Use of Drones for Landscape-scale Surveys to Meet Conservation Organisation Needs

Matthew Jordan

“A thesis submitted in partial fulfilment of the requirements of the University of the West of England (UWE), Bristol for the degree of Doctor of Philosophy (PhD)”

College of Health, Science and Society, School of Applied Sciences, University of the West of England, Bristol July 2023

Abstract

Monitoring is an important part of current conservation work but is currently overlooked over other aspects of conservation due to a lack of resources. Drones represent a potential solution to this lack of monitoring and have been shown to be more accurate and time-efficient than current, ground-based methods. With the shift to evidence-based conservation, evaluating site conditions and monitoring the progress of conservation action plans is essential to ensure limited conservation resources are put to best use. However, current ground-based methods vary in their objectivity and resource efficiency, and monitoring as a whole is often deprioritised. Drones represent an alternative method for conservation monitoring, and whilst the current literature shows that drone are overall more accurate than traditional, ground-based studies, the conservation sector has been reluctant to utilise drones. The current literature on drone use in conservation often focuses on drone accuracy, without considering the context and logistical considerations of conservation organisations. This thesis addresses that gap in knowledge by assessing the potential for incorporating drones into UK conservation, a sector that has been slow to incorporate drone-based methods into their operations.

Drones were found to be more efficient and provide more accurate data than existing, ground-based methods in two out of three case studies. However, only one case study, which focused on vegetation surveys to meet site condition assessments, was considered by the Wildlife Trusts for integration. The Wildlife Trusts did not seem overly receptive to the idea of using drones, primarily due to a lack of resources available to invest in new technologies, regardless of what benefits they may bring. This aligns with the main barriers to conservation progress identified in interviews, which were a lack of finances and trained staff, but contrasts with the current research, which focuses primarily on drone technical limitations such as battery life and weather condition dependencies.

These results demonstrate that logistical considerations such as cost, training and bureaucracy are the main factors limiting drone integration into UK conservation groups, with the potential benefits and capabilities of the technology beyond its ability to meet conservation group needs less important to conservation employees.

Word Count: 41, 797

Acknowledgements

First of all, I would like to thank my Director of Studies, Dr Jim Vafidis, who agreed to take me on as a PhD student, put up with my frantic emails, and took me from someone who had only flown a drone a couple of times to where I am now. I would also like to thank the rest of my supervisory team; Dr Mark Steer, Dr Kathy Fawcett, Dr Kathy Meakin and Dr Emma Weitkamp, for giving me encouragement, feedback, and ideas at various points throughout the last three years. To Dr Pete Maxfield, for reviewing my thesis at various points and giving me valuable feedback, and to Dr Angeliki Savvantoglou, for setting me up with all the GIS software I would need, and setting me up with it all over again when none of it worked. Thank you to Dr Joel Allainguillaume, Dr Matt Wood, and Professor Chad Staddon for helping me through my viva and giving me the final pieces of feedback to perfect my thesis. I would also like to thank UWE as a whole, their support services and especially the UWE Library, for providing me with help at 2am when trying to learn how to develop a search string.

I would like to thank everyone from the various Wildlife Trusts, who took the time to be interviewed, despite the chaos of the COVID pandemic, and especially Alison Riggs and Paul Tinsley-Marshall for spreading my interview requests around the Wildlife Trust intranet. At the Gloucestershire Wildlife Trust, without whom I wouldn't have been able to do my case studies, I would like to thank Dr Gareth Parry, Dr Cat McNicol, Ellen Winter and Juliet Hynes for agreeing to speak with me and giving me invaluable information on the various projects at the trust to help me develop me case studies. To Kevin Caster, Alan Sumnall, Del Jones and Martin Ineson, who helped me with site specific queries and gave me permission to fly on the sites. I would also like to thank the British Model Flying Association for letting me fly at all, and Gloucestershire Airport Air Traffic Control for allowing me to fly close to their restricted flight zone so I could collect essential information. To Jenny Bamford at Forestry England, who spent months reworking a filming permission form so I could fly my drone over the sites they help manage. And to everyone else behind the scenes at the Trusts, without whom I would've been unable to collect any data.

I would like to thank my friends for being there when I was stressed, and for cheering me up with jokes, games, and roleplays when the work seemed overwhelming. Special thanks to Nicole Skidmore, who helped keep me sane with pizza and support throughout my research, and good luck to her with her own PhD write up.

I would like to thank my Mum and Dad for reading all the work I sent to them and being endlessly supportive of me. To my brother Chris, who is always there as both my brother and one of my best friends throughout my life. Thank you to the rest of my family as well, who have all wished me the best and have done nothing but encourage me throughout the years and decades.

Finally, a big thanks to everyone else who has contributed and helped me, not only throughout the course of my PhD, but throughout my life. I wouldn't be where I am now without you, and if I have forgotten anyone, it's not personal. I just have a terrible memory.

Contents

1 Introduction

1.1 Conservation and how it has Changed

Wildlife Conservation is the act of protecting species and their habitats and maintaining and restoring ecosystems to protect biological diversity. Since the beginning of modern conservation in the mid-19th century, the methods and approaches used in conservation have changed and evolved, and even the meaning of conservation has changed. Early conservation began as a way to maintain valued natural resources such as game, timber, fire wood, and fertile land for the long term benefit of human society (Gifford, 1945). However, throughout the 20th century, the meaning of conservation developed to include the idea of environmentalism, a philosophy based around the protection of the wider environment, often from the effects of damaging human actions. During this period, conservation encompassed a wide range of approaches including minimising or removing any human impact on nature and letting habitats develop naturally, and more interventionist approaches focused on using resources to protect, maintain or improve ecosystems (Hossell *et al.*, 2003; Michael, 2002). In many countries, including the UK, conservation is aligned with environmentalism and environmental ethics and has taken on a more preservation-based approach, focusing on preserving and protecting ecosystem structure and function from environmentally damaging practices such as deforestation, intensive agriculture and urban development. Conservation is also aligned with the concept of sustainability; using resources in such a way that "meets the needs of the present without compromising the ability of future generations to meet their own needs" (UNGA, 1987).

Throughout the 21st century, conservation has also shifted to a more evidence-based approach, following on from similar shifts to evidence-based approaches in public health, psychology, and education (Trinder and Reynolds, 2008). Evidence-based conservation uses data to inform conservation actions such as condition assessments, management plans and action efficiency. This data can vary from peer-reviewed publications and information from experts in the field of conservation to data collected by conservation groups at the site level. Previously, a mix of anecdotal and evidence-based conservation actions was taken, which included actions taken based on anecdotal evidence, intuition, or traditional methods, which could lead to inefficient use of conservation resources. (Sutherland *et al.,* 2004).

Finally, one of the most recent changes in conservation in the UK is the shift from a focus at the site level towards the 'landscape scale'. Nature reserves and other protected areas of conservation were often considered in isolation of their surrounding habitats and influences (Powers and Jetz, 2019). Efforts to protect and enhance these ecosystems were insufficient to sustain national levels of biodiversity as the sites were too small, too isolated and unconnected with other similar ecosystems and too poorly buffered from surrounding negative influences (IPBES, 2019; Cardinale *et al.,* 2012; Lawton *et al*., 2010).

Landscape-scale conservation considers these sites as part of a network within a larger landscape which can operate at the regional, national, or even international scale. In the UK, the 2010 Making Space for Nature report emphasises the need for landscape-scale conservation, focusing on "more, bigger, better and joined" nature reserves (Lawton *et al.,* 2010), and the joining up of smaller sites to form larger systems through nature recovery networks. These networks are created through the development and regeneration of land to form connected sites that can have a much bigger collective impact on biodiversity. Many UK conservation organisations, such as the Wildlife Trusts, Royal Society for the Protection of Birds (RSPB), and the Wildfowl and Wetlands Trust (WWT) have adopted the landscape-scale approach in their national strategies.

1.2 Why Conservation is Important

Functioning healthy ecosystems are essential for supporting life and ecosystem damage and destruction can have wide-reaching effects on human wellbeing. Forests and soil act as carbon sinks, accumulating and storing over two billion tons of organic carbon a year (Pan *et al.,* 2011). Deforestation and intensive farming releases the carbon from these carbon sinks, increasing the levels of carbon dioxide in the atmosphere and accelerating global climate change (Rosa *et al.,* 2016). Twenty five percent of annual greenhouse gas production comes from loss of trees as a result of logging alone (Climate Institute, 2017) and the destruction of habitat can lead to sharp declines or the extinction of species. Species decline can also have an impact on the global environment. For example, pollination by wild invertebrate species is critically important for global food supplies and is required to obtain adequate yields in 85% of food crops (Zattara and Aizen, 2021). Many bee species contribute towards sustainable development goals by regulating natural cycles such as carbon sequestration, acting as biological pest control, dispersing seeds, and even providing jobs and income through beekeeping and acting as bio-inspiration for scientific developments (Patel *et al.,* 2020). Due to habitat loss, the use of pesticides, and the introduction of non-native species by humans, many bee species have experienced large, continuing declines over the last 30 years (Zattara and Aizen, 2021; Cameron and Sadd, 2020). These changes can greatly decrease human quality of life and threaten future generations by lowering pollination rates and increasing pest species, both of which lowers crop yield, affecting food security worldwide. Ecosystem destruction and increasing climate change can also lead to more extreme weather events and rising sea levels, as the destruction of habitats such as woodlands and upland peatlands have been associated with increased flood risk downstream (Dittrich *et al.*, 2018). Coastal flooding and sea level rise due to glacial melt caused by global warming also represents a major threat to approximately half of the world's population which lives within 100km of the sea (Wolanski *et al.,* 2019).

Financially, conservation is also a large industry that provides employment opportunities and economic output. The wildlife conservation and environmental protection sector in the UK provides full-time employment for approximately 21,600 people (Office for National Statistics, 2022) and results in high levels of economic output through tourism and sponsorships. In 2011, the UK natural environment was valued at £27.5 billion and supported up to 750,000 full-time jobs (RSPB, 2011). This money also increases the economic output and job opportunities in the surrounding communities, most of which are in more rural or remote areas that would otherwise lack economic opportunities.

Economically, it is more beneficial to undertake conservation than not. A World Wide Fund for Nature (WWF) report in 2020 found that a lack of global conservation and habitat preservation could result in a $9.87 trillion loss in global GDP, as opposed to a $0.23 trillion increase in global GDP if global conservation targets are met by 2050.

Aside from environmental concerns, food security, maintaining air and water quality, mitigating flood risk and economic benefits, conservation is also important due to the value humans have placed on the natural world. People enjoy experiencing natural ecosystems as part of their leisure and recreation and they value the biodiversity that can be found in them (Vining, 2003).

1.3 Conservation Monitoring

Monitoring involves the collection, analysis and interpretation of field data to determine the status of an attribute, and it is an essential part of any conservation project or intervention action. Monitoring can involve collecting data on animal, plant or fungi species, population counts, vegetation structure, hydrology, or any other information that indicates the state of a conservation target, whether it is an individual, a population, a community, a habitat, an interaction, a function, or even a whole ecosystem. This data can then be used as evidence in evidence-based conservation management, informing whether an action is needed, to what extent, how often, when and where. At a basic level, monitoring provides information on the status of a conservation objective, such as meeting a target level of vegetation cover or water level , or the presence or absence of a protected or pest species (Global Trees Campaign, 2014). This information can then be used to help conservation groups make informed decisions about what conservation action to take, such as increased scrub removal, digging channels to allow for greater water presence on a site, or changing a habitat to make it more suitable for particular species (Berger-Tal and Lahoz-Monfort, 2018).

Data collected from monitoring is essential to meaningfully set these conservation targets. Many conservation targets, especially at the site level, may have been set based on inaccurate, or even no, data, especially if set before the shift to evidence-based conservation. This can mean that a set conservation target, such as a particular percentage of vegetation cover on a site, may not truly reflect the most suitable target for that site if the target was set relative to inaccurate data. Data collected from monitoring can also be compared to how well a site is performing in terms of desired species or habitats, and used to set new, more accurate targets.

Finally, monitoring at multiple points over time, such as annually, or before and after a conservation intervention, allows the impact of any actions or changes to be assessed (Marsh and Trenham, 2008; Bibby and Alder, 2003). This data can then be used to assess whether each conservation intervention was successful or not, or to learn how a site is naturally changing over time so conservation actions can be developed around this change (Estes Jr *et al.,* 2021). This in turn leads to conservation resources being used more efficiently as any ineffective management actions can be discontinued.

Monitoring is especially important in landscape-scale conservation, as it allows data on how sites and habitats are linked together, and which areas of land need to be focused on to create more connected sites or nature recovery networks, to be collected through land cover assessments. The higher scale at which landscape conservation operates, often focusing on collections of sites instead of single sites, necessitates a larger investment of resources, so any inefficiencies due to resources being used on ineffective conservation strategies are likely to result in a much higher loss. This makes it even more important to ensure that any conservation resources are being put to good use on actions that will result in a positive change (Guerrero, McAllister and Wilson, 2015).

Funding for monitoring is rarely prioritised within the conservation sector perhaps because it does not directly result in physical conservation action on the ground, which is more visible to stakeholders, funders and members of the public. Monitoring becomes under-resourced, resulting in [incomplete/ infrequent] data, which fail to adequately inform conservation strategies (Murdoch *et al.,* 2007).

1.4 UK Conservation Organisations

Conservation is a large and growing sector in the UK. In 2019/20, £360 million of public sector funding was spent on biodiversity in England; a real term increase of 76% compared to the £205 million spent in 2000/01 (Department for Environment, Food and Rural Affairs, 2021). Despite this increase in funding, UK conservation organisations such as the Wildlife Trusts, the National Trust, and the Royal Society for the Protection of Birds, are inadequately resourced (RSPB, 2018; Murdoch *et al.,* 2007), which prevents them from carrying out larger scale, more effective conservation work. One of the biggest is that as the population increases, there is a need for more resources, such as food, housing materials and land. This has led to increasing levels of production and increased consumption of resources, which causes damage to the environment, and requires a greater conservation effort to offset (Environment Agency, 2020). A lack of resources also limits conservation organisation effectiveness and forces them to prioritise which sites and/or species to conserve. This can result in a lack of monitoring capabilities in favour of carrying out conservation management, as conservation management can result in change and progress towards conservation targets which is essential to continue obtaining funding. Conservation organisations can also have problems convincing people of the need for conservation, which is important in obtaining land for conservation and resources. An example of this can be found when during interactions with private landowners who are often reluctant to let their land be used for conservation purposes, or to manage their land with conservation objectives in mind due to conflicts with other land-owning objectives such as land development (Lawrence and Dandy, 2014). More staff are also needed to carry out conservation work, as current conservation work relies heavily on volunteers due to a lack of budgetary support for protected areas (Halpenny and Caissie, 2003). These volunteers often lack the specialist skills required for robust data collection or ecological surveying, requiring either time and money to train or the hiring of specialists (Brown and Williams, 2019).

In terms of monitoring specifically, there are also problems with current techniques that affect their feasibility and efficiency. Ground-based surveys such as structured walks, condition assessment and sample collection is time-consuming and labour-intensive, whilst predictions based on models rely extensively on smaller samples of data extrapolated to cover a whole site or period of time. This means that any model-based data contains a significant degree of uncertainty, which can lead to inaccurate data (Gonzalez *et al.,* 2016; Witmer, 2005). If conservation management plans are then developed based on this inaccurate data, they can be ineffective, or have unintended effects which require correction, both of which waste time, money, and manpower (Katzner *et al.,* 2011). Conservation monitoring is also often highly decentralised and lack standardised protocols, with many different organisations doing their own surveys with differing methods. For example, population monitoring programs can vary from large-scale multispecies programmes determining population numbers, to single-site-based programs that attempt to determine species presence (Marsh and Trenham, 2008). This lack of centralisation and standardisation can make it hard to compare conservation efforts or combine efforts, which is vitally important when carrying out landscape-scale conservation, which often requires collaboration between multiple organisations (Floress *et al.,* 2018; Leonard, Baldwin and Hanks, 2017).

1.5 The Wildlife Trusts

The Wildlife Trusts is an independent charitable organisation comprised of 46 separate local trusts across the UK under the umbrella group of The Royal Society of Wildlife Trusts,. The group was founded in 1912 and focused on buying wildlife sites to establish nature reserves. Most of the local Trusts across the UK were established in the 1980s, and they took the name of The Royal Society of Wildlife Trusts in 2004. (The Wildlife Trusts, 2022). The Wildlife Trusts are the third-largest landowners in the voluntary sector, managing over 2,300 nature reserves that cover almost 104,000 hectares, or 0.43% of the UK (The Wildlife Trusts, 2021).

The Wildlife Trusts focus on improving biodiversity and habitat quality through land management and conservation (The Wildlife Trusts, 2022).

This means that every action the Wildlife Trusts perform has to be justified within this remit, especially when limited by resources. As a UK conservation organisation, it is assumed that many of the problems affecting conservation organisations as a whole in the UK also affect the Wildlife Trusts. As a charity, the Wildlife Trusts rely on membership costs and donations to fund their conservation efforts, as well as corporate partnerships and government grants for specific projects. Their conservation monitoring relies primarily on ground-based surveys, and they make frequent use of volunteers to carry out their survey methods, which may lack the training of more specialist personnel. However, one potential contemporary technology that could be used to mitigate some of those problems is unmanned aerial vehicles (UAVs), or, hereafter, 'drones'.

1.6 An Overview of Drones

Drones are unmanned aircraft (Cavoukian, 2012), which are controlled remotely and can be pre-programmed and even flown autonomously using algorithms to adapt their flight path as they fly (Gupta, Ghonge and Jawandhiva, 2013). The first use of what could technically be considered a drone occurred during the blockade of the Republic of Venice in 1849, where Austrians launched hundreds of balloons with bombs attached over the city (Custers, 2016). The first remotely operated drones were developed during WW1 and officially entered into military service in 1935 (Mills, 2019). Currently, and in the past, drones have primarily been used for military purposes, such as military surveillance of the deployment of ordnance, and in agriculture, where drones have been used to assess the health of crops and detect pest species using multispectral sensors (Harsh, Singh and Pathak, 2022), for the precision release of fertilisers or pesticides (Devi *et al.,* 2020), and even for the physical sampling of crop samples (Van de Merwe *et al.,* 2020). In the last 10 years, drones have started to become widely used outside of these fields (Massuti and Tomasello, 2018), and both commercial and recreational drone use is becoming increasingly common (Wu *et al.,* 2019). Over the last decade, drone technology has advanced greatly, and there is now a wide range of drones designed for numerous purposes, including sample collection, remote monitoring and videography. Drone capabilities and what equipment drones are equipped with also varies, from cameras and sensors to physical collection tools such as vials or boring devices (Derrouaoui *et al.,* 2022; Hassanalian and Abdelkefi, 2017). Drones vary greatly in size, from the largest drone; the Boeing-Condor, having a wingspan of 61m (Nixon, 2001), to Smart Dust drones that are less than a millimetre in size (Niccolai *et al.,* 2019).

Drones have potential as an alternative to existing survey methods, such as ground-based surveys, manned aircraft, or satellite imagery. Whilst drones vary in price, many drones are relatively inexpensive, especially compared to manned aircraft such as helicopter or planes (Tang and Shao, 2015), and have lower logistical and bureaucratic requirements, with drone training being cheaper and quicker than pilot training for manned aircraft and drone flight permission being quicker and simpler to obtain (Jones, Pearlstine and Percival, 2006). Another possible advantage of drones is that they are able to operate in areas that may be inaccessible by foot (Shahmoradi *et al.,* 2020), and can enter dangerous areas such as mountains or dense forest with no risk to the operator (Linchant *et al.,* 2015). Likewise, the destruction of a drone carries no risk to the operator, whereas the destruction of a manned aircraft can cause severe damage or death to its operators. The remote nature of the drone operator compared to a manned aircraft also presents a safer, more relaxed environment that may allow for better decision-making when dealing with unexpected situations such as a hardware failure or mid-air collision (Ahirwar *et al.,* 2019).

Compared to on-foot travel, drones can cover a larger area in less time and can observe areas at a much larger scale, which makes surveying of any kind much more efficient. This is due to their increased speed and lack of impediment due to topographical or ground-based features, such as hills, vegetation and buildings (IEEE, 2020). Compared to satellite surveying, drones can obtain much higher resolution and more up-to-date imagery , with hyperspectral drones able to achieve a resolution of 100nm in real time compared to high-resolution satellites which have a spatial resolution of 1m and can only collect information on a site daily. (Inoue, 2020; Wich, 2015), which may be useful if small-scale data, such as information of specific stands of vegetation or individual animals, is needed. Drones are also able to carry out repetitive, standardised tasks such as population counts involving large numbers of animals through the use of pre-programmed routes, which might otherwise require a lot of effort and time to perform (Ahirwar *et al.,* 2019).

1.7 Perceptions of Drones

Public perception is an important factor in drone use, especially when looking at implementing them into existing sectors that will bring them into contact with the public. An Australian study in 2015 found that people generally held quite a neutral attitude towards drones, seeing them as neither overly unsafe or threatening, nor as overly beneficial or useful (Clothier *et al.,* 2015). However, more recent studies have shown a more negative perception of drones, with the public seeing drones as a risky technology that could interfere with their privacy or daily lives (Serafinelli, 2022; Smith *et al.,* 2022; Aydin, 2019) . A lack of knowledge regarding drone uses, such as how widely they are used and the kinds of surveying they are used for, was also found. This lack of knowledge can lead to public concerns around privacy and surveillance. One of the main uses of drones in many sectors, including conservation, is to survey and monitor areas using high-resolution cameras, which can lead to surveillance fears. If a member of the public sees a drone in their local area, there is no easy way to determine its ownership or the legality of the drone flight, and so they may believe that the high-resolution camera technology is being used to take pictures or videos of them without their consent or to view them in private locations, such as their gardens (Finn and Wright, 2016).

Another potential reason for the public's negative perception towards drones may be their origin in the military. Drones were originally developed for military attacks and surveillance and are still used for this in the present day. Eighty nine percent of participants in a survey looking at public perceptions of commercial drones said that the media and online sources were their main source of drone information (Keilman, 2019), which focus primarily on drone use in warzones and misuse of military drones (Serafinelli, 2022). This association with military use may negatively affect how people perceive other, non-military use of drones.

Finally, a possible reason for the negative perception of drones could be fears of illegal use and concerns about the damage drones can do when misused. There have been several high-profile incidents with drones, such as drone interference at Gatwick airport in 2018, which grounded air traffic, causing major delays (Shackle, 2020), or disruptions to air traffic at Heathrow airport in 2019 (BBC News, 2019). Local incidents can also cause worries about illegal drone use, as many people who fly drones recreationally tend to be unaware of, or ignore safety and legal flight requirements, which can cause a lack of trust in drone pilots. If misused, drones could also cause disturbance, injury or even death, if a drone collides with a person or aircraft (Serafinelli, 2022).

However, scientific research applications of drones are highly accepted by the public (Clothier *et al.,* 2015), so their use in conservation may not be viewed with the same negative perception. This may be due to the perception of scientists are more trained or more accountable and therefore less likely to misuse drones, whether intentionally or accidentally. However, it is important to note that a member of the public may not be able to discern between the use of a drone for scientific research and the use of a drone recreationally on a nature reserve.

1.8 Current Uses of Drones for Conservation

In the conservation sector, there is high potential for drones, especially for conservation groups that lack the resources to carry out other highly quantified survey methods. Many of the potential uses of drones in conservation are derived from agricultural uses, including the surveying of vegetation/habitat types which was derived from crop monitoring, and wildlife surveys dervied from livestock monitoring. When carring out wildlife surveys such as population counts or nest surveys (Hodgson *et al.,* 2018), drones have been shown to provide more accurate and quantified data than traditional, ground-based surveys, both when surveying through direct observation of animals, or through indirect signs such as nests, tracks, or dung (Hodgson *et al.,* 2018; Wich, 2015). Drones have also been shown to provide more accurate data than traditional ground or satellite-based methods at habitat mapping and land cover analysis, mainly in the form of quantification of vegetation structure such as vegetation or land cover assessments, or detection of particular indicator species or groups (Wich and Piel, 2021).

The use of drones varies across different countries. Drone legislation varies greatly from country to country (Tsiamis, Efthymiou, and Tsagarakis, 2019), primarily due to the different rates at which drones were intergrated into these countries. Whilst most countries who use drones for conservation use them for vegetation and wildlife surveys, scale greatly affects how they are used (Wich and Piel, 2021) and what capabilities the drones are required to have. For example, wildlife surveys in countries with large game reserves, such as South Africa take place over huge areas, leading to an increase in drones with longer flight time, such as fixed-wing drones. This difference in scale also means that not all potential conservation applications of drones will be of use to UK conservation groups. An example of this is the use of drones to detect poachers or otherwise prevent poaching. In larger areas in other countries, where there is not enough time to cover the whole area on foot or in a car (Negru, Manea and Jiga, 2022), the use of drones to prevent poaching is highly valued, as opposed to the U.K, which has smaller wildlife reserves than many other countries that can be asily traversed. Using drones for anti-poaching measures also has the benefit of placing the remote operator out of harm's way, as opposed to field-based wildlife protection which may bring the conservationist into direct contact with poachers (Hambrecht *et al.,* 2019). This is also less of a concern in the UK, where armed conflicts with poachers have been rare.

Other applications of drones which provide highly accurate and precise outputs include monitoring diseases such as ash dieback (*Hymenoscyphus fraxineus*) (Panzavolta *et al.,* 2021), collecting soil, water and animal samples (Shelare *et al.,* 2021;Baez *et al.,* 2021; Keller and Willke, 2019). Many of these studies focus on whether a drone can carry out a certain survey, or whether drones could be useful for a particular aspect of conservation. There is little research on how the logistical considerations of drones (cost, time, etc.) affect their use by conservation groups and even less on how these uses align with the current needs and practises of conservation organisations. Without this information, a lot of the research on drone applications in conservation is currently limited to the idea of being more theoretical than applied, stating what drones can do and providing isolated examples through studies, without taking steps to ensure that this technology and research can be used by conservation organisations to improve their practices and advance the field of conservation.

In keeping with this idea, although the research regarding drones in conservation indicates they would be of great use to conservation groups, drone implementation in the UK conservation sector has been slow. There may be multiple reasons why drones have not been incorporated more into the UK conservation sector. The conservation sector is often slow to implement new technologies and methods and is quite stagnant in terms of its surveying methods. It is also possible that conservation groups are not familiar enough with drone capabilities to want to incorporate them, as it has been shown that there is still a general lack of knowledge relating to drones (Smith *et al.,* 2022). Another explanation could be that the current applications of drones are not relevant to the needs of conservation groups. Whilst an argument could be made that accurate data of any sort could theoretically be useful, the limited resources of conservation groups mean that any data collected by drones needs to be directly related to a management goal or problem, to get the most value out of it (Nichols and Williams, 2006). For this reason, when planning any kind of monitoring or surveying, it is essential to collaborate with conservation groups and site managers, to ensure that the data collected can be put to good, efficient use (Jones *et al.,* 2013). Finally, negative opinions regarding drones could be acting as a barrier to their implementation.

1.9 Thesis Rationale

This project will assess the potential for incorporating drones - an established contemporary technology with high theoretical applications for UK conservation groups- into UK conservation, a sector known for substantial inertia, poor resourcing, and a possible negative bias towards drones. I believe that this research is necessary to take the wealth of existing data on drone uses in conservation and apply it to the needs of conservation organisations. This research could help conservation organisations to make better use of drones and improve the accuracy and efficiency of their monitoring efforts, allowing for more informed conservation. It will also provide information as to why drone incorporation into the UK conservation sector has been so slow, as well as how the logistics of carrying out drone monitoring affects their use in conservation, especially compared to existing methods.

To do this, it is important to have a robust knowledge of what current drone capabilities in conservation are, especially compared to existing conservation methods. The current needs of conservation organisations, as well as their views towards drones, are also needed. Finally, knowledge of the practicalities of using drones in the conservation sector is required.

This project will try and obtain this information by assessing how the uses of drones align with the beliefs and needs of conservation organisations, specifically the Wildlife Trusts, and how using drones for the kinds of practical projects the Wildlife Trusts perform compares to existing methods, not only in terms of accuracy and validity of data, but also in terms of time, cost, training, and any other considerations that may come up during these practical projects.

I believe that this approach of applying existing research and examining how it compares with the needs, resources, and existing practises of conservation groups, as well as the development of novel drone methods for monitoring, constitutes an original piece of research that will fill a gap in the current field of drones and nature conservation.

1.10 Research Aim and Objectives

The primary research aim of this PhD thesis is to answer the following research question:

Can drones be better incorporated into UK conservation organisations, and how do they compare to existing methods used by these groups?

To answer this question several objectives must be fulfilled (Figure 1):

Objective 1: Using a systematic review, identify the current uses and capabilities of drone technology in the field of conservation and identify any patterns in the current research that might inform the use of drone technology in nature conservation.

Objective 2: Identify the current needs of conservation organisations, as well as their beliefs and current practises, regarding drones and any potential barriers to drone use.

Objective 3: By comparing where the needs and beliefs of conservation organisations align with drone capabilities outlined in the systematic review, identify the potential for drone integration into conservation organisations, and design and carry out case studies based on these areas of potential. Use these case studies to identify any advantages and disadvantages of drone use compared to existing methods, as well as any logistical considerations that need to be taken into account.

Objective 4: Using the information from the case studies and feedback on the case studies obtained from the Wildlife Trusts, determine the potential and capabilities of drones in the context of conservation monitoring that could be used to help incorporate drones into conservation organisations, as well as aspects of drone use that should be considered when making use of drones, such as cost, time, accuracy etc.

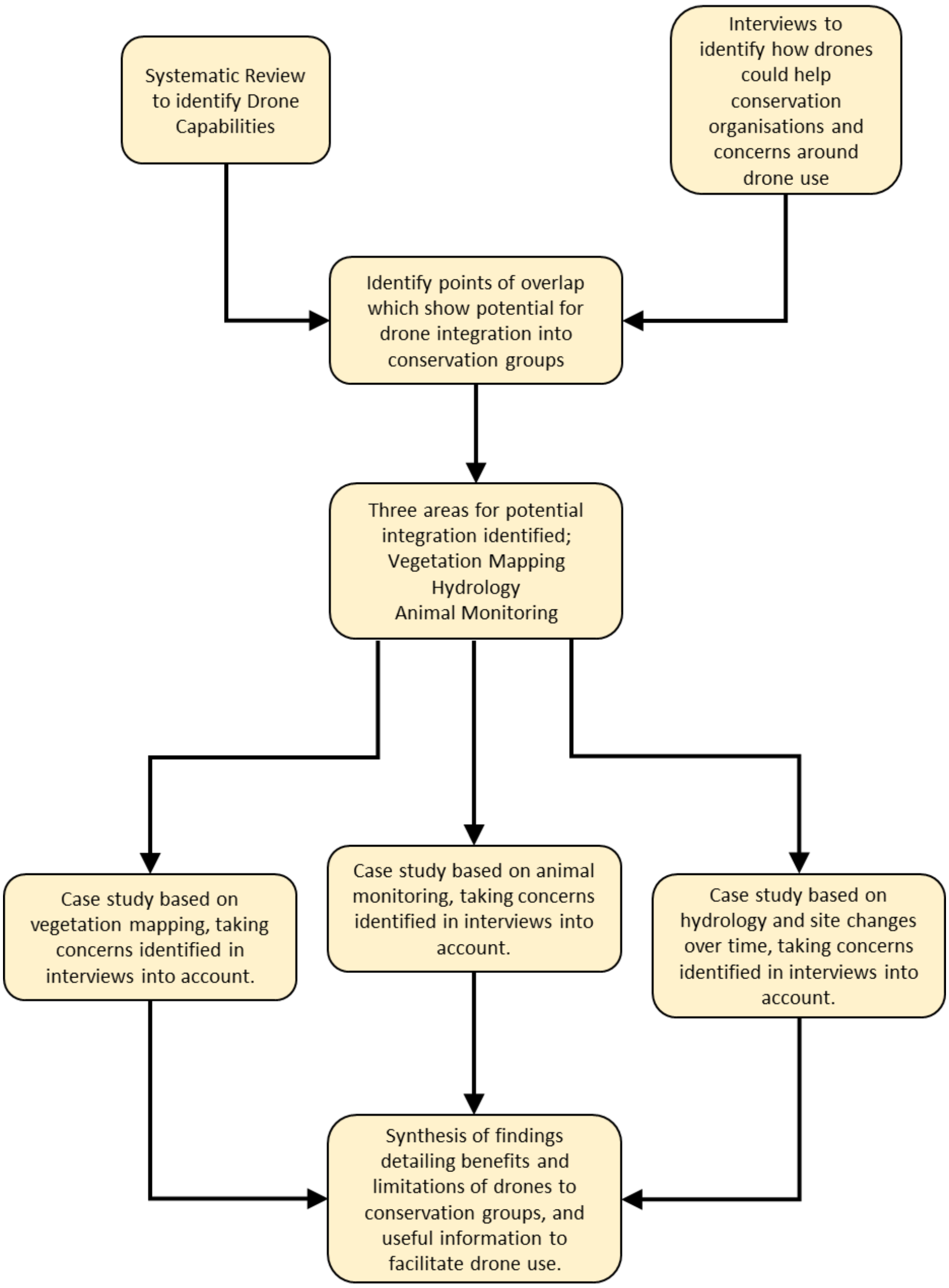


Fig 1. An Outline of the Narrative Flow of the Thesis

1.11 Thesis Format

Each chapter of this thesis will help work towards the research aim and objectives above. Chapter 2 seeks to identify current uses and capabilities of drones as it relates to conservation (Objective 1) through a systematic review exploring at the uses of drones in temperate nature conservation and how they compare to other methods. Chapter 3 describes interviews that were carried out with members of the Wildlife Trusts, and how thematic analysis was used to identify their current needs and beliefs regarding drones (Objective 2). Chapters 4-6 detail the case studies that were developed in conjunction and based on the conservation needs of the Gloucestershire Wildlife Trust, using the information collected to date, the findings of those case studies and feedback from the Gloucestershire Wildlife Trust on the methods used (Objective 3). Finally, Chapter 7 focuses on the synthesising of the data and conclusions in the previous chapters (Objective 4), as well as addressing whether this thesis has successfully met its research aim and objectives.

2 What are Drone Capabilities in Temperate Conservation, Compared to Existing Methods?

2.1 Background and Chapter Objectives

To know how drones can be better incorporated into UK conservation organisations, their current capabilities and effectiveness in the field of conservation compared to existing methods must be reviewed. This review must be robust, and relevant to UK conservation organisations. For these reasons, a systematic review was chosen to analyse existing literature. A systematic review was chosen over a literature review for its comprehensiveness and highly structured methodology that helps to minimise reviewer bias (Bearman *et al.,* 2021).

The primary objective of this review is to synthesise and analyse experimental studies that show the capabilities of drones in the field of temperate wildlife conservation as compared to traditional monitoring methods. Temperate wildlife conservation was chosen specifcally due to the differing needs of wildlife organisations in different areas, and the decision to focus on UK conservation.

2.2.1 PICO Elements of the Review

A good structure for developing the focus of a systematic review is to focus on its PICO elements. These are four elements (Population, Intervention, Comparator, Outcome) that are extracted from the primary objective and used as the eligibility criteria to inform the data extraction later on in the review. The PICO elements developed for this review are as follows:

Population- Any area taking place within a temperate region. Here, a temperate region is defined as any area within the temperate zone, which is between 35- and 66 33'-degrees latitude north or south of the equator. All studies that did not take place within that temperate zone were excluded. However, there are areas within that temperate zone which could still be considered tropical. Therefore, if the article referred to its study site as tropical or subtropical, then it was also excluded. Studies consisting of multiple parts, with one or more parts taking place within both a temperate and a non-temperate area were excluded unless the section of the study taking place in the temperate zone provided enough information in isolation to meet the other eligibility criteria and the data coding requirements. Temperate areas were chosen to ensure that any drone use was relevant to UK conservation organisations, as the entirety of the UK lies within this temperate zone, and drone use in non-temperate areas will have different environmental and logistical concerns that may not be relevant to UK conservation.

Intervention- In this study, the intervention was classed as any drone-based experiment, monitoring, or management in the field of nature conservation, which is defined as anything that has the aim of protecting wildlife species and their habitats in order to prevent threats to those wildlife, including extinction. Any articles which did not meet these criteria were excluded, Additionally, any studies related to agriculture, such as crop yields, farming practices, or animals kept for farming purposes were excluded, as although they may meet the technical definition of protecting wildlife species, they are not considered part of wildlife conservation. Any study that could potentially aid in wildlife conservation but does not mention conservation as an application of its research was also excluded. Drones are referred to by a variety of names (unmanned aerial vehicle, unmanned aerial systems, remote piloted aircraft), all of which were included in the search if possible. Only drone technology was included as the inclusion of other technology would not align with the research aims of the thesis and would disperse the focus of the work.

Comparator- Comparators in this study would be any sites not analysed by drones that are used as controls or comparators in relevant studies, or wildlife conservation methods that don't involve drones that are carried out on similar sites. Terms relating to quasi-experimental and experimental design will be used here, to filter out studies that do not have a comparator, as we cannot know the impact the use of drones has had without either comparable results from non-drone-based conservation methods or no conservation methods. This is important for drones to be useful to conservation groups, as a potential use of drones is irrelevant if it does not improve in some way upon existing methods used by conservation groups.

Outcome- The outcomes for this study are any results from the use of drones and any study that had results from the use of drones that indicated their impact. Theoretically, any results in a study that met the comparator eligibility criteria above will be indicating the impact of drones, as the comparison between drone-based and non-drone-based methodology allows the impact of drones to be inferred. These results could be positive or negative and could be quantitative or qualitative. These could be overarching statements on the impact of drones or related to specific goals, such as measuring biomass or monitoring disease spread. This is needed to understand in what way drones compare to existing methods, as opposed to simply knowing that a drone is more suitable than existing methods in an undefined or theoretical manner.

2.3 Methods

2.3.1 Searching for Articles

Search Languages

Only publications that are written in English were included in the review, due to a lack of resources or ability to review publications in other languages.

Database Searches

Three databases were used to collect published material: ScienceDirect (https://www.sciencedirect.com/), Scopus (https://www.scopus.com) and PubMed (https://pubmed.ncbi.nlm.nih.gov/). Searches on these search engines were carried out using a UWE subscription. Other search engines such as Web of Sciences and CAB direct were considered but were unavailable due to a lack of a subscription. The chosen databases were selected after discussion with the review team and specialists at the UWE library.

Internet Searches

As well as databases of peer-reviewed studies, Google Scholar (https://scholar.google.com/), a web-based search engine, was used. This allowed for the collection of not only more peer-reviewed studies but grey literature such as articles, theses, reports, and books to enhance the comprehensiveness of the review. The first 200 results were taken from google scholar after searching by relevance, as the results started to become less relevant after the first 200, and any relevant results were collated with the peer-reviewed studies.

Specialist and Supplementary Searches

The reference lists of any relevant journal articles were used, with any duplicate references excluded, and the remaining articles screened in the same way as the initial studies. This was carried out again on the reference lists of any relevant articles found in this way until no new relevant studies were found. This increased the comprehensiveness of the review, as well as the chances of finding any relevant articles that could not be found on the chosen search engines, such as articles that were too old.

