020; Li et al., 2018). Moreover, Torres-Sánchez et al. (2018) found that overlapping influences the computation time and digital surface model accuracy on unnamed aerial devices (UAV) images.

Finally, an important parameter considered for the orthomosaic generation of the multispectral images was the spectral reflectance taken for each band. The spectral reflectance gives us important information about an object. Every single material, vegetation, soil, water, etc. reflects the sun's radiation in a different way, which allows us to distinguish them from each other (Artiola et al., 2004). Moreover, the spectral signature provides information about the respective wavelength for each reflectivity. An example of a spectral reflectance curve for vegetation, soil and water is shown in Figure 3. This allows us to distinguish between different types of vegetation or even different types of soil. In vegetation, the spectrum is determined by the pigmentation of the chlorophyll of the plant. Chlorophyll absorbs strongly in the blue (450 nm) and red (670 nm) regions; those are known as the chlorophyll absorption bands (Govender et al., 2009). It is important to point out that the spectral

reflectance curves provide us with a graphic representation of the spectral reaction of a material over different wavelengths of the electromagnetic spectrum.

Figure 3

Spectral Reflectance Curve for Vegetation, Soil and Water



Note. Retrieved from Huete (2004).

Processing

In this phase, once the orthomosaic was generated by the Pix4D® software, it was imported into the ArcGIS® software, along with the delimitation of each of the farms, and a manual digitization of the different land use and land cover classes was performed. Also, a digitalization of scattered trees in the farm paddocks was made. The manual digitization was performed under photointerpretation criteria and with the help of technical field personnel and the farm management plan proposal. Some of the visual parameters that are handled in the interpretation of aerial photographs are tone, texture, structure, shadow, size, shape, temporal criteria, context, association, etc. (Chuvienco Salinero, 2000; Jensen, 2014). For this project, the spectral criteria (brightness, color), special simple criteria (shape, size, texture) and complex criteria (shadow, context, and association) were used. Finally, the 12

different land use and land cover classes generated were adapted using the Corine land cover nomenclature by following the Corine land cover technical guide (Bossard et al., 2000). These classes are shown in Table 1.

Table 1

Land Use and Land Cover Classes Adapted Nomenclature

Classes	Description
Broad-leaved forest	A region covered in forests and woodlands that has a coniferous and/or deciduous tree companion that is either native or imported that may be used to create timber or other forest products. Most of the land is covered by buildings.
Discontinuous urban fabric	Discontinuous yet major surfaces are occupied by structures like buildings, roads, and artificially surfaced regions that are connected to bare soil and vegetated areas.
Grassland	Land occupied by grasses, especially used for cattle grazing.
Industrial or commercial unit	Most of the land is made up of artificially paved areas without any flora, along with structures and/or vegetation.
Live fences	Field boundaries formed by trees or shrubs.
Transitional Woodland /shrub	Transitional bushy and herbaceous vegetation with occasional scattered trees.
Water courses	Natural watercourses serving as water drainage channels. Includes canals.
Annual crop	Crops that complete their cycle in a single growing season.
Artificial water bodies	Artificial watercourses serving as water drainage channels. Includes canals.
Permanent crops	All surfaces occupied by permanent crops, not under a rotation system.
Corrals	Enclosure for confining livestock.
Pastures	Grass is the dominant flowering species in the dense herbaceous cover, which is not rotated, although it is harvested mechanically.

By-Product Analysis.

Once the orthomosaic and the Digital Elevation Model (DEM) of the images were generated by the Pix4D® software, the data was then imported into the ArcGIS® software and processed to visualize the DEM. In simple words, a DEM is a representation of the earth's elevation at different locations. DEM are commonly available on GEO tiff raster format. Once the DEM was imported into

the software, a slope map was generated with the ArcGIS® slope tool based on the DEM map and then a reclassification of the layer was performed with the help of a reclassifying tool. The slope gradient class used was defined using the slope gradient classification provided by FAO (2006). The slope can be defined as the angle, inclination, or gradient of a straight line where it describes the steepness of the ground's surface (Mokhtar et al., 2019). The main importance of the analysis of this element lies in the fact that it is an important tool for landslide monitoring and prevention; it helps us to describe landforms, to model surface runoff and to estimate slope erosion potentialities (Miliareisis et al., 2005; Oorthuis et al., 2021; Pennock, 2003). At the same time, determination of slope is important for establishing the type of agriculture, yields and methods of cultivation in an area (Fombe & Tossa, 2015). In addition, a flow direction map based on the DEM was generated with the help of the Surfer® software. Flow direction maps are an important tool for identifying the areas of accumulation, their direction, and the areas contributing to runoff on land surfaces (Viji et al., 2015).

Additionally, a Normalized Difference Vegetation Index (NDVI) was generated. The NDVI is mainly used to discriminate between two covers with very different reflective behaviors (Chuvieco, 2015). In other words, this index helps us to discriminate between vegetation masses, and helps us to determine their health and the vegetated areas by means of the radiometric behavior of the vegetation, using the near-infrared and red bands. The spectral signatures of healthy vegetation generally show a behavior where the plant's chlorophyll absorbs visible red light and reflects near infra-red light. When a plant is under stress from pests, diseases or water stress, its reflectivity decreases in the near infra-red band and increases in the red band, as there is less absorption by the chlorophyll (Chuvieco, 2015).

Finally, the NDVI values range from -1 to +1, where a -1 value can represent an unhealthy vegetation or unvegetated area, and a +1 value can represent an abundant or a healthy vegetated area. The DEM, slope, contour lines and NDVI map will be used to guide management actions on each farm. Every farm has a management plan, whose objectives are essentially based on the regeneration

of the landscape and the sustainable use of resources. These variables are important to establish the management category and management actions that will lead to a sustainable use of resources and conservation of ecosystems.

Post-Processing

After classifying the images captured by the drone, the cartographic design of the classification of land use and land cover, Slope, NDVI and Contour lines was done using the ArcGis® software. And finally, the maps went through a correction process through the application of the following tools in the ArcGis® software as well.

Majority Filter

This filter re-samples the cells in a raster according to the majority value of the neighbor cells.

Boundary Clean

This tool allows us to simplify a raster by smoothing the boundaries between zones.

Region Group

This tool helps us to make our own zones, focal statistics to smooth hill shade, reclassify to change values, and point density to create a density surface.

Set Null

The set null tool allows us to identify cell location to no data based on a specific criterion.

Nibble

This tool allows us to assign the value of the nearest neighbor of a raster by selecting an area of it.

Flight Protocol Manual Creation

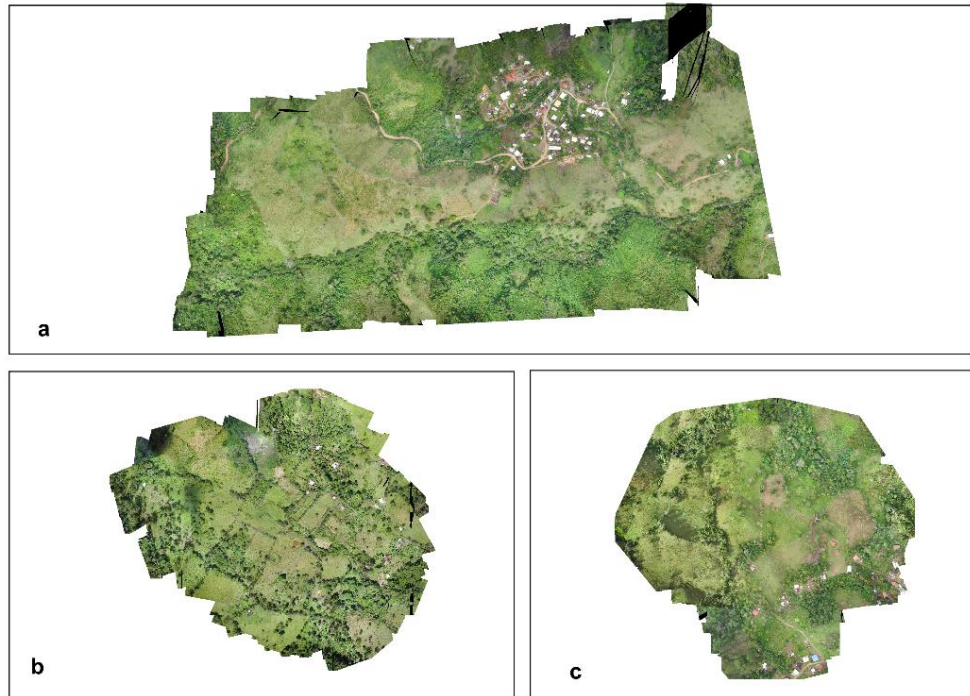
The creation of the flight protocol manual and pre-processing of RGB and multispectral images were first carried out by a literature and multimedia review about the specifications and applications of the equipment and programs to be used. Next, training on each of the physical parts of the eBee Ag® drone and its operation was conducted. At the same time, training of Pix4D® and ArcGIS® software operation was done. This knowledge was complemented and put into practice with field visits to farms

within the buffer zone of the Río Plátano Biosphere Reserve and the Zamorano campus (Annex A). After having more specific knowledge about the operation of the equipment and program to be used, the contents of the manual were defined. The manual contains seven sections divided into the following: Introduction, pre-flight information, preflight protocol sheet, flight planning design with eMotion®, drone to computer image transfer, Pix4D® RGB image processing, Pix4D® multispectral image processing, quality report example and interpretation.

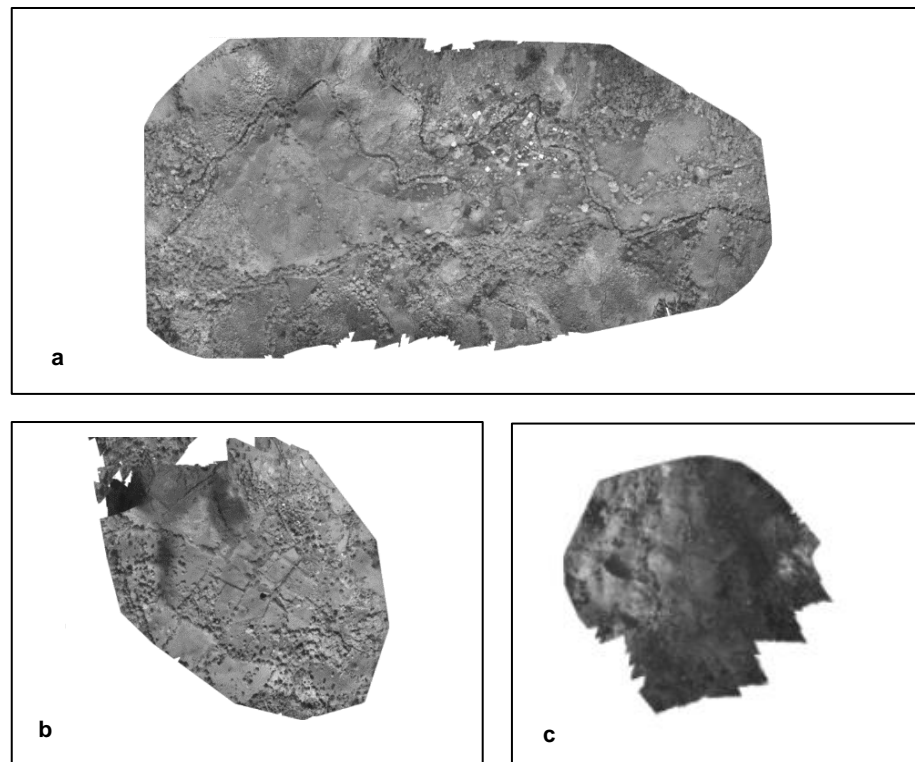
Once the parts of the manual had been defined, the development of the manual began. The manual contains step-by-step information on the use and procedures for obtaining and processing RGB and multispectral images with the eBee Ag® fixed-wing drone. Also, it includes instructions for safe operation of the drone, as well as efficient time management and organization of the collected data. With the help of the manual, the users are able to learn about the factors to be considered prior to a drone flight, learn about the different stages of data processing and data collection, and learn about photogrammetric data processing in Pix4D® as well.

Results and Discussion

A photointerpretation analysis was carried out to determine the actual status of land use and land cover on each cattle farm under the study intervention. It is important to mention that all the farms have a cadaster registration and have a usufruct contract, at the same time all the study farms have a dual-purpose production system and cacao production in the case of the Las Arenas and Nueva Esperanza farms. Some of the factors analyzed through the photointerpretation process were the different land use and land cover present on the farms. The slope, elevation, Normalized Difference Vegetation Index (NDVI) and the presence of scattered trees in the farm paddocks were considered as well. As a result of the drone flights, a combined total of 180 RGB images were captured for the La Llorona farm, but the quality report generated from the Pix4d® software showed that only 142 images could be calibrated and therefore used for the orthomosaic generation of this farm (Figure 4a); each image had a resolution of 0.058 meters. Similarly, 133 images were captured of the Nueva Esperanza farm, but only 125 could be calibrated and used for the orthomosaic generation (Figure 4b); each image had a resolution of 0.042 m. Additionally, 146 images were captured of the Las Arenas farm, but only 140 were utilized for the final orthomosaic generation (Figure 4c); each image had a resolution of 0.042 meters.

Figure 4*RGB Orthomosaic Images Generation*

In addition to the RGB images, a total of 1,408 multispectral images were captured specifically of the La Llorona farm (Figure 5a). Furthermore, 1,040 images were captured of the Nueva Esperanza farm (Figure 5b), and 1,128 images were captured of Las Arenas farm (Figure 5c). The quality report generated showed that 100% of the images of each farm could be calibrated and therefore used for the multispectral orthomosaic generation.

Figure 5*Multispectral Orthomosaic Images Generation***NDVI-Analysis**

Throughout the use of multispectral imagery, with the red and near infrared bands, NDVI maps were generated of each farm to determine the status and the areas occupied by vegetation on the farms. It is possible to monitor vegetation and its health throughout the spectral reflectance provided by its chlorophyll. The NDVI values taken from the La Llorona farm (Figure 6) show that in the northern part of the farm values between 0.59 and 0.94 were found. This is associated with high, dense vegetation according to the NDVI values classes from different objects (Table 1) established by Korchagina et al., (2020). On the other hand, in the middle part of the farm, the values go between 0.42 and 0.69. Finally, the values on the southern part of the farm are in the majority 0.42 to 0.69, which is associated with sparse vegetation in the area. Also, the south-western part of the farm

presented values in the majority that go from 0.69 to 0.94 - this due to the presence of broad-leaved forest located near a stream.

Table 2

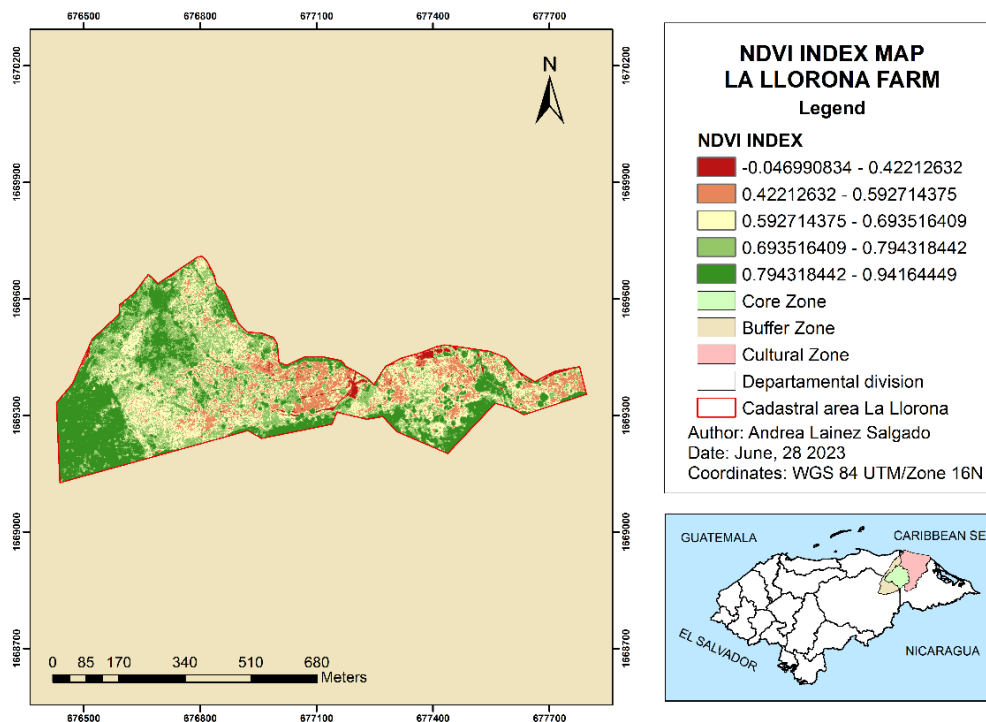
NDVI Values for Different Types of Objects

Type of object NDVI value	NDVI Value
High, dense vegetation (forest)	0.7 – 1.0
Sparse vegetation (shrubs, pastures)	0.2 – 0.5
Open soil	0.025 – 0.2
Clouds	0
Snow, ice, dust, rocks	-0.1 – 0.1
Water	-0.42 - -0.33
Artificial materials (concrete, asphalt)	-0.5

Note. Retrieved from Korchagina et al., 2020.

Figure 6

La Llorona Farm-Normalized Difference Vegetation Index (NDVI) map

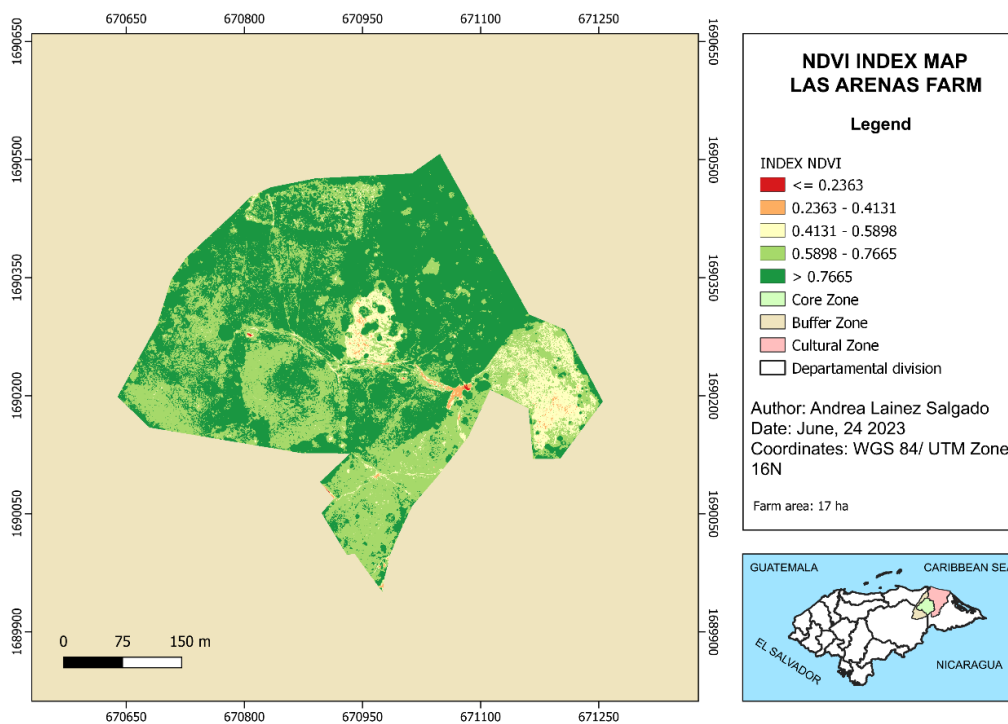


On the other hand, the NDVI values taken from the Las Arenas farm (Figure 7), show more healthy and vegetated areas than the La Llorona farm. In the northern part of Las Arenas, NDVI values

between 0.58 and > 0.76 were found, which suggested areas with high vegetation and sparse vegetation. Thus, areas coincide with the land occupied by shade coffee, cacao, cut grass, and annual crops. In the same way, in the southern part of the farm, values go between 0.58 and 0.76. Finally, the values in the south-eastern part of the farm, in the majority, go from 0.41 to 0.58; the values near zero area associated with no vegetation cover such as bare soil or water bodies, while values near +1 indicate a very vegetated area, normally associated with forest (Choubin et al., 2019).

