A conservation practitioner's guide to the use of unmanned aerial vehicles (UAVs) for peatland monitoring and conservation: an exploration of the successes, challenges and learning of a UAV-based approach

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1. Introduction

Unmanned Aerial Vehicles (UAVs), also known as drones, Remotely Piloted Aircraft Systems (RPAS), Unmanned Aircraft Systems (UAS), Model Aircraft and Radio Controlled Aircraft, are aircrafts without a human pilot on board.

Unmanned Aerial Vehicles are being used around the world by researchers and other organisations for a range of conservation applications. One of the most common applications for drones is mapping (Wich & Koh, 2018), which can take many forms, including 2D base maps, 3D terrain models, habitat, land use, human activities, archaeology, disaster response and precision agriculture. Other UAV applications include surveillance (e.g. terrestrial and marine) and animal detection (e.g. behaviour, condition, density, distribution, migration, social interaction).

Imagery derived from UAVs is also being applied in peatland environments, and may provide unprecedented levels of detail for identifying target areas for restoration and enhancing subsequent monitoring (Clutterbuck et al., 2018).

In 2016, with funding from the EU LIFE fund, Moors for the Future Partnership (MFFP) purchased a UAV to capture earth observation data, with the aim of monitoring the impact of peatland conservation actions at a landscape scale, alongside traditional field monitoring at the site scale.

Moors for the Future Partnership has been working since 2003 to protect the most degraded peatlands in Europe. Using innovative conservation techniques, over 35 square kilometres of bare and degraded peat bogs across the Peak District and South Pennine Moors have been transformed.

In 2016, MFFP had no prior experience of using UAVs. At this time there was a lot of literature on the various applications of UAVs in environmental monitoring, which share the outcomes of research projects, but very little information available on the practicalities and experiences encountered when using UAVs (but see Cunliffe et al., 2017; Duffy et al., 2018).

The aim of this document is to provide a guide to the use of UAVs for conservation practitioners, which is based upon MFFP's experiences (successes, challenges and lessons learned) of using UAVs for peatland monitoring and conservation. We hope that it will enable other practitioners to make better informed decisions on the appropriate approach to take, whether sufficient resources (budget and people) are available, and whether the chosen approach will deliver the desired outputs. It covers a range of subjects from airspace and regulations to UAV platforms and data storage. Most sections contain a 'guide' section and a 'MFFP experiences' section. It can be read from cover to cover but it can also be dipped into as you would a text book if there are particular areas you want to find out about.

To the best of our knowledge the information provided is accurate at the time of writing. However, it is particularly important to stay up-to-date with drone regulations, which have been known to change frequently. This is best achieved via official websites such as Civil Aviation Authority (caa.co.uk) and Introduction – Dronesafe.

2. UK airspace and regulations

Airspace in the UK is managed and designated by three organisations: the UK Government (largely the Department for Transport (DfT)); the Civil Aviation Authority (CAA); and NATS Holdings (formerly National Air Traffic Services) (Butcher & Haylen, 2018).

The Government is responsible for overall aviation policy. The CAA is the aviation regulator and is responsible for the planning and regulation of all UK airspace. Its overarching duty is to maintain a high standard of safety in the provision of air traffic services. NATS Holdings is the monopoly provider of en-route air traffic navigation services to aircraft flying in UK airspace (Butcher & Haylen, 2018).

2.1. Regulations relating to the use of small unmanned aircraft

UAVs can cause injury or damage if they are not used responsibly. Consequently, they are subject to specific regulations relating to the way they are operated, which are underpinned by UK law. At the time of writing, these regulations are contained in Commission Implementing Regulation (EU) 2019/947 'The UAS Implementing Regulation' (CAA, 2015a). A consolidated version of the UAS Implementing Regulation can be found in CAP 1789A (CAA, 2021a). These are mainly safety regulations but they also cover some matters relating to privacy and security (CAA, 2015a). The Air Navigation Order 2016, as amended, also sets out some requirements that apply to UAVs, and the most relevant ones are:

- Article 240 – Endangering safety of an aircraft
- Article 241 – Endangering safety of any person or property (CAA, 2015a)

From 30 November 2019, the requirement for a UAV operator (the person or organisation that manages how a UAV is used) to be registered, and the remote pilot (the person responsible for carrying out the flight safely) to demonstrate competence became mandatory in law (CAA, 2020a). This means that most drones and model aircraft must be registered before flying outdoors in the UK. There are three main requirements: 1) to pass an online test to get a flyer ID; 2) to register for an operator ID; and 3) to label any drones and model aircraft with the operator ID (CAA, 2021b). Registration allows drones and model aircraft to be flown in the Open A1 and A3 sub-categories (basic, low-risk flying) (CAA, 2019a). There are a basic set of regulations for flying unmanned aircraft within the UK (CAA, 2015b) – see The Drone and Model Aircraft Code | UK Civil Aviation Authority (caa.co.uk). Operating within these limits will ensure that you remain in the 'Open Category', meaning that authorisation from the CAA to fly is not required (CAA, 2015b). Further authorisation, now known as an 'Operational Authorisation', is required for more advanced flying, or to fly drones or model aircraft weighing more than 25kg (CAA, 2019a). For further information on Operational Authorisation for Specific and Certified category operations see Unmanned aircraft and drones | UK Civil Aviation Authority (caa.co.uk).

2.2. Regulations relating to the commercial use of small unmanned aircraft prior to 31 December 2020

Prior to 31 December 2020, there was a distinction between flying commercially[1] and flying for pleasure or recreation. This distinction no longer exists; the rules are now based on risk and weight of drone (CAA, 2020b). This section is included to provide context on the process that MFFP went through to be able to operate commercially. It also provides some context for the reader of the extent and frequency of ongoing changes within the operation of UAVs in the UK, something which operators must keep up to date with, and adapt to.

Previously, permission had be obtained from the CAA before commencement of commercial UAV operations. According to Cunliffe et al. (2017), even researchers who had long enjoyed the freedom of operating separately from 'hobbyists' and 'commercial' operators were now finding that their institutions were demanding evidence of operational competence.

To obtain CAA Permission for Commercial Operations (PfCO), a remote pilot was required to demonstrate sufficient understanding of aviation theory, including airmanship, airspace, aviation law and good flying practice; pass a practical flight assessment; and develop protocols for safe drone deployment, alongside maintenance and flight records (Cunliffe et al., 2017) and set these out in an Operations Manual (OM). Cunliffe et al. (2017) share their OM as supplemental material to an article "A UK Civil Aviation Authority (CAA)-approved operations manual for safe deployment of lightweight drones in research". However, there have been amendments to the Air Navigation Order (ANO) since 2017 and applications may be rejected if they do not reflect the latest amendments to the ANO. This emphasises the importance of staying up-to-date with drone regulations and it is suggested that this is best achieved via official websites such as Civil Aviation Authority (caa.co.uk) and Introduction – Dronesafe.

MFFP were required to provide evidence of operational competence, including CAA PfCO, before being granted permission to fly on land owned by other conservation organisations and utility companies. In all cases these other organisations are partners within MFFP and directly involved in the project for which the data was being collected.

2.3. Regulations relating to the operation of drones in different countries

Civilian airspace in many countries of the world is regulated by National Aviation Authorities (NAAs). Regulation for the operation of drones differs between countries and it is important that operators always consult these before operating and where needed apply for the necessary permits (Wich & Koh, 2019).

While no complete database of UAV regulations exists, the Global Drone Regulations Database (| Global Drone Regulations Database) is a good starting point. This database provides a country directory with summaries of national UAV laws.

[1] Commercial operations are defined by the CAA as "… any flight by a small unmanned aircraft… in return for remuneration or other valuable consideration" (ANO, 2016), i.e. using a UAV for payment in any way.

3. Remote pilot assessment process

The CAA does not organise or run assessment courses; instead they approve commercial organisations, known as Recognised Assessment Entities (RAE) (formerly National Qualified Entities (NQEs)), to do this assessment on their behalf. Proof of remote pilot competence from an RAE is required before applying for Operational Authorisation (formerly PfCO) (CAA, 2015c).

