The use of digital aerial photography as support for restoration, management and habitat monitoring programmes

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Summary

With the rapid loss of biodiversity we face nowadays, urgent action needs to be taken in order to stop it, or at least to reduce it. Habitat restoration, new management approaches and monitoring programmes are some of the best ways to do so. However, these initiatives are often not taken seriously by scientists and stakeholders, and sometimes they are seen as a waste of time or too much work for very little gain.

Ecological assessment and monitoring is intrinsically spatially-explicit, and imagery from airborne devices is an important source of information. In order to make data acquisition easier and faster, we used a digital camera coupled to a supporting structure built to hang on an inflatable kite or a pole (close-range photogrammetry). The resulting photos were transferred into a computer, which is then used generate a three-dimensional digital terrain model (3D DTM) and an orthophotomap. Then, by means of visual interpretation on a Geographical Information System (GIS) software, depending on the study area, different approaches were taken to extract ecologically relevant information.

This way, several maps were obtained, each of them being an example of how this method can have a wide array of applications: detailed habitat mapping to support active management, an ecological restoration plan proposal for a fine-grained habitat mosaic, and a sampling grid where the spatial patterns of individuals of different plant species were identified and studied statistically. These high-quality cartographic results were obtained in a rather easy and fast way, meaning that this method can save time, effort and money, and might therefore be the answer to some of the problems with ecological research nowadays.

Key-words

Biodiversity loss, DTM, GIS, Natura 2000, orthophotomap, photointerpretation, priority habitat, remote sensing

Resumo

Devido à acelerada perda de biodiversidade que enfrentamos hoje em dia, é necessário tomar medidas para parar ou pelo menos reduzir essa perda. Restauro ecológico, novas medidas de gestão e programas de monitorização são das melhores ferramentas que temos para o conseguir. Infelizmente, estas iniciativas não são levadas a sério pelos cientistas e outros intervenientes, visto que muitas vezes são vistas como uma perda de tempo, requerem esforço a mais e dão resultados pouco úteis.

Monitorização e avaliações ecológicas precisam necessariamente de informação espacial, e, como tal, imagens aéreas são importantes fontes de informação. Com vista a tornar a aquisição de dados mais simples e mais rápida, utilizou-se uma máquina fotográfica digital montada num suporte construído para ser suspenso num papagaio ou numa cana (fotogrametria digital à curta distância). As fotografias obtidas foram transferidas para um computador que gera modelos digitais de terreno tridimensionais e ortofotomapas. Posteriormente, dependendo da área de estudo em questão e com recurso à interpretação visual das imagens obtidas num ambiente de Sistema de Informação Geográfica (SIG), fizeram-se várias análises com vista a extrair informações ecologicamente relevantes.

Deste modo, obtiveram-se vários mapas, cada um constituindo um exemplo das várias aplicações que este método pode ter: cartografia detalhada de habitats para apoiar a gestão activa da área, um plano de restauro ecológico para um local onde se encontra um mosaico de habitats muito fino e uma grelha de amostragem para a análise dos padrões espaciais de indivíduos de espécies vegetais diferentes, onde foram efetuadas análises estatísticas. Estas cartografias de alta-resolução foram todas obtidas de um modo mais simples e rápido do que o seriam caso fossem utilizadas técnicas mais tradicionais que se usam actualmente, o que significa que este método pode poupar tempo, esforço e dinheiro, constituindo assim uma solução para alguns dos problemas dos estudos ecológicos nos tempos que correm.

Palavras-chave

Deteção remota, fotointerpretação, habitat prioritário, MDT, Natura 2000, ortofotomapa, perda de biodiversidade, SIG

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List of abbreviations

GIS – Geographical Information System

DTM – Digital Terrain Model

DEM - Digital Elevation Model

CRP - Close-range photogrammetry

CBD - Convention on Biological Diversity

GEO BON – Group for Earth Observations Biological Observation Network

GCP’s – Ground Control Points

DGPS – Differential Global Positioning System

1. Introduction

1.1. Biodiversity loss

Biodiversity loss is a serious global problem that since the Rio Summit in 1992 has been getting increased attention. This loss has been found to be a consequence of human activities and as such, during the Convention on Biological Diversity, numerous countries made a commitment to reduce biodiversity losses significantly by 2010, a goal that has not been reached. However, this is no reason to stop trying, it is necessary to halt future losses and promote the sustainable use of biodiversity (Duro *et al.*, 2007; Walpole *et al.*, 2009; Sullivan *et al.*, 2011).

The Habitats Directive (92/43/EEC), which together with the Birds Directive (79/409/EEC) make up the Natura 2000 network, the main framework for biodiversity conservation in the European Union, legally obliges member states to report on the conservation status of habitats listed under Annex I, where the protected habitats are listed, every six years. It becomes obvious that monitoring programmes are a necessity in order to abide by the law (Vanden Borre *et al.*, 2011). The Group on Earth Observations Biodiversity Observation Network (GEO BON) is an example of a wide initiative that tries to promote biodiversity monitoring worldwide, and although it is a global initiative, not only European, it may help the countries in Europe to fulfil their obligation (http://www.earthobservations.org/geobon.shtml). It is not limited to habitat monitoring, as it encompasses everything from the genetic to ecosystem level and it is a way for several organizations to share their monitoring data, improving the quality, increasing the amount and making the data more readily available for policymakers, managers and all interested users (Pereira *et al.*, 2010; Scholes *et al.*, 2012).

Along with monitoring, conservation and restoration projects are also invaluable to stop or even invert the current negative trends of biodiversity. Ecological restoration is the process through which a damaged, degraded or destroyed ecosystem is assisted in recovering (Society for Ecological Restoration International Science & Policy Working Group, 2004). However, when attention is given to increase one particular ecosystem function or service, the provision of the remaining services often suffers a decline. In cases such as agricultural ecosystems, the greatest challenge is to maintain productivity while also strengthening the provision of other ecosystem services, meaning that one of the greatest challenges of ecological restoration is to conciliate the economic, cultural and natural views of an ecosystem’s services (Rey Benayas and Bullock, 2012).

1.2. Scope and key issues of ecological monitoring

When well planned, monitoring provides data that can be used for multiple purposes, making it a great tool for long-term ecological studies and providing solid information to support the formulation of environmental policies, unlike the perception of some scientists and policymakers (Strayer *et al.*, 1986; Lovett *et al.*, 2007; Lindenmayer and Likens, 2009). However, the importance and need for monitoring goes beyond that. Some habitats need active human intervention in order to avoid ecological succession and the consequent transformation in another kind of habitat (ALFA, 2004; Redhead *et al.*, 2012). Management programmes applied on these habitats have to be evaluated in order to be adjusted (if necessary), and this is accomplished through periodic monitoring. On the other hand, a periodically monitored habitat may show signs of change and that will prompt the creation of a conservation or management programme. This means that monitoring is both a consequence and a reason of, and for, management and conservation.

The first step in the process of designing a successful monitoring programme is to clearly define what needs to be monitored, meaning that collecting a lot of data without purpose and then figuring out what to do with it is the wrong way to proceed (Lovett *et al.*, 2007; Lindenmayer and Likens, 2009). After the subject to monitor is selected, adequate and robust methods to do so must be selected. Data can be acquired *in situ* by, for example, collecting samples, taking notes, measurements of various parameters, or it can be acquired via remote sensing. It might seem obvious what to choose if the study requires measuring of water parameters or habitat mapping, but if the study requires counting individuals of a tree species it can depend on the size of the study area or the money available.

A solid sampling design is also crucial to the success of the programme as it will ensure that data are adequate and statistically significant (Lindenmayer and Likens, 2009). It is very important not to change methods during the programme, and if such need arises, results from both the new and old methods must be collected in order to establish comparability. This process does not end after the results are obtained, as it is also important how we use and make the data available. Data should be stored in various locations and made available as soon as possible so that its usefulness is maximized and it can be evaluated, analysed and published by other scientists or concerned individuals. The best way to ensure this, however, is to integrate the data in an integrative research project where it will be used for experimentation, running models or cross-site comparisons, for example (Lovett *et al.*, 2007).

1.3. Remote sensing in ecological monitoring

Monitoring large areas will require more time, money and effort, and many areas have physically inaccessible places, making it harder to monitor them *in situ.* This is one of the many reasons to use remote sensing: it allows broad area coverage with less effort and money; it's repeatable over long time periods and is especially useful when studying heterogeneous environments. It will not replace the need for traditional monitoring approaches on a finer scale, but it will guide those efforts and consequently improve their efficiency (Ekebom and Erkkila, 2003; Duro *et al.*, 2007; Hamada *et al.*, 2011; Sullivan *et al.*, 2011; Redhead *et al.*, 2012).

Remote sensed data is highly varied in spectral, spatial and temporal resolution, as well as in areas captured, since it can have numerous sources and, depending on the goal, different methods will be more or less adequate, e.g. collecting aerial photography for mapping coastal habitats (Ekebom and Erkkila, 2003), using LANDSAT images to study land-cover variations through time (Gillanders *et al.*, 2008) or even to develop a model to predict the distribution of biodiversity hotspots in semi-natural habitats in order to identify priority areas for targeting management and conservation projects (Sullivan *et al.*, 2011).

In spite of the growing recognition of the potential of remote sensing, the community of users is still small compared to the potential users. This could be mostly due to unfamiliarity with the technologies, and that may also explain why computer-assisted analysis of remotely sensed data is only limited to exemplary and pilot projects (Vanden Borre *et al.*, 2011). Still, studies such as those by Díaz Varela *et al.* (2007) and Bock *et al.* (2005) tried to apply these technologies for Natura 2000 habitats with promising results. Bock *et al.* (2005) used four different study areas, each with different objectives, to illustrate the results of the SPIN project ("Spatial Indicators for European Nature Conservation"). They used different image sources and different automatic image processing techniques in order to map habitats, assess land cover changes, identify and apply spatial indicators, and disaggregate and downscale soil information. Dias Varela *et al.* (2007) assessed various semi-automatic classification methods and concluded that using these methods to analyse vegetation characteristics by means of medium resolution satellite imagery can sometimes prove difficult due to the different structures and the existence of ecotones between habitats that cause overlapping of infrared signatures. Also, habitats that are similar in structure, ecological function or floristic composition can show similar spectral signatures, which can be problematic for this kind of analysis.

1.4. Close-range photogrammetry

Photogrammetry consists in the measurement of exact distances and in the collection of three-dimensional data for a given object from two or more photos of that object. Our ability to see in three-dimensions comes from the different perspective that our brain receives from our right and left eyes, and photogrammetry was based on this principle (Stylianidis *et al.*, 2003; Matthews, 2008). It is especially useful for the creation of maps, and it has been the backbone of numerous maps since the 1930's (Matthews, 2008), but it is also used in other areas, such as archaeology and industry. This means that remote sensing is closely tied with photogrammetry, because the photos provided by remote sensing (whether they are aerial digital photographs or satellite imagery) can be processed by photogrammetric software in order to generate DEMs, orthophotomaps or simple thematic maps (Stylianidis *et al.*, 2003). Close-range photogrammetry (CRP) is the term used when the object-to-image distance is less than 300 meters (Matthews, 2008).

Davis and Johnson (1991) used a small balloon found on shops to float a camera, and a radio-control system usually found on model cars to control the shutter, as a way to show that airborne monitoring could be achieved at a low monetary cost. Others, like Arteaga *et al.* (2008), used photogrammetric techniques to study dune dynamics and evolution or, as is the case of Stylianidis *et al.* (2003), to monitor slope displacement in order to assess collapse risks. Bird (2010) used a unipod to lift a camera and followed a small stream so that a high-resolution DEM could be extracted. Remote sensing would not work because the riparian forest canopy would cover up the stream, as is the case of various habitats, but good results were obtained in this study, in spite of problems related with the light quality, as the author was under the canopy and occasionally branches obscured the camera.

1.5. Research objectives

In this research we explored some of the many potential applications of close-range photogrammetry to support detailed ecological assessment, restoration and monitoring. To do so, we used a close-range photogrammetry system devised by Henriques (2006), in which a conventional digital camera is applied to a special supporting structure, which in turn is hung on an inflatable kite or a pole, in order to obtain very-high spatial resolution aerial photographs which can then be visually interpreted on a GIS software, followed by field validation of the results.