Figure 7

Las Arenas Farm- Normalized Difference Vegetation Index (NDVI) Map

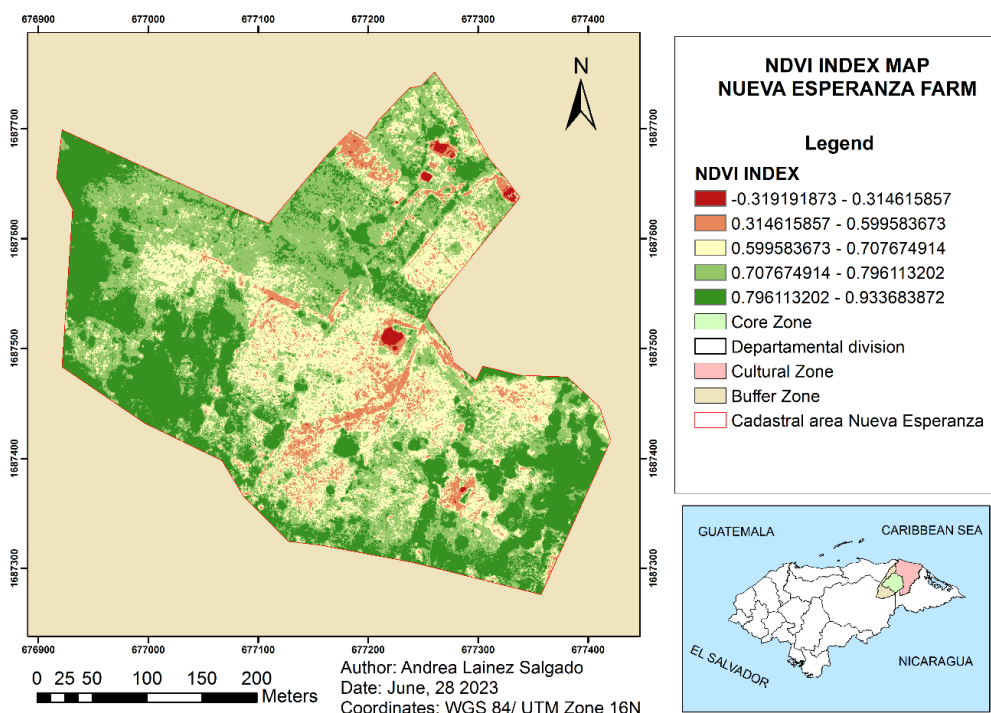


Finally, the results taken from the NDVI map of the Nueva Esperanza farm (Figure 8) show that most of the area presents values from 0.70 to 0.93. In the center of the farm, most of the area shows values from 0.59 to 0.31. The low vegetation present in these last values could be linked to overgrazing in the area. The importance of the knowledge of the areas covered with vegetation on each of these farms lies in the fact that it can help us to conduct conservation activities on the farms, since vegetation cover has a high effectiveness on the regulation of soil erosion, runoff and prevention

of landslides (Tang et al., 2021; Yao et al., 2018; Zhu et al., 2010). This is due to the roots of plants that help to stabilize the soil and vegetation cover and create protection against the impact of raindrops. At the same time, vegetation can help conserve the physical, chemical and biological properties of the soil (Scavo et al., 2022).

Figure 8

Nueva Esperanza Farm- Normalized Difference Vegetation Index (NDVI) Map

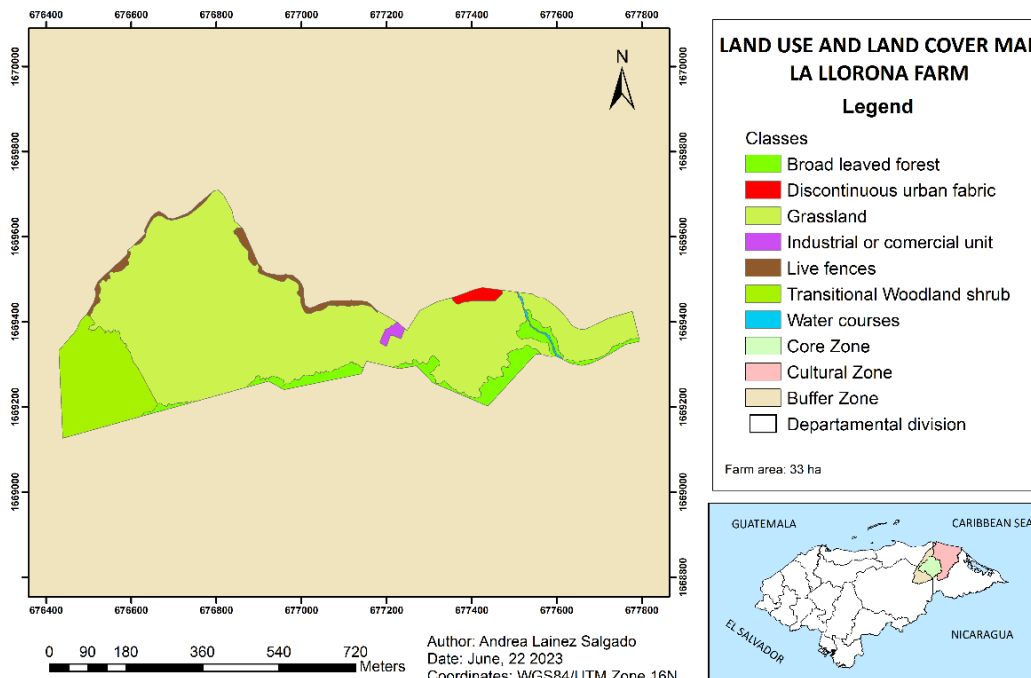


Land Use and Land Cover-Analysis

According to the analysis of the La Llorona farm regarding to its land use and land coverages (Figure 9) a total of seven land use and land cover categories were identified. These correspond to Broad-leaved Forest, Discontinuous urban fabric, Grassland, Industrial or commercial unit, Live fences, Transitional, Woodland shrub and Water courses.

Figure 9

La Llorona Farm-Land Use and Land Cover Classification Map



From the distribution of land use and land cover as a function of area in hectares and percentage of total area on La Llorona Farm (Table 3) it was found that from the 33 ha that constitute the La Llorona farm, a total of 0.070 ha corresponds to natural water courses, representing 0.21% of the total area of the farm. Construction sites make up 0.15 ha, representing 0.45% of the total area of the farm. The live fences placed around the boundaries of the farm and to create a delimitation between different paddocks correspond to 0.85 ha, which represents 2.56% of the area. Also, it was determined that 0.15 ha correspond to industrial or commercial units, which represent 0.45% of the total area. The 2.06 ha (6.22%) and 4.24 ha (12.83%) correspond to broad-leaved forest and transitional woodland shrub respectively. Finally, it was determined that 25.42 ha correspond to grassland, representing 76.86% of the total area.

Table 3

Distribution of Land Use and Land Cover as a Function of Area in Hectares and Percentage of Total

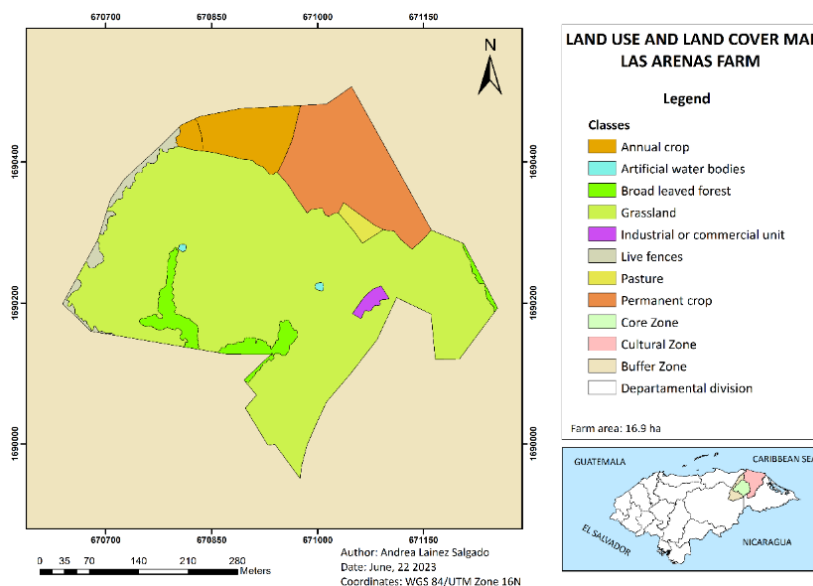
Area on La Llorona Farm

Classes	Area in ha and average of the total area	
	Ha	%
Broad-leaved forest	2.06	6.22
Discontinuous urban fabric	0.27	0.83
Grassland	25.42	76.86
Industrial or commercial unit	0.15	0.45
Live fences	0.85	2.56
Transitional Woodland shrub	4.24	12.83
Water courses	0.07	0.21
Grand Total	33.08	100

According to the land use/land cover analysis of the Las Arenas farm (Figure 10) seven categories were identified, which are similar to the uses on the La Llorona farm, except for the categories of Annual crops, Artificial water bodies and Permanent crops, which are not present on the La Llorona farm.

Figure 10

Las Arenas Farm-Land Use and Land Cover Classification Map



From the distribution of land use and land cover as a function of area in hectares and percentage of total area on Las Arenas Farm (Table 4) it was found that from the 17.4 ha that constitute the Las Arenas farm, a total of 1.07 ha corresponds to annual crops, such as beans and maize. This represents 6.32% of the total area of the farm. 0.02 ha, representing 0.12% of the total area of the farm, corresponds to artificial water bodies used as drinking troughs for livestock. The broad-leaved forest occupies an area of 0.46 ha which represents 2.72% of the total area. On the other hand, grassland constitutes 12.50 ha which represents 73.93% of the area, becoming the majority occupation of the land. Industrial and commercial units represent 0.09 ha corresponding to 0.56% of the area. The live fences placed around the boundaries of the farm to create a delimitation between different paddocks correspond to 0.27 ha, representing 1.61% of the total area. Finally, permanent crops, which correspond to sugar cane, cover a total area of 2.48 ha which represents 14.70% of the area.

Table 4

Distribution of Land Use and Land Cover as a Function of Area in Hectares and Percentage of Total Area on Las Arenas Farm

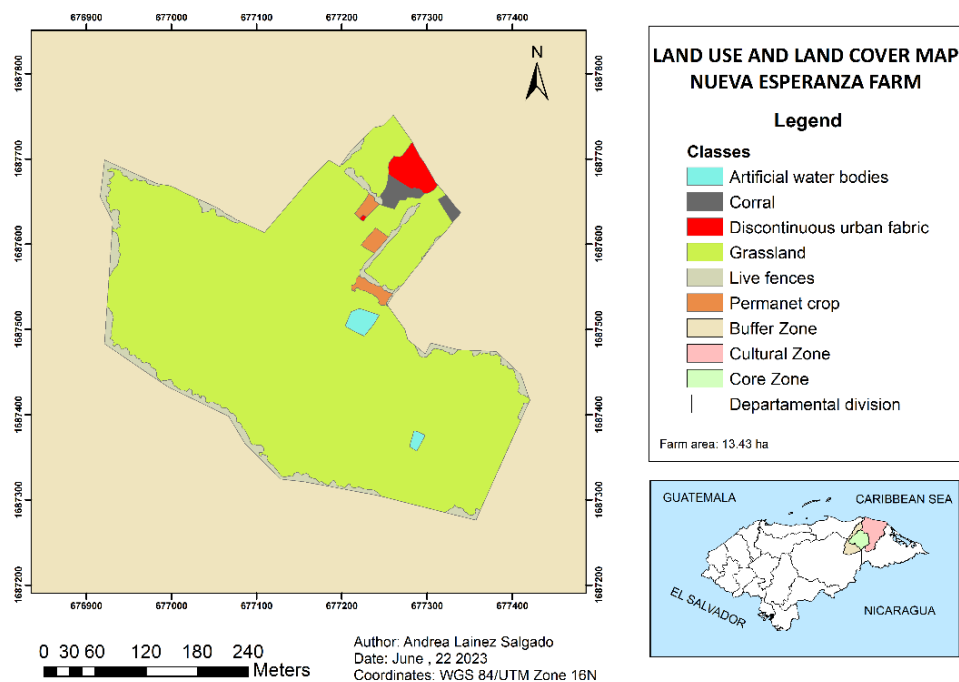
Classes	Area in ha and average of the total area	
	Ha	%
Annual crop	1.07	6.32
Artificial water bodies	0.02	0.12
Broad-leaved forest	0.46	2.72
Grassland	12.50	73.94
Industrial or commercial unit	0.09	0.56
Live fences	0.27	1.61
Permanent crop	2.48	14.70
Grand Total	16.90	100

According to the analysis of the Nueva Esperanza farm regarding to its land use and land coverages (Figure 11) a total of six categories of land use and land cover were identified. Those categories correspond to artificial water bodies, discontinuous urban fabrics, grassland, live fences,

permanent crops, and corrals. The land use and land cover classes present in the three cattle farms are very similar and only differ in one or two categories.

Figure 11

Nueva Esperanza Farm-Land Use and Land Cover Classification



From the distribution of land use and land cover as a function of area in hectares and percentage of total area on the Nueva Esperanza Farm (Table 5) it was found that from the 13.43 ha that constitute the Nueva Esperanza farm, a total of 0.10 ha corresponds to artificial water bodies mainly used as drinking troughs for livestock, this represents 0.76% of the area. Construction sites constitute 0.18 ha, representing 1.38% of the area. Also, corrals occupied a total area of 0.13 ha, representing 0.98% of the total area. On the other hand, grassland occupied a total area of 12.18 ha representing 90.69% of the total area, making it the primary land use on the farm. Live fences placed around the boundaries of the farm and to create a delimitation between different paddocks correspond to 0.67 ha, representing 5.05% of the total area. Finally, permanent crops like cacao occupied 0.14 ha which represents 1.11% of the total area.

Table 5

Distribution of Land Use and Land Cover as a Function of Area in Hectares and Percentage of Total

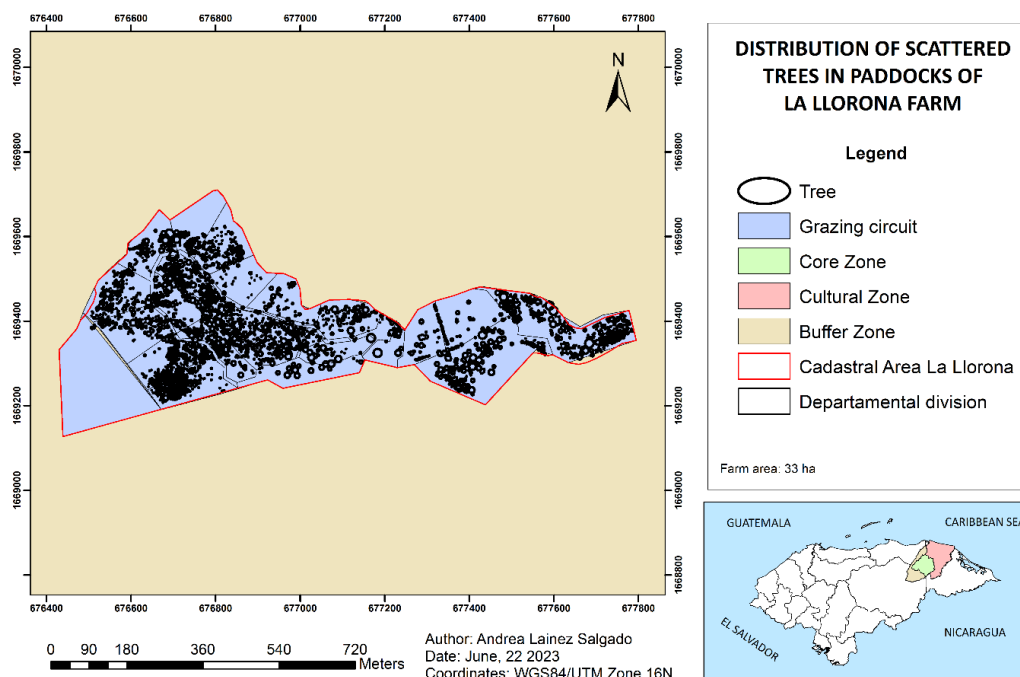
Area on The Nueva Esperanza Farm

Classes	Area in ha and average of the total area	
	Ha	%
Artificial water bodies	0.10	0.76
Discontinuous urban fabric	0.18	1.38
Corral	0.13	0.98
Grassland	12.18	90.69
Live fences	0.67	5.05
Permanent crop	0.14	1.11
Total	13.43	100

Scattered Tree Distribution-Analysis

Scattered trees in a livestock grazing system are considered as keystone structures (Rivest et al., 2013) that play an important role for the maintenance of biodiversity, ecosystem function and services, as well as additional income generation for farmers, shade and livestock feed production, among many other important features (Pezo & Ibrahim, 1998). Knowledge of the amount of forest cover within the farms is an important factor for the management of each farm, as this helps to determine if the producers are complying with the farm management plan proposal of the reserve and the CUF that were established to maintain sustainable management of the resources in the biosphere, including the conservation of tree cover. From this analysis, abundant individuals of natural regeneration, products of secondary succession, were observed on all the farms. The La Llorona farm currently has 23 paddocks, five of which are designated as transition paddocks, and the rest are used as intensive paddocks. Grassland with scattered trees was found in each of the paddocks (Figure 12) and one of the five transition paddocks was found to have abundant tree cover (> 10%), therefore it was classified as Transitional Woodland shrub.

Figure 12

La Llorona Farm-Scattered Tree Distribution Map

A total number of 4,741 scattered trees were mapped, from the scattered tree division analysis of La Llorona farm (Table 6) 3.16% of the trees were scattered in transition paddocks and 6.22% were in Intensive paddocks. This in turn indicates that 9.39% of the total area of the farm has scattered trees.