MFFP staff attended a NQE full-course which involved 3 days of classroom lessons and exercises; a written theory test; and a flight assessment (arranged for a later date). After successfully completing the theory test, we developed an operations manual, attended manufacturers training (see section 3.1) and practiced aircraft operations and flying skills before taking the practical flight assessment. Guidance with developing an OM was provided as part of the course. The flight assessment tests the applicant's aircraft operation, flying skills and the procedures described within the applicant's OM (CAA, 2015c). It is worth checking that the NQE you choose has experience of flying the type of aircraft you will be assessed on. The MFFP aircraft requires a large area for take-off and landing, e.g. 350 m for a belly landing. MFFP staff attended practical assessments at two different sites; both sites were too small to perform a belly landing, as well as making other aspects of the assessment more difficult. They were not sites we would have surveyed using that particular aircraft.

3.1. Manufacturers training

Depending on the complexity of the UAV chosen and the level of experience within the team, it may be necessary, or at least beneficial to attend a training course with the manufacturer of the UAV.

No one within the MFFP team had previous experience of flying UAVs before the start of the project. After purchasing the UAV, four members of the team attended a five-day manufacturers training course. We were trained in teams of two, in which one team member was the pilot and the other the commander. We were required to remain in these roles for the duration of the training. Following the manufacturers training, the 'pilots' cross-trained the 'commanders' in the pilot role and vice-versa. The training covered a wide variety of skills required to fly a UAV, for example, principles of flight, equipment, assembly of equipment, flight planning, pre-mission UAV checks, camera set-up, launching (all team members), flying (pilot only), landing (pilot only), flight debrief etc. During the training we experienced strong winds and consequently spent more time in the classroom than outside. Over the five-days, one pilot performed three flights, totalling 1 hour 15 minutes and the other pilot performed two flights, totalling 1 hour. Both pilots practiced one belly landing and one parachute landing.

3.2. Flying practice & currency

When MFFP applied for PfCO, remote pilots were expected to have logged at least 2 hours total flight time within the last 3 calendar months on the type of UAV applicable to the operational authorisation. This flight time had to be undertaken during 'live flight' and not on any form of UAV simulator (CAA, 2019b).

Following manufacturer's training, MFFP carried out in-house practice and training until we were sufficiently confident to take the practical assessment. Following the practical assessment the pilot was required to have completed a minimum of 2 hours of UAV flight time within the 3 months preceding the PfCO application and provide logbook evidence as proof.

The whole process leading to formal CAA PfCO certification took approximately 8 months to complete. This is relatively consistent with Cunliffe et al. (2017) for whom the process took 1 year.

This currency was also reflected in the operations manual. The minimum levels of currency defined by MFFP in our 2018 operations manual were:

- Manufacturer's training
- NQE full-course, including practical assessment
- 40 minutes of flying to include assisted[2] mode per month
- 2 hours of flying to include assisted mode per quarter.

In the event that circumstances prevented pilots from maintaining minimum levels of currency, the monthly and quarterly minimum currency requirements had to be completed to a satisfactory level before recommencing commercial operations.

One of the difficulties we experienced was in finding a training site that was large enough and where we could obtain landowner permission. We were unable to practice on the sites that we would be flying in the future because we were in training and those landowners were only able to give permission once CAA permission was obtained. We ended up with two training sites; one was approximately 50 miles away and the other was a gliding club. The gliding club agreed to allow us to fly on days where the cloud base was too low for gliding but may have been suitable for UAV flights but these conditions never occurred and consequently we never trained at this site.

3.3. UAV insurance

If you are operating an unmanned aircraft for anything other than fun, recreation, sport or as a hobby you must have insurance cover for the aircraft that meets EC Regulation No. 785/2004 (CAA, 2015d). There are now a number of companies offering commercial UAV insurance so it is worth shopping around.

In the experience of MFFP, there were no companies willing to provide insurance before we had successfully completed our theory test, and few companies willing to provide insurance whilst we were 'in training', i.e. before we applied for our PfCO. It is also worth checking what level of public liability insurance different landowners require. In our experience this has ranged from £2–10 million.

[2] In assisted mode the autopilot provides a smoothed flight that also prevents the pilot exceeding a set amount of bank (roll) or pitch (elevation). The pilot has full control over throttle.

3.4. Landowner permission

Landowner permission must be obtained for the take-off and landing site that is being used; this was also a requirement contained within our PfCO. However, best practice, is that landowner and tenant permission should also be obtained for any land that will be covered by the flight.

In 2017, MFFP were not granted tenant permission to fly over certain land holdings until the autumn. By autumn the light levels and weather had deteriorated and we were unable to survey all of the required sites. In 2018, permission was granted on all sites, although the process required and time taken to obtain permission varied considerably depending on the landowner. In 2019, MFFP decided to return to 'traditional' aerial photography from manned aircraft (see section 12.4.2 for further details). One of the justifications for this was that aerial photography removes risks to image-capture associated with site access restrictions, increasing the likelihood of finding 'windows' of good weather for flying (Clutterbuck et al., 2019). However, the summer of 2019 was generally wet, with just a few more settled periods. Furthermore, due to the proximity of the sites to Manchester airport, the contractor was often denied access by air traffic control. Ultimately, access was granted but at a higher altitude resulting in lower resolution data than originally anticipated. In addition, this flight did not take place until October resulting in shadow across the image. This caused issues with the classification as shadow was confused with other dark land cover classes; therefore reducing the overall accuracy of the classified map.

3.5. SSSI consent

In addition to landowner permission, Natural England's (NE) SSSI permission (consent) is required if the land to be covered by the flight is a Site of Special Scientific Interest (SSSI). The request for permission (Notice of Proposal) should be submitted by the landowner/ occupier (NE, 2020).

4. UAV Platform

There are three common types of UAVs used in conservation: multirotor, fixed-wing and hybrid VTOL (vertical take-off and landing). A multirotor relies on one or more rotors that generate the lift required for flight. A multirotor is able to move forwards, backwards, left and right by adjusting the relative speeds at which its rotors are spinning (Wich & Koh, 2018).

A fixed-wing looks and functions like a manned aircraft. It has one or two horizontal propellers that generate thrust to move the UAV forwards. Lift is generated by the movement of air over and under the wings, which allows the UAV to take off and maintain straight and level flight. The direction of flight is changed by the movement of its control surfaces, i.e. ailerons and elevators (Wich & Koh, 2018).

A hybrid VTOL combines the features of the multirotor and fixed-wing aircraft. The most important Pros and Cons of each are related to launch locations, payload, flight time and pilot experience (Wich & Koh, 2018).

Once a decision has been made regarding the type of platform, it is also important to consider the complexity of the system. For example, how easy it is to set up, launch, fly and maintain; this varies considerably, even between platforms of the same type. Similarly, consideration should be given to the software the UAV is supplied with, how easy it is to use and whether it is able to do what you need it to do.

If you are purchasing a UAV, it makes sense to purchase something that is easily maintained, has a strong user community, and works well as an integrated system (Calvo, 2016–17).

MFFP purchased a 5 kg modular fixed-wing aircraft with swappable sensor pods which permits a greater range of sensors to be supported. It was supplied with high-resolution sensors and is able to capture RGB and multispectral imagery simultaneously. It also has high wind resistance, is weatherproof, has high endurance, and has three landing modes, including a parachute (useful for landing on uneven ground). The manufacturers of the aircraft are UK based, making access to technical support easier.

The flight software used by MFFP did not allow the UAV to follow the terrain (i.e. through the use of a digital elevation model). This would have been a useful feature, given the environment in which MFFP work.

5. UAV Sensors

An important consideration when using UAVs to collect data is to determine whether the system will need one sensor or multiple sensors during the same flight, or whether data with multiple sensors can be collected over multiple flights. According to Wich & Koh (2018), the latter is likely to be an option when flights are conducted for land-cover classification because the objects of interest are motionless.

The MFFP UAV was supplied with a Sony A6000 DSLR camera for visible spectrum (RGB) images and a MicaSense RedEdge multispectral camera for multispectral images. The Sony A6000 has a ground resolution of 2.4 cm per pixel at 120 meters above ground level. Image formats include JPEG or RAW. The MicaSense RedEdge has 5 wavelength bands including Blue, Green, Red, Red Edge, and Near Infra-Red. Monochrome ground resolution is 8.2 cm per pixel at 120 meters above ground level. Image formats include RAW, 12 bit DNG or 16 bit TIFF.

