

Final Project Report

1. Contestant profile

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2. Project overview

Title:	Biodiversity restoration - can drones provide an accurate, efficient and safe survey method?
Contest:	UK
Quarry name:	Batts Combe Quarry, UK
Prize category: (select all appropriate)	<input type="checkbox"/> Education and Raising Awareness <input checked="" type="checkbox"/> Habitat and Species Research <input type="checkbox"/> Biodiversity Management <input type="checkbox"/> Student Project <input type="checkbox"/> Beyond Quarry Borders

Abstract

Drone technology is increasingly being used for scientific research and remote sensing as part of environmental monitoring. It has a wide range of applications, for example in agriculture, coastal erosion, animal tracking and land-use. It is increasingly being used in environmental monitoring, including ecological monitoring, alongside satellite images and aerial photography. It is a developing area with applications being trialled and refined, taking advantage of the high resolution images that can be captured.

This project aimed to determine the efficiency and accuracy of ecological surveys undertaken using a drone compared to conventional survey techniques in monitoring biodiversity restoration within quarries. In many quarries, large stretches of benches are inaccessible or dangerous to access for ecological surveys, making it difficult to determine the success of biodiversity restoration or the extent of natural colonisation. Batts Combe is relatively unusual in that a number of quarry benches are accessible via an access track that cuts east-west across the quarry face.



Both quadrat-based survey and drone-based survey work (through image capture, processing and analysis using ImageJ and Bio7) was undertaken on accessible study areas: quarry benches and adjacent donor and receptor meadow areas to determine the utility of drones in biodiversity (restoration) monitoring. Data quality and time taken to collect and analyse data were used to evaluate the accuracy and effectiveness of drone-based survey. Some preliminary work was also undertaken on floral abundance, plant Species spectral signatures and modelling Habitat Quality Indicators. Safety and cost-effectiveness were also considered.

Across all study areas fewer species were identified and recorded through the drone image methodology than ground-based fieldwork. Cover estimates for bare soil in bench sites varied between survey/estimation methods but were not significantly different. On quarry benches, species cover estimates from drone-derived images were consistently lower for grasses and forbs compared to ground-based survey. In contrast at the meadow study areas, where there was negligible bare ground or rock/scree recorded, forb cover estimates derived from image and in the field were similar but cover estimates for grasses were recorded at approximately half those recorded in the field. Some species were more easily recorded from drone images than others e.g. grasses such as *Brachypodium sylvaticum*, *Briza media*, and *Festuca* species, plus larger forbs such as *Plantago lanceolata*, *Lotus corniculatus*, *Leucanthemum vulgare* and composites including *Leontodon* species. National Vegetation Classification analyses produced outcomes with lower match coefficients when using drone-survey data than ground-survey data, reflecting fewer species being recorded via drone images. Floristic abundance estimates proved to be feasible if time-consuming when based on image analysis.

In terms of accuracy, drone-based surveys are still in the developmental stage. Nevertheless, the results from this research were encouraging. By using drone-based survey a better and more immediate overview could be gained of biodiversity restoration at Batts Combe Quarry. Responding to such data would increase plant and associated species abundance in the extraction site and in the wider environment.

This novel survey technique, using cutting edge technology, bridges the gap between remote sensing and ground-based survey. As well as informing biodiversity restoration and management, it may well also improve understanding of natural colonisation from adjacent SSSIs and support landscape-scale conservation work.

Through adopting and developing drone-based aerial surveillance, HeidelbergCement could take a leading role in this developing technology for ecological monitoring and so enable better biodiversity restoration and management.



Introduction

Originally for military purposes Unmanned Aerial Vehicles (UAV's) [AKA drones], drone technology is increasingly being used for scientific research and remote sensing as part of environmental monitoring (Lisein *et al.*, 2013). It is a developing area with applications being trialled and refined. Current applications include: agricultural monitoring (Scaioni *et al.*, 2009; Krishna, 2016), characterizing river morphology over time (Lejot *et al.*, 2007), monitoring the behaviour of animal species (Struthers *et al.*, 2015), as well as sampling animal populations (Jones *et al.*, 2006; Van Gemert *et al.*, 2014; Weissensteiner *et al.*, 2015), canopy cover and light conditions within forests (Getzin *et al.*, 2012; Getzin *et al.*, 2014), habitat mapping and visualising human land use (Koh and Wich, 2012) and even assessing construction work (Eisenbeiss, 2004). Specialised sensory equipment can be added to drones to record chemical variations in the environment, such as methane emissions from landfills (Fjelsted *et al.*, 2015). The utility of drones will increase with developments in their technology e.g. camera resolutions producing sharper images and use of filters for working with infra-red and ultraviolet light. In terms of ecological applications, drones are becoming useful in bridging the gap between relatively low resolution remote-sensed images and detailed ecological field survey (Thomas, 2016).

Biodiversity surveying and monitoring usually requires surveyors to physically visit a site and record species frequency or abundance, usually by performing traditional sampling techniques such as random sampling with quadrats (Buckland *et al.*, 2005). Such recording is implemented for plant species surveys, particularly as the surveyor's confidence enforced by physically seeing and identifying species on site (Laliberte *et al.*, 2004). However manually surveying is often regarded as a time consuming process and questions of surveyor competence and data quality, due to variation between surveyors, has been raised (Cherrill and McClean, 1999; Scott and Hallam, 2003). Ground based surveys can also be limited in terms of access to particular sites however aerial drones remove this limitation by flying and recording images or data in these inaccessible areas (Koh and Wich, 2012) and within restricted timeframes such as in intertidal zones (Pickles, 2016). Quarries, such as at Batts Combe in the UK's Mendip hills, are examples of areas where accessibility to people is restricted, both physically by the topography and for safety purposes, yet require surveying to monitor biodiversity restoration projects (Gilardelli *et al.*, 2013). Conducting ecological surveys in such quarries may be achieved by deploying drones.

In many quarries, large stretches of benches are inaccessible or dangerous to access for ecological surveys, making it difficult to determine the success of biodiversity restoration or the extent of natural colonisation. Batts Combe is relatively unusual in that a number of quarry benches are accessible via an access track that cuts east-west across the quarry face. This access makes it possible to reach some bench sections that have been restored or have colonised naturally and so enables a range of survey techniques to be tested and evaluated.

Aims and Objectives

This research project aimed to take advantage of the easy access to restored/colonised benches and other areas at Batts Combe to directly compare the effectiveness of surveys undertaken using conventional quadrat-based survey with that of using drone-based methods. If the drone-based method were to prove sufficiently accurate then it could provide a new tool for surveying and monitoring biodiversity restoration on inaccessible quarry benches and other areas. Data from such surveys could provide useful new data on biodiversity value and the appropriateness of restoration techniques. Such data might be available more rapidly, better informing restoration and management decisions in response to need. Therefore, findings from this project could have wider application to biodiversity monitoring in limestone quarries elsewhere in Mendip and in hard rock quarries in general around the world.

This project aimed to determine the efficiency and accuracy of ecological surveys undertaken using a drone compared to conventional survey techniques in monitoring biodiversity restoration within quarries. The objectives were to:

1. research target species for survey and identify suitable bench sites at Batts Combe for survey trials.
2. develop a novel technique for using drones to take images of species for subsequent analysis and quantification of species abundance.
3. trial drone-based surveys of species abundance and compare with standard methods used directly in the field of the same sites.

4. analyse and compare data derived from the two techniques and review accuracy and ease of use.

Background Information

Batts Combe Quarry (OS Grid Reference ST 45870 54435 - site entrance) is a large (approximately 60ha) carboniferous limestone quarry set in a total landholding of 180ha (Hanson/HeidelbergCement Group, 2013) located near Cheddar, UK (Fig 1). It is operated by Hanson Aggregates/Heidelberg Cement and provides aggregate for construction and high quality calcium carbonate for industrial and manufacturing purposes.

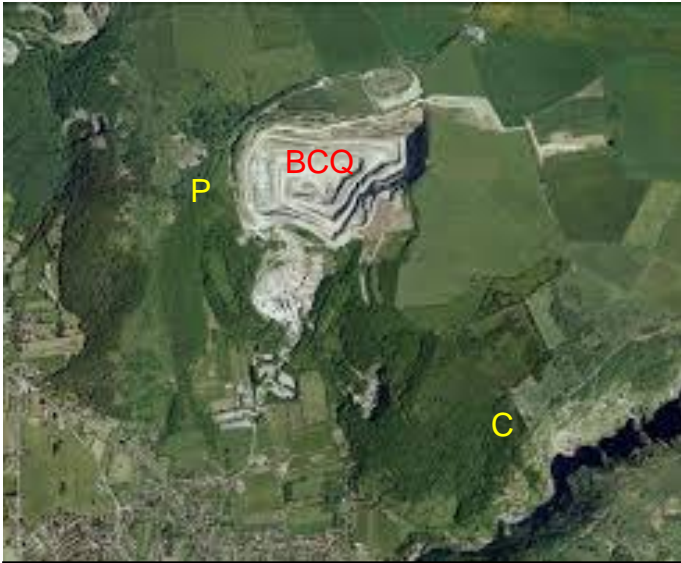


Figure 1. A satellite image of Batts Combe Quarry (BCQ) illustrating proximity to the biodiversity hotspots the Perch SSSI (P) and the Cheddar Complex SSSI (C) (Adapted from Hanson/HeidelbergCement, 2013)

The quarry supports a range of priority habitats including lowland mixed deciduous woodland, lowland calcareous grassland, rock outcrop and scree, and open mosaic (Pick, 2015). In turn these habitats supports a diverse range of priority and key species including: slow worm, adder, grass snake, bat species including greater and lesser horseshoe, dormice, cheddar whitebeam, cheddar pink, and butterfly species small pearl bordered fritillary, grayling, small blue, and the small heath. The quarry area and adjacent habitat [The Perch SSSI (to the west, owned by Hanson; Natural England, 2016^a) and the Cheddar Complex SSSI (to the east; Natural England, 2016^b)] are or have been managed by Hanson in collaboration with Somerset Wildlife Trust Mendip Hills Living Landscape), Somerset County Council, FWAG, The National Trust and Natural England to conserve and enhance the status of priority species and habitats. This improvement has been steered through the Restoration Plan and the Biodiversity Action Plan for the quarry site.