Table 6*La Llorona Farm-Scattered Tree Division Per Paddock Class*

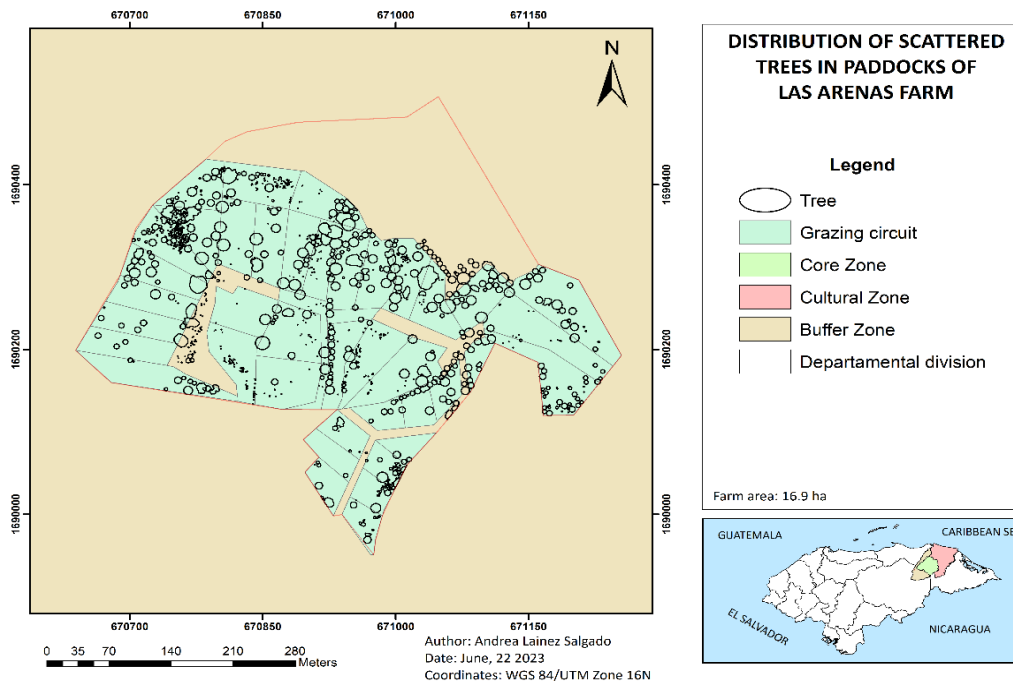
Tree number	Ha	m ²	%	% Total area
4,741	3.10	31065.54	PT 3.16	PI 6.22 9.39

Note. PI: Intensive paddocks, PT: Transition paddocks

On the contrary, the Las Arenas farm currently has a greater number of paddocks, however this farm does not present transition paddocks but only intensive paddocks (39 intensive paddocks), where as well as the La Llorona farm, scattered trees were found and mapped (Figure 13).

Figure 13

Las Arenas Farm- Scattered Tree Distribution Map



From the scattered tree division analysis of Las Arenas farm (Table 7) it was found that a total number of 1,062 scattered trees were mapped, which represents 2.10 ha of the total area of the farm. This instead represents that 12.09% of the total area of the farm has scattered trees in Intensive paddocks.

Table 7

Las Arenas Farm-Scattered Tree Division per Paddock Class

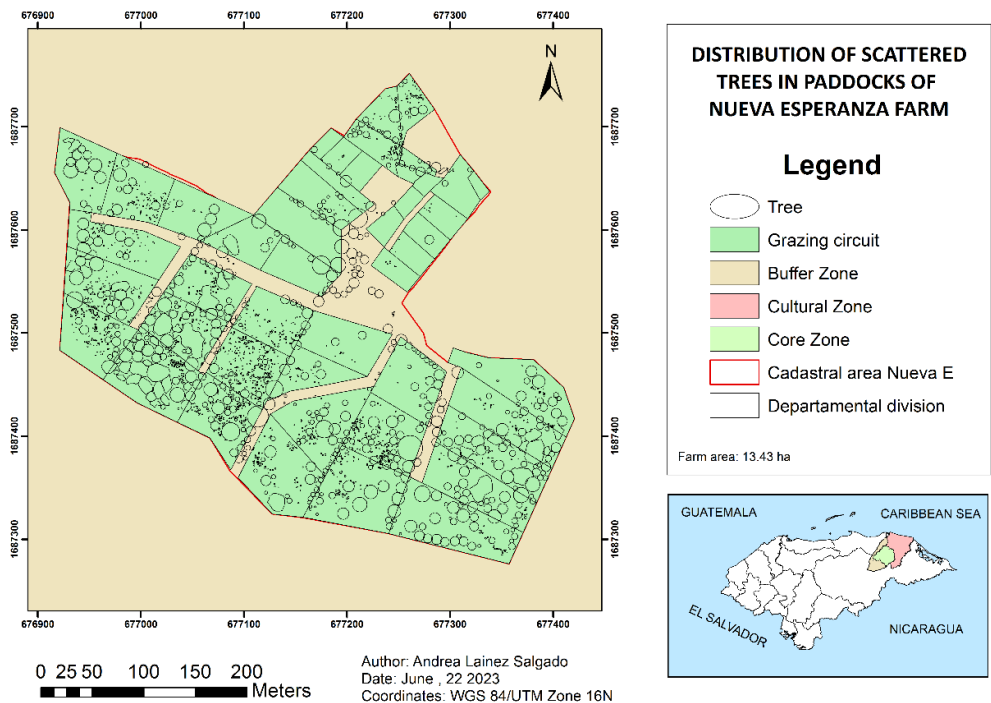
Tree number	ha	m2	%PI
1,062	2.10	21037.16	12.09

Note. PI: Intensive paddocks

Finally, the Nuevas Esperanza farm presents a greater number of paddocks in comparison to the Las Arenas and La Llorona farms. Currently, this farm has 43 intensive paddocks where abundant scattered trees were found and mapped (Figure 14).

Figure 14

Nueva Esperanza Farm- Scattered Tree Distribution Map



From the scattered tree division analysis of the Nueva Esperanza farm (Table 8) it was found that a total number of 2,056 scattered trees were mapped, which represents 3.15 ha of the total area of the farm. This instead represents that 23.52% of the total area of the farm has scattered trees in Intensive paddocks.

Table 8

Nueva Esperanza Farm-Scattered Tree Division per Paddock Class

Tree number	Ha	m ²	% PI
2056	3.15	31599.31	23.52

Note. PI: Intensive paddocks

From the three farms, the one with the highest tree cover was Nueva Esperanza, followed by Las Arenas and finally La Llorona. Through the quantification of tree coverage present on each farm, and according to the definition of forest by “Ley forestal, áreas protegidas y vida silvestre” of Honduras (2008), under Decree No. 156-2007, that states that a forest is an association of natural or planted

trees and shrubs with a ten percent cover, it can be estimated regarding to the Llorona farm, that this could be considered almost under the category of a forest. At the same time, since it has a coverage less than 10%, this area could be considered as degraded and not deforested. Therefore, strategies to increase the tree coverage on this farm should be implemented, since the farm management plan proposal established by the MiBiosfera Project suggests the need of increasing their forest land cover to at least 10%.

In the same way, under that concept, the Las Arenas farm could be considered as a forest area, since it has more than 10% of tree coverage, and practices such as agroforestry should continue to be promoted to maintain its coverage. The Nueva Esperanza farm could be considered under the category of forest as well, following the definition of the Honduran forestry law, since it has an estimated tree coverage of 23.5%. Therefore, this area should not be classified a deforested. At the same time, this farm could be considered to have an ideal range of forest cover, as it matches the desired cover in the farm management plan proposal (> 10%) and does not exceed 30% cover, which has been shown to be not ideal for agroforestry systems, as it results in the reduction of pasture production and animal stocking rates (Souza de Abreu et al., 2000). Studies have shown that a tree coverage of 22% to 30% (high tree cover) contributes positively to reducing heat stress and increasing animal production (Betancourt et al., 2003; Souza de Abreu et al., 2000).

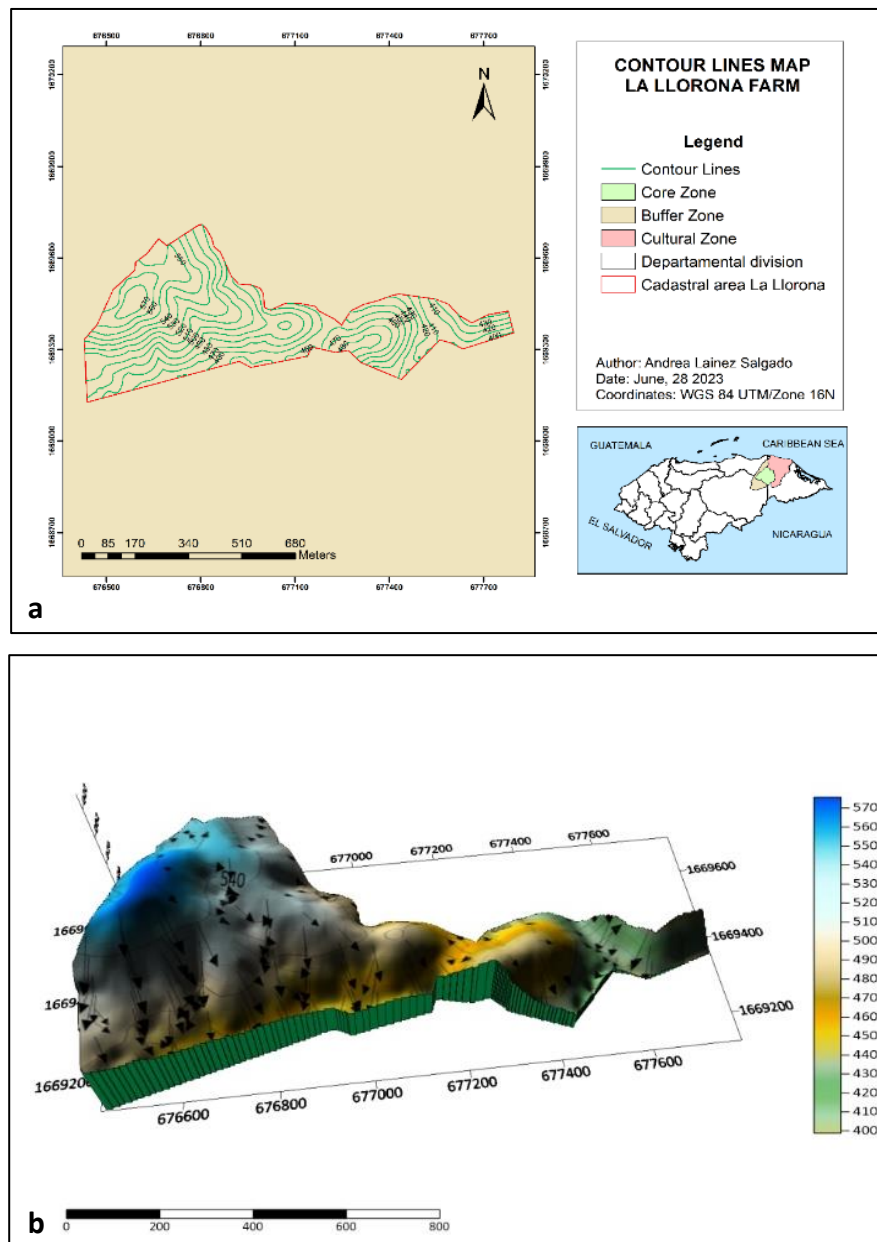
Finally, it is worth mentioning that this type of monitoring should be carried out on each of the cattle farms in the buffer zone of the Río Plátano Biosphere Reserve, in order to generate a database of the state of land use and cover of these farms, through the application of monitoring following the protocol established in the flight manual and image pre-processing (Annex B). With this, it will be able to determine the necessary measures to ensure proper management of the biosphere and improvement of the use of the resources of these farms. This will also ensure compliance with the provisions of the biosphere management plan, the farm management plan proposal and usufruct contracts. At the same time, this will allow generating the necessary actions to reduce deforestation,

increase reforestation actions, mitigation of greenhouse gases (GHG) emissions and the improvement of production. which will have a positive impact on local communities, allowing farm producers to be inserted into value chains, through certification of their products and implementation of instruments that increase resilience to climate change.

Contour lines-Analysis

One of the results generated by the Pix4d® Software was the DEM which helps us to generate the contour lines and flow direction maps of the terrains. The contour lines provide us with important information about terrain relief. Also, the flow direction is an important tool as well as the contour lines since it helps us to identify the direction in which the runoff goes along the terrain. At the same time, flow direction maps can help us to identify areas in which soil erosion may be a great concern and therefore soil conservation activities must be implemented. The elevation ranges provided by the contour lines (Figure 15a) on the La Llorona farm establish that the highest point of the farm was found in its northern part, with an altitude of 570 mamsl and the lowest altitude was found in the southern part of the farm with 400 mamsl. The contour lines also suggested the presence of high hills at the northern part of the farm and contour lines in close proximity suggested the presence of a steep slope (Navarro Hudiel, 2008). On the other hand, the direction flows (Figure 15b) suggested that the water will flow mainly to the western part of the farm. Also, with the flow direction, the presence of concave, convex, straight convex, and straight slope forms are suggested.

Figure 15

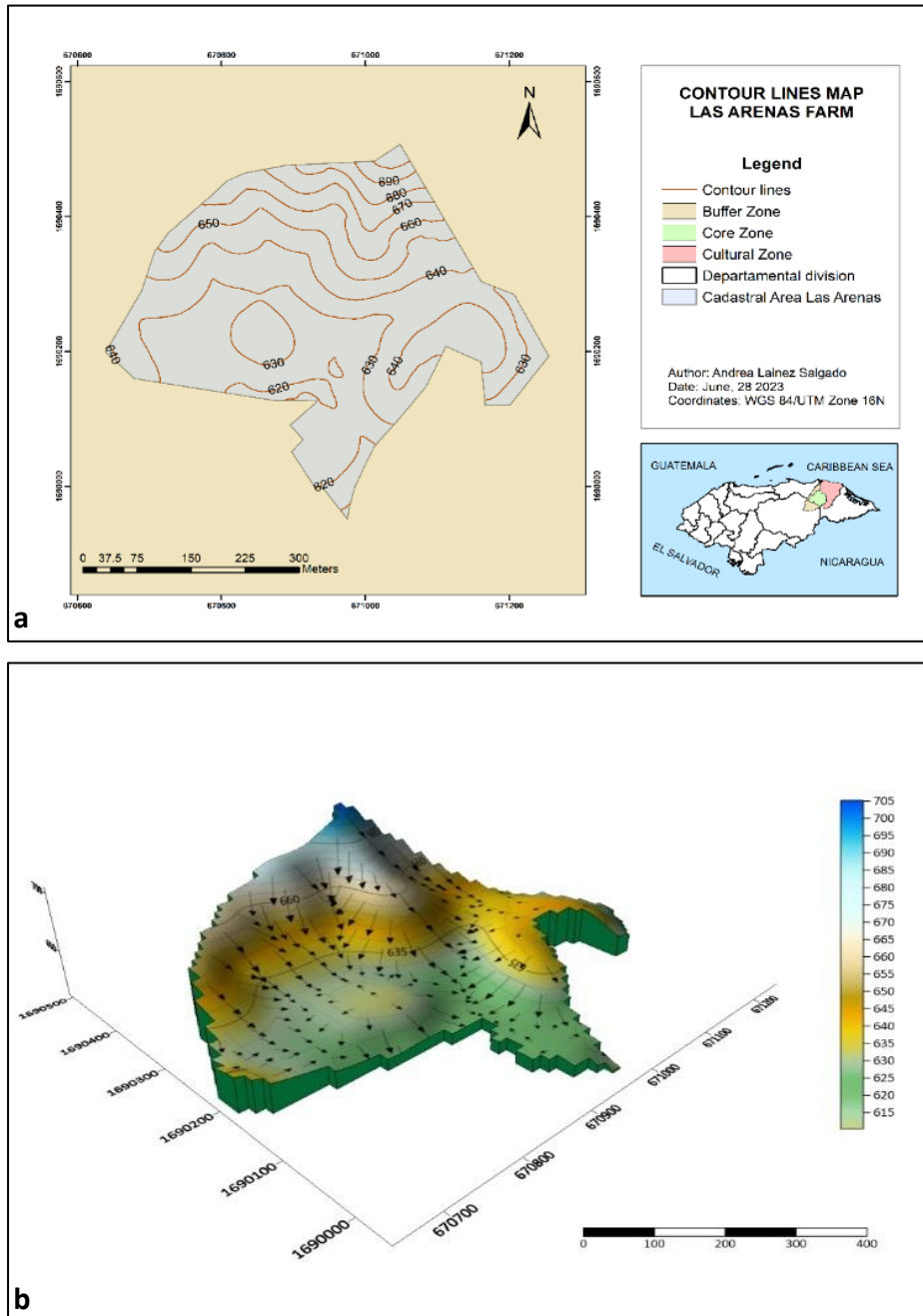
La Llorona Farm-Contour Lines and Flow Direction Maps

From the contour lines map of the Las Arenas farm (Figure 16a), we could see that the highest point of the farm was found in its northern part with an altitude of 690 mamsl and the altitude decreases as we get closer to the southern part of the farm, where an altitude of 620 mamsl was found. At the same time, spaced contour lines suggested the presence of a gentle slope (Navarro Hudiel, 2008). The flow direction map (Figure 16b) suggested that the direction of runoff is directed

to the southern part of the farm. Also, the flow direction suggested the presence of straight and straight-convex slope forms.