This system was used to produce habitat maps and biodiversity assessments in three different applied research contexts: (1) plant community structure assessment in sand dunes to support coastal erosion monitoring, (2) habitat mapping for comparative evaluation of alternative management options; and (3) habitat mapping and topographic modelling for habitat restoration.

These three studies were developed in order to address the following general questions:

(I) Are the resulting close-range photos adequate and useful for the objectives of each assessment?

(II) Can this method be applied successfully in distinct environments and for different goals? and

(III) Is this approach effective and cost-efficient, in comparison to others currently used to support ecological assessment and monitoring?

2. Materials and methods

2.1. Acquisition and processing of close range aerial photos

2.1.1. Data acquisition

- Preparing the study area

The field work starts with setting up a Differential Global Positioning System (DGPS) system and connect it to the national GPS network in order to measure fixed points that will be used to optimize and orthorectify the models and maps. Then, before taking the pictures, paper targets are scattered all over the study area in such a way that each two photos contain at least one of these targets, so that the software program can later use these fixed points, also called Ground Control Points (GCP's), to give internal orientation and optimize the Digital Terrain Model (DTM) generated from the pictures. These targets are made of a sheet of thick paper with a number on them and they have a colour that is different from their surroundings so that they can be easily spotted in the several pictures. They are pinned to the ground by a steel stake and create a "grid", which will play a critical role in the DTM generation, meaning that the more GCP's available, the more accurate the model will be. The position of each of these GCP's is carefully measured with the DGPS system, with positional error values of approximately 20 millimetres in x, y and z-axis. In this work it was used a Trimble 5800 unlimited, L1/L2 dual frequency DGPS system.

- Kite system

The system used was designed and assembled by Henriques (2006) and used on his thesis. It consists of a special radio-controlled housing structure made of aluminium, designed to hold any consumer-grade digital camera (currently using a Sony Cyber-shot DSC-HX7V with 16,2 Megapixels) attached to strings which double as a connection to the inflatable kite and a way to make the camera perpendicular to the ground plane. This stabilization system is known as a Picavet's suspension (for more information see http://www.kaper.us/basics/BASICS_picavet.html).

The housing structure can make the camera rotate on a horizontal or vertical plane, which allows 360 degree coverage of both planes, but in this study the camera was pointed down, toward the ground plane. It also has a mechanism that controls the camera's shutter button, and both this mechanism and the rotation mechanisms are achieved using four radio-controlled servo-motors.

After the housing structure is attached to the kite, with adequate atmospheric conditions, the kite inflates and flies at a sufficient height for the structure to be suspended (20-300 metres). One person must be holding the kite's rope and handling it (the handler), while another holds the remote to control the camera's movement and to activate the shutter at regular intervals (the helper). The handler and the helper then must cover the whole study area, which is why it is helpful to have more people on the field to help the handler know where the camera is floating over, while taking care not to be caught in the photos.

- Pole system

This system is very simple and was designed by Henriques (2006) as well. It allows for photos to be taken at a lower altitude (2-8 metres) and, consequently, have higher resolution. It's a system more suited for study areas that don't require broad coverage and for studies that might require finer resolutions.

The same housing structure is used, but this time it is attached to a regular fishing pole. This elevates the camera and solves the problem Bird (2010) had: he caught himself in the photos, leading to lower accuracy due to the higher amount of masks the software had to apply to avoid moving objects in the pictures, reducing the number of available common points. In this case, there is also one handler and one helper: after the route established, the handler holds the pole and waits for the structure to stabilize and then the helper snaps a photo. The handler takes a few more steps and the process is repeated all over the route chosen in order to cover the whole study area.

2.1.2. Data processing

- DTM and orthophotomap generation

Prior to any photogrammetric post processing, the used camera is submitted to a calibration process in order to get the camera systematic error for further correction. These errors include the effects of barrel-shaped distortions (wide-angle lenses), pincushion-shaped distortions (telephoto lenses) or any other lens deformation that can cause image distortion. To minimize the resulting geometric errors a Brown model (in Moffit & Mikhail, 1980) is used to determine all the correction parameters.

To obtain a precise orthophotomap and a DTM, the obtained pictures must have enough overlap. Preferably, each picture must have more than 60% overlap with all the surrounding ones. Pictures are processed with a photogrammetric application in order to determine common points between them. The detection of common points is limited to a maximum of 40000 between each pair of pictures. Statistical algorithms are applied to optimize the collection of the best-correlated points and provide the elimination of outliers. The EXIF information contained in the pictures, such as focal length and image pixel dimensions, is used, in conjunction with the detected common points, correctly triangulated, to obtain a rough 3D point cloud. A bundle block adjustment algorithm (Triggs *et al*, 1999) is then used to refine the coordinates of the 3D point cloud that defines the scene geometry, as well as the relative motion and optical characteristics of the used camera. This algorithm allows the creation of a relative geometrically proportional dense 3D point cloud, obtained from the overlapping points, as well as the relative positions of the camera when each picture was captured. After this process, CGP's obtained from the DGPS coordinates, are used to give the model internal orientation, and optimize all points to the best possible real geodesic position. CGP's are visually identified in each picture and their xyz coordinates are declared to allow them to be tied to the correct real world position. Once the 3D point cloud is completely optimized, points are interpolated to build a continuous 3D surface, based on a mesh of triangular polygons, that defines the final geometry of the DEM. The orthophotomap is obtained by blending all the available pictures based on their common tie points, using a "mosaic" algorithm and using the DEM to eliminate distortions caused by the terrain shape.

In this work the following applications were used to achieve all the above tasks: Trimble Geomatics Office (for DGPS data post-processing, see http://www.trimble.com/index.aspx); and Agisoft Photoscan (for photogrammetric calculations and DEM and orthophotomap generation, see http://www.agisoft.ru/products).

3. Results and discussion

3.1. Fine-scale monitoring of vegetation dynamics in coastal dunes

- ### Context and objectives

The motivations for this study result from previous research in coastal dynamics and dune vegetation (Honrado *et al.* 2010, Macedo *et al.* 2010), which has been aimed to study the vegetation responses to stress and identify robust indicators of changes in vegetation dynamics, in order to implement them in monitoring programmes to assess impacts of environmental changes and restoration programmes.

Given the reduced area and in order to maximize the resolution of the model, only the pole system was used to analyse and map the test area. This is important because the goal of this project was to identify indicators based on individual plants or plant species, and some of them might be too small to distinguish even in a model generated from the kite system, thus requiring a finer resolution.

- ### Study area and field survey

The study area is a coastal dune system located in Aguçadoura beach, in Póvoa de Varzim, Oporto district, and was the smallest study area used in the present thesis. Coastal habitats are very prone to stress and disturbance since they are the interface between land and ocean, which in turn, also makes them very dynamic (Honrado *et al.* 2010). This particular study area only showed mild signs of human disturbance and some interesting evidences of facilitation among plant species, making it an interesting area to apply these new techniques because it showcases their potential.

Field work from which this data was obtained was carried out on the 24th of July, 2012.

- Raw DTM's and orthophotomaps

Figures 1 to 3 illustrate the main results obtained during the field survey (orthophotomaps and a digital terrain model. Many important aspects of dune ecosystems and particularly of their vegetation can be easily observed.

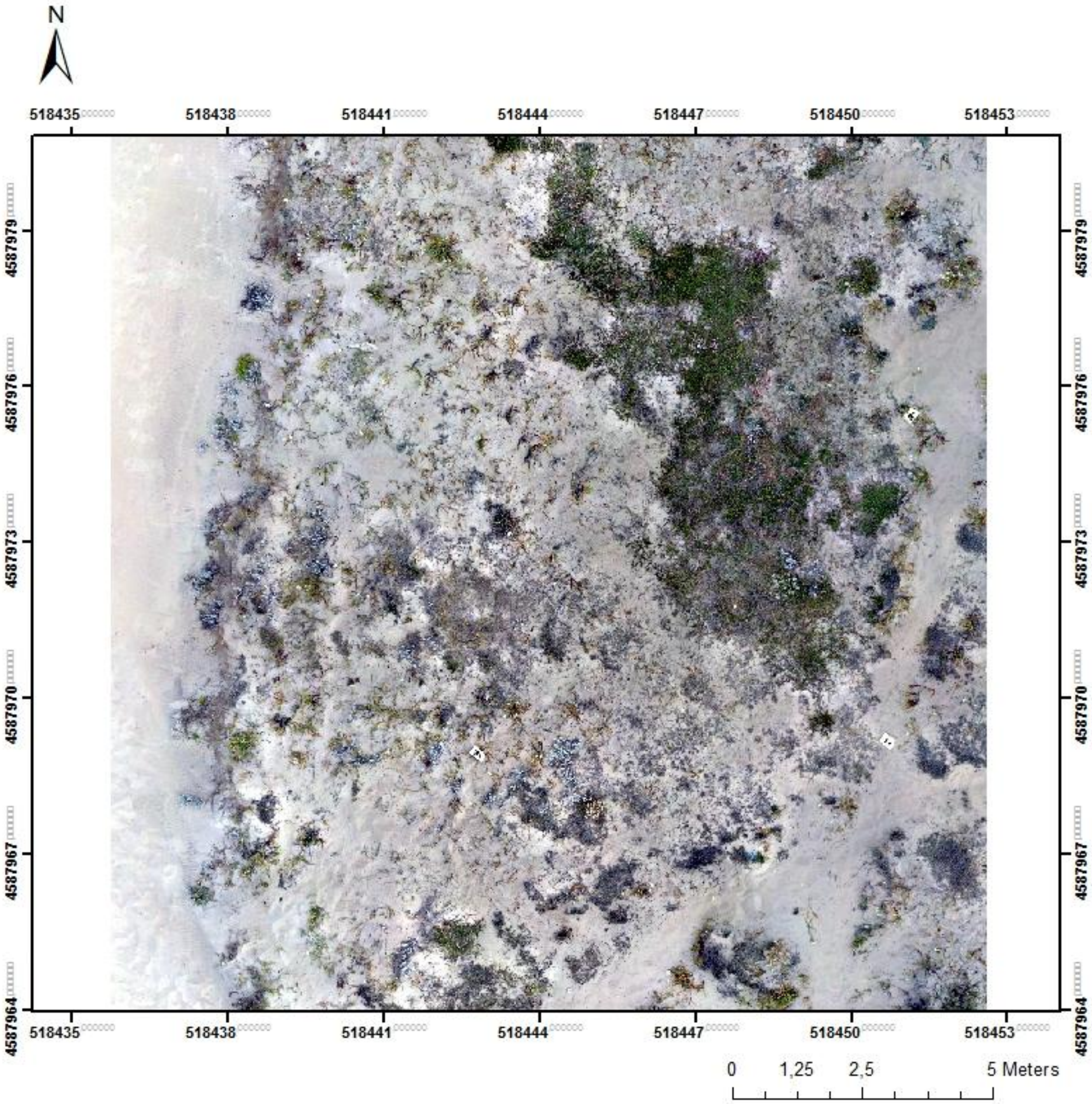

Figure 1 – Raw orthophotomap for the general area of the Aguçadoura beach.