Search String Development

A search string is a string of terms that will be searched in the various databases and search engines that are utilised in the review. The PICO criteria were used to develop and refine the search string that was used in the review.

Librarians and specialists were contacted to inform the use of Boolean operators (conjunctions used to combine or exclude words in a search) in the various selected databases, as well as direction from the guidelines of the websites that were used in the review. The search term combination and Boolean operators were tested in a search on Scopus, and Boolean operators were tweaked based on how the different publication databases operated. For example, Science Direct only allowed a maximum of eight Boolean operators, and so their search string was much shorter than the others. A small test list was developed with help of the review team and relevant experts, which was used to test the comprehensiveness of the search string. The iterative design of the search string, along with the final search strings and the test list can be found in Appendix 1.

2.3.2 Article Screening Process and Eligibility Criteria

Publications were first screened using their title and abstract, and then using the full texts. At each of the two screening stages, studies were included or excluded based on eligibility criteria determined using the PICO elements of the research question (Figure 2). The number of publications included and excluded at each stage was recorded.

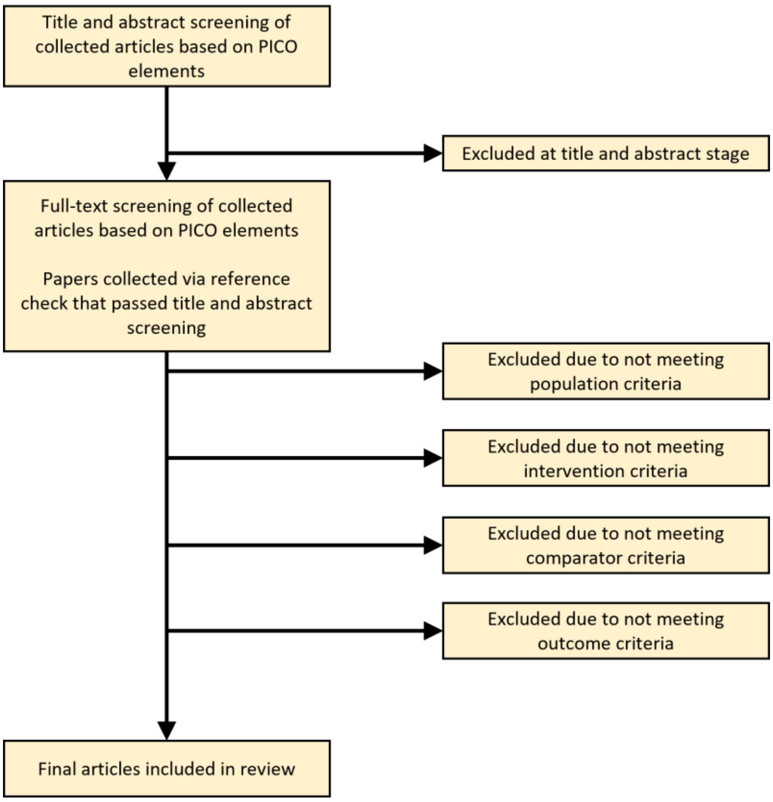


Fig 2. A Decision Tree Showing the Screening Process of Articles Collected via the Search String

Study Validity Assessment

When assessing study validity, both external and internal validity need to be taken into account. The eligibility criteria exclude studies that do not meet the criteria of the question, improving the external validity of the review, as well as excluding studies that do not meet certain criteria that would affect internal validity, such as not having a comparison or control group. To assess the internal validity of the studies screened, a series of questions were answered for each study, based on the biases laid out in the Environmental Evidence guidelines for systematic reviews (Collaboration for Environmental Evidence, 2021). For each question, a study could be given the result 'Yes', 'Partially', 'No', or 'Unknown'. These questions help address the main biases that affect internal validity: Attrition Bias, Detection Bias, Performance Bias, Reporting Bias and Selection Bias. Question 1 identifies potential attrition bias, question 2 is designed to identify possible detection bias, question 3 is designed to detect possible performance bias, and question 4 is designed to further identify performance bias, as well as possible selection bias. The questions used are provided below:

1. Is all mentioned and measured data and outcomes present, with no obvious missing data or outcomes that could have affected the results of the study, or affected the intervention or comparators of the study in a way that would make the study ineligible?

- Yes (All mentioned and measured data and outcomes are present, there are no apparent gaps)
- Partially (There is mention of data or outcomes that cannot be found in the study, but it is minor/unclear whether they have affected the results/conclusions of the study)
- No (There is obviously missing data or outcomes that could impact the results of the study or make it ineligible)
- Unclear (There is not enough information to judge whether there is missing data or outcomes)

2. Was the type of outcome being measured consistent across all study groups, and believed to have been appropriate for accurately answering the research aims of the study?

- Yes (The outcome being measured is consistent and appropriate for the aim(s) of the study)
- Partially (There are minor differences in the type of outcome being assessed or there are slight biases/inaccurate conclusions that could be drawn from the outcome due to the methodology used. If a study meets both of these criteria, then it will be classed as a 'No')
- No (The outcome being measured differs between study groups or is not appropriate for determining the impact of the intervention)
- Unclear (There is not enough information to know if the outcome assessment for different study groups is consistent, or whether it is the appropriate method to answer the research question(s))

3. Are all variables that could affect the outcome of the study accounted for, minimised or controlled to a degree that they are not affecting the outcome of the study? Such variables could include factors that are mentioned in the study but not accounted for,

or effect modifiers that are not minimised, such as time of day, time of year, existing biases in the investigators etc.

- Yes (All variables that could affect the outcome of the study apart from the intervention are accounted for, minimised or controlled)
- Partially (There are some remaining variables that could potentially affect the outcome of the study in minor ways, but these are acknowledged)
- No (There are variables outside of the intervention that could be affecting/responsible for the outcome of the study)
- Unclear (There is not enough information to know whether variables that could affect the outcome are controlled)

4. Are differences/confounding factors between comparison groups accounted for? Ways to do this could include randomisation or minimising and controlling any variables as mentioned in question 3.

- Yes (Any confounding factors between comparisons or experimental groups are accounted for/minimised or controlled, or the study is fully randomised and blind)
- Partially (There are some confounding factors between comparisons or experimental groups that could be affecting the outcomes between different groups, but they are acknowledged or partially accounted for)
- No (There are several confounding factors between different experimental groups that could be affecting their outcomes, making comparisons between them inaccurate)
- Unclear (There is not enough information to judge whether any confounding factors between comparisons/experimental groups are accounted for or controlled)

Any study that had more than two 'Partially' answers, or more than one 'No' answer, was eliminated from the analysis.

2.3.3 Data Coding and Extraction Strategy

A checklist of which data to extract from the included studies was used to obtain relevant information. Both qualitative and quantitative data was extracted. The checklist is provided below:

1. Article title
2. Author(s)
3. Article type
4. Year of publication
5. Location of study
6. What outcome/observation is being measured
7. Type of data being collected
8. Comparators/controls used
9. Study design
10. Method of evaluating results/comparing groups
11. Type of result obtained (standard deviation, correlation, mean etc.)
12. Results/conclusion(s) drawn
13. Possible confounding variables/study biases

2.3.4 Reasons for Heterogeneity

Potential effect modifiers and reasons for heterogeneity were identified and listed. There were several factors that could cause heterogeneity in the impact of drone-based methods compared to traditional methods in temperate wildlife conservation, especially with such a broad range of different approaches and factors within wildlife conservation. Some potential factors identified before the start of the review included:

- The country in which the study took place and the socioeconomic or political state of that country.
- The conservation outcome/effect the drones are being used to impact
- What comparator is being used to assess the impact of drone use
- The date or time at which both the drone use and the comparator methodology took place
- The ecosystem of the site where the study takes place
- Any funding or support obtained from other organisations

This list was not designed to be exhaustive, merely giving some of the more notable variables, and was collated through discussion with specialists and the review team. An exhaustive list of variables identified in studies screened at the full-text level was collated.

2.3.5 Data Synthesis

Data were synthesised through a narrative synthesis of the studies, looking at any patterns of trends within the data. Descriptive statistics were also carried out and included in the narrative synthesis in the form of tables. The data was also divided into sub-groups based on different outcomes and different comparator groups, to analyse any patterns within those groups that may not be apparent when looking at the data as a whole. Sub-group analysis was carried out on the data, using the different kinds of outcome being measured as the sub-groups to identify any patterns within a particular sub-group. Due to the broad range of different outcomes and the high levels of heterogeneity, quantitative assessment of the studies was unable to take place. The study validity assessment was used to assess the validity of the studies and identify any potential biases in the data.

2.4 Results

2.4.1 Article Screening

In total, 16,585 papers were acquired. Of those, 88 passed the title and abstract page, with 16,497 excluded. The majority of the papers were excluded for not being about drones and their uses in wildlife conservation, instead discussing the technical and engineering aspects of drones, referring to male honeybee drones, or discussing the potential of dronedarone, a drug used to treat atrial fibrillation.

Of those initial 88, 32 passed full-text screening, with 56 excluded. After analysing the reference lists of any papers that passed full-text screening, extracting any that passed title and abstract screening, and removing duplicates, 26 more papers were found, of which 11 passed full-text screening. After analysing the reference lists of those additional 11 papers, extracting any that passed title and abstract screening, and removing duplicates, no new papers were found. In total, 43 papers were retained for full-text screening, with 71 being excluded.

Of the 71 excluded papers, 15 were excluded after not meeting the population criteria, with 14 of the papers being excluded due to the study location being too close to the equator, and one paper being excluded due to the study location being too far away from the equator. Twenty-one papers were excluded after not meeting the intervention criteria, with six papers being unrelated to the field of conservation, eight papers containing no experiment, and seven papers not using drones, instead using other methods such as aircraft (four papers), satellites (two papers) or terrestrial machinery (one paper). Thirty-five papers were excluded after not meeting the comparator criteria, with 27 papers containing no comparison to other methods, and eight papers containing comparators that were also drone-based, and therefore had no comparator to non-drone-based methods. All papers screened met the outcome criteria (Figure 3).

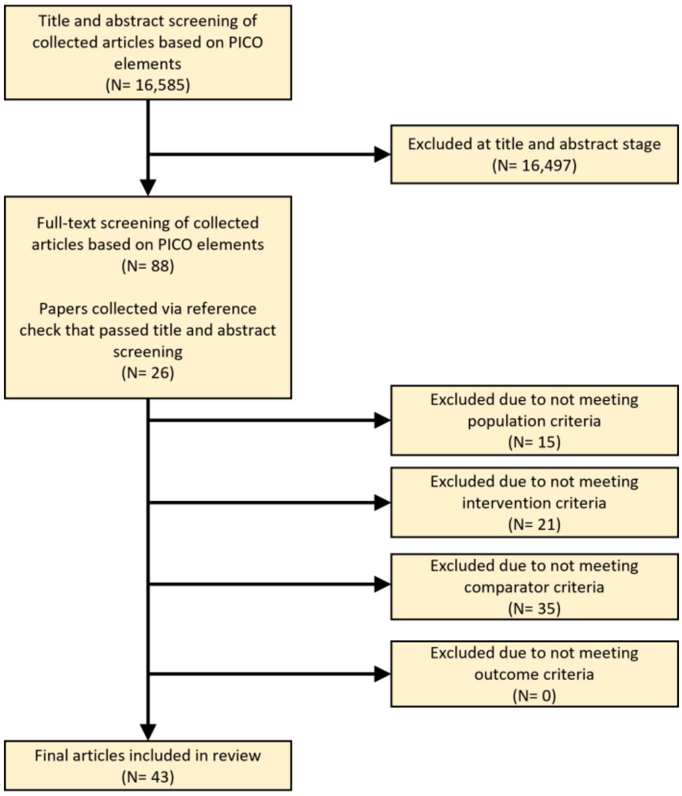


Fig 3. The Screening Decision Tree with the Number of Articles Included and Excluded at each Point

2.4.2 Study Validity

Of the 4 questions asked across all 43 studies that passed full-text screening (for a total of 172 questions), 144 (83.8%) resulted in 'Yes' answers, with 27 (15.7%) 'Partially' answers, and one (0.6%) 'No' answer (Table 1). No study was eliminated due to more than two 'Partially' answers or more than one 'No' answer.

Table 1. A Summary of the Study Validity Question Results

	Question 1			Question 2			Question 3			Question 4		
	Yes	Partially	No	Yes	Partially	No	Yes	Partially	No	Yes	Partially	No

Nº of Studies	38	5	0	41	2	0	31	11	1	33	10	0
Studies (%)	88.4	11.6	0	95.3	4.7	0	72.1	25.6	2.3	76.7	23.3	0

2.4.3 Coded Data

To aid in analysis, and given the high levels of heterogeneity of the studies, it was decided to split the studies into categories. The studies were split into categories based on the type of comparator group, to allow the effectiveness of drones compared to other methods to be assessed in more detail. The studies were split into four different categories. Where a study could be included in more than one category, whichever output the study placed more emphasis on was used to determine its category.

In order of prevalence, the categories were:

- Terrestrial/Field-based Comparison (34 Studies)
- Satellite Imagery Comparison (4 Studies)
- Fixed-wing Aircraft Comparison (4 Studies)
- Known Control Point Comparison (1 Study)

Each study was also summarised into one of three groups based on the comparison between the drone and the non-drone-based methods (Table 2):

- Positive (it was concluded that overall, the drone was a better alternative to the non-drone-based methods)
- Neutral (It was concluded that the drone was an equal alternative to the non-drone-based methods or that each method has its advantages and disadvantages to the point where one could not be recommended over another)
- Negative (It was concluded that the drone was a worse alternative to the non-drone-based methods)

Table 2. Summary of the Number of Positive, Neutral and Negative Studies for each Comparison Type

Outcome being Investigated	Drone Effectiveness	Number of Studies	Percentage of Studies within that Outcome	Total Percentage of Studies

Terrestrial/Field-based Comparison	Positive	13	(38%)	(30.2%)
	Neutral	18	(53%)	(41.8%)
	Negative	3	(9%)	(7%)
Satellite Imagery Comparison	Positive	3	(75%)	(7%)
	Neutral	1	(25%)	(2.3%)
	Negative	0	(0%)	(0%)
Fixed-wing Aircraft Comparison	Positive	2	(50%)	(4.7%)
	Neutral	2	(50%)	(4.7%)
	Negative	0	(0%)	(0%)
Known Control Point Comparison	Positive	0	(0%)	(0%)
	Neutral	0	(0%)	(0%)
	Negative	1	(100%)	(2.3%)

A chi-squared test of independence was carried out on the Terrestrial/Field-based Comparison category to determine whether there was a significant difference between the spread of positive, neutral, and negative studies, with the other categories excluded due to a low observed frequencies that would lead to issues with low expected frequencies. A significant difference was found in the spread of studies within the category, X^2 (2, N =34) = 10.32, p =0.01. Studies in the Terrestrial/Field-based Comparison category were more likely to be positive or neutral than negative (Dytham, 2010).

Another potential way to split the screened studies which could provide useful context is by the outcome they are studying. Using the extracted data, five categories were created.

In order of prevalence, the categories were:

- Ground Cover and Features (23 studies)
- Animal Population Monitoring (11 studies)
- Habitat Damage/Destruction Monitoring (4 studies)
- Hydrology (4 studies)
- Animal Disturbance (1 study)

As with the previous categorisation, where a study could be included in more than one category, whichever was the main feature of interest in the study was used to determine its category. These categories were then combined to give three main categories, with animal disturbance being grouped into animal population monitoring, and habitat damage being grouped into ground cover and features, due to all four studies looking at habitat damage or destruction doing so by monitoring changes in ground cover or ground features such as vegetation structure or topography (Table 3).

Within animal population monitoring, a subcategory was created to include all studies that focused on drone disturbance. Six out of the 12 animal population studies looked at disturbance, with one study focusing on it (Brisson-Curadeau, 2017) and five other mentioning it as an aspect of their research.

Table 3. Summary of the Number of Positive, Neutral and Negative Studies for each Outcome Category

Outcome being Investigated	Drone Effectiveness	Number of Studies	Percentage of Studies within that Outcome	Total Percentage of Studies
Ground Cover and Features	Positive	12	(44%)	(27.9%)
	Neutral	13	(48%)	(30.2%)
	Negative	2	(8%)	(4.7%)
Animal Population Monitoring	Positive	4	(33%)	(9.3%)
	Neutral	6	(50%)	(13.8%)
	Negative	2	(17%)	(4.7%)
Hydrology	Positive	2	(50%)	(4.7%)
	Neutral	2	(50%)	(4.7%)
	Negative	0	(0%)	(0%)

A chi-squared test of independence was carried out on the data to see if there was a significant difference between the spread of positive, neutral and negative studies for the Ground Cover and Features category (Dytham, 2010), with the other categories excluded due to a low observed frequencies that would lead to issues with low expected frequencies. A significant difference was found in the spread of studies within the Ground Cover and Features category, X^2 (2, N =27) = 8.18, p =0.05. Studies in the Ground Cover and Features category were more likely to be positive or neutral than negative.

2.4.4 Study Heterogeneity

A very high level of heterogeneity was observed between the analysed studies. A complete list of factors affecting heterogeneity found in the screened papers is presented below:

- Time of day

- Year of study
- Length of time between experiment and write up
- Study location
- Weather conditions
- Type of drone/equipment used
- Whether the type of drone/equipment used was consistent throughout the study
- Type of drone data collected
- Resolution of drone data collected
- Method of drone data analysis
- Level of photo overlap in drone picture-based studies
- Outcome being assessed
- Comparator group
- Type of comparator data obtained
- Length of time between experimental group and comparator group data collection
- Type of data analysis
- Analysis software used
- Real animals being counted vs decoy animals
- Species being assessed
- Habitat
- Size of the study area
- Whether the comparator data was obtained by the same group or other people
- Level of expertise of researchers
- Whether the drone-based method was the experimental or control group
- Intended application of research
- Source(s) of funding
- The organisation carrying out the research

2.5 Discussion

Overall, the main findings of the systematic review were that the accuracy of drones was comparable or better than existing methods, whilst being much more efficient. However, some particular areas were identified as being unsuitable for drones, such as bioacoustics or the collection of physical samples. Logistical considerations were rarely addressed, with most of the research focusing on drone capabilities and accuracy over the ease of use or resources required to obtain and use.

2.5.1 Effectiveness of Drones for Ground Cover and Feature Studies

Ground Cover and Features were the most common kind of outcome being measured, making up 27 of the 43 reviewed studies (62.8%). This aligns with the information found during the literature review, which suggests that one of the primary uses of drones within conservation is mapping habitats, due to their ability to obtain high-detail imagery in a short amount of time (Wich and Piel, 2021; Wich and Koh, 2018; Koh and Wich, 2012).

The majority of studies found that drone-based monitoring had a higher (Ancin-Murguzur *et al.,* 2019) or comparable level of accuracy compared to ground-based methods. This level of accuracy was consistent across a range of data types, including plant characteristics such as diameter, height, and volume (Hyyppä *et al.,* 2020), general vegetation cover or habitat classification (Breckenridge *et al.,* 2011), and ground feature characteristics (Kinzel *et al.,* 2015). This was also true even when ground-based technology, such as terrestrial laser scanning, or ground-based LiDAR (Light Detection And Ranging) was used (Moloney *et al.,* 2018; Brede *et al.,* 2017). Multiple studies also showed that drone surveying of habitats took less time to carry out and had a simpler methodology and analysis than ground-based surveys when obtaining the same level of accuracy (Ventura *et al.,* 2016; Breckenridge and Dakins, 2011). However, it was noted that the time taken to carry out drone-based surveys increased significantly when including analysis time, although it was still lower than the time taken for the ground-based methods (Barnas *et al.,* 2019). The high-resolution imagery obtained by drones also made it easier to process data at a later date or when outside of the field, as opposed to relying on memory or lower resolution images (Näsi *et al.,* 2018). Three studies compared drones to manned aircraft surveying (Dash *et al.,* 2019; Resop, Lehmann and Hession, 2019; Näsi *et al.,* 2018), and three studies compared drones to satellite imagery (Berra, Gaulton and Barr, 2019; Fernández-Guisuraga *et al.,* 2018; De Giglio *et al.,* 2017). In these studies, drone imagery was shown to be higher resolution and allowed for a greater level of detail than the compared method.

In one study, by Gray *et al.* (2018), both drone imagery and field methods were used as different control methods for satellite data and were compared to each other. Whilst this did limit the available information, as more focus was directed towards the experimental method, drone surveys were seen as quicker and easier to carry out compared to field surveys and to produce comparable levels of detail. This shows that even in situations where the drone-based method is not the experimental group, which can make it more likely to be reported as better than the control group due to publication bias preventing the publication of papers that are not seen as impactful, drones are shown to be quicker and more efficient than field-based methods.

Whilst the majority of neutral studies showed drone capabilities are comparable or not significantly different from other methods, some studies were neutral due to the drone-based methods having both positives and negatives compared to other methods. Whilst the accuracy and speed of drones were the most often-cited positives, reliance on good weather conditions was highlighted as a factor that limited drone capabilities, with drones unable to fly on days with high wind or rain. This was a limitation of drones compared to both ground-based surveys (Dandois, Olano and Ellis, 2015) and manned aircraft (Resop, Lehmann and Hession, 2019), which were more durable and therefore able to fly in tougher weather conditions.

In the two studies that concluded drones were less suitable than existing methods, one investigated the ability of drones to identify and measure fallen trees (Inoue *et al.,* 2014), and found that whilst drones identified 80-90% of fallen trees over 30cm in diameter or 10m in length, many that were narrower or shorter were missed compared to ground-based surveys. It was concluded that a higher level of overlap in the pictures may have given multiple angles to help distinguish fallen trees from the ground, but this has not been confirmed. The other looked at the ability of UAVs to detect and map invasive squarrose knapweed (Hardin *et al.,* 2007). Overall, the percentage of knapweed detected using the UAV ranged from approximately 5% in spring to around 50% in summer. Whilst it was confirmed that knapweed could be detected using drones under the right seasonal conditions, the inability of the UAV to handle sub-ideal weather and the ground-based characteristics of the plant that are used during classification made drones unsuitable for this kind of detection. This shows that drones may not be suitable for the detection of highly specific vegetation, such as individual species or plants of a particular size range, especially if that size range is small.

2.5.2 Effectiveness of Drones for Animal Population Monitoring Studies

Animal Population monitoring, despite being the second most common outcome being measured, only comprised 12 out of the 43 reviewed papers (27.8%). Of those 12, four of them concluded that drones were a better alternative to the comparator method, six concluded that drones were either comparable, or had both positives and negatives over existing methods, and two found that drones were not as effective as the comparator method.

Overall it was found that the ability of drones to carry out animal counts was comparable to counts carried out using ground-based counts (Chabot, Craik and Bird, 2015), but were quicker and cheaper when using RGB (standard colour) cameras (Brisson-Curadeau, 2017), with one study reporting a time reduction of 85% and a cost reduction of 88% when using drones to count Eurasian oystercatchers, compared with ground-based surveys (Valle and Scarton, 2018). One study found that counts of large bird colonies using drone-based imagery were more accurate, containing fewer errors than the same counts carried out on the ground, even when using experienced ecologists (Hodgson *et al.,* 2018). However, this study used decoy birds meant to simulate real colonies. It is therefore possible that when surveying real colonies, which will not necessarily be stationary, that one or both methods may be less effective.

When compared to aircraft, drone-based surveys were also found to be comparable in accuracy to counts performed from manned aircraft (Rexer-Huber and Parker, 2020). Drones were also found to be useful in accessing hard-to-reach areas (Brisson-Curadeau, 2017) and had more flexibility in terms of carrying out flights in small periods of good weather although, as with ground cover surveys, the ability of drones to fly in bad weather was found to be limited in comparison to other methods (Rexer-Huber and Parker, 2020; Valle and Scarton, 2018).

One study comparing drone and ground-based ability to survey multiple species of geese found that drones were less suitable than ground-based methods for identifying animals with colouration that matched their surroundings, but were able to detect high-contrast animals from the air that could not be seen from the ground (Chabot and Bird, 2012), meaning that the species of focus is something to consider when planning animal surveys and that ground-based surveys may be more appropriate when dealing with more camouflaged animals.

In terms of indirect animal monitoring, such as locating nests or signs, the only study which assessed this used thermal imagery (Scholten *et al.,* 2019). In the study, drone-based thermal imagery was found to be comparable to ground-based thermal methods in terms of both accuracy and time, although other studies using thermal imagery to pick up animals encountered problems in areas with dense canopies or other vegetation that obscured the animals (Gooday *et al*., 2018).

One aspect of animal monitoring that was shown to have severe limitations when carried out using a drone was bioacoustics. A study comparing the ability of drones to count songbirds using bioacoustics compared to ground-based stations found that the noise created by the drone prevented the detection of low-frequency songs and led to overall underestimations of abundance (Wilson, Barr and Zagorski, 2017). Given that most drones produce significant noise when in close proximity, they would not be suitable for bioacoustics studies unless some way to remove or separate out the noise produced by the drone was developed.

One study comparing drones to known control points used a VHF receiver mounted on a quadcopter drone to attempt to locate five transmitters, normally used for animal tracking, placed at fixed locations (Desrochers *et al.,* 2018). Whilst the study stated that drones could be used in this way as a cost-effective alternative to field-based animal tracking in difficult terrain, it concluded that 'the precision of the detection-by-drone method is likely insufficient for finer-scale applications such as finding nests or dens or documenting microhabitat use'. This study shows that whilst drones may offer benefits in terms of resource efficiency and time compared to other methods, they lack the precision that can be obtained in the field, and would not be suitable for verifying the location of known, fixed points. It may also mean that any specific coordinates obtained solely using drones may be inaccurate. However, it is hard to draw generalised conclusions from a single paper, and further research would need to be done to see whether the efficiency of drones is worth the decrease in precision, or whether drone precision may be higher when using other techniques, such as deep learning or elevation models to identify items at known points.

Drone Disturbance

Six out of the 12 animal population monitoring studies investigated disturbance as an aspect of their research. Overall conclusions varied, with some studies finding that drones caused very little disturbance, comparable (Weissensteiner, Poelstra and Wolf, 2015) or even less than ground-based methods (Chabot and Bird, 2012). Take-off and landing may be an exception to this (Rexer-Huber and Parker, 2020), as the proximity of the drone to the ground increased the levels of noise at ground level, and therefore disturbance. Therefore, to minimise disturbance, drones should be launched and landed at a suitable distance from any animals.

However, some studies did find that drones caused more animal disturbance than manual surveys (Scholten *et al.,* 2019), although the level of habitat disturbance and destruction was lower, which was backed up by other studies (Weissensteiner, Poelstra and Wolf, 2015). This disturbance was significant at lower altitudes, with the majority of studies that concluded there was minimal disturbance flying at higher altitudes than studies that concluded drones caused high levels of disturbance, with a height of 20-30m enough to visibly alarm birds (Valle and Scarton, 2018).

Of the six studies that had disturbance as an aspect of their research, one focused primarily on drone disturbance, as opposed to it only being a secondary aspect of the research. This study (Brisson-Curadeau, 2017) found that drones caused minimal disturbance, measured in the form of flushing birds and failed eggs, with manual approaches causing more disturbance. The exception to this was when predators were in the area, which resulted in high levels of disturbance, regardless of method.

2.5.3 Effectiveness of Drones for Hydrology Studies

Hydrology was the least common type of outcome being measured, making up four papers out of the 43 papers reviewed (9.4%). Of those four papers, two of them focused on the ability of drones to carry out physical sampling (Song *et al.,* 2017; Chung *et al.,* 2015), and were the only two papers to do so out of the 43 reviewed papers.

Both of these papers focused on the sampling of water for the assessment of temperature. The main differences between the studies are that the paper by Chung *et al.* (2015) used a temperature sensor mounted on a drone, recording temperature levels at the water's surface, and compared the drone results to *in-situ* sensors. In comparison, the study carried out by Song *et al.* (2017) used a small collection device to collect water samples at a variety of depths, which were then assessed for temperature and conductivity using a detached sensor.

The study by Chung *et al.* (2015) found problems due to the sensor dipping in and out of the water whilst trying to control the drone, making it difficult to collect accurate results. This shows that there may be problems with drones as a tool for physical sampling if the sampling requires a very fine level of motor control. However, when results were obtained, they were found to be generally comparable to those obtained using in-situ sensors. This lack of any improvement in accuracy, combined with the extra effort in having to carry out drone flights every time more data is required, means that drones would not be suitable for physical sampling when there are already *in-situ* sensors in place.

The study carried out by Song *et al.* (2017) compared the drone-collected samples not only to sensors but to manually collected water samples. They found that 'UAV-based *in-situ* readings better represented the spatial and temporal variations of thermal and chemical distributions in water bodies compared to manual and sensor readings'. One of the main reasons for this was that the manual collection of water and reading of the sensor, as well as the longer sampling time required to carry out those methods, caused significant disturbance to the water, disrupting the temperature and conductivity of the water as it mixed. The deeper depths at which water was collected, as well as the fact that the drone merely collected samples for analysis as opposed to using an attached sensor, means that they did not experience the same problems as the study by Chung *et al.* (2015). This shows that one of the main advantages of drones when assessing hydrology is the ability to access areas without disturbing them. This increased accessibility may also be useful when surveying inaccessible areas, where sensors could be not placed.

One study used reflectance values to assess the turbidity changes of a river, using manual turbidity assessments along transects as a comparison (Ehmann, Kelleher and Condon, 2018). They found that the drone readings significantly correlated with the transect results and that the two methods were also comparable in terms of time. In this situation, unless a drone had already been purchased, it would not offer any significant benefit over existing methods.

The final study was the only hydrology-focused study to compare drone-based methods to a non-field-based method, assessing the ability of drone imagery compared to satellite imagery when identifying a small stream (Spence and Mengistu, 2015). It was found that in areas where the stream could not be seen on some satellite images due to the lower resolution, it could still be identified on the drone images. This matches up with findings in other outcomes comparing drone imagery to satellite or manned aircraft imagery, where the higher resolution of drone imagery allows more detail and smaller features to be identified.

2.5.4 Study Validity

When looking at non-yes answers to Study Validity assessment questions, the majority of them were answers to Question 3, which focused on whether any unwanted variables that could affect the outcome of the study are accounted for or minimised, and Question 4, which ensured that differences between comparison groups were accounted for. Both of these questions were designed to check for performance bias, with question 4 also checking for selection bias. The high number of non-yes answers for these questions as opposed to questions 1 and 2 indicate that performance bias and selection bias were likely the most prevalent biases affecting internal study validity. The single 'No' answer was for question 3, and was due to forbs, one of the vegetation types being surveyed, undergoing physical changes due to senescence between the collection of drone data and the field surveys (Breckenridge *et al.,* 2011). The most common reason for non-yes answers was also due to a difference in time between data collection of the two groups, which was particularly significant in studies comparing drone imagery to satellite imagery (Berra, Gaulton and Barr, 2019; De Giglio *et al.,* 2017).

Another reason for this increased level of performance and selection bias may be due to the type of studies in the review. One of the main ways to avoid performance and selection bias is to ensure that any study carried out is double-blind and that any study units are randomised (Savović *et al.,* 2012). This is more suitable for experiments in the medical field when looking at the effects of different interventions on participants. In many of the studies included in the review, there is no way for the study to be double-blind, as the outputs from drones are often visibly different to data collected using field surveys, and are impossible to collect without knowing what method you are using. It is also very difficult to randomise the study units, as often the same areas or individual plants and animals are surveyed using both methods. The high number of variables when conducting studies in the field, such as differences in weather, time of year etc., also make it difficult to control all variables to a degree that they will not affect the study.

Due to this risk of performance and selection bias, it is important to consider when drawing any conclusions from this review that other variables or baseline differences in the characteristics of the study units may be affecting the results in a subset of studies. However, this subset is overall low with 21 'Partially' answers (12.2% of total answers) and 1 'No' Answer (0.6% of total answers) out of a total of 172 questions. It could also be argued that the inability to control all variables in the area of study reflects the conditions under which conservation groups will have to carry out survey work. This is arguably due to a greater focus on making use of limited resources, and less of a focus on carrying out surveying in a scientifically rigorous way compared to an academic research setting. However, it is still a point of interest and should be included when discussing drone potential in conservation.

2.5.5: Strengths and Limitations of Review

One strength of this review is that it was comprehensive in its coverage, allowing for a robust level of detail on drone use in temperate areas and how it compares to existing methods. The focused eligibility criteria also ensured that only relevant papers were reviewed, and whilst these strict criteria could have potentially excluded relevant papers regarding the impact of drones, such as papers reviewing drone usage without a comparator group, a brief comparison of the systematic review and the main findings of the literature review used to gather information for Chapter 1 did not highlight any missing topics or aspects of drone use.

However, a downside of the comprehensiveness of the search was that the number of papers that were screened and didn't pass the title and abstract screening phase was very high, with 16,497 excluded, and a large number of papers in irrelevant fields, including apiculture and pharmaceutical research, that took a long period of time to screen. A more focused search string could have lowered the number of irrelevant papers that were acquired. However, due to the broad number of terms used to describe drones (unmanned aerial vehicles, remote piloted systems, unmanned air vehicles, unmanned aircraft systems etc.), it was decided to keep the search string quite open to ensure that as many relevant papers as possible could be acquired.

Another limitation is the potential of publication bias, which is when the result of a study biases the decision to publish it or not. This most often takes the form of a tendency to publish papers with significant results, or papers with results that favour the experimental group (Cooper, Hedges and Valentine, 2009). This is backed up by the fact that out of the 43 reviewed papers, only one used the drone-based method as a control to test a non-drone-based method (Gray *et al.,* 2018). This may also explain a higher prevalence of positive and neutral studies over negative studies, especially in categories with a higher number of studies overall, such as ground cover and feature studies, or studies that compared drone and field-based methods. More research would need to be carried out to explore to what extent publication bias may have affected the results of the review.

Logistical considerations, such as the cost and bureaucracy of drone flights were also rarely considered, with only a small number of papers carrying out a cost-benefit analysis or similar evaluation between methods (Rexer-Huber and Parker, 2020; Song *et al.,* 2017). Whilst these factors may not be as relevant in a research setting, in which the answering of the research question primarily focuses around the capabilities of drones, they are likely to be a major factor when considering the use of drones among conservation organisations, and so more information on how drones compare to existing methods in terms of time, cost and necessary qualifications would be needed for an effective comparison.

2.6 Conclusion

In conclusion, this systematic review has helped to provide information on the current uses and capabilities of drones in the field of conservation compared to existing methods. Drones were most commonly used for the surveying of ground cover and features, animal population monitoring, and hydrology surveys, with the majority of studies comparing drones to ground-based methods.

Whilst a range of different outcomes were found, the most common conclusions were that the accuracy of drones was comparable to existing ground-based methods and manned aircraft, and superior to satellite imagery, whilst being quicker and easier to carry out than existing methods. In addition to this, drones were shown to be useful in accessing areas that were inaccessible to other methods. However, drones were shown to be unsuitable for particular areas of research, including physical sampling and bioacoustics, and there was insufficient information on logistical considerations to know whether drones are a cost-effective option for conservation organisations. Conclusions regarding the amount of disturbance caused by drones compared to other methods varied, but it was consistently shown that higher altitudes resulted in a lower level of disturbance and that the risk of disturbance was greater during take-off and landing. However, possible publication bias should be taken into account when looking at these conclusions, as well as performance and selection bias, albeit to a lesser extent, although the variation in results due to uncontrolled differences between methods is likely to match conditions found when using drones for conservation purposes, and so may be less relevant outside of a research setting.

These conclusions will be carried forward and compared to information gathered on the current needs of conservation organisations. Points of overlap will then be identified, and case studies developed based on those points of overlap. Considerations raised in both the interviews and the systematic review will also be incorporated into the case studies, to ensure that information relevant to the incorporation of drones into conservation organisations is acquired.

3 Identifying Wildlife Trust Views on Drone Benefits and Barriers

3.1 Introduction

Now that the information on the capabilities of drones, how they theoretically compare to existing methods, and their uses, has been determined by the systematic review, this dissertation will determine to what extent this aligns with the needs of conservation organisations.

3.1.1 Importance of Working with Conservation Organisations

Conservation organisations play an important role in maintaining and protecting biodiversity and supporting and managing various sites and projects around the UK. It is now mandatory for a conservation organisation to be established in areas where there are nationally protected sites, such as sites of special scientific interest (SSSIs) (Jenkins, 2020). The conservation sector is also growing in size. In 2019/2020, £360 million of public sector funding was spent on biodiversity in England, an increase of 76% compared to 2000/2001, and non-governmental organisations (NGOs) spent £266 million on biodiversity in 2019/2020 compared to £199 million in 2010/2011 (Department for Environment, Food and Rural Affairs, 2021). As the conservation sector grows, the work of conservation organisations is going to become increasingly important, and when considering any new conservation policy or research, it is important to consider and work with conservation organisations, as they will be aware of practical and logistical considerations that may not be present in a purely theoretical/research setting, but are important to know when planning any conservation research or policy.

3.1.2 Changing State of Conservation

One of these considerations is the current state of conservation, and how it is expected to change. As mentioned in Chapter 1, over the last ten years, there has been a shift from site-based conservation and looking at nature reserves as independent units, to landscape-scale conservation, where sites are considered part of a larger landscape, and parcels of conserved land are joined up to create ecological networks (Natural England, 2016; Lawton *et al.,* 2010). The 2021 Environment Act also set new targets and policies regarding biodiversity and land use, such as allowing the option to purchase biodiversity units to offset biodiversity loss when planning site development. This, combined with the cancellation of direct payment subsidiaries for agriculture, means that a lot of land has become available for conservation that wasn't before, which could potentially lead to a shift in habitat regeneration on a local scale (The Environment Act, 2021).

This constantly changing state of conservation can lead to changes in the challenges conservation organisations face, especially at a local level, which in turn changes the conservation actions they can carry out, both in terms of logistical considerations such as resources and time, but also in terms of their conservation needs. This further highlights the importance of obtaining the views of conservation organisations, as they will know what the current needs are at a smaller scale.

3.1.3 Conservation Organisation Needs and Perceptions

Another reason why obtaining the views and beliefs of conservation organisations is important is to understand their needs as an organisation. Conservation groups in different parts of the country may have different problems and different conservation needs that may not be identified in a more controlled research setting. Working with conservation organisations also provides information on the perception of drones within conservation organisations, as opposed to just the advantages and disadvantages of drones when carrying out research. It is important to gauge not just practical thoughts and the actual capabilities of drones, but also perceived problems and benefits, as they could affect people's opinions on drones and potentially affect a conservation organisation's willingness to incorporate drones into their methods.

To obtain these views on how drones could help conservation organisations, and any thoughts regarding the benefits or problems of drone use, a thematic analysis of interviews was used to analyse the views of conservation organisation employees, specifically the UK Wildlife Trusts, regarding the current challenges they face in the field of conservation, and the potential benefits or problems of using drones within the organisation.

3.1.4 Aim of Study

This study aimed to explore Wildlife Trust employees' views and beliefs on the current challenges in UK conservation and the potential benefits and problems of using drones in UK conservation.