The quarry restoration is staged and progressive (Hanson/HeidelbergCement, 2013). The work includes creating species-rich grassland on the spoil area. In addition, it

aims to establish a mix of woodland including Cheddar Whitebeam *Sorbus cheddarensis* (Houston *et al.*, 2009), species-rich grassland and open habitats on quarry benches on the south-facing aspect of the quarry. Once the quarry is worked out its south-facing aspect will be very visible from the Somerset levels; consequently the success of restoring this area is important due to this high profile. In addition restoration could link biodiversity hotspots (SSSIs) on either side the quarry. As well as planting and sowing, a number of plant species have colonised through natural dispersal; presumably from the adjacent SSSIs. Restoration management includes some control of nurse tree species (Italian Alder) and grazing by goats and sheep to control scrub encroachment.

Several of the Biodiversity Action Plan Targets (Hanson/HeidelbergCement, 2013) could be informed by drone-based monitoring. Targets 1 and 3 promote the maintenance, improvement and extension of species-rich grasslands, the plant and invertebrate species they support, the management of habits and control of invasive species. Target 5 aims to increase the extent of grassland and woodland, calcareous grassland and bare ground habitats through restoration to provide corridors and stepping stones for grassland and woodland species. Such habitat connectivity/continuity supports the aims of the Mendip Hills Living Landscape project (The Wildlife Trusts, undated^b), including the 'Seeds for Change' project aimed at increasing landscape permeability for invertebrates through increasing floral abundance and diversity in agricultural grasslands (Somerset Wildlife Trust, 2012; The Wildlife Trusts, undated^a). In addition open mosaic habitats such as those within the quarry are often valued for their pioneer communities and flower-rich grasslands (Riding *et al.*, 2010) which in turn support important for UK Biodiversity Action Plan (UKBAP) invertebrate species (Lush *et al.*, 2013). Target 6 aims to improve site knowledge through monitoring species and habitats via a range of partner organisations. Such knowledge is vital in monitoring restoration progress to determine success, inform and adjust management and to tackle invasive species (Parker (1995).

Methodology

This research was undertaken by three students from Bath Spa University (Tom Bell, Rozy Gray and Rich Spiers) working in collaboration with four members of staff (Derek Beard, Graham Smith, Darrel Watts and David Watson).

Both quadrat-based survey and drone-based survey work (through image capture, processing and analysis) was undertaken on accessible quarry benches and adjacent donor and receptor meadow areas to determine the utility of drones in biodiversity (restoration) monitoring. Data quality and time taken to collect and analyse data were used to evaluate the accuracy and effectiveness of drone-based survey. The approach was experimental and phased, developing in order to address the core aims and objectives but also responding to initial findings and feedback following presentation to Quarry Life judges in July 2016.

Study Areas. Within the quarry, three different areas of study that were accessible by foot were identified in consultation with Hanson's Landscape Architect to compare both drone and quadrat surveying (Pick, 2016). These sites included: a bench within the quarry, the donor meadow site and receptor meadow site (Fig. 2). The bench had been restored in 1997 using a mixture of quarry waste and subsoil and was sown with an amenity grass mix nurse crop (Hanson/HeidelbergCement 2016). The bench site was subdivided into the back wall lower slope (slope) and the floor of the bench (flat), as these areas clearly differed in terms of vegetation composition presumably due to differences in physical conditions, especially drainage. The Donor Meadow site was a well-established grassland, maintained to prevent

scrub encroachment) and used to provide green hay which in 2009 was strewn on the quarry tip, known as the Receptor Meadow site with a view to create species-rich grassland (Pick, 2016).



Figure 2. Study Areas: Bench (yellow), Donor Meadow (red) and Receptor (Restored) Meadow (blue).

Ground-based Survey. Stratified random sampling of vegetation was undertaken by the team within study areas over three days from 16th to 24th June 2016. At each site, standard National Vegetation Classification survey was employed (after Rodwell, 1993). The estimated abundance (cover as a percentage) of individual species, litter, bare soil and rock and

scree were recorded in 2X2m quadrats placed within homogeneous stands of vegetation. A total of five quadrats were recorded at each study area, with five quadrats recorded on both the slope and the flat sections of the bench study area. Plant species were the main focus in survey work and invertebrates were noted as casual records.

Drone-based Survey. Drone flights using a DJI Phantom 3 Professional (DJI, 2016) were undertaken by or under the supervision of trained personnel. The drone was chosen as a relatively inexpensive but relatively sophisticated piece of equipment which has also been used in research trials by Natural England's Field Unit (Thomas, 2016).

Drone flights were conducted on the same days as ground-based vegetation surveys, within the same homogeneous stands of vegetation. One metre rulers were scattered within each study area to enable image scaling. The drone was calibrated to enable its GPS features then flown within each area of study taking a combination of both still images and video recording. The drone was flown between approximately 2 and 5m above ground level and still images (when hovering) captured (12 Megapixels covering between 7 and 40 square metres, depending upon the situation and elevation). More images were taken than used, with images selected to represent the homogeneous stands of vegetation. Plant species were the main focus of surveys; it proved impossible to survey invertebrate species (e.g. butterflies) due to the down-draught caused by the drone.

Image Processing and Analysis. Up to five images were selected from drone flights over each study area as being representative samples of homogeneous stands in each area.

Analogous to ground-based survey, un-edited images were viewed on standard pc monitors and used as a basis for estimating [by eye] the abundance of grasses, herbs, bare ground and rock/scree. Estimating cover values that combined to give 100% cover in total per sample was chosen as the preferred method of assessing two dimensional images, though potential inaccuracies were acknowledged. In addition images were inspected and the presence of species recorded within each image. Zoom controls and adjustments to image brightness and contrast were used to aid identification of smaller species or to inspect plant morphology e.g. presence/absence of tendrils.

In addition, with a view to semi-automating analysis (to save staff time), drone camera-captured still images were processed and analysed using the ImageJ component integrated within the software Bio7 (version 2.4.0) (after Austenfeld and Beyschlag, 2012; ImageJ, 2016). True colour images were processed and enhanced into transformed RGB colour composite 3-band intensity hue saturation (IHS) images, similarly to the image processing described by Laliberte *et al.* (2006).

Image processing included sharpening and correcting by creating and subtracting backgrounds with a sliding paraboloid and disabled smoothing function within ImageJ. Images were then further enhanced by increasing the contrast to display clearer distinct differences between visible features within images. The conversion into IHS images by this process removed shadows within the images and allowed for easier mapping and estimation of vegetation, rock and bare ground abundances (cover as a percentage) based on colour segmentation, whereby different features within the image were represented by different colour frequencies (after Bernhardt and Griffing (2001). Cover estimates for vegetation cover, bare soil and rock/scree were determined in turn through Bio7 using a pixel counter and the ImageJ threshold plug-ins to select image features based on their intensity, hue and saturation. Standard IHS settings were developed to determine the extent of each cover type by depicting each type as black in turn and using the software to determine the number of black pixels and so cover (%) (Table 1).


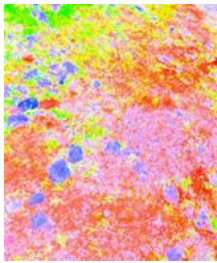
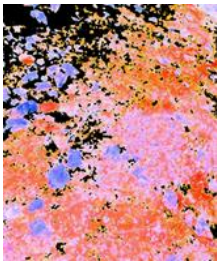
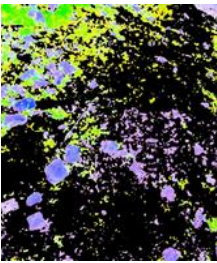
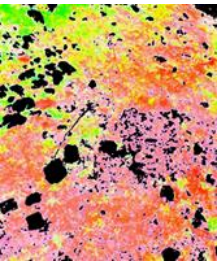
Floral Abundance. Attempts were also made to evaluate the use of drone-derived images in determining floral abundance as this is a measure used to evaluate habitat restoration for invertebrates; field based survey was used for the Seeds for Change project (Somerset Wildlife Trust, 2012; The Wildlife Trusts, undated^a) to improve habitat permeability and promote invertebrate mobility. Floral abundance estimates was achieved by inspecting images and manually counting inflorescences that could be distinguished within the images.

Plant Species Signatures. Attempts were also made to characterise the spectral signatures of species that were key to certain habitats, for example constant species (Rodwell, 2003) or those of particular importance as nectar sources e.g. Wild Marjoram *Origanum vulgare*.

Floristic and Data Analysis; Modelling Habitat Quality Indicators. Data were collated using Microsoft Excel (Microsoft, 2016). Generalised Linear Models (GLMs) were used to evaluate potential habitat quality indicators by relating ground and drone derived data was undertaken using R (RFSC, 2016). GLM was also used to determine the level of confidence in data derived for bare soil and rock and scree for ground-based data and image derived data. NVC classifications are sometimes used as a means of monitoring restoration progress or management effectiveness. Therefore further attempts to assess drone survey comparability, species presence data from ground-based and image-based data (assessed by eye) were analysed to determine National Vegetation Classification System communities using MAVIS (Dart Computing, 2000). Similarly, a minimum variance cluster analysis (Ward, 1963) was conducted using R (RFSC, 2016) to determine the level of similarity between ground-based and image-based data for each of the four study areas.