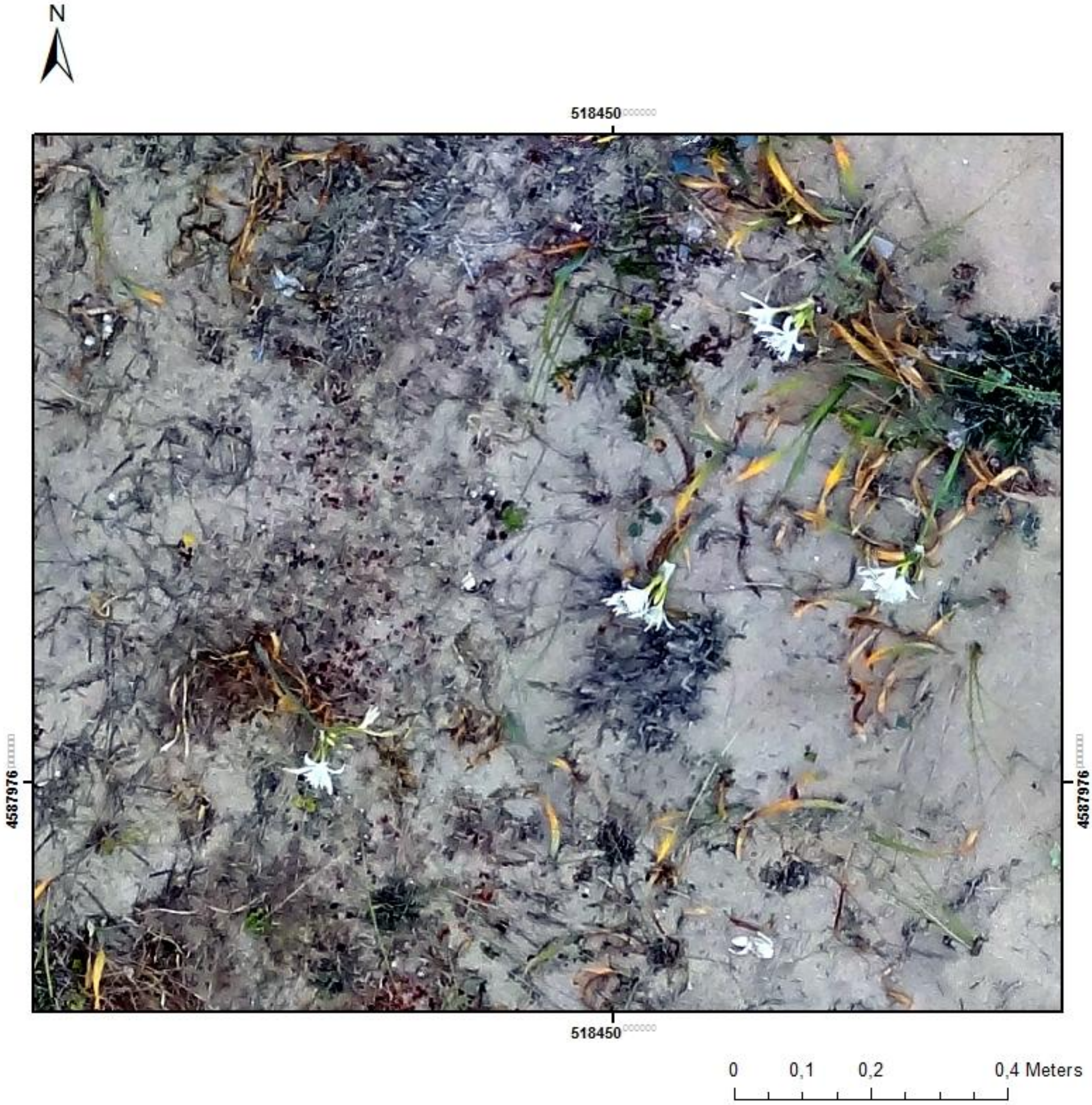

Figure 2 – Zoomed region of the raw orthophotomap of the Aguçadoura beach study area.

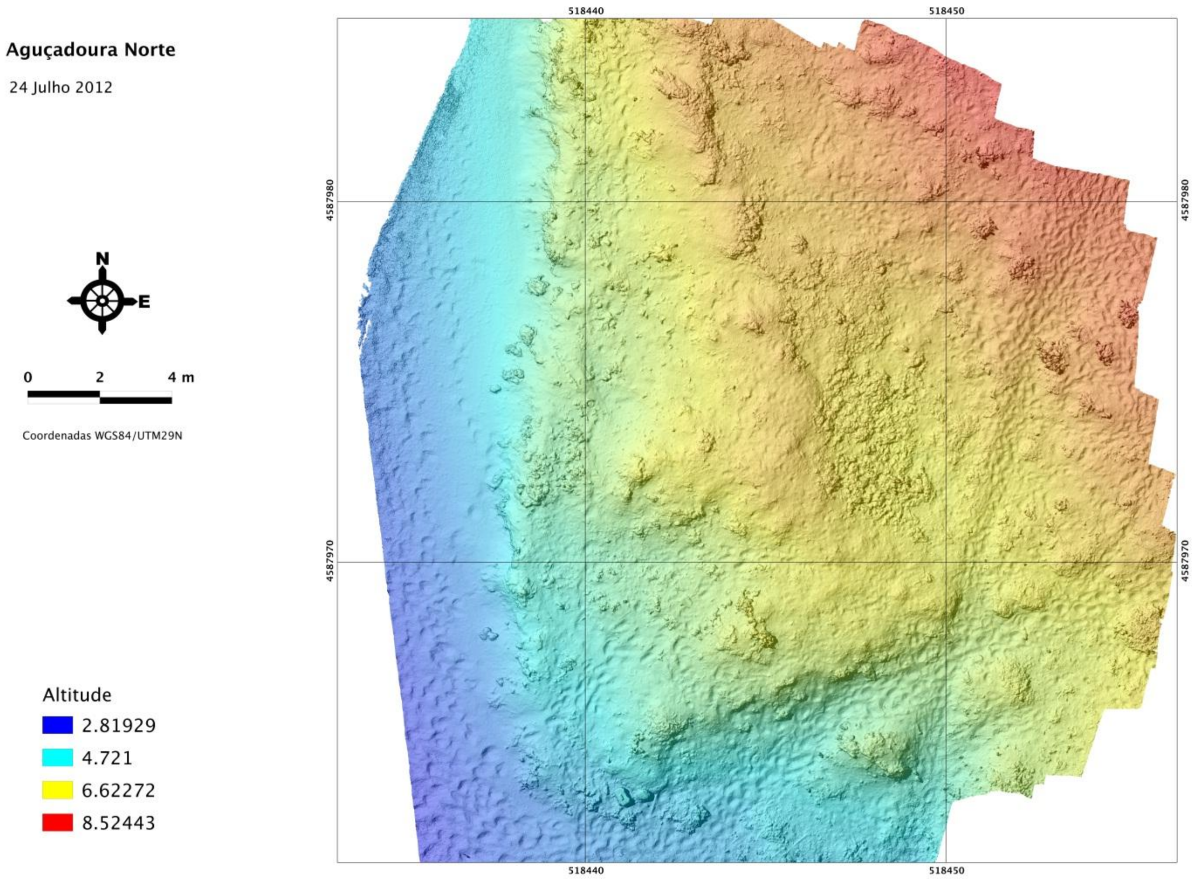

Figure 3 – DTM of Aguçadoura beach area.

- Statistical analysis and results

A 10 by 5 meter grid with 1 by 1 meter squares was generated using the “Create fishnet” tool in ArcMap 10.1, and flowers of species *Pancratium maritimum* and *Euphorbia paralias* were marked in different shapefiles by means of visual interpretation (Figure 4).

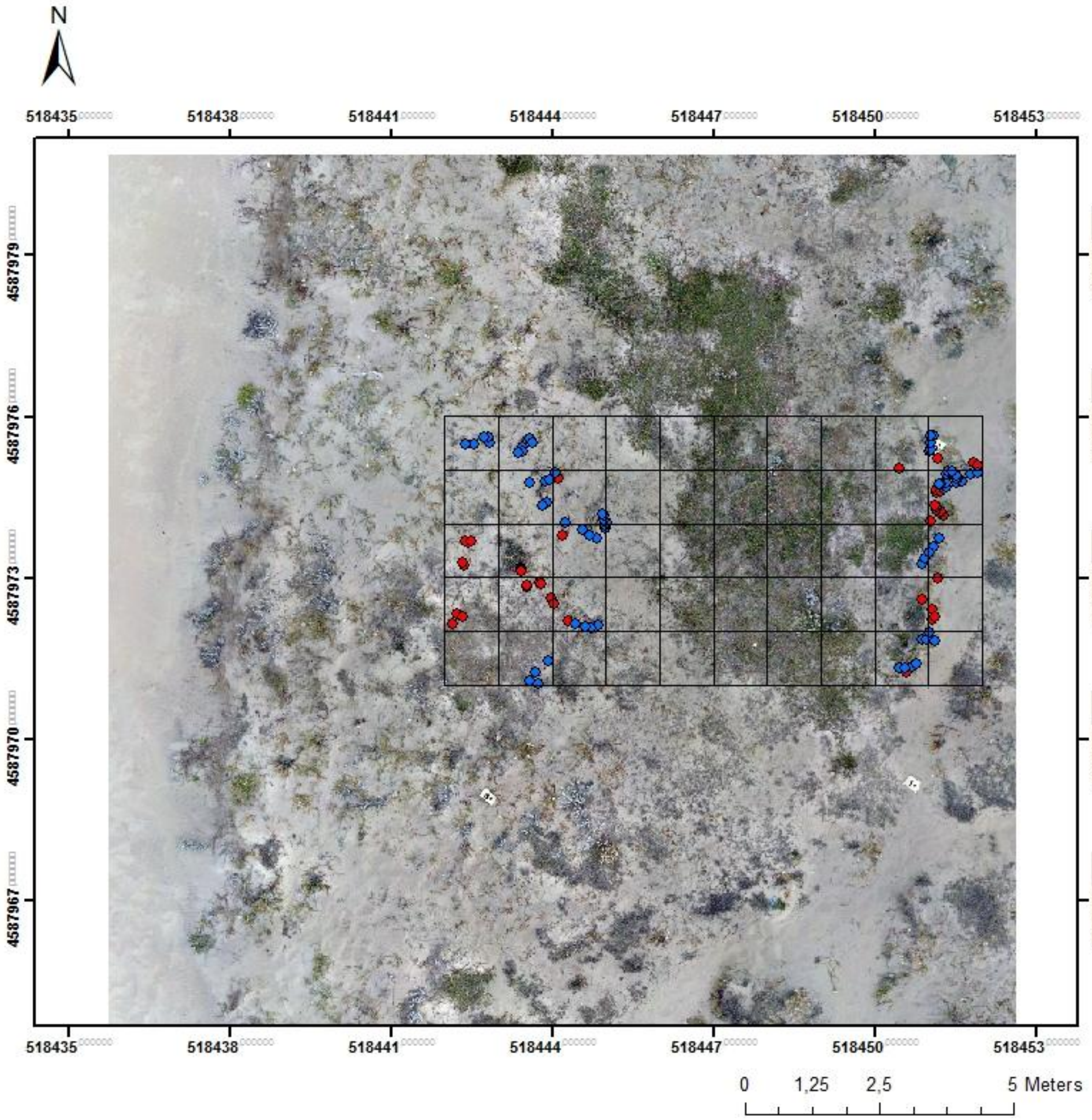

Figure 4 – Sampling grid and point data for the Aguçadoura beach area.

Then, using the "Point Proximity" tool, selecting the input features as the points in the *Euphorbia* shapefile, distances to each point of the *Pancratium* shapefile were calculated. Using these data, as well as the coordinates of each point in each shapefile, the corresponding attribute tables were exported to Microsoft Excel 2010. Spatial point pattern analysis was then conducted using O-ring statistic measures, through the mark-correlation g(r) function (g-function). The univariate g-function measures the expected number of neighbourhood points in a ring of radius r centred in an arbitrary point (i.e. the focal point, which is not counted) divided by the overall intensity of the pattern. The bivariate g-function is an extension of the first, comprising type 1 and type 2 points (where type 1 and type 2 points represent the patterns of two different species)

(Wiegand and Moloney, 2004). The maximum value of the radius was set to 25 decimetres, representing an acceptable *Euphorbia* seed dispersion distance (Baiges *et al.,* 1991), since the reproductive process of *Pancratium* is mainly vegetative. The width of the ring was set to 1 in order to avoid the jagged effect. Point-point distances were converted to decimetres in order to facilitate the visualization and interpretation of the results.

Statistical significance of the results was achieved by testing the real g-functions against 199 functions simulated by null models. The 5th highest and lowest values for the generated g-functions were used to construct simulation envelopes: if the real g(r) was smaller or greater at a given scale r than the 5th lowest or higher values, the species was regarded as having a less, or more, diverse local neighbourhood at scale r than expected by the null model (with a 95% confidence interval), respectively. As such, the univariate g-function form was interpreted as a measure of species assembly at the individual scale, i.e., intraspecific relations for each individual species: *Euphorbia paralias* and *Pancratium maritimum*. The bivariate form was applied in order to detect interspecific assembly between both species considering (a) *Euphorbia* as a focal species (fixed pattern) and *Pancratium* as a neighbourhood species (randomized pattern), and (b) *Pancratium* as a focal species (fixed pattern) and *Euphorbia* as a neighbourhood species (randomized pattern). Due to the un-homogeneous pattern of the species (Figure 4) the heterogeneous Poisson process was chosen for the null models. All analyses were performed using the software *Programita* (Wiegand and Moloney, 2004) and details on the estimators of the g-functions and edge correction formulas can be found in Wiegand and Moloney (2004). The results are summarized in Figures 5 to 8.