3.2 Methodology

3.2.1 Reflexivity Acknowledgement

As someone who works and carries out research in the field of drone technology and its applications for wildlife conservation, and because of the nature of qualitative research, the data collection and analysis will inevitably be shaped by me (Braun and Clarke, 2013). As someone with an interest in conservation, and multiple qualifications in the field, this study is considered “insider research” where the researcher “conducts studies with populations, communities, and identity groups of which they are also members” (Kanuha, 2000).

One advantage of this approach is that it allows for the researcher's pool of existing knowledge relating to their field to be utilised, allowing for a higher level of awareness regarding the lives and experiences of the study participants (Gair, 2012). This may allow for more detailed and complex information to be given during the interviews. However, insider research also carries a risk of bias, such as a desire to prove an experimental effect or to dismiss viewpoints that conflict with any existing beliefs (Asselin, 2003). To minimise this bias, a strict, established methodology was followed when extracting and analysing information. A concerted effort was also made to remain detached from the experiences of the participants (Kahuna, 2000), and avoid the oversharing of personal experiences, which can bias participant opinion (Asselin, 2003).

3.2.2 Data Collection

Overall, it was determined that a qualitative approach would be most suitable, given the research aims. Qualitative research allows the collection of a range of more detailed responses from the participants and allows the data to be analysed in much more depth (Braun and Clarke, 2013).

Data was collected through online, semi-structured interviews. Semi-structured interviews with open-ended questions were chosen as they are suitable for exploring the views and beliefs of individuals regarding specific topics (Gill *et al.,* 2008), and are more flexible than quantitative methods or other, more structured qualitative methods such as questionnaires or structured interviews. This allowed for the discovery and elaboration of points and information through follow-up questions, and for more detail to be obtained (Terry and Braun, 2017; Gill *et al.,* 2008).

The interviews were carried out online so that a wider range of employees from different Wildlife Trusts could be reached (Braun and Clarke, 2013), allowing for more interviews than could have otherwise been carried out. The interviews were also done online to minimise the risk of catching or spreading COVID-19 (since this research was conducted during the COVID-19 pandemic), as well as to comply with government guidelines encouraging working from home where possible. Finally, doing interviews online made it easier to record the interviews, through software built into the programs used for the interviews.

Development of Interview Questions

Based on the aims of the research, interview questions were designed based on three domain summaries (Clarke, 2017):

- The current challenges within UK conservation
- Potential benefits or advantages to drone use in conservation
- Potential problems or negative consequences of drone use for conservation

Both the benefits and problems of drone use were included as topics, as opposed to asking a participant their general views on drone use, which could then potentially include only positive or negative responses. This was done to obtain a wider range of potential considerations that could then be taken into account by drone users when planning missions.

As well as addressing these three points, follow-up questions were devised and used if more information on a particular aspect of a participant's response was needed. There was also an opportunity at the end for the participants to voice any thoughts or beliefs that were not expressed in the previous questions. The final interview schedule was as follows:

1. Tell me a little about your job with [insert name of organisation]?
2. Within [insert job/organisation], what are the most significant challenges you face in managing and monitoring habitats for wildlife?
3. Beyond those you face in your [insert job role here], are there other key challenges facing those trying to manage and monitor habitats for wildlife?
4. [If yes to Question 3, or if not enough detail provided] What are those challenges? / Tell me more about [insert challenge here]?
5. Have you or your organisation used UAVs (Unmanned Aerial Vehicles) as part of your conservation actions and if so, what for?
6. [If Yes to Question 5] Can you tell me a little about your experience with UAVs for conservation?
7. Possible prompt questions to get more detail on Question 6: What went well? / What didn’t work?/ What challenges did they face?
8. What, if any, opportunities do you see for the use of UAVs in conservation in the future?

9. What, in your opinion, could be the main barriers to making greater use of UAVs in UK Wildlife conservation?
10. Possible prompt questions to follow up on question 9: What do you see as the main barriers to UAV use within your organisation/job role specifically?
11. What negative consequences of UAV use do you see occurring within your organisation, if any?
12. Do you have any other thoughts on UK wildlife conservation and UAV use?

This question list was asked to all participants. The interviews lasted approximately thirty minutes.

Participant Selection

Participants were recruited through a message placed on Wildnet; a professional network used by Wildlife Trust employees. In total there were 11 participants from eight different Wildlife Trusts. The Wildlife Trusts specifically were chosen as the focus for these interviews due to existing professional connections, and their presence as a large UK conservation organisation that works across the country. The employees ranged in seniority, including both management and senior positions as well as lower-level team members. The job roles of the participants fell into two broad categories; GIS (Geographic Information Systems) or data management, which focused mainly on monitoring or working with monitoring data, and reserve management, which focused primarily on the maintenance and care of the site, as well as ensuring conservation goals were met.

Interview Procedure

Interviews were carried out on either Skype or Zoom, with the individual software used down to the participant's preference. The interviews were recorded using the recording function built into the software, although a manual recording device was also used, in the event that the inbuilt recording software failed.

Ethical Approval

Information sheets, privacy notices and consent forms were sent to all participants prior to the interviews taking place. All information, including transcripts and signed consent forms, was kept confidential on an encrypted hard drive. Participants were anonymised at the point of transcription and were free to withdraw for any reason up until this point.

3.2.3 Data Analysis

Thematic analysis (TA) was used to analyse the interviews and was chosen due to its accessibility as a method as it does not require a high level of expertise in qualitative analysis (Braun and Clarke, 2012), its flexibility, and its focus on the experiences and beliefs of participants (Braun and Clarke, 2017). It also allows for a high level of information to be gathered from smaller sample sizes than other, primarily quantitative methods (Braun and Clarke, 2019). Deductive TA was used, where the research was based on finding answers to known research aims (Braun and Clarke, 2012).

The interview audio was transcribed, after which it was anonymised, and the audio recordings destroyed. Data that correlated to the search questions was extracted from the transcripts and given a code; a short label identifying what the information was about. Related codes were then grouped into broader themes containing multiple codes. Following this, the themes were grouped into which of the three domain summaries they addressed; the current challenges in UK conservation, the potential benefits of drones for conservation, or potential problems or barriers around drone use. Finally, the themes were compared to the transcripts to ensure that the themes were actually present in the data and that any relevant information hadn't been omitted.

3.3 Results

Within the 11 interviews carried out, seven main themes were identified. Each of these themes was present in the majority of the interviews. Of the seven themes, two focused on the current challenges in UK conservation, three looked at the potential benefits of drones within the conservation field, and two focused on potential problems or negative consequences regarding drone use for conservation. Below, each theme is discussed in more detail. Before each theme is a table containing a list of the codes that make up the theme (Tables 4-10). References points (RPs) are identified throughout the results, which can then be referred back to when addressing the interview findings in later chapters.

3.3.1 Current State of Conservation

Theme 1: Limitations due to Resources and Personnel

Table 4. Codes present within the 'Limitations due to Resources and Personnel' Theme

Codes
Lack of Money
Political Developments Affecting Funding

Lack of Staff	
Reliance on Volunteers	
Lack of Specialist Knowledge	

"Funding is a widespread issue among conservation. Yeah, there are financial opportunities out there, but compared to other sectors, it does tend to be, not overlooked, but in the grand scheme of things…" **D**

"And in terms of management, I guess it kind of relates back to the monitoring because we have finite resources financially and physically…" **E**

A lack of financial resources was the most common issue in terms of a lack of resources (RP1). This lack of money is widely recognised as a worldwide issue in conservation (Waldron, 2013) and was seen across most of the interviews.

"The funding is being decreased across the board really […] I don't want to make it political, but with Brexit as well, the money is on its way down." **G**

"Basically, here it's the countryside stewardship agreements and the HLS projects, and those were funded by the euro so these will be going. The government has promised that they will continue in some way for the next couple of years but after that, that'll be gone as well" **C**

Another point that was brought up in multiple interviews was how recent political developments, particularly Brexit, had negatively affected funding. This suggests that Brexit may have been negative for these conservation organisations, cutting them off from European conservation funds and other resources (RP2).

"Well, it's financial really. The thing that is budget, massively. We're a charity and we just don't have the money to invest in fancy systems basically, or to hire staff really." **G**

However, a lack of funding due to Brexit or other political factors was not mentioned in the majority of interviews, despite most of these interviews still mentioning a lack of funding. Even the interviews which did mention political reasons for a lack of funding mentioned it as an addition to an existing lack of finances, implying that these political factors are simply exacerbating existing problems, rather than causing them.

"We rely a lot on volunteers as a network to sort things out." **D**

> “I have a couple of colleagues who are mainly focused on doing survey work out on the reserves, but they also liaise with a small army of volunteers who are also out doing survey work as well” **A**

> “With staff resources, there’s no shortage of people who want to work in conservation, but having the finances to actually have those staff and have them do things, that’s the problem.” **T**

Another large limitation in terms of resources that was mentioned was a lack of staff. This was sometimes tied into the finances, with the lack of funding preventing the Trusts from hiring new staff, but it was also identified as a problem generally, leading to a reliance on unpaid volunteers.

> “The other challenges are, I guess, the specialist skills you need for quite a lot of surveys. Some things we have to rely on contractors or expert volunteers because, I don’t know, rare invertebrate groups or things like that, some of the plant surveys, the NVC surveys are pretty tricky. They all require someone who’s very qualified to do these things, so there’s only so much you can do with enthusiastic volunteers, so yeah, it’s mainly balancing what we need to do, with what we can afford.” **J**

> “It’s resources in terms of myself, volunteer effort, volunteer skill, because I mean, to be able to identify a plant you need to be a good botanist […] the resources are low, the required volunteers often don’t have the- the right skills to do it, so there’s a requirement to train them to do it” **T**

This heavy use of volunteers appears to have been a positive for the Wildlife Trusts, allowing them to carry out conservation work they otherwise would not have been able to. However, the reliance on unpaid volunteers means the Trusts lack the specialist skills needed for particular surveys or conservation work. This then leads to a need to either hire specialists, which takes away from the Trust's already limited financial resources, or train them, which the volunteer may be unwilling to go through for no money, and can take significant time.

Theme 2: Limitations due to Lack of Time

Table 5. Codes present within the ‘Limitations due to Lack of Time’ Theme

Codes
Too Much Area to Cover

De-prioritisation of Monitoring
Time Spent Managing People
Lack of Detail due to Time Constraints

> "We don't get a lot of time to do monitoring and anything like that, because you just don't have time." **C**

> "So yeah, that's a big problem for us. And compared to other trusts, other groups, the land we're covering is comparatively smaller so I'd imagine that big groups with big estates to manage have an ever harder time than I do in terms of monitoring those" **E**

The second theme identified as a major challenge within the field of conservation is limitations due to the lack of time. This was less prevalent than the previous theme but was still mentioned as a major problem preventing a lot of conservation work from taking place, even in smaller Wildlife Trusts.

> "We have a surveyor, literally one surveyor for all of our sites. He's very good, but he just doesn't have enough time in his life to monitor all the sites, so we have about 10,000 hectares of land, roughly, that we manage, that's just sites that we manage ourselves. There's also partnerships and stuff as well, so it's just impossible for him to cover that sort of area." **G**

> "So if you've got a mosaic of scrub in a grassland site, and you wanna map in detail the scrub if it's all scattered around, trying to do it on a piece of paper is nigh on impossible and even using something like software to capture things in the field is still pretty time consuming" **A**

This problem ties back into the previous theme, particularly with regards to a lack of personnel, as it means that the smaller staff have more work to split between them, resulting in more to get done in a limited period. This can then lead to certain aspects of conservation, such as surveying or monitoring, being deprioritised or not done on as much of a regular basis as they ideally would be. This can then lead to outdated, or a complete lack of, information regarding those sites, making it hard to determine what conservation action should be taken and to determine the impact of that action.

> "Trying to cover all the sites, so in our case 100 sites or more, just nature reserves is tough. And then also trying to do the stuff in between, like working with land owners, local wildlife sites, things like that that are outside of our nature reserves

and trying to find any time to do that kind of stuff on top is pretty impossible really but we do what we can" **J**

"Managing people is a major issue, probably takes up half that time, I would think, then the other half of the time we squeeze in all the various work we gotta do, which is the maintenance work, and then trying to find the time to do the improvement work and [chuckles] actually making things better and to not just keep going as we do." **R**

Time is also needed to run other aspects of the Trusts, such as interacting with landowners and the general public, which, while necessary, can further take away from the time available to carry out conservation work.

3.3.2 Potential Benefits of Drones within Wildlife Trusts

Theme 1: Improvements over Ground-Based Methods

Table 6. Codes present within the 'Improvements over Ground-Based Methods' Theme

Codes
High Resource Efficiency of Drones
Drones can Survey Inaccessible Areas
Drones are Quicker than Ground-Based Methods
Drones are more Accurate than Ground-Based Methods

"Yeah, the main problem with habitat monitoring is being able to establish different kinds of habitat and where the boundaries are between them, to be able to do that from the ground, and also to be able to map those kinds of habitats effectively is very difficult to do from the ground, which is why we started using drones." **J**

"I think a big one [advantage] is the cost to scale effectiveness of how you can collect data. You can obviously achieve much greater coverage with less resource using this kind of approach and that's always what we're looking for, better cost efficiency" **P**

The most common theme when looking at the potential benefits or applications of drones was the advantages of drones over ground-based methods. One aspect of this was the high resource efficiency of drones (RP3). This ties back into previous themes that highlighted a lack of resources as one of the main considerations in conservation currently. Any method with high resource efficiency would therefore be highly desirable to conservation groups.

> "Now in my view, it ought to be possible to do some more specific ground truthing using a UAV rather than having to go out and literally walk a 2-mile pipeline or whatever" **S**

> "We can do things we're doing now quicker, and better potentially and allowing access to different areas, potentially." **A**

> "Flying a drone over, high, and being able to accurately count stuff later on is a time saver for us. "**C**

Participants also noted that the use of drones could save a lot of time in terms of surveying, as large areas could be covered more quickly. This allows more time to be spent on other aspects, such as monitoring of sites that previously would not have been monitored due to the lack of time, and the training of volunteers to carry out more specialist tasks that can lead to more information and better-informed conservation plans.

> "We also have the advantage that we could go to areas where we couldn't get access to before, so riverbanks, scree slopes, so all these areas that aren't impossible to get to, but are quite difficult so a drone flying over the bank, so it just makes it easier to get to those areas." **D**

Finally, drones could allow for the surveying of previously inaccessible areas, or areas that were technically surveyable, but were dangerous or too time-consuming to accurately survey, such as mountainous or boggy habitats. This could lead to improvements in the conservation of these areas and the unique communities that exist within them.

Theme 2: Drones for Assessment of Habitat Features

Table 7. Codes present within the 'Drones for Assessment of Habitat Features' Theme

Codes
Ground Cover Mapping
Useful for Tracking and Identifying Animals
Topography Mapping
Litter/Damage Detection
Mapping Water or Hydrology
Drones for Monitoring Change over Time

> "Doing that kind of detailed mapping work from aerial photography, habitat mapping is definitely one area where I think, feel, they could be useful" **A**

> "I think they're going to be more widely used. Particularly for habitat mapping, they're going to be brilliant." **C**

The most common specific application of drones that was mentioned was the use of drones for the assessment of habitat features, quality and structure (RP4). This is one of the most common uses of drones in the literature and is generally seen as one of the applications that drones are most suitable for, being able to achieve more accurate, reliable results than other methods (Forsmoo *et al.,* 2018; Inoue *et al.,* 2014; Getzin, Wiegand and Schöning, 2012) (RP5). Habitat mapping specifically was mentioned in multiple interviews.

> "Some have had the mention of doing vegetation mapping on meadows, because we've got a lot of meadows […] and there was some indication that you might be able to do some species ID on that one, or at least structure, so some survey work you can do is looking at structure in the fields and how dense it is, how tall it is." **R**

> "What we're really interested in doing is monitoring habitat quality […] we're interested in all of the potential metrics you might use to assess habitat quality." **P**

> "Certainly invasive species as well. There's quite a few invasive species that are very clear from a drone. So things like Crassula, floating pennyworth that are very bright green compared to surrounding vegetation, especially at the right time of year." **J**

Multiple applications of drone-based mapping data were mentioned, including the quantification of vegetation features, such as tree height or habitat cover, planning specific conservation actions such as the removal of particular species or sections of a habitat, or using certain metrics, such as the absence of invasive species, to gain a general feel for the quality of the habitat on-site.

> "A couple of our sites are rewilding projects so we can monitor things like scrub coverage, so that's also good for, like, stewardship agreements where we have to keep the scrub below 5 or 10% and [drones] can give us a more accurate estimate than trying to measure the scrub on the ground. Things like bare ground as well." **H**

Scrub cover in particular was brought up in a few interviews as an area of interest (RP5). Scrub is an important habitat type, often acting as an ecotone between woodland and more open habitat, and contains diverse communities and species that greatly increase biodiversity (Gimingham et al., 1979), making it a potential topic of interest for conservation groups.

> "Also when we've done things like river restoration where we've taken rivers out of culverts and things like that, you could potentially see changes like, not only in where the water is blowing and standing at different times of the year but also in terms of like, where it's going to go in terms of, if you have flooding, or if you have a bad year for water levels, then where is it going to disappear first." **H**

> "Also nesting herons, we've tried, and standing water as well, so where water is sitting on the site so that works quite well." **E**

Another aspect of habitat mapping that was mentioned, although not as prevalent as vegetation mapping, was mapping water levels, or hydrology (RP6). Drones were mentioned to be useful for identifying and mapping standing water, as well as potential areas at risk of flooding.

> "I think the potential exploration of thermal imaging for finding scarce species, and curlews a particularly good example; they're a real conservation priority, they tend, in our part of the world, to be in massive hay meadows with three-foot-tall grass. As you might know, they become impossible to find once they've got eggs, so the idea of being able to go up 200 feet out of the way, where you won't cause any disturbance and get a good- a good look at them would be very valuable" **S**

> "On a day-to-day level, it could help us with operations like checking on livestock. We have livestock on our grassland nature reserves and they get checked by volunteers and staff. If there's a way to do that using drones then I guess that would be an efficient way to do it." **E**

Outside of habitat mapping, the use of drones for tracking animals was also mentioned in multiple interviews (RP7). Monitoring of both grazing livestock and wild animals, particularly birds (RP8), was brought up as a potential use of drones, as well as the potential for animals to be identified quicker, more accurately and with less disturbance than existing, ground-based methods (RP9).

> "As a collaborative partner the Trust is involved in the lowlands curlews working group and we have used drones for looking for nests in dense vegetation using thermal imaging." **S**

> "With large flocks of birds, if you want to very accurately count numbers, using photography or video from drones might be very useful for that rather than guesstimating at the time." **A**

Technology such as thermal imagery or real-time tracking of animals was also mentioned in multiple interviews (RP10), as well as identifying the presence of particular animal species through indirect signs such as nests or burrows.

> "For a number of our sites that are, say lowland meadows or chalk grassland where we've been trying to restore them from a condition where they've been quite heavily scrubbed over, seeing change over time using them [drones] would be helpful because you could compare back to see what was the extent of the scrub versus the grassland was." **E**

> "Looking at canopy cover, it would be very useful to start thinking about their use in the way that we use fixed-point photography, so you could look at habitat change and habitat mosaic change over time" **S**

> "So for particular species, especially breeding or nesting species on-site, I think it would be very important, or very interesting anyway, to be able to look at those year-on-year and see 'Are we preserving what we actually want to preserve?' or are we just throwing a whole bunch of money into it, and losing them anyway" **D**

The final main use identified within the assessment of habitat features was investigating how habitat and animal populations change over time. This is important for measuring the impact of any conservation action, but can sometimes be overlooked in favour of more exciting aspects of conservation that are more likely to attract funding.

Theme 3: High Interest in Drone Potential

Table 8. Codes present within the 'High Interest in Drone Potential' Theme

Codes
Drones have High Potential
Desire to use Drones More
Lots of Applications
A Growing Field

> "We do use drones occasionally but not a huge amount, we're hoping to expand that. We think there's a lot they could do." **E**

> "I think that drones, in general, have lots of potential, from a constructive, planned approach are going to be really good in the future, again, I don't exactly know how, but yeah, definitely very interested." **C**

As well as interest in specific applications and benefits of drones, there was also a general belief that drones have a lot of potential in the field of conservation, even if the participants were unable to identify any specific uses. This theme ties into one of the themes regarding potential barriers to drone use, which is a lack of available knowledge about drone capabilities. However, it does show that this lack of knowledge has not dampened enthusiasm regarding drone use.

> "It seems to me a burgeoning field that ought to offer huge opportunities for us" **S**

> "So, I'm pretty certain they're going to become more common, more used and become a new field in conservation that we haven't really used before. And we definitely want to be there, to be involved and in on all that when it happens." **D**

> "Yeah, there's loads [of applications]. I think they're going to be more widely used […] so just generally it seems like there's lots of applications and lots of potential there I think." **C**

Some of the participants referred to how quickly drone technology and its use was expanding, and how the field as a whole is continuing to grow, showing interest in future drone applications.

3.3.3 Potential Problems with Drone Use

Theme 1: Inaccessible Drone Knowledge

Table 9. Codes present within the 'Inaccessible Drone Knowledge' Theme

Codes
Drone Literature is Inaccessible
Inaccessibility to Non-Specialists
High Complexity of Drone Use
Uncertainty Regarding Drone Capabilities
Romanticised Image of Drones

> "I think it's probably relatively simple to go and collect data, but then how we actually make use of that, we're still yet to learn and I think its [Pause- 2 seconds] It's not yet as accessible to relatively non-specialist people I guess. How we actually go about making use of the data" **P**

> “I think at the moment they’re probably not being used to their full potential […] I think the main barriers being around the complexity of training and people not really being sure what they’re doing” **A**

People are unsure what exactly drones can do, with the main literature on drone capabilities taking the form of experiments published in peer-reviewed journal articles, or books, which can be inaccessible due to cost (RP11). This can make information on how to use drones difficult to find or obtain without a significant time or cost investment, which can make people less likely to start using drones as part of their conservation efforts as they don’t know what they can do, despite potentially having problems that drones could help to solve (RP12).

> “I mean it’s probably just the industry in general, but I’ve seen claims that these things can do magic, that they can do everything you want. Um, so it’s probably good to be realistic about what drones can achieve” **J**

> “The challenge is unlocking that potential now we have the equipment; how can we best apply it to greatest effect? Within the organisation, I guess lots of- lots of colleagues see the fact that we’ve got this thing now and everybody’s like ‘oh, can we use it for this? Can we use it for that?” **P**

Multiple participants also felt that there were unrealistic expectations regarding drone capabilities, such as overestimating their abilities or underestimating drone limitations. This romanticised image of drones in conservation could then later lead to wasted resources spent on drone technology that cannot help them, as well as disappointment if drones do not meet that image, leading to a backlash against them and a souring of perceptions of drones within the industry. This makes it very important to be honest about drone limitations, and not to build up their potential to an unrealistic level.

> “It would be good if there was a bit more communication between the people who were doing it and what they learnt, as well.” **J**

One solution to this problem would be better, more accessible resources and summaries on drone capabilities and limitations, or teaching people about drones so that they know whether or not drones could help them. Another option could also be some way for people to use drones for themselves without a large initial investment, such as helping out on existing projects involving other organisations that already use drones or test flights.

Theme 2: Complex Legality and Bureaucracy Regarding Drone Flights

Table 10. Codes present within the 'Complex Legality and Bureaucracy Regarding Drone Flights' Theme

Codes
Complexity of Drone Licensing
In-Depth Training Required
Difficulties due to Frequent Legislation Changes
Legal Restrictions

> "[A problem is] Maybe licensing, depending on the sites. I know Natural England do use drones so yeah, hopefully that will get easier but yeah certainly I think licensing will be the hardest and most complicated bit definitely." **C**

The last major theme in the analysis was potential problems around the legality of flying drones and the bureaucracy needed to achieve the relevant permits and licenses.

> "I was put off by the pretty, well it seemed like pretty in-depth training and maintaining log books and all the rest of it." **A**

> "Well, you've probably found that the current licensing scheme is very difficult, so it will take people a long time to get qualified" **J**

Drone flights can require a lot of permissions and licensing, especially when being conducted for commercial operations. Obtaining drone qualifications which allow you to carry out flights can be time-consuming and costly, which can be off-putting, especially if there is a risk that the drone will end up not being as useful as predicted (RP13). It also deters people from trying out drones, as this cannot be done without a large investment.

> "Well, I've been stuck in a holding pattern for more than half a year now because of the changes that are upcoming regarding commercial uses of drones […] I don't have permission for commercial operation, I was planning to have that, to wait until the new legislation around commercial use came into force and that's no longer a distinction" **A**

Legislation changes can also have an effect. Often if legislation changes are upcoming, especially ones that will invalidate previous permissions or require new training, then it is easier to wait for the new legislation to come into effect, which can delay drone use in conservation.

> "I know they potentially may be changing the restrictions again, but I'm not too sure about that. I think it may be regulations and legal requirements that are the main thing stopping us." **G**

If legislation changes too frequently, it can also prevent people from flying drones, as they may not be sure of what the current legislation is, or keeping up with the constantly changing regulations may be too much hassle.

> "We have one nature reserve for example, which is no more than 300m from the end of an airport runway. So that site would never, ever be able to use a drone on it. it's just not going to happen. So there are- we have those restrictions." **T**

> "The main problem we were coming across was basically landowner permission. We would like to fly and map a lot of areas ideally, just so we know what we've got to work with because we don't actually know what the land cover across the county is, and the only way to know that is to go out and survey it ourselves, but you're not allowed to just fly over everybody's property taking pictures, unfortunately." **G**

Finally, existing legislation based around safety and privacy concerns may prevent conservation groups from carrying out drone flights on some or all of their sites. The interviews revealed a variety of ways in which drone restrictions could prevent flights, from not being allowed to fly over uninvolved people, to not being able to fly in restricted airspaces, to difficulties in obtaining land-owner permission, the latter of which could be a problem considering the shift to landscape-scale conservation, which often involves looking at larger areas that could be owned by multiple different people rather than specific sites owned by conservation groups

3.4 Discussion

3.4.1 Theme Exploration and Consistency

This study explored the views of Wildlife Trust employees from a range of different Trusts. The most commonly ocurring subject was the idea of resource efficiency. Both of the main themes regarding the current challenges in UK conservation are related to a lack of resources, from time and money to specialist personnel. All of these issues link together, in that an increase in funding would allow for the hiring and training of more personnel, allowing the existing work to be divided up between more people, reducing individual workloads and allowing for more time for additional conservation work to be carried out. One of the main perceived benefits of drones identified in the analysis also ties into the idea of resources, as the high resource efficiency of drones over existing ground-based methods would be highly valuable in the resource-limited environment these groups work in. Drones could allow for more conservation actions to be carried out more quickly and with fewer people required, freeing up time and personnel. The study also identified a high level of interest in drone technology and its potential, with a primary focus on the mapping and assessment of habitat features. This aligns with research on drone capabilities (Calvo, 2016) as well as the systematic review, and also ties into the shift towards landscape-scale conservation, which requires large amounts of data on habitat structure and species populations (Lawton *et al.,* 2010).

The main potential problems of drone use identified in the study seemed to support the idea of drones being useful to conservation groups, as they were not problems regarding the accuracy, speed or resource efficiency of the data drones could provide. Rather, the main problems identified in the interviews were based around a lack of clarity and available information on how to use drones, both in terms of what they can do, and in terms of how to navigate the bureaucracy around using them. This suggests that one of the ways to best help conservation organisations regarding drone use would be the development and dissemination of clear informative guidelines on drone capabilities, how to use them, and the various restrictions and regulations around their use. It's possible that there are other potential problems with drone use that weren't identified in the study, and that the lack of knowledge regarding drone capabilities meant that the participants weren't able to identify these problems. Another study focusing specifically on conservation group employees who have used drones multiple times, or are otherwise familiar with drones, may identify these problems, which would also need to be considered when using drones for conservation.

Overall, the themes identified had a high level of consistency across the Trusts, with all of the main themes present in seven or more of the 11 interviews, suggesting that the problems with conservation, as well as the potential benefits and problems of drone use, are similar across the country. The decision to focus purely on employees of one conservation organisation; the Wildlife Trusts, may potentially make the results of the analysis less applicable to other conservation groups. However, the consistency of the main themes across the majority of the interviews would appear to indicate that these themes would apply to other UK conservation groups with similar goals, although more research on the differences between UK conservation organisations, or more analyses featuring participants from other conservation groups would need to be carried out to be certain.

The findings of the thematic analysis are novel, varying significantly from the findings of the literature, especially when looking at the main problems with drone use. Problems with a lack of knowledge on drone use and legislative issues were both almost entirely absent from the literature, which focused much more on the technical limitations of drones. This highlights the importance of working with conservation groups directly, and allows concerns which were not identified in the literature, but that are highly prevelant within the wildlife trusts, to be incorporated and assessed in future research.

3.4.2 Strengths of Research

The chosen methodology of online qualitative interviews was a good fit for this study, as it allowed a wide range of viewpoints and opinions to be collected, and a deeper level of understanding to be reached regarding the research questions. The open-ended questions allowed participants to more easily share their points of view and provided opportunities for probing questions to expand on particular topics or statements. Closed questions or a questionnaire would not have been able to collect information with as much detail or richness.

Thematic Analysis was likewise a suitable form of analysis, allowing for a large amount of data to be analysed quickly, and for key information on the views, beliefs, and opinions of the participants to be easily extracted. The information is also analysed in a very consistent and rigorous way, which increases the scientific validity of the results, and reduces the chance of bias due to insider research.

3.4.3 Limitations of Research

One main limitation with the method, and any kind of data collection based on voluntary participation, is that only people who are willing to talk about the issue will sign up. This leads to an increased chance of the participants having a vested interest in the issue, which could skew results. However, a possible counterpoint to this is that one of the most prevalent themes was a lack of knowledge regarding drones and their capabilities, which would not be expected in a participant pool with a vested interest in drones.

One limitation was the lack of participants. Although 11 is considered more than enough of a sample size for this kind of research, more participants would have allowed for a greater number of opinions that may have identified further themes that were not present in the

Wildlife Trusts that were interviewed. An aspect of the interviews that was not explored due to this limited number of participants was the difference in conservation needs between rural and urban conservation organisations. Two of the eleven interviews were with employees of the London Wildlife Trust, and although some of the themes were the same, such as an issue with the legality of flights, especially due to restricted air space, there were also several issues raised that were unique to those two interviews, such as problems regarding having the space to establish conservation areas and the amount of damage the public could cause. Because of this, the information and themes identified through the majority of these interviews can only necessarily be considered relevant to rural areas and more research would need to be done on urban areas to understand the unique problems they may face when integrating drones into their conservation work.

Finally, it is essential to bear in mind the ever-changing state of conservation. Policy changes and new publications can vastly change the way conservation is perceived and carried out, as evidenced by the shift to landscape-scale conservation and the recent changes in policy (Environment Act, 2021; Natural England, 2016), which may impact conservation over the next few years.

3.5 Conclusion

In conclusion, this study explored Wildlife Trust employees' views and beliefs on the current challenges in UK conservation, as well as the potential benefits and problems when using drones in UK conservation.

The current state of conservation was found to be defined by a lack of resources such as money, staffing, and time, which limits the amount of conservation work that can be carried out. Drones were believed to have several advantages over ground-based methods in terms of resource efficiency and accuracy, particularly for habitat mapping and the assessment of habitat features. The main problems identified during the interviews regarding drone use primarily focused on the complexity of their use, both in terms of the inaccessibility of drone information, and the complex legal and bureaucratic systems around licensing and flying drones.

Whilst the methodology of the study was strong, allowing for a wide range of detailed information to be acquired and analysed, potential limitations due to the lack of participants meant that the findings of the study are not necessarily applicable to more urban-based conservation groups, and any results obtained may become less relevant as time goes on due to changes in the state of conservation.

These conclusions will be carried forward and compared to information on drone capabilities identified in the systematic review. Points of overlap will then be identified and case studies developed based on those points of overlap. Considerations brought up in both the interviews and the systematic review will also be incorporated into the case studies, to ensure that the case studies gather data relevant to the incorporation of drones into conservation organisations.

3.6 Development of Case Studies based on Systematic Review and Interview Findings

With the information from the systematic review showing the capabilities of drones, and the interviews identifying conservation views and beliefs regarding drones, information from both sources was compared to identify points of overlap that could form the basis for practical projects. These projects would evaluate how drones could be of use to conservation organisations, how to deal with the logistical concerns or potential problems outlined in the systematic review and interviews, and how drone-based methods compared to existing methods.

Both the systematic review and the interviews mentioned vegetation structure and animal monitoring as two areas where drones could be useful. Hydrology was also mentioned in both the systematic review and the interviews, although to a lesser extent. In terms of potential problems with drone use, the systematic review and interviews varied in their conclusions, with the literature citing a dependence on good weather conditions, potential issues caused by disturbance, and a lack of accuracy and precision in particular areas, such as physical sampling and bioacoustics, as the main problems with drone use. In contrast to this, the interviews identified a lack of knowledge regarding drones and the complexity around legally flying drones to be the main problems with drone use. Because of this, areas where drones were found to lack precision and accuracy over existing methods were avoided. Issues due to weather, disturbance, ease of use, and legal issues were also noted down to be compared to existing ground-based methods, as well as time, cost, and accuracy comparisons.

It was also important that all of the case studies addressed actual conservation concerns or worked towards existing conservation projects within the Wildlife Trusts, to ensure that the findings could be applied, rather than being theoretical. A decision was made to work specifically with the Gloucestershire Wildlife Trust, due to existing contacts within the organisation and the proximity of their sites, with most of their sites being located within an hour's drive.

It was decided that three case studies would be carried out. To match up with the information collected in the systematic review and interviews, and to ensure a good range was obtained across the case studies, it was decided that one of these case studies would focus on vegetation structure, one would focus on animal monitoring, and one would focus on hydrology. After comparing these criteria with the current conservation needs of the Gloucestershire Wildlife Trust, the following case studies were developed:

- Assessing the level of scrub present at Daneway Banks, and how it compares to previous years.
- Counting grazing livestock and other warm animals at three sites; Crabtree Hill, Edgehills Bog and Wigpool.
- Quantifying seasonal changes in the extent of surface water at two sites; Ashleworth Ham and Coombe Hill

The following three chapters will explore each of these case studies in more detail and lay out the methods used and results obtained from these case studies, as well as how they compared to existing methods and how any of the concerns raised in the systematic review and interview affected the project.

4 Case Study 1: Mapping Temporal Changes in Scrub Cover

4.1 Introduction

4.1.1 Effective Conservation Management

Conservation organisations often develop objectives to guide them towards improving habitats and restoring populations. The development of objectives is based on knowledge of the species or habitat and when working towards an objective, progress needs to be monitored. For example, a common management objective is maintaining suitable habitat for a particular species, this objective is based on the knowledge that certain environmental conditions provide suitable habitat and progress is monitored through the assessment of those environmental conditions. Habitats and sites are highly dynamic (Zeller *et al*., 2020), meaning that this monitoring must be carried out regularly to ensure that any information collected on the site is up-to-date. This information then allows conservation organisations to constantly evaluate their progress and adjust their management plans. This would in turn lead to more effective meeting of conservation objectives, as well as more accurate estimates as to when conservation objectives will be met, allowing targets to be pushed back or moved forward as the rate of progress changes and better informing future management objectives (Pullin *et al.,* 2013; Kapos et al., 2009).

4.1.2 Scrub Cover

An example of one of these objectives involves the maintaining of scrub cover at particular levels. Scrub is an important habitat type, often acting as an ecotone between woodland and more open habitat and containing their own diverse communities and species (Gimingham *et al*., 1979). The Joint Nature Conservation Committee (JNCC) defines scrub as 'all stages from the scattered bushes to closed canopy vegetation… usually less than 5 m tall' (Mortimer *et al*., 2000). This encompasses a wide range of vegetation, including shrubs, bushes, and young/short trees. Often, scrub habitats are found in areas in a state of ecological succession from open habitats such as grassland, to woodland, although scrub can also be part of climax vegetation. Scrub edge is often rich in flowering plants, tall grasses and herbs which are essential for numerous small mammals and insects (El Balti, 2021). Scrub can also increase the biodiversity of a site, often having more species variety than woodland, and can act as a suitable alternative habitat if a species is displaced from its natural habitat (Keith *et al*., 2014; McArthur *et al*., 2007).

However, too much scrub can start encroaching on existing woodland and grassland habitats and, if not managed, the scrub can succeed into woodland, which would not be suitable habitat for many grassland and heathland species. Because of this, a lot of UK site management goes into scrub control and the managing of scrub levels, and many site designations, such as sites of special scientific interest (SSSIs) and special areas of conservation (SACs) have conditions related to maintaining and managing suitable amounts of scrub on a site. As part of this, it is important to know how scrub levels are changing on a site over time as a result of scrub management, to know whether more or less scrub management is required, as well as to ensure that current scrub management methods are having an effect.

4.1.3 Case Study Aims

This case study aims to evaluate the effectiveness of drone-based photogrammetry to measure scrub cover and how it changes over time at a nature reserve, and how drone-based methods compare to existing structured walks.

4.1.4 How this Case Study ties into Previous Work

Scrub assessment and monitoring was identified as a useful application of drones in the systematic review (Breckenridge *et al*., 2011)and the monitoring of vegetation structure was the most common use of drones identified within the literature (Hyyppä *et al*., 2020; Ancin-Murguzur *et al*., 2019). Vegetation structure was also an area of interest identified in the interviews (RP4), with scrub specifically being mentioned by multiple conservation practitioners (RP5).

The Gloucestershire Wildlife Trust and Royal Entomological Society also have an interest in monitoring scrub levels at Daneway Banks, to help meet scrub management objectives.

The study will involve a comparison of existing ground-based methods in terms of accuracy, but also logistical concerns identified in the systematic review and practitioner interviews including weather dependency, disturbance to wildlife and the public, survey duration, cost (RP1), and any legal issues (RP13).

4.2 Methods

4.2.1 Study Site

Daneway Banks (Grid Reference SO939037; Figure 4) is a nature reserve located in Gloucestershire.