Resource Efficiency. The cost of equipment and requirements for undertaking surveys was noted. In addition the amount of time spent in field survey, drone flights, image analysis and subsequent data analysis was noted on the basis of obtaining data from 5 samples from each study area.

Table 1. Workflow for analysis of drone-derived image processing to provide cover estimates of features based on pixel counts. See text for details. Only partial images are presented as examples.

				
a) The original unedited true colour RGB image taken by the drone.	b) IHS image (RGB transformed image) of the bench flat emphasises distinct visual differences between vegetation, bare soil, and rock and scree features.	c) Total cover (%) of vegetation (black) was determined by colour thresholding saturation and brightness between 0-255 with a hue range of 36-130. Total vegetation = 24.69%.	d) Total cover (%) of soil (black) was determined by colour thresholding saturation and brightness between 0-255 with a hue range of 0-35 and 215-255. Total soil cover = 62.71%.	e) Total cover (%) of rock and scree (black) was determined by colour thresholding saturation and brightness between 0-255 with a hue range of 131-214. Total rock and scree cover = 12.6%.

Consultation with the Conservation Sector. The use of drones for ecological survey is a developing area and a little has been published in journals. Telephone interviews were undertaken with other practitioners currently developing and deploying drone-based survey. In particular selected speakers at the [CIEEM Autumn conference](#) (1st/2nd November 2016) on 'Skills for the Future: Understanding the impacts of new tools, techniques and approaches' were contacted, including members of the Natural England Field Unit and Environmental Records Centres.

Results

Ground-based Survey. 46 grass and forb species were recorded in bench flat quadrats, 61 in the bench slope, 45 in the receptor meadow and 56 in the donor meadow. Mean numbers of grass and forb species per quadrat in each area were similar (21.4 to 30.4) (Table 2), though the species composition differed, in particular between the bench areas (early successional, sparse grasslands where much of the cover was bare soil or rock/scree) and meadow areas (tall, dense grassland swards, which had mean total cover values of 132.6 and 141.6%). The greatest amounts of bare soil (mean 41%), rock and scree (mean 30%) were recorded in the bench flat samples and least in the receptor and donor meadows (both zero cover (%) for both parameters). It was noted that the bench flat area was poorly drained, with scattered shallow pools of water.

Drone-based Survey. In general fewer species were recorded from drone derived images than through field survey: 32 grass and forb species were recorded in bench flat quadrats, 31 in the bench slope, 37 in the receptor meadow and 42 in the donor meadow. Mean numbers of grass and forb species per quadrat in each area were similar (19.8 to 27.4) (Table 2), though generally lower than found in ground-based survey. Total cover values were capped at 100% (see method), however it was clear that on the bench areas the drone-based estimates of bare soil cover were generally greater (means 25.4 and 54.0%) compared to the ground-based surveys (12.4 and 41% respectively). In contrast rock and scree mean cover estimates from drone images were generally lower (8.6 and 21.0%) compared to ground-based survey (13.4 and 30.0% respectively). The (arguably) more objective cover estimates for bare soil derived from pixel counts closely agreed with the drone image estimate than the ground survey estimate on the bench slope but was closer to the ground survey estimate in the more open habitat of the bench flat.

Table 2. Summary statistics [Mean values (Standard Deviations)] for floristic survey data (estimation by eye unless otherwise stated) derived from ground-based survey and drone-derived image survey in study areas, June 2016 n = 5 for each study area unless otherwise stated. Key: - = SD not calculated. ND = No data.

Parameter	Study Area							
	Bench slope		Bench flat		Receptor Meadow		Donor Meadow	
	Ground	Drone Image	Ground	Drone Image	Ground	Drone Image (n=4)	Ground	Drone Image
No. grass and forb species recorded	30.4 (2.3)	20.2 (3.8)	21.4 (3.4)	19.8 (4.1)	23.8 (3.3)	23.3 (8.1)	25.8 (2.2)	27.4 (2.9)
Cover grasses (%)	53.4 (15.0)	14.0 (8.2)	20.4 (12.0)	8.0 (2.7)	87.8 (27.1)	48.8 (22.9)	76.2 (6.6)	36.0 (22.2)
Cover forbs (%)	83.6 (7.6)	52.0 (16.4)	29.0 (9.4)	17.0 (2.7)	44.8 (14.8)	50.5 (23.4)	65.4 (19.0)	63.8 (22.1)
Cover Bare Soil (%)	12.4 (6.8)	25.4 (16.9)	41.0 (18.8)	54.0 (6.5)	0.0 (0.0)	0.8 (1.5)	0.0 (0.0)	0.2 (0.4)
Cover Rock/Scree (%)	13.4 (11.5)	8.6 (7.7)	30.0 (24.2)	21.0 (9.6)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Total Cover (%)	168.8 (22.5)	100.0 -	123.0 (8.3)	100.0 -	132.6 (23.0)	100.0 -	141.6 (14.6)	100.0 -
Bare Soil (pixel analysis) (%)	ND	27.4 (15.0)	ND	43.7 (27.1)	ND	ND	ND	ND
Rock/Scree (pixel analysis) (%)	ND	3.7 (2.6)	ND	20.0 (11.0)	ND	ND	ND	ND

Rock/scree pixel count cover estimates may indicate that field and image estimates by eye generally over estimate rock and scree. As with bare soil, the pixel-based cover estimate was closest to the ground survey estimate in the bench flat study area. GLM analysis showed no significant difference between ground survey estimates, drone image estimates or pixel counts for bare ground or for rock and scree.

In the bench areas, cover estimates from drone-derived images were consistently lower for grasses and forbs compared to ground-based survey. In contrast at the meadow study areas, where there was negligible bare ground or rock/scree recorded, forb cover estimates derived from image and in the field were similar but cover estimates for grasses were recorded at approximately half those recorded in the field.

Species relatively easily recorded from images included grasses such as *Brachypodium sylvaticum*, *Briza media*, and *Festuca* species, plus larger forbs such as *Plantago lanceolate*, *Lotus corniculatus*, *Leucanthemum vulgare* and composites including *Leontodon* species. Scrub species such as *Buddleia* were also easily identifiable. Difficulty was experienced in distinguishing between some species and genera in drone-derived images e.g. yellow composites such as those belonging to *Leontodon* genus and *Trifolium campestre/dubium*. Smaller species such as *Linum* spp were probably under recorded. In addition some species were simply hidden from view by over-topping species e.g. in the Meadow areas. However the resolution of images was sufficient to observe variation in floret colour and the presence/absence of small features, such a tendrils (given the right aspect).

Floral Abundance. Manual counting of flower heads visible in drone-based images provide feasible, if time consuming (per image). Inflorescence abundance varied substantially between study areas and between samples. The mean number of inflorescences per image ranged from 95.5 (SD 64.1) in the Receptor Meadow to 685.8 (SD 460.9) on the bench slope.

Plant Species Signatures and Evaluation of Potential Habitat Quality Indicators. Beyond developing a series of IHS settings to distinguish between vegetation, bare soil and rock/scree, limited progress was made in identifying settings that would enable species signatures to be developed to quantify species abundance through image analysis. Initial outcomes from developing Habitat Quality Indicators were more successful, especially where species abundance could be related to the abundance of a physical feature or assemblage of species. Wild Marjoram *Origanum vulgare* was trialled due to its

important for invertebrates and being characteristic of open mosaic habitats (Fig 3). GLM analysis indicated that its abundance to be very strongly associated with cover of other forbs ($p \leq 0.001$) but negatively associated with increasing bare soil ($p \leq 0.001$) and rock ($p \leq 0.005$). These parameters may be used as a proxy for *O. vulgare* if it can't be identified through a spectral signature.

NVC classifications. Match coefficients for image derived data were typically lower than for those based on ground survey (Table 3). The Donor meadow community (Mesotrophophic grassland with some calcareous influences) bore the greatest similarity between ground and image-based NVC analysis. Least confidence (based on match coefficients) was found in image-based NVC analysis for the two bench communities, though the bench flat analyses produced similar communities. The greatest difference in communities identified was for the Receptor Meadow which, rather than the species-rich MG5 as indicated by ground based data, the image-based data suggested a less interesting sward (MG1) or even a community of waysides (OV23) of much less conservation value. The different outcomes may reflect coarse grass species overtopping species of greater conservation value.

Table 3. National Vegetation Classification (NVC) analysis of Plant communities based on species presence data recorded from ground-based survey and drone-derived images. NVC communities presented with top three match coefficients. Key to NVC communities: CG2 = *Festuca ovina* - *Avenula pratensis* grassland; CG3 = *Bromus erectus* grassland; CG4 = *Brachypodium pinnatum* grassland; MC9 = *Festuca rubra* - *Holcus lanatus* Maritime grassland; MG1 = *Arrhenatherum elatioris* grassland MG5 = *Cynosurus cristatus* - *Centaurea nigra* grassland; OV23 = *Lolium perenne* - *Dactylis glomerata* community.

Study Area							
Bench slope		Bench flat		Receptor Meadow		Donor Meadow	
Ground	Drone Image	Ground	Drone Image	Ground	Drone Image (n=4)	Ground	Drone Image
CG2c 44.02	CG4 34.35	CG2c 42.84	CG2c 35.12	MG5a 66.10	MG6a 50.22	MG1e 55.34	MG1e 52.39
MG1e 42.98	CG2c 34.33	CG3 42.38	CG3c 33.21	MG5 64.44	OV23 46.33	MG5b 54.98	MG5b 50.49
MG1 42.39	MC9c 34.17	CG3b 42.14	CG4b 33.16	MG5b 62.80	MG6 45.91	CG3b 53.75	MG5 50.15

Minimum Variance Cluster Analysis of species presence data from ground-survey and image-derived data. The species composition of the Receptor and Donor areas were similar (Fig. 4); for each of these study areas the ground-based and drone-derived species data were similar. Bench data also bore similarities, however it seemed that the method of recording the species data was of greater relevance than whether the data were from the flat or slope areas of the bench.