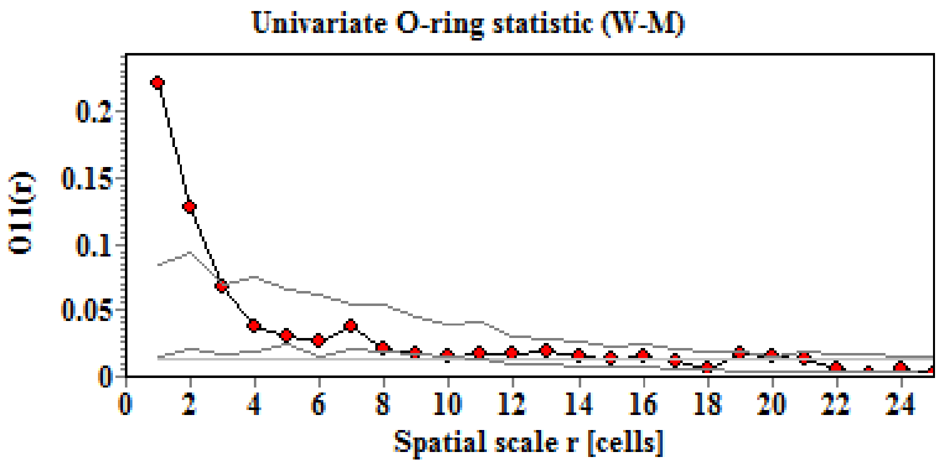

Figure 5 – *Euphorbia paralias* univariate O-ring statistic.

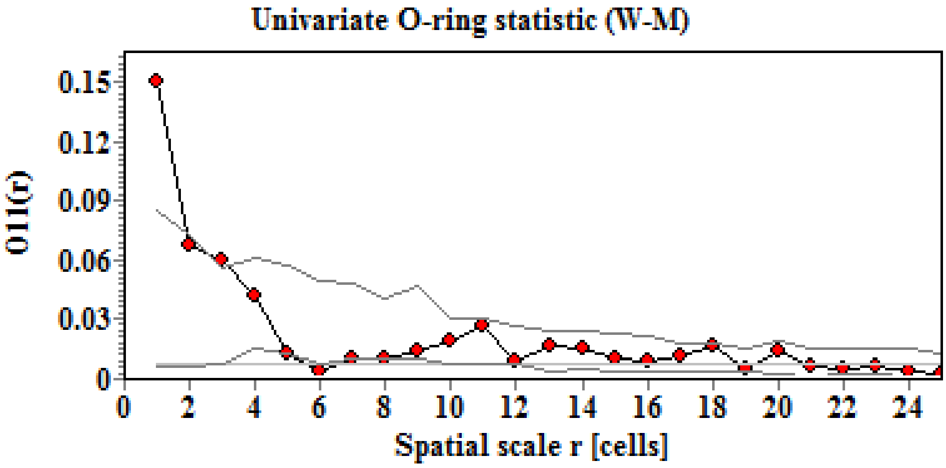

Figure 6 – *Pancratium maritimum* univariate O-ring statistic.

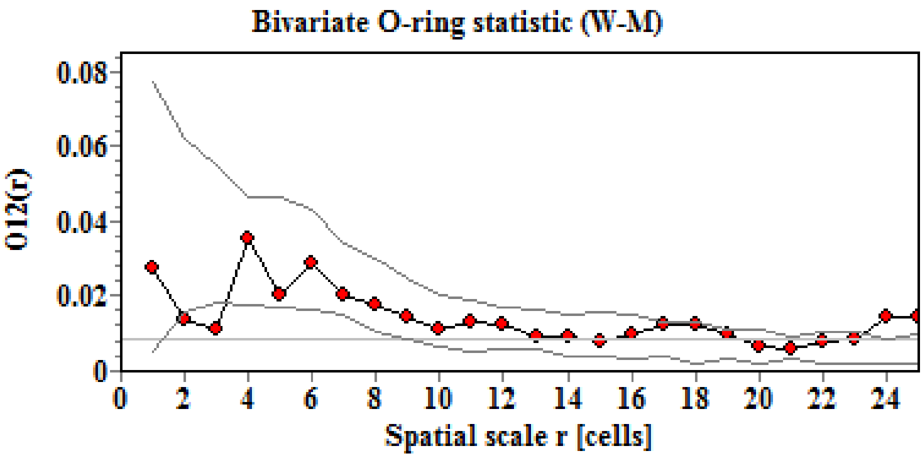

Figure 7 – Bivariate O-ring statistic with *Euphorbia paralias* as focal species.

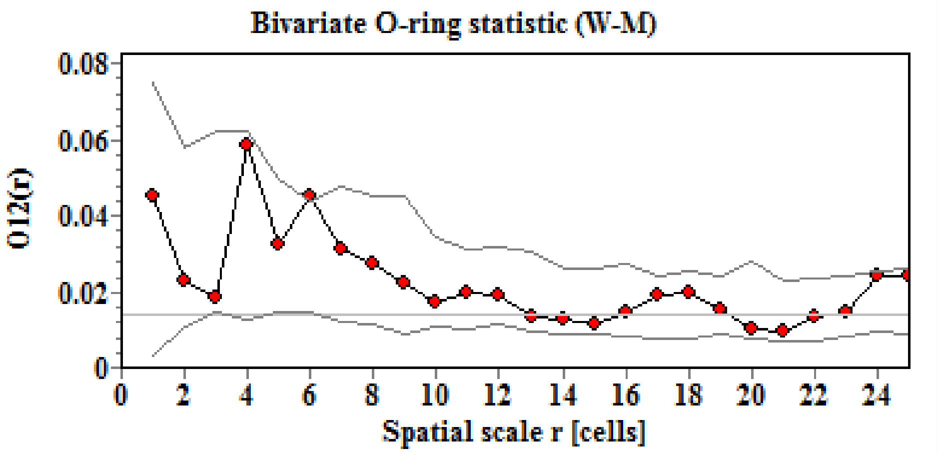

Figure 8 – Bivariate O-ring statistic with *Pancratium maritimum* as focal species.

- Discussion of results

Euphorbia plants shows significant intraspecific aggregation when considering radius values up to 3 metres (Figure 5), since the O-ring function curve is greater than upper curve, generated using the confidence envelopes. *Pancratium* plants shows an even finer aggregation, as it is only significant for radius values up to 2 metres (Figure 6). There was a large area near the centre where none of the species occurred and it represented a large part of the area studied, which could explain the fine aggregation pattern found.

According to Figure 7, *Pancratium* plants show significant segregation from *Euphorbia* plants for radius values of 2 and 3 metres, since the curve for the O-ring function found is lower than the bottom curve generated using the confidence envelopes. However, for radius values of 18, 23, 24 and 25 metres there is significant aggregation. The opposite situation (Figure 8) shows no significant value for both segregation and aggregation. Looking at Figure 4, we can see that there are two areas of occurrence interrupted by the aforementioned area where none of the species occurs: closer to the shoreline (towards west) and the interior-most area (to the east). This suggests that the presence of *Euphorbia* could inhibit the presence of *Pancratium* in some way, perhaps through competition for scarce resources, which would explain the pattern found on the west side. The pattern found on the east side could be explained due to that area being more prone to trampling, which would alter the balance of competition between the two species. The fact that there were no significant values when *Pancratium* was considered as focal species could possibly mean that *Euphorbia* has a more dominant role in their interaction.

3.2. Management of priority habitat types in mountain areas

- ### Context and objectives

One test area was selected from the study areas of a currently ongoing project named LIFE+ Higro (LIFE09 NAT/PT/000043), whose targets are the 4020* and 6230* priority habitats, listed in Annex I of the EU Habitats Directive (see Appendix 1 for a complete list of all habitats referred in the text). This project aims to implement active management plans for the conservation of these habitats, given their poor conservation status in the selected study areas and the threat posed by abandonment of pastoral activities in mountain areas. Applying the techniques developed in this work, the kite system was used to map and analyse the existing habitats and will serve to do so periodically, so that the efficiency of the management measures taken here, as a consequence of the LIFE+ Higro project, can be evaluated.

- ### Study area

Serra de Arga is located in the north-western part of Portugal, near Caminha and Viana do Castelo, and inside the Atlantic biogeographic region of Europe. The priority habitats found in the five sections considered are the 4020pt2* and 6230* habitats, as well as other non-priority habitats of interest to the project such as 3130pt2, 4030pt2 and 7140pt2. Both the 4020pt2* and the 6230* habitats can be found in all sectors of the study area, but while the 4020pt2* is well conserved in some places, the 6230* habitat is degraded or very degraded whenever it is found, most likely due to overgrazing and fire. As for the non-priority habitats 3130pt and 7140pt2, they are rare, since they are only found in one section, and very degraded. The 4030pt2 habitat occurs in some areas where the 4020pt2* habitat would occur, but the later was so badly degraded that it was substituted by the 4030pt2 habitat. The RELAPE (threatened or endangered rare, endemic or localized) plant species found were *Gentiana pneumonanthe, Genista berberidea, Serratula tinctoria* subsp. *seoanei* and *Arnica montana* subsp. *atlantica.*

Field work from which this data were obtained was carried out on the 19th of October, 2011.

- Raw DTM's and orthophotomaps

Figures 9 to 11 illustrate the main results obtained during the field survey (orthophotomaps and a digital terrain model. Many important aspects of these habitat mosaics can be easily observed.

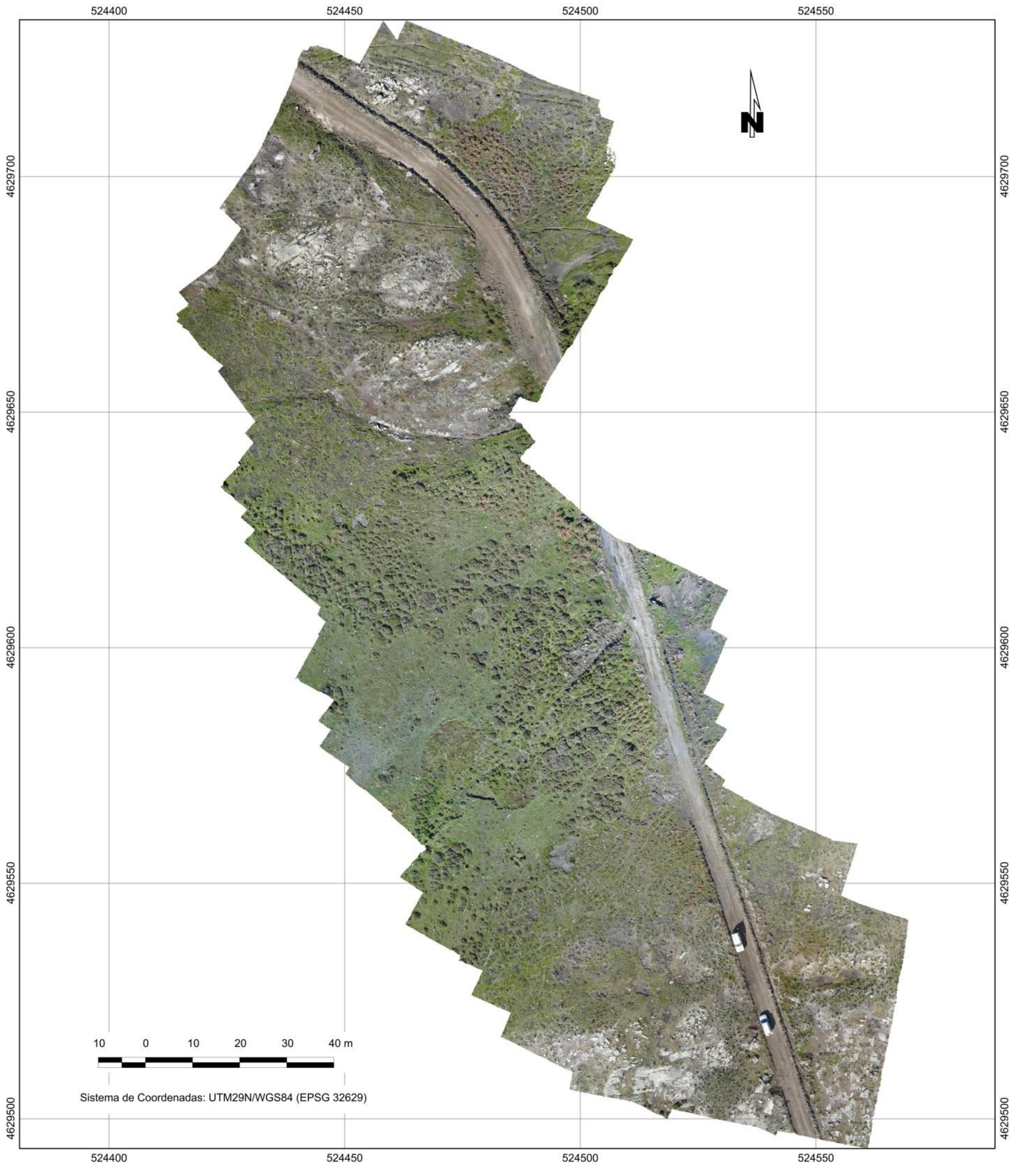

Figure 9 – Raw orthophotomap of Serra de Arga study area.