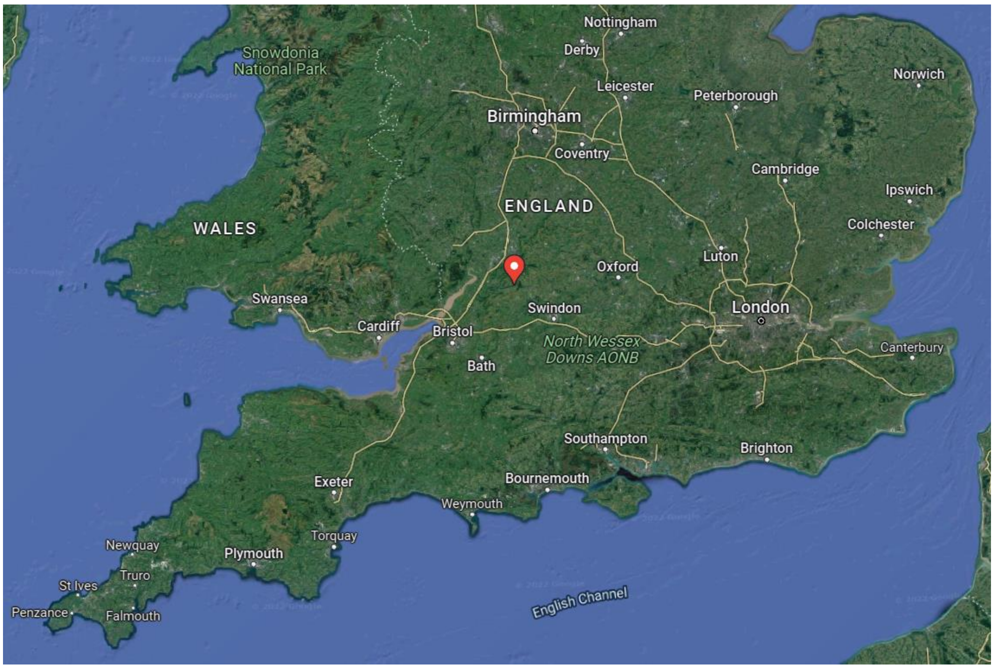


Fig 4. Location map for Daneway Banks (Daneway Banks marked with red pin)

The site is 16.9-hectares and is designated as an SSSI as a representation of species-rich unimproved grassland on calcareous and neutral soils. The site is also comprised of areas of woodland made up primarily of European Beech (*Fagus sylvatica*), Common Yew (*Taxus baccata*) and Common Whitebeam (*Sorbus aria*), and scattered scrub including Blackthorn (*Prunus spinose*), Common Hawthorn (*Crataegus monogyna*) and Dog-rose (*Rosa canina*). Topographically, the site is a south, south-east facing hill, with the height of the site varying from 122m above sea level at its lowest point, to 175m above sea level at its highest. The site is grazed by sheep and ponies from mid-autumn to spring to keep the sward height low and is left ungrazed through spring and summer (Royal Entomological Society, 2021). Manual removal of scrub is also carried out regularly. The goals of the site are to maintain scrub levels both within and on the edge of the calcareous grassland, due to it being an important habitat for bird and invertebrate species, whilst keeping overall scrub levels below 10% (pers. comm) and ensuring that excessive scrub levels are controlled (Natural England, 2003).

4.2.2 Drone Flights

As well as the most recent dataset collected in 2021 as part of this thesis, previous datasets collected via drone flights in 2015 and 2017 were used in this case study to assess temporal changes in scrub cover.

A different drone was used for each of the Daneway Banks datasets. Drone choice was determined by availability and to ensure comparable outputs. All flights were pre-programmed with 80% photo overlap so orthomosaics could be easily created from the photos, and all images were saved as tagged image file format (tiff) on SD cards.

2015 and 2017 Datasets

The Daneway Banks 2015 flights were carried out on July 8th, 2015. A fixed-wing aircraft UAV equipped with an ILCE – 5000 19MP camera was used for these flights. The flight was a pre-programmed transect (Figure 5) and a total of 468 photos were taken across a single flight, with an average ground sampling distance (GSD) of 4.42cm/px. Of those 468 photos, 467 were incorporated into the dataset, with one photo unable to be calibrated.

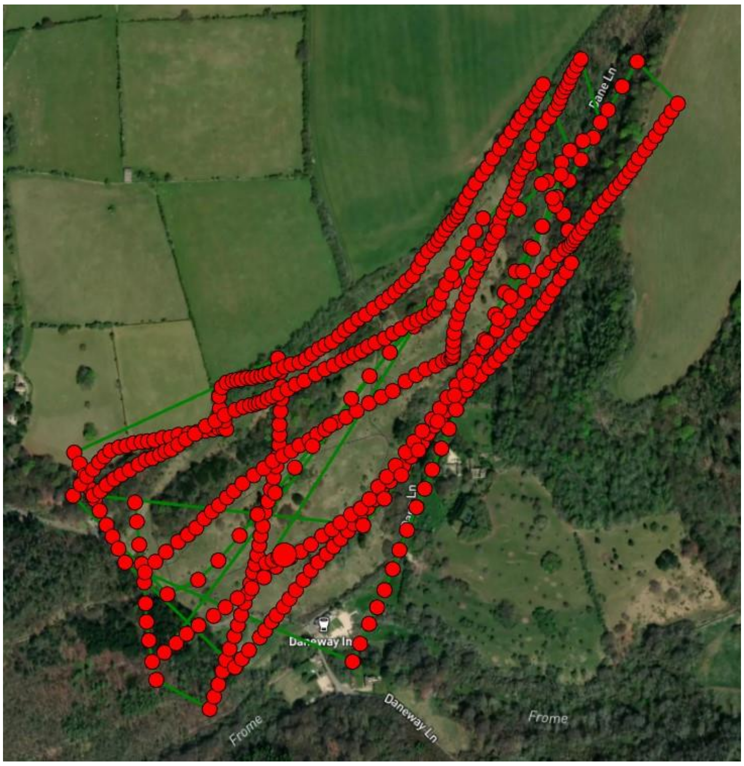


Fig 5. The Flight Path and Photograph Locations for the 2015 Daneway Banks Drone Flight

The Daneway Banks 2017 flights were carried out on July 3rd, 2017. A DJI T600 Inspire 1 quadcopter was used for these flights, equipped with a 12MP Zenmuse 3 RGB camera. Pix4D Capture (Pix4D, 2022) was used to pre-programme double grid transects that the UAV would follow (Figure 6), to allow for 3D modelling of the site. 1,127 photos were taken across five flights at a height of 50m, with an average GSD of 2.49cm/px and a total flight time of 78 minutes. Of those 1,127 photos, 1,119 were incorporated into the dataset, with eight photos unable to be calibrated.

Fig 6. The Flight Path and Photograph Locations for the 2017 Daneway Banks Drone Flights

2021 Dataset

The Daneway Banks 2021 flights were carried out on May 28th, 2021. A Mavic 2 Zoom quadcopter was used for these flights, using a 12 MP 1/ 2.3" CMOS RBG sensor. As with the 2017 flights, Pix4D Capture (Pix4D, 2022) was used to pre-program double grid transects that the UAV would follow (Figure 7), to allow for 3D modelling of the site. In total, 828 photos were taken across five flights at a height of 25m, with an average GSD of 2.53cm/px. A lower height was chosen to allow for a more comparable GSD to the 2017 flights. The total time to carry out the flights was 1 hour and 20 minutes, and the total flight time was 41 minutes. Of that 1 hour and 20 minutes, no flights could be carried out during the first 25 minutes due to light rain. Of the 828 photos obtained, 821 were incorporated into the dataset, with seven photos unable to be calibrated.

Fig 7. The Flight Path and Photograph Locations for the 2021 Daneway Banks Drone Flights

4.2.3 Field Survey

As a comparison, a ground-based scrub cover survey was carried out on May 28th 2021 using a structured walk approach, as recommended by Common Standards Monitoring Guidance (Joint Nature Conservation Committee, 2019). This walk took the form of a 'W' shape to ensure that the majority of the site was covered. The total length of the walk was 900m.

Starting at the beginning of the walk, and at 100m intervals, a visual inspection was made and estimates about the percentage cover of 'Grass and Bare Ground', 'Scrub', and 'Trees' were made. These categories were used to ensure comparability with the drone flight data. In total, ten points were surveyed along the walk (Figure 8), and the total survey time was 1 hour and five minutes.

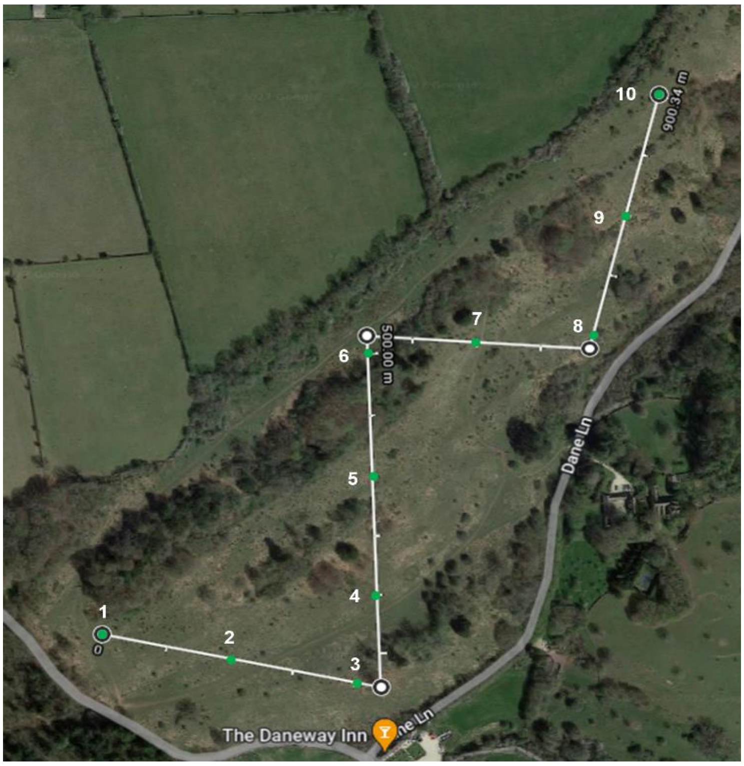


Fig 8. The Structured Walk Route for Daneway Banks, with Numbered Survey Points

These scrub cover estimates were then qualitatively analysed to estimate scrub cover across the whole site. An alternative analysis method was also carried out in which all land cover values were averaged to obtain a value for the whole site. This approach is less accurate however, as it treats the land cover values as consistent across the whole site, rather than recognising areas of varied land cover throughout the site and intra-site communities and micro-habitats which could affect vegetation levels in different parts of the site.

4.2.4 Data Analysis

Pix4D Mapper (Pix4D, 2022) was used to create geo-referenced orthomosaics of the site, using densified point clouds (Figure 9) from which an orthomosaic could be derived.

Fig 9. A 3D Model of Daneway Banks and the Surrounding Area created using a Densified Point Cloud

Digital surface models (DSMs) and digital terrain models (DTMs) were also created using height information collected by the drones during flight.

The DSMs and DTMs were exported as raster tiff files and imported into ArcGIS Pro 2.7 (Esri, 2022). The raster calculator tool was used to subtract the DTM from the DSM to remove any topographical variation and obtain a vegetation height raster.

The vegetation height raster was then classified into three height bands; Ground Vegetation and Other Surfaces (minimum height value to 1m), Scrub (1-5m) and Other Vegetation (above 5m). This classification was used based on ground verification of the shortest scrub found on-site and using the definition of scrub established by the JNCC (Mortimer *et al*., 2000). An attribute table was created looking at the total cover of each of the three height bands across the site. The percentage area of this cover was then calculated using the following equation:

$$\textbf{(Size of feature (m}^2\textbf{)/Total Ground Cover (m}^2\textbf{)) x 100}$$

To quantify temporal changes in scrub cover over time, these percentage values were then compared to each other, and the percentage increase or decrease in scrub cover between datasets was calculated.

To identify specific patches of scrub that had grown or been lost over time, the scrub height band for each dataset was isolated using the 'Setnull' tool to change all other values to null. These isolated scrub raster layers were then combined using the raster calculator to give maps of scrub change from 2015-2021. Patches of scrub change were then split into areas of scrub growth or areas of scrub loss and coloured, to allow for easy assessment of scrub loss and growth.

To identify the direction of change for both scrub growth and scrub loss, the ground cover raster for the 2015 and 2021 datasets were reclassified to give each category of ground cover a unique value. The following equation was then used to give a unique value for each direction of change:

$$\mathbf{X_{(Change)}=X_{(2021)}-X_{(2015)}}$$

The Setnull tool was then used to change all values that did not relate to the creation or loss of scrub to null, leaving a map showing only where the ground cover changed to or from scrub. Attribute tables were then created showing what percentage of the area fit into which category.

4.3 Results

4.3.1 Drone Flight Data

The total area of the Daneway Banks Nature Reserve is 16.927 hectares (Natural England, 2012) or 169,270 m^2. For 2015, the on-site scrub was comprised of 1,533 separate stands, with a size range between 0.03 m^2 and 2,170.35 m^2. The total area of scrub on the site was 24,763.7 m^2, comprising 14.63% of the total site (Figure 10).

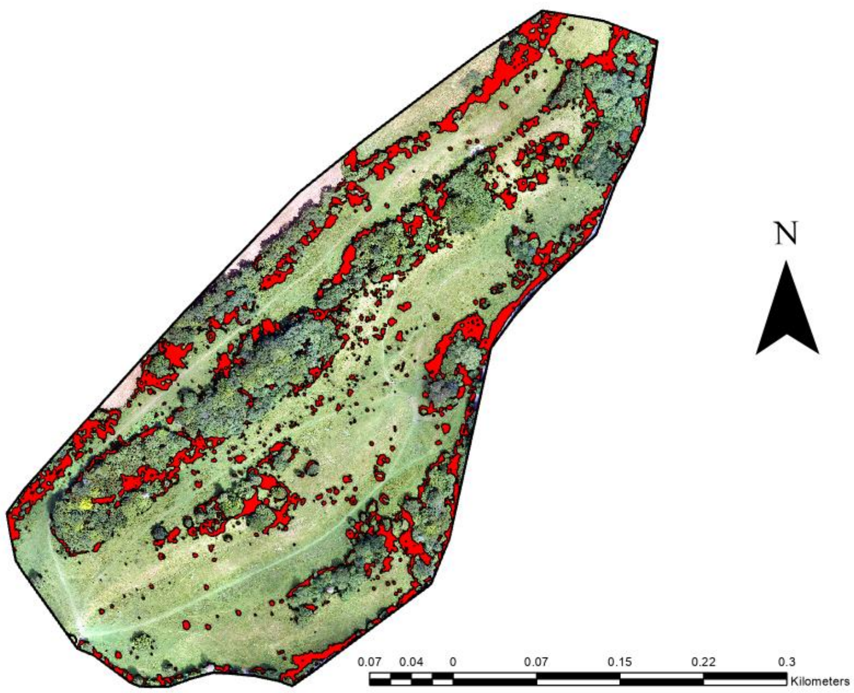


Fig 10. Scrub Cover at Daneway Banks in 2015 (Scrub coloured Red)

In 2017, there was a total of 2,555 separate stands of scrub, with a size range between $0.01m^2$ and $2,288.92m^2$. The total area of scrub on-site was $27,968m^2$, making up 16.52% of the total site (Figure 11), a difference of 1.89% and an increase of 12.92% from 2015.

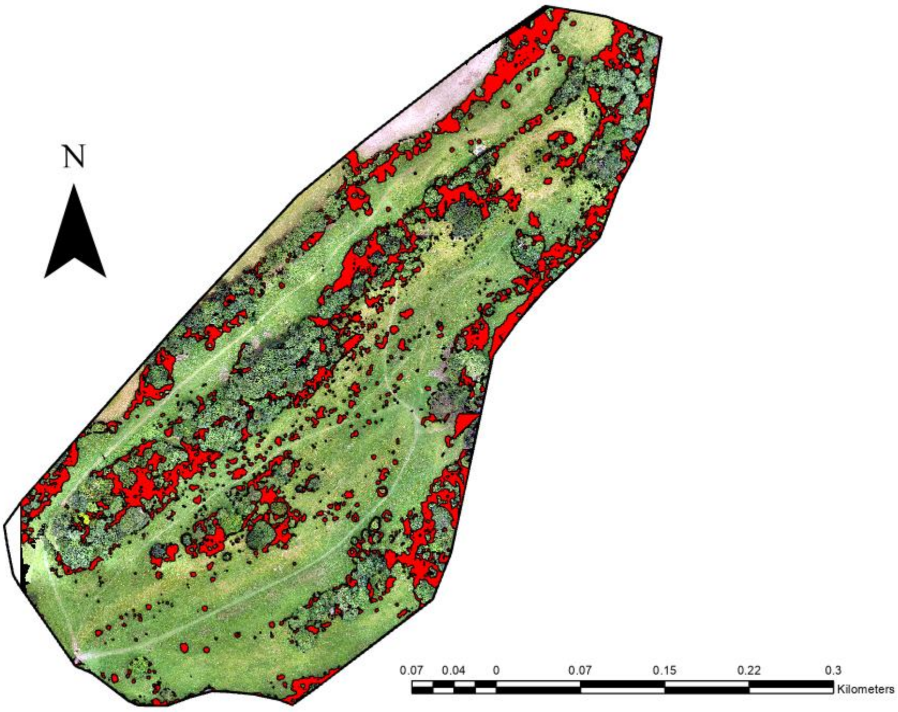


Fig 11. Scrub Cover at Daneway Banks in 2017 (Scrub coloured Red)

In 2021, there were 2,420 separate scrub stands, with a size range between 0.01 m^2 and 1,556.78 m^2. The total area of scrub on-site was 25,200.1 m^2, making up 14.89% of the total size (Figure 12), a difference of 1.63% and a decrease of 9.87% from 2017, and an increase of 1.78% from 2015.

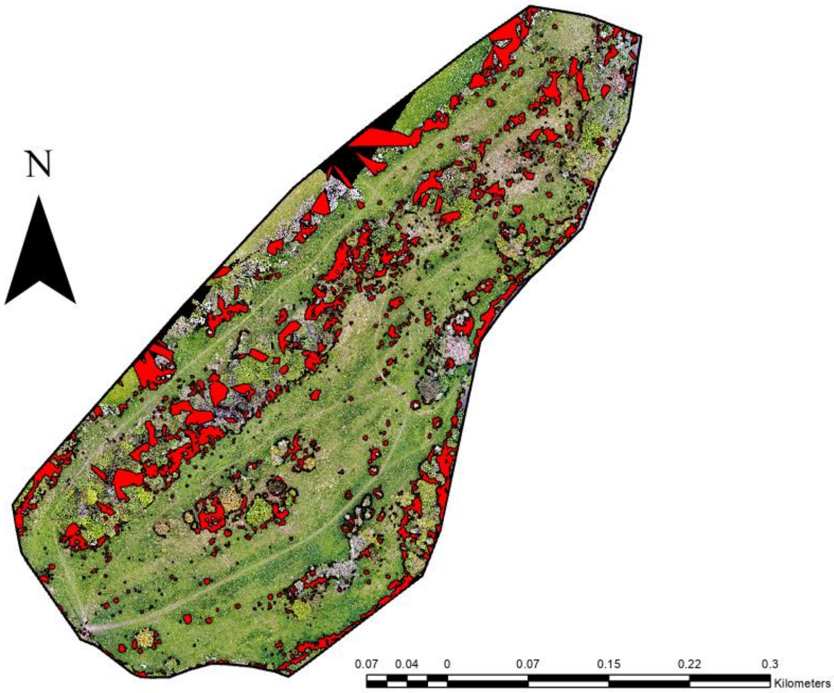


Fig 12. Scrub Cover at Daneway Banks in 2021 (Scrub coloured Red)

The total area for scrub growth and loss between 2015 and 2021 (Figure 13) were as follows:

Scrub Growth: 9,051.04m^2 (5.35% of total area)

Scrub Loss: 15,875.87m^2 (9.38% of total area)

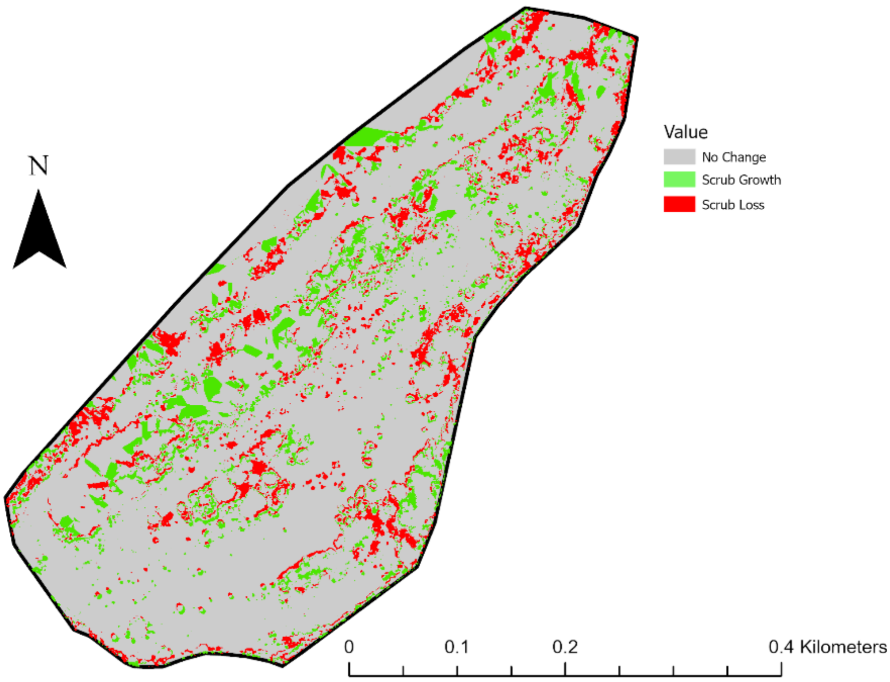


Fig 13. Scrub Growth and Loss at Daneway Banks between 2015 and 2021

When looking at the direction of change between 2015 and 2021, 57.19% (3.06% of total site area) of new scrub in 2021 was grass or bare ground in 2015, and 42.81% (2.29% of total study area) of new scrub was trees in 2015. In terms of scrub loss between 2015 and 2021, 73.73% (6.92% of total study area) of scrub lost between 2015 and 2021 became grass or bare ground, and 26.27% (2.46% of total study area) of scrub lost between 2015 and 2021 became trees (Figure 14).

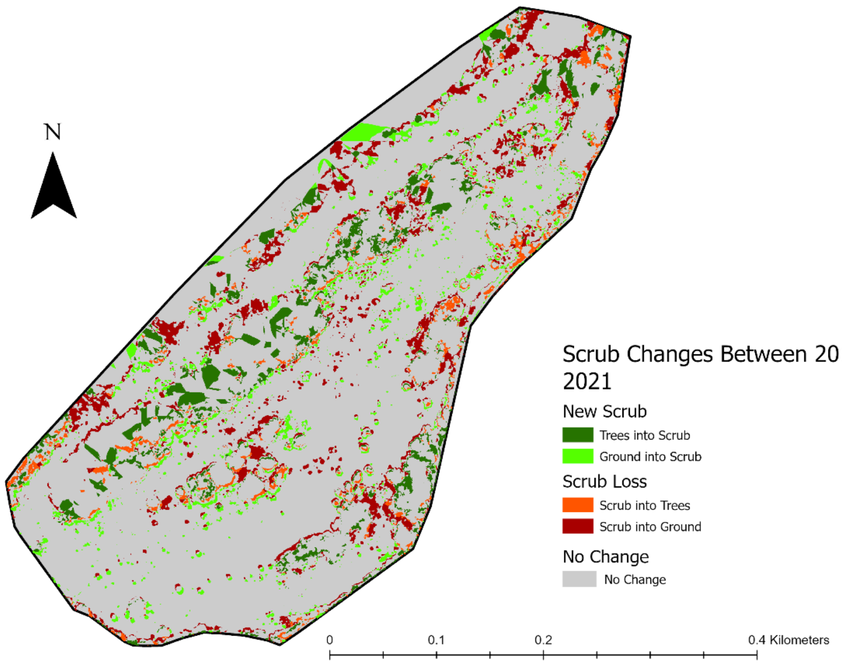


Fig 14. Scrub Growth and Loss at Daneway Banks between 2015 and 2021, including Directional Change

4.3.2 Field Survey Data

Scrub levels at all ten points along the structured walk varied from 5% to 25% (Table 11). The average level of scrub across all ten points was 11.6%, which would make up approximately 19,635m^2.

Table 11. Field Survey Data for Daneway Banks

Survey Point	Grass and Ground (%)	Scrub (%)	Trees (%)
1	80	15	5
2	95	5	0
3	85	8	7

4	80	5	15
5	65	10	25
6	55	10	35
7	70	12	18
8	85	10	5
9	65	20	15
10	55	25	20

Scrub levels were lower in the south-western area of the site, with scrub cover lower than 10% at survey points 2-4.

4.4 Discussion

From 2015 to 2021, scrub levels were found to have increased before later decreasing slightly, although at all survey times, scrub levels were above the site management goal. It was found that the drone-based scrub monitoring was more accurate than the existing, ground-based method, although the drone-based method was slower due to a dependance on good weather conditions and, whilst still being cheap, was more expensive than the structured walk. Wildlife trust employees showed a high level of interest in the method, with high potential for intergration into trust methods.

4.4.1 Temporal Changes in Scrub Cover

Scrub levels at Daneway Banks increased from 14.63% to 16.52% from 2015-2017, before dropping down to 14.89% in 2021. Whilst the decrease from 2017-2021 is due to increased managed cutting and clearing of scrub, they have still not obtained scrub levels below the 2015 survey of 14.63%, and so more flights would need to be carried out to ensure that the decline in scrub levels continued. All recorded levels of scrub are also above the target scrub levels of no more than 10%, or 16,927 m^2. Further scrub management would be needed to reduce scrub to the appropriate levels. The 2021 scrub level dataset could be used to plan the removal of specific areas of scrub, as well as help to visualise how much scrub would need to be removed to meet conservation goals. For example, the removal of large scrub stands along the northern and southern borders of the site (Figure 15) would reduce scrub levels down to 16,749 m^2, or 9.89% of the site, meeting site management goals.

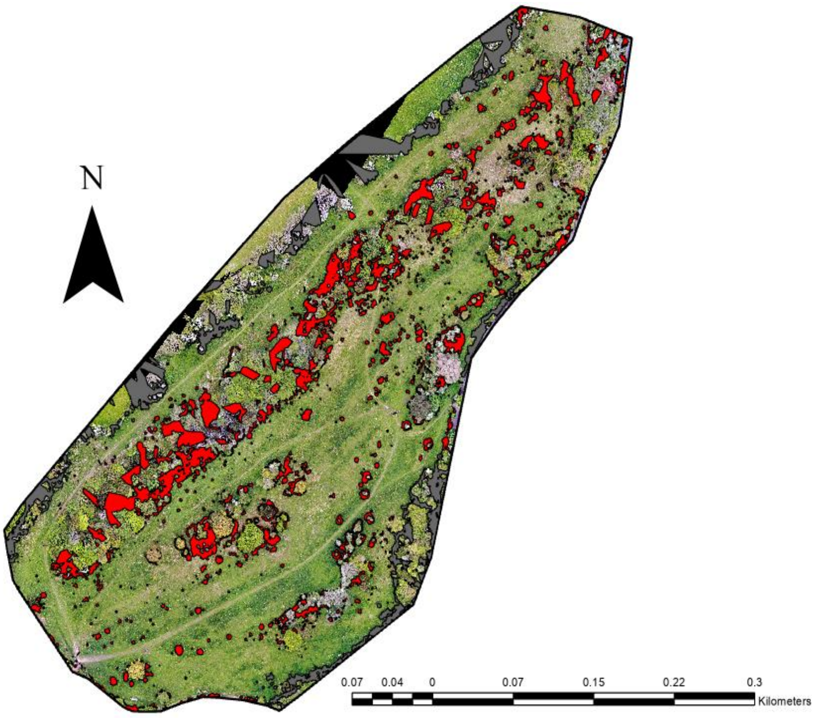
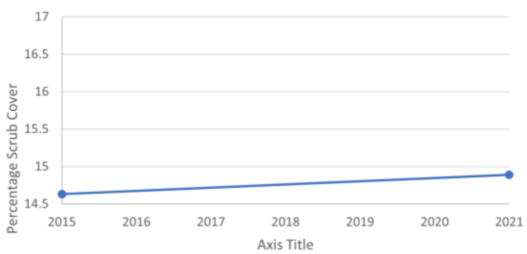


Fig 15. Potential Scrub Management Plan to meet Site Goals at Daneway Banks (Removed Scrub coloured Grey)

The results show the importance of frequent surveying, as without the 2017 dataset, it would appear as though scrub levels are slowly increasing when in actuality, scrub levels have been steadily decreasing between 2017 and 2021, a decrease which would not have been noticeable without the 2017 survey (Figure 16). More frequent surveying may highlight further variation in scrub levels and allow management plans to be adjusted more frequently to match current scrub levels, allowing for more accurate management targets.



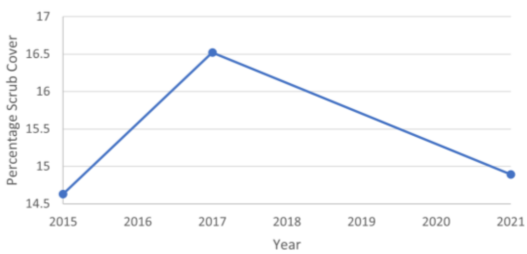


Fig 16. Changes in Scrub Cover on Daneway Banks, not including (left) and including (right) the 2017 Dataset

Assuming scrub levels continue to decrease at a steady rate, it is expected that Daneway Banks will meet its management goal of no more than 10% scrub in 2033. Without the 2017 dataset, assuming a consistent change in scrub levels, in 2033 estimates would put scrub levels at 15.41% (Figure 17). This provides a tangible example as to the importance of frequent monitoring for the accurate setting of management targets, and further surveys should be carried out regularly so management goals can be updated as the rate of change in scrub levels varies.

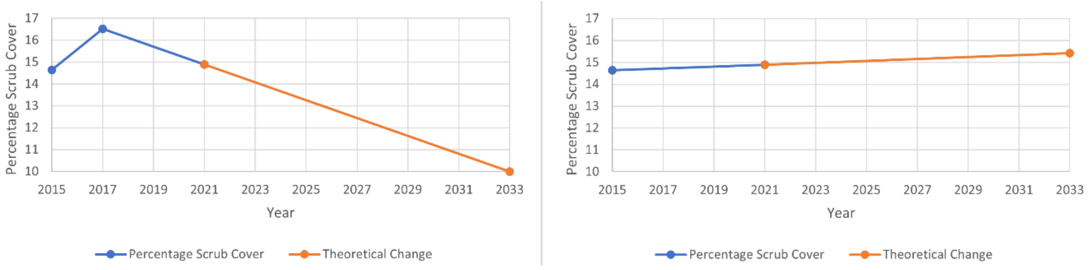


Fig 17. Theoretical Changes in Scrub Levels between 2021 and 2033 including (left) and not including (right) the 2017 Dataset

The directional change at Daneway Banks showed that increased scrub levels were occurring both as a result of new scrub growing from grassland, and scrub growing in areas that were once woodland. The latter could be undesirable on Daneway Banks due to the management goals of preserving the grassland on-site, despite it technically meeting the goal of removing scrub. Future management targets would need to specify the removal of scrub, rather than just having scrub below a certain level, which could technically be achieved by letting sufficient levels of scrubland on-site succeed into woodland. The majority of scrub loss was due to clearance or reduction of scrub, leading to increased levels of grassland, which is desirable due to the site goals of preserving open grassland.

Since the management of the site prioritises the maintaining of grassland habitat and the prevention of succession of grassland, it may be more suitable to view changes in scrub levels as a shift towards either vegetation succession or reduction, with reduction being the management goal. This approach allows an increase in scrub levels to be beneficial if it is due to tree clearance, as it progresses the site towards a higher level of open habitat, and is rare in the literature, with most research on scrub levels focusing solely on the amount of scrub cover (Charton, Sclater and Menges, 2021; El Balti, 2021), as opposed to whether the loss of scrub is causing an increase in grassland or other favourable habitat. To create maps showing where vegetation succession or reduction was taking place, the previous maps showing the direction of scrub change were reclassified, with the Ground to Scrub, and Scrub to Trees categories being combined into a Vegetation Succession Category, and the Trees to Scrub, and Scrub to Ground categories combined into a Vegetation Reduction category.

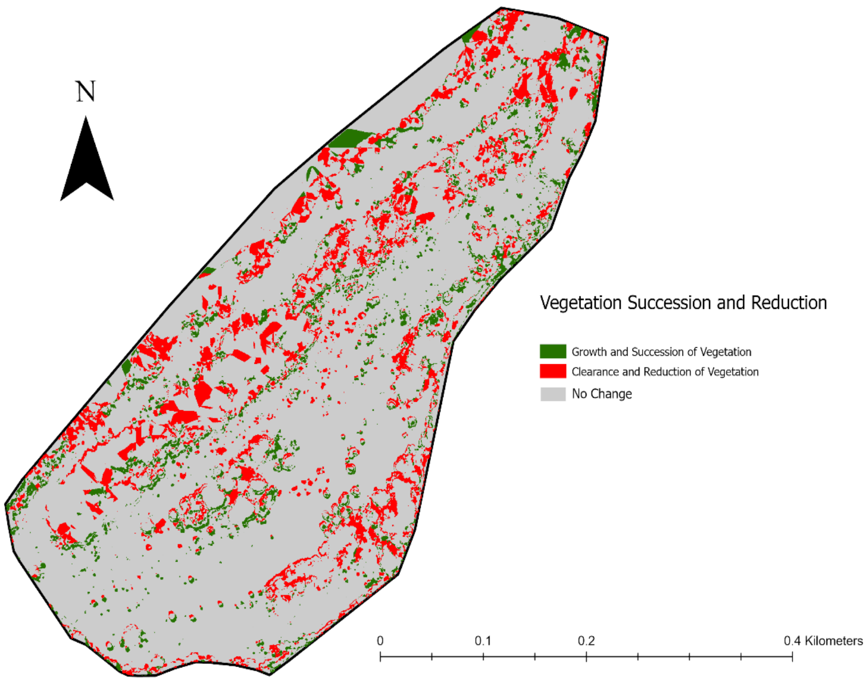


Fig 18. Scrub cover Changes at Daneway Banks between 2015 and 2021 Categorised into a Shift toward Vegetation Succession or Vegetation Reduction

When viewing changes in scrub levels in this way (Figure 18), the site shows only a slight shift towards reduction, with 58.04% of scrub change favouring a shift towards vegetation reduction and the establishment of more open habitat, and 41.96% of scrub change favouring a shift towards succession. This shift towards vegetation reduction could be increased if less new scrub was growing in areas that were previously open grassland. Scrub management targets could then be met by preventing the growth of new scrub in grassland areas, as opposed to the clearance of existing scrub.

However, the scrub management goal of no more than 10% scrub is based on ideal levels of scrub estimated using ground-based surveys, which are highly subjective and often inaccurate (Katzner *et al*., 2011). Scrub levels of no more than 10% may therefore not be a suitable target, as they are based on a subjective, ground-based assessment of what 10% scrub would look like. Because of this, it may be more suitable to establish new management targets based on photogrammetric point cloud data rather than basing conservation goals on data collected via inaccurate means. This could then allow for new management goals to be set and monitored more closely with annual surveys.

In this study, the standard maximum height for scrub of 5m was used (Mortimer *et al*., 2000). However, what constitutes scrub can vary from site to site, and ground-based surveying could be used to determine the shortest and tallest scrub on site, allowing a more specific and accurate height range for scrub. Analysis could then be carried out on the same datasets using this new height range to get scrub levels that are more specific to the individual site being surveyed.

One thing that this survey doesn't take into account is intra-site communities. It is possible that on some sites, management goals may include differing scrub levels for different parts of the site. However, this would be easy to achieve by dividing the site up into these areas and running each area as a different site.

4.4.2 Comparison of Methods

Accuracy and Detail

Comparing the results from the 2021 drone data and the field survey, the scrub levels obtained from the field survey were overall lower than the drone, at 11.6% compared to 14.89%. However, the field survey relied much more on subjective assessment, making a broad estimate of what was within visual range. The walk also didn't cover all of the site, requiring extrapolation to predict overall scrub levels. In comparison, the drone results covered the entire site, with no extrapolation required, and the results were based on quantitative categorisations, with no subjective assessment. This makes the drone data both more detailed and more accurate, making it more useful when trying to assess scrub levels, especially on sites with specific management goals. This aligns with the literature, with drones identified as being more accurate (Ancin-Murguzur *et al.,* 2019) than existing ground-based methods.

Time

The two methods were comparable in time, with the drone taking 1 hour and 20 minutes, and the walk taking 1 hour and 5 minutes. However, the drone flights were delayed for 25 minutes due to rain. In a situation with good weather conditions, the drone flights could be carried out in 55 minutes, making them quicker than the field survey. However, bad weather conditions could significantly delay or even completely prevent drone flights, whereas a structured walk could be carried out in bad weather conditions. This dependance on good weather conditions compared to ground-based surveys was identified in the literature as one of the main disadvantages of drones (Dandois, Olano and Ellis, 2015), as was the theoretically faster survey time given ideal weather conditions (Ventura *et al.,* 2016).

Cost

The cost of the employee time and any costs involved in the travel to and from the site, such as travel time and fuel expenses, are not considered when comparing methods as these would be present in both methods. The cost of the walk is free, as it requires no equipment beyond a way to note down scrub levels. The method outlined here costs approximately £1000 for the drone, and £1259.67 for a month of Pix4D Mapper and a Year of ArcGIS Pro (Esri, 2021; Pix4D, 2021) for a total price of approximately £2259.67. This makes the drone-based method, as outlined here, significantly more expensive than ground-based methods, which may prevent conservation organisations from using drones, especially considering a lack of resources was one of the main challenges in conservation as identified in the interviews (RP1).

However, the price of the drone-based method can be reduced. Free software alternatives such as Web Open Drone Map (WebODM) and QGIS can be used in place of Pix4D and ArcGIS Pro respectively, and although they are more limited in their outputs, they are capable of carrying out this method for quantifying scrub cover, as well as identifying temporal change, directional change and succession and reduction maps. This study also only requires RGB imagery, and a drone with the same camera as the drone used in this study can be obtained for approximately £200 (Dronetech, 2022). Whilst more expensive than ground-based methods, once purchased the drone can be reused, splitting the cost over multiple surveys and making it more cost-effective.

Disturbance

No disturbance was observed using either method, although both methods had the potential to disturb wildlife and no livestock were on site on the day of the 2021 drone flight or field survey. The drone creates significant noise, primarily during take-off and landing when close to the ground. This was identified as a potential cause of disturbance in the systematic review and could alarm nearby animals. However, the structured walk required travelling in a straight line off the established paths through the site, which could also cause disturbance to animals and plants.

Bureaucracy

No legal issues or permissions were required to carry out the field survey. For the drone survey, using the method presented in this study, a flyer ID and operator ID (if you own and are responsible for the drone being used) are required. Obtaining both of these is £10 and requires a 40-question, multiple choice quiz around drone permissions and safeties to be completed. Using a drone under these conditions requires a distance of at least 50m horizontally to be kept from uninvolved people (Civil Aviation Authority, 2022). To fly the drone closer to people would require a drone of less than 250g to be used, or an A2 certificate of competency (A2 CofC), which costs £100 and can be completed in less than 24 hours. This could require a higher time and cost investment or would require drone flights to be carried out at a time when the site is almost empty or for the site to be closed whilst drone flights are carried out. However, using a drone that weighs less than 250g, such as the one mentioned above (Dronetech, 2022) would allow the drone to be flown close to, and even over people, without an A2 CofC requirement (Civil Aviation Authority, 2022). This would put the total cost of the drone and training at £210 and allow the drone to be flown whilst the site remains open. Whilst this legislation is not necessarily complex, a lack of knowledge on the specifics of which drones could be flown under which circumstances cand make planning drone-based action difficult without prior knowledge of the legislation. This is backed up by the views of wildlife trust employees in the interviews.