Resource Efficiency. Costs for the drone and supporting equipment and consumables were approximately £3000. It was estimated that it would normally take 24 person hours to undertake ground-based survey at the four study sites selected an 23 person hours to take images by drone and record data from them. Note these time estimates excluded travel to/from the quarry site and within site, and excluded post data capture/generation data analysis and reporting time that applied to both data sets equally. It took approximately 45 minutes to count inflorescences in an image, though the time taken was dependent on the size and resolution of the image, the nature of the community and so number of species visible.distinguishable, and the number of plants flowering, which is seasonally dependent

Discussion

The application of drones to ecological survey is a novel and innovative area with techniques, protocols and proofs of concept still being developed. Little has been published in journals to date. The scope of this research project was relatively modest and sample sizes were relatively small. Nevertheless it complements other developmental work being undertaken in the UK, including that by the Natural England Field Unit to determine its use in SSSI condition surveys, in reserve monitoring and management and in ecological monitoring in general (Pickles, 2016; Thomas, 2016).

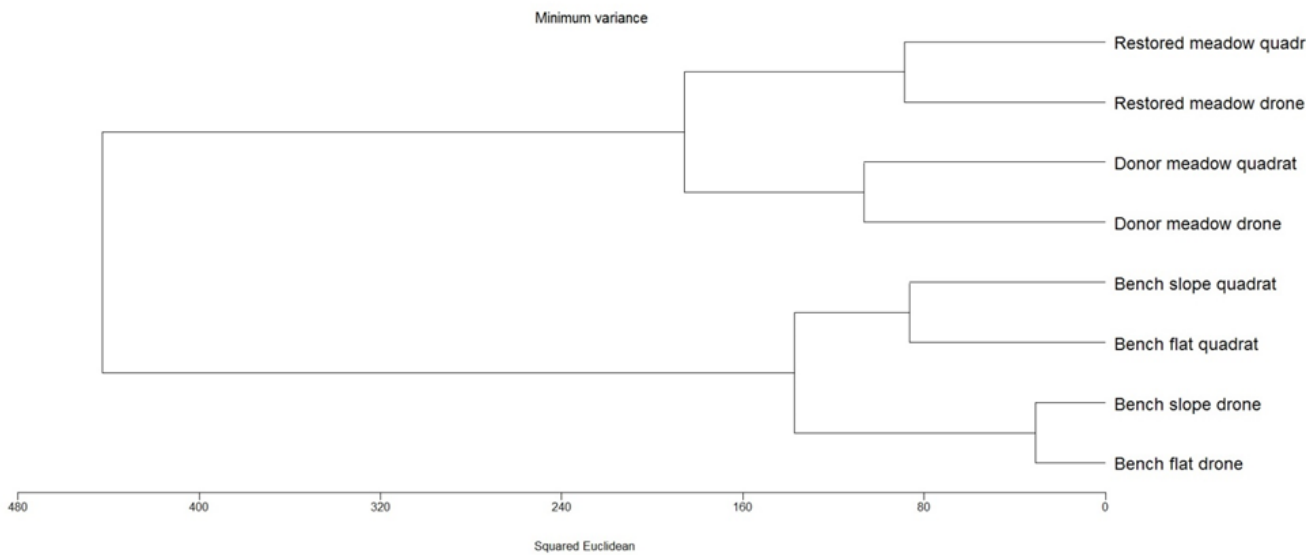


Figure 4. Minimum Variance Cluster Analysis of species presence recorded in ground-based quadrat survey data and from inspection of drone-derived images from the study areas.

Comparison of Ground and Drone-image-based Survey. Across all study sites (i.e. open mosaics and more mature grasslands) fewer species were identified and recorded through the drone image methodology than ground-based fieldwork. Cover estimates for bare soil in bench sites varied between survey/estimation methods but were not significantly different. This outcome may reflect sample size, the ability to delve into vegetation in the field to record different strata, and possibly biases inherent and specific to field or to image-based recording. Whether estimates of grass and forb abundance differed between survey methods seemed to relate to plant community type, with grasses and forbs being under estimated in more open, developing communities. In mature grasslands estimation of forbs abundance gave similar results but again grass species abundance was underestimated. This outcome suggests that the applicability of estimation of cover from images may suit monitoring of some communities more than others.

Remote sensing by satellite imagery or aerial photography has distinct benefits (covering large areas within a survey) but is limited in producing imagery sufficiently detailed to distinguish between specific plant species (Turner *et al.*, 2012). Although there were some difficulties in identifying species from drone-derived images, these high resolution images enabled between half and two-thirds of species to be recorded that were also recorded in the field. This partial reduction in species recorded will have reduced match coefficients and led to some differences in communities identified in NVC analyses. These differences are probably also reflected in outcomes from the Cluster analysis. Differences in NVC classifications may have also resulted from different samples being surveyed in ground and drone image samples but still within the same sward. Such differences might explain why the Receptor Meadow was identified as being of lower conservation interest (MG1 or OV23) than suggested by ground survey (MG5). Alternatively, without the ability to inspect lower strata in the grassland via images, some species may have been missed in image inspection. In monitoring terms, a drone survey that indicated a reduction in diversity would prompt a focused, more detailed survey on the ground to verify or refute findings and ultimately inform the restoration management prescription. Overall NVC analyses should be treated with some caution until the drone-survey technique has improved.

From the numbers of inflorescences recorded from images, assessing floral abundance seems to be entirely feasible, though time consuming, using drone-derived images. However distinguishing between species' inflorescences to determine floral diversity may sometimes be difficult (e.g. *Leontodon* spp). However in terms of habitat quality for invertebrates, it is ensuring the presence of a range of inflorescence classes or guilds that is key (Somerset Wildlife Trust, 2012; The Wildlife Trusts, undated^a).

Factors affecting Drone Surveying, Imagery and Analysis. As with any ecological survey work, weather conditions will determine whether survey can be undertaken and the quality of the data. The Phantom is a 'fair weather' drone (DJI,

2016) and should not be flown in any precipitation. Temperatures should be between 0 and 40 °C and it should not be flown above Beaufort Scale 2 wind conditions. The amount and quality of light can influence image quality spectral analysis. High incident light levels will reflect from plant surfaces and reduce image quality. Plant hue will also be affected by development stage and by environmental stresses such as drought. Of course flowering is seasonal and if recording community distribution is dependent on a constant or key plant e.g. Thyme being in flower for its colour signature to be recorded, then drone flights need to coincide with peak flowering time (Pickles, 2016). This issue affects ground-survey in a similar manner, as species identification is usually easier in the flowering season. In this research, the failure to developing plant signatures may have been due to very high resolution images being captured, resulting in the multiple hues of flowers e.g. *O. vulgare* making simple spectral analysis very difficult to achieve.

Added value of the project for biodiversity, the society and the company – Survey Accuracy, Efficiency and Safety

Remote sensing by satellite imagery or aerial photography enables large areas to be covered quickly but the imagery is too poor to distinguish between specific plant species (Turner *et al.*, 2012). As noted at Batts Combe the capability of drones to fly at lower altitudes and record higher resolution imagery can make it easier to distinguish between species in the images captured (Scaioni *et al.*, 2009; Hunt *et al.*, 2010). Subsequent analysis e.g. NVC can add value, though the accuracy of assessments could be improved by using larger sample sizes and refining the survey technique. The project has demonstrated that high quality images can be collected quickly, rapidly viewed and could the inform biodiversity management decisions on issues such as vegetation establishment following restoration. In addition, the technique can reveal whether open mosaic habitats, so valuable for invertebrates, are being overgrown as shrub species are easily identifiable. The images will also provide a date-stamped data set which can be archived. Together these data will enable the company to more easily chart the progress of biodiversity restoration and colonisation in both accessible and normally inaccessible areas of quarries. Drone surveys can be used to rapidly identify areas of particular interest and concern in large sites such as quarried and so better target biodiversity monitoring and management resources (Thomas, 2016).

The staff time invested in obtaining survey data from drone images is equivalent to that used for ground surveying when working in accessible areas. However, to concur with other research (Rango *et al.*, 2009; Martin *et al.*, 2012), it would obviously be much quicker, safer and cheaper (no rope work) to use drone surveys for high-level benches and other inaccessible areas. Safety requirements put in place by the Civil Aviation Authority must also be abided by. However in a relatively discrete site like Batts Combe, several Kilometres from an airport or flightpath the risk is minimal. In addition training in drone use aids safe operation as well as technical ability. The size of the quarry also makes drone-based ecological survey more attractive (especially if linked to geological drone surveys) as tailored aerial photography and satellite imagery would be an expensive option.

In terms of accuracy, drone-based surveys are still in the developmental stage (Pickles, 2016; Thomas, 2016). Overall, by using drone-based survey the company will have a greater and more immediate overview of the extent to which it is meeting its Biodiversity Restoration and BAP Targets. Responding to such data would increase plant and associated species abundance in the extraction site and in the wider environment. Restoration would be more successful, helping the restored quarry to blend into the escarpment to the benefit of people on the Somerset Levels and in the Cheddar area.

This novel survey technique, using cutting edge technology, bridges the gap between remote sensing and ground-based survey. As well as informing biodiversity restoration and management, it may well also inform the company's understanding of natural colonisation from adjacent SSSIs and support landscape-scale conservation work undertaken by NGOs in the region e.g. the Living Landscape project on Mendip undertaken by Somerset Wildlife Trust. It would also be in step with approaches being researched and adopted by national Governmental conservation bodies such as Natural England.