Figure 10 – Zoomed region of the raw orthophotomap of the Serra de Arga study area.

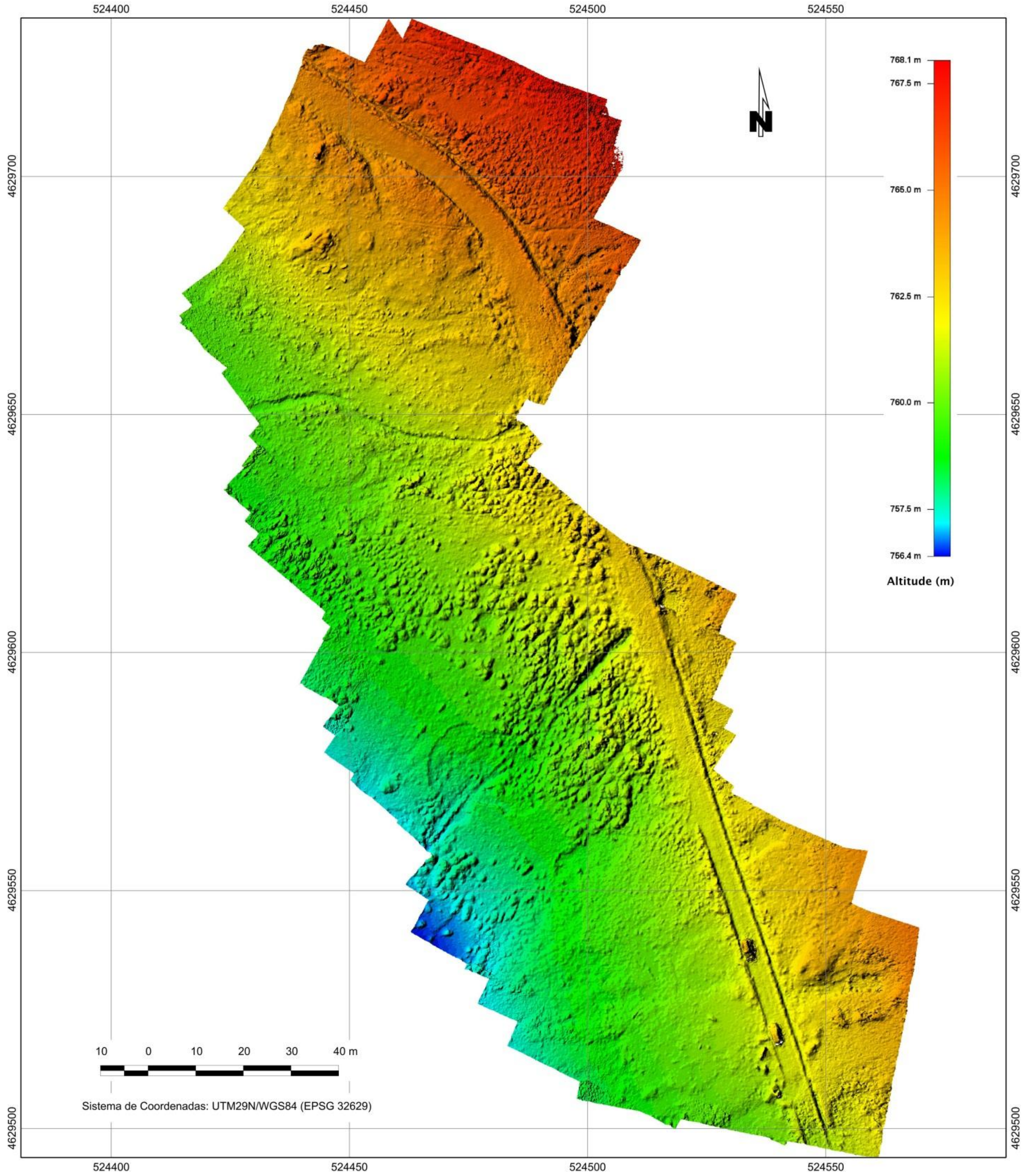

Figure 11 – DTM of Serra de Arga study area.

- Field sampling

Using the placed paper targets as a center of 1 by 1 metre square-shaped area, in each paper target we recorded the cover percentage of the various plant classes (herbs, shrubs, legumes and moss) and naked soil or burnt area as well as the dominant plant species in each of the various classes. These data will be used in later stages of the project to support the interpretation process as well as the accuracy evaluation process. The layout of these sampling points can be seen in Figure 12.

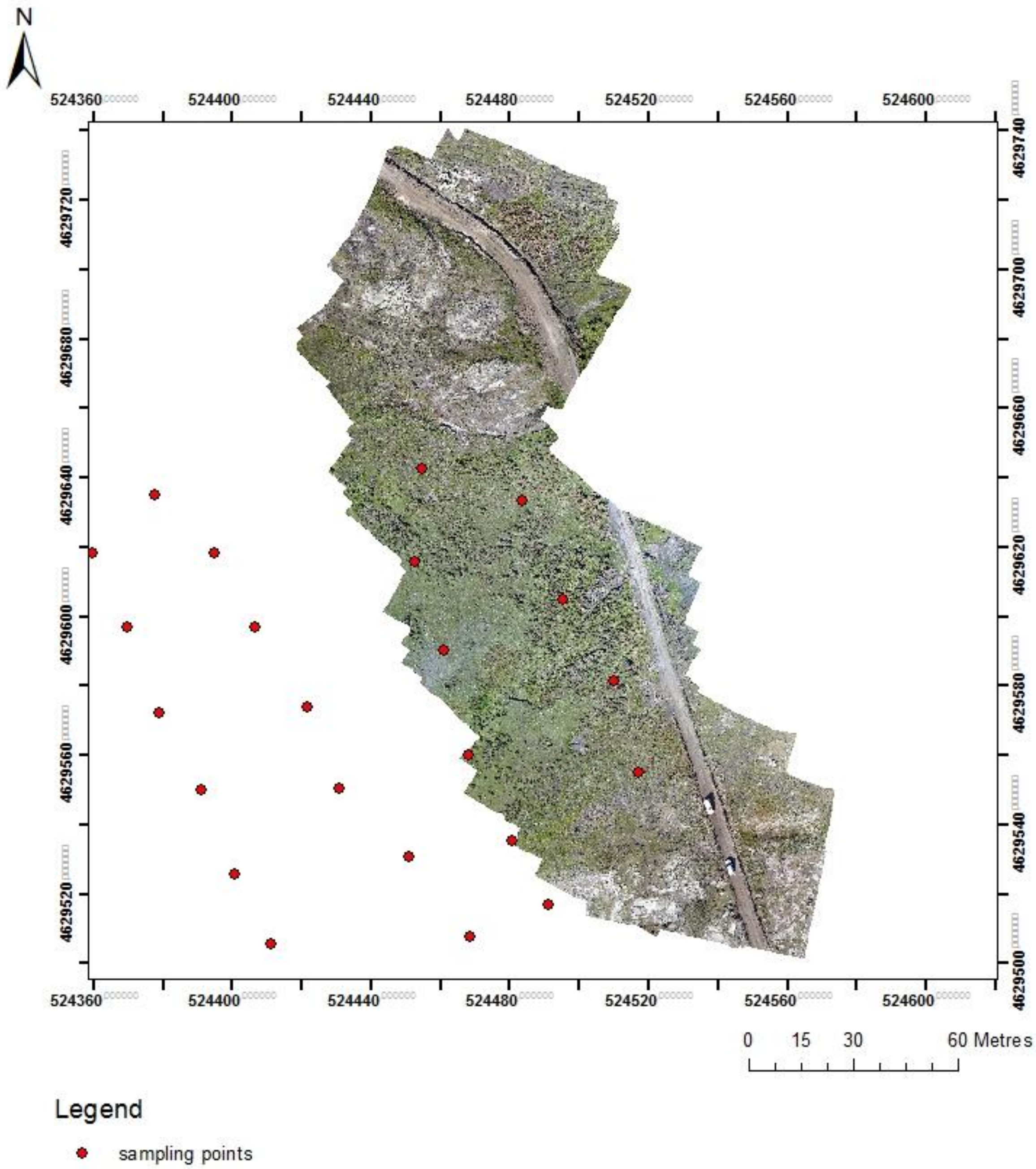

Figure 12 – Layout of the sampling points.

- Habitat mapping

Using ArcCatalog 10.1 a new polygon shapefile was created and added to the orthophotomap in ArcMap 10.1. A 30 by 30 metre square was placed in a way that it encompassed at least two sampling points and different habitats were mapped via visual interpretation of both the orthophotomap (for colours and shapes) and the DTM (for the textures) (Figures 13 and 14). Then, using the “Create Fishnet” function of the ArcToolbox, a grid divided into 2 by 2 metre squares was generated over the previously created square (Figure 15). By means of visual interpretation, each square was given a value according to the habitat which occupied most of the square, creating a map with 2 metre pixels (Figure 16).

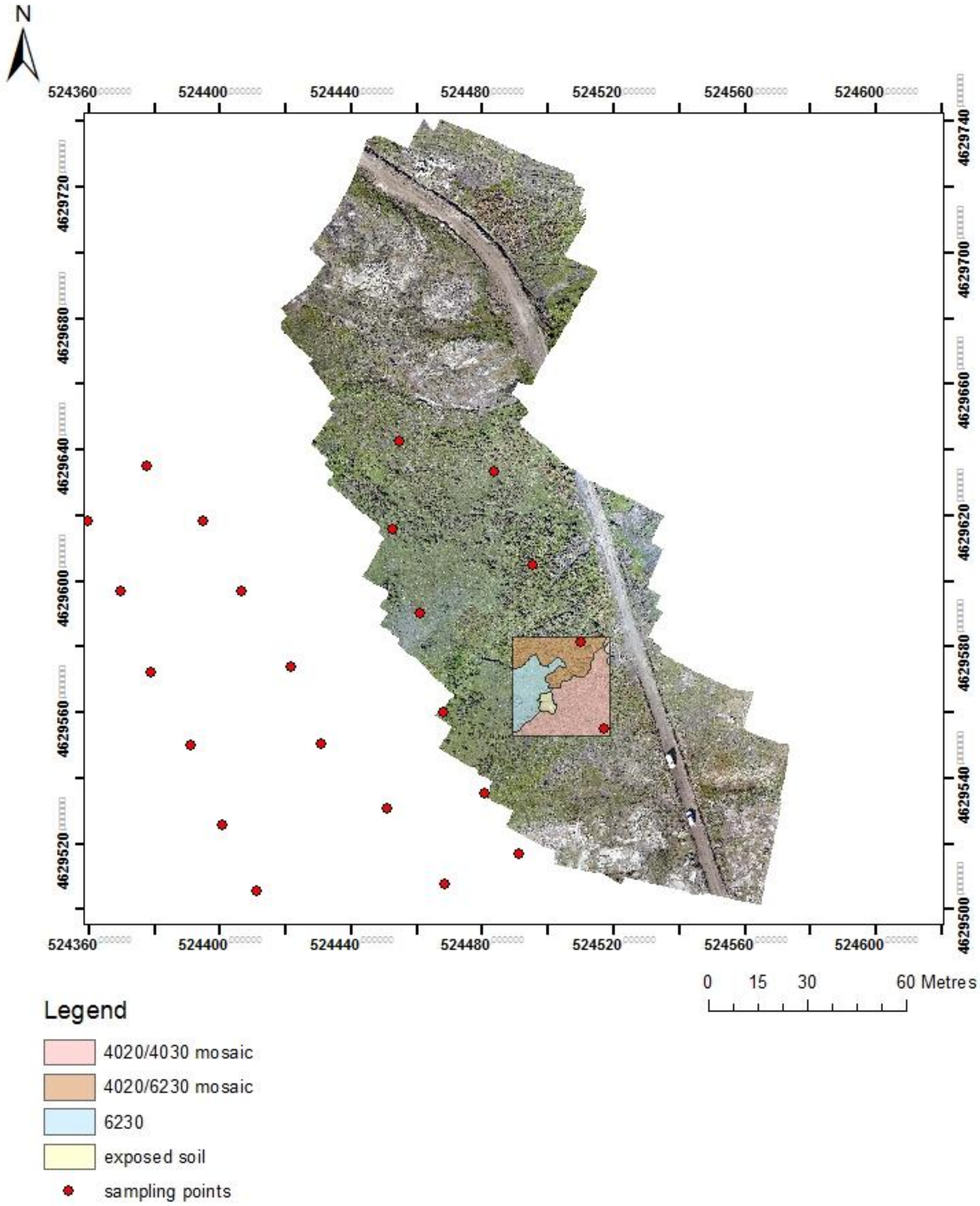

Figure 13 – Area chosen for habitat mapping.