As discussed above, one of the reasons the MFFP UAV was purchased was because it could capture RGB and multispectral imagery simultaneously. However, due to issues with this platform (discussed further in Sections 10.1, 10.3, 10.4, 10.5 and 10.6), an alternate solution using sensors mounted on a senseFly eBee platform was subsequently adopted.

The eBee can be flown independently with either a S.O.D.A. (Sensor Optimised for Drone Applications) or 'Parrot Sequoia' to collect RGB and 4-band (G, R, RE, NIR) imagery respectively. This approach requires two flights rather than one to capture both sets of imagery and must be flown lower (at approximately 60–70 m above the ground) to achieve comparable spatial resolution. This approach increases the number of flight lines required to capture the area and therefore increases image capture time (Clutterbuck et al., 2019).

In contrast to Wich and Koh (2018), we found that collecting data with multiple sensors over multiple flights did present a number of issues (see section 12.4.2).

6. Pre-flight Planning

The safety and success of a UAV flight is, to a large extent, dependent on thorough pre-flight planning. The following section details the pre-flight planning procedure implemented by MFFP.

6.1. Pre-deployment survey

A pre-deployment survey is a desk-based activity to collate and record information relevant to a flight on a specific site. It also ensures that all pre-flight planning activities are carried out and that all flights are carried out safely and legally.

There are a number of planning aids that can be used to assist in completing the pre-deployment survey including: Ordnance Survey maps; Aviation charts 1:250,000; Google Earth; Sky Demon Light (http://www.skydemonlight.com/ – a free basic flight planning tool); Altitude Angels (https://www.altitudeangel.com/solutions/drone-safety-map/) – online drone safety maps; No fly drones (www.noflydrones.co.uk) – a free tool showing no fly zones in the UK); NATS AIS (http://www.nats-uk.ead-it.com/public/index.php.html – providing an Aeronautical Information Service); Drone Assist app – a drone safety app from NATS; NOTAM[3] (Notices to Airmen) Info (https://notaminfo.com/ – providing up-to-date NOTAMS plotted on a map); various online resources for checking weather (see section 10.2).

MFFP record this information on a pre-deployment survey form.

The pre-deployment survey form includes information on the following:
Section 1: Job details

- Date; name of pilot, commander and observer; brief description of the aim of the flight

Section 2: Site details

- Landowner and tenant name, contact details and permission; coordinates; altitude; address (or nearest address); whether there is vehicular access; nearest hospital and telephone number for nearest hospital and police

Section 3a: Airspace

- Controlled or uncontrolled; classification; ATC permission required; controlled airspace within 40km

Section 3b: Airports within 40km

- Airport, contact number, whether permission is required.

Section 3c: Airspace hazards

- Danger, restricted and prohibited areas; other air spaces, users and hazards.

Section 4: Ground assessment (in relation to the potential risk and proposed mitigation)

[3] NOTAMs are official notices that tell people about activities that may be a hazard to flying (CAA, 2019a).

- Congested areas, isolated structures, conservation areas (including local bye-laws), third-party infringement, roads and right of ways, livestock, recreational places and any other restrictions.

Section 5: Weather (to be checked 24 hours prior to deployment)

- Wind speed and direction; temperature; humidity; sunrise/ sunset; and general forecast.

Section 6: Notes, flight plans and comments

Section 7: Approval to operate

- Confirmation that, on the basis of the flight planning assessment, you believe that the flight can be conducted safely, in accordance the required regulations.

6.2. On-site survey

In addition to the pre-deployment survey, an on-site survey should be carried out on arrival at site, and prior to flying. The on-site survey provides an assessment of potential risks that may not have been identified during the pre-deployment survey, i.e. weather and line of sight, aiding decision making about where and when it is safe to fly.

The on-site survey form includes information on the following: weather; permission; air traffic control; communications; buildings; people; take-off and landing area; obstructions; line of sight; animals/ livestock. It also includes a dynamic risk assessment, with space to record potential risks and mitigation.

MFFP record this information on an on-site survey form.

6.3. Flight operations

Having a working document such as an OM (see section 2.2) will allow for consistent and safe flight operations, as well as reassuring collaborators and land owners that flight operations are being conducted in a professional manner (Cunliffe et al., 2017). Flight operations, as defined in an OM, will be specific to each organisation and to the drone being flown.

At MFFP we follow assembly and pre-flight checks which are specific to our aircraft. These checks are about preparing the UAV for take-off and flight, as well as ensuring propeller safety protocols are adhered to. If the UAV fails any of the checks then the UAV is not flown until the issue is resolved.

Prior to take-off, the pilot in command provides a pre-flight briefing. This briefing details who is performing what task and the route the aircraft will take. During the flight it is important to know where the aircraft is on its route and what the next expected behaviour will be. The commander relays information from the ground-control station software to the pilot, while the pilot maintains visual contact with the aircraft. Where possible spotters are also used, the spotter is responsible for assisting the pilot in the duties associated with collision avoidance and informing the pilot of any notable sightings or sounds; ensuring the pilot is not disturbed by the public; ensuring that prior to landing the landing area is clear of people and animals and indicating this to the pilot; clearly pointing to the location in which the UAV landed and continuing to point until the UAV is retrieved.

7. Flight Records

It is strongly recommended that comprehensive flight logs are maintained of both deployment and experience. Flight logs contribute towards safety; these records can prove invaluable when presenting a safety case to institutions, regulators, collaborators and landowners (Duffy et al. 2017). Accurate record keeping and planning provides a means of better understanding performance in the air, and monitoring and analysing flights, platforms and batteries. Making notes of how you felt during a particular flight, for example, in windy conditions, will help you better understand yourself as a pilot and increase your confidence and safety (Calvo, 2016–17).

MFFP complete and retain the following flight record documents after each flight:

1) Pre-deployment survey (see section 6.1)
2) Request for NOTAM Action
3) NOTAMs
4) On-site survey form (see section 6.2)
5) Battery register form
6) UAV flight log
7) UAV flight report form
8) Record of flying time
9) UAV flight and issues log
10) UAV follow-up actions
11) UAV modification record

8. Logistics

Calvo (2016–17) recommends that when working in remote locations, the drone and all supporting equipment for a full day of field operations should be able to be carried easily by a single person through rough terrain. Unless you have a means of charging batteries on site you will also need to ensure that you have sufficient batteries for drones, cameras, ground station (laptop or tablet), GPS and any other electronics you require.

The MFFP UAV is not easily carried by a single person, and while Calvo (2016–17) may be referring to significantly more remote locations than the top of Kinder Scout in the Peak District, it is nevertheless important to consider how you will transport your equipment to site and how many people will be required.

To reach MFFP's sites on Kinder Scout takes approximately 1.5 hours by foot. The UAV and all ancillary equipment can be packed into two 35L and two 50L rucksacks. A keyboard bag was used to carry the wings. This required at least five people to transport the equipment onto site, bearing in mind that everyone still needs to be able to carry sufficient food, water and clothing for a potentially long day on the hill.

In our case, the number of people required to transport equipment to field sites is acceptable because that number of people can easily be used once on site to set out ground-control point (GCP) targets and mark locations with a Differential Global Navigation

Satellite System (DGNSS), unpack equipment, set up the launch line, assemble the UAV and carry out pre-flight checks, pilot, command and act as observers during the flight.

The MFFP UAV has a lot of ancillary equipment; therefore, equipment checklists are used to pack bags at base but are also taken to the field to ensure that all the equipment is checked back in at the end of the day.

9. Ground Control

One of the challenges with most forms of UAV acquired data is relatively poor spatial accuracy (Duffy et al., 2018). Depending on the intended use of the data, this may or may not be a problem.

MFFP started collecting UAV data to monitor land cover change between years, including increases in the extent of *Sphagnum* moss. As *Sphagnum* has been shown to grow at rates of less than 50mm per year (Küttim et al., 2019), very high spatial accuracy is required in order to identify these small-scale changes. The spatial accuracy of the MicaSense RedEdge™, used by MFFP, is at best 2–3 metres (MicaSense, 2015). In order to process the UAV-derived imagery with the accuracy required a number of ground-control point (GCP) targets were positioned on the ground for each survey (Clutterbuck & Yallop, 2017). The location of the GCPs were marked using a DGNSS. MFFP use the Trimble Geo 7X, which, besides being very user friendly, can achieve positional accuracy of *c.* 2–3 cm, once the data has been post-processed.