4.5 Effects of Drone Scale on Results

One factor that could affect the results of the drone flight is the height at which the drone was flown. A higher flight height could result in less detailed pictures, which could then miss smaller patches of scrub. To investigate this, a drone was flown at a height of 30m, 50m, and 75m over a 100m x 100m section of scrubland, and the scrub levels were quantified (Table 12), to see if the results varied at different heights. No trees were present in the area, so the land cover was split into Grass and Ground, and Scrub.

Table 12. Land Cover Percentages for a 100m^2 area at different heights

Height	Grass and Ground (%)	Scrub (%)
75m	96	4
50m	96.4	3.6
30m	96.4	3.6

The results showed a slight decrease in detail between the 75m data and the 50m and 30m data, with percentage scrub cover changing from 4% at 75m, to 3.6% at lower altitudes. However, there was no difference in land cover percentages between the 50m and 30m datasets. In summary, when carrying out temporal surveys looking at scrub cover, varying heights at or below 50m can be used without a noticeable change in detail.

4.6 Wildlife Trust Feedback

Feedback from the Gloucestershire Wildlife Trust on the methods and results obtained was largely positive. The potential of the method to provide more quantified justification for scrub management plans was mentioned as a positive, as well as the ability of the drone-based data to give specific values, locations, and the ability to identify mature scrub stands specifically. This specific data then provides parameters that can be reported back to Natural England as part of SSSI condition assessments. Whilst there was a consensus that the information collected using the drone was already known by site managers, the ability of the data to conceptualise that information in a easy to understand visual format was believed to have great potential for wildlife trust members and new employees, including new site managers. The drone-based method was also believed to be quicker than the ground-based method to a greater degree than the case study indicated, as the ground-based method carried out in the case study only investigated percentage habitat cover. Ground surveys carried out by the Wildlife Trust involve several more tasks that take significantly more time. These tasks, such as the presence of bare ground or canopy density, could also be assessed using the drone data, making the drone-based method more time-saving than previously thought.

Some of the main concerns raised regarding the drone-based method was the unknown level of expertise required to carry it out, which raised questions about whether the trust would need to hire a professional to carry out the survey, as well as the risk of technical issues that they would not know how to solve if they were carrying out this method themselves using the case study as a guide. It was also brought up that the drone-based data did not provide certain information that would be known to site-managers, such as the locations of hibernacula and other important site features. Overall, there was a belief that this method could be integrated not only the Gloucestershire Wildlife Trust, but at an organisation-wide level across all of the Wildlife Trusts, and that it would provide significant benefits over the current surveying methods.

4.7 Conclusions

These data shows that drones are suitable for carrying out scrub assessments and can be used for long-term temporal studies to obtain highly accurate, standardised data that can be used to inform conservation management plans. Whilst scrub levels at Daneway Banks have declined in recent years, they have still not met their site management goals, and more scrub management would need to be carried out. Drones were found to be more accurate than existing structured walk methods and comparable in time. Both methods have the potential for disturbance, although no disturbance was identified for either method. Drones were more limited by weather conditions and required a higher cost investment, as well as more bureaucracy to use, although this cost could be minimised to £210, and the drone could be reused once purchased. Using a smaller drone could also limit the training and permissions process, allowing drones to be flown much easier. This method was seen by the GWT to have high potential for integration assuming sufficient resources could be found, with the possibility of using it across all of the Wildlife Trusts, allowing for the conceptualisation of accurate specific information that could save time and assist in site condition assessments.

5 Case Study 2: Monitoring of Livestock and Other Grazing Animals on Trust Sites

5.1 Introduction

5.1.1 Conservation Grazing and Animal Monitoring

Grazing animals can have a large effect on their habitat and are major drivers of ecosystem change (Rupprecht, Gilhaus and Hölzel, 2016), creating open spaces through the grazing of shrubs and saplings, keeping sward height low, and controlling more aggressive plant species that can dominate habitats. The presence of large herbivores in an ecosystem can also affect the habitat through the trampling which clears vegetation and creates space and opportunity for new seedlings to grow (Eichberg and Donath, 2017), the dispersal of seeds via fur or dung (Will and Tackenberg, 2008), and the changing of soil composition through the excretion of faeces and urine (Ma *et al.,* 2016). Grazing animals can act as keystone species through the maintaining of short vegetation and the prevention of woodland succession. This makes grazing animals a useful tool in the conservation of heathland and grassland habitats, and they can be especially impactful in the maintenance or restoration of these habitats and their biodiversity (Smit and Putman, 2011). Whilst in the 1990s, there was debate around whether site management through grazing was effective as a conservation method (WallisDeVries, Wieren and Bakker, 1998), grazing is now generally accepted as an effective and natural way of maintaining grassland and heathland whilst keeping biodiversity high (National Trust, 2019). However, any grazing as a form of conservation must be carefully managed to ensure it is having the desired effect, as different grazing species can alter the ecosystem in different ways. For example, cattle tend to eat a variety of common plant species and eat vegetation by wrapping their tongue around clods and uprooting them which, along with trampling, creates a variety of vegetation heights, allowing for the formation of microhabitats (National Trust, 2019; Smit and Putman, 2011). In contrast, sheep often graze on bramble (*Rubus fruticosus)* and scrub, making them more useful for heavily overgrown sites, and graze using their front teeth, which creates a more uniform sward height (National Trust, 2019).

The amount of grazing occurring on a site and the number of animals also needs to be monitored and managed, as both overgrazing and under grazing can be detrimental to a site. Under grazing can lead to the open habitat succeeding into woodland, which can lead to the loss of rare grassland or heathland species, such as the Snake's-head fritillary (*Fritillaria meleagris*). Overgrazing can be equally damaging, preventing new plant growth and leading to habitats dominated by close-cropped grasses, a decrease in water quality, and increased levels of soil erosion leading to large areas of bare ground (Varga *et al.,* 2021; English Nature, 2005). This makes it important to know the numbers and locations of grazing animals on a site, both in terms of livestock such as cattle, sheep and ponies, and wild animals such as deer, which also contribute to over-grazing (Parliamentary Office of Science and Technology, 2009). Current methods for this are primarily visual observation of animals which, whilst effective for livestock where the number of animals is already known, may not be suitable for assessing the number of wild animals such as deer on a site. Drones and thermal camera technology represent a potential alternative method of locating both livestock and wildlife on grazed sites. In this study, we assess the potential of a drone equipped with a thermal camera to locate both livestock and wildlife.

5.1.2 Case Study Aims

This case study aims to compare the effectiveness of drone-based thermal imagery and ground-based visual observation of warm animals across three sites, using an existing stock list as a control.

5.1.3 How this Case Study ties into Previous Work

Animal monitoring was the second-most prominent use of drones identified in the systematic review and was identified as an area where drones could be useful compared to existing methods (Rexer-Huber and Parker, 2020; Hodgson *et al.,* 2018). It was also mentioned frequently in the interviews as a potential advantage of drones (RP7), with thermal imagery being mentioned specifically (RP10). The concept of being able to check on livestock in a way that is quicker and causes less disturbance than existing methods was also a point of interest in multiple interviews (RP9).

The study sites are part of a Gloucestershire Wildlife Trust grazing programme, and there is an existing interest in monitoring the livestock on-site, as well as any other wildlife that could be affecting the scrub and grass levels of the site. As with the previous case study, this study also allows the drone-based method to be compared to existing ground-based methods in terms of accuracy and the logistical concerns identified in the systematic review and interviews (RP1, RP13).

5.2 Methods

5.2.1 Study Sites

Three UK nature reserves are investigated in this study, all in the Forest of Dean (Figure 19); Crabtree Hill (Grid Reference SO632134), which is itself part of a larger site called Woorgreens (Grid Reference SO628126), Edgehills Bog (Grid Reference SO660163), and Wigpool (Grid Reference SO651196). All three sites are owned by Forestry England and managed by the Gloucestershire Wildlife Trust, and were once woodland, before being cleared to create heathland habitat. Highland Cattle, Hebridean Sheep, Herdwick Sheep and Exmoor Ponies are used on all three sites at various points throughout the year as part of a larger grazing programme to maintain the heathland, and invasive birch (*Betula pendula*) trees are manually removed from all sites regularly to encourage open habitat (Gloucestershire Wildlife Trust, 2021c; Gloucestershire Wildlife Trust, 2021d; Gloucestershire Wildlife Trust, 2021e).

Fig 19. Location map for Crabtree Hill (red pin), Edgehills Bog (blue pin) and Wigpool (green pin)

Crabtree Hill is an area of heathland north of Woorgreens Lake and is part of the larger Woorgreens site, which is approximately 42 hectares in size. The aim of the Crabtree Hill portion of the site is to maintain heathland, which is characterised by poor acidic soils, and the main vegetation on-site is Ling (*Calluna vulgaris*), Bell Heather (*Erica cinerea*) and Gorse (*Ulex europaeus*), whilst Roe Deer (*Capreolus capreolus*), Fallow Deer (*Dama dama*) and Wild Boar (*Sus scrofa*) have all been recorded on-site. The total Crabtree Hill study area was 15.24-hectares or 152,400 m^2.

Edgehills Bog is a 1-hectare site situated on the eastern boundary ridge of the Forest of Dean. Whilst the surrounding area is woodland, primarily English Oak (*Quercus robur*) and various conifer species, the site itself and some surrounding areas were cleared in the 1980s. Careful management of Gorse, Bracken (*Pteridium aquilinum*) and other scrub on-site is carried out to maintain species such as Purple moor-grass (*Molinia caerulea*), sphagnum mosses, and bilberry (Gloucestershire Wildlife Trust, 2021d). The study area for Edgehills Bog included the nature reserve and surrounding area and was 7.38-hectares or 73,800 m^2 in total.

Wigpool is a 2-hectare site and is a valuable habitat for reptiles, dragonflies, and birds. As well as the grazing and removal of birch trees common to all three sites, management at Wigpool also includes the management of Bracken and the flailing of tall gorse to create a diverse habitat of dwarf shrubs, which are optimal for heathland wildlife. Whilst Wigpool contains all the species found at the other two sites, Grey Willow (*Salix cinerea*) and Alder trees are also found in the drier areas of the site (Gloucestershire Wildlife Trust, 2021e). The study area for Wigpool included the nature reserve and some surrounding areas and was 4.07-hectares or 40,700 m^2 in total.

5.2.2 Drone Flights

Drone flights were carried out at all three sites approximately every three weeks between the 5th August and the 8th October. The exact flight dates were:

- 5th August
- 25th August
- 18th September
- 8th October

The three-week gap between flights, and the exact dates the flights took place, were determined by availability and dates that were approved by Forestry England, who own the sites.

A Mavic 2 Enterprise Dual drone was used for all flights. The Mavic 2 Enterprise Dual was chosen due to its thermal camera, which allowed for easier detection of both livestock and wildlife, as well as its low cost compared to other thermal drones. All flights were carried out at an altitude of 50m, with the drone flying a pre-programmed route (Figures 20-22) over the study areas, taking both RGB and thermal images simultaneously. The flight height was chosen based on the size of the Crabtree Hill site to ensure the study area could be covered in a suitable amount of time and using the batteries available and to ensure that the drone was high enough to cause no disturbance to animals on-site. The same height was then used for the Edgehills Bog and Wigpool sites to increase the standardisation of the data collection. The same route was used for each subsequent survey to make sure that the same study area was covered. All images from the flights were saved as tagged image file format (tiff) on SD cards.

Fig 20. Flight Path and Photograph Locations for the Crabtree Hill Drone Survey

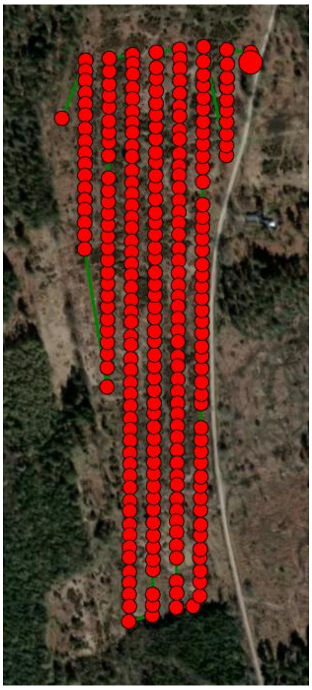


Fig 21. Flight Path and Photograph Locations for the Edgehills Bog Drone Survey

Fig 22. Flight Path and Photograph Locations for the Wigpool Drone Survey

All flights were carried out in the morning, allowing for animals to be picked up more easily by the thermal camera, and minimising the possibility of encountering any people on-site.

5.2.3 Manual Count

Immediately after each drone-based survey, an on-foot survey of the study area was carried out, following roughly the same path as the drone-based survey to ensure the study area was completely surveyed. Constant visual observation was carried out throughout the walk, and any animals observed were noted down.

5.2.4 Data Analysis

A thermal orthomosaic was unable to be created from the thermal images collected with the drone, due to the low resolution of the thermal camera and insufficient overlap of the images. The inability to create thermal orthomosaics required each picture to be examined individually for animals. To simplify the process, a script was created in R statistical software that processed the images, removing any thermal signatures that were less than 1.8 standard deviations above the mean (R script Appendix 2). This removed background thermal signatures such as vegetation, highlighting only high changes in thermal values. The 1.8 standard deviation value was chosen after testing the script on pictures with known livestock in them. The processed images were then compared to the original thermal and RGB images (Figure 23) in order to identify the location of animals.

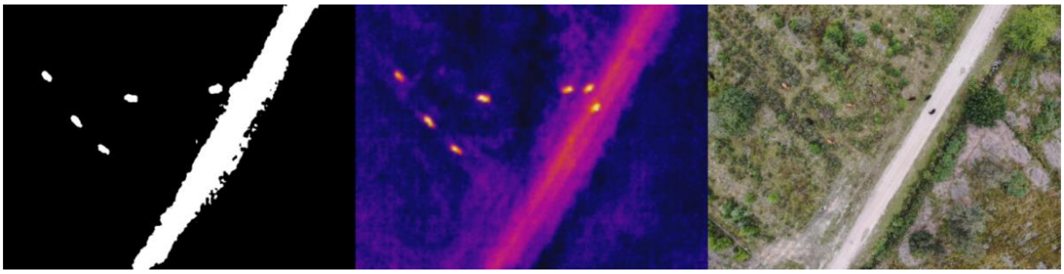


Fig 23. An example of a Processed Thermal Image (left), the Original Thermal Image (centre), and the Corresponding RGB Photo (right) showing Cattle on Crabtree Hill.

The number and category of animals in each visit and each site from RGB imagery, thermal imagery and ground based surveys were compiled and compared to the ground-based observations.

The variation in the total number of animals counted at each site was tested using a negative binomial generalised linear model using a 'log' link function using two independent variables including survey method, with three categories including control (stock list), drone, and ground, and visit number (1-4). The best fitting model was selected through model comparison with alternative link functions (including 'square root' and 'identity') and other suitable families (including 'Poisson' and 'Quasipoisson'). The criteria for model fit included higher values of explained deviance and lower Aikaike's Information Criterion AIC values (Arnold, 2010).

Model validation involved checking residual distributions for compliance with the assumptions of linear modelling including normal distribution of residuals, equality of variance, no excessively influential observations, and overdispersion, following guidance included in Thomas *et al*., 2021 and Zuur *et al*., 2007.

5.2.5 Stock List

After the analysis was complete, the Gloucestershire Wildlife Trust was contacted, and a full stock list of known animals on-site was obtained, with no animals present at Edgehills Bog or Wigpool, and nine cattle and five ponies at Woorgreens, of which Crabtree Hill is a part. This stock list was then used as a control, allowing both the drone survey and field survey results to be compared to known livestock amounts so the accuracy can be assessed.

5.3 Results

5.4.1 Livestock and Wildlife Detection

The three methods all detected animals at Crabtree hill including ponies, cattle and wild deer.

Based on the numbers of animals detected using the three survey methods, there was a significant difference between survey methods (df = 2, residual deviance= 16.511, p= 0.00026; Figure 24). The differences were detectable at Crabtree Hill, and Edgehills Bog. However, if wild animals were removed, then both the drone and ground-based results would be identical (Table 13; Figures 24-26).

Across the four surveys, a total of 21 livestock were detected at Crabtree Hill for both the drone and ground-based methods, out of a potential maximum 56 detections (i.e., 14 animals detectable on each of the four survey dates). This gives both drone methods an accuracy of 37.5%, meaning neither method could accurately locate livestock, and that both methods are identical in terms of accuracy when surveying livestock.

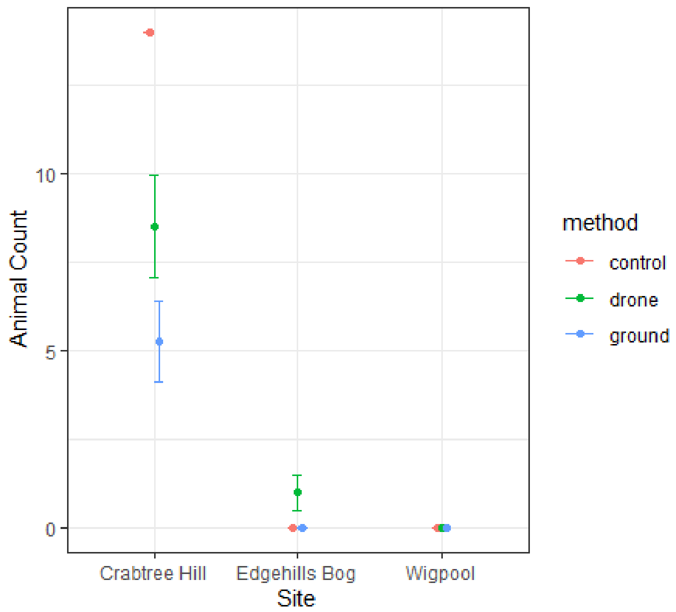


Fig 24. Comparison of animals found across all sites and methods (error bars represent the standard error).

5.3.1 Drone Flight Data

Survey Set 1 (5th August)

Across the three sites, eleven animals were detected during the first survey set on the 5th of August. Nine animals were detected at Crabtree Hill; 4 ponies and 5 deer.

Fig 25. Thermal and RGB Imagery of three Ponies at Crabtree Hill on the 5th August (Ponies circled Red).

Two animals, both deer, were detected using the thermal imagery at Edgehills Bog. No animals were detected at Wigpool.

Survey Set 2 (25th August)

Thirteen animals were detected using thermal imagery from the 25th August surveys. Eleven animals were detected at Crabtree Hill, with eight cattle and three deer detected. Two deer were detected at Edgehills Bog. No animals were detected at Wigpool.

Survey Set 3 (18th September)

Five animals were detected using thermal imagery from the 18th September surveys, all at Crabtree Hill, with four ponies and one deer detected. No animals were detected at Edgehills Bog or Wigpool.

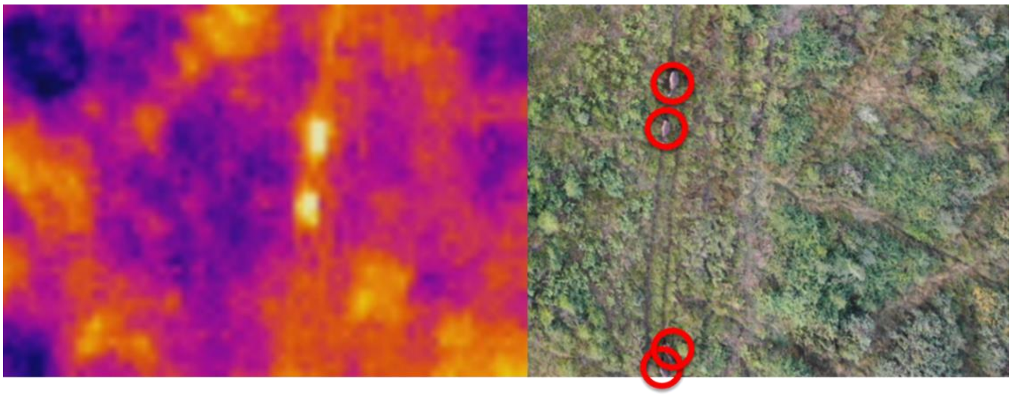


Fig 26. Thermal and RGB Imagery of four Ponies at Crabtree Hill on the 18th September (Ponies circled Red, two Ponies Visible only on RGB Image).

Survey Set 4 (8th October)

Nine animals were detected using thermal imagery from the 8th October surveys, all at Crabtree Hill, with five ponies and four deer detected. No animals were detected at Edgehills Bog or Wigpool.

In total, 38 animals were detected using the drone thermal camera across the four survey dates at the three sites. Thermal and RGB imagery of all detected animals can be found in Appendix 3.

Table 13. A Summary of Animals Detected at Crabtree Hill, Edgehills Bog and Wigpool.

Survey Date	Site	Drone findings	Ground findings	Control (stock list)
5th August	Crabtree Hill	4 Ponies, 5 Deer	4 Ponies	5 Ponies, 9 Cattle
	Edgehills Bog	2 Deer	None	None
	Wigpool	None	None	None
25th August	Crabtree Hill	8 Cattle, 3 Deer	8 Cattle	5 Ponies, 9 Cattle
	Edgehills Bog	2 Deer	None	None
	Wigpool	None	None	None
18th September	Crabtree Hill	4 Ponies, 1 Deer	4 Ponies	5 Ponies, 9 Cattle
	Edgehills Bog	None	None	None
	Wigpool	None	None	None

8th October	Crabtree Hill	5 Ponies, 4 Deer	5 Ponies	5 Ponies, 9 Cattle
	Edgehills Bog	None	None	None
	Wigpool	None	None	None
Total		38 Animals; 13 Ponies, 8 Cattle, 17 Deer	21 Animals; 13 Ponies, 8 Cattle	56 Animals; 20 Ponies, 36 Cattle

5.3.2 Manual Count Data

In total, 21 animals were detected during the manual counts across the four survey dates at the three sites. All detected animals were livestock (Figures 27-28) and were detected at Crabtree Hill.

Fig 27. Cattle Detected during a Manual Count at Crabtree Hill on the 25th August.

Fig 28. Ponies Detected during a Manual Count at Crabtree Hill on the 18th September.

5.4 Discussion

Overall, both methods were found to have an accuracy of 37.5% when it came to detecting the ponies and cattle on-site, making both methods equally inaccurate when surveying livestock. Both methods took a similar amount of time, although the drone-based method required significantly more beaurocracy and was much more expsneive. Overall, the lack of increased accuracy combine with the extra cost and logistics made this method unsuitable for intergration into the Wildlife Trusts.

Both the ground and drone-based methods were equally accurate, detecting 37.5% of all livestock on-site. The thermal imagery also picked up a total of 17 non-livestock animals, with 15 deer detected and two animals which were unable to be identified due to being obscured by scrub. One factor that may have affected the results was the study area, as the livestock are located across the entire Woorgreens site, whilst the surveys only covered the northern section of the site that makes up Crabtree Hill. Potentially, livestock could be located in an area of the Woorgreens site that was not surveyed on any of the survey dates, and therefore would not be detected. A complete survey of an area containing livestock would need to be carried out to determine whether the inaccuracy was due to the inability of either method to detect animals that were present, or the fact that fewer animals were present in the study area. This was considered, but was unable to be carried out due to legislative reasons limiting the survey period between August and October.

The ground-based survey recorded zero additional animals aside from the livestock, showing that drones may be more useful for the detection of non-livestock animals such as deer. Current deer levels on the sites are unknown, although it is assumed there are deer on-site given the presence of deer in the Forest of Dean (pers. comm). Although this method is unable to give us definitive numbers of the number of deer on-site, due to the inaccuracy of animal detection, it shows that drones can be used to detect non-livestock wildlife, which could be useful in situations where confirmation of the presence of deer is an objective.

5.4.1 Thermal Imagery Assessment

The use of thermal images which were then processed had both advantages and disadvantages. One advantage was that the processing automatically removed images which did not contain significant heat signatures. This drastically reduced the number of images that had to be searched by an average of 75.9%, making data analysis much quicker. The processing also helped to identify false positives, where thermal imagery suggested the presence of an animal, but the processed image revealed a shape with a more broken and granular outline, which indicated an increase in heat caused by patches of bare ground (Figure 29).

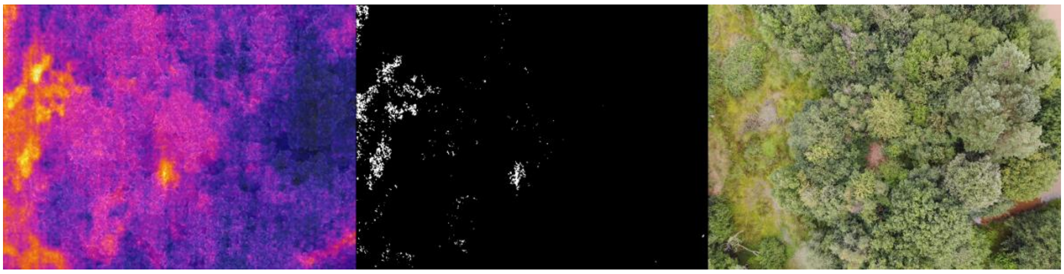


Fig 29. Pictures Showing how Image Processing Helped to Identify False Positives.

However, the processing did not distinguish between overlapping heat signatures of differing intensity. This meant that heat signatures caused by animals that were present in hotter areas, such as paths or other areas of bare ground, would not be picked up by the processed image, requiring a manual check of the thermal imagery (Figure 30). This lack of accuracy in the processed images means that any images with vegetation or land cover-based heat signatures would need to be checked against the thermal and RGB imagery to ensure no animals were present, severely negating the time advantage the processed imagery brings.

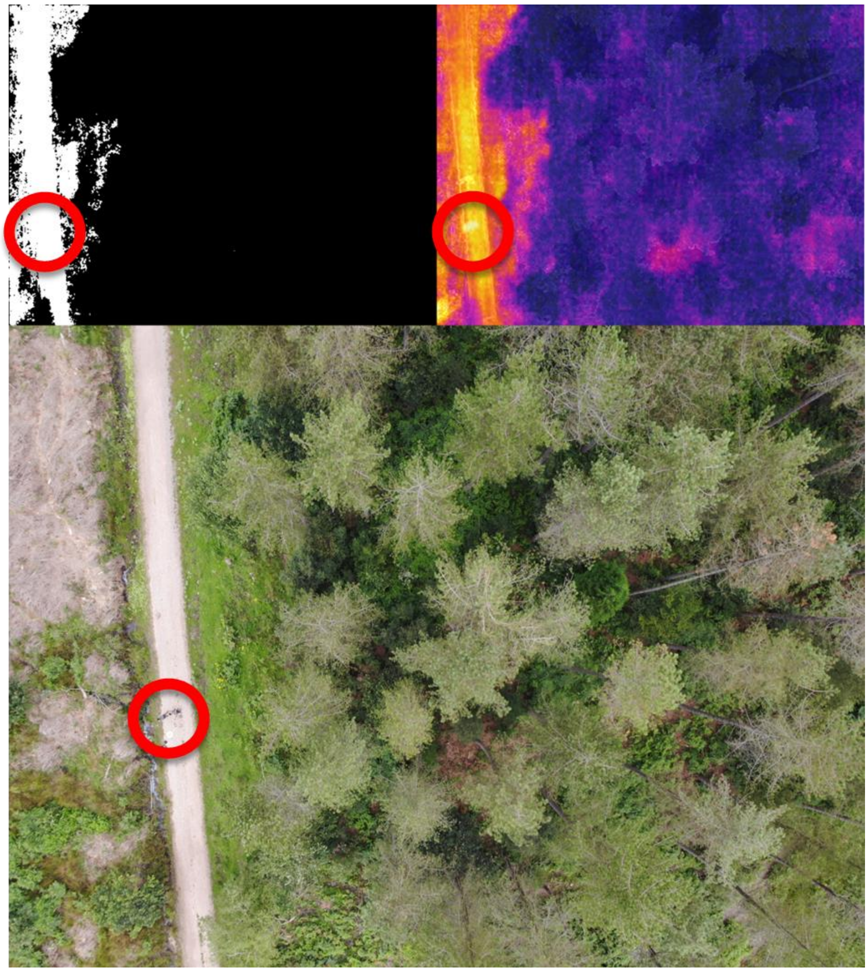


Fig 30. Images Showing how Overlapping Heat Signatures Can Mask the Presence of Living Things, Primarily in Processed Images (Drone Pilot circled Red).

Another disadvantage of the thermal imagery used was that the resolution was much lower than the RGB imagery, at 640x480 pixels, or 0.31 megapixels compared to a resolution of 4056x3040 or 12.3 megapixels for the RGB imagery. This meant that the thermal imagery was too low resolution to be used to create an orthomosaic, resulting in a need to individually check each image. Potentially, each animals could also be counted multiple times on different photos that were close together, as the locations of each image relative to the others was harder to judge when not stitched together. The other problem with the low resolution was that the thermal imagery didn't cover the same area as the RGB images (Figure 31).

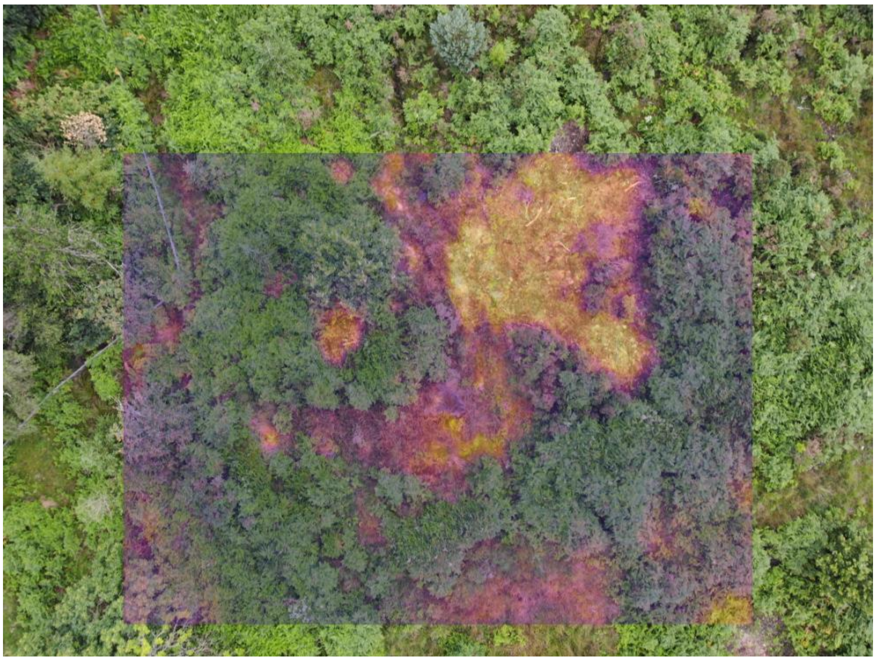


Fig 31. An RGB Image and Corresponding Thermal Image, Overlaid to show Differences in Image Size.

This meant that with the current levels of overlap in the images, areas in between RGB images would be missed with the thermal camera, leading to animals not being picked up on the thermal imagery, despite being present in the RGB imagery, leading to animals potentially being missed (Figure 32).

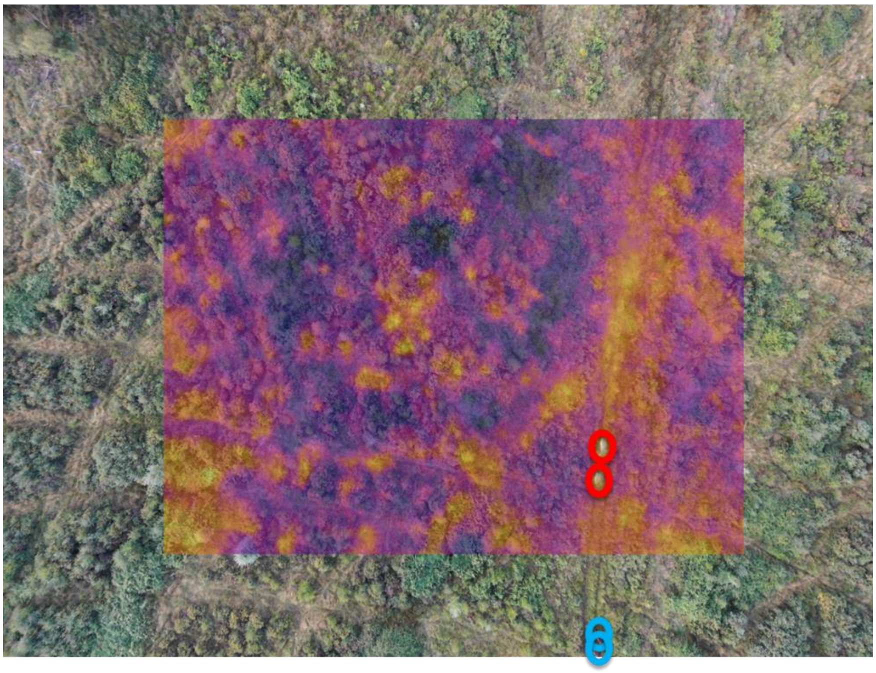


Fig 32. An RGB Image and Overlaid Corresponding Thermal Image, showing how Animals can be Missed on Thermal Imagery despite being Present in RGB Imagery (Ponies on Thermal and RGB Imagery circled Red. Ponies Present only in RGB Imagery circled Blue).

One solution to the low resolution of the thermal images would be to use a higher-quality thermal camera. This would allow the images to be stitched together into an orthomosaic, allowing for sites to be analysed more easily without the need for processing, and the increased quality of the camera would pick up smaller differences in heat, making animals stand out more compared to vegetation and allowing small animals such as rabbits or rodents to be detected. Higher-quality thermal cameras have also been proven to be able to detect non-direct signs of animals, such as burrows (Cox *et al.,* 2021). However this would increase the cost of the drone-based method beyond the budget of a UK conservation organisation carrying out animal surveys, given the current underfunding of conservation groups (RSPB, 2018; Murdoch *et al.,* 2007).

5.4.2 Comparison of Methods

Accuracy and Detail

Both the drone and manual survey methods detected 21 out of a potential 56 livestock (37.5%). This makes both methods equally accurate at surveying livestock. Unlike Study 1, both methods are also equally quantified and objective, not relying on estimates or extrapolation of results. However, the manual survey allows for a closer, more detailed view of the livestock, allowing visual health checks to be carried out, whereas the drone survey only allows the presence of the animal to be confirmed. This means that in any situation where a more detailed visual check of livestock is required, a manual survey would be more suitable and allow for more detail to be obtained without any decrease in accuracy compared to drone-based thermal imagery.

The drone surveys detected 17 additional animals, all of which were deer, whilst the manual surveys detected no additional wildlife. This makes the drone survey more effective at detecting non-livestock wildlife, although due to the low accuracy of the livestock detection, it cannot be concluded that drone-based thermal surveys are more effective for determining overall animal numbers on a site. This contrasts with the literature, which identifies animal surveying as an area where drones could provide an advantage over ground-based methods (Chabot, Craik and Bird, 2015). However, many studies in the literature focused on bird counts specifically (Hodgson *et al.,* 2018; Valle and Scarton, 2018), which involve larger numbers of animals and a higher difficulty in picking out individuals compared to larger, more domesticated animals such as livestock. This means that drones may provide advantages when counting larger numbers of animals, or in situations where animals are harder to identify or may be more prone to fleeing.

Time

Overall, both methods were similar with regards to survey time, with the drone survey method slightly quicker than the manual surveys (Figures 33-35). However, the drone-based method was, on average, only 7.2 minutes quicker than the manual counts, which may not be significantly quicker enough to justify using a drone-based survey method over a manual survey considering the increased cost of the drone method.

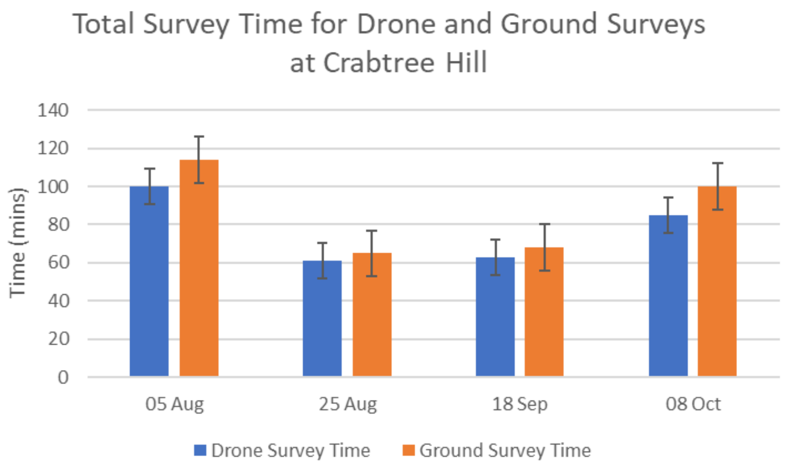


Fig 33. Total Survey Time of Drone and Ground-based Surveys at Crabtree Hill

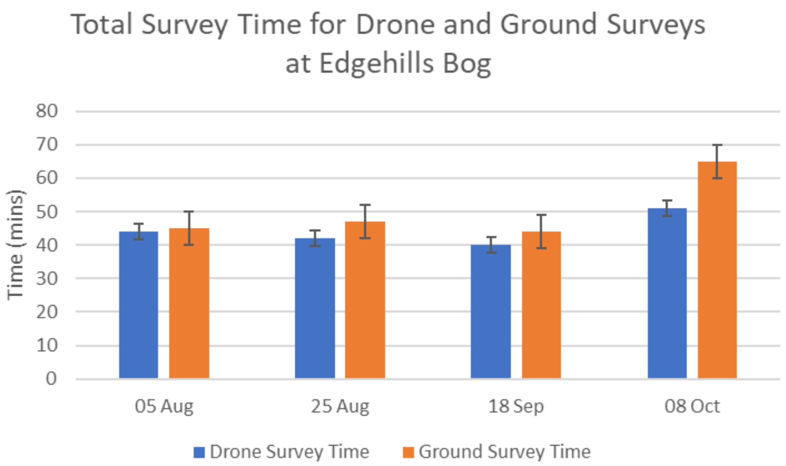


Fig 34. Total Survey Time of the Drone and Ground-based Surveys at Edgehills Bog

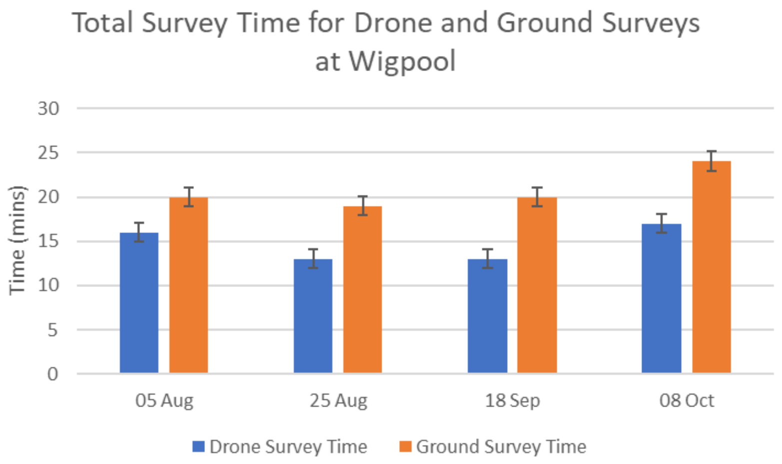


Fig 35. Total Survey Time of the Drone and Ground-based Surveys at Wigpool

Cost

For both methods, the cost of travel to and from the sites is not included, as this will be equal regardless of the method. The manual survey method was free, as it only involved walking around the site and noting down the number and type of animals detected. The Mavic 2 Enterprise Dual used to carry out the thermal surveys costs approximately £3,000 (Heliguy, 2022), whilst more expensive drones which can provide an increased thermal image resolution capable of creating orthomosaics cost around ten thousand pounds or higher (Dronefly, 2022). Although the method used in this study does not require any specialist software, the price of the drone may be beyond the budget of many conservation groups, especially when the accuracy and time are equivalent to ground-based methods. This shows the importance of logistical considerations, as literature looking at the use of thermal imagery to perform animal counts does not assess the cost of the potential equipment, nor how the price of equipment may exclude conservation groups from carrying out the surveys (Scholten *et al.,* 2019; Gooday *et al.*, 2018).