Figure 16

Las Arenas Farm- Contour Lines and Flow Direction Maps

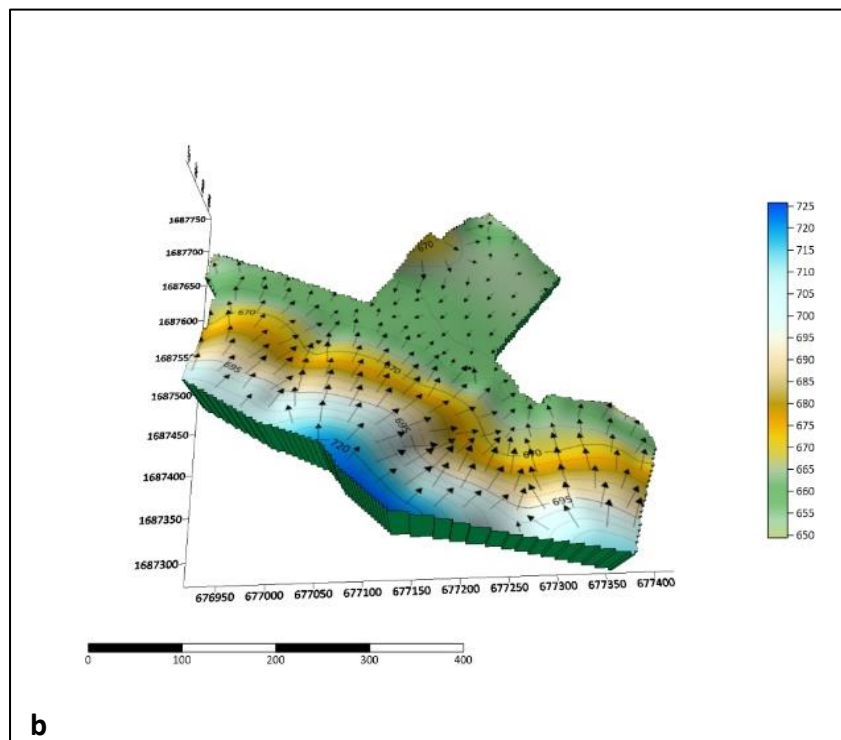
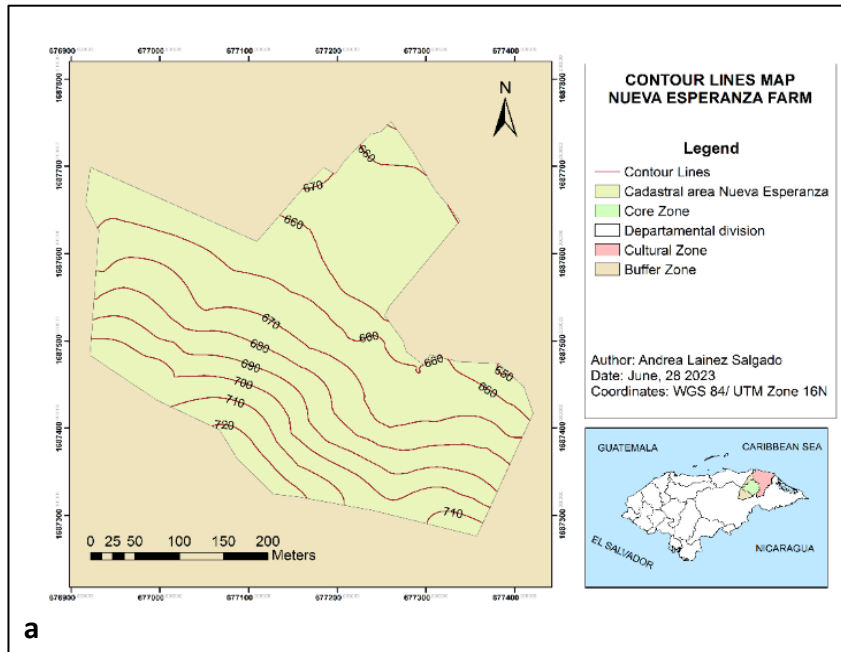


From the contour lines map of the Nueva Esperanza farm (Figure 17a), we could see that the highest point of the farm was found in its southern part with an altitude of 720 mamsl and the altitude

decreases as we get closer to the northern part of the farm, where we can find an altitude of 660 mamsl. As elevation increases on contour lines, it may suggest the presence of ridges in the terrain. The straighter contour lines present on the farm suggest the presence of a homogenous area and the separated curves are associated with gentle slopes. On the contrary, contour lines in close proximity may indicate the presence of a steep slope (Navarro Hudiel, 2008). The direction flow (Figure 17b) indicates a runoff direction to the northern part of the farm, coming from the southern part of the farm where the direction of flow suggests the presence of a straight slope form. Finally, it is worth mentioning that the importance of the generation of these maps relays in the fact that they are useful tools to represent the outline of a specific landform or terrain. The contour lines on these maps were employed to show places with varying elevations, the distance between them, as well as the slope forms of the terrain.

Figure 17

Nueva Esperanza Farm-Contour Lines and Flow Direction Maps

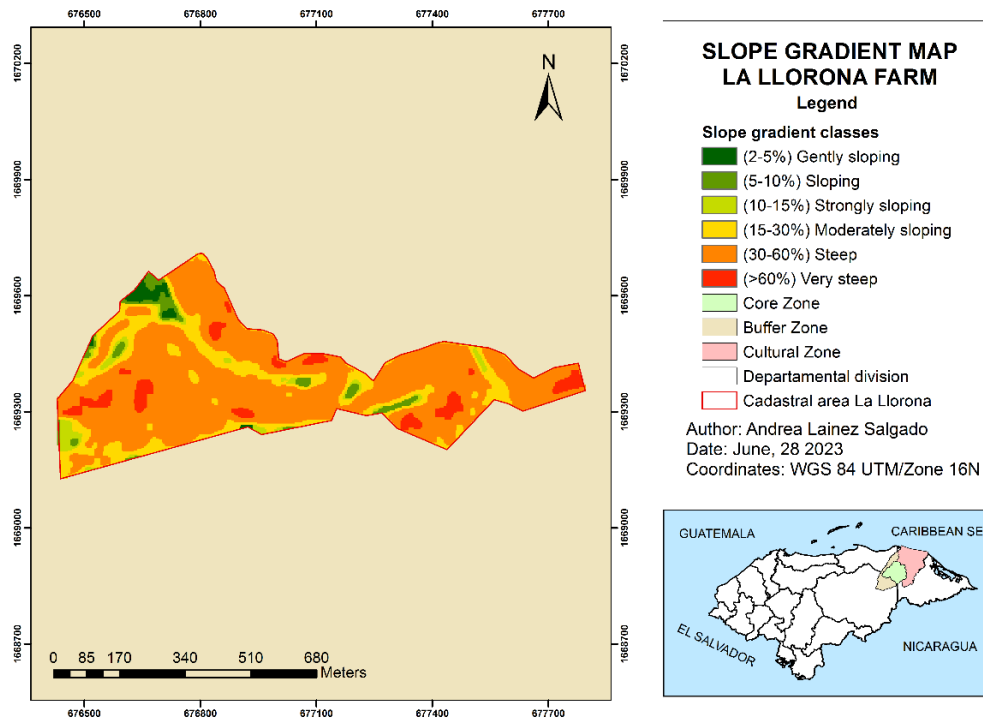


Slope-Analysis

The farms under intervention consist of different slope ranges that go from a gently sloping to a very steep slope. In order to carry out agricultural activities in the biosphere's buffer zone, the reserve's management plan (2013) establishes that these activities must be carried out under agroforestry systems, soil conservation, and the rational and sustainable use of resources. The slope values then become an important factor because, in order to achieve rational pasture management on the farms, it is necessary to consider the slope, since it is possible to determine the risk of erosion caused by grazing (Mwendera et al., 1997). Moreover, Wilson et al., 2022, showed in their study that slope can influence animal resting behavior and animal rumination. Therefore, the determination of slope is an essential factor for the sustainable management of the resources on the farms.

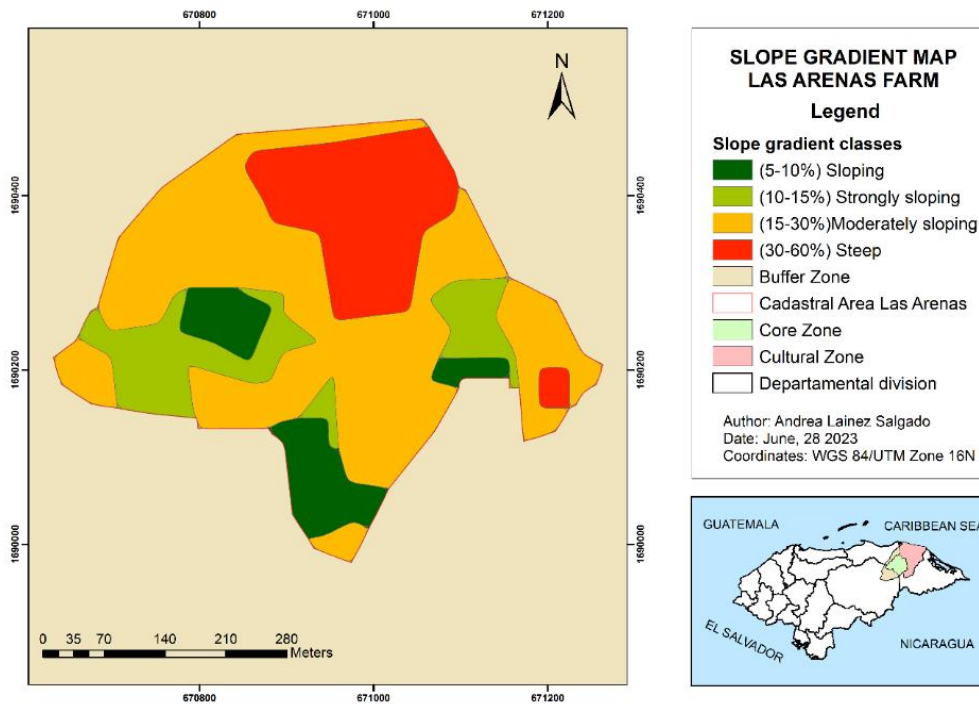
The result from the slope gradient map of the La Llorona farm (Figure 18) shows six categories of slopes where 1.46% of the total area correspond to gently sloping. 3.09% and 3.05% correspond to sloping and strongly sloping areas respectively. Very steep slope represents 5.86% of the area and 17.72% corresponds to a moderately sloping area. Finally, 68.80% of the total area of the farm presents a steep slope (30 - 60%).

Figure 18

La Llorona Farm-Slope gradient map

The results from the slope gradient map of the Las Arenas farm (Figure 19) shows four categories of slopes where 10.71% of the total area corresponds to sloping. 14.78% and 20.42% correspond to strongly sloping and steep areas respectively. Contrary to the values of La Llorona farm, the greatest slope percentage (54.08%) of the Las Arenas farm has a slightly lower slope that corresponds to the category of moderately steep (15 - 30%).

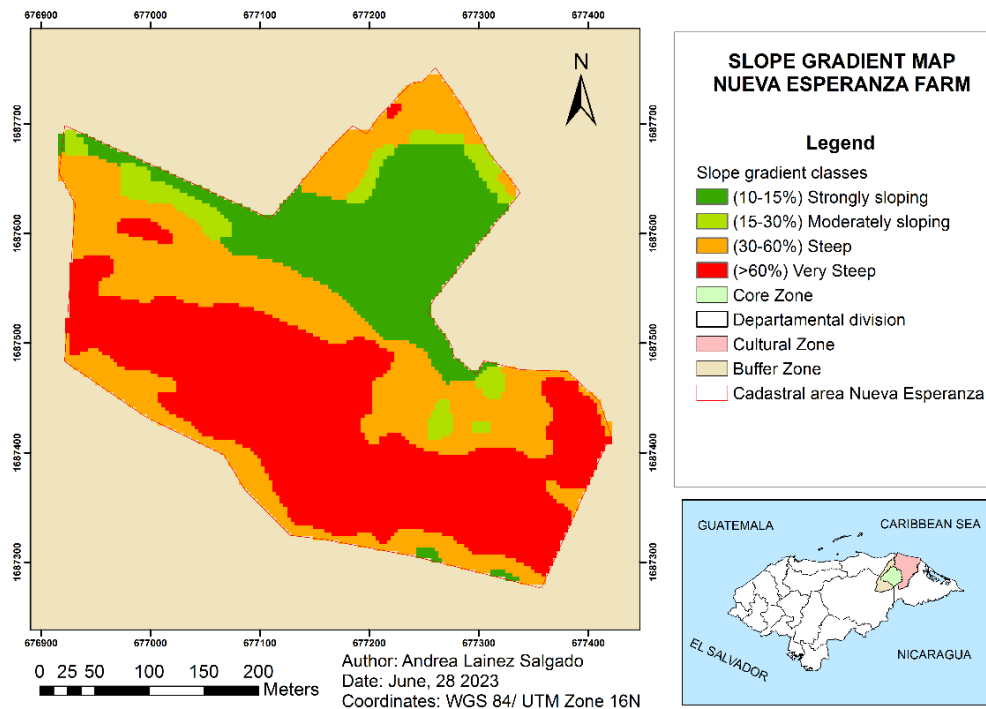
Figure 19

Las Arenas Farm- Slope Gradient Map

On the other hand, the result from the slope gradient map of the Nueva Esperanza Farm (Figure 20) shows four categories. Compared to the other two farms (Las Arenas and La Llorona), Nueva Esperanza has the highest value of slopes with a 41.12% of the total area of the farm with a very steep (> 60%) area. Also, it has slopes where 20.59% of the total area correspond to a strongly sloping area. And finally, 4.98% and 33.29% of the area have moderately sloping and steep slope areas respectively.

Figure 20

Nueva Esperanza Farm- Slope Gradient Map



With the help of slope maps and the land use and land cover maps, it was estimated that 60% of the total area the La Llorona farm was occupied by grassland in steep (30 - 60%) slopes. Also, for the Nueva Esperanza farm, it was determined that 40% of the total area was occupied by grassland in very steep (> 60%) slopes. And finally, the Las Arenas farm presented 43% of the total area occupied by grassland in moderately sloping (15 - 30%) areas. This can be valuable information for the generation of a land use capability classification of the cattle farms. Land use capability takes into consideration different soil characteristics (slope, effective depth, texture, drainage, etc.) to determine their potential for agricultural and other land uses (Noor, 1981). Klingebiel and Montgomery (1961) mention that soils with a moderately steep slope and a very steep slope should be limited to semi-intensive grazing, implementation of cover crops and soil conservation practices, and even in those areas with steep slopes should be considered for protection areas.

Conclusions

From the classification process, a total of 12 classes of uses and coverages were generated from three farms. These classes constitute Broad-leaved Forest, Discontinuous urban fabric, Grassland, Industrial or commercial unit, Live fences, Transitional Woodland/shrub, Water courses, Annual crop, Artificial water bodies, Permanent crops, Corrals and Pastures. Within the three farms, the predominant land use was grassland and Nueva Esperanza was the farm with the highest tree cover (23.52%), followed by the Las Arenas farm (12.09%).

From the by-product maps generation, it was possible to determine that the highest average slopes on the farms were in the range of 15 to > 60%. For La Llorona farm it was found that 60% of the total area was occupied by grassland in steep (30 - 60%) slopes which represents a significant area of the farm where precautions must be taken to avoid soil degradation, in comparison with the other two farms where 40% of the total area was occupied by grassland in very steep (> 60%, Nueva Esperanza) slopes and 43% of the farm area was occupied by grassland in moderately sloping (15 - 30%, Las Arenas) which represent smaller areas occupied by grasslands on slopes that are not too steep. This can be a valuable information for the generation of a land use capability classification of the cattle farms along with the contour lines and flow directions. Since land use capability takes into consideration the slope as a main characteristic to determine a soil potential for agricultural and other land uses and the flow direction, contour lines and NDVI values can help us to determine the most appropriate measures for conservation and restoration at the sites most vulnerable to soil degradation.

Through the creation of the flight manual, it was possible to identify some of the most important factors to consider for the planning of the drone flight, with the establishment of a pre-flight sheet that can be used to identify in detail the status of the drone before, during and after the flight, to ensure a safe and smooth flight.

Recommendations

It is recommended to encourage a slight increase in tree cover on the La Llorona farm, since it almost meets the desired tree coverage (> 10%) established in the farm management plan proposal. It is also important to maintain the tree cover of Nueva Esperanza and the Las Arenas farm.

It is recommended to continue monitoring the land cover and tree cover of the farms to determine the capacity of carbon sequestration through the application of remote sensing systems. This will allow to identify those farms that can enjoy the benefits of certifications.

The flight manual was designed for the use of RGB and multispectral imaging with the eBee Ag[®] drone. It is recommended to follow this manual, as it provides a step-by-step process for field flight planning and pre-processing of the respective images. It also has a description of the main factors to consider for a correct use and handling of the drone and the main parameters to consider for image pre-processing.

The use of scattered tree distribution and land use and land cover maps in a future study are recommended, as an indicator of compliance with the usufruct contract of the farms.

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Annexes

Annex A

Data collection Field practice on farms within the buffer zone of Río Plátano Biosphere Reserve



Annex B

Flight Protocol Manual



Flight Protocol Manual and Pre-processing of RGB And Multispectral Images

Created by Andrea Lainez



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- Pix4d Multispectral Image Processing **Error! Bookmark not defined.**
- Quality Report Example And Interpretation..... 89

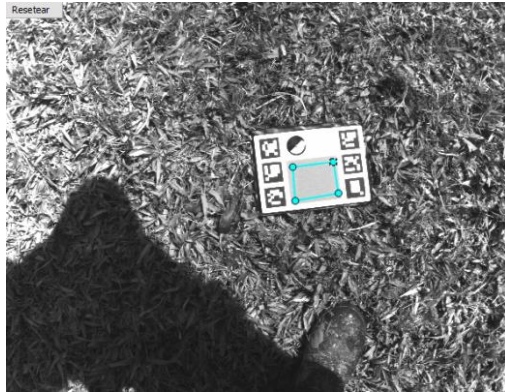
Introduction

This manual contains step-by-step information on the use and procedures for obtaining and processing RGB and multispectral images with the eBee Ag ® fixed-wing drone. This manual includes instructions for safe operation of the drone, as well as efficient time management and organization of the collected data. With the help of this manual, you will put the following knowledge into practice:

- Learn about the factors to be considered prior to a drone flight.
- Learn about the different stages of data processing and data collection.
- Learn about photogrammetric data processing in Pix4D

Pre-Flight Information

1. Install RTK on field and turn it on
2. Configuration of RTK on your computer. In this step you will have to communicate your computer by Bluetooth with the RTK.
3. Assemble drone
4. Check preflight protocol
5. Perform eMotion flight pre-check.
6. Perform Multispectral camera calibration with calibration panel.



7. Start Flight
8. Make use of the flight protocol sheet through the time duration of mission.

Preflight Protocol Sheet

It is necessary to have this document and make sure to comply with all the steps stipulated in it, before, during and after the flight, in order to ensure a safe and smooth flight.