9.1. GCP target design

When used, ground-control point (GCP) targets should be designed in accordance with (i) the spatial resolution (i.e. being at least 6–8 pixels in diameter) (James et al. 2017, cited in Duffy et al. 2017) and (ii) the electromagnetic sensitivity of the sensor (i.e. identifiable in all spectral bands, particularly when working with non-visible spectrum data) (Duffy et al. 2018).

A range of GCP target designs were extensively explored with data captured using both the SONY A6000 and MicaSense RedEdge in the same flight. The most successful design (i.e. visible in both sets of imagery) is shown in Figure 9-1 (Brooke & Clutterbuck, 2019).

The GCP targets comprise a double-cross pattern with a large black square and smaller white square in the centre. They are constructed from black and white corrugated polypropylene sheets (2mm thick) (Clutterbuck & Yallop, 2017; Brooke & Clutterbuck, 2019) to ensure they are sufficiently lightweight and easy to transport on to site. The white square is attached to the top of a peg. The peg is pushed through pre-cut holes in the black square and cross and secured into the ground to prevent the target blowing away. On occasions, wind caused the white cross to blow up, covering the white square and some of the black square. This was resolved by using wooden skewers to hold the cross down.

This target was discovered to be less visible in the thermal data. Brooke & Clutterbuck (2019), tested a cross target made from aluminium foil, with the same dimensions as the larger black cross used in the multisensor target, and found it to be more easily identifiable in thermal imagery than black polypropylene.

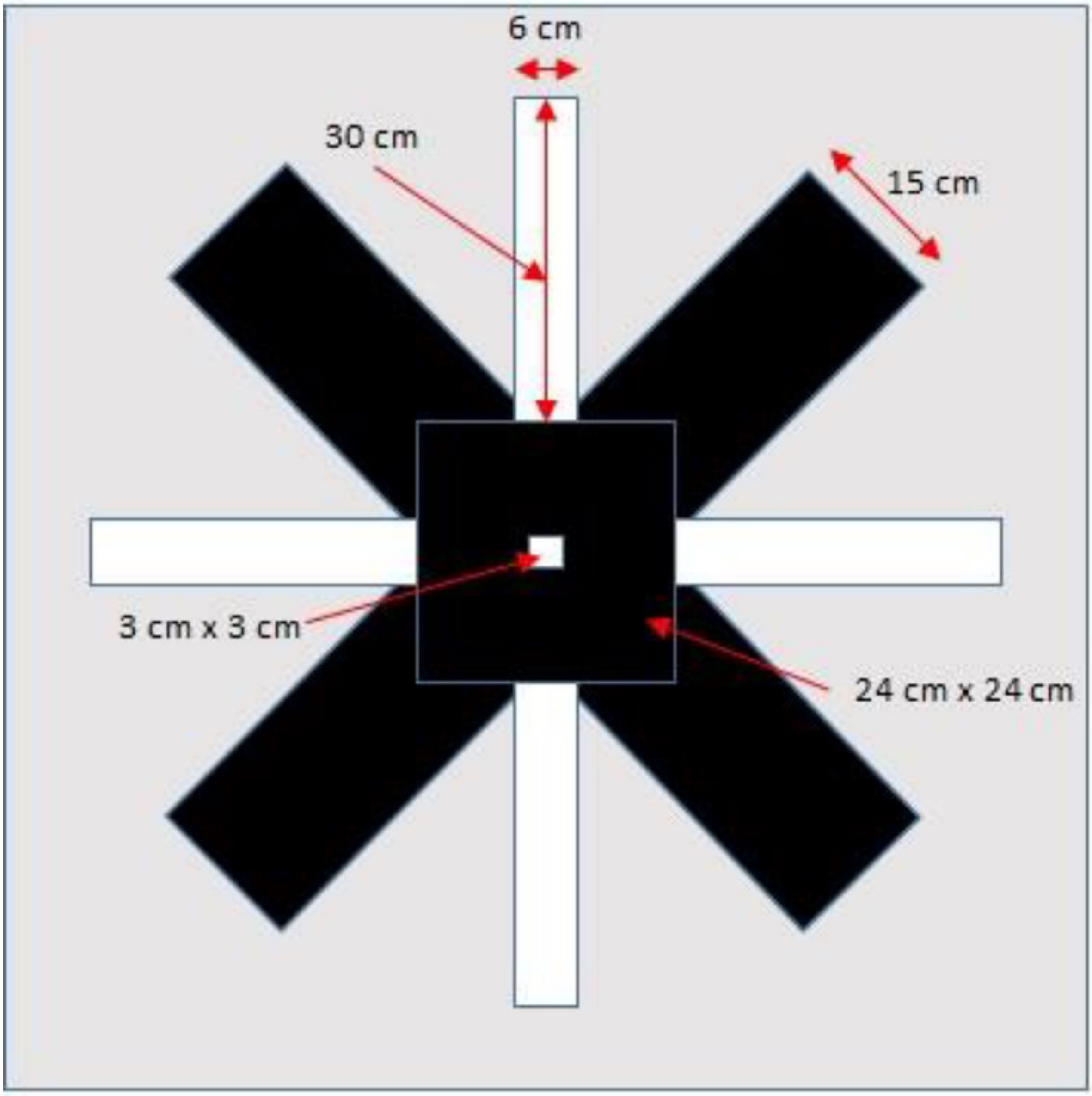

Figure 9-1: Multisensor target design (Brooke & Clutterbuck, 2019)

9.2. GCP number and distribution

For relatively small surveys covering 20–30 ha, GCPs distributed on a 100 m triangular grid provide excellent results and provide redundancy in case one or more GCPs move during the flight or are not visible for some reason in the data collected (and would therefore be excluded from image processing). For larger surveys, GCPs distributed on a 150 m triangular grid have to date found equally good results (Clutterbuck & Yallop, 2017). The location of the GCPs can be marked using a DGNSS.

Each survey carried out by MFFP covered *c.* 50 ha. For each survey the main area of interest (AOI) was a *c.* 1 ha 'field laboratory' located in the centre of the 50 ha survey. The time required to set out and record the location of GCP targets on a 100 m triangular grid using DGNSS equipment was unfeasible in the time available. As the field laboratories and associated catchments were the most important part of the survey area, GCPs were distributed on a 100 m triangular grid within and directly around the catchment and on a 150 m triangular grid for the remainder of the survey area (totalling c. 29 GCPs per flight area; see Figure 9-2). To make the most effective use of the ground survey team's time, GCPs locations were loaded directly onto Garmin units, the GCPs were numbered to help the teams set targets out without missing any, and printed copies of the GCP map were provided to all members of the flight crew and ground survey team.

Appropriate target design, highly accurate GCP coordinates and well-distributed GCPs on each survey site enabled Pix4D to process the imagery and report consistently low mean error. For RGB data (from the S.O.D.A. camera), the mean overall RMSE (in x, y and z) was consistently comparable to and often lower than the pixel size and for the multispectral data (from the Sequoia), the mean overall RMSE was less than half the pixel size (Clutterbuck et al., 2019).