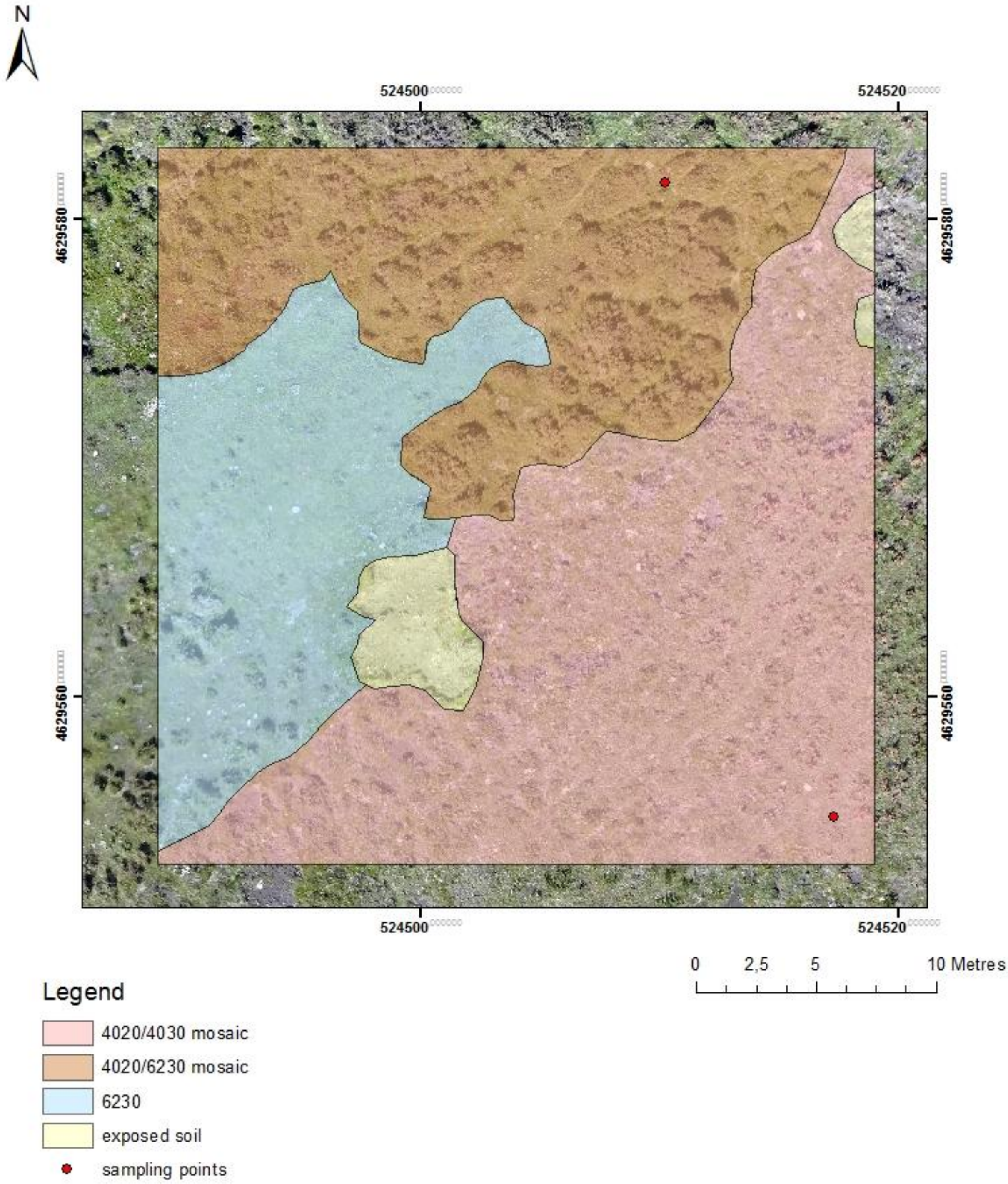

Figure 14 – Zoomed layout of the area chosen for habitat mapping

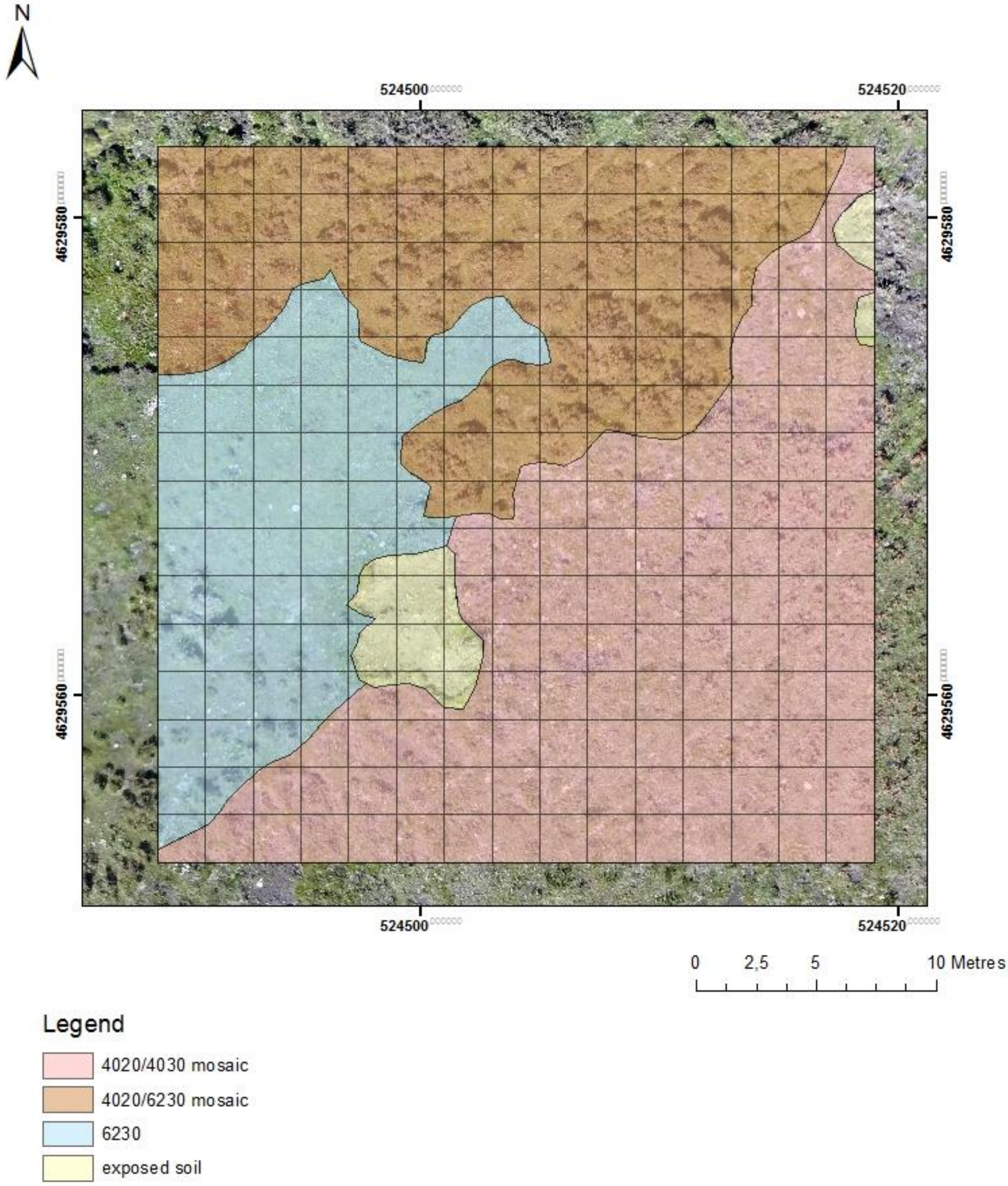

Figure 15 – Grid generated for reclassification.

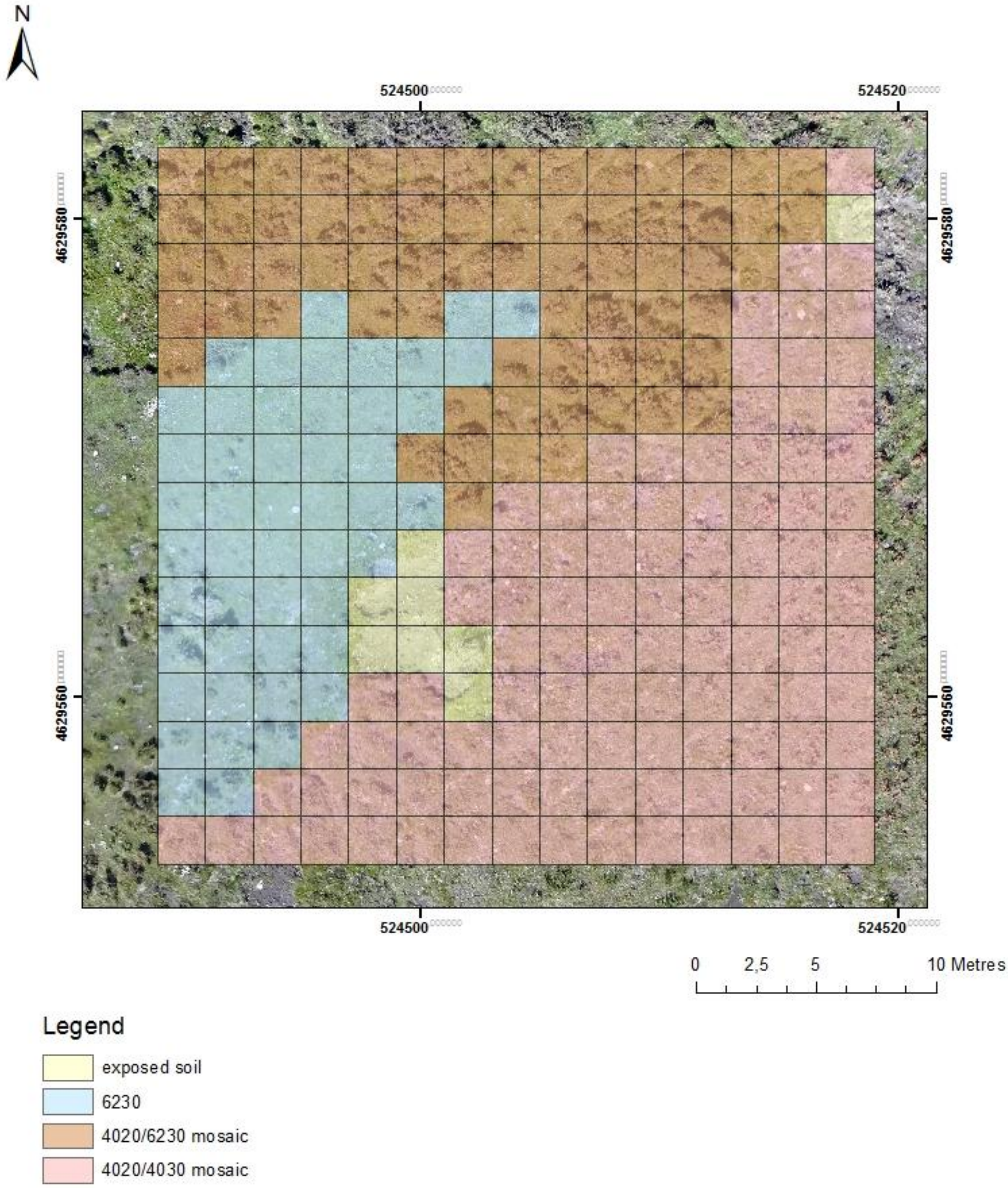

Figure 16 – Reclassification of the habitat mapping.