Conclusions and Recommendations

Through adopting and developing drone-based aerial surveillance, HeidelbergCement could take a leading role in this developing technology for ecological monitoring and so enable better biodiversity restoration and management.

To be kept and filled in at the end of your report

Project tags (select all appropriate):

This will be use to classify your project in the project archive (that is also available online)

Project focus:

- ☒ Biodiversity management
- ☐ Cooperation programmes
- ☐ Education and Raising awareness
- ☒ Endangered and protected species
- ☐ Invasive species
- ☒ Landscape management - rehabilitation
- ☐ Rehabilitation
- ☒ Scientific research
- ☐ Soil management
- ☐ Urban ecology
- ☐ Water management

Flora:

- ☐ Conifers and cycads
- ☐ Ferns
- ☒ Flowering plants
- ☐ Fungi
- ☐ Mosses and liverworts

Fauna:

- ☐ Amphibians
- ☐ Birds
- ☒ Dragonflies & Butterflies
- ☐ Fish
- ☐ Mammals
- ☐ Reptiles
- ☐ Spiders
- ☒ Other insects
- ☐ Other species

Habitat:

- ☐ Cave
- ☒ Cliffs
- ☐ Fields - crops/culture
- ☐ Forest
- ☒ Grassland
- ☐ Human settlement
- ☒ Open areas of rocky grounds
- ☐ Recreational areas
- ☒ Scree
- ☐ Shrubs & groves
- ☐ Soil
- ☐ Wander biotopes
- ☐ Water bodies (flowing, standing)
- ☐ Wetland

Stakeholders:

- ☒ Authorities
- ☒ Local community
- ☒ NGOs
- ☐ Schools
- ☒ Universities

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Annex 3. Images of Study Sites



Bench slope (left) and Bench Flat (right)



Receptor Meadow



Donor Meadow

Annex 4. Ground-based Survey Data

Bench Slope a Bench Flat Ground flora Composition based on 5 2x2 m Quadrats (Cover, %). Full data sets in Excel format available on request.

Scientific name	Common name	Bench slope, Quadrat					Bench flat, Quadrat				
		1	2	3	4	5	1	2	3	4	5
<i>Achillea millefolium</i>	Yarrow	2	1	2	2	10	2	3	3	1	2
<i>Agrimonia eupatoria</i>	Common Agrimony										
<i>Agrostis capillaris</i>	Common Bent Grass			1		2					
<i>Agrostis Stolonifera</i>	Creeping Bent Grass	2			5	5			2	15	
<i>Alopecurus pratensis</i>	Meadow Foxtail										
<i>Anthoxanthum odoratum</i>	Sweet Vernal Grass								1		
<i>Arrhenatherum elatius</i>	False Oat Grass	2		2							
<i>Avenula pratensis</i>	Meadow Oat-grass										
<i>Blackstonia perfoliata</i>	Yellow-wort		1								1
<i>Brachypodium sylvaticum</i>	Wood False Brome	10	10				1				
<i>Briza media</i>	Quaking Grass										
<i>Bromopsis erecta</i>	Upright Brome Grass										
<i>Bromus sterilis</i>	Sterile Brome	2									
<i>Buddleia davidii</i>	Buddleia		5	2		2	2	2	1		5
<i>Carex flacca</i>	Glaucous Sedge	10	40	40	30	25	7	15	30	7	2
<i>Catapodium rigidum</i>	Ferngrass	1	2	2	1	1	1				
<i>Centaurea nigra</i>	Black knapweed	2	1	2	2	2	2	1	2	1	
<i>Centaurea scabiosa</i>	Greater Knapweed										
<i>Centaurea erythraea</i>	Common Centaury						1				
<i>Cerastium fontanum</i>	Common mouse-ear										
<i>Cirsium arvense</i>	Creeping Thistle										
<i>Cirsium vulgare</i>	Spear Thistle					1					
<i>Clematis vitalba</i>	Old Man's Beard	1				5		1			
<i>Conopodium majus</i>	Pig-nut										
<i>Crataegus monogyna</i>	Common Hawthorn			1		1					
<i>Crepis capillaris</i>	smooth hawk's-beard			1	2		1				1
<i>Crepis vesicaria</i>	Beaked Hawk's-beard	2	1	1	2	2					
<i>Cynosurus cristatus</i>	Crested Dog's-tail		1								
<i>Dactylis glomerata</i>	Cock's-foot Grass		1	2	2	1	1			1	1
<i>Dactylorhiza fuchsii</i>	Common Spotted Orchid								1		
<i>Danthonia decumbens</i>	Heath grass										
<i>Daucus carota</i>	Wild Carrot	2	5	3	2			2	1	1	
<i>Deschampsia cespitosa</i>	Tufted Hairgrass										1
<i>Erigeron acer</i>	Blue Fleabane	2				1					
<i>Eupatorium cannabinum</i>	Hemp-agrimony	3						1			
<i>Festuca rubra/ovina</i>	Fine-leaved Fescue Grass	10	5	20	20	20	10	3	2	3	3
<i>Festuca arundinacea</i>	Tall Fescue							1			
<i>Festuca pratensis</i>	Meadow Fescue										
<i>Fragaria vesca</i>	Wild Strawberry						5				
<i>Fraxinus excelsior</i>	European ash		1	1			1		1		
<i>Gallium mollugo</i>	Hedge bedstraw										2
<i>Gallium verum</i>	Ladies Bedstraw		2								
<i>Geranium molle</i>	Dove's-foot										
<i>Glechoma hederacea</i>	ground-ivy				2						
<i>Helictotrichon pubescens</i>	Downy Oat Grass										
<i>Heracleum sphondylium</i>	Hogweed										
<i>Hieracium agg.</i>	Hawkweed			1				1			1
<i>Holcus lanatus</i>	Yorkshire Fog	1	1	2	2	3	1	2	1	1	2
<i>Hypericum maculatum</i>	Imperforate St. John's-wort										
Hypericum perforatum	Common St. John's-wort								1	1	
<i>Hypericum pulchrum</i>	Slender St. John's-wort										
<i>Hypochaeris radicata</i>	Cat's-ear						1				

Inula conyzia	Ploughman's-spikenard	1		2							
Jacobaea vulgaris	Ragwort		2	1	1	1			1		
Knautia arvensis	Field scabious										
Lathyrus pratensis	meadow Vetchling			2	1	2					
Leontodon hispidus	Rough Hawk-bit	10	20	5	5	2	2	5	5	2	
leontodon saxatilis	lesser Hawk-bit		10	1			2		2		
Leucanthemum vulgare	Ox-Eye Daisy	10	3	10	7		1	2	3	2	1
Unum bienne	Pale Flax					5	1	1		1	1
Unum Catharticum	Purg'ing Flax		1	1	1	2	1	1	1		1
Lolium perenne	Rye-grass		2								
Lotus corniculatus	Common Birds-foot Trefoil	10	10	25	25	10	5	7	10	2	2
Luzula campestris	Field Wood-rush			1							
Medicago lupulina	Black Medick	2	2	2	2						1
Nostoc Spp.	Algae (Cyanobacteria)	1	1								
Ophrys apifera	Bee Orchid					1					
Origanum vulgare	Wild Marjoram	10	15	5	10	25	2	1			1
Phleum pratense	Timothy Grass										
Pimpinella saxifraga	Burnet Saxifage										
Plantago lanceolata	Plantain Ribwort		2	1	10	3	1	1	2	1	
Plantago major	Broadleaf plantain									1	
poa pratensis	Smooth Meadow Grass	1	1								
Poa trivialis	Rough Meadow Grass	1			5	3		1			
Potentilla anglica	Trailing Tormentil	5	2								
Potentilla erecta	Cinquefoil	5	2								
Primula veris	Cowslip										
Prunella vulgaris	Self-heal	1	1	2	3	5	1	1	1	2	1
Prunus spinosa	Blachthorn										
Ranunculus acris	Meadow Buttercup										
Ranunculus bulbosus	Bulbous Buttercup	2									
Ranunculus repens	Creeping Buttercup										
Rhinanthus minor	yellow rattle										
Rosa arvensis	Field Rose							1			
Rubus fruticosus	Bramble	1									
Rumex acetosa	sheep's sorrel										
Salix cinerea	grey willow							1			
Sanguisorba minor	Salad burnet										
Sonchus asper	spiny-leaved sow thistle				1						
Taraxacum officinale (agg)	Dandelion	1							1		1
Tragopogon pratensis	Goats-beard										
Trifolium campestre	Hop Trefoil			5	4	2	1	3	2		
Trifolium dubium	lesser hop trefoil										2
Trifolium pratense	Red Clover				2						
Trifolium repens	White Clover		1		5						
Trisetum flavescens	Yellow Oat Grass										
Tussilago farfara	Coltsfoot		1								
Ulex europaeus	European Gorse						1				
Veronica chamaedrys	Germander Speedwell										1
Viola cracca	Tufted Vetch					1					
Viola sativa	Common Vetch	2	1		1	1					
Viola riviniana	Dog Wood violet										
Viola hirta	Hairy Violet										
	moss		1								
	Rock	20	5	2	30	10	30	20	5	25	70
	Bare Soil	10	20	2	15	15	50	40	45	60	

Receptor and Donor Meadow Ground flora Composition based on 5 2x2 m Quadrats (Cover, %). Full data sets in Excel format available on request.