Date: _____
 Start time: _____
 End time: _____
 Flight location: _____

Pilot: _____
 Observer 1: _____
 Observer 2: _____
 Drone model: _____

Visible satellites: _____
 # Photos taken: _____
 Sensor used: _____

1. Preflight		
Requirement to be verified	Complies	Observation
Drone structure	yes no	
Wings	yes no	
Propellers	yes no	
Rubber belts	yes no	
Pitot tube	yes no	
Laptop battery	yes no	
Electric generator	yes no	
Drone battery	yes no	
RC battery	yes no	
Camara	yes no	
Lidar sensor	yes no	
SSD memory	yes no	

3. During flight		
Requirement to be verified	Complies	Observation
Status in eMotion	yes no	
Air traffic	yes no	
Weather	yes no	

4. Before landing		
Requirement to be verified	Complies	Observation
Wind	yes no	
Landing point	yes no	

2. Before flight		
Requirement to be verified	Complies	Observation
Pilot visibility	yes no	
Laptop volume	yes no	
Modem/Radio	yes no	
Work area	yes no	
Wind direction	yes no	
Starting point	yes no	
Landing point	yes no	
Mission in 3D	yes no	
RTK connected	yes no	
Camera calibration	yes no	

5. During landing		
Requirement to be verified	Complies	Observation
Approach	yes no	
Abort button	yes no	
Attentive pilot	yes no	

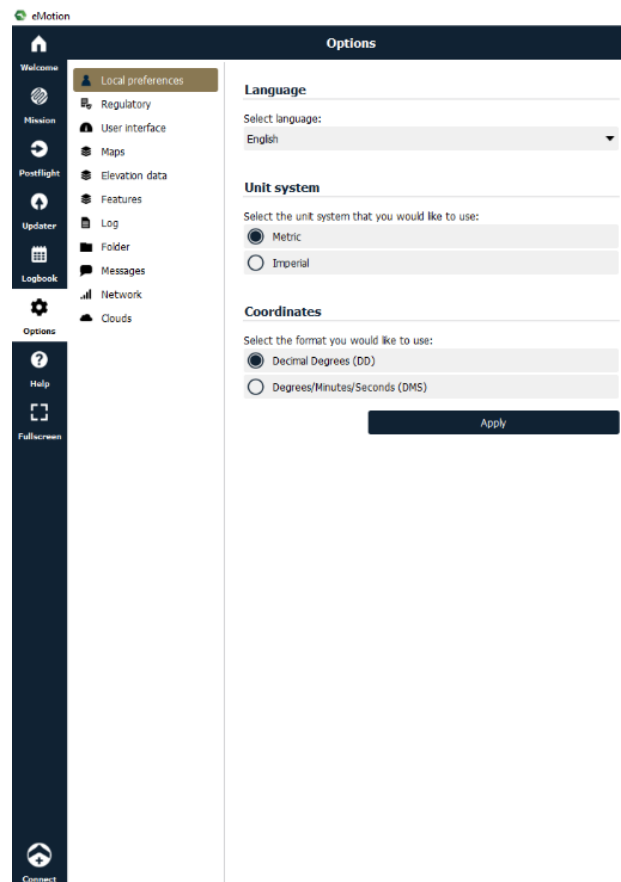
6. After landing		
Requirement to be verified	Complies	Observation
Battery	yes no	
Drone structure	yes no	
Flight data	yes no	

Flight Planning Design With eMotion®

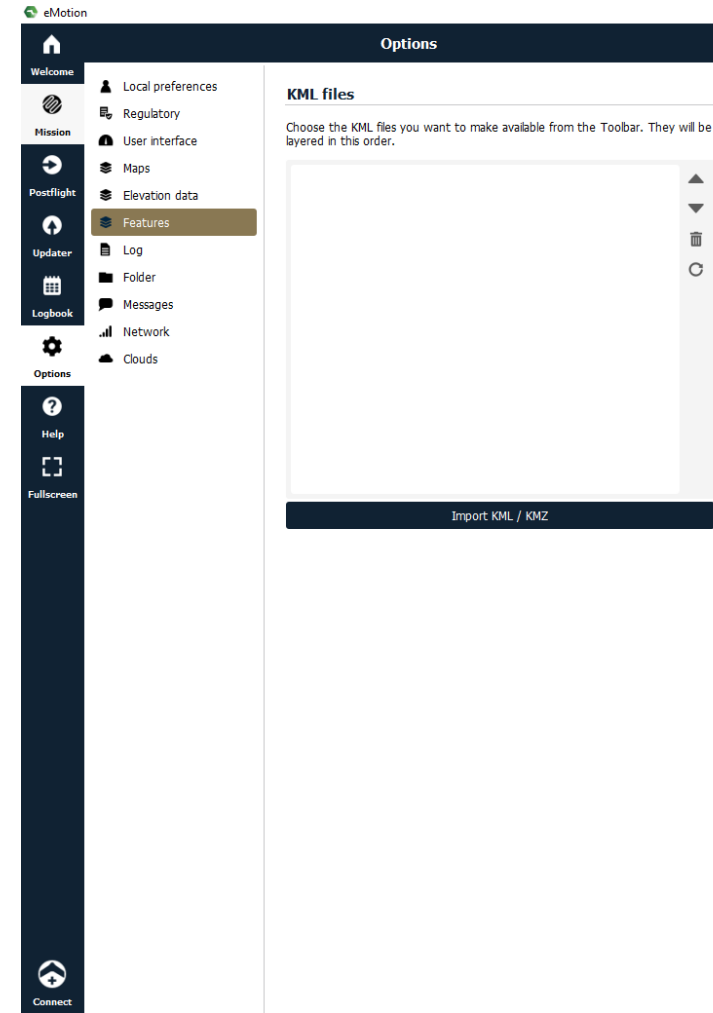
You Must follow the next steps in order to design the flight plan.

Importing KML into eMotion Project

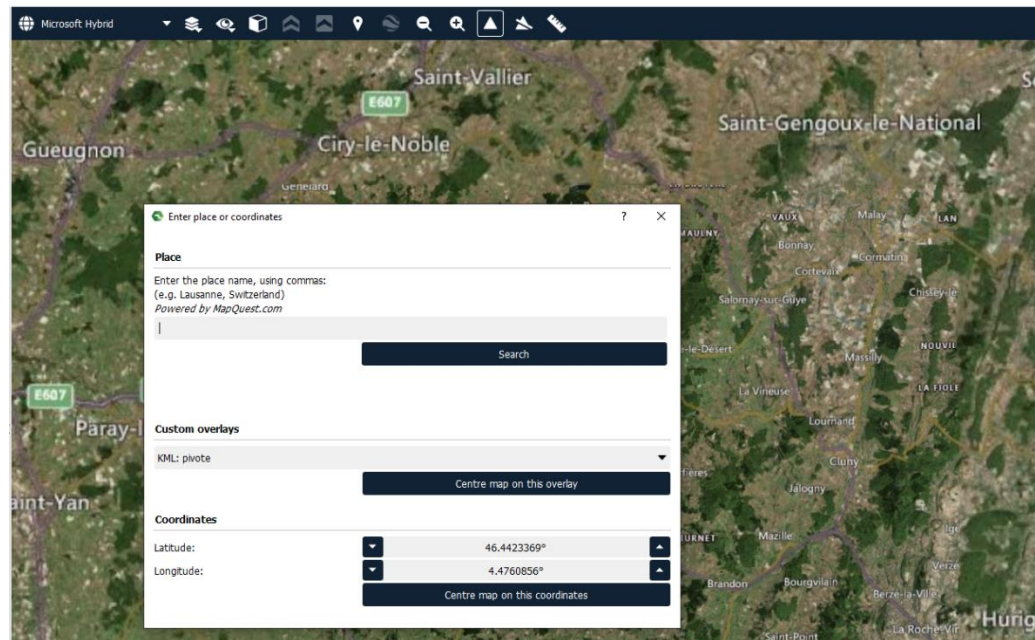
1. Open eMotion software
2. Create a new mission folder and save in the desired directory
3. To define the work area, go to the options tab area where you must have a KML of the work area.
4. Go to features.



5. Import your KML file.



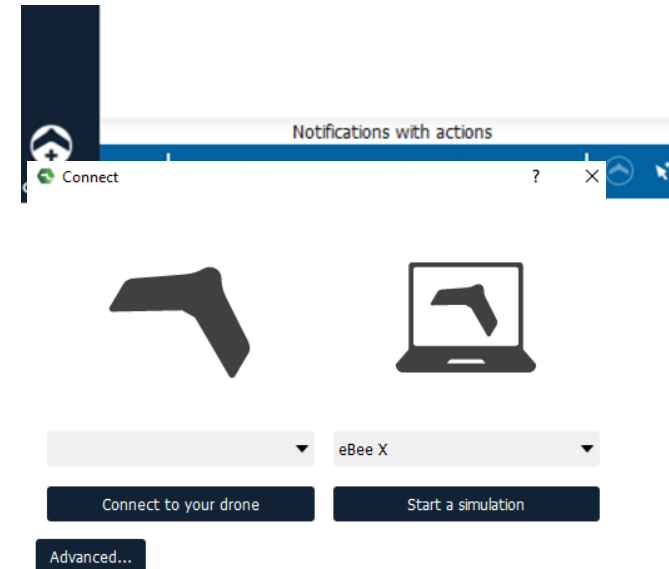
6. To display the KML on screen Go to place or coordinates tab on the top of the screen.
7. Go to the custom overlay part and select you kml file.
8. Select center map on this overlay it will take you to the location in which you are going to program the flight.



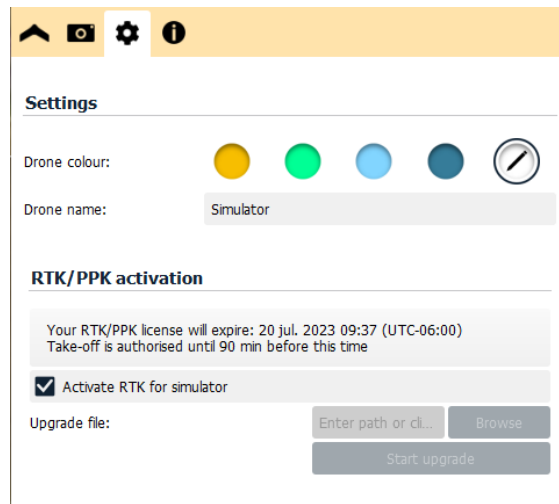
next, you need to program the drone mapping mission. For this you need to follow the steps on “Drone Mapping Mission Design”

Conect To Simulator

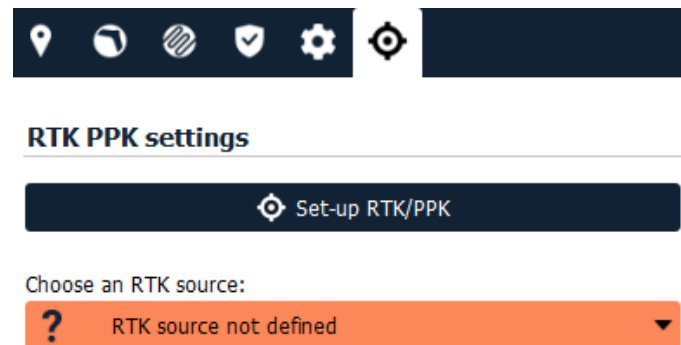
1. First, go to “connect” tab at the bottom and left side of the screen. and select “start flight” or “start simulation”



2. the next step is to select or stablish the RTK, for this operation you need to go to configuration symbol on your simulation and activate thr RTK for you simulation on the “RTK/PPK activation” part.

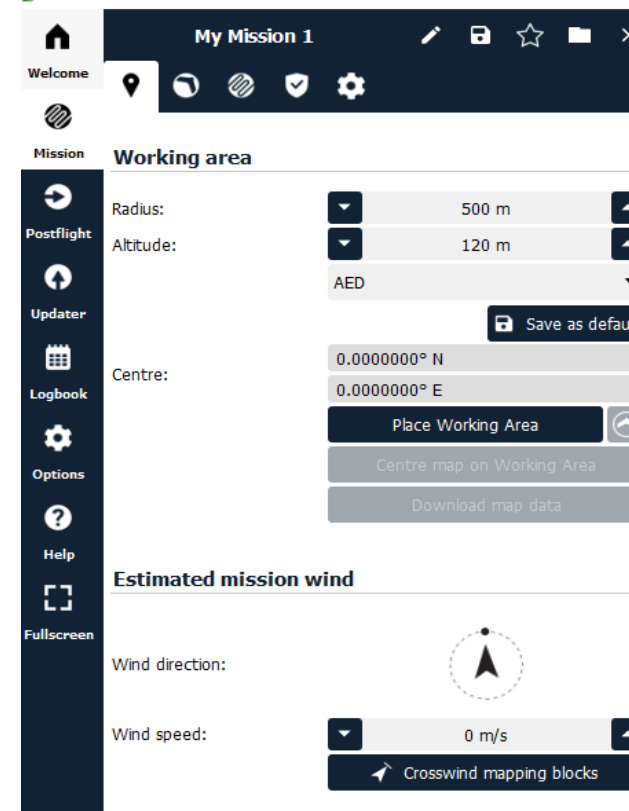


Next, go to "RTK PPK Settings" tab on my mission tab and choose an RTK source. Generally, you will need to select the "BT UNDERSCORE RTK STATION"

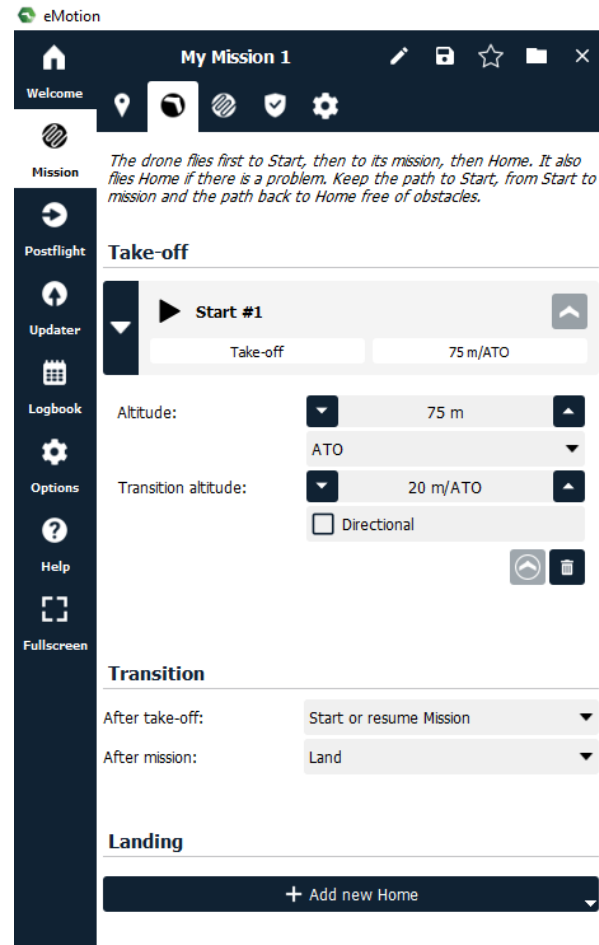


Drone Mapping Mission Design

1. Go to the "Mission" tab on the left side of the screen.
2. Next, go to the tab "working area" on the top of the screen. This looks like a location sign.
3. Following, select the radius and altitude you will use on the flight. Some of the consideration you should take into account when designing the area in which you will be working are for example, that there are no trees near the take-off and landing area, that the drone can fly at an altitude where there are no obstacles with which it can crash.

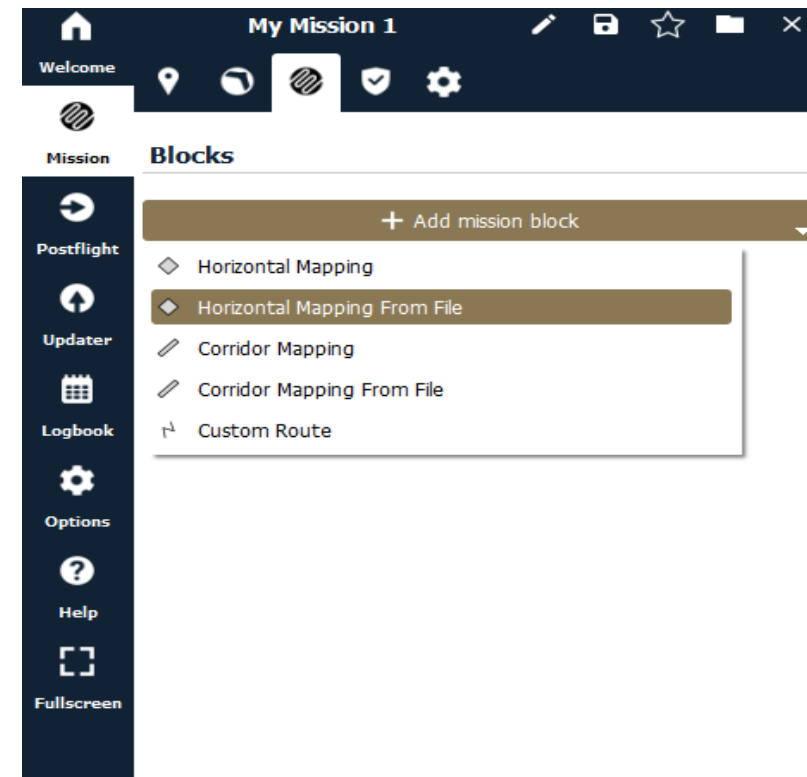


- Next, you need to go to the "Take-Off" tab and select the point from which you want to start the flight. Also, you need to select the landing area for the end of the flight by selecting "add new home" at the bottom of the screen.
- Go to Start #1 and change the altitude and transition altitude as you need. This by taking into consideration the presence of obstacles in the area such as trees, buildings, power lines, etc.



Mission Blocks

- For the design of the mission blocks you need to go to the "add mission blocks" tab on the top of the screen.
- Next, select the second option "horizontal mapping from file" this option allows you to draw an area manually at the same time.



- Subsequently, go to resolution and change this parameter as you need. Then select the images overlapping by clicking on "lat overlap" (It is usually changed to 70% (although it will depend). The images are overlapped to reduce the lens distortion in the desired output)

My Mission 1

Welcome

Mission **Blocks**

pivote

Horizontal Mapping 2.6 cm/px 13:16 11.6 ha

Name: pivote

Camera: S.O.D.A.

Plan above: Elevation data - AED

Resolution: 2.60 cm/px

Lat. overlap: 70 %

Long. overlap: 60 %

Reverse flight

Perpendicular lines

Interlaced flight lines

Area: 11.6 ha, 0.12 km²

Flight altitude: 114.8 m/AED

Photos: 126

Between photos: 38 m

Image coverage: 142x95 m

Est. flight time: 00:13:16

Est. flight distance: 8741 m

Flight line spacing: 43 m

Waypoints: 34

Reset progress

Show waypoints

Save as default

Safety actions

- Go to the safety action tab to modify anything you need; however, it already has selected the most common options by default

My Mission 1

Welcome

Mission **Safety actions**

*Actions taken by the drone for security reasons.
If deactivated, the drone instead tries to complete the command or continue the mission.
Deactivating increases the risk of an incident or loss of the drone.*

Return to Home

if strong wind detected

in case of airspeed malfunction

if the camera reports a fault

in low light (or if lens cap on)

if endurance is low

if GNSS accuracy degrades

if ground speed is exceeded

if ground modem link is lost for 300s

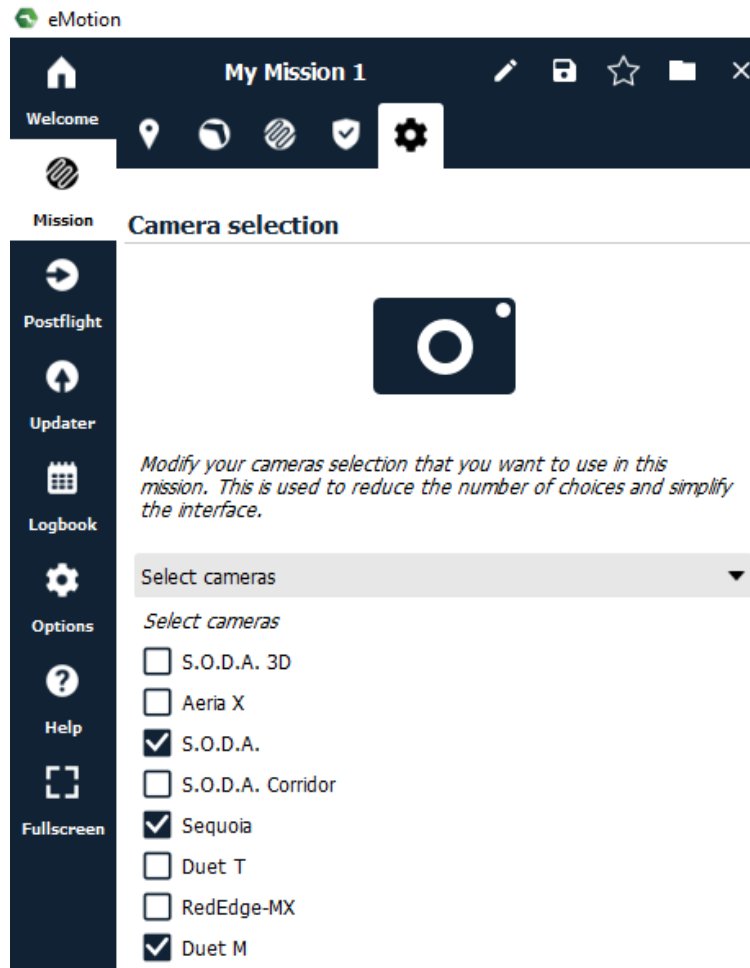
Climb

if ground proximity is detected

Restore factory settings

Save as default

- Then go to camera selection and select the Duet m and sequoia option.