- Discussion of results

The orthophotomap was visually interpreted by a person with no previous photointerpretation experience, which could lead to some error. Having an experienced technician could improve the accuracy of the results. Moreover, the orthophotomap was generated from photos acquired during a day with some fog, cloudy skies and inconstant wind, meaning that the model obtained could have better quality and could have helped more with the photointerpretation process. Using computer-assisted image classification could also be another technique alternative or complimentary to the one used, especially if the camera used had a multi-spectral lens that could capture the infrared band.

In spite of this, the results obtained were considered good and served their purpose quite well, as the different textures of the habitats can be easily identified both in the DTM and the orthophotomap, and the resolution is sufficient to distinguish habitats with similar textures. Also, since the multispectral images obtained from the WorldView-2 commercial satellite have a pixel resolution of approximately 2 metres (http://www.landinfo.com/WorldView2.htm, visited on September 24th, 2012), by creating the 2 metre pixel grid over the image and reclassifying it, a direct comparison between the images can be made, which further augments the possibilities for other types of studies.

3.3. Restoration of endangered habitat mosaics in mountain areas

- ### Context and objectives

This study area was the target of an ecological restoration programme, an action that was part of a project called "*Valorização e divulgação de habitats naturais nas serras e rios do Baixo Tâmega*" promoted by the Associação de Municípios do Baixo Tâmega (AMBT). After the diagnosis, a restoration programme was planned and the area must be monitored to evaluate the effect of the measures proposed. The kite system presented in this work served as a basis for the diagnosis and mapping of the habitats and will serve as a tool to monitor the site periodically.

- ### Study area and field surveys

The area was named "*Turfeira da Almofrela*" since it was a peatland area in Serra da Aboboreira (which is part of the Alvão-Marão mountain range), near Almofrela village, in the Baião municipality, Oporto district. This study area was much smaller than the previously described one, (0,5 hectares). However, generally the same priority habitats were found, with the 4020pt2* habitat surrounding the core area, in mosaic with the 4030 habitat, where the 6230* habitat existed in mosaic with the 7140 and 7150 habitats, in spite of its rarity. Other habitats were found, often in mosaic with the aforementioned ones, for example the 3260, 6410 and 6510. This study area also included a patch of ploughed soil that interrupts the continuity of these habitats. The surrounding area showed signs of fire, with some of the 4020pt2* and the 4030 habitats being charred or recovering from charring, while the core area was relatively well conserved but showed signs of eutrophication and was always at risk due to the agricultural activities present nearby.

Field work from which this data was obtained was carried out on May 17th and 31st, 2011.

- Raw DTM's and orthophotomaps

Figures 17 to 19 illustrate the main results obtained during the field survey (orthophotomaps and a digital terrain model. Many important aspects of peatland ecosystems and particularly of their vegetation and disturbances can be easily observed.

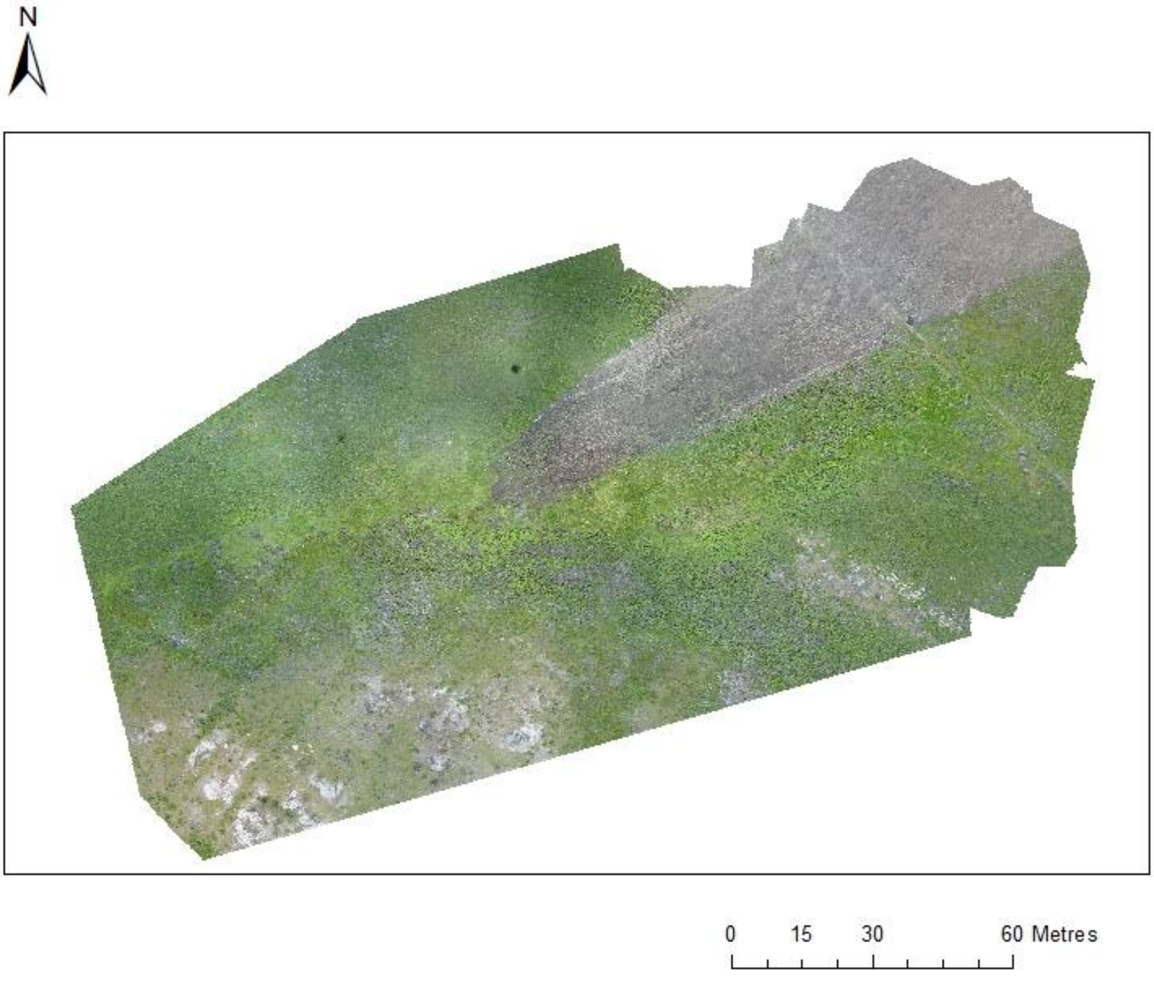

Figure 17 – Orthophotomap of the Turfeira da Almofrela study area.

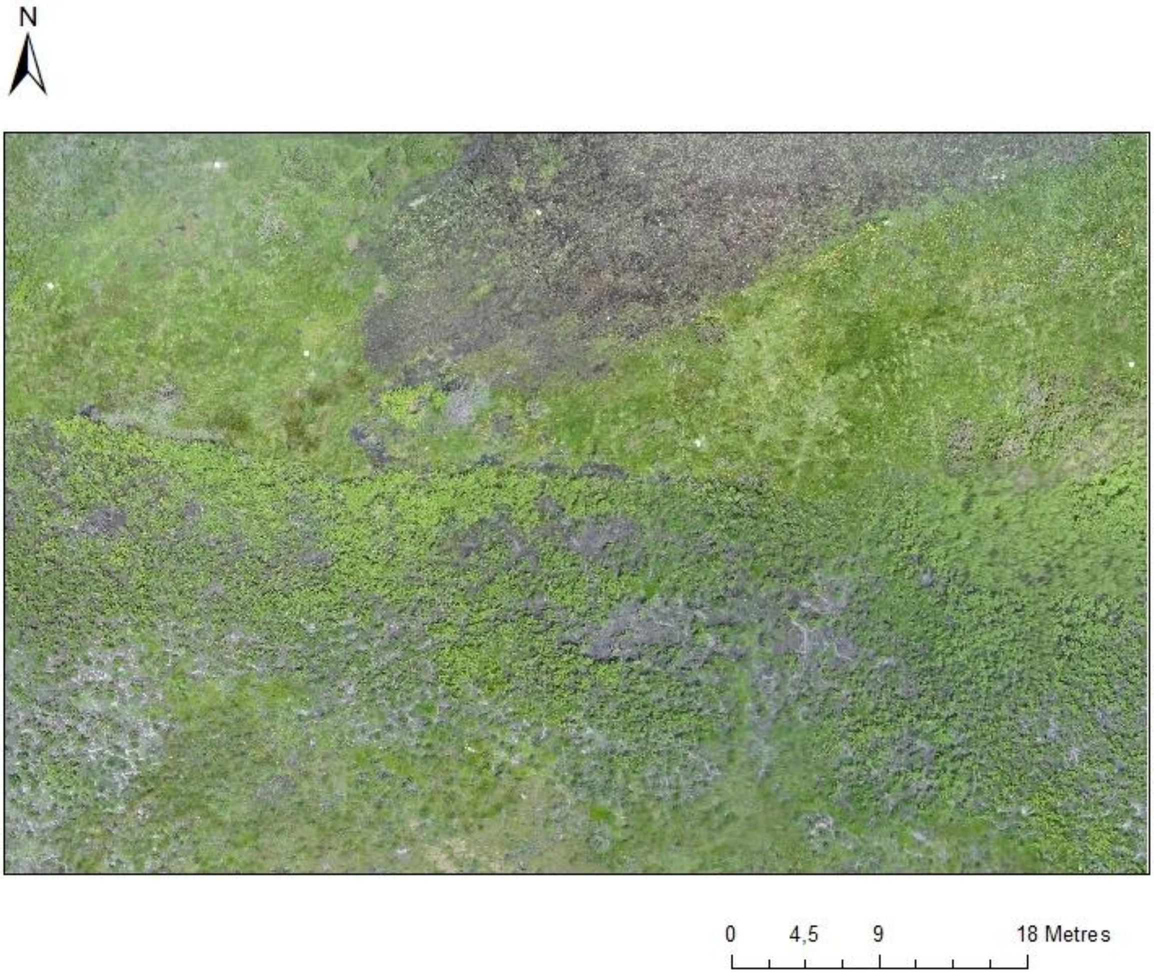

Figure 18 – Zoomed region of the raw orthophotomap of the Turfeira da Almofrela study area.