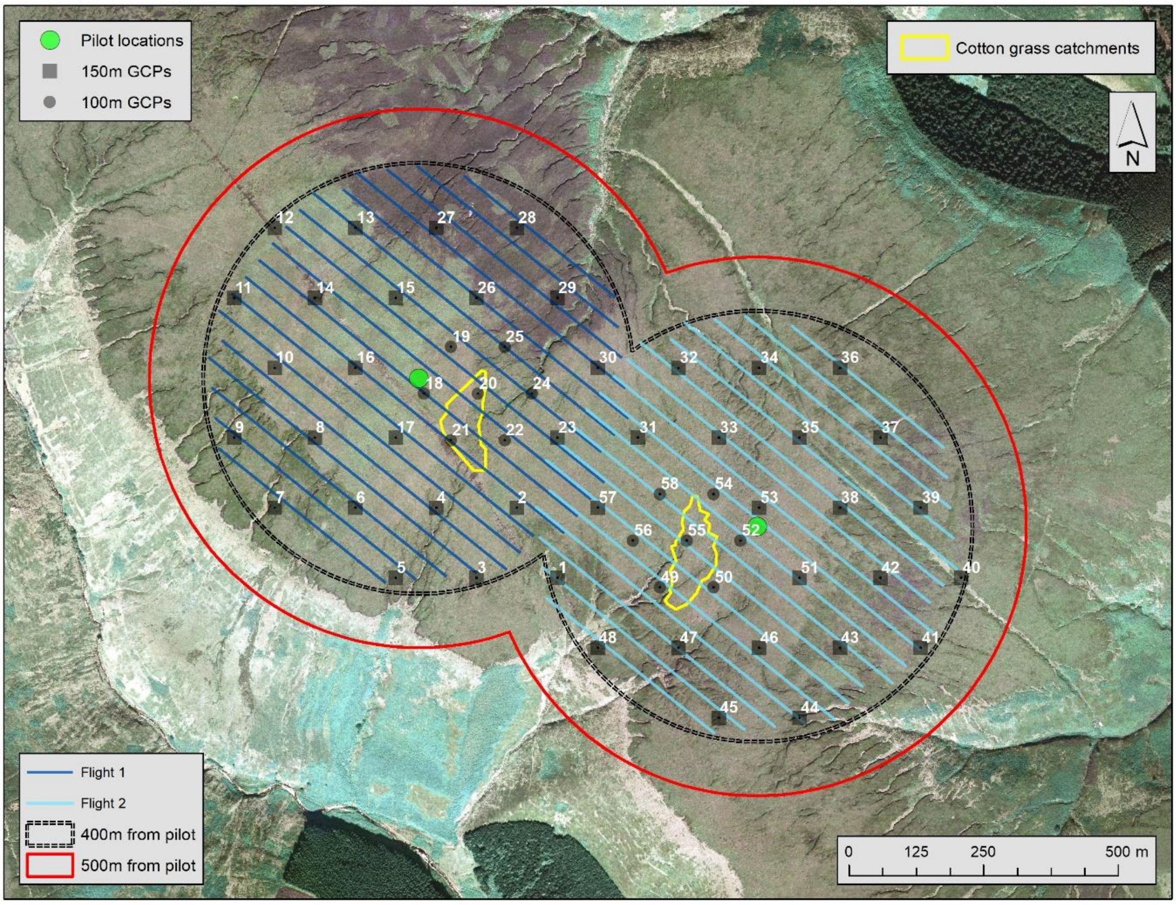

Figure 9-2: Distribution of GCPs for surveys on *Eriophorum* dominated sites

10. Flying

10.1. Pilot experience

Another important consideration when choosing an aircraft type is the level of experience within the team. A multirotor can be flown with minimal or no training and experience, while a fixed-wing requires experience and training to effectively pilot, especially for take-off and landing (see section 3.1). A hybrid VTOL sits somewhere in the middle, requiring an intermediate level of pilot experience (Wich & Koh, 2018).

MFFP have experienced some issues due to limited pilot experience, including:

- Motor burn out caused by the throttle not being fully off following a landing.
- UAV launched in wrong mode, resulting in a failed launch.
- UAV stalled and crashed due to low speed.
- Displaced autopilot, not identified in pre-flight checks caused two further stalls.

According to Calvo (2016–17), "if you are a researcher who wants to start using drones as part of your projects, working together with a specialist might save thousands of dollars in crashed platforms and hundreds of hours in attempts", indicating that this is not just the experience of MFFP.

10.2. Weather and local environment considerations

Detailed weather forecasts should be checked the day before and on the morning of the flight, and if necessary, the flight should be postponed.

There are a number of useful on-line resources for checking the weather, such as the Met Office (www.metoffice.gov.uk), Metcheck (www.metcheck.co.uk) and xc weather (http://xcweather.co.uk/). UAV Forecast (https://www.uavforecast.com/) shows 24 hours of hourly forecast for free and includes information on gusts, temperature, precipitation probability, cloud cover, visibility, visible satellites and an indication of whether it is good to fly or not.

In addition to checking weather forecasts, it is always necessary to check weather conditions on arrival at the site. This is particularly important for wind speed and direction.

Duffy et al. (2017), suggest carrying a handheld anemometer to check that wind conditions are within the operational range of your UAV, for example, a maximum launch wind speed of 20 Knots (23 mph) is recommended for the MFFP UAV. Generally, wind speed increases with height; therefore, it is useful to get the anemometer as high as possible, for example, MFFP generally attach an anemometer to the end of a 6 ft. garden cane. It is also informative to observe the movement of trees and clouds. MFFP have had a number of flights in which we have launched but the UAV has struggled against the wind and some cases we have landed because it has been too windy.

A wind sock will also give an indication of wind speed, as well as wind direction. Some UAVs need to be launched and landed into the wind and if you are flying a pre-programmed route it may be necessary, or at least beneficial (i.e. greater endurance), to orientate the survey grid according to the wind direction. For example, if flying the MFFP UAV in an easterly wind, the flight lines would be orientated in a north-south pattern, with the first flight line located to the west of the survey area, allowing the UAV to turn into the wind at the end of each flight line.

According to The Drone and Model Aircraft Code, a UAV should not be flown within 50 metres of people, including people in buildings and transport, which is not under the control of the SUA operator or the remote pilot of the aircraft (CAA, 2021c). For MFFP, this has meant that certain sites could not be flown in certain wind directions, because launching into the wind would take the aircraft over nearby roads.

It is also important to know the operational range of your UAV in relation to other weather parameters such as rain and temperature. The MFFP UAV is weatherproof and able to operate in temperatures of -10°C to +40°C. However, just because it is possible to fly does not mean that the data collected, e.g. during rain, would be of a suitable quality, or that the pilot would function well.

It is also important to be aware of the effect of weather on battery life. In both windy and cold conditions flight time may be reduced due to shorter battery life.

10.3. Damage and redundancy

One consideration when deploying UAVs, particularly in remote locations, is contingency and redundancy in all aspects of the system, i.e. ground-control station (GCS), UAV, etc. The specific spares you carry will be related to your particular aircraft but as a minimum, Duffy et al. (2017), advise UAV operators to carry multiple replacement batteries (UAV and controllers), a battery checker, replacement propellers, a basic toolkit, electrical tape and cable ties.

MFFP works on a variety of moorland sites which are accessed by foot, taking between 15 minutes and 1.5 hours. It is so important that all of the necessary equipment is taken to site. If one small item is forgotten it may mean that the whole day is wasted. To ensure this does not happen it is a good idea to use equipment checklists. The MFFP UAV and all the associated equipment has to be packed into a number of bags and we have an equipment checklist for each bag. We also take a copy of the checklists to site to ensure that all of the equipment is returned to base at the end of the day.

On the MFFP UAV, the camera hatch regularly detaches during a belly landing; therefore, we always carry additional camera hatches with us. Other spares that we carry include batteries (camera, DGNSS, laptop and UAV), electrical and glass weave tape (for minor repairs), cam locks (for attaching the wings to the aircraft body), propellers, and a small toolbox containing screwdrivers, nuts and washers, scalpels and a wrench.

10.4. Launch and landing

One consideration when choosing an aircraft type is the likely launch and landing locations. Both multirotor and hybrid VTOL drones can take off and land in a small area and can be launched in a wide range of environmental conditions. In contrast, fixed-wing drones often require a larger, more open and flat area for launch and landing (Wich & Koh, 2018).

For example, the MFFP UAV, which is launched using a Safe Launch Bungee System, requires an area of approximately 300 m by 150 m for take-off, which is unbounded by high trees or obstacles. For landing, 350 m is required for the aircraft to glide down a horizontal flight path over which the flight altitude gradually decreases (Wich & Koh, 2018). The orientation of this area will also depend on the wind direction, with launch and landing performed into the wind. This means that some sites, where space is more limited, can only be surveyed in certain wind directions.

The Safe Launch Bungee System was developed to get a relatively heavy aircraft airborne without an undercarriage or runway. The UAV has a top and bottom harness that allows considerable forces from the launch line to be transferred without stress through the body of the aircraft to the hand of the launcher. On release, the launching forces acceleration of the aircraft gently, but swiftly, to flying speed.