Scientific name	Common name	Receptor meadow, Quadrat					Donor Meadow, Quadrat				
		1	2	3	4	5	1	2	3	4	5
<i>Achillea millefolium</i>	Yarrow			1			5	1		2	10
<i>Agrimonia eupatoria</i>	Common Agrimony	1					2	2	2		1
<i>Agrostis capillaris</i>	Common Bent Grass	15	2	5				5	3	3	
<i>Agrostis Stolonifera</i>	Creeping Bent Grass	5	2			2	5				
<i>Alopecurus pratensis</i>	Meadow Foxtail						2				
<i>Anthoxanthum odoratum</i>	Sweet Vernal Grass	1		2	2	1	20	30	30	10	5
<i>Arrhenatherum elatius</i>	False Oat Grass			3		5	5	10		15	15
<i>Avenula pratensis</i>	Meadow Oat-grass										
<i>Blackstonia perfoliata</i>	Yellow-wort							10			
<i>Brachypodium sylvaticum</i>	Wood False Brome			1							
<i>Briza media</i>	Quaking Grass			1			5	2	3		2
<i>Bromopsis erecta</i>	Upright Brome Grass			5			2	2		15	1
<i>Bromus sterilis</i>	Sterile Brome										
<i>Buddleia davidii</i>	Buddleia										
<i>Carex flacca</i>	Glaucous Sedge		2	2	2	5	5	5	2	20	10
<i>Catapodium rigidum</i>	Ferngrass										
<i>Centaurea nigra</i>	Black knapweed	3	2	10	2	3	15	5	1		2
<i>Centaurea scabiosa</i>	Greater Knapweed							5			
<i>Centaurea erythraea</i>	Common Centaury										
<i>Cerastium fontanum</i>	Common mouse-ear	1	1			1					
<i>Cirsium arvense</i>	Creeping Thistle	3	1	1	2	2					
<i>Cirsium vulgare</i>	Spear Thistle										
<i>Clematis vitalba</i>	Old Man's Beard										
<i>Conopodium majus</i>	Pig-nut						7			10	1
<i>Crataegus monogyna</i>	Common Hawthorn							20	5	25	1
<i>Crepis capillaris</i>	smooth hawk's-beard										
<i>Crepis vesicaria</i>	Beaked Hawk's-beard										
<i>Cynosurus cristatus</i>	Crested Dog's-tail	5	1			30			1		
<i>Dactylis glomerata</i>	Cock's-foot Grass	15	25	25	1	10	5	2	2	3	5
<i>Dactylorhiza fuchsii</i>	Common Spotted Orchid						1			1	
<i>Danthonia decumbens</i>	Heath grass								2		
<i>Daucus carota</i>	Wild Carrot										
<i>Deschampsia cespitosa</i>	Tufted Hairgrass										
<i>Erigeron acer</i>	Blue Fleabane										
<i>Eupatorium cannabinum</i>	Hemp-agrimony	1	1								
<i>Festuca rubra/ovina</i>	Fine-leaved Fescue Grass	2	2	10	15	40	2	10	30	10	40
<i>Festuca arundinacea</i>	Tall Fescue										
<i>Festuca pratensis</i>	Meadow Fescue				10	5	1				5
<i>Fragaria vesca</i>	Wild Strawberry										
<i>Fraxinus excelsior</i>	European ash										
<i>Galium mollugo</i>	Hedge bedstraw										
<i>Galium verum</i>	Ladies Bedstraw			5		3	5	15	5	10	5
<i>Geranium molle</i>	Dove's-foot										
<i>Glechoma hederacea</i>	ground-ivy	1									
<i>Helictotrichon pubescens</i>	Downy Oat Grass			2			20	2			
<i>Heracleum sphondylium</i>	Hogweed			1							
<i>Hieracium agg..</i>	Hawkweed						1				
<i>Holcus lanatus</i>	Yorkshire Fog	5	5		20	20					
<i>Hypericum maculatum</i>	Imperforate St. John's-wort										
<i>Hypericum perforatum</i>	Common St. John's-wort										
<i>Hypericum pulchrum</i>	Slender St. John's-wort									1	
<i>Hypochaeris radicata</i>	Cat's-ear										

<i>Inula conyzia</i>	Ploughman's-spikenard									
<i>Jacobaea vulgaris</i>	Ragwort									
<i>Knautia arvensis</i>	Field scabious								1	
<i>Lathyrus pratensis</i>	meadow Vetchling	1	7		5		2	2	10	5
<i>Leontodon hispidus</i>	Rough Hawk-bit	1	1	2		1	3	1	1	3
<i>Leontodon saxatilis</i>	lesser Hawk-bit									
<i>Leucanthemum vulgare</i>	Ox-Eye Daisy			1		1			5	
<i>Linum bienne</i>	Pale Flax									
<i>Linum Catharticum</i>	Purging Flax						1		1	
<i>Lolium perenne</i>	Rye-grass	1	2		5	2	5			
<i>Lotus corniculatus</i>	Common Birds-foot Trefoil			5	2	5	2	2	5	2
<i>Luzula campestris</i>	Field Wood-rush								1	
<i>Medicago lupulina</i>	Black Medick									
<i>Nostoc Spp.</i>	Algae (Cyanobacteria)									
<i>Ophrys apifera</i>	Bee Orchid									
<i>Origanum vulgare</i>	Wild Marjoram							5		2
<i>Phleum pratense</i>	Timothy Grass	10	1							
<i>Pimpinella saxifraga</i>	Burnet Saxifrage						2			1
<i>Plantago lanceolata</i>	Plantain Ribwort	3	15		3	5	2	2	3	3
<i>Plantago major</i>	Broadleaf plantain									
<i>Poa pratensis</i>	Smooth Meadow Grass			2		1				
<i>Poa trivialis</i>	Rough Meadow Grass	50	20	10	20	3				3
Potentilla anglica	Trailing Tormentil									1
<i>Potentilla erecta</i>	Cinquefoil							10	10	2
<i>Primula veris</i>	Cowslip	2	2		1	2	2		1	
<i>Prunella vulgaris</i>	Self-heal									
<i>Prunus spinosa</i>	Blachthorn									1
<i>Ranunculus acris</i>	Meadow Buttercup	2		1						
<i>Ranunculus bulbosus</i>	Bulbous Buttercup						1			
<i>Ranunculus repens</i>	Creeping Buttercup	5	2		2					
<i>Rhinanthus minor</i>	yellow rattle									5
<i>Rosa arvensis</i>	Field Rose		1							1
<i>Rubus fruticosus</i>	Bramble		10							5
<i>Rumex acetosa</i>	sheep's sorrel									1
<i>Salix cinerea</i>	grey willow									
<i>Sanguisorba minor</i>	Salad burnet				1			5		
<i>Sonchus asper</i>	spiny-leaved sow thistle									
<i>Taraxacum officinale</i> (agg)	Dandelion	2	3	5		2				
<i>Tragopogon pratensis</i>	Goats-beard									1
<i>Trifolium campestre</i>	Hop Trefoil									
<i>Trifolium dubium</i>	lesser hop trefoil									
<i>Trifolium pratense</i>	Red Clover		1	15	5	1			2	2
<i>Trifolium repens</i>	White Clover	3	20	2	10	15				
<i>Trisetum flavescens</i>	Yellow Oat Grass		1				1			
<i>Tussilago farfara</i>	Coltsfoot	1				2				
<i>Ulex europaeus</i>	European Gorse					1		2		
<i>Veronica chamaedrys</i>	Germander Speedwell									
<i>Vicia cracca</i>	Tufted Vetch							1	3	2
<i>Vicia sativa</i>	Common Vetch						2			2
<i>Viola riviniana</i>	Dog Wood violet							5	3	
<i>Viola hirta</i>	Hairy Violet			1				2		
	moss									
	Rock									
	Bare Soil									

Annex 5. Drone-based Image-derived Data

Species Presence Data

	Image title	0011	0013	0020	0023	0025	0028	0031	0033	0035	0038	0041	0048	0044	0042	0048	0029	0030	0031	0032
	site	ch	fiet	ch	fiet	ch	fiet	ch	slope	slope	s	slope	slope	s	slope	slope	s	slope	slope	s
Scientific name	Common name																			
<i>Achillea millefolium</i>	Yarrow		1			1		1	1	1	1	1								
<i>Agrimonia eupatoria</i>	Common Agrimony														1					
<i>Agrostis capillaris</i>	Common Bent Grass				1							1	1	1	1					1
<i>Agrostis stolonifera</i>	Creeping Bent Grass	1			1							1	1	1	1					1
<i>Alapacurus pratensis</i>	Meadow Foxtail																1	1		1
<i>Anisantha sterilis</i>	Sterile Brome																			
<i>Anthoxanthum odoratum</i>	Sweet Vernal Grass											1				1				
<i>Arrhenatherum elatius</i>	False Oat Grass											1	1	1	1	1	1			
<i>Blackstonia perfoliata</i>	Yellow-wort																			
<i>Brachypodium sylvaticum</i>	Wood False Brome	1	1	1	1		1				1									
<i>Brisa media</i>	Quaking Grass											1	1	1	1	1				
<i>Bromopsis erecta</i>	Upright Brome															1	1	1		1
<i>Buddleia davidii</i>	Buddleia	1	1	1	1	1		1			1									
<i>Carex flacca</i>	Gleucous Sedge	1	1	1	1	1	1	1	1	1	1									
<i>Cotopodium rigidum</i>	Rem-ress																			
<i>Centaurea nigra</i>	Black Knapweed		1	1		1	1	1			1				1		1	1	1	1
<i>Centaurea scabiosa</i>	Greater Knapweed																			
<i>Centaurea erythraea</i>	Common Centaury																			
<i>Cerastium fontanum</i>	Common Mouse-ear																			
<i>Cirsium anense</i>	Creeping Thistle																			
<i>Cirsium vulgare</i>	Spear Thistle																1	1		
<i>Clematis vitalba</i>	Old Man's Beard	1	1	1					1		1	1								
<i>Conopodium majus</i>	Pg-nut											1	1		1					
<i>Crataegus monogyna</i>	Common Hawthorn																			
<i>Crepis capillaris</i>	Smooth Hawk's-beard	1	1				1			1	1									
<i>Crepis vesicaria</i>	Besked Hawk's-beard	1	1				1			1	1									
<i>Cynurus cristatus</i>	Crested Dog's-tail																1	1	1	1
<i>Dactylis glomerata</i>	Cock's-foot Grass							1				1	1	1	1	1	1	1		1
<i>Dactylorhiza fuchsii</i>	Common Spotted Orchid			?																
<i>Danthonia decumbens</i>	Heath grass																			
<i>Daucus carota</i>	Wild Carrot					1		1			1	1								
<i>Deschampsia cespitosa</i>	Tufted Hairgrass																			
<i>Erigeron acer</i>	Blue Fleabane																			
<i>Eupatorium cannabinum</i>	Hemp-grimony																			
<i>Festuca rubra/ovina</i>	Rine-leaved Rescue Grass	1		1	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1
<i>Festuca arundinacea</i>	Tall Fescue																			
<i>Festuca pratensis</i>	Meadow Fescue																			
<i>Fragaria vesca</i>	Wild Strawberry		1	1																
<i>Fraxinus excelsior</i>	European ash																			
<i>Gallium mollugo</i>	Hedge bedstraw																			
<i>Gallium verum</i>	Ladies Bedstraw												1						1	1
<i>Geranium molle</i>	Dove's-foot																			
<i>Glechoma hederacea</i>	ground-ivy																			
<i>Helictotrichon pratensis</i>	Meadow Oat-grass											1	1	1	1	1	1			
<i>Helictotrichon pubescens</i>	Downy Oat Grass											1	1	1	1	1	1			
<i>Heracleum sphondylium</i>	Hogweed													1						
<i>Hieracium agg.</i>	Hawweed																			
<i>Holcus lanatus</i>	Yorkshire Fog							1	1	1		1								1
<i>Hypericum maculatum</i>	Imperforate St John's-wort																			
<i>Hypericum perforatum</i>	Common St John's-wort																			
<i>Hypericum pulchrum</i>	Slender St John's-wort																			
<i>Hypochaeris radicata</i>	Celt's-ear																			