- Before starting your flight, you need to change the direction of the line according to the wind direction. to change the direction of flight lines, click on lines, then select the gray circle and rotate. in this step, it must be considered that the take-off of the drone must be done downwind and the landing must be done upwind.



- To see the wind direction, go to working area tab and go to "estimate mission wind" once you have finished this part you can start your flight.

Drone To Computer Image Transfer

1. Open eMotion Software
2. Open the mission in which you made the flights.
3. Go to "postflight" and select the date of the flight you made.
4. Select "show flight with images only"
5. Go to create project folder and select in the name format "flight date+project number"
6. Within this part write the name of the project and save on your computer. Select "next" once you have finished the previous part.

The screenshot shows the eMotion Flight data manager interface. The left sidebar contains navigation icons for Welcome, Mission, Postflight, Updater, Logbook, Options, Help, Fullscreen, and Connect. The main content area is titled "Flight data manager" and displays the following steps:

1/8 Choose which flight to process
Create a project folder
 If you used this computer to fly, it saved a log of your flight.

A - Select a flight

Did you use this computer to fly? Yes

Show flights with images only

1. Select the date you flew:

	Mon	Tue	Wed	Thu	Fri	Sat	Sun
17	24	25	26	27	28	29	30
18	1	2	3	4	5	6	7
19	8	9	10	11	12	13	14
20	15	16	17	18	19	20	21
21	22	23	24	25	26	27	28
22	29	30	31	1	2	3	4

2. Select a flight from this day: [36] 2023-05-05 15:27 | IX-02-69675 | 101 images

B - Create a project folder

Name format: Flight date + project name

Project name: e.g. Date, Location, Drone, etc...

Preview: 2023_05_05

Create in: C:/Vuelo_Erick Browse

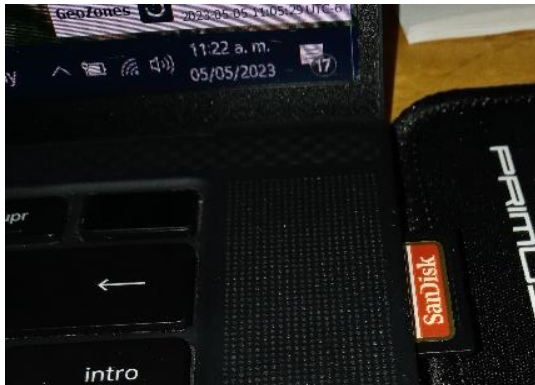
Before next step

Get ready to read the flight logs. Connect your drone or insert the drone SD card to your computer.

Your computer saves a simple flight log during the mission. The drone carries a detailed log. You can improve results by importing both logs.

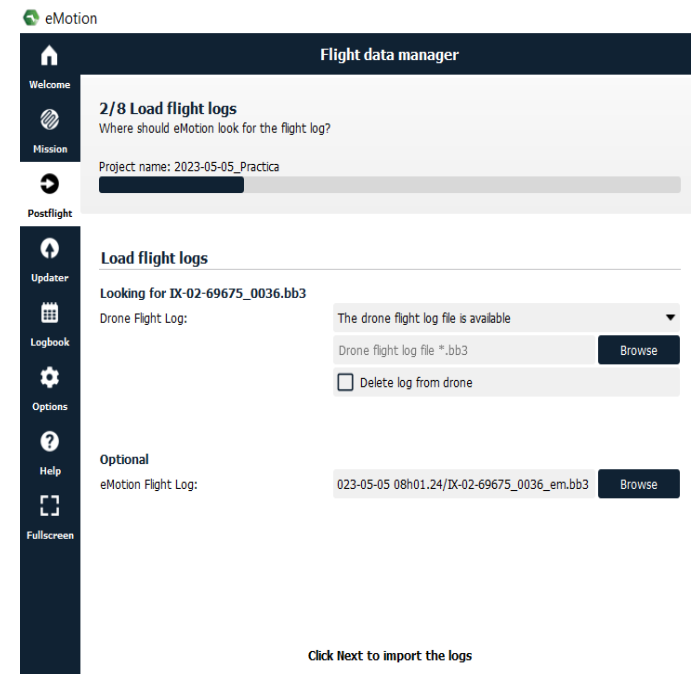
Buttons: Close, Cancel, Next

- Remove memory from the drone and connect a USB cable with the drone and your computer. the battery should be connected to the drone and the drone should show a color change in its Pitot LED.

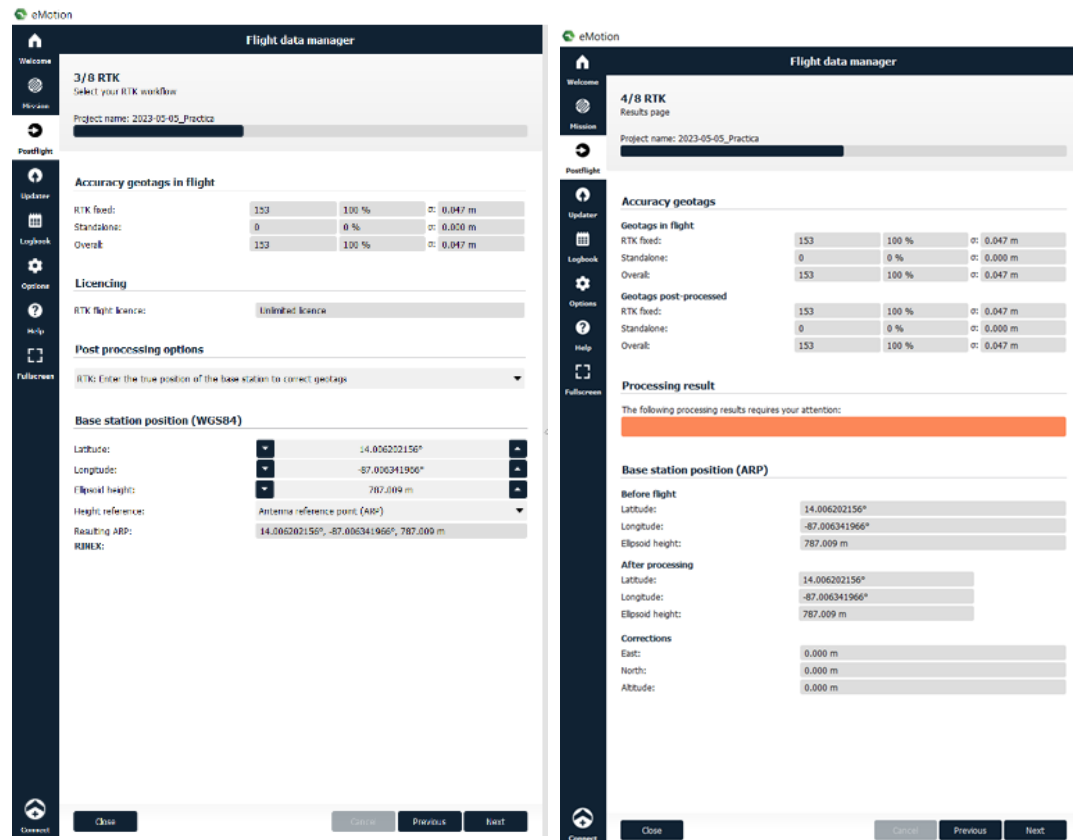


- Go to “data flight manager” and select the folder with the ID of the flight you did to import the images taken by the drone.
- Following you must upload the drone logs to eMotion. For this, you must look for those files on your computer with the name “Logs” Once you upload the logs on your computer select “next”

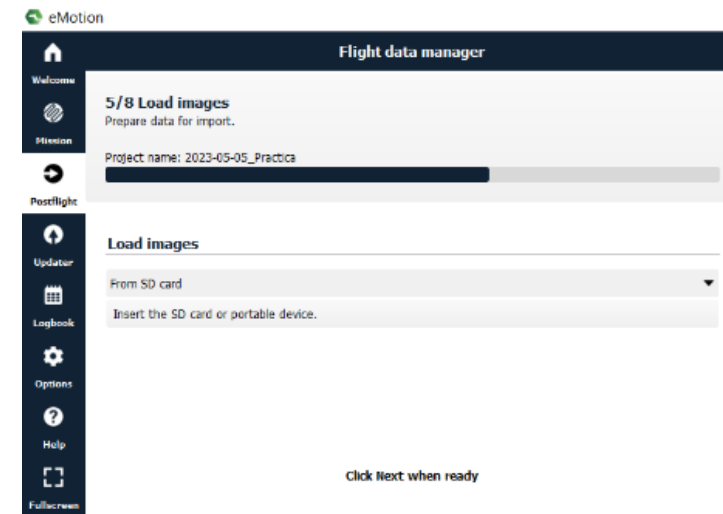
- Upload the logs from the drone to eMotion. For example, you need to look for a carpet with the name of you flight ID, in this example the ID number is IX-02-69675_0036.bb3 so we need to look for the carpet with the bb3 ending ID. Once you are done with this press “next”



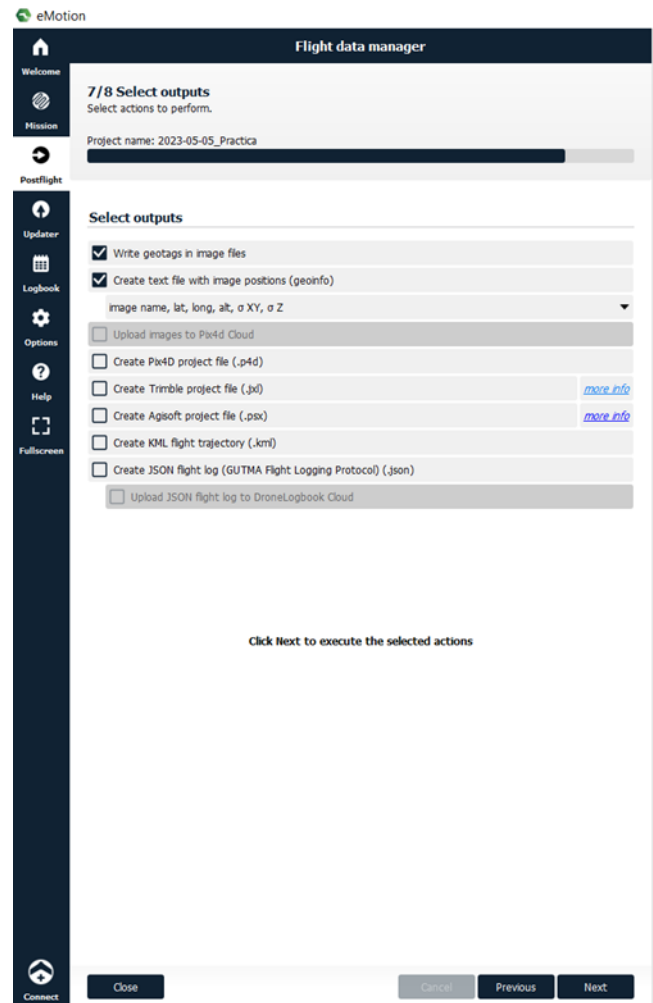
11. On step 3 of flight data manager make sure that in "post processing option" select the first option or the default option with the name "enter the true position of the base selection to connect geotag" and press next. , then for step 4 leave data as a default and select "next"



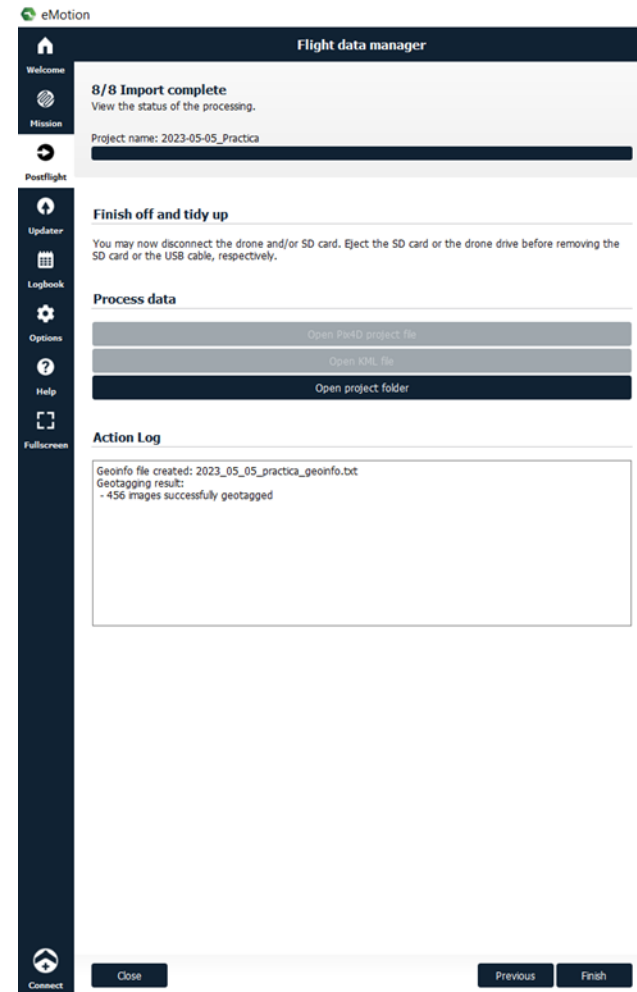
12. On step 5 of flight data manager, you must install the drone images memory in the computer and select the folder of files of the images taken by the drone (folder DCMI) and select next.



13. Following on select outputs select the first 2 options *“generate images”* and *“generate a txt”* (this last one is the files with the coordinates for each image) this is done in order to correct the images and have better precision. You can also select other options as you see fit.

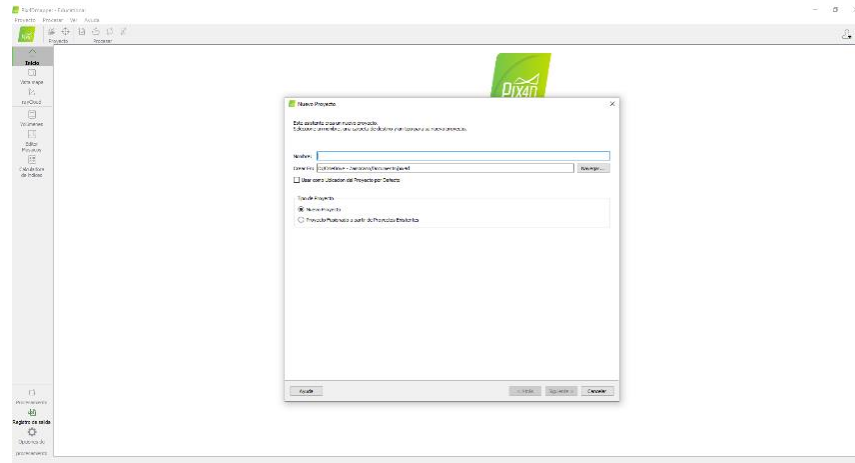


14. Once you have finished select *“Finish”* and repeat with the other missions you have performed that day. And finally eject the drone.

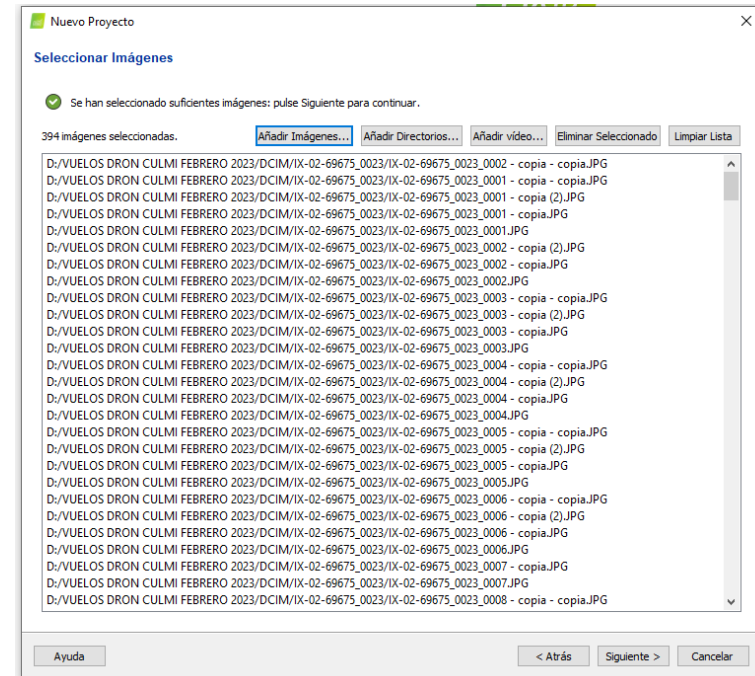


PIX4D RGB IMAGE PROCESSING

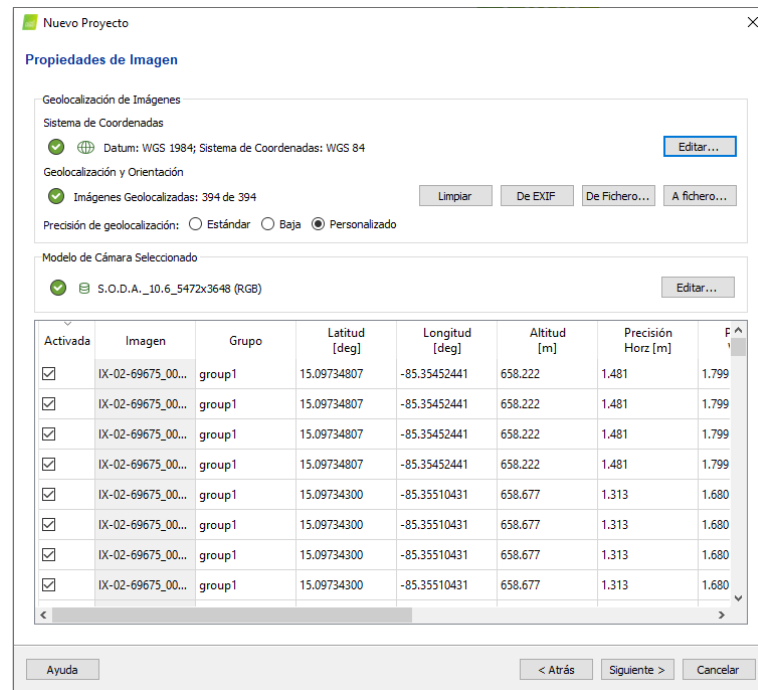
1. Open PIX4D program
2. Open new project
3. Select name of the project
4. Save on folder and select next.