MFFP has, however, had a number of issues with the Safe Launch Bungee System, including:

- The air-trigger barb (which attaches the air trigger to the UAV) sheared off when the launch line was under full tension causing an early release.
- The UAV failed to detach from the air trigger during a launch, causing the aircraft to be pulled back to the ground and crash.
- The air trigger and barb bent when the launch line was under full tension, causing an early release.
- The launch line was sucked into the prop on a launch. The air trigger chipped the ends off the prop, causing the UAV to nosedive and crash land. On this occasion, we think the crash was actually caused by a displaced autopilot, rather than the launch line per se.
- During the first launch with a new air trigger the UAV released early and looped back towards the launcher.

Due to the number of incidents with the launch line and health and safety concerns over the potential injury that could be caused by a launch line incident a decision was made to temporarily stop flying with the MFFP UAV until a solution could be found.

10.5. Other technical challenges

MFFP has also experienced a number of other technical challenges, relating to sensors, software and the UAV platform itself. With regards to sensors, movement of cameras during launch has impacted on image quality. In the example below the two images are sequential. Figure 10-1 was the last image taken prior to launch. Figure 10-1Figure 10-2 is the first image captured over the survey area. Here the SONY camera shifted from its optimal position in the UAV after being set up and the aircraft frame obscures one edge of the image. These will not be suitable for image processing. On occasions we also carried out flights in which the MicaSense RedEdge did not capture images. In both cases, the flight had to be repeated.

The flight software generally functioned well; however, on one occasion (during a practical assessment), an error occurred with the flight software which prevented the flight from taking place. We were told by the software provider that the error occurred because too many waypoints were added to the flight plan. This theory was tested by MFFP, by creating plans and sequentially adding more waypoints but we were unable to recreate the error. The reason for this error was never established.

With regards to the platform itself, for a period of time we suffered from poor and intermittent radio signal between the ground station and the UAV. This issue persisted for some time before it was noticed that the pin in the co-axial connection was not protruding sufficiently.

Figure 10-1: Last image taken prior to launch

Figure 10-2: First image captured over the survey area

10.6. Wear and tear

In addition to the various issues described above, there are also issues that occur as a result of wear and tear and genuine accidents. The ideal scenario would be to operate with full redundancy, i.e. have a second UAV which operates in parallel with the primary UAV so that both are sharing the demand. Should the primary UAV fail, the second UAV takes the full service. However, in many projects, this is not financially viable. Of course, most challenges are not insurmountable, but it is useful to consider the range of issues that can occur which prevent successful data capture and whether you are equipped, both in terms of resources and expertise, to deal with them.

For example, with a fixed=wing UAV it can be difficult to predict the exact landing location and we have had occasions where the UAV has sustained damage due to landing on stones beneath vegetation. On one such occasion, damage was caused to the nose and parachute servo arm. Given more experience, these repairs could have been carried out in the field but at that point we had no experience of changing servo arms nor spares with us.

In terms of wear and tear; MFFP were carrying out pre-flight checks in the field when we noticed a big difference in the amount of deflection of the ailerons. This was caused by wear and tear to the wing servo which required replacement. This issue actually took from 30th June until 7th August to be fully resolved; resulting in a large period of potential flying time being lost.

11. Ground survey

In order to classify aerial photographs into a land-cover map (image classification) it is necessary to have ground-truth data for both image training and error determination. It is also important to collect data in a way that is relevant to the resolution of the aerial data. The following section presents the ground survey methodology used by MFFP.

11.1. Methodology

In 2018, the location of 'single-species stands' of approximately 20 x 20 cm were recorded using a Trimble Geo 7X DGNSS. For each species, the survey team aimed to record a minimum of 20 samples per site. The survey team walked between the GCP target locations to ensure good site coverage. Usually, one day per site was spent conducting the ground survey.

It was found that this method did not provide sufficient records, or spatial distribution (Clutterbuck et al., 2019). Despite the surveyors covering the whole site, the spatial distribution of records was clustered because single-species stands occurred more frequently in gullies, while the vegetation on the tops was more heterogeneous and therefore unsuitable for recording.

As a result, image classification for this first round of reporting was therefore undertaken utilising all available ground-truth data for image training, rather than adopting standard procedures of retaining 50% for error determination. This prevented the comprehensive testing of protocols most suited for processing UAV imagery of these habitats (Clutterbuck et al., 2019).

In 2019, every effort was made to increase the number and spatial distribution of vegetation survey samples. Each survey site was divided into approximately 100 grid squares. A circular area of approximately 30m radius in the centre of each survey grid square, the search locus, was searched for 'single-species stands' of approximately 50 x 50 cm. One sample of each species were marked using the Trimble DGNSS at each search locus (Clutterbuck & Yallop, 2019). A 'running tally' of each species was kept and additional samples recorded if species with a low number of records were observed in transit to each sample location. The overall aim of the sampling effort was to attempt to identify 100 examples of all species present at each study site. At the cessation of field survey the target of 100 samples at each site was only achieved for some species, either as a result of absolute scarcity or the lack of single stands of adequate size (Clutterbuck et al., 2020).

With only one Trimble unit, a survey team of three was found to be the most efficient. At the first search locus all three surveyors marked 'single-species stands' using canes. Once marked, two surveyors remained at the first site to record the locations, using the Trimble, and collect the markers, while the third surveyor moved onto the second site to start marking stands. When the first site was complete, the two surveyors moved onto the second site. The Trimble user remained with the marker of the second site, while the third surveyor moved onto the next site, and so on in this leap-frogging manner. This method was very time consuming. Between 13 and 16 days per site was spent conducting the surveys.

12. Data

There are many important considerations when thinking about data including: data privacy; data transfer, storage and backup; data processing and analyses; and data quality. It is important that the complete workflow from capturing the data until the results that are required are carefully thought through before starting to acquire or use a UAV (Wich and Koh, 2018).

12.1. Data privacy

Where UAVs are used for commercial work, operators will need to comply with data protection obligations. UAVs may record images of individuals inadvertently and although individuals may not always be directly identifiable from the footage, they may be identified through the context. As such, it is important that you can provide good justification for their use by carrying out a robust privacy impact assessment (PIA) (ICO, 2017).

A PIA is a process which assists organisations in identifying and minimising the privacy risks of new projects or policies (ICO, 2013). Any processes established as a result of a PIA must also comply with General Data Protection Regulation (GDPR). Further information on carrying out a PIA and on GDPR can be found on the Information Commissioner's Office (ICO) website (https://ico.org.uk/).

Suggestions for minimising the privacy risks associated with UAV data include:

- Wearing high visibility clothing that identifies operators as UAV operators
- Placing signage in appropriate locations to explain that a UAV is operating with a camera and what the data will be used for
- Staffing footpaths to communicate information with any members of the public
- Having a privacy notice on your website that you can direct people to
- Ensuring that any data collected is stored securely (see Figure 12-1)
- Ensuring that data is only used for the initial purpose it was collected for
- Considering (and justifying) suitable retention times for the data

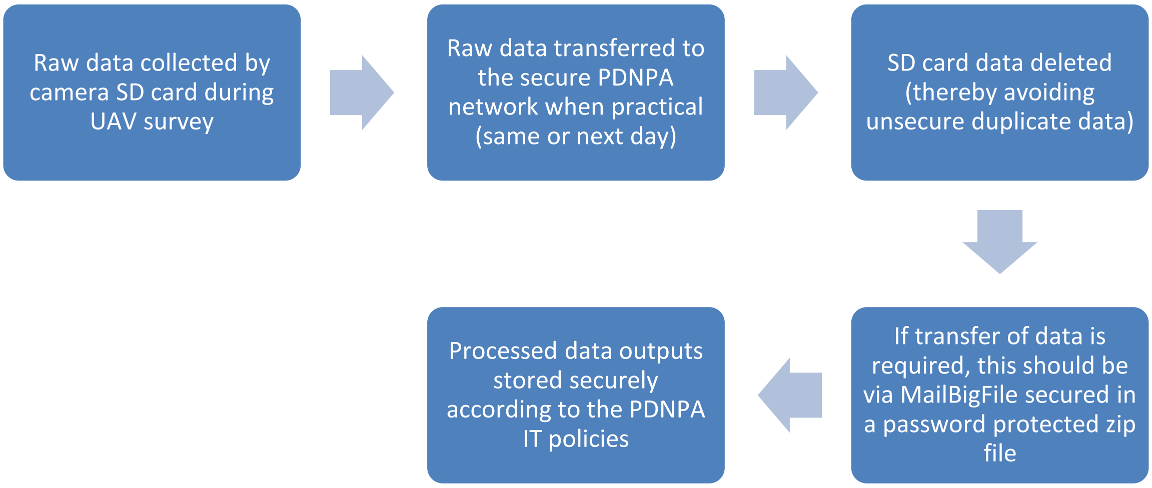

Figure 12-1: Secure data storage workflow

12.2. Data transfer, storage and backup

It is necessary to ensure that sufficient data storage is available for all the data that will be collected; to know how much data storage will be required; how the data will be backed up; how much this will cost; how long the data will be retained for; and if the data is to be retained permanently, how it will be stored longer term.