[illegible]

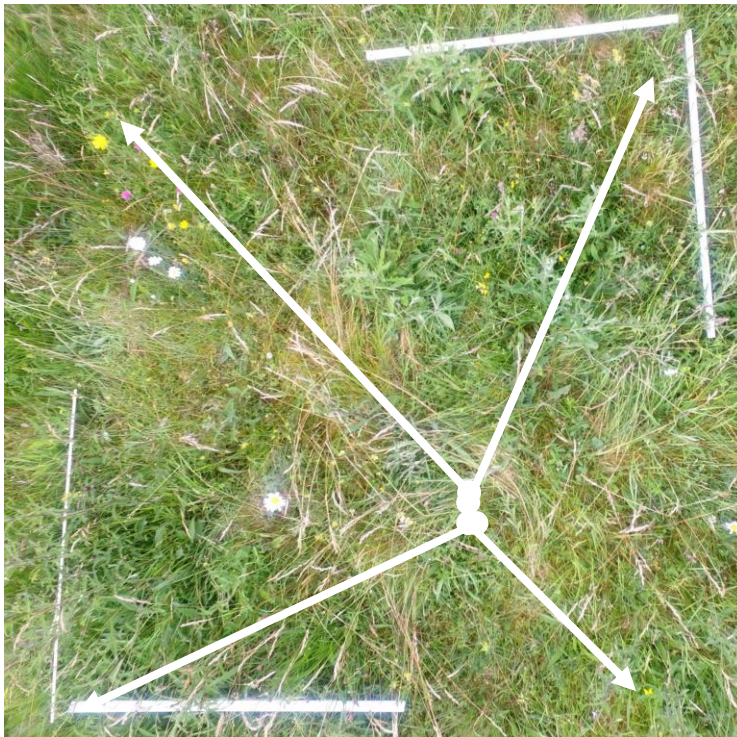
Cover Estimates from images

Image title	Site	grasses %	forbs %	soil %	rock%
DJI_0011	Bench	10	15	50	25
DJI_0013	Bench	10	20	60	10
DJI_0020	Bench	10	20	55	15
DJI_0023	Bench	5	15	45	35
DJI_0025	Bench	5	15	60	20
DJI_0028	Bench	5	60	33	2
DJI_0031	Bench	20	40	20	20
DJI_0033	Bench	25	60	5	10
DJI_0035	Bench	10	70	19	1
DJI_0038	Bench	10	30	50	10
DJI_0001	Donor	30	69	1	0
DJI_0008	Donor	75	25	0	0
DJI_0014	Donor	25	75	0	0
DJI_0022	Donor	20	80	0	0
DJI_0028	Donor	30	70	0	0
DJI_0029	Recept	15	85	0	0
DJI_0030	Recept	55	45	0	0
DJI_0031	Recept	60	37	3	0
DJI_0032	Recept	65	35	0	0

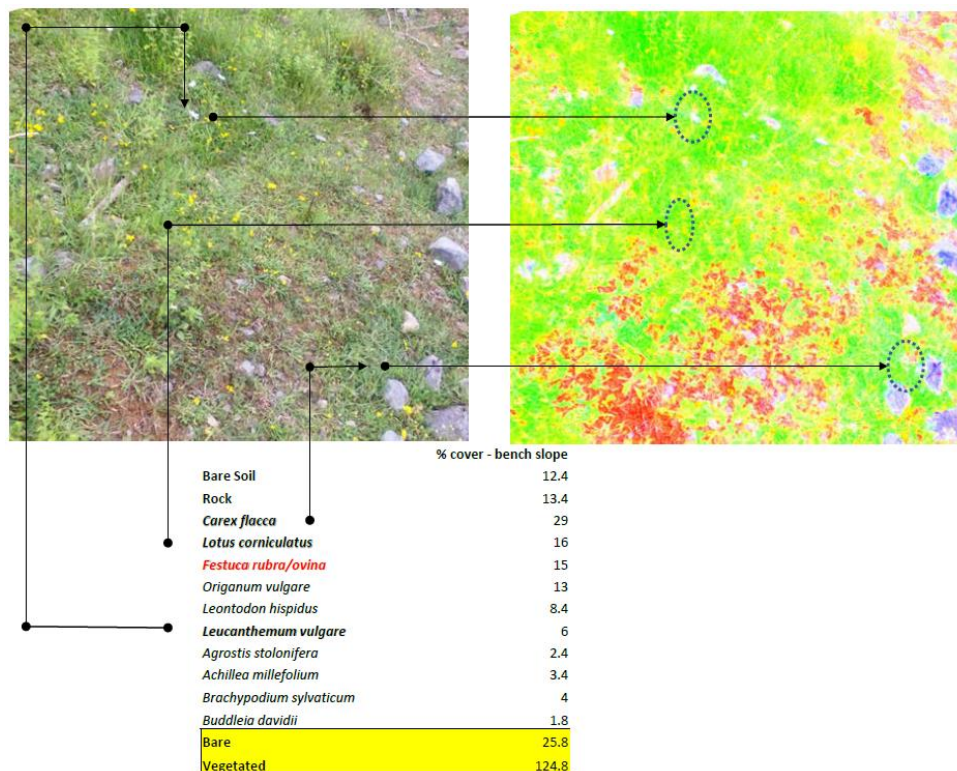
Determination of Pixel Counts for bench images using image processing and analysis

Image title	site	Total pixels	veg pixels	soil pixels	rock pixels	veg %	soil %	rock %
DJI_0011-1	bench fla	6348000	3197280	778752	2371968	50.37%	12.27%	37.37%
DJI_0013-1	bench fla	12000000	7134819	1955814	2909367	59.46%	16.30%	24.24%
DJI_0020-1	bench fla	7632000	2240554	4533573	857873	29.36%	59.40%	11.24%
DJI_0023-1	bench fla	8736336	2156674	5478651	1101011	24.69%	62.71%	12.60%
DJI_0025-1	bench fla	8790624	1554873	5979072	1256679	17.69%	68.02%	14.30%
DJI_0028-1	bench slo	12000000	7110750	4605179	284071	59.26%	38.38%	2.37%
DJI_0031-1	bench slo	5550000	4076611	1010766	462623	73.45%	18.21%	8.34%
DJI_0033-1	bench slo	9468000	7810897	1426244	230859	82.50%	15.06%	2.44%
DJI_0035-1	bench slo	12000000	9704254	2062172	233574	80.87%	17.18%	1.95%
DJI_0038-1	bench slo	12000000	5750460	5790701	458839	47.92%	48.26%	3.82%

Annex 6. Drone-derived Images and analysis



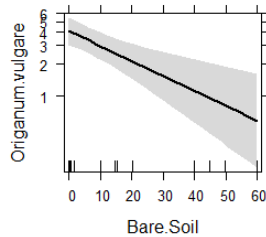
This image illustrates how drone-derived images can be distorted (the vectors should be centred within the 2x2m quadrat). However such distortion can be corrected through using ImageJ.



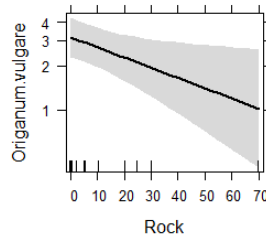
This pair of images illustrates how features from unedited images can be represented in a processed image. Some features are easier to identify than others.