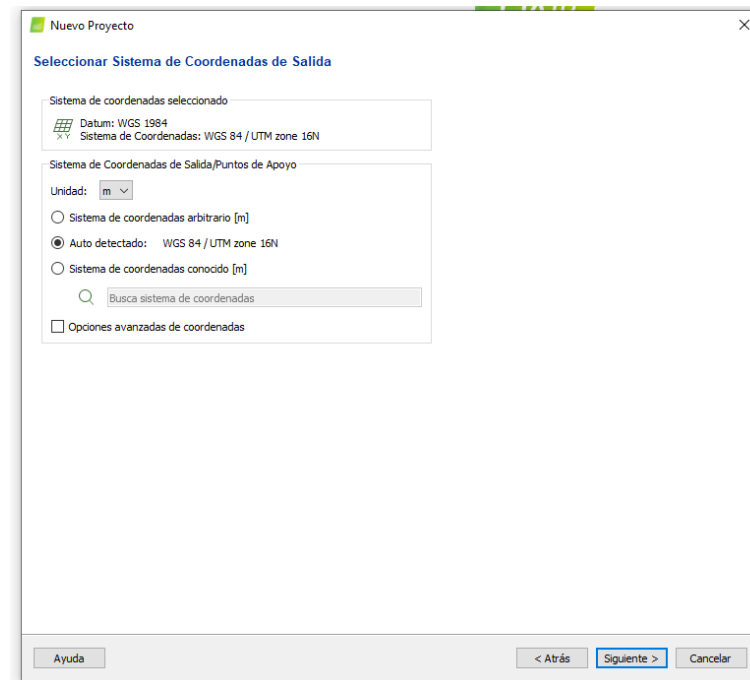
5. Select Add images and select the RGB image from the folders. Once you have added the images, select ‘Next’



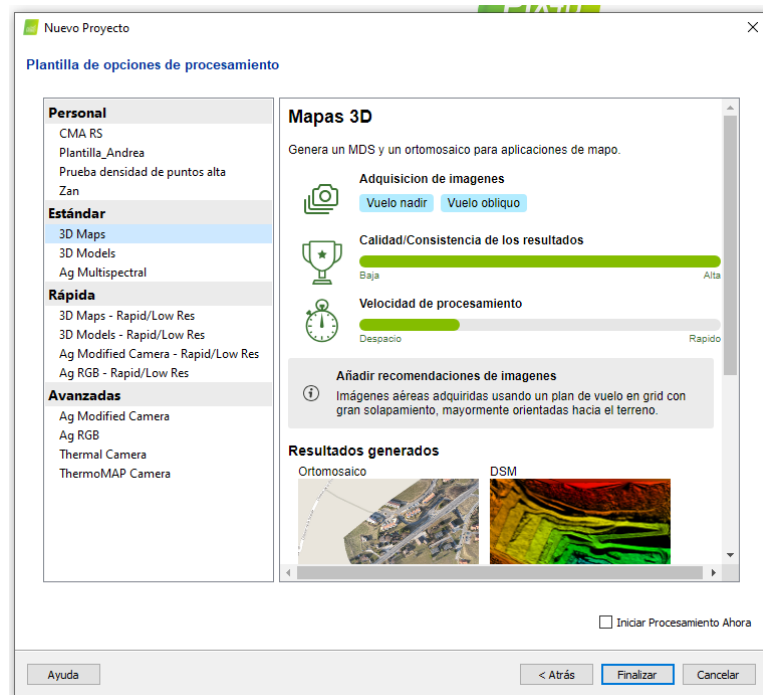
6. On properties of images, check that the coordinates system is the adequate and images are Geolocalized. (Both of this character most have a green check on the side)
7. Check that the sensor is well calibrated. (This must have a green check on the side)
8. Once you have checked the coordinates system, image geolocalization and the camera model (sensor) select ‘Next’



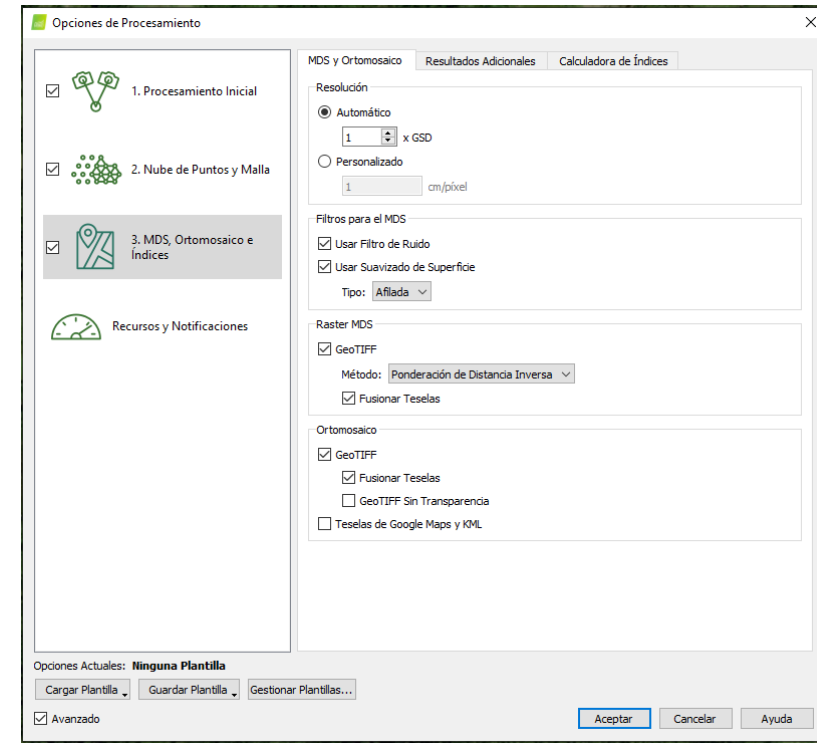
9. Select the correct coordinates system and select “next”



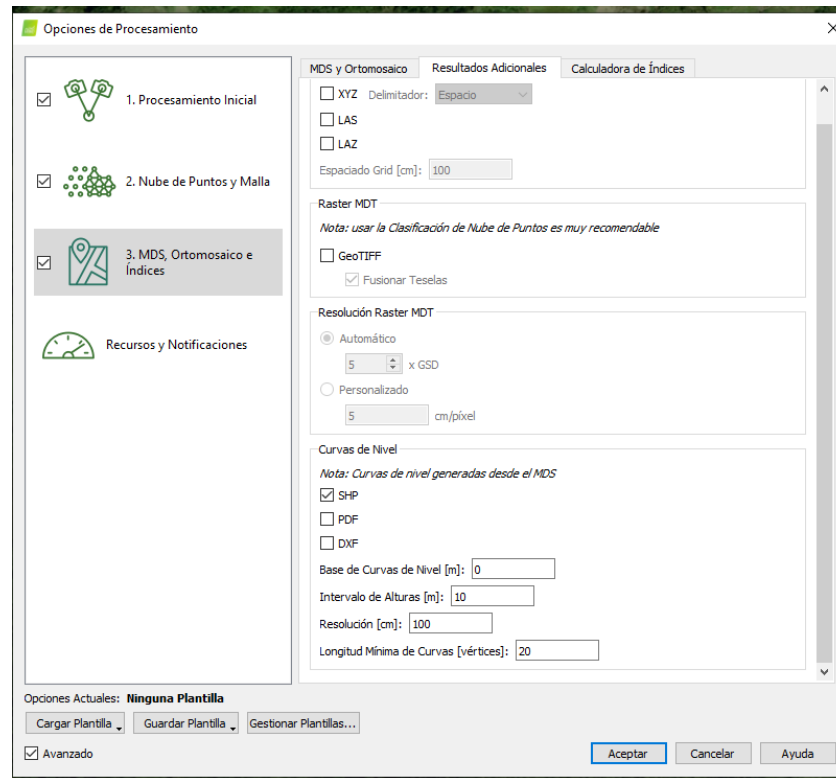
10. In the processing options template go to standard and select 3D maps and select “End”



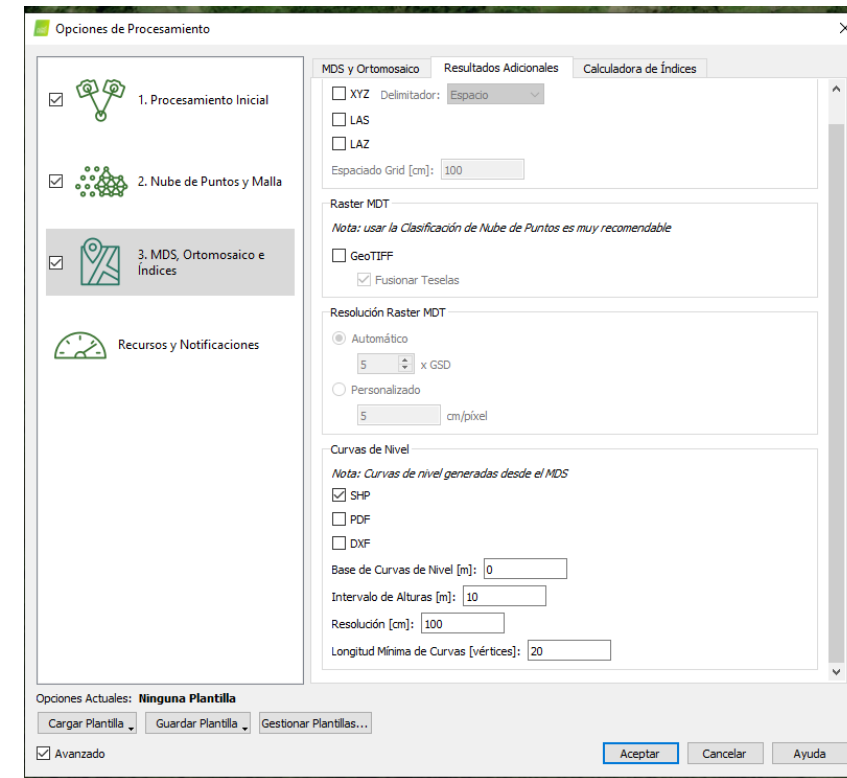
11. Go to the processing tab and select "processing options".
12. Select initial processing (Those parameters generally are predetermined)
13. Select Point clouds and meshes (Those parameters generally are predetermined)
14. Select MDS, orthomosaic and Index. Go to the first tab "MDS and orthomosaic."



15. Within the MDS and orthomosaic tab you must go to "Raster MDS and Raster MDT" and select "GeoTIFF".
16. Next if you need the Slope, you must go to the second tab "Additional Results" and select in Slope "SHP"



17. Check your resolution and Curve interval.



18. Finally select "Accept" and select start processing button that is down below of the window.



19. If you did 2 flights areas before starting the processing of the images you should select "map view" and "processing area".

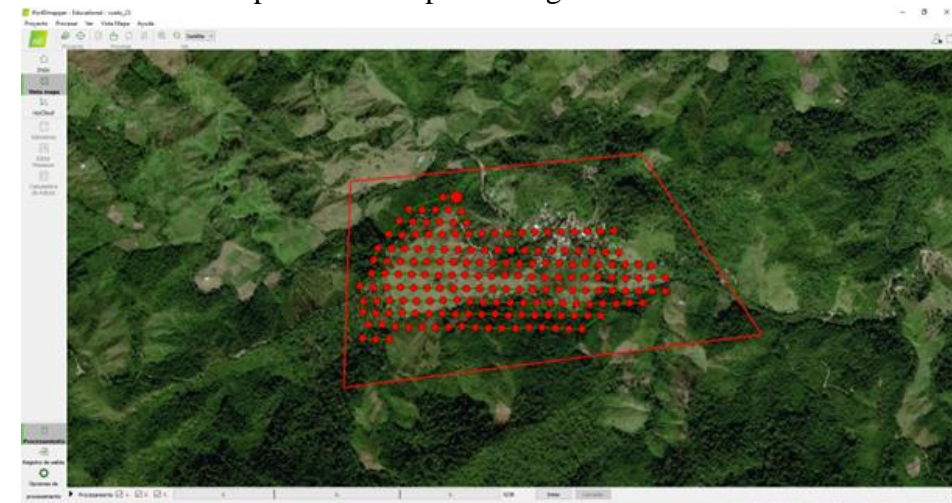
20. Select "drawing".

21. Select "accept"



22. Start drawing the rectangle of the area you need and do two double click with the right side of your mouse to end the drawing.

23. Then select "accept" and start processing.



At the end of the processing, it will generate a point cloud and mesh that will look like this.

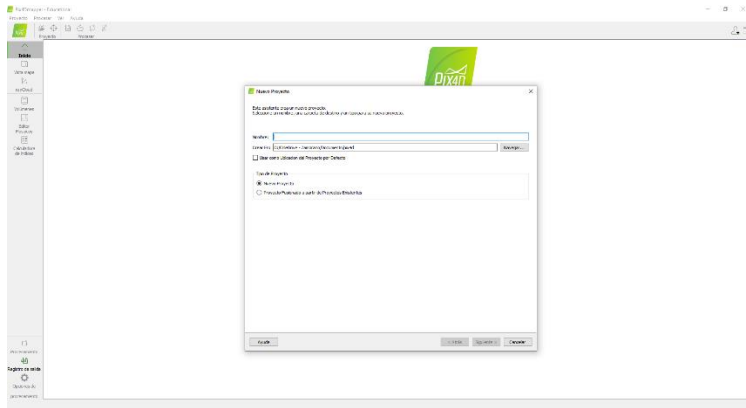
Also, it will be generated a carpet with all the data of the point cloud and mesh, MDS,MDT, Orthomosaic and Index. An example of a final orthomosaic it is shown as follow.



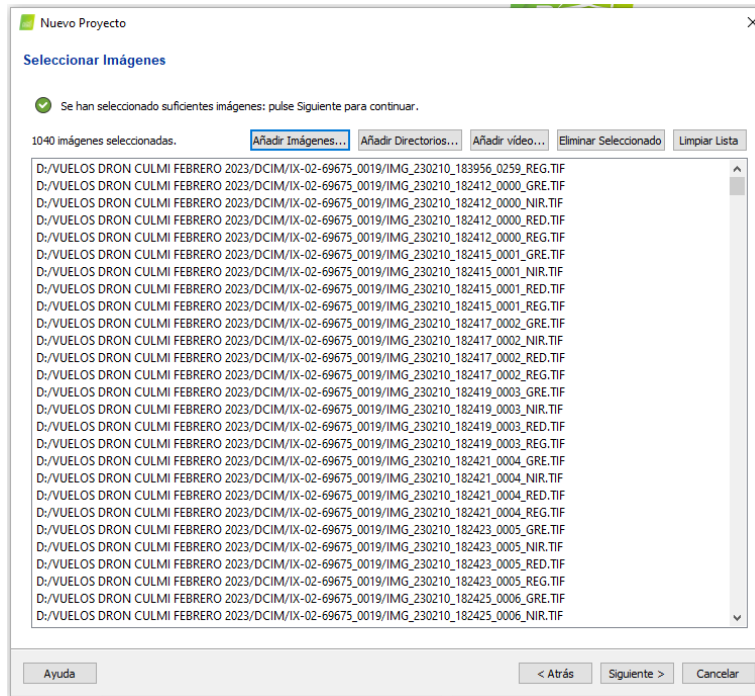
It is important to point out that at the end of the processing of the images the Pix4D software will be generated a quality report of the processed images. It is important to be able to understand this quality report to get the best data possible. An example of a quality report and it's interpretation it is shown at the end of this manual.

PIX4D MULTISPECTRAL IMAGE PROCESSING

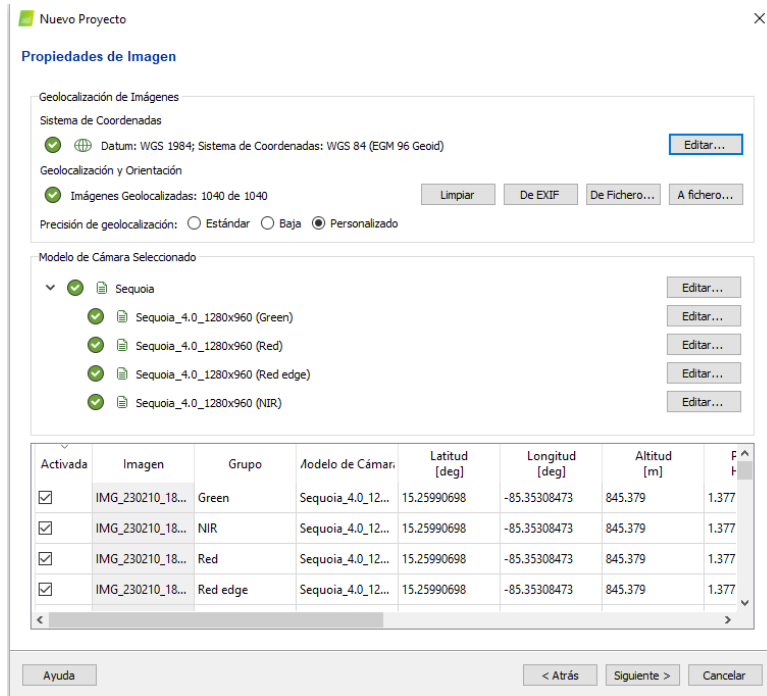
1. Open PIX4D program
2. Open new project
3. Select name of the project
4. Save on folder.



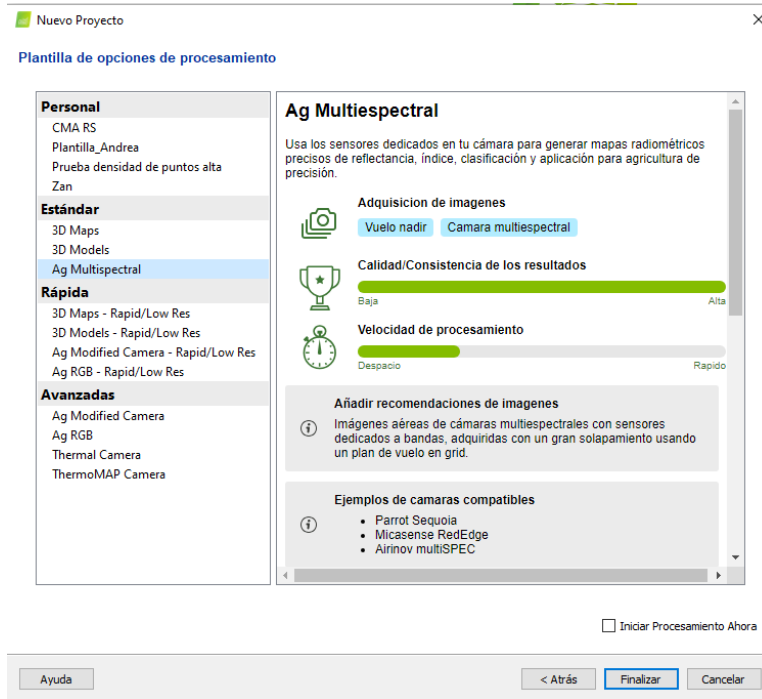
5. Select and Add the Multispectral image from the folders.



6. On properties of images, check that the coordinates system is the adequate and images are localized. (Both of these characters must have a green check on the side).
7. Check that the sensor is well calibrated. (This must have a green check on the side)
8. Select the correct coordinates system and select next.