Disturbance

Both methods caused no disturbance. The drone was kept at a sufficiently high height to cause no disturbance, and take-off and landing were carried out away from any nearby animals. A suitable distance was also observed during the manual count and no adverse reactions to either the drone flight or the manual count were recorded, potentially due to the livestock's acclimatisation to people on the sites.

Bureaucracy

No legal issues or permissions were required to carry out the ground-based survey. For the drone survey, in addition to the flyer ID, operator ID and flight restrictions mentioned in the Daneway Banks study, extra permissions had to be obtained from Forestry England, as the site was jointly managed by them and the Gloucestershire Wildlife Trust. This required the filling out of multiple forms over approximately three months and required that the flights be limited to between August and October, so as not to interfere with Forestry operations. This significantly added to the time taken to begin the flights, as well as the complexity of planning the flights.

5.5 Wildlife Trust Feedback

Whilst the Gloucestershire Wildlife Trust believed that the methods used in this case study could have potential in specific situations, such as part of a release programme or for the monitoring of trespassing people, it was overall determined that it did not provide substantial advantages over the existing ground-based methods. The outputs were considered to be flawed since each image is a 'snapshot in time' and did not represent the whole site in the same moment and as such is prone to inaccuracy. One potential for inaccuracy raised by Wildlife Trust employees that was not mentioned in the case study was the potential for animals to move, resulting in them being recorded at multiple times in the same survey. Other remote methods such as GPS collars could provide more real-time information on animal locations and movements, as well as being cheaper and simpler to use. Regular visual checks are also required to assess the health of livestock, meaning that the drone-based method would not provide any benefit over existing methods, as the drone data is too low-resolution to carry out health checks.

5.6 Conclusions

This data shows that both drone-based thermal imagery surveys and manual ground-based surveys are equally accurate at detecting livestock, with only 37.5% of livestock detected using either method, although the ability of the livestock to move outside of the study area makes the accuracy hard to assess, and a survey of a complete site where it is known that all livestock are present in the study area would need to be carried out to determine whether either method is effective at counting livestock. The drone also detected 17 deer, making it more effective at detecting non-livestock wildlife than the manual count. Whilst drone-based monitoring of larger animals is effective in other countries with more diverse megafauna and larger-scale sites where manual counts are unfeasible (Lamprey *et al.,* 2020), in the context of smaller, UK nature reserves, drones were found to provide no benefit over ground-based manual counts unless there is a specific focus on the detection of non-livestock large animals such as deer. The drone provided a negligible increase in speed whilst costing significantly more than the manual counts due to the thermal camera requirements, with higher quality thermal cameras which are capable of producing images which can be stitched together into an orthomosaic costing over £10,000. The drone also required significantly more legal permissions due to the jointly managed nature of the sites. Despite this increased cost and bureaucracy, both methods were equally accurate and caused very little disturbance given the acclimatisation of livestock to people. Given the requirement for manual checks to assess livestock health, it was concluded that the drone provided no advantage over ground-based methods, and whilst there is potential for the method in specific situations such as during release programmes, existing traditional benefits are more suitable for the assessment and monitoring of livestock and other warm animals.

6 Case Study 3: Quantifying Seasonal Changes in Water Extent

6.1 Introduction

6.1.1 Wetlands and their Importance

Wetlands are defined as ecosystems where permanent or seasonal flooding occurs, including marshes, bogs, flooded grasslands and wet woodlands (Keddy, 2010). Wetlands are an important habitat type as they have a high level of heterogeneity in soil conditions and hydrology, resulting in a large number of ecological niches that can support a high level of biodiversity (McCartney and de la Hera, 2004). In the UK, seasonal wetlands provide suitable conditions for many distinctive species, including acting as important breeding habitat for migratory wildfowl and waders (Wilson, Ausden and Milsom, 2004; Gilvear and Bradley, 2000). Many species such as spoon-billed sandpipers (*Calidris pygmaea*) and water voles (*Arvicola amphibious*) have exhibited continuous declines in breeding populations due to losses and fragmentation of wetland habitat and the increasing effect of climate change drying up their habitats across their migratory range (British Trust for Ornithology, 2019; Wilson, Ausden and Milsom, 2004).

Hydrological changes have severe impacts on these wetland habitats. Decreases in surface water can have a negative effect on wetland biodiversity, with an overall succession towards species-poor habitats (Runhaar, van Gool and Groen, 1996). Seasonal changes in surface water, if disrupted by water drainage or climate change, can drive phenological mismatches between events of high energetic demand, such as breeding or migratory fuelling, and food availability , causing severe population declines (Smart and Gill, 2003). For these reasons, extent of surface water and how it changes is a useful metric for assessing the health of a wetland site.

Understanding the extent of seasonal changes is also important when looking at long-term changes in water levels, as increases or decreases in water levels over multiple years driven by climate change could be mistakenly attributed to seasonal changes or normal fluctuations caused by variation in weather (McCartney and de la Hera, 2004). Because of this, the seasonal changes in the hydrology of a site are best understood through regular accurate measurement to ensure efficient wetland habitat conservation (Donnelly *et al.,* 2019; Gilvear and Bradley, 2000). Current methods for assessing surface water often lack accuracy and efficiency (Lorah, Ready and Rinn, 2018). On-foot estimates of water extent can be time-consuming, especially in areas where flooding has occurred. Accessibility can also be an issue, leading to accessibility-based surveying where more accessible areas are focused on and surveyed more often, or to a greater degree, than less accessible areas, leading to inaccurate and often highly biased results that do not reflect the actual condition of a site (Marta *et al.,* 2019). This provides a potential area in which drones could be used. Existing drone-based methods often use multispectral, thermal or LiDAR sensors to measure reflectance and temperature to differentiate water and non-water surfaces (Dierssen *et al.,* 2021; Mano *et al.,* 2020). However, these sensors can be expensive, costing tens of thousands of pounds, and would not be affordable for conservation organisations which struggle with funding, as identified in the interviews (RP1). A cheaper alternative to these methods is the use of standard visible light RGB sensors to generate orthomosaics which can identify water through deep-learning assisted remote sensing.

Deep-learning is a subset of machine-learning which uses computer-generated neural networks to solve problems or make predictions. This approach could be used to automatically classify remote-sensing imagery obtained using pixel-based classification (Hamylton *et al.,* 2020; Lguensat *et al.,* 2018). This would allow for areas of water in the imagery to be detected and classified, giving highly accurate measures of surface water extent. This method does not require expensive multispectral or thermal sensors, instead only needing a standard visible light sensor, making it more accessible to conservation groups. This represents a novel method for accurately measuring surface water extent on a site and a way in which conservation organisations could use drones to measure water extent whilst keeping the overall equipment cost low.

In this study, the potential of deep learning to quantify seasonal changes in surface water extent was assessed at two wetland nature reserves in the UK using UAV-derived aerial imagery, and how this compares to existing ground-based methods.

6.1.2 Case Study Aims

This case study aims to identify seasonal changes in surface water extent between March, June and October at Coombe Hill Canal and Meadows, and Ashleworth Ham, and evaluate how drone-based methods compare to dip wells.

6.1.3 How this Case Study Ties into Previous Work

Hydrology was mentioned less frequently than both ground features and animal monitoring in both the systematic reviews and the interviews. However it was still prevalent in both as an area where drones could potentially be useful (Spence and Mengistu, 2015) (RP6), and the Gloucestershire Wildlife Trust have an interest in assessing the potential of drones to survey changes in water at wetland sites.

6.2 Methods

6.2.1 Study Sites

This study investigates Coombe Hill Canal and Meadows (Grid Reference SO885272)and Ashleworth Ham (Grid Reference SO833263) (Figure 36).

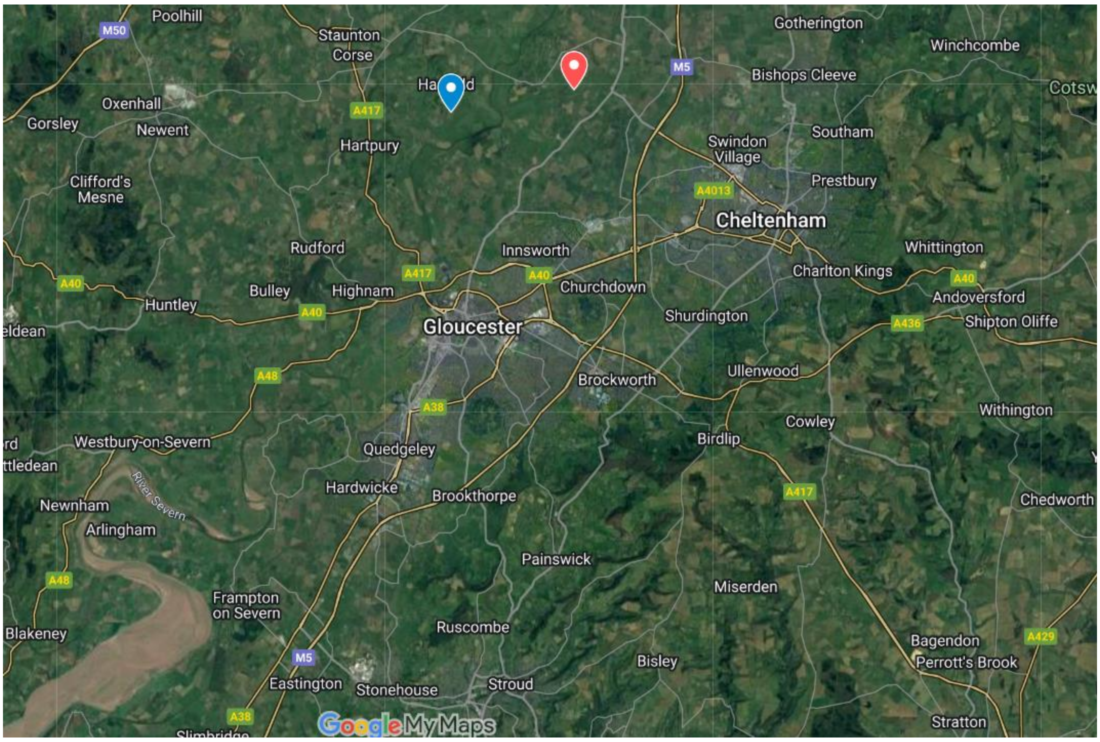


Fig 36. Location map for Coombe Hill (red pin) and Ashleworth Ham (blue pin)

Coombe Hill Canal and Meadows is a nature reserve within the Severn Vale and is designated as an SSSI for its diverse assemblages of birds, invertebrates and plants. The site is allowed to flood during the winter months, attracting large numbers of over-wintering wildfowl such as northern pintail (*Anas acuta*) and Eurasian teal (*Anas crecca*). Decreases in surface water extent in the spring then provides suitable foraging and breeding habitats for waders including common snipe (*Gallinago gallinago*), Eurasian curlew (*Numenius arquata*) and northern lapwing (*Vanellus vanellus*). The site is primarily lowland wet grassland but includes an extensive system of drainage ditches that flood to varying extents throughout the year (Gloucestershire Wildlife Trust, 2021a).

Ashleworth Ham is also a designated nature reserve and SSSI for being an important feeding ground for migrant wildfowl such as shoveler (*Spatula clypeata*), Bewick's swan (*Cygnus bewickii*) and white-fronted goose (*Anser albifrons*) as well as waders including snipe, curlew and lapwing (Gloucestershire Wildlife Trust, 2021b). As with Coombe Hill, the site is found in the Severn Vale and usually floods during the winter months.

6.2.2 Drone Flights

Drone flights were carried out on both sites in March, June and October 2021. A DJI Mavic 2 Enterprise quadcopter was used for the Coombe Hill flights, whereas a DJI Mavic 2 Zoom quadcopter was used for the Ashleworth Ham flights. Both drones provided the same output in terms of picture quality and resolution. For Coombe Hill, only the areas of the reserve north of the canal could be flown over due to the site's proximity to Gloucestershire Airport, placing the southern side of the reserve within the airport's Flight Restriction Zone, leaving a study area of 37.62-hectares. The Ashleworth Ham study area was increased from the existing site boundaries, which encompassed a single field, in order to include surrounding fields which also had substantial flooding, giving a total study area of 20.85-hectares. Using Pix4Dcapture, a pre-programmed route was designed to cover the study areas, which the drones flew over at a height of 75m, with 80% photo overlap so orthomosaics could easily be created from the photos. This flight height was chosen due to the size of the Coombe Hill study area, to ensure that all areas could be covered in a suitable time, with the Ashleworth Ham flight heights being carried out at the same height to increase the standardisation of the data collection. These flights were then repeated in June and October. The same route was used to ensure the study area was the same for each dataset (Figures 37-38). All images from the flights were saved as tagged image file format (tiff) on SD cards.

Fig 37. Flight Path and Photograph Locations for the Coombe Hill Canal and Meadows Drone Survey

Fig 38. Flight Path and Photograph Locations for the Ashleworth Ham Drone Survey

During the March Coombe Hill and Ashleworth Ham surveys, a total of 11 ground control points (GCPs) were placed, and their coordinates were taken with a highly accurate GPS, with four placed during the Coombe Hill survey, and seven placed during the Ashleworth Ham survey. These ground control points could then be used to assess any error in the geopositioning of the pictures during the data analysis. GCPs could not be placed for the second and third Coombe Hill flights due to site inaccessibility caused by flooding. A 4-minute disturbance check was also carried out before the first flight, in which a drone was flown over the site at 75m to assess any impact on birds within the study area. Overall, survey times were shorter in the June and October surveys, due to no GCPs being placed and an increased familiarity with the method (Table 14).

Table 14: Survey Details for Coombe Hill and Ashleworth Ham Drone Surveys

Survey Date	Site	Total Survey Time (mins)	Flight Time (mins)	Pictures Used	Average Ground Sampling Distance (GSD) (cm/px.)
19/03/2021	Coombe Hill	204	58	904	2.37

22/03/2021	Ashleworth Ham	70	24	461	2.60
14/06/2021	Coombe Hill	175	58	629	3.25
14/06/2021	Ashleworth Ham	48	24	390	2.66
21/10/2021	Coombe Hill	177	58	944	2.48
21/10/2021	Ashleworth Ham	51	24	427	2.47

6.2.3 Dip-wells

Both Coombe Hill and Ashleworth Ham use dip-wells on-site to determine the depth of the water table. This means that any point where water is high enough to cover the top of the dip-well indicates surface water. This data can be used to create a map of known water extent in March, June and October 2021, which can then be compared to the drone data. Each site contained two dip-wells within the study area (Figures 39-40).

Fig 39. Dip-well locations within the Coombe Hill Canal and Meadows Study Area (Dip-wells Labelled C1 and C2)

Fig 40. Dip-well locations within the Ashleworth Ham Study Area (Dip-wells Labelled A1 and A2)

6.2.4 Data Analysis

Drone Flight Data

For each set of flights, Pix4D Mapper (Pix4D, 2022) was used to create geo-referenced orthomosaics of the study area, using Structure from Motion (SfM) algorithms and using points matched in multiple photos to create a densified point cloud (Figures 41-42) from which the orthomosaics were generated. These orthomosaics were then exported as raster tiff files and imported into ArcGIS Pro 2.8 (Esri, 2022).

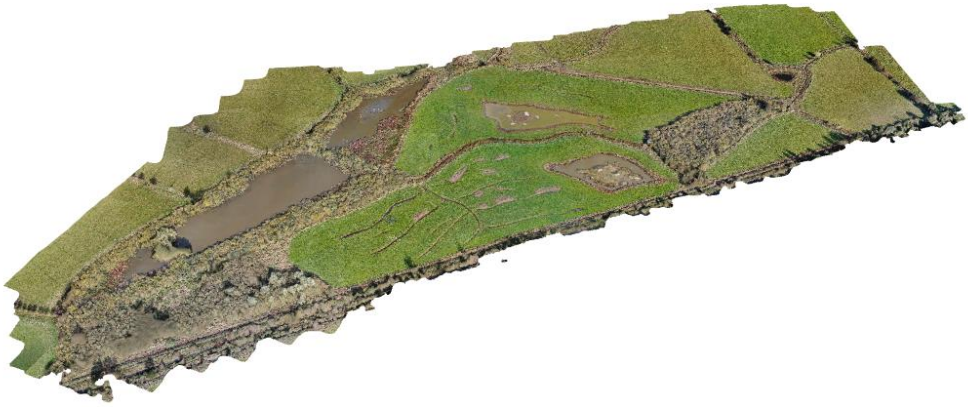


Fig 41. A 3D Model of the Study Area of Coombe Hill Canal and Meadows created using a Densified Point Cloud

Fig 42. A 3D Model of Ashleworth Ham and Surrounding Fields created using a Densified Point Cloud

Two additional orthomosaics were created for the March Coombe Hill and Ashleworth Ham flights using the GCPs, to assess the level of error between orthomosaics utilising GCPs, and orthomosaics without GCPs. The root mean square error between the two orthomosaics was found to be 9.24cm longitude and 9.72cm latitude for Coombe Hill, and 1.67cm longitude and 3.21cm latitude for Ashleworth Ham, meaning any results could be off by a maximum of 89.8cm^2 for Coombe Hill, and 5.36cm^2 for Ashleworth Ham.

The ‘Label Objects for Deep Learning’ tool within ArcGIS Pro was used to create a labelled dataset containing known samples of surface water and non-surface water (including bare ground, vegetation, roads etc.) using the March Coombe orthomosaic, with 37 samples of surface water, and 24 samples of non-surface-water. The samples were then exported as a deep learning training dataset and the ‘Train Deep Learning Model’ tool was then used to create a deep learning package based on that dataset. Finally, the ‘Classify Pixels Using Deep Learning’ tool was used to classify all the Coombe Hill and Ashleworth Ham orthomosaics into surface water or non-surface water using the trained deep learning model (Figure 43).

Once the orthomosaics had been classified, non-surface water cells were removed, leaving only the surface water information. This information was then expressed as a percentage of the total study area to get the percentage water cover. All three surface water raster layers for each site were also overlaid on top of each other, allowing the seasonal change in surface water cover to be easily observed.

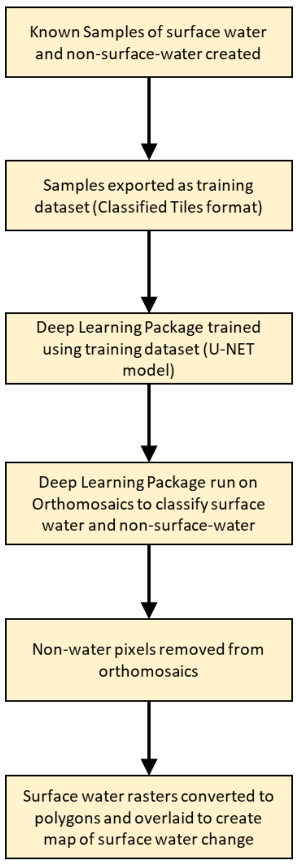


Fig 43. A Workflow for the Creation of a Surface Water Classifying Deep Learning Package and Seasonal Changes Maps

Dip Well Data

Dip-well data was provided by the Gloucestershire Wildlife Trust. Since the dip-well water levels were recorded at different points compared to the drone flights, the closest data point was used as a comparison. For the March drone flights, the Coombe Hill dip-well comparison data was from 22nd March and the Ashleworth Ham dip-well comparison data was from 15th March. For the June drone flights, the dip-well comparison data was from June 12th and the Ashleworth Ham dip-well comparison data was from 13th June. Finally, for the October drone flights, the dip-well comparison data was from 18th October and the Ashleworth Ham dip-well comparison data was from 14th October.

Once dip-well data was collected, an estimate of surrounding water extent was manually added onto the map, based on whether any water was recorded at the dip-wells above the top of the dip-well, which would indicate surface water, and the depth of water recorded above the top of the dip-well, with deeper water levels indicating a larger surrounding area of water.

6.3 Results

6.3.1 Drone Flight Data

Coombe Hill Canal and Meadows

The total Coombe Hill Canal and Meadows study area was 37.62-hectares or 376,200 m^2. In March 2021, surface water covered 171,200m^2, or 45.5% of the study area. This decreased by 57.36% between March and June, with water only covering 73, 000m^2 (19.4%) of the study site, and decreased by a further 56.44% between June and October, with water covering 31,800m^2 (8.45%) of the study site. Overall, from March to October 2021, surface water decreased by 81.43%, with 139,400m^2, or 37.05% of the total site, free of surface water in October compared to March (Figure 44).

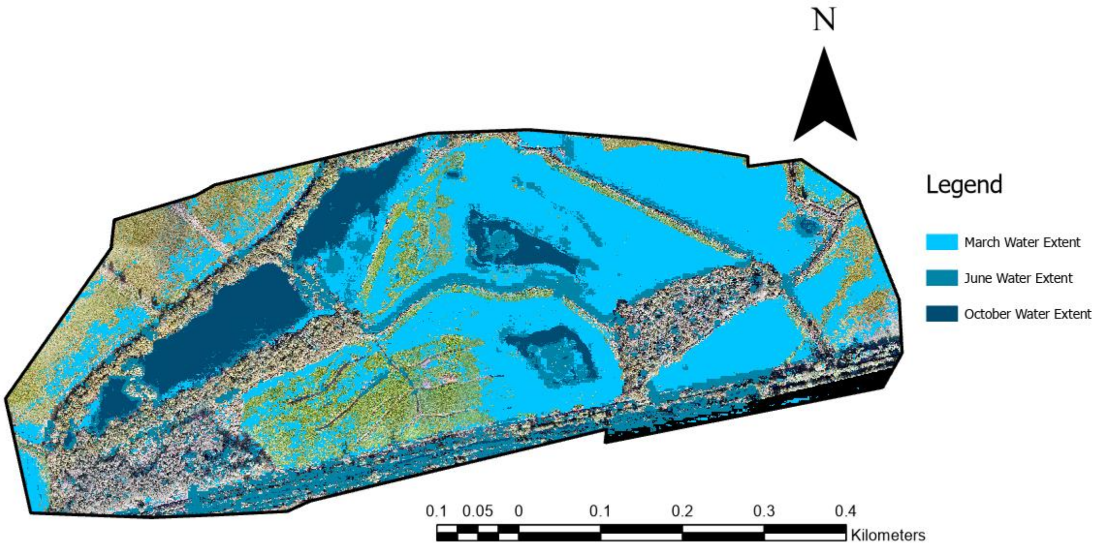


Fig 44. Changes in Surface Water Extent at Coombe Hill Canal and Meadows from March-October 2021

Ashleworth Ham

The total Ashleworth Ham study area was 20.85-hectares or 208,500 m^2. In March 2021, surface water covered 105,400m^2, or 50.56% of the study area. This decreased by 94.69% between March and June, with water only covering 5,600m^2 (2.69%) of the study site, and decreased by a further 21.43% between June and October, with water covering 4,400m^2 (2.11%) of the study site. Overall, from March to October 2021, surface water decreased by 95.83%, with 101,000m^2, or 48.45% of the total site, free of surface water in October compared to March (Figure 45).

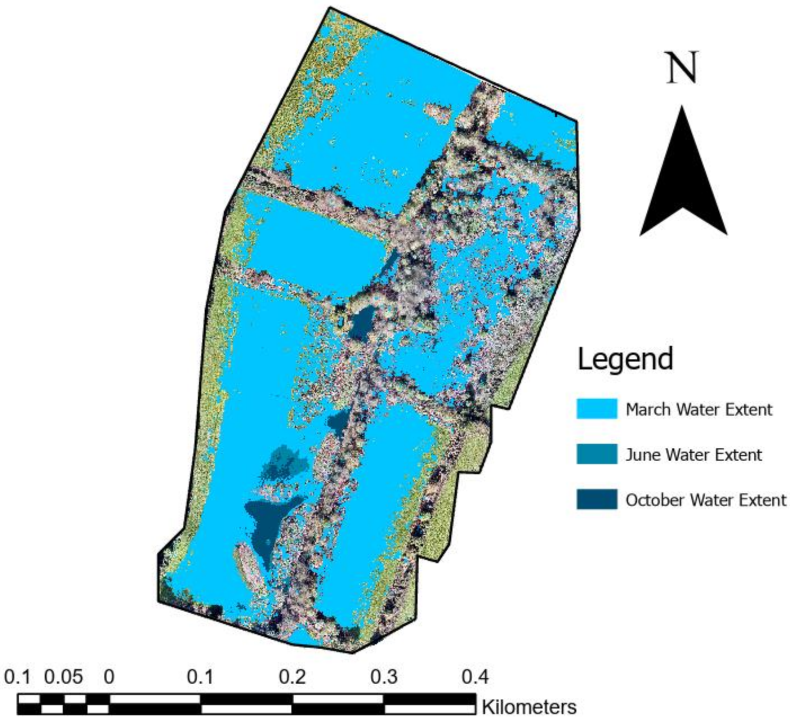


Fig 45. Changes in Surface Water Extent at Ashleworth Ham from March-October 20216.

6.3.2 Dip-well Data

At Coombe Hill Canal, both dip-wells were submerged by 0.13m, or 13cm of water. This indicates 13cm of surface water (Figure 46). No water was recorded at either dip-well during June or October.

Fig 46. Known Surface Water Extent at Coombe Hill Canal and Meadows in March 2021 based on Dip-well Data (Dip-wells Labelled C1 and C2)

At Ashleworth Ham, both dip-wells were submerged in March, indicating high water levels, although no specific levels were recorded (Figure 47). During June, water was found to be present in the water table at both dip-wells, but not on the surface. During October, no water was recorded at either dip-well.

Fig 47. Known Surface Water Extent at Ashleworth Ham in March 2021 based on Dip-well Data (Dip-wells Labelled A1 and A2)

6.4 Discussion

Across both sites, water levels decreased by over 80% across the study period. Whilst the accuracy of the drone-based methods were much higher than the dip-well data, and the flights caused less disturbance than manually checking the dip-wells would have, the flights and creation of the Deep Learning package took longer. The method was seen as having potential for intergration into the Wildlife Trusts, but was currently seen as beyond their requirements for water surveying.

6.4.1 Seasonal Changes in Water Levels

Both sites showed a high decrease in water coverage from March to October, with water levels decreasing by over 80% for both sites (Figure 48). Despite this decrease in water coverage, both sites contained permanent pools that retained water across the entire study period, and Coombe Hill Canal featured several semi-permanent seasonal channels, which retained water through March to July, although the exact period between July and

October when these channels dried up is unknown. Despite an overall decrease in water at both sites, the manner in which water levels dropped at each site varied.

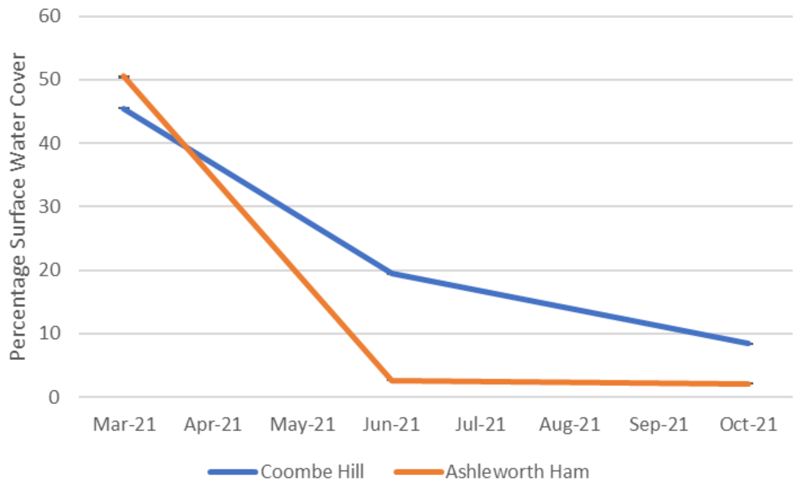


Fig 48. Changes in Surface Water Extent at both sites between March and October 2021 with error bars

At Coombe Hill, water levels declined significantly between both March and June, and June and October, although the rate at which surface water levels decreased did slow between June and October. In contrast, water levels at Ashleworth Ham dropped sharply between March and June but remained relatively constant between June and October. This implies that water levels at Ashleworth Ham had plateaued until water levels began rising again in the winter, whereas Coombe Hill water levels could have potentially continued to decrease. In future studies, an extra set of flights in December could help to identify whether Coombe Hill water levels continued decreasing.

Management goals for both sites primarily revolve around ensuring a suitable wetland habitat (pers. comm). The lack of specific management targets makes it difficult to know whether the obtained results are an indicator of good wetland health, or whether more site management would need to be carried out. However, both flooding and drainage of the sites was required to provide suitable floodplains, as well as foraging and breeding habitat for migratory birds, so a high level of change in surface water levels would be desirable. Aside from measuring seasonal changes, these flights could also be carried out over multiple years, to assess whether water levels as a whole were decreasing or increasing year on year, which could affect the suitability of the habitat long term. The method could also be used by conservation groups to monitor surface water extent for other reasons, such as when carrying out wetland restoration or implementing drainage systems, to monitor progress and inform management targets.

The June and October data collection was carried out quicker than the March dataset, despite having the same total flight time. This was due to an increased familiarity with the methods, and a lack of GCPs. Whilst GCPs have been shown to provide higher accuracy than solely using the GPS integrated into the drone (Hugenholtz *et al.,* 2016) and are useful in a research setting where high accuracy would take precedence over logistical concerns such as price, they were found to not provide enough of a benefit within the context of a local Wildlife Trust carrying out site surveying. The highest possible error of $89.8cm^2$ was negligible when comparing areas of thousands of metres squared, and the prohibitive cost of high precision GPSs would increase the price of the method beyond the budget of many conservation groups, whilst offering only a slight increase in accuracy.

One advantage of this method over other drone-based methods such as reflectance or LiDAR is that it can be carried out using a simple RGB camera. This lowers the cost of the drone hardware significantly, allowing the same RGB drone that was hypothesised as a suitable option in Study 1 to be utilised here. Whilst deep learning has been used for ecological monitoring, primarily for identifying species and carrying out population counts (Christin, Hervet and Lecomte, 2019), the use of deep learning to identify surface water is a novel method that has potentially for future hydrology monitoring and land-classification .

6.4.2 Comparison of Methods

Accuracy and Detail

The drone-based surveys were much more accurate than the dip-wells, as the drone data provided quantified water levels, as well as specific information on where water was located on-site without a need to extrapolate. The dip-wells, in contrast, could only provide information on water presence at their location and given that water was mentioned to occur on-site as a result of rainfall, it cannot even be concluded that water at a dip-well has spread from an area of permanent water. The low number of dip-wells, as well as their clustered locations, make it very difficult to draw any conclusions about water levels on the site outside of their immediate area, although visual observation of the site will have been carried out as the dip-well data was gathered, allowing for the collection of visual, non-quantifiable data on the sites that can be used to assume that water levels were high in March, and lower in June and October. More dip-wells across the site would be needed to obtain any meaningful results. However, accessing these dip-wells could be a problem when water levels are high, making them harder to reach or completely inaccessible. Drones, however, can be flown over inaccessible areas with no extra difficulty.

A potential difference between the dip-well data and the drone data could be due to a difference in time between data collection, with a range of 2-7 days between drone flights and dip-well data collection. However, the lack of any significant data from the dip-wells makes it highly unlikely that this has impacted the results in any meaningful way.

Time

Whilst the exact time taken to check the dip-well results is not known, it is presumed to be the time it would take to walk to the dip-wells and take a reading. Assuming that all dip-well sites are accessible, the drone-based data collection would be significantly longer, taking on average 2 hours and 56 minutes for data collection (not including the placement of GCPs, which are not recommended when carrying out this kind of survey work and increased the survey time) at Coombe Hill and 49.5 minutes for Ashleworth Ham. Another potential issue with the drone-based method in terms of time is battery life. When surveying both Coombe Hill and Ashleworth Ham on the same day, four batteries were used. If a conservation group did not have that many batteries or wanted to survey a larger site, either more batteries would need to be obtained, increasing the cost of the method, or the flights would need to be split across multiple days, increasing the survey time as multiple trips to and from the site would be required.

Cost

As with the Daneway Banks study, this method can be carried out with a drone equipped with an RGB camera, which can be obtained for approximately £210 (Dronetech, 2022). Whilst the deep learning method used in this case study is more complex than the methods of Studies 1 and 2, it is still simple, able to be easily carried out by someone with no prior experience by following a published protocol, and does not require extensive experience with spatial analysis or deep learning. It can also be carried out on free GIS software (Cresson, 2022), although the method involved may be more complex. The creation of the deep learning model is mostly automated, so whilst it can take some time to create the initial deep learning package and classify a site, with the initial deep learning package taking approximately 13.5 hours to create, and the 37.62-hectare Coombe Hill study area taking approximately 9 hours to classify on a consumer-grade laptop, the classification can be left once started and completed without any further input. Once created, the deep learning package can also be applied to any similar site at no extra time cost, lessening analysis time substantially once the initial deep learning package has been created. This package can then be easily copied and transferred between devices, allowing the same package to be used by multiple conservation groups. This means that whilst it may require a time investment to create, once made conservation organisations can use the deep learning model to perform this kind of analysis without requiring a significant long-term time and money investment.

Although high-quality dip wells and water level meters are expensive and the exact price can vary, affordable dip wells can easily be made using plastic pipe and installed in soft terrain (Farr and Whiteman, 2014). However, the increased quantity of dip wells required to obtain useful data may make costs comparable to the initial drone cost, whilst providing less accuracy.

Disturbance

One potential problem identified in the systematic review with using a drone for data collection was the possibility of disturbance, with large numbers of birds present on-site throughout the year. Whilst it has been shown that drones can cause disturbance to both terrestrial and aquatic birds (Weston *et al.,* 2020), other research shows that drones cause less disturbance than other methods, specifically ground-based methods (Valle and Scarton, 2020; Borrelle and Fletcher, 2017). To assess disturbance, a 4-minute disturbance check was carried out on the 19th March, in which a drone was flown over the site to assess any impact on birds within the study area. A height of 75m was chosen for the disturbance check and the drone flights as this had been shown to minimise disturbance, even when flying over breeding sites (Mesquita *et al.,* 2021). As in the previous case studies, take-off and landing were also carried out at a suitable distance away from any animals. Overall, no disturbance was observed during the disturbance check or any of the subsequent drone flights. It is unknown whether collecting data caused any disturbance, although it is unlikely given the location of the dip-wells at the edge of the study area. However, if more dip-wells were added, which would be necessary to obtain suitable levels of data on water coverage, accessing them without causing disturbance would likely be difficult, given the birds would be foraging and breeding in the same locations where dip-wells would need to be placed.

Bureaucracy

No legal issues or permissions were required when using the dip-wells. To carry out the drone flights, the same permissions would be required as mentioned in Study 1, including lessened restrictions if the lighter drone was used instead of the larger Mavic drones used in this method.

However, one additional legal issue that affected the drone flights carried out at Coombe Hill was an inability to survey the southern meadows, due to the proximity of Gloucestershire Airport, placing the southern meadows within its Flight Restriction Zone (FRZ). Whilst this did not impact the drone flights carried out, any survey work done in the southern meadows, or any sites within an airport's FRZ would require additional permission from the air traffic control of the airport, which could delay or prevent drone flights.

6.5 Wildlife Trust Feedback

Overall, opinions on the potential for the integration of deep-learning AI and drone-based data for the assessment on water levels on wetland sites were mixed. The data was believed to provide a good baseline, especially for assessing the long-term impact of climate change and changes in water levels across multiple years. It was seen as more detailed and more useful than current dip well data, which is collected monthly by a volunteer. The ability of the deep learning package to be used across multiple sites was also believed to have high potential for the establishing of baseline data on site water levels, as well as how water behaves on the site during periods of flooding. The very short time it takes sites to flood (with wetland sites often flooding overnight) was seen to be a major barrier to the use of this method for more short-term flood modelling, and more information on water depth and temperature would be useful to further inform site management goals. Overall, the method was seen as a good baseline, with potential for long-term data collection, and as something that would ideally be implemented, but that was currently beyond the requirements of the Wildlife Trust's current operations.

6.6 Conclusions

Overall, the drone-based deep learning method was shown to accurately obtain information on seasonal changes in water extent, with potential for use in other areas where surface water information is needed. Water levels at both sites decreased greatly from March to October, with water levels at Ashleworth Ham decreasing to a greater degree, and more quickly than water levels at Coombe Hill. Current dip-well data was found to be insufficient for drawing any conclusions about water levels. On top of increased costs to obtain the drone, the deep learning method required a bigger time investment both for carrying out the flights and for carrying out the deep learning. Once made, however, the deep learning package can be quickly and easily applied to any map, making it quick and accurate after the initial time investment. The drone-based method was also found to cause no disturbance at the 75m heights at which the flights were carried out, compared to the potential disturbance that would be caused by manual checking of dip-wells in important areas. More dip-wells would be needed throughout the site to provide meaningful data, at which point, the increased accuracy of the drones and potential lower disturbance would need to be weighed against the longer survey time. Whilst the method did provide more accurate information and was seen as superior to current dip-well methods, it was currently seen as providing information at a level of detail that was not required for the current site management plans, potentially being useful only for more long-term site assessments.

7 Synthesis of Findings

7.1 Drone Capabilities

In order to identify the current uses and capabilities of drone technology in the field of conservation, a systematic review was carried out investigating how temperate drone use compared to existing, non drone-based methods. It was found that drones were statistically more likely to be considered a better or equal alternative to terrestrial, or field-based methods in literature where the two methods were compared (Ancin-Murguzur et al., 2019) . Within the context of the literature, the idea of drones being an equal or better alternative took the form of drone-based methods having a higher or comparable level of accuracy to other methods. This was consistent across a range of data types and drone uses, including vegetation surveying (Hyyppä et al., 2020), animal monitoring, (Chabot, Craik and Bird, 2015), and terrain mapping (Moloney et al., 2018; Kinzel et al., 2015). Drone-based surveys were also found to take less time to carry out, had a simpler methodology and analysis, and greater replicability of methods than ground-based methods while obtaining the same level of accuracy (Barnas et al., 2019; Valle and Scarton, 2018; Ventura et al., 2016; Breckenridge and Dakins, 2011). Studies comparing drones to manned aircraft surveying (Dash *et al.,* 2019; Resop, Lehmann and Hession, 2019; Näsi *et al.,* 2018), and satellite imagery (Berra, Gaulton and Barr, 2019; Fernández-Guisuraga *et al.,* 2018; De Giglio *et al.,* 2017) had similar findings, with drone imagery shown to be higher resolution and allowed for a greater level of detail than the compared method. However, the low number of these papers made statistical analysis impossible, and more research would need to be carried out to further comapre drone-based methods with aircraft and satellite imagery.