Habitat Evaluation – Indicators from Analysis of Drone Data

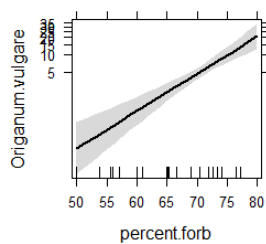
Bare.Soil effect plot



Rock effect plot



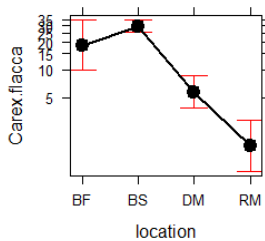
percent.forb effect plot



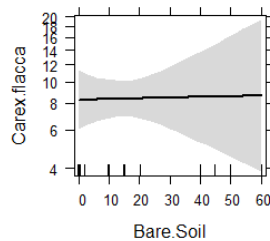
Marjoram is both important for invertebrates and a characteristic species of “Open Mosaic Habitats on Previously Developed Land.”

In these GLM effect plots *Origanum vulgare* was very strongly associated with cover of other broad-leaved flowering plants, and negatively associated with increasing grass cover, bare soil and rock. Drone images can identify areas with a high cover of forbs on inaccessible benches. Using the meta data in PLANTATT (Hill, M.O., Preston, C.D. & Roy, D.B. (2004)), we can predict plant assemblages (of plants with similar attributes) which are likely to be present.

location effect plot

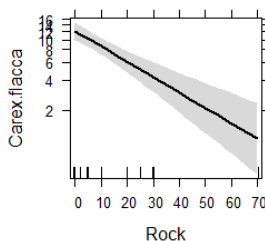


Bare.Soil effect plot



Carex flacca (Glaucous Sedge) occurred at all four sampled sites. Abundance was negatively correlated with rock, but the presence or absence bare soil wasn't a significant factor.

Rock effect plot



Annex 7. Specification of Drone used in this research

“DJI Phantom 3 Professional” Drone – Introduction and Technical Specifications

The remote controlled vehicle used by the Bath Spa Quarry Life Award team was a Phantom 3 produced by DJI Ltd. (Da Jiang Innovations Science and Technology Company) of China. The vehicle has 4 rotors in a square configuration, making it a quadcopter. It is powered by onboard rechargeable batteries and piloted from a hand-held radio control. A camera mounted on the underside can be used to record still images and videos. Also the camera can live stream to a tablet or smart-phone with the DJI GO app which can also be used to direct the vehicle by map/GPS coordinates and waypoints.



Useful Links

DJI Official Website – <http://www.dji.com/>

Phantom 3 Technical Specs page – <http://www.dji.com/phantom-3-pro/info>

DJI Wiki (contains in depth manuals and instructions relating to the Phantom) – http://wiki.dji.com/en/index.php/Main_Page

A simple guide to the DJI GO app by DroneLife.com – <http://dronelife.com/2015/09/15/a-look-inside-the-dji-go-app/>

The Civil Aviation Authority regulations page relating to drones – <https://www.caa.co.uk/Consumers/Model-aircraft-and-drones/Flying-drones/>

DJI's full list of Restricted Airspace and No-Fly Zones for Drones in the UK – <http://www.dji.com/flysafe/no-fly>

Important Terminology

In the strictest sense, the Phantom 3 is not a true “drone” as it is primarily piloted from a distance using a handheld controller. The Phantom 3 model used can be programmed to fly a pre-determined course but has little autonomous decision making ability of its own. The CAA (Civil Aviation Authority) official terminology refers to these vehicles as RPAS's (Remotely Piloted Aircraft Systems) or UAV's (Unmanned Aerial Vehicles).

However, the term “drone” is a widely used colloquialism for this kind of flying vehicle and for ease, shall be used to refer to the vehicle from here on.

Technical Specifications

Link to DJI website for full/complex specifications (voltages, transmission frequencies etc.) <http://www.dji.com/phantom-3-pro/info>

The Drone

Name – DJI Phantom 3 Pro

Configuration – 4 rotors, unmanned quadcopter

Gross Weight – 1280g

Body Diameter – 350mm

Max Ascent and Descent Speed – 5m/s and 3m/s

Max Horizontal Speed – 16m/s (in calm, still conditions)

Max Service Ceiling – 6000m (Default limit set to 120m above take-off but fully adjustable)

Controller Transmission Distance – Up to 3.5km without interference (European standards compliant)

Operating Temperature for all Components – 0 to 40 degrees Celsius

Battery Type – Lithium Ion rechargeable and dismountable packs

In-Flight Charge Life – 20 minutes approximately when full charge (dependant on ambient temperature and the level of manoeuvring in-flight)

Maximum distance from operator – 500m

Camera

Megapixels – 12

Frames per Second – 30

Video Resolution – 4k

Lens – f/2.8

Field of View – 94 degrees

Stabilisation – Gimbal with vibration dampening mountings (keeps camera exactly upright and focussed on one spot and minimises transfer of vibration from drone to the camera)

Gimbal Axis – Pitch, Roll and Yaw

Gimbal Range – Pitch -90 to +30 degrees

Media Storage – Micro SD Card (mounted on-board the drone body). Max size – 64 Gigabytes. Speed Class 10 required

Annex 8. Flight Guide - Essential Kit for Drone Flight

Before taking the drone out for flying survey work, the pilot should ensure they have the following items packed in a suitable kit bag-

Phantom Drone Chassis - (packed in waterproof hard case with foam lining)

1x DJI Phantom radio control handset + Recharging Cable – (Necessary for drone piloting. Comes with adjustable clip for mounting tablet/smart device on the handset. Powered by internal rechargeable battery so taking the charging cable could be useful if power is available on site. Approximate battery life of the handset is 3 – 4 hours)

REMEMBER TO FULLY CHARGE HANDSET BATTERY BEFORE UNDERTAKING ANY FIELDWORK

4x Plastic Rotor Blades - (A set of rotors consists of 4 blades. Two of which are black tipped and the other two silver tipped. These must be mounted on the correct motors fore and aft to ensure the blades are spinning in the correct direction to generate lift)

2x Spare Rotor Blade sets - (Very important as snapped rotors after collisions/crashes are common. The blades are designed to break and be replaced easily so take as many spare sets as required)

1x Rotor Spanner + Selection of Small Screwdrivers – (Used for tightening the rotor blades on for flight and screwdrivers and a small general purpose toolkit is useful for minor repairs in the field)

Lithium-ion battery and Spares - (From the DJI specification and the experience of the author, the usual battery duration is approximately 20 minutes, dependant on ambient temperature and how hard and fast the pilot is manoeuvring the Phantom. Using 20 minutes as a guide, it is best practice to estimate how much flight time is required and take as many spare batteries as needed. Battery charging times are many hours so pre-charging is essential but take the charger set if power is available on site if required) **REMEMBER TO FULLY CHARGE ALL BATTERIES BEFORE UNDERTAKING ANY FIELDWORK**

1x Tablet or Smart Phone with DJI GO app installed – (A tablet is best used for screen size but most android or apple smart devices can install the app and may be used to view the flight controls and GPS flight map. App available from the Google Play Store or the App Store) **REMEMBER TO FULLY CHARGE SMART DEVICE BEFORE UNDERTAKING ANY FIELDWORK**

1x Micro USB or Apple device cord – (For connecting the table device with the DJI GO app to the radio control handset, essential for using the control and camera livestream features of the app with the drone in flight)

1x Sun Visor for the Tablet Screen – (Tablet touchscreens are generally hard to see outdoors due to sun glare, a visor mounted on the control handset will negate this and provide shelter for the tablet from the weather)

1x Waterproof Plastic Ground Sheet – (Can be placed on to the ground to provide a flat landing site for the drone. Can double as a rain cover to place over the drone when landed. Small heavy weights should be taken to prevent the sheet from blowing away)

Media Storage – Several Micro SD Card 64 Gigabytes storage recommended. Speed Class 10 required

Pre-flight Checklist

1. Unpack drone kit on waterproof ground sheet or appropriate flat surface
2. Switch on control handset and attached tablet with DJI GO app activated
3. Screw on rotor blades with spanner ensuring they are tight down and that the colour coded blades are attached to the appropriate colour coded, fore and aft motor shafts
4. Insert battery pack. Switch on drone by pressing switch on battery pack once, releasing, then holding the button for 2 seconds until a tone is heard
5. Ensure battery pack charge indicator lights show full charge
6. The ventral mounted camera will now rotate on its mount automatically for a few seconds, detecting what orientation it is in. The camera will now remain pointing forwards, stable on its gimbal.
7. Sync the on-board GPS system by picking up the drone by the landing skids, then holding it at chest height, slowly rotate on the spot until the GPS indicator lights on top show green. Do this above the ground sheet/landing site as this will be location which the drone remembers as its "Home" site.
8. Ensure the DJI GO app is synced with the drone, showing the correct GPS map location, flight control readouts and camera livestream
9. **Carefully look around the ground of the flight area.** Look for any people or animals which may be in the way and ensure they are informed of the flight or moved away. Check again for potential obstacles. **If unsafe, do not fly.**
10. **Carefully look at the sky above the flight area.** Look for any other low flying aircraft, hang gliders, parasails etc. Look for dangerous obstacles such as power/telecom wires, tall trees, buildings. **Keep well clear of these or abandon the flight if the airspace is not clear and safe.**
11. **Make sure the rotor blades are not obstructed and clear of debris**
12. **Drone now ready for flight**

Annex 9. Estimation of working hours taken for ground-based and drone-image-based survey methods.

	Ground-based Survey	Drone-based Survey
Field Survey [four study areas; 5 samples per area; two staff; breaks excluded]	12 hours [3 hrs per study area] 24 people hours	4 hours [1 hour per study area] 8 people hours
Image inspection [unedited images inspected to determine species presence and cover estimates]	N/A	15 hours [20 images @ 45 minutes per image; breaks excluded] 15 people hours [by any number of people].
Total time [to produce equivalent data sets for analysis through approach used in this research]	24 hours	23 hours
Additional work on pixel cover estimates [correcting and processing images and obtaining pixel counts]		6.5 hours