It is also important to consider redundancy. According to Calvo (2016–17), having a secure, redundant, up-to-date backup system is essential. A backup system is not such, unless there is redundancy. One external hard drive plus your computer's internal hard drive is not a safe system. All hard drives may eventually fail, so follow the rule of three. Backing up in at least three hard drives is a good idea.

In the experience of MFFP, we are collecting too much data to be stored on the Peak District National Park Authority (PDNPA) servers, and as such money had to be found within the project to purchase additional primary storage and backup, which has not been an insignificant amount of money. Once this particular project has finished there will not be funds available to continue paying for additional server space. At this point only the essential, most up-to-date data will be kept on the server, with the remaining data transferred to hard drives, following the rule of three.

To get an idea of how much data you may collect see Table 12-1. All data captured in Table 12-1 was captured with a senseFLY eBee platform flown at 60–70m above ground.

Table 12-1: Total storage space required for a 70ha site flown with three different sensors

Sensor	**Ground sample distance (cm)**	**Flight area (ha)**	**No. of images**	**Total size (GB)**
SODA (RGB)	2.2	70	803	6.7
Sequoia (4-band G, R, RE, NIR)	9.6	75	5656	13.2
thermoMAP	16.8	70	15785	6.7
				26.6

In addition to ensuring that any data collected is stored securely (see Figure 12-1), it is also good practice to download and post-process data as quickly as possible on return from the field, including any ancillary data, such as DGNSS data. A consistent folder structure and naming protocol is essential to ensure good data management. As an example we provide the structure used by MFFP below (Figure 12-2).

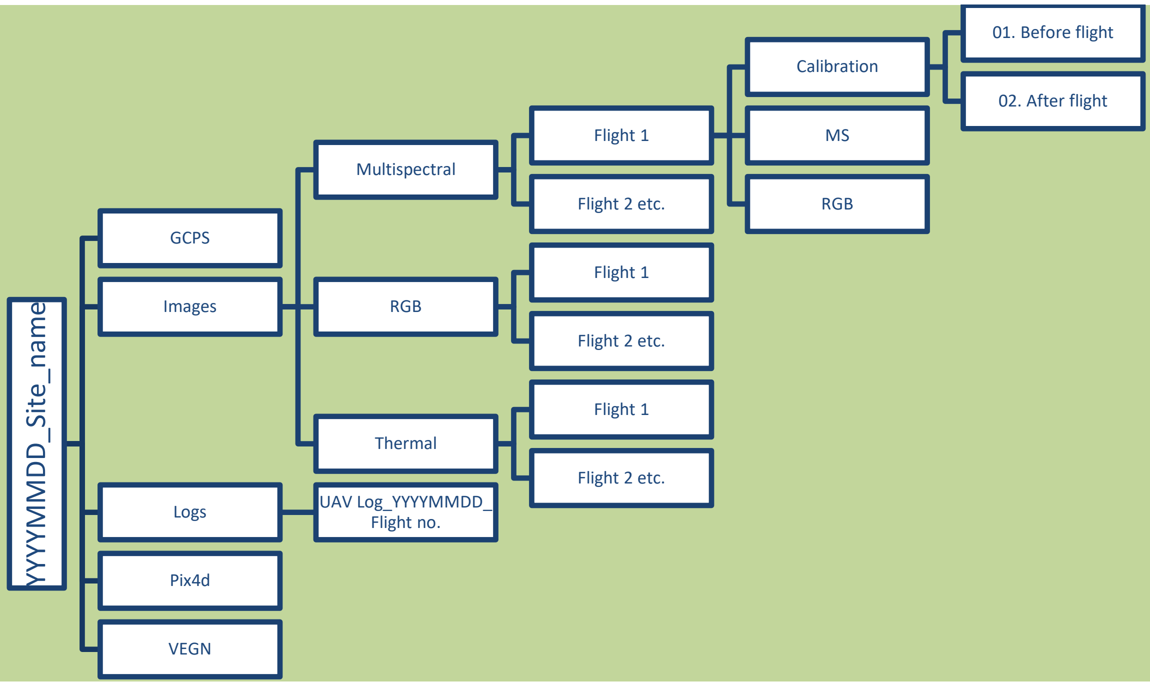

Figure 12-2: MFFP folder structure and naming protocol

12.3. Data processing and analyses

When planning data processing and analyses it is necessary to consider what type of processing and analyses will be conducted; what software and hardware are needed; whether in-house capacity and knowledge is available; or whether parts of the processing and analyses need to be outsourced.

MFFP took a two-pronged approach in which MFFP processed the data using Pix4D Mapper Pro to produce point clouds, orthomosiacs (e.g. flat top view) and digital surface models (DSMs (e.g. 3D layer)) and then outsourced the analyses to experts to classify the imagery.

In order to process the images efficiently MFFP used Pix4D and a high-specification computer. The processing itself is not overly time consuming. With Pix4D, there are three processing stages (initial; point cloud and mesh; and DSM, othomosiac and index) when intervention is necessary but after which the software can be left to run the process. The time-consuming element is marking the location of the GCPs, particularly in the multispectral dataset in which it is necessary to mark the GCPs in each independent multispectral band.

This is because low-cost multispectral cameras developed for UAVs, including the RedEdge and Sequoia, have independent sensors for each spectral band. Manufacturing tolerances mean that each sensor will be oriented to some extent at different angles to each other giving slightly different fields of view. Therefore, GCPs have to be marked in imagery for each band so that the resultant orthomosaic for each is aligned with the orthomosaic of the other bands (Clutterbuck et al., 2019).

12.4. UAV Data Quality

The development of SfM (Surface-from-Motion) has made it possible to derive high-quality outputs (i.e. point clouds, orthomosiacs and DSMs) despite the challenges associated with conventional photogrammetry (Wich and Koh, 2018). Among these are the variability in camera pose (attitude) and illumination between images, perspective distortion due to low flights, limited accuracy of GPS and IMU on board the UAV, perspective distortions due to the lower flight altitude of drones compared to manned aircraft, and lens distortion (Wich & Koh, 2018 and references therein). Below we describe some of the challenges faced by MFFP in the classification of UAV-captured imagery.

12.4.1. Quantity and quality of field data

The success of image classification was limited by small sample numbers, as well as incomplete spatial distribution across the imaged areas. Alongside that issue it became apparent during processing that target sample numbers for each species needed increasing beyond the original estimations (see Section 11.1) (Clutterbuck et al., 2019).

As a result, image classification was undertaken utilising all available ground-truth data for image training. This meant that no formal error assessment could be carried out, without which it is difficult to assess the classification accuracies achieved by the supervised classification. However, for some sites the identified distributions of outlier classes like bare peat and rock seem to match visual interpretation of RGB imagery. There is little evidence for the accuracy of other classes. In a limited exploration of classification accuracy for one site (the site with the most available field data), the overall classification accuracy was measured at 43%. The accuracies for different classes varied from very good for a few classes to very poor for others. Unambiguously "good" classes were bare peat and rock, which is unsurprising given their clear NIR responses. "Poor" classes included species like *Juncus effusus* (10% user accuracy), *Empetrum nigrum* and *Chamaenerion angustifolium* (13%). *Juncus effusus* was confused by the classifier with *Agrostis*, cushion moss, *Deschampsia flexuosa*, *Eriophorum angustifolium* and *Polytrichum spp.* (Clutterbuck et al., 2019).

12.4.2. Large area coverage and multiple sensors and flights

UAVs, at the altitudes to which they are restricted in the UK, produce high spatial resolutions but extremely limited 'footprints' necessitating flying numerous flight-lines. As a result, the time required to cover even modest areas can be considerable. Over this period, light levels, colour balance and the angle of the sun are changing. During 2018, these issues were compounded by the need to fly each area twice using different sensors (see Section 5) to provide the required B, G, R, NIR imagery. Predicting the effect this has on the accuracies of automated image-classification is complex, however it can be stated that it is unlikely to be beneficial (Clutterbuck et al., 2019).