Vegetation structure assessment was the most common use of drones in the literature, fitting within the Ground Cover and Features category. Literature comparing drone-based methods to other methods of vegetation structure assessment found that the drone-based method was statistically more like to be considered a better or equal alternative, although publication bias may have skewed these results, as papers showing drones as worse than existing methods may have been denied publication. Drones were found to have a higher or comparable level of accuracy and when obtaining the same level of accuracy, were found to be quicker with simpler methods (Ventura *et al.,* 2016) and could be processed at a later date without any loss in accuracy (Näsi *et al.,* 2018).

Animal monitoring was the second most common use of drones, and drone counts of small groups of animals in the literature were found to be comparable to ground-based methods (Chabot, Craik and Bird, 2015). However, when surveying larger groups, drones were found to be more accurate, cheaper and quicker (Brisson-Curadeau, 2017). Compared to manned aircraft, drones were found to be comparable in accuracy, whilst being cheaper and more replicable (Rexer-Huber and Parker, 2020). However, RGB cameras were found to be ineffective at detecting animals with colouration similar to their surroundings (Chabot and Bird, 2012) and drone-based thermal imagery, whilst being more effective at detecting animals, was found to have difficulties in areas with dense canopies (Gooday *et al*., 2018).

Conclusions on levels of disturbance compared to other methods varied, with some studies concluding drones caused little disturbance, less or equal to ground-based methods (Weissensteiner, Poelstra and Wolf, 2015; Chabot and Bird, 2012), whilst other studies concluded that drones caused more disturbance (Scholten *et al.,* 2019). Most studies identified take-off and landing as periods with the greatest disturbance potential (Rexer-Huber and Parker, 2020), suggesting that they should be conducted away from animals, and that disturbance was lower at higher flight altitudes (Valle and Scarton, 2018). Drones were also found to cause less habitat disturbance and damage than ground-based methods (Weissensteiner, Poelstra and Wolf, 2015), specifically in hydrology, where ground-based methods of water collection disturbed sediment and thermal gradients (Song *et al*., 2017).

Drones used for physical sampling of water were found to lack precision whilst not being significantly more accurate (Song *et al*., 2017; Chung *et al*., 2015), making them unsuitable and limiting their use primarily to image-based water surveying. However, studies that focused on mapping water found that drones were equal to field-based methods in terms of accuracy ((Ehmann, Kelleher and Condon, 2018), or more accurate when compared to satellite imagery (Spence and Mengistu, 2015).

The main problem identified in the systematic review regarding drone use was a dependence on good weather conditions (Rexer-Huber and Parker, 2020; Dandois, Olano and Ellis, 2015) compared to both ground-based surveys (Dandois, Olano and Ellis, 2015) and manned aircraft (Resop, Lehmann and Hession, 2019), which were more durable and therefore able to fly in tougher weather conditions. This could prevent surveys from being carried out or greatly add to the amount of time required to carry out drone-based surveys. Drones were also found to lack accuracy and precision in areas where incredibly fine assessment was required, such as individual plant identification (Hardin *et al.,* 2007) or the detection of very short or narrow features (Inoue *et al.,* 2014) as well as physical sampling (Chung *et al*., 2015) and bioacoustics (Wilson, Barr and Zagorski, 2017).

The logistical considerations of drone use, such as the cost of equipment and the legal requirements for flying, were rarely investigated in the literature, with most of the research focusing on drone uses and capabilities over the resources required to obtain and fly drones. This makes it hard to draw any conclusions on the potential for conservation organisations to obtain and use drones. Whilst this makes sense when carrying out research, where the accuracy of the drone method is often the primary concern, it is a large gap in the current literature that could greatly affect the uptake of drones in industry, especially conservation which struggles with underfunding. This led to a focus on logistical considerations such as time, cost, disturbance and legislation, as well as accuracy, when developing and carrying out the case studies.

The main biases identified in the literature were due to differences in the study units between the drone and control methods, as well as potential bias due to researcher knowledge of the two methods. This is primarily due to an inability to double-blind the findings of any research due to visible differences in output (Savović *et al.,* 2012), as well as an inability to randomise the study units and the high number of variables out in the field. Many of these issues would apply to any monitoring-based comparisons, with the study validity questions seeming more suited towards traditional, laboratory-based conditions where variables can be more easily controlled and the results randomised and double-blinded. These issues also reflect the conditions conservation groups will be working under, and these biases were only found to be prevalent in around 12.8% of the total reviewed literature, making them less relevant in the context of integrating drones into conservation organisations. However, they remain considerations when assessing any drone-based literature.

Overall, the systematic review identified the high or comparable levels of accuracy, achieved in a shorter period of time and with simpler methodologies that allowed for greater replicability, as the primary enabler to further uptake of UAVs in nature conservation. The main blockers to further drone uptake is their dependance on good weather conditions and a lack of accuracy and precision in specific fields such as bioacoustics and physical sampling. Disturbance was identified as a potential enabler or blocker, although, assuming take-off and landing are performed away from any animals, a height of 50m was concluded to be sufficient to avoid disturbance in most cases, with a height of 75m recommended for breeding or sensitive animals.

7.2 Conservation Organisation Views

Interviews were carried out with Wildlife Trust employees, to identify the current needs of conservation organisations, as well as their beliefs and current practises, regarding drones and any potential barriers to drone use. A lack of financial resources was the most commonly brought-up conservation challenge in the interviews (RP1), which was exacerbated by political factors such as Brexit cutting off European conservation funding (RP2). This means that any drone-based alternative monitoring method would need to either be cheaper than existing methods, or provide a significant increase in efficiency or accuracy to be worth the extra cost.

This lack of funding also resulted in a reliance on unpaid volunteers over trained staff. Whilst this has been positive, allowing conservation work to be carried out where it otherwise couldn't be, it results in a lack of specialist skills which may be needed for specific conservation work. Fewer staff members also means that more work needs to be split between current employees, resulting in a lack of time to carry out all the required work. This has caused a deprioritisation or certain aspects of conservation, such as monitoring, leading to outdated information or a lack of information which makes it hard to determine what specific conservation actions will have the most impact.

Drones were identified as as having a high resource efficiency (RP3), able to carry out work quicker than existing methods. This would be of interest to conservation groups due to their lack of resources (RP1). There was also a high level of general interest in drones within the Wildlife Trusts, and it was believed that drones have high potential within the field of conservation. This high potential was expected to increase as drone technology advances and drones become cheaper and more accessible. This also ties into the findings of the systematic review, which found that one of the main benefits of drones was their ability to carry out work in a shorter period of time whilst maintaining or improving accuracy.

As in the systematic review, vegetation structure was the most common potential use identified in the interviews (RP4), with drones believed to obtain more accurate, reliable vegetation data than other methods (RP5). Quantification of certain habitat features, specifically scrub cover, was specifically mentioned (RP5), as well as looking at how vegetation structure changes over time, which is often overlooked due to a lack of resources to cover every site and prioritisation of sites that haven't yet been monitored.

Animal monitoring was also a major use of drones brought up (RP7). The use of thermal imagery was mentioned specifically (RP10), as was using drones for bird counts (RP8). The concept of monitoring nests and burrows was also brought up but was perceived to require expensive, high-resolution thermal sensors. Disturbance was rarely mentioned in the interviews, with drones being seen as having the potential to cause less disturbance than ground-based surveys (RP9). Finally, the mapping of standing water and assessing flood risk were both mentioned as areas where drones could be useful (RP6).

Drone legislation and bureaucracy was identified as one of the main barriers to drone use primarily due to a lack of clarity on the requirements for drone use (RP12, RP13). There was also some confusion caused by legislation changes such as the new laws brought into effect on 31st December 2020 in the UK, including the recategorisation of drones, and a removal of distinction between commercial and non-commercial flights. Limitations caused by restricted airspace or landowner permissions were also brought up as potential factors that could limit or prevent drone flights.

The other main barrier to drone use was a lack of knowledge regarding drones, resulting in a lack of knowledge on drone best practices (RP12), with peer-reviewed journals inaccessible due to cost (RP11). This lack of knowledge could lead to unrealistic expectations, such as overestimating their capabilities that could then lead to disappointment or wasted resources if the drone was unable to meet the conservation organisations needs.

All themes identified in the interviews were consistent across most of the Wildlife Trusts, except for the London Wildlife Trust, showing that these viewpoints are widespread amongst conservation organisations covering the wider countryside, although more research would need to be conducted on drone use in urban centres specifically to identify how drones could be of use in those environments, as they present very different problems such as privacy concerns and issues due to restricted air space, and fewer issues with funding due to a higher proportion of funding being allocated to them.

In conclusion, a low level of financial resources, leading to a lack of trained staff and not enough time to carry out conservation actions, was the biggest problem affecting current conservation work. Whilst this does mean that the lack of funding could prevent the uptake of drones, acting as a blocker, the high resource efficiency of drones could instead act as an enabler, helping to overcome some of the current challenges faced by conservation groups. The overall interest in drones also acts as an enabler, although not enough to overcome the logistical problems without further benefits. The main blockers to further uptake of UAV use was the complicated legislation around drones, which was exacerbated by recent changes to drone laws, and a lack of knowledge regarding drone uses leading to unrealistic expectations and an unwillingness to spend a large amount of money on a new tool without being fully informed about its capabilities.

7.3 Case Studies

7.3.1 Vegetation Structure

Study 1, which looked at a drone-based method for mapping scrub cover compared to an existing structured walk method, found that the drone-based method was more quantified and accurate, representing a complete census of all vegetation at the site, unlike the ground-based survey which relied on subjective assessment and extrapolation of scrub cover from 10 sample data. The ability to store drone imagery and use/review it at a later date also allowed temporal changes in scrub levels to be assessed. For example, it was possible to measure an increase in scrub levels at Daneway Banks from 14.63% cover to 16.52% cover between 2015 and 2017, before dropping down to 14.89% cover in 2021. With standardised methods it is simple to identify change between data sets, and the data can be further manipulated to show directional change in vegetation structure that distinguish vegetation succession or reduction, which is a novel way of assessing directional scrub change on a site which is more helpful and relevant to site management goals than just scrub growth and loss. The data was also shown to be suitable for planning specific management actions, such as the removal of individual scrub stands. The study highlights the importance of frequent surveying to properly judge conservation objective progress. For example, without the 2017 dataset at Daneway Banks, very different conclusions about the direction of scrub cover change could be made, with it seeming as though scrub levels are slowly increasing, instead of decreasing. The ground-based 10 point sample method was only 15 minutes quicker than the entire drone flight, although this was due to a 25 minute launch delay due to bad weather.

No disturbance was observed during the study, with take-off and landings carried out at a significant distance away from any observed animals. However, the ground-based method was identified as having higher potential for habitat damage than the drone-based method, as it involved walking off the paths in a straight line through vegetation.

For all drone flights, a flyer ID (for the drone pilot) and operator ID (for the drone owner and responsible party) was required. Obtaining both of these cost £10 and required a 40-question, multiple choice quiz around drone permissions and safeties to be completed.

Using a drone under these conditions required a distance of at least 50m horizontally to be kept from uninvolved people. To fly the drone closer to people would require a drone of less than 250g to be used, or an A2 certificate of competency (A2 CofC), which costs £100 and is made up of a video course and online assessment that can be completed in less than 24 hours. Using a drone that weighs less than 250g, would allow the drone to be flown close to, and even over people, without an A2 CofC requirement.

The study was carried out with a drone equipped with an RGB sensor. Whilst the cost of the drone was around £1,000, it was found that the study could be carried out with a drone costing approximately £200, reducing cost significantly. This drone also weighs under 250g, allowing it to be flown closer to and over people without needing to obtain an A2 CofC. The analsysis software used in the study cost £1259.67 for a subscription that provided enough time to analyse the data. However, free software is available with the same capabilities, reducing software costs to £0. This means that the study could be carried out for a total price of £210, with the drone costing £200 and the Flyer/Operator ID costing £10. Whilst this is more expensive than the structured walk method, which cost nothing, the increased accuracy and ability to reuse the drone over multiple years, as opposed to having to pay every time a drone survey is carried out, gives it greater value for money.

A potential concern when assessing drone uses in conservation was ensuring that the accuracy of the drones did not vary significantly at different heights, as different heights would be required depending on the size of the site and what animals were on-site, to prevent disturbance. As part of this study, drone scale was investigated, and it was found that there was a slight decrease in detail at 75m, with scrub cover levels changing from 3.6% at 50m, to 4% at 75m. However, the lack of any change in quality between 50m and 30m, allows a drone to be flown at 50m without any decrease in detail for studies involving habitat classification such as vegetation cover or water extent. However even the decrease between 50m and 75m is minor, and whilst flying at 50m or lower is recommended to ensure maximum accuracy, flights can be carried out at higher altitudes where it is necessary to save time or avoid disturbance, without a major decrease in accuracy.

Feedback from the GWT on the potential of drones for the assessment of vegetation structure using the method outlined in Study 1 was positive, with a high level of interest in the specificity of the results, and the ability of the method to visualise information previously only known to experienced site managers. The potential for it to be integrated at a national level was also discussed. In conclusion, the drone method provided outputs that have greater accuracy, more detail, higher replicability and more useful information for management than the ground-based method, and it was seen to provide significant benefits over existing methods, with a high possibility of use within the Wildlife Trusts.

7.3.2 Animal Monitoring

Study 2, which compared drone-based thermal imagery to ground-based visual observation for livestock counting, found both drone and manual methods to be equally accurate at detecting livestock, detecting 21 animals out of 56 (37.5%), although both methods could have potentially higher accuracy, as it is unknown whether all livestock were within the survey area at the time of the survey. The drone was found to be more effective at detecting non-livestock wildlife, but the lack of accuracy means that only the presence of those animals can be concluded, as opposed to any specific data on numbers. In contrast, the manual survey allowed for more detailed visual checks, such as health checks to be carried out, whereas the drone data does not.

Thermal imagery was shown to be useful in picking up animals, making it easier than just using RGB imagery, and the processing of images helped to narrow down the number of images that needed to be checked. However, the method has problems with low-resolution images not picking up all animals present in the corresponding RGB picture, as well as being unable to create an orthorectified mosaic of images, which would be much easier and quicker to assess and could provide a basis for automated detection and counting using deep learning. Overlapping heat fields being hidden in processed images was also an issue. The drone and ground-based methods were found to be comparable in time, with the drone being, on average, 7.2 minutes quicker than the manual survey.

Generally, no disturbance was observed during the study, with take-off and landings carried out at a significant distance away from any observed animals, and a suitable distance kept from livestock during the ground-based surveys.

A drone equipped with a thermal camera was used for the study, which cost approximately £3,000. More expensive thermal cameras which could negate some of the accuracy and analysis issues identified in the study cost upwards of £10,000, making high-resolution thermal imagery unviable for conservation organisations without a source of funding and high usage to justify the cost. In comparison, the ground-based method is free, assuming the use of unpaid volunteers, and provides similar levels of accuracy and speed. As with the previous study, a flyer ID (for the drone pilot) and operator ID (for the drone owner and responsible party) was required. A drone equipped with a thermal camera was not available under 250g, meaning that further qualifications may be needed depending on proximity to uninvolved people.

The site was jointly managed between GWT and Forestry England. This required legal permissions to fly from all involved groups, which took three months to obtain. This means that any flights on jointly managed sites would need to be planned well in advance, or the flights may be delayed.

Wildlife Trust feedback concluded that this method did not provide any advantage over existing methods, especially as ground-based checks would still need to be carried out to assess animal health. In summary, drones do not provide enough of an increase in accuracy to be worth the extra cost and legal requirements, and the inability to assess livestock health using the drone data makes existing ground-based surveys of livestock a more suitable method.

7.3.3 Hydrology

Study 3, which compared a drone-based deep learning model to existing dipwells for the quantiifcation of surface water on wetland sites, found the accuracy of the drone method to be high, with GCPs used to confirm accuracy. The overall error was found to be 89. 8cm^2 (2.4x10^{-8}% of total site area) for Coombe Hill, and 5.36cm^2 (2.6x10^{-9}% of total site area) for Ashleworth Ham. Whilst the use of GCPs did increase accuracy, the increase was negligible, and the high cost and extra time taken to use them makes them unnecessary for this kind of survey. Using deep learning to assess standing water extent on a site is a novel method and can be carried out using an RGB camera and an orthorectified mosaic, without requiring sensors capable of reflectance or LiDAR, both of which are more expensive and complicated to use. Both sites showed a severe decrease in water from March to October, with a decrease of 81.43% of surface water at Coombe Hill, and 95.83% at Ashleworth Ham. The drone-based method provided complete coverage of the site, unlike the than the dip wells which would have required a much larger network of dip wells to obtain the same coverage, which would also drastically increase the survey time. Alternatively, a visual inspection could be done but that would be based on subjective assessment and extrapolation, some areas would be inaccessible due to the water, and would cause significant disturbance to birds on-site. The drone-based method took significantly longer than the presumed time to go to the existing dip wells and take a reading, taking on average 2 hours and 56 minutes for Coombe hill and 49.5 minutes for Ashleworth Ham. The analysis also took a significant period of time, taking over a day in total to analyse, although once started, the analysis could be left to run without needing any input, and the deep learning packages created can be reused. Despite this increase in time taken, the increased accuracy of the drone-based method, as well as the ease of use and lack of disturbance compared to manual surveys means that, in conclusion, it is likely a more suitable method, except in situations where time is the most important factor.

Before the first survey, a disturbance check was carried out. Due to the presence of potentially breeding wading birds, all flights were carried out at 75m so as to minimise disturbance. No obvious signs of disturbance were observed during any of the flights. Any dip wells placed in locations near breeding birds, which would be required to obtain suitable coverage, would presumably cause significant disturbance to reach, unless more expensive digital readers were used which may be beyond the budget of conservation organisations, and more expensive than the drone-based method outlined in the case study.

As with the previous studies, a flyer ID (for the drone pilot) and operator ID (for the drone owner and responsible party) was required. As this study only requires a drone equipped with an RGB sensor, the same equipment and requirements used in Study 1 could be applied here, allowing the flights to be carried out for £210. It is unknown how this compared to the cost of installing sufficient numbers of dip wells to draw meaningful conclusions.

A potential source of bias in this study was a difference in time between the data collection of the two methods, with a gap of 2-7 days between the drone flights and the collection of the dip well data. This was due to the dip well data being collected at set dates by Wildlife Trust employees. However, the lack of any significant data from the dip-wells makes it highly unlikely that this has impacted the results in any meaningful way. Another problem that could affect drone surveys in similar areas was the presence of a restricted airspace zone due to the proximity of an airport as this prevented the southern meadows from being surveyed and required calling the relevant air traffic control on the day to inform them of the flights.

Wildlife Trust feedback was that the method was seen as a good baseline, with potential for long-term data collection, and as something that would ideally be implemented, but that was currently beyond the requirements of the Wildlife Trust's current operations, given the very short time it takes sites to flood (with wetland sites often flooding overnight), and the need for more information on water depth and temperature in order to help inform site management goals. This means that whilst the increased level of detail and ability to provide a long term assessment of changes in water level was acknowledged, the method was unlikely to be implemented.

7.4 Future Work

The research carried out during the development of this thesis has identified multiple areas where further research could be carried out. Bird counts were mentioned as another potential use of drones both in the literature (Hodgson *et al.,* 2018) and the interviews (RP8), and drones may provide more of a benefit when carrying out bird counts, where animal numbers are much higher than during livestock or large mammal counts. However, a suitable site for bird counts was not available during the creation of the case studies. Another potential area to investigate would be other areas in the UK where water cover assessment may be more important, or whether RGB imagery can be used to determine information on water depth and temperature, allowing for more comprehensive data on wetland sites that may be of more use conservation organisations. Determining site management goals for wetland sites or carrying out surveys where site management goals are already in place would allow for the method to be more tailored, ensuring that it was working to meet existing conservation goals, as scrub cover was in Study 1. These studies could also be carried out in different countries to identify differing conservation needs and whether drones could be of use, as it has been found that drone-based animal monitoring is very useful in countries with high numbers of game and large reserves.

Urban areas were found to have very different needs to other Wildlife Trusts, with better funding but less space, and more of a focus on potential damage caused by the public. More interviews, focusing specifically on urban conservation would need to be carried out to assess whether there is potential for drones to be implemented in more urban settings and whether the increased money found in urban Trusts allows for more options regarding monitoring methods.

All the case studies carried out in this thesis were based on existing uses of drones identified in the literature and interviews, although the development of novel methods and consideration of logistical considerations helped fill a gap in the current research. However, studies could be carried out on the potential of drones for conservation uses that are less prevalent in the literature, such as for litter/pollution detection or assessing ice sheet degradation. Finally, during the course of this research, the UK passed the Environment Act 2021, with many of the regulations coming into force in 2022. Research would need to be carried out into how the Act has changed the state of conservation in the UK and what that means for monitoring methods, including drone-based monitoring.

7.5 Conclusion

Overall, it was found that there were many enablers to further uptake of UAVs in nature conservation. The ability of drones to obtain accurate data quickly was identified in the systematic review, the interviews and the case studies, and the high resource efficiency of drones was identified in the interviews, with the case studies showing that whilst drones did often cost more than ground-based methods, they were high value for money and allowed work to be carried out quickly and without requiring too much training. Another enabler was the high level or replicability, allowing for both short and long-term temporal changes to be assessed.

The areas in which drones were percieved to be most useful matched up with the literature, with vegetation structure, animal monitoring and hydrology mentioned in both the systematic review and the interviews. This shows that Wildlife Trust expectations on drone use may be more accurate than they realise, allowing drones to be used in those areas without fear of wasted resources.

In contrast to the main enablers, the potential problems with UAVs varied greatly between the systematic review and the interviews, with the systematic review highlighting a dependance on good weather conditions and the lack of precision in certain fields to be blockers, whilst the wildlife trusts identified a lack of resources and the complexity of drone legislation as the main blockers.

Ultimately, a lack of resources within the field of conservation was the main blocker preventing further UAV uptake. This blocker was so severe, that despite there being more enablers to drone uptake, drones could not be considered for implementation unless they exactly met the needs of the organisation in a cost-efficient way. However, as the cost of drones continues to decrease, they will become more accessible to conservation groups. With cost less of an issue, the multiple benefits of drones may result in a massive uptake of drone use, and will allow conservation groups to carry out quicker and more accurate monitoring, allowing for more targeted conservation action and more efficient use of resources, which will in turn further reduce the lack of resources these groups have, potentially removing a lack of resources as a blocker entirely.

This thesis has assessed the potential for incorporating drones into UK conservation organisations and answered the primary research question; 'How can drones be better incorporated into UK conservation organisations?'. The findings of the thesis, as well as the novel methods used in the case studies, the information collected in the interviews, and the focus on logistical issues of drone use constitutes an original piece of research that meets the PGR doctoral descriptors, and is a new and useful contribution to existing knowledge.

References

- Ahirwar, S., Swarnkar, R., Bhukya, S. and Namwade, G. (2019) Application of Drone in Agriculture. *International Journal of Current Microbiology and Applied Sciences* [online]. 8 (1), pp. 2500-2505. [Accessed 26 March 2022].
- Ancin-Murguzur, F.J., Munoz, L., Monz, C. and Hausner, V.H. (2019) Drones as a Tool to Monitor Human Impacts and Vegetation Changes in Parks and Protected Areas. *Remote Sensing in Ecology and Conservation* [online]. 6 (1), pp. 105-113. [Accessed 22 April 2022].
- Arnold, T.W. (2010) Uninformative Parameters and Model Selection Using Akaike's Information Criterion. *The Journal of Wildlife Management* [online]. 74 (6), pp. 1175-1178. [Accessed 26 June 2023].
- Asselin, M.E. (2003) Insider Research: Issues to Consider When Doing Qualitative Research in Your Own Setting. *Journal For Nurses in Staff Development* [online]. 19 (2), pp. 99-103. [Accessed 24 January 2022].
- Aydin, B. (2019) Public Acceptance of Drones: Knowledge, Attitudes, and Practice. *Technology in Society* [online]. 59 [Accessed 29 March 2022].
- Baez, V.M., Poyrekar, S., Ibarra, M., Haikal, Y., Jafari, N.H., Becker, A.T. (2021) Wetland Soil Strength Tester and Core Sampler Using a Drone. *2021 IEEE International Conference on Robotics and Automation (ICRA).* China, 30 May- 5 June 2021. IEEE.
- Barnas, A.F., Darby, B.J., Vandeberg, G.S., Rockwell, R.F. and Ellis-Felege, S.N. (2019) A Comparison of Drone Imagery and Ground-based Methods for Estimating the Extent of Habitat Destruction by Lesser Snow Geese (*Anser caerulescens caerulescens*) in La Pérouse Bay. *PLOS One* [online]. [Accessed 22 April 2022].
- BBC News. (2019) Heathrow airport: Drone sighting halts departures. *BBC News* [online]. 08 January. Available from: https://www.bbc.co.uk/news/uk-46803713 [Accessed 19 October 2022].
- Bearman, M., Smith, C.D., Carbone, A., Slade, S., Baik, C., Hughes-Warrington, M. and Neumann, D.L. (2021) Systematic Review Methodology in Higher Education. *Higher Education Research & Development* [online]. 31 (5), pp. 625-640. [Accessed 07 April 2022].
- Berger-Tal, O. and Lahoz-Monfort, J.J. (2018) Conservation Technology: The Next Generation. *Conservation Letters: A Journal of the Society For Conservation Biology* [online]. 11 (6), p. e12458. [Accessed 23 March 2022].

- Berra, E.F., Gaulton, R. and Barr, S. (2019) Assessing Spring Phenology of a Temperate Woodland: A Multiscale Comparison of Ground, Unmanned Aerial Vehicle and Landsat Satellite Observations. *Remote Sensing of Environment* [online]. 223, pp. 229-242. [Accessed 22 April 2022].
- Bibby, C. and Alder, C. (2003) *The Conservation Project Manual* [online]. Cambridge: Bp Conservation Programme. [Accessed 23 March 2022].
- Borrelle, S.B. and Fletcher, A.T. (2017) Will Drones Reduce Investigator Disturbance to Surface-nesting Seabirds? *Marine Ornithology* [online]. 45 (1), pp. 89-94. [Accessed 11 February 2022].
- Braun, V. and Clarke, V. (2019) To Saturate or Not to Saturate? Questioning Data Saturation as a Useful Concept for Thematic Analysis and Sample-size Rationales. *Qualitative Research in Sport, Exercise and Health* [online]. 13 (2), pp. 201-216. [Accessed 27 January 2022].
- Braun, V. and Clarke, V. (2013). *Successful Qualitative Research: A Practical Guide for Beginners*. London: SAGE.
- Braun, V., & Clarke, V. (2012) Thematic Analysis. In: H. Cooper., P. M. Camic., D. L. Long., A. T. Panter., D. Rindskopf., K. J. Sher., ed. (2012) *APA handbook of research methods in psychology, Vol. 2. Research designs: Quantitative, qualitative, neuropsychological, and biological. Washington D.C.: American Psychological Association,* pp. 57–71. [Accessed 30 June 2020].
- Breckenridge, R.P. and Dakins, M.E. (2011) Evaluation of Bare Ground on Rangelands Using Unmanned Aerial Vehicles: A Case Study. *GIScience and Remote Sensing* [online]. 48 (1), pp. 74-85. [Accessed 22 April 2022].
- Breckenridge, R.P., Dakins, M., Bunting, S., Harbour, J.L. and White, S. (2011) Comparison of Unmanned Aerial Vehicle Platforms for Assessing Vegetation Cover in Sagebrush Steppe Ecosystems. *Rangeland Ecology & Management* [online]. 64 (5), pp. 521-532. [Accessed 18 April 2022].
- Brede, B., Lau, A., Bartholomeus, H.M. and Kooistra, L. (2017) Comparing RIEGL RiCOPTER UAV LiDAR Derived Canopy Height and DBH with Terrestrial LiDAR. *Sensors* [online]. 17 (10) [Accessed 22 April 2022].
- Brisson-Curadeau, E., Bird, D., Burke, C., Fifield, D.A., Pace, P., Sherley, R.B. and Elliot, K.H. (2017) Seabird Species Vary in Behavioural Response to Drone Census. *Scientific Reports* [online]. 7 (17884) [Accessed 23 April 2022].

- British Trust for Ornithology (2019) *The 2018 Breeding Bird Survey Report* [online]. Thetford: BTO. Available from: https://www.bto.org/sites/default/files/bbs-report-2018.pdf [Accessed 07 February 2022].
- Brown, E.D. and Williams, B.K. (2019) The Potential for Citizen Science to Produce Reliable and Useful Information in Ecology. *Conservation Biology* [online]. 33 (3), pp. 561-569. [Accessed 22 October 2022].
- Calvo, K. (2016) *Drones for Conservation- Field Guide for Photographers, Researchers, Conservationists and Archaeologists*. Milton Keynes: Blurb.
- Cameron, S.A. and Sadd, B.M. (2020) Global Trends in Bumble Bee Health. *Global Trends in Bumble Bee Health* [online]. 65, pp. 209-232. [Accessed 15 March 2022].
- Cardinale, B.J., Duffy, J.E., Gonzalez, A., Hooper, D.U., Perrings, C., Venail, P., Narwani, A., Mace, G.M., Tilman, D., Wardle, D.A., Kinzig, A.P., Daily, G.C., Loreau, M., Grace, J.B., Larigauderie, A., Srivastava, D.S. and Naeem, S. (2012) Biodiversity Loss and Its Impact on Humanity. *Nature* [online]. 486, pp. 59-67. [Accessed 23 March 2022].
- Cavoukian, A. (2012) *Privacy and Drones: Unmanned Aerial Vehicles*. Ontario: Information & Privacy Commissioner Ontario, Canada.
- Chabot, D., Craik, S.R. and Bird, D.M. (2015) Population Census of a Large Common Tern Colony with a Small Unmanned Aircraft. *PLOS One* [online]. [Accessed 23 April 2022].
- Chabot, D. and Bird, D.M. (2012) Evaluation of an Off-the-shelf Unmanned Aircraft System for Surveying Flocks of Geese. *Waterbirds* [online]. 35 (1), pp. 170-174. [Accessed 23 April 2022].
- Charton, K.T., Sclater, V. and Menges, E.S. (2021) Mapping Spatially Explicit Vegetation Gaps in Florida Rosemary Scrub Using Unmanned Aerial Vehicles. *Ecosphere* [online]. 12 (4), p. e03470. [Accessed 04 June 2023].
- Christin, S., Hervet, E. and Lecomte, N. (2019) Applications For Deep Learning in Ecology. *Methods in Ecology and Evolution* [online]. 10 (10), pp. 1632-1644. [Accessed 28 May 2023].
- Chung, M., Detweiler, C., Hamilton, M., Higgins, J., Ore, J. and Thompson, S. (2015) Obtaining the Thermal Structure of Lakes from the Air. *Water* [online]. 7 (11), pp. 6467-6482. [Accessed 23 April 2022].
- Civil Aviation Authority (2022) The Drone and Model Aircraft Code. Available from: https://register-drones.caa.co.uk/drone-code Accessed 24 June 2022

- Clarke, V. (2017). *Thematic analysis: What is it, when is it useful, and what does 'best practice' look like* [lecture]. University of the West of England. November.
- Clarke, V. and Braun, V. (2017) Thematic Analysis. *The Journal of Positive Psychology* [online]. 12 (3), pp. 297-298. [Accessed 25 January 2022].
- Climate Institute (2017) *Deforestation and Climate Change* [online]. Washington D.C.: The Climate Institute. Available from: http://climate.org/wp-content/uploads/2017/04/deforestation-final_r1.pdf [Accessed 15 March 2022].
- Clothier, R.A., Greer, D.A., Greer, D.G. and Mehta, A.M. (2015) Risk Perception and the Public Acceptance of Drones. *Risk Analysis* [online]. 35 (6), pp. 1167-1183. [Accessed 29 March 2022].
- Collaboration for Environmental Evidence (2021) *3. Planning a CEE Evidence Synthesis*. Available from: https://environmentalevidence.org/information-for-authors/3-planning-a-cee-evidence-synthesis/ [Accessed 08 April 2022].
- Cooper, H., Hedges, L.V. and Valentine, J.C. (2009) *The Handbook of Research Synthesis and Meta-analysis*. New York: Russell Sage Foundation.
- Cox, T.E., Matthews, R., Halverson, G. and Morris, S. (2021) Hot Stuff in the Bushes: Thermal Imagers and the Detection of Burrows in Vegetated Sites. *Ecology and Evolution* [online]. 11 (11), pp. 6406-6414. [Accessed 06 August 2022].
- Cresson, R. (2022) *Deep Learning for Remote Sensing Images with Open Source Software*. Florida: CRC Press.
- Custers, B., ed. (2016) *The Future of Drone Use: Opportunities and Threats from Ethical and Legal Perspectives*. New York: Springer.
- Dandois, J.P., Olano, M. and Ellis, E.C. (2015) Optimal Altitude, Overlap, and Weather Conditions For Computer Vision UAV Estimates of Forest Structure. *Remote Sensing* [online]. 7 (10), pp. 13895-13920. [Accessed 22 April 2022].
- Dash, J.P., Watt, M.S., Paul, T.S.H., Morgenroth, J. and Pearse, G.D. (2019) Early Detection of Invasive Exotic Trees Using UAV and Manned Aircraft Multispectral and LiDAR Data. *Remote Sensing* [online]. 11 (15), p. 1812. [Accessed 22 April 2022].
- De Giglio, M., Goffo, F., Greggio, N., Merloni, N., Dubbini, M. and Barbarella, M. (2017) Satellite and Unmanned Aerial Vehicle Data for the Classification of Sand

Dune Vegetation. *International Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences* [online]. 42 (4), pp. 43-50. [Accessed 22 April 2022].

- Department for Environment, Food and Rural Affairs (2021) *Biodiversity 2020: A strategy for England's wildlife and ecosystem services.* [online]. London: Department for Environment, Food and Rural Affairs. Available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1026846/England_biodiversity_indicators_2021_FINAL_REVISEDv3.pdf [Accessed 25 January 2022]
- Derrouaoui, S.D., Bouzid, Y., Guiatni, M. and Dib, I. (2022) A Comprehensive Review on Reconfigurable Drones: Classification, Characteristics, Design and Control Technologies. *Unmanned Systems* [online]. 10 (1), pp. 3-29. [Accessed 26 March 2022].
- Desrochers, A., Tremblay, J.A., Aubry, Y., Chabot, D., Pace, P. and Bird, D.M. (2018) Estimating Wildlife Tag Location Errors from a VHF Receiver Mounted on a Drone. *Drones* [online]. 2 (4), p. 44. [Accessed 19 April 2022].
- Devi, K.G., Sowmiya, N., Yasoda, K., Muthulakshmi, K. and Kishore, B. (2020) Review on Application of Drones For Crop Health Monitoring and Spraying Pesticides and Fertilizer. *Journal of Critical Reviews* [online]. 7 (6), pp. 667-672. [Accessed 04 June 2023].
- Dierssen, H.M., Ackleson, S.G., Joyce, K.E., Hestir, E.L., Castagna, A., Lavender, S. and McManus, M.A. (2021) Living Up to the Hype of Hyperspectral Aquatic Remote Sensing: Science, Resources and Outlook. *Frontiers in Environmental Science* [online]. 9 [Accessed 10 February 2022].
- Dittrich, R., Ball, T., Wreford, A., Moran, D. and Spray, C.J. (2018) A Cost-benefit Analysis of Afforestation as a Climate Change Adaptation Measure to Reduce Flood Risk. *Journal of Flood Risk Management* [online]. 12 (4), e12482. [Accessed 17 October 2022].
- Donnelly, J.P., Naugle, D.E., Collins, D.P., Dugger, B.D., Allred, B.W., Tack, J.D. and Dreitz, V.J. (2019) Synchronizing Conservation to Seasonal Wetland Hydrology and Waterbird Migration in Semi-arid Landscapes. *Ecosphere* [online]. 10 (6), p. e02758. [Accessed 06 February 2022].
- Dronefly (2022) *DJI Matrice 210 RTK V2 Drone*. Available from: https://www.dronefly.com/dji-matrice-210-rtk-g.html [Accessed 11 August 2022].

- Dronetech (2022) *Dronemotion Lite*. Available from: https://dronetech-uk.com/products/dronemotion-lite-2-batteries?variant=42119803797720&gclid=CjwKCAjwwdWVBhA4EiwAjcYJEI437CEmNAY4-zxVEW4DNnf4hCZuA1SOrCOKeZHTpsW76f7V6rQw9hoCS5MQAvD_BwE. [Accessed 24 June 2022]
- Dytham, C. (2010) *Choosing and Using Statistics: A Biologist's Guide* [online]. 3rd ed. New Jersey: Wiley-Blackwell. [Accessed 22 April 2022].
- Ehmann, K., Kelleher, C. and Condon, L.E. (2018) Monitoring Turbidity from Above: Deploying Small Unoccupied Aerial Vehicles to Image In-stream Turbidity. *Hydrological Processes* [online]. 33 (6), pp. 1013-1021. [Accessed 23 April 2022].
- Eichberg, C. and Donath, T.W. (2017) Sheep Trampling on Surface-lying Seeds Improves Seedling Recruitment in Open Sand Ecosystems. *Restoration Ecology* [online]. 26 (S2), pp. S211-S219. [Accessed 01 August 2022].
- El Balti N (2021) Heathland, Scrub and Savanna: Overview, Recent Trends and Outlook. In: Hobohm C (ed) Perspectives for Biodiversity and Ecosystems. Environ. Chall. and Solut. Springer Cham, New York City, pp 361-381. https://doi.org/10.1007/978-3-030-57710-0_15 Accessed 13 December 2021
- English Nature. (2005) *The Importance of Livestock Grazing for Wildlife Conservation*. Peterborough: English Nature.
- *Environment Act 2021* [online]. *Chapter 1.* (2021) Legislation.gov. Available from: https://www.legislation.gov.uk/ukpga/2021/30/contents/enacted [Accessed 25 January 2022].
- Environment Agency (2020) *The State of the Environment: Health, People and the Environment* [online]. London: Environment Agency. Available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/915134/State_of_the_environment_health_people_and_the_environment.pdf [Accessed 23 March 2022].
- Esri (2022) *ArcGIS Pro Overview*. Available from: https://www.esri.com/en-us/arcgis/products/arcgis-pro/overview [Accessed 17 November 2022]
- Esri (2021) *ArcGIS Pro Pricing*. Available from: https://www.esriuk.com/en-gb/store/products/buy/arcgis-pro. [Accessed 15 December 2021]
- Estes Jr, M., Anderson, C., Appeltans, W., Bax, N., Bednaršek, N., Canonico, G., Djavidnia, S., Escobar, E., Fietzek, P., Gregoire, M., Hazen, E., Kavanaugh, M.,

Lejzerowicz, F., Lombard, F., Miloslavich, P., Möller, K.O., Monk, J., Montes, E., Moustahfid, H., Muelbert, M.M.C., Muller-Karger, F., Reeves, L.E.P., Satterthwaite, E.V., Schmidt, J.O., Sequeira, A.M.M., Turner, W. and Weatherdon, L.V. (2021) Enhanced Monitoring of Life in the Sea Is a Critical Component of Conservation Management and Sustainable Economic Growth. *Marine Policy* [online]. 132, p. 104699. [Accessed 23 March 2022].