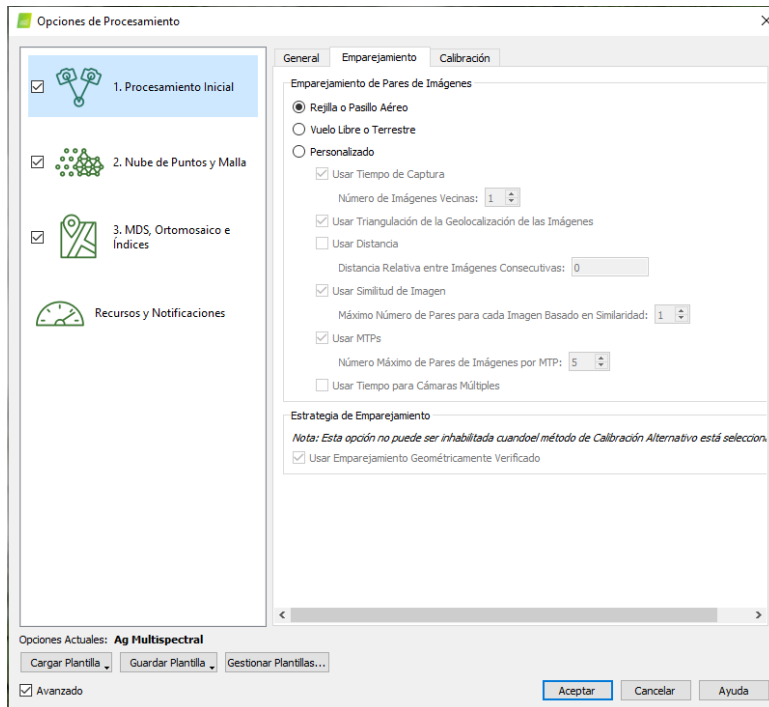


9. Following, go to standard and select ``Ag multispectral``.
10. Select End

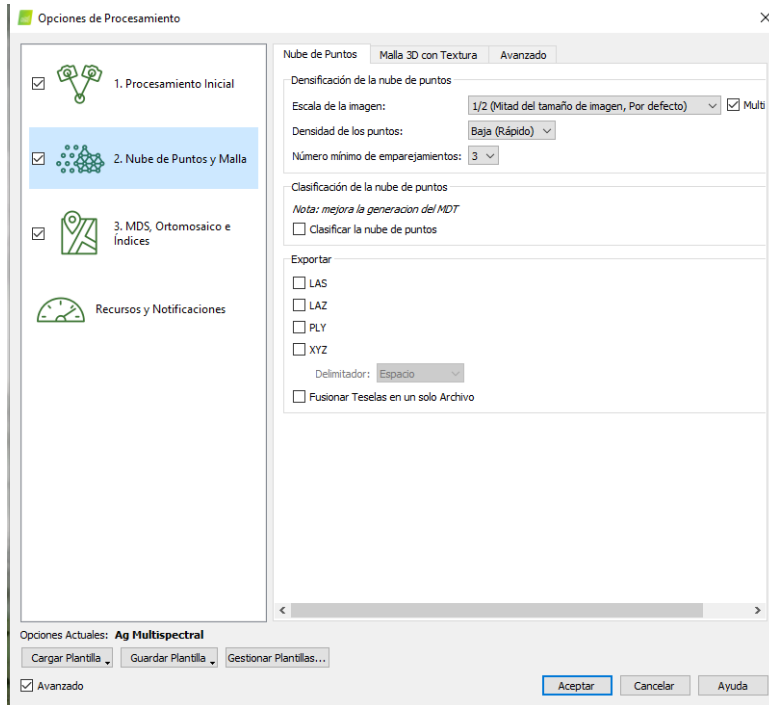


11. Go to processing options.

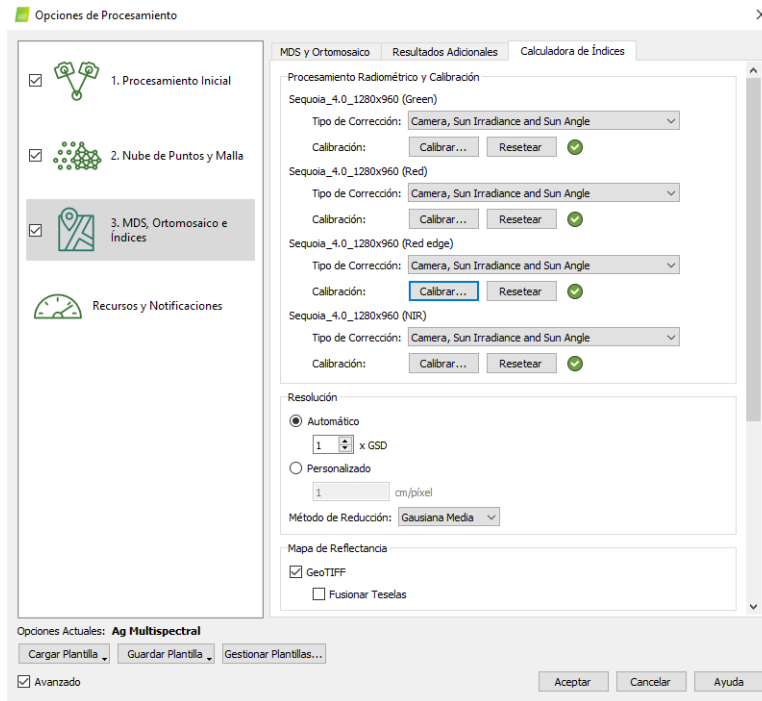
12. Select initial processing (Those parameters generally are predetermined)



13. Select Point clouds and meshes (Those parameters generally are predetermined)

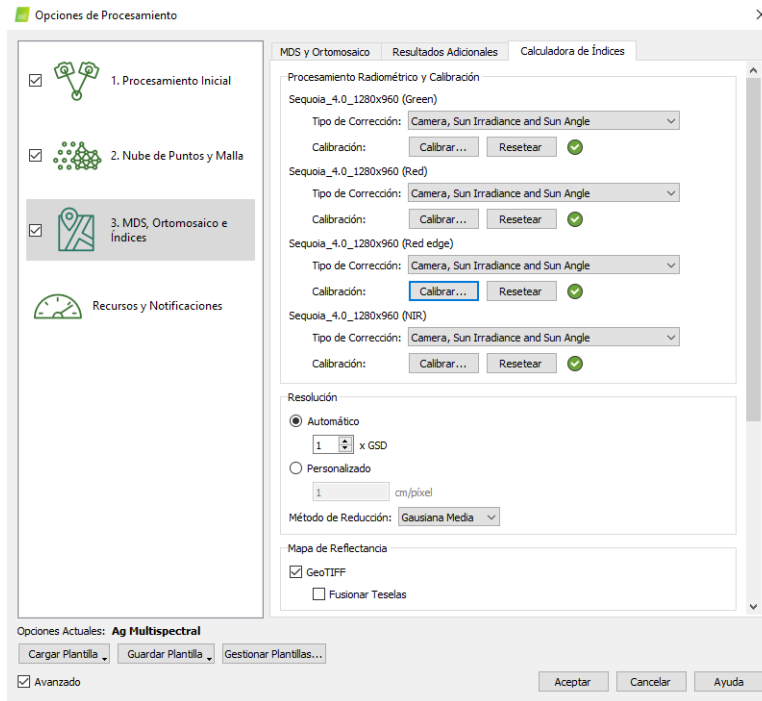


14. Select MDS, orthomosaic and Index. Within this you must go to the third tab (index calculator).



15. Check the images are well calibrated.

16. If the images are not calibrated, you need to select the bottom calibrate and select the calibration images for each band taken for the drone before you started the flight on field.



17. Inside the image, you should move the points as close as possible to the corners of the image square and select “accept”



18. If you need NDVI select the NDVI index and “accept”

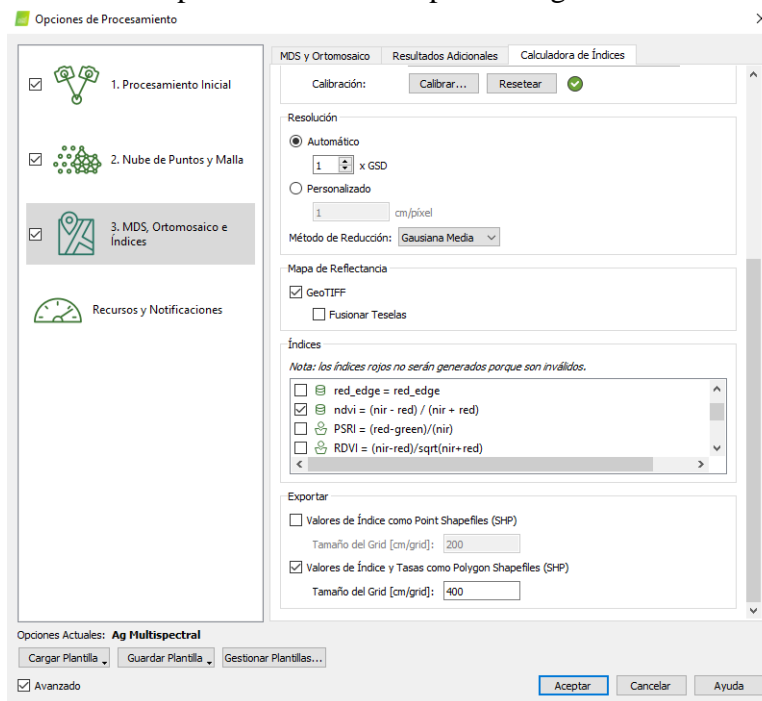
19. Also, you can create NDVI by using the index calculator tool on Pix4D. you can access to the following link that will indicate you how to do it.

<https://support.pix4d.com/hc/en-us/articles/202558289-Menu-View-Index-Calculator>

20. Next if you need the Slope, you must select Slope SHP

21. Check your resolution and Curve interval.

22. Finally select "Accept" and select start processing button that is down below of the window.



23. If you did 2 flights areas before starting the processing of the images you should select map view and processing area.

24. Select drawing.

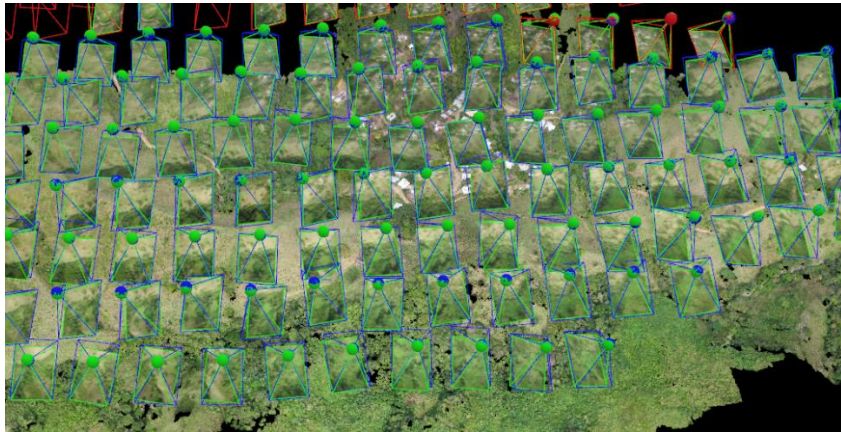
25. Select "accept"

26. Start drawing the rectangle of the area you need.

27. Then select "accept" and start processing.



At the end of the processing, it will generate a point cloud and mesh that will look like this.



Also, it will be generated a carpet with all the data of the point cloud and mesh, MDS,MDT, Orthomosaic and Index.











It is important to point out that at the end of the processing of the images the Pix4D software will generate a quality report of the processed images. It is important to be able to understand this quality report to get the best data possible. An example of a quality report and its interpretation it is shown at the end of this manual.

QUALITY REPORT EXAMPLE AND INTERPRETATION

The quality report is an important tool to determine the accuracy of the images taken by the drone. For this reason, it's important to know how to interpretate it.

In a quality report first, it will be shown a quality check like this.

Quality Check 1

 Images	median of 10000 keypoints per image	
 Dataset	1040 out of 1040 images calibrated (100%), all images enabled, 2 blocks	
 Camera Optimization	0.04% relative difference between initial and optimized internal camera parameters	
 Matching	median of 3413.46 matches per calibrated image	
 Georeferencing	yes, no 3D GCP	

On the first box it appears the number of key points per images. A key point is a distinctive point in an input image. The green check mark on the right side of the box, indicates that images have enough visual content to be processed. If a yellow checkmark appears on this part, this will indicate us that not much visual content could be extracted from the images, and this can lead to a low quality of the results. On the other hand, if a red checkmark appears on this part of the box, it will indicate us that less than 500 key points have been extracted per images, that will lead us to poor quality results. In the last two cases to fix those problems it will be recommended increase the overlap of the images to 80-90%

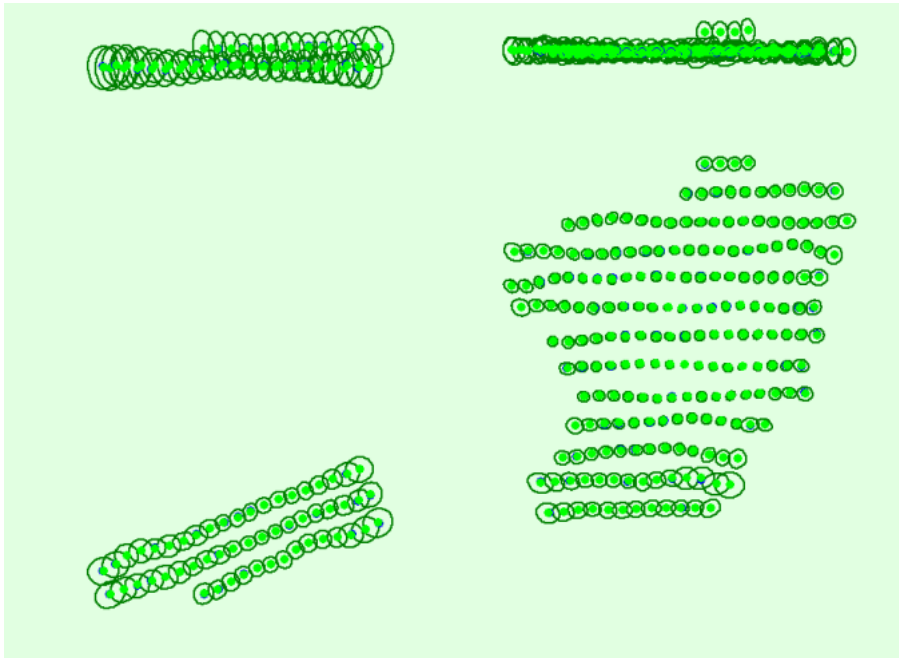
On the second box it appears the data set of the images. This means, the number of enable images that have been calibrated and the number of images used for the construction of the orthomosaic. The green check mark on the right side of the box, indicates that all or almost all images have been calibrated in a single block. If a yellow checkmark appears on this part, this will indicate us that many images have not been calibrated or multiples blocks have been generated. On the other hand, if a red checkmark appears on this part of the box, it will indicate us that less than 60% of enable images were calibrated and it is important to check them.

On the third box it appears the camera optimization. A camera optimization indicates the perspective lens and the fisheye lens. The green check mark on the right side of the box, indicates that the initial camera model should have 5% of the optimized value. If a yellow checkmark appears on this part, this will indicate us that there are some areas with a flat and homogenous area that do not provide enough visual information for an optimal camera calibration. On the other hand, if a red checkmark appears on this part of the box, it will be necessary to check the camera optimization.

On the fourth box it appears the matching, that indicates us the matches per calibrated images. The green check mark on the right side of the box, indicates that the results are likely to be a high quality in the calibrated area. If a yellow checkmark appears on this part, this will indicate us that there is a low number of matches and this can lead to unreliable results. On the other hand, if a red checkmark appears on this part of the box, it will indicate us that less than 50 matches have been computed per images.

On the fifth box it appears if the project is georeferenced or not. The green check mark indicates that the project is georeferenced. A yellow check mark it will indicate us either that there is an error of ground control points (GCP) more than 2 times the average of ground sampling distance (GSD) or no GCP were used. And finally, a red check mark it will indicate us an error superior to 4 times the GSD, which means a severe issue with the data.

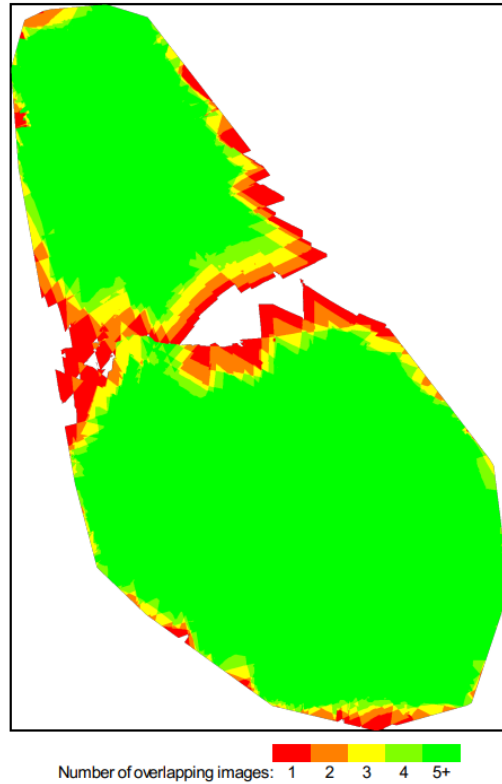
The quality report also generated a figure of the computed images/GCPs/ Manual tie points position, that shows us if the data collected fitted together well. If all the dots are green as is shown on the figure down below it is a good indicator that our reconstruction is good.



On the other hand, if red dots appear in our figure, this may indicate that some parts of our images are not calibrated.

Another figure generated is the overlap. That show us the number overlapping images compute for each pixel of the orthomosaic. Green area indicates an overlap over 5 images per pixel, while a yellow and red area indicate a low overlap which can lead a low quality results.

Overlap



Finally, an important part to have in mind in this quality report is the radiometric calibration. A radiometric calibration is a way of converting source data that have physical units of reflectance, which is used to build quantitative spectral, spatial, and temporal representations of the environment. In this camera radiometric calibration it will be shown on the first box the name of the camera. Then the band of the camera to which radiometric calibration was applied and finally the type of radiometric calibration applied to the images of a band (camera only, camera and sun irradiance or camera, sun irradiance and sun angle).

Camera Radiometric Correction

Camera Name	Band	Radiometric Correction Type	Reflectance target
Sequoia_4.0_1280x960	Green	Camera, Sun Irradiance and Sun Angle	✓
Sequoia_4.0_1280x960	Red	Camera, Sun Irradiance and Sun Angle	✓
Sequoia_4.0_1280x960	Red edge	Camera, Sun Irradiance and Sun Angle	✓
Sequoia_4.0_1280x960	NIR	Camera, Sun Irradiance and Sun Angle	✓

If you need detailed information of the interpretation of the quality report, you can access to the following links.

<https://support.pix4d.com/hc/en-us/articles/202558689-Quality-Report-Help-PIX4Dmapper#label1>

<https://support.pix4d.com/hc/en-us/articles/202558679-Quality-report->