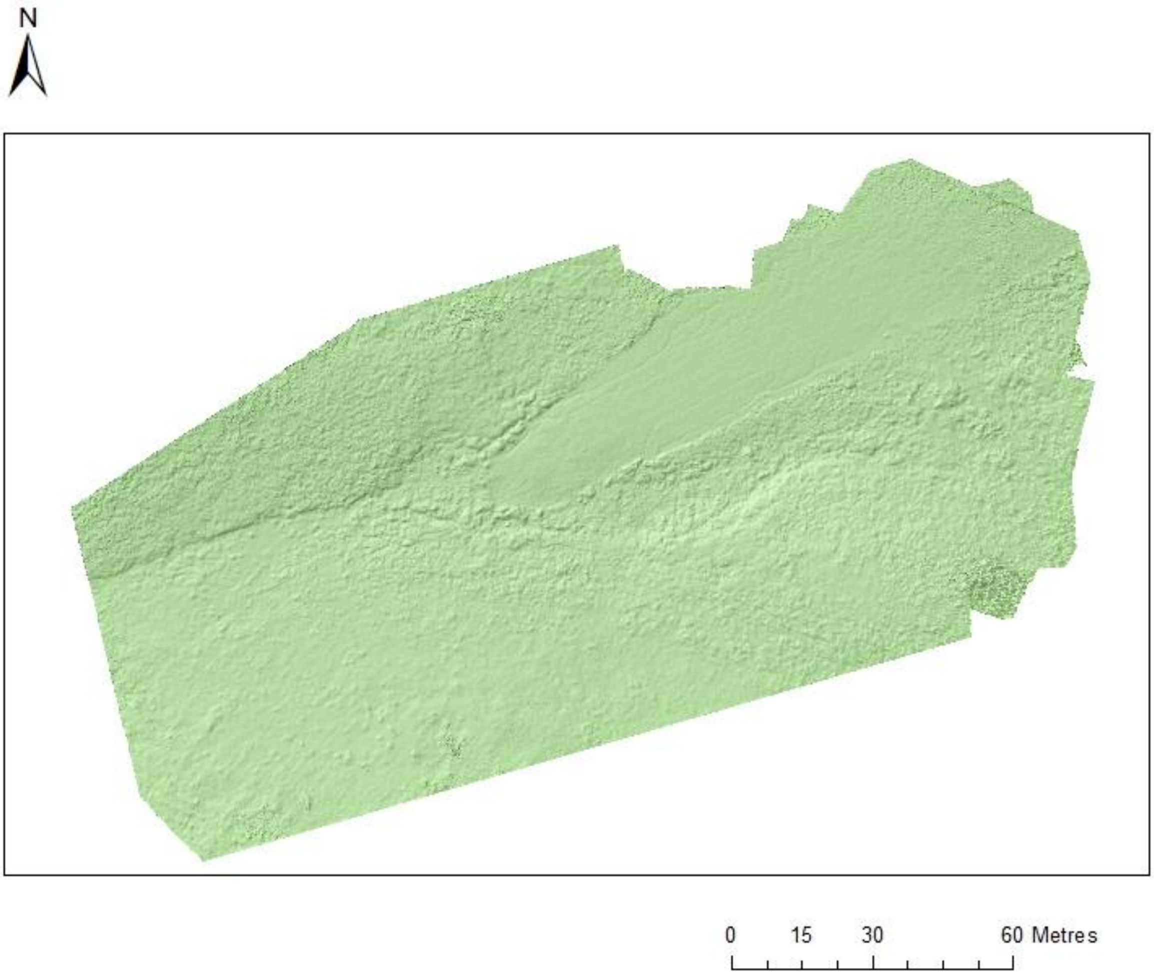

Figure 19 – DTM of the Turfeira da Almofrela study area.

- Restoration plan proposal

Orthophotomaps and the digital terrain model allowed the identification of the areas requiring some type of restoration as well as the best locations for specific actions (Figures 17 to 19). After the diagnosis, the measures needed in order to help the ecosystem recover to a healthier state were chosen. Then, by means of visual assessment of the models generated, the best places to apply the measures were chosen and marked on a map generated from the topographic study of the area (Figure 20).

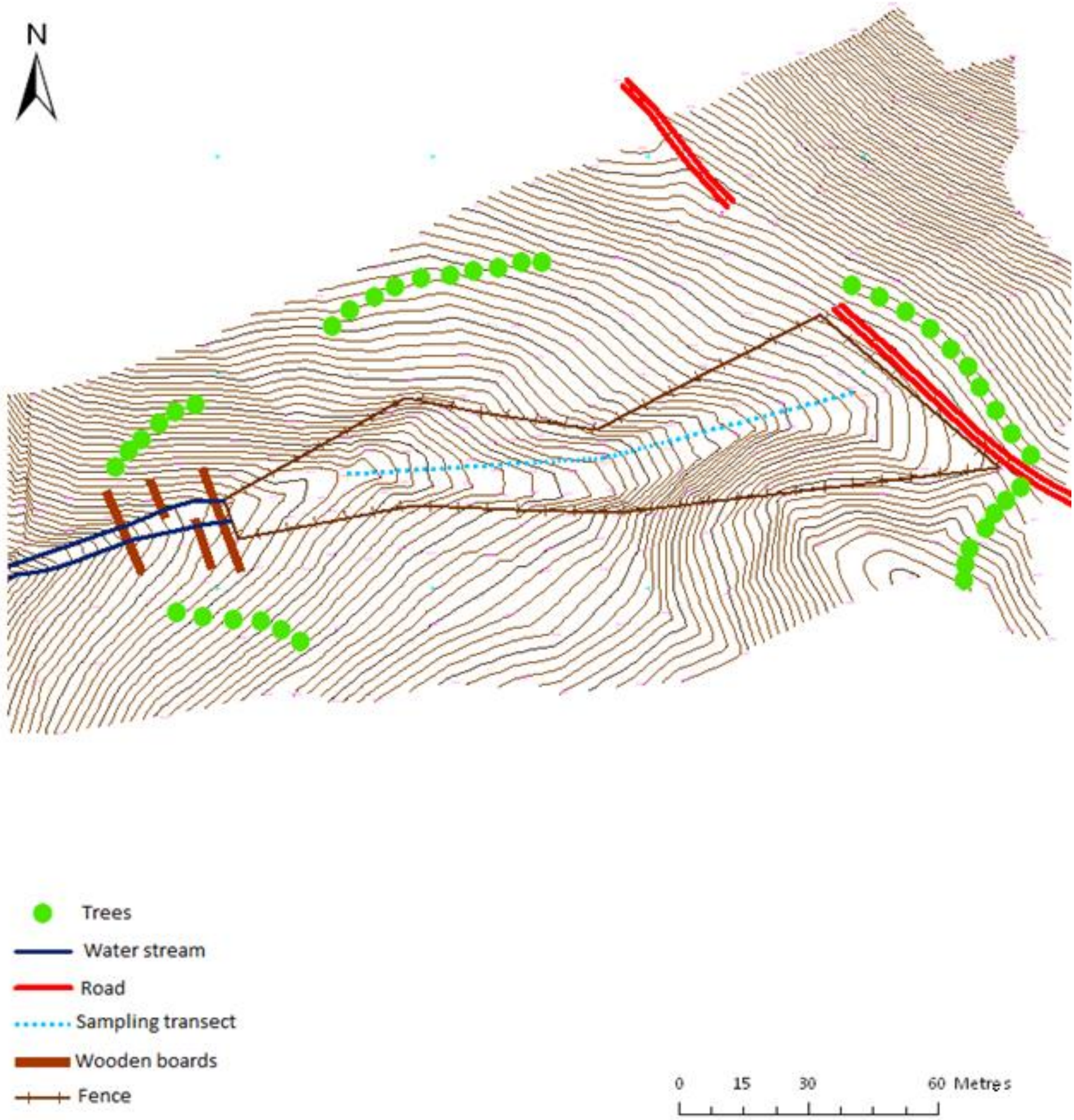

Figure 20 – Proposed restoration plan.

- Discussion of results

The resulting models allowed for a broader view of the area, and made it easier to select the best areas to apply the various measures chosen (Figure 20). Trees were picked to block the wind, to reduce evaporation and were chosen to be placed on the higher parts of the slopes; the peatland area was limited by a fence, in order to avoid stomping, grazing and the alteration of the water surface dynamics and allow the vegetation to regenerate; small obstacles were placed in the water stream that forms after the peatland in order to slow the water flow, reducing erosion and allowing the flooding of the soil, which is necessary in a peatland.

Moreover, the quality of the orthophotomaps and of the digital terrain models, together with the cost-efficiency of the methodology, will allow an easy and low-cost monitoring design to be implemented, thereby supporting the assessment of the effectiveness of interventions as well as the possible identification of new ones being necessary.

4. Conclusions

4.1. Synthesis of main results

This work was meant to illustrate the wide range of applications of close-range systems in various stages of scientific studies with different scopes and goals. It has proven to be a powerful tool for various kinds of studies, able to support ecological research at various stages and different levels: it can generate results as a final stage of the study, as was the case of the habitat mapping in Serra de Arga; it can support the final stage of a study, as it did in the case of the restoration of Turfeira da Almofrela, where the models generated were used to evaluate the study area and choose where to take specific actions, before presenting the final proposal; and it can be an initial stage of the study, as we used it in the Aguçadoura dune area, where we used the models to run statistical analyses in an attempt to discover patterns that would not be so easily discovered with regular field sampling.

Even with results obtained with less-than-ideal conditions in some occasions, the results were good enough in order to run the analyses and tests we have shown in this work. This fact, which could otherwise be a negative point, in this work serves to cement the proof that these systems have great potential and can, and should, be explored further in order to unlock their full potential. As such, the answer to the first two questions posed in the beginning of this work is a resounding "yes". The last question shall be answered in the next section.

4.2. Advantages and limitations

We used these systems in three different projects, each with its own ecological problem and objectives, and it showed that they work very well, be it for monitoring habitats, planning ecological restoration interventions, or to study population dynamics. It has shown great promise for ecological research of various kinds, but there are still limitations that must be overcome.

These systems are hindered by adverse atmospheric conditions, especially regarding wind and rain: the kite requires a certain amount of wind to fly and rise, and too much wind will make the kite uncontrollable; rain also makes it impossible to use these systems, since neither the camera nor the radio-controls on the supporting structure are water-proof; fog can also diminish the quality of the pictures, as well as low clouds, especially on mountain areas, where the kite flies high and clouds float low; lastly, this device requires at least two people to work it and one of them must be familiar with the device, especially in the case of the kite.

When compared with devices built for the same purpose, such as the SenseFly swinglet CAM (http://www.sensefly.com/products/swinglet-cam), this device lacks the automatic image processing and the autonomous flight as well, and it requires the downloading of the pictures and the processing through software in order to obtain the final products. The SenseFly swinglet CAM also requires some processing, but the picture data obtainment is much more automated. On the other hand, both of the systems tested here were built for much less money than what the SenseFly swinglet CAM, and the products obtained had very good resolution and served their purpose well.

Compared to hiring an aerial photography service, which would be cheaper than the SenseFly device, the systems tested here are still cheaper and very effective, since once it had been built, it can be used at zero cost (except for local transportation) from there on, whilst each time a field campaign had to be done, it would have to be paid. That would make monitoring extremely expensive if it had to be done over short periods of time, and these systems overcome that problem.

When it comes to using traditional remotely sensed data, such as LIDAR or other satellite imagery, the products obtained with these systems have much greater spatial resolution and are much more adequate for studying smaller areas. Satellite imagery still proves to be more useful on greater scales, but these systems were designed for smaller areas so this is not an issue.

In short, although they are still limited by atmospheric conditions and need experienced handlers, close-range systems provide a cost-effective, fast and easy way to obtain various kinds of data for ecological studies in general, meaning that the answer to the last question is "yes" as well.

4.3. Future perspectives

The goal of this work was to encourage using these systems on other types of projects, ecological studies and trying to implement them in existing ones. Given the good results obtained, further use and development of these systems can improve the results obtained and consequently the quality of the studies undertaken. This could mean that monitoring will no longer be seen as waste of time and money, and that more and better long-term ecological studies will be planned.

We hope that more systems like this are developed, that their structure is improved and that new and more creative ways to use them are found.

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Appendix 1 - List of mentioned habitats

This section contains the code and respective designation of all habitats mentioned in the main text. The EU Habitats Directive can be found in the following location:
http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CONSLEG:1992L0043:20070101:EN:PDF

3130 - Oligotrophic to mesotrophic standing waters with vegetation of the *Littorelletea uniflorae* and/or of the *Isoëto-Nanojuncetea*

3260 - Water courses of plain to montane levels with the *Ranunculion fluitantis* and *Callitricho-Batrachion* vegetation

4020* - Temperate Atlantic wet heaths with *Erica ciliaris* and *Erica tetralix*

4030 - European dry heaths

6230* - Species-rich *Nardus* grasslands, on silicious substrates in mountain areas (and submountain areas in Continental Europe)

6410 - *Molinia* meadows on calcareous, peaty or clayey-silt-laden soils (*Molinion caeruleae*)

6510 - Lowland hay meadows (*Alopecurus pratensis, Sanguisorba officinalis*)

7140 - Transition mires and quaking bogs

7150 - Depressions on peat substrates of the *Rhynchosporion*