UAV data collection took place between mid-July and the end of August 2018. We were very fortunate with the weather; however, the length of time required to collect data with multiple sensors over multiple flights affected the quality of the data. As the multispectral data for each site were collected over a period of 1–2 hours, sun-angle and illumination changed during this time creating visible striping in the data. These stripes have been identified as single taxa in the classified product (e.g. *Vaccinium myrtillus*). In addition, the proportion of the same taxa identified in the classified data for adjacent survey areas appears unrealistic. For example, at one site around 20% of the area was classified as Feather Moss, while in the overlapping adjacent site, the cover of Feather Moss was <3%.

To resolve this issue, MFFP decided to return to 'traditional' airborne digital image capture via a contractor. These can now be obtained close to, or better than, the resolution anticipated for the UAV capture. The images required to cover each MFFP field laboratory and surrounding area can be captured in a day. This overcomes many of the potential concerns associated with the slow process required to 'build' coverage of large areas with UAVs, e.g. transitions in light intensity, changes in light angle, potential for image blur in strong wind, incomplete capture in a single flight due to change in weather or equipment failure.

We also thought that airborne photography would remove the risks to image capture associated with site access restrictions, increasing the likelihood of finding 'windows' of good weather for flying; however see section 3.4.

13. Summary

The aim of this document is to provide a guide to the use of UAVs for conservation practitioners, which is based upon MFFP's experiences (successes, challenges and lessons learned) of using UAVs for peatland monitoring and conservation. We hope that it will enable other practitioners to make more informed decisions on the appropriate approach to take, whether sufficient resources (budget and people) are available, and whether the chosen approach will deliver the desired outputs. Table 13-1 summarises the main successes, challenges and lessons learnt by MFFP during our journey into using UAVs for peatland monitoring and conservation.

Table 13-1: Summary of main successes, challenges and lessons learnt

Successes	Challenges	Lessons learnt
Ability to respond to and capitalise on suitable flying days	Availability of training sites	Consider the level of experience within the team
Excellent geometric accuracy	Landowner/ tenant permission	Consider the complexity of the UAV system
Excellent resolution	Technical issues with equipment	Consider the difficulties of 'large' area coverage

14. References

ANO 2016 (2016) *The Air Navigation Order 2016* (Online). The Air Navigation Order 2016 (legislation.gov.uk). Accessed 10 March 2021.

Brooke, C. & Clutterbuck, B. (2019) Mapping Heterogeneous Buried Archaeological Features Using Multisensor Data from Unmanned Aerial Vehicles. *Remote Sensing*; 12(1): 41.

Butcher, L. & Haylen, A. (2018) *Airspace Change and Modernisation* (Online) https://researchbriefings.files.parliament.uk/documents/CBP-7889/CBP-7889.pdf. Accessed 13 February 2020.

CAA (2015a) *Information for the public about UAS and drones* (Online). Information for the public about UAS and drones | UK Civil Aviation Authority (caa.co.uk). Accessed 10 March 2021.

CAA (2015b) *Flying in the open category* (Online). Flying in the open category | UK Civil Aviation Authority (caa.co.uk). Accessed 11 March 2021.

CAA (2015c) *Guidance on using unmanned aircraft and drones for commercial work* (Online). https://www.caa.co.uk/Commercial-industry/Aircraft/Unmanned-aircraft/Small-drones/Guidance-on-using-unmanned-aircraft-and-drones-for-commercial-work/. Accessed 10 March 2020.

CAA (2015d) Flying in the specific category (Online). https://www.caa.co.uk/Commercial-industry/Aircraft/Unmanned-aircraft/Small-drones/Flying-in-the-specific-category/. Accessed 1 July 2021.

CAA (2019a) The Drone and Model Aircraft Code (Online). Getting what you need to fly | UK Civil Aviation Authority (caa.co.uk). Accessed 11 March 2021.

CAA (2019b) *CAP 722: Unmanned Aircraft System Operations in UK Airspace – Guidance & Policy* (Online). https://publicapps.caa.co.uk/modalapplication.aspx?appid=11&mode=detail&id=415. Accessed 13 February 2020.

CAA (2020a) *Unmanned Aircraft Systems Drone and Model Aircraft Registration and Education System (DMARES) Enforcement Guidance CAP 1974 Second Edition* (Online). Drone and Model Aircraft Registration and Education System (DMARES) Enforcement Guidance (caa.co.uk). Accessed 11 March 2021.

CAA (2020b) *Using a drone for work* (Online). DRONE RULES: USING A DRONE FOR WORK (caa.co.uk). Accessed 11 March 2021.

CAA (2021a) *CAP 1789A UK Consolidation – Regulation (EU) 2019/947 (as retained in UK law)* (Online). UK Consolidation - Regulation (EU) 2019/947 (as retained in UK law) (caa.co.uk). Accessed 10 March 2021.

CAA (2021b) Registering to use a drone or model aircraft (Online). Registering a drone or model aircraft | UK Civil Aviation Authority (caa.co.uk). Accessed 11 March 2021.

CAA (2021c) Where you can fly (Online). https://register-drones.caa.co.uk/drone-code/where-you-can-fly. Accessed 1 July 2021.

Calvo, K. (2016-17) *Drones for Conservation: Field Guide for Photographers, Researchers, Conservationists and Archaeologists*.

Clutterbuck, B. and Yallop, A. (2017) *Indicative protocol for UAV flights and ground truthing for Moors for the Future Partnership*. Nottingham Trent University and CS Conservation Survey.

Clutterbuck, B., Chico, G., Labadz, J., Midgley, N. (2018) The potential of geospatial technology for monitoring peatland environments. In: J.M. FERNÁNDEZ-GARCÍA and K.J. PÉREZ, eds., *Inventory, value and restoration of peatlands and mires: recent contributions.* Bilbao: Provincial Council of Bizkaia, pp. 167–181.

Clutterbuck, B., Yallop, A. and Thacker, J. (2019) *Technical Report: MFFP UAV vegetation mapping Phase 1*. Nottingham Trent University and CS Conservation Survey.

Clutterbuck, B. & Yallop, A. (2019) *Vegetation survey protocol – July 2019*. Nottingham Trent University and CS Conservation Survey.

Clutterbuck, B., Yallop, A. and Thacker, J. (2020) *Technical Report: Monitoring the impact of blanket bog conservation in the South Pennine Moors Special Area of Conservation using an Unmanned Aerial Vehicle Phase 2*. Nottingham Trent University and CS Conservation Survey.

Cunliffe, A. M., Anderson, K., DeBell, L. & Duffy, J. P. (2017) A UK Civil Aviation (CAA)-approved operations manual for safe deployment of lightweight drones in research. *International Journal of Remote Sensing*; 38 (8–10): 2737–2744.

Duffy, J. P., Cunliffe, A. M., DeBell, L., Sandbrook, C., Wich, S. A., Shutler, J. D., Myers-Smith, I. H., Varela, M. R. & Anderson, K. (2018). Location, location, location: considerations when using lightweight drones in challenging environments. *Remote Sensing in Ecology and Conservation*; 4 (1): 7–19.

ICO (2013) *Conducting privacy impact assessments code of practice* (Online). https://ico.org.uk/media/about-the-ico/consultations/2052/draft-conducting-privacy-impact-assessments-code-of-practice.pdf. Accessed 23 April 2020.

ICO (2017) *In the picture: A data protection code of practice for surveillance cameras and personal information v.1.2* (Online). https://ico.org.uk/media/for-organisations/documents/1542/cctv-code-of-practice.pdf. Accessed 23 April 2020.

Küttim, M., Küttim, L., Ilomets, M., Laine, A. M. (2019) Controls of *Sphagnum* growth and the role of winter. *Ecological Research*; 2020 (35): 219–234.

Natural England (2020) *Give notice and get consent for a planned activity on an SSSI* (Online). https://www.gov.uk/government/publications/request-permission-for-works-or-an-activity-on-an-sssi. Accessed 3 March 2020.

Wich, S. A. and Koh, L. (2018) Conservation Drones Mapping and monitoring Biodiversity. Oxford University Press, UK.