- Farr, G., Whiteman, M. (2014) Ecohydrological Methods for The Investigation of Significant Damage at Groundwater Dependent Terrestrial Ecosystems. *International Association of Hydrogeologists.* Republic or Ireland, April 2014.
- Fernández-Guisuraga, J.M., Sanz-Ablanedo, E., Suárez-Seoane, S. and Calvo, L. (2018) Using Unmanned Aerial Vehicles in Postfire Vegetation Survey Campaigns Through Large and Heterogeneous Areas: Opportunities and Challenges. *Sensors* [online]. 18 (2), p. 586. [Accessed 22 April 2022].
- Finn, R.L. and Wright, D. (2016) Privacy, Data Protection and Ethics for Civil Drone Practice: A Survey of Industry, Regulators and Civil Society Organisations. *Computer Law & Security Review* [online]. 32 (4), pp. 577-586. [Accessed 29 March 2022].
- Floress, K., Connolly, S., Halvorsen, K.E., Egan, A., Schuler, T., Hill, A., DeSenze, P., Fenimore, S. and Karriker, K. (2018) Implementing Landscape Scale Conservation Across Organizational Boundaries: Lessons from the Central Appalachian Region, United States. *Environmental Management* [online]. 62, pp. 845-857. [Accessed 023 March 2022].
- Forsmoo, J., Anderson, K., Macleod, C.J.A., Wilkinson, M.E. and Brazier, R. Drone-based Structure-from-motion Photogrammetry Captures Grassland Sward Height Variability. Journal of Applied Ecology. 2018:55(6) 2587-2599. Available from: https://doi.org/10.1111/1365-2664.13148
- Gair, S. (2012) Feeling Their Stories: Contemplating Empathy, Insider/Outsider Positionings, and Enriching Qualitative Research [online]. *Qualitative Health Research*. 22 (1), pp. 134-143. [Accessed 24 January 2022].
- Getzin, S., Wiegand, K. and Schöning, I. Assessing Biodiversity in Forests Using Very High-resolution Images and Unmanned Aerial Vehicles. Methods in Ecology and Evolution. 2012:3(2): 397-404. Available from: https://besjournals.onlinelibrary.wiley.com/doi/10.1111/j.2041-210X.2011.00158.x [Accessed 27 January 2022].

- Gifford, J.C. (1945) *Living by the Land: Conservation, with Special Reference to Proper Use of the Land*. Florida: Glade House.
- Gill, P., Stewart, K., Treasure, E. and Chadwick, B. (2008) Methods of Data Collection in Qualitative Research: Interviews and Focus Groups. *British Dental Journal* [online]. 204, pp. 291-295. [Accessed 24 January 2022].
- Gilvear, D.J. and Bradley, C. (2000) Hydrological Monitoring and Surveillance for Wetland Conservation and Management; a UK Perspective. *Physics and Chemistry of the Earth, Part B: Hydrology, Oceans and Atmosphere* [online]. 25, pp. 571-588. [Accessed 06 February 2022].
- Gimingham CH, Chapman SB, Webb NR (1979) European heathland. In: Specht RL (ed). *Ecosystems of the world 9A. Heathland and related shrublands* [online]. Elsevier, Amsterdam, pp 365–399
- Global Trees Campaign (2014) *How to Make a Monitoring Plan for Threatened Tree Species* [online]. Cambridge: Fauna & Flora International, Botanic Gardens Conservation International. Available from: https://www.globaltrees.org/wp-content/uploads/2014/01/GTC-Brief-3-monitoring-plan-hi-res.pdf#:~:text=Monitoring%20should%20be%20an%20important,the%20success%20of%20management%20actions. [Accessed 23 March 2022].
- Gloucestershire Wildlife Trust (2021b) *Ashleworth Ham*. Available from: https://www.gloucestershirewildlifetrust.co.uk/nature-reserves/ashleworth-ham [Accessed 06 February 2022].
- Gloucestershire Wildlife Trust (2021a) *Coombe Hill Canal and Meadows*. Available from: https://www.gloucestershirewildlifetrust.co.uk/nature-reserves/coombe-hill-canal-and-meadows [Accessed 06 February 2022].
- Gloucestershire Wildlife Trust (2021d) E*dgehills Bog*. Available from: https://www.gloucestershirewildlifetrust.co.uk/nature-reserves/edgehills-bog [Accessed 26 July 2022].
- Gloucestershire Wildlife Trust (2021e) *Wigpool*. Available from: https://www.gloucestershirewildlifetrust.co.uk/nature-reserves/wigpool [Accessed 26 July 2022].
- Gloucestershire Wildlife Trust (2021c) *Woorgreens*. Available from: https://www.gloucestershirewildlifetrust.co.uk/nature-reserves/woorgreens [Accessed 26 July 2022].

- Gonzalez, L.F., Montes, G.A., Puig, E., Johnson, S., Mengersen, K. and Gaston, K.J. (2016) Unmanned Aerial Vehicles (UAVS) and Artificial Intelligence Revolutionizing Wildlife Monitoring and Conservation. *Sensors* [online]. 16 (1), p. 97. [Accessed 23 March 2022].
- Gooday, O.J., Key, N., Goldstien, S. and Zawar-Reza, P. (2018) An Assessment of Thermal-image Acquisition with an Unmanned Aerial Vehicle (UAV) For Direct Counts of Coastal Marine Mammals Ashore. *Journal of Unmanned Vehicle Systems* [online]. 6 (2) [Accessed 23 April 2022].
- Gray, P.C., Ridge, J.T., Poulin, S.K., Seymour, A.C., Schwantes, A.M., Swenson, J.J. and Johnston, D.W. (2018) Integrating Drone Imagery Into High Resolution Satellite Remote Sensing Assessments of Estuarine Environments. *Remote Sensing* [online]. 10 (8), p. 1257. [Accessed 22 April 2022].
- Guerrero, A.M., McAllister, R.R.J. and Wilson, K.A. (2015) Achieving Cross-scale Collaboration For Large Scale Conservation Initiatives. Conservation Letters: A Journal of the Society for Conservation Biology [online]. 8 (2), pp. 107-117. [Accessed 23 March 2022].
- Gupta, S.G., Ghonge, M. and Jawandhiya, P.M. (2013) Review of Unmanned Aircraft System (UAS). *International Journal of Advanced Research in Computer Engineering & Technology* [online]. 2 (4) [Accessed 26 March 2022].
- Halpenny, E.A. and Caissie, L.T. (2003) Volunteering on Nature Conservation Projects: Volunteer Experience, Attitudes and Values. *Tourism Recreation Research* [online]. 28 (3) [Accessed 22 October 2022].
- Hamylton, S.M., Morris, R.H., Carvalho, R.C., Roder, N., Barlow, P., Mills, K. and Wang, L. (2020) Evaluating Techniques For Mapping Island Vegetation From Unmanned Aerial Vehicle (UAV) Images: Pixel Classification, Visual Interpretation and Machine Learning Approaches. *International Journal of Applied Earth Observation and Geoinformation* [online]. 89, p. 102085. [Accessed 10 February 2022].
- Hambrecht, L., Brown, R.P., Piel, A.K. and Wich, S.A. (2019) Detecting ‘Poachers’ with Drones: Factors Influencing the Probability of Detection with TIR and RGB Imaging in Miombo Woodlands, Tanzania. *Biological Conservation* [online]. 233, pp. 109-117. [Accessed 30 March 2022].

- Harsh, S., Singh, D. and Pathak, S. (2022) Efficient and Cost-effective Drone – NDVI System For Precision Farming. *International Journal of New Practices in Management and Engineering* [online]. 10 (4), pp. 14-19. [Accessed 04 June 2023].
- Hardin, P.J., Jackson, M.W., Anderson, V.J. and Johnson, R. (2007) Detecting Squarrose Knapweed (*Centaurea virgata* Lam. Ssp. *squarrosa* Gugl.) Using a Remotely Piloted Vehicle: A Utah Case Study. *GIScience and Remote Sensing* [online]. 44 (3), pp. 203-219. [Accessed 22 April 2022].
- Hassanalian, M. and Abdelkefi, A. (2017) Classifications, Applications, and Design Challenges of Drones: A Review. *Progress in Aerospace Sciences* [online]. 91, pp. 99-131. [Accessed 26 March 2022].
- Heliguy (2022) *Mavic 2 Enterprise Dual*. Available from: https://www.heliguy.com/products/dji-mavic-2-enterprise-dual [Accessed 11 August 2022].
- Hodgson, J.C., Mott, R., Baylis, S.M., Pham, T.T., Wotherspoon, S., Kilpatrick, A.D., Segaran, R.R., Reid, I., Terauds, A. and Koh, L.P. (2018) Drones Count Wildlife More Accurately and Precisely Than Humans. *Methods in Ecology and Evolution* [online]. 9 (5), pp. 1160-1167. [Accessed 30 March 2022].
- Hossell, J.E., Ellis, N.E., Harley, M.J. and Hepburn, I.R. (2003) Climate Change and Nature Conservation: Implications For Policy and Practice in Britain and Ireland. *Journal For Nature Conservation* [online]. 11 (1), pp. 67-73. [Accessed 15 March 2022].
- Hugenholtz, C., Brown, O., Walker, J., Barchyn, T., Nesbit, P., Kucharczyk, M. and Myshak, S. (2016) Spatial Accuracy of UAV-derived Orthoimagery and Topography: Comparing Photogrammetric Models Processed with Direct Geo-referencing and Ground Control Points. *Geomatica* [online]. 70 (1) [Accessed 27 June 2022].
- Hyyppä, E., Hyyppä, J., Hakala, T., Kukko, A., Wulder, M.A., White, J.C., Pyörälä, J., Yu, X., Wang, Y., Virtanen, J., Pohjavirta, O., Liang, X., Holopainen, M. and Kaartinen, H. (2020) Under-canopy UAV Laser Scanning For Accurate Forest Field Measurements. *ISPRS Journal of Photogrammetry and Remote Sensing* [online]. 164, pp. 41-60. [Accessed 22 April 2022].
- IEEE (2020). *DroTrack: High-speed Drone-based Object Tracking Under Uncertainty* [online]. Scotland: Institute of Electrical and Electronics Engineers (IEEE). Available from: https://ieeexplore.ieee.org/abstract/document/9177571 [Accessed 26 March 2022].

- Inoue, T., Nagai, S., Yamashita, S., Fadaei, H., Ishii, R., Okabe, K., Taki, H., Honda, Y., Kajiwara, K. and Suzuki, R. (2014) Unmanned Aerial Survey of Fallen Trees in a Deciduous Broadleaved Forest in Eastern Japan. *PLOS One* [online]. [Accessed 22 April 2022].
- Inoue, Y. (2020) Satellite- and Drone-based Remote Sensing of Crops and Soils for Smart Farming – a Review. *Soil Science and Plant Nutrition* [online]. 66 (6), pp. 798-810. [Accessed 26 March 2022].
- IPBES (2019). *Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services* Germany: Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). Available from: https://zenodo.org/record/3553579#.Yj8cjyjP02w [Accessed 22 March 2022].
- Jenkins, R. (2020) How conservation groups help to protect biodiversity on the Defence estate. *Inside DIO* [blog]. 5 June. Available from: https://insidedio.blog.gov.uk/2020/06/05/how-conservation-groups-help-to-protect-biodiversity-on-the-defence-estate/ [Accessed 25 January 2022].
- Joint Nature Conservation Committee (2019) *Common Standards Monitoring Guidance*. Available from: https://jncc.gov.uk/our-work/common-standards-monitoring-guidance/ [Accessed 21 June 2022].
- Jones, J.P.G., Asner, G.P., Butchart, S.H.M., Karanth, K.U. (2013) The 'Why', 'What' and 'How' of Monitoring for Conservation. In: Macdonald, D.W., Willis, K.J., ed (2013) *Key Topics in Conservation Biology 2* [online]. New Jersey: John Wiley & Sons, Ltd, 327-343. [Accessed 23 March 2022].
- Jones, G.P., Pearlstine, L.G. and Percival, H.F. (2006) An Assessment of Small Unmanned Aerial Vehicles for Wildlife Research. *Wildlife Society Bulletin* [online]. 34 (3), pp. 750-758. [Accessed 26 March 2022].
- Kanuha, V.K. (2000) "Being" Native Versus "Going Native": Conducting Social Work Research as an Insider. *Social Work* [online]. 45 (5), pp. 439-447. [Accessed 24 January 2022].
- Kapos, V., Balmford, A., Aveling, R., Bubb, P., Carey, P., Entwistle, A., Hopkins, J., Mulliken, T., Safford, R., Stattersfield, A., Walpole, M. and Manica, A. (2009) Outcomes, Not Implementation, Predict Conservation Success. *Oryx* [online]. 43 (3), pp. 336-342. [Accessed 02 February 2022].

- Katzner, T.E., Ivy, J.A.R., Bragin, E.A., Milner-Gulland, E.J. and Dewoody, J.A. (2011) Conservation Implications of Inaccurate Estimation of Cryptic Population Size. Animal Conservation [online]. 14 (4), pp. 328-332. [Accessed 23 March 2022].
- Keddy, P.A. (2010) *Wetland Ecology: Principles and Conservation*. 2nd ed. Cambridge: Cambridge University Press.
- Keilman, R. (2019) Drones on the Rise: Societal Misperceptions of Small Unmanned Aircraft Systems. *The Journal of Purdue Undergraduate Research* [online]. 9 (5) [Accessed 29 March 2022].
- Keith DA, Lindenmayer D, Lowe DA, Russell-Smith J, Barrett S, Enright NJ, Fox BJ, Guerin G, Paton DC, Tozer MG, Yates CJ (2014) Heathland. In: Burns E et al (eds) Biodiversity and environmental change monitoring, challenges and direction [online]. CSIRO Publishing, Collingwood, pp 216–285
- Keller, B. and Willke, T. (2019) Snotbot: A Whale of a Deep-learning Project. *Ieee Spectrum* [online]. 56 (12), pp. 41-53. [Accessed 30 March 2022].
- Kinzel, P.J., Bauer, M., Feller, M., Holmquist-Johnson, C. and Preston, T. (2015) Experimental Flights Using a Small Unmanned Aircraft System For Mapping Emergent Sandbars. *Great Plains Research* [online]. 25 (1), pp. 39-52. [Accessed 22 April 2022].
- Koh, L.P. and Wich, S.A. (2012) Dawn of Drone Ecology: Low-cost Autonomous Aerial Vehicles For Conservation. *Tropical Conservation Science* [online]. 5 (2), pp. 121-132. [Accessed 20 April 2022].
- Lamprey, R., Pope, F., Ngene, S., Norton-Griffiths, M., Frederick, H., Okita-Ouma, B. and Douglas-Hamilton, I. (2020) Comparing an Automated High-definition Oblique Camera System to Rear-seat-observers in a Wildlife Survey in Tsavo, Kenya: Taking Multi-species Aerial Counts to the Next Level. *Biological Conservation* [online]. 241, p. 108243. [Accessed 08 August 2022].
- Lawrence, A. and Dandy, N. (2014) Private Landowners' Approaches to Planting and Managing Forests in the UK: What's the Evidence?. *Land Use Policy* [online]. 36, pp. 351-360. [Accessed 23 October 2022].
- Lawton, J., Brown, V., Elphick, C., Fitter, A., Forshaw, J., Haddow, R., Hilborne, S., Leafe, R., Mace, G., Southgate, M., Sutherland, W., Tew, T., Varley, J. and Wynne, G. (2010) *Making Space for Nature: A Review of England's Wildlife Sites and Ecological Network*. [online]. London. Available from: https://webarchive.nationalarchives.gov.uk/ukgwa/20170305123119/http://assets

.kew.org/files/Making%20Space%20For%20Nature%20-%20The%20Lawton%20Report.pdf [Accessed 22 March 2022].

- Leonard, P.B., Baldwin, R.F. and Hanks, R.D. (2017) Landscape-scale Conservation Design Across Biotic Realms: Sequential Integration of Aquatic and Terrestrial Landscapes. *Scientific Reports* [online]. 7 (1), pp. 1-12. [Accessed 23 March 2022].
- Lguensat, R., Sun, M., Fablet, R., Tandeo, P., Mason, E., Chen, G. (2018) EddyNet: A Deep Neural Network For Pixel-Wise Classification of Oceanic Eddies. *2018 IEEE International Geoscience and Remote Sensing Symposium.* 22-27 July 2018: IEEE, 1764-1767
- Linchant, J., Lisein, J., Semeki, J., Lejeune, P. and Vermeulen, C. (2015) Are Unmanned Aircraft Systems (UASs) the Future of Wildlife Monitoring? a Review of Accomplishments and Challenges. *Mammal Review* [online]. 45 (4), pp. 239-252. [Accessed 26 March 2022].
- Lorah, P., Ready, A. and Rinn, E. (2018) Using Drones to Generate New Data for Conservation Insights. *International Journal of Geospatial and Environmental Research* [online]. 5 (2) [Accessed 10 February 2022].
- Ma, K., Liu, J., Balkovič, J., Skalský, R., Azevedo, L.B. and Kraxner, F. (2016) Changes in Soil Organic Carbon Stocks of Wetlands on China's Zoige Plateau From 1980 to 2010. *Ecological Modelling* [online]. 327, pp. 18-28. [Accessed 01 August 2022].
- Mano, K., Sakai, K., Tachibana, K., Sakita, K. and Nishiyama, S. (2020) The Measurement Accuracy and Measurement Characteristics of Green Lidar Drone. *International Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences* [online]. XLIII-B1 (B1), pp. 479-483. [Accessed 10 February 2022].
- Marsh, D.M. and Trenham, P.C. (2008) Current Trends in Plant and Animal Population Monitoring. Conservation Biology [online]. 22 (3), pp. 647-655. [Accessed 23 March 2022].
- Marta, S., Lacasella, F., Romano, A. and Ficetola, G.F. (2019) Cost-effective Spatial Sampling Designs for Field Surveys of Species Distribution. *Biodiversity and Conservation* [online]. 28, p. 2891–2908. [Accessed 10 February 2022].
- Masutti, A. and Tomasello, F. (2018) *International Regulation of Non-military Drones*. United Kingdom: Edward Elgar Publishing.
- McArthur ED, Kitchen SG (2007). Shrubland ecosystems: Importance, distinguishing characteristics, and dynamics. In: Sosebee RE, Wester DB, Britton CM, McArthur

ED, Kitchen SG Proceedings: Shrubland dynamics -- fire and water. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Lubbock, pp 3-10.

- McCartney, M.P. and de la Hera, A. (2004) Hydrological Assessment for Wetland Conservation at Wicken Fen. *Wetlands Ecology and Management* [online]. 12, pp. 189-204. [Accessed 06 February 2022].
- Mesquita, G.P., Rodríguez-Teijeiro, J.D., Wich, S.A. and Mulero-Pázmány, M. (2021) Measuring Disturbance at Swift Breeding Colonies Due to the Visual Aspects of a Drone: A Quasi-experiment Study. *Current Zoology* [online]. 67 (2), pp. 157-163. [Accessed 11 February 2022].
- Michael, M.A. (2002) Why Not Interfere with Nature?. *Ethical Theory and Moral Practice* [online]. 5 (1), pp. 89-112. [Accessed 15 March 2022].
- Mills, S., ed. (2019) *The Dawn of the Drone: From the Back-room Boys of World War One*. Oxford: Casemate Publishers.
- Moloney, J.G., Hilton, M.J., Sirguey, P. and Simons-Smith, T. (2018) Coastal Dune Surveying Using a Low-cost Remotely Piloted Aerial System (RPAS). *Journal of Coastal Research* [online]. 34 (5), pp. 1244-1255. [Accessed 22 April 2022].
- Mortimer SR, Turner AJ, Brown VK, Fuller RJ, Good JEG, Bell SA, Stevens PA, Norris D, Bayfield N, Ward LK (2000) The Nature Conservation Value of Scrub in Britain. JNCC Report 308 [Accessed 10 December 2021].
- Murdoch, W., Polasky, S., Wilson, K.A., Possingham, H.P., Kareiva, P. and Shaw, R. (2007) Maximizing Return on Investment in Conservation. *Biological Conservation* [online]. 139, pp. 375-388. [Accessed 22 March 2022].
- Näsi, R., Honkavaara, E., Blomqvist, M., Lyytikäinen-Saarenmaa, P., Hakala, T., Viljanen, N., Kantola, T. and Holopainen, M. (2018) Remote Sensing of Bark Beetle Damage in Urban Forests at Individual Tree Level Using a Novel Hyperspectral Camera from UAV and Aircraft. *Urban Forestry & Urban Greening* [online]. 30, pp. 72-83. [Accessed 22 April 2022].
- National Trust (2019) *Conservation Grazing.* Available from: https://www.nationaltrust.org.uk/woolbeding-countryside/features/conservation-grazing [Accessed 01 August 2022].
- Natural England (2016) *Conservation 21 Natural England's Conservation Strategy for the 21st Century.* [online]. York: Natural England. Available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/562046/conservation-21.pdf [Accessed 25 January 2022]

- Natural England (2012) Condition of SSSI Units for Site Daneway Banks SSSI. Natural England, York https://designatedsites.naturalengland.org.uk/ReportUnitCondition.aspx?SiteCode=S1001427&ReportTitle=Daneway%20Banks%20SSSI Accessed 10 December 2021
- Natural England (2003) A statement of English Nature's views about the management of Daneway Banks Site of Special Scientific Interest (SSSI). Natural England York, https://designatedsites.naturalengland.org.uk/PDFsForWeb/VAM/1001427.pdf Accessed 09 December 2021
- Negru, S.A., Manea, M. and Jiga, G. (2022) Design of a Vtol UAV for Anti-poaching Surveillance Missions in the Danube Delta. *International Journal of Modeling and Optimization* [online]. 12 (1) [Accessed 30 March 2022].
- Niccolai, L., Bassetto, M., Quarta, A.A. and Mengali, G. (2019) A Review of Smart Dust Architecture, Dynamics, and Mission Applications. *Progress in Aerospace Sciences* [online]. 106, pp. 1-14. [Accessed 26 March 2022].
- Nichols, J.D. and Williams, B.K. (2006) Monitoring for Conservation. *Trends in Ecology & Evolution* [online]. 21 (12), pp. 668-673. [Accessed 23 March 2022].
- Nixon, D. (2001) *The Boeing Condor* [online]. Report number: 2001-01-3029. California: SAE International. Available from: https://www.sae.org/publications/technical-papers/content/2001-01-3029/ [Accessed 26 March 2022].
- Office for National Statistics (2022) *"Nature jobs" using environmental goods and services sector data: 2019* [online]. London: Office for National Statistics. Available from: https://www.ons.gov.uk/economy/environmentalaccounts/articles/naturejobsusingenvironmentalgoodsandservicessectordata/2019 [Accessed 17 October 2022].
- Pan, Y., Birdsey, R.A., Fang, J., Houghton, R., Kauppi, P.E., Kurz, W.A., Phillips, O.L., Shvidenko, A., Lewis, S.L., Canadell, J.G., Ciais, P., Jackson, R.B., Pacala, S.W., McGuire, A.D., Piao, S., Rautiainen, A., Sitch, S. and Hayes, D. (2011) A Large and Persistent Carbon Sink in the World's Forests. *Science* [online]. 333 (6045), pp. 988-993. [Accessed 15 March 2003].
- Panzavolta, T., Bracalini, M., Benigno, A. and Moricca, S. (2021) Alien Invasive Pathogens and Pests Harming Trees, Forests, and Plantations: Pathways, Global

Consequences and Management. *Forests* [online]. 12 (10) [Accessed 30 March 2022].

- Parliamentary Office of Science and Technology (2009) *Wild Deer* [online]. London: Parliamentary Office of Science and Technology. (325). Available from: https://www.parliament.uk/globalassets/documents/post/postpn325.pdf [Accessed 01 August 2022].
- Patel, V., Pauli, N., Biggs, E., Barbour, L. and Boruff, B. (2020) Why Bees Are Critical for Achieving Sustainable Development. *Ambio* [online]. 50 (1), pp. 49-59. [Accessed 15 March 2022].
- Pix4D (2022) *Pix4D Homepage*. Available from: https://www.pix4d.com [Accessed 17 November 2022].
- Pix4D (2021) *Pix4D Software and Hardware Pricing*. Available from: https://www.pix4d.com/pricing [Accessed 15 December 2021].
- Powers, R.P. and Jetz, W. (2019) Global Habitat Loss and Extinction Risk of Terrestrial Vertebrates Under Future Land-use-change Scenarios. *Nature Climate Change* [online]. 9, pp. 323-329. [Accessed 23 March 2022].
- Pullin, A.S., Sutherland, W., Gardner, T., Kapos, V., Fa, J.E. (2013) Conservation Priorities: Identifying Need, Taking Action and Evaluating Success. In: Macdonald, D.W., Willis, K.J. ed. (2013) Key Topics in Conservation Biology 2 [online]. New Jersey: John Wiley & Sons Inc, pp. 1-22. [Accessed 22 February 2022].
- Resop, J.P., Lehmann, L. and Hession, W.C. (2019) Drone Laser Scanning for Modeling Riverscape Topography and Vegetation: Comparison with Traditional Aerial LiDAR. *Drones* [online]. 3 (2), p. 35. [Accessed 22 April 2022].
- Rexer-Huber, K. and Parker, G.C. (2020) Bounty Islands Drone Trials: Feasibility for Population Assessment of NZ Fur Seal. *Final Report to the Conservation Services Programme, Department of Conservation* [online]. Parker Conservation: Dunedin, p. 18. [Accessed 23 April 2022].
- Rosa, I.M.D., Smith, M.J., Wearn, O.R., Purves, D. and Ewers, R.M. (2016) The Environmental Legacy of Modern Tropical Deforestation. *Current Biology* [online]. 26 (16), pp. 2161-2166. [Accessed 15 March 2022].
- Royal Society for the Protection of Birds (RSPB) (2018) *Bridging the Finance Gap. How do we Increase Financing for Conservation?* [online]. Bedfordshire: RSPB. Available from:

https://www.rspb.org.uk/globalassets/downloads/documents/abouttherspb/bridging-the-finance-gap.pdf [Accessed 15 March 2022].

- Royal Society for the Protection of Birds (RSPB) (2011) *Natural Foundations: Conservation and local employment in the UK* [online]. Bedfordshire: RSPB. Available from: https://www.rspb.org.uk/globalassets/downloads/documents/positions/economics/natural-foundations---conservation-and-local-employment-in-the-uk.pdf [Accessed 15 March 2022].
- Runhaar, J., van Gool, C.R. and Groen, C.L.G. (1996) Impact of Hydrological Changes on Nature Conservation Areas in the Netherlands. *Biological Conservation* [online]. 76 (3), pp. 269-276. [Accessed 06 February 2022].
- Rupprecht, D., Gilhaus, K. and Hölzel, N. (2016) Effects of Year-round Grazing on the Vegetation of Nutrient-poor Grass- and Heathlands—evidence From a Large-scale Survey. *Agriculture, Ecosystems & Environment* [online]. 234, pp. 16-22. [Accessed 01 August 2022].
- Savović, J., Jones, H.E., Altman, D.G., Harris, R.J., Jűni, P., Pildal, J., Als-Nielsen, B., Balk, E.M., Gluud, C., Gluud, L.L., Ioannidis, J.P.A., Schulz, K.F., Beynon, R., Welton, N., Wood, L., Moher, D., Deeks, J.J. and Sterne, J.A.C. (2012) Influence of Reported Study Design Characteristics on Intervention Effect Estimates From Randomised Controlled Trials: Combined Analysis of Meta-epidemiological Studies. *Health Technology Assessment* [online]. 16 (35), pp. 1-82. [Accessed 19 April 2022].
- Scholten, C.N., Kamphuis, A.J., Vredevoogd, K.J., Lee-Strydhorst, K.G., Atma, J.L., Shea, C.B., Lamberg, O.N. and Proppe, D.S. (2019) Real-time Thermal Imagery from an Unmanned Aerial Vehicle Can Locate Ground Nests of a Grassland Songbird at Rates Similar to Traditional Methods. *Biological Conservation* [online]. 233, pp. 241-246. [Accessed 23 April 2022].
- Shackle, S. (2020) The mystery of the Gatwick drone. *The Guardian* [online]. 01 December. Available from: https://www.theguardian.com/uk-news/2020/dec/01/the-mystery-of-the-gatwick-drone [Accessed 29 March 2022].
- Shahmoradi, J., Mirzaeinia, A., Roghanchi, P. and Hassanalian, M. (2020) Monitoring of Inaccessible Areas in GPS-denied Underground Mines Using a Fully Autonomous Encased Safety Inspection Drone. *AIAA Scitech 2020 Forum* [online]., p. 1961. [Accessed 26 March 2022].

- Shelare, S.D., Aglawe, K.R., Waghmare, S.N. and Belkhode, P.N. (2021) Advances in Water Sample Collections with a Drone – a Review. *Materials Today: Proceedings* [online]. 47 (14), pp. 4490-4494. [Accessed 30 March 2022].
- Serafinelli, E. (2022) Imagining the Social Future of Drones. *Convergence: The International Journal of Research into New Media Technologies* [online]. doi:10.1177/13548565211054904. [Accessed 29 March 2022].
- Smart, J. and Gill, J.A. (2003) Climate Change and the Potential Impact on Breeding Waders in the UK. *Wader Study Group Bulletin* [online]. 100, pp. 80-85. [Accessed 06 February 2022].
- Smit, C., Putman, R. (2011) Large herbivores as environmental engineers. In: Putman, R., Apollonio, M., Andersen, R. (2011) *Ungulate Management in Europe: Problems and Practices* [online]. Cambridge: Cambridge University Press, pp. 260-283. [Accessed 01 August 2022].
- Smith, A., Dickinson, J.E., Marsden, G., Cherrett, T., Oakey, A. and Grote, M. (2022) Public Acceptance of the Use of Drones for Logistics: The State of Play and Moving Towards More Informed Debate. *Technology in Society* [online]. 68 [Accessed 30 March 2022].
- Song, K., Brewer, A., Ahmadian, S., Shankar, A., Detweiler, C. and Burgin, A.J. (2017) Using Unmanned Aerial Vehicles to Sample Aquatic Ecosystems. *Limnology and Oceanography Methods* [online]. 15 (12), pp. 1021-1030. [Accessed 23 April 2022].
- Spence, C. and Mengistu, S. (2015) Deployment of an Unmanned Aerial System to Assist in Mapping an Intermittent Stream. *Hydrological Processes* [online]. 30 (3), pp. 493-500. [Accessed 23 April 2022].
- Sutherland, W.J., Pullin, A.S., Dolman, P.M. and Knight, T.M. (2004) The Need for Evidence-based Conservation. *Trends in Ecology and Evolution* [online]. 19 (6), pp. 305-308. [Accessed 23 March 2022].
- Tang, L. and Shao, G. (2015) Drone Remote Sensing For Forestry Research and Practices. *Journal of Forestry Research* [online]. 26, pp. 791-797. [Accessed 26 March 2022].
- The Wildlife Trusts (2022) *About Us*. Available from: https://www.wildlifetrusts.org/about-us [Accessed 23 March 2022].
- Thomas, R.J., Lello, J., Medieros, R., Pollard, A., Seward, A., Smith, J., Vafidis, J.O. and Vaughan, I. (2021) *Data Analysis with R Statistical Software; a Guidebook For Scientists*. Caerphilly: Ecoexplore.

- Terry, G. & Braun, V. (2017) Short but Often Sweet. In: Virginia Braun, Victoria Clarke & Debra Gray (ed.). *Collecting Qualitative Data. A Practical Guide to Textual, Media and Virtual Techniques., null Cambridge University Press*. 1st edition. Cambridge: Cambridge University Press.
- The Wildlife Trusts (2022) *Our History*. Available from: https://www.wildlifetrusts.org/about-us/our-history [Accessed 23 March 2022].
- The Wildlife Trusts (2021) *Our Year for Wildlife: The Wildlife Trusts' Impact Report 2020/21* [online]. Nottinghamshire: The Royal Society of Wildlife Trusts. Available from: https://27c4bf0dca9302ffeab0-d2028b6e56b96076478d6319339c3ead.ssl.cf1.rackcdn.com/TWT%20Digital%20Impact%20Report%202020-21.pdf [Accessed 23 March 2022].
- Trinder, L. and Reynolds, S. (2008) *Evidence-based Practice: A Critical Appraisal*. New Jersey: Wiley-Blackwell.
- Tsiamis, N., Efthymiou, L. and Tsagarakis, K.P. (2019) A Comparative Analysis of the Legislation Evolution For Drone Use in Oecd Countries. *Drones* [online]. 3 (4), p. 75. [Accessed 04 June 2023].
- United Nations General Assembly (1987) *Report of the World Commission on Environment and Development: Our Common Future*. Transmitted to the General Assembly as an Annex to document A/42/427 – Development and International Co-operation: Environment. Available from: https://sustainabledevelopment.un.org/content/documents/5987our-common-future.pdf [Accessed 26 October 2022]
- Vafidis, J., Lucksted, I., Gall, M., Maxfield, P., Meakin, K. and Steer, M. (2021) Mapping Scrub Vegetation Cover from Photogrammetric Point Clouds: A Useful Tool in Reserve Management. *Ecology and Evolution* [online]. 11 (11), pp. 6789-6797. [Accessed 09 December 2021].
- Valle, R.G. and Scarton, F. (2020) Drones Improve Effectiveness and Reduce Disturbance of Censusing Common Redshanks *Tringa totanus* Breeding on Salt Marshes. *Ardea* [online]. 107 (3), pp. 275-282. [Accessed 11 February 2022].
- Valle, R.G. and Scarton, F. (2018) Effectiveness, Efficiency, and Safety of Censusing Eurasian Oystercatchers *Haematopus ostralegus* by Unmanned Aircraft. *Marine Ornithology* [online]. 47 (1), pp. 81-87. [Accessed 23 April 2022].

- Van de Merwe, D., Burchfield, D.R., Witt, T.D., Price, K.P. and Sharda, A. (2020) Drones in Agriculture. *Advances in Agronomy* [online]. 162, pp. 1-30. [Accessed 28 May 2023].
- Varga, K., Csízi, I., Monori, I. and Valkó, O. (2021) Threats and Challenges Related to Grazing Paddocks: Recovery of Extremely Overgrazed Grassland After Grazing Exclusion. *Arid Land Research and Management* [online]. 35 (3) [Accessed 01 August 2022].
- Ventura, D., Bruno, M., Lasinio, G.J., Belluscio, A. and Ardizzone, G. (2016) A Low-cost Drone Based Application for Identifying and Mapping of Coastal Fish Nursery Grounds. *Estuarine, Coastal and Shelf Science* [online]. 171, pp. 85-98. [Accessed 22 April 2022].
- Vining, J. (2003) The Connection to Other Animals and Caring for Nature. *Human Ecology Review* [online]. 10 (2), pp. 87-99. [Accessed 15 March 2022].
- Waldron, A., Mooers, A.O., Miller, D.C., Nibbelink, N., Redding, D., Kuhn, T.S., Roberts, J.T. and Gittleman, J.L. (2013) Targeting Global Conservation Funding to Limit Immediate Biodiversity Declines. *Proceedings of the National Academy of Sciences of the United States of America* [online]. 110 (29), pp. 12144-12148. [Accessed 27 January 2022].
- WallisDeVries, M.F., Wieren, S.E. and Bakker, J.P. (1998) *Grazing and Conservation Management*. Netherlands: Springer Dordrecht.
- Weissensteiner, M., Poelstra, J. and Wolf, J.B.W. (2015) Low-budget Ready-to-fly Unmanned Aerial Vehicles an Effective Tool for Evaluating the Nesting Status of Canopy-breeding Bird Species. *Journal of Avian Biology* [online]. 46 (4) [Accessed 23 April 2022].
- Wich, S.A. and Piel, A.K. (2021) *Conservation Technology* [online]. Oxford: Oxford University Press. [Accessed 30 March 2022].
- Wich, S.A. (2015) Drones and Conservation. In: Kakaes, K., Greenwood, F., Lippincott, M., Dosemagen, S., Meier, P., Wich, S., (2015) *Drones and Aerial Observation: New Technologies for Property Rights, Human Rights and Global Development* [online]. Washington D.C.: New America, pp. 63-70. [Accessed 30 March 2022].
- Wich, S.A., Hudson, M., Andrianandrasana, H., Longmore, S.N. (2021) Drones for Conservation. In: Wich, S.A., Piel, A.K., (2021) *Conservation Technology* [online]. Oxford: Oxford University Press, 35-52. [Accessed 27 January 2022].

- Wich, S.A. and Koh, L.P. (2018) *Conservation Drones: Mapping and Monitoring Biodiversity*. Oxford: Oxford University Press.
- Will, H. and Tackenberg, O. (2008) A Mechanistic Simulation Model of Seed Dispersal by Animals. *Journal of Ecology* [online]. 96 (5), pp. 1011-1022. [Accessed 01 August 2022].
- Wilson, A.M., Ausden, M. and Milsom, T.P. (2004) Changes in Breeding Wader Populations on Lowland Wet Grasslands in England and Wales: Causes and Potential Solutions. *Ibis* [online]. 146 (s2), pp. 32-40. [Accessed 06 February 2022].
- Wilson, A.M., Barr, J. and Zagorski, M. (2017) The Feasibility of Counting Songbirds Using Unmanned Aerial Vehicles. *The Auk* [online]. 134 (2), pp. 350-362. [Accessed 23 April 2022].
- Witmer, G.W. (2005) Wildlife Population Monitoring: Some Practical Considerations. *Wildlife Research* [online]. 32 (3), pp. 259-263. [Accessed 23 March 2022].
- Wolanksi, E., Day, J.W., Elliott, M. and Ramachandran, R. (2019) *Coasts and Estuaries: The Future* [online]. Amsterdam: Elsevier. [Accessed 15 March 2022].
- World Wide Fund for Nature (WWF) (2020) *Global Futures: Modelling the global economic impacts of environmental change to support policy-making* [online]. Minnesota: WWF. Available from: https://www.wwf.org.uk/sites/default/files/2020-02/Global_Futures_Technical_Report.pdf [Accessed 15 March 2022].
- Wu, D., Li, R., Zhang, F. and Liu, J. (2019) A Review on Drone-based Harmful Algae Blooms Monitoring. *Environmental Monitoring and Assessment* [online]. 191 (4), p. 211. [Accessed 30 March 2022].
- Zattara, E.E. and Aizen, M.A. (2021) Worldwide Occurrence Records Suggest a Global Decline in Bee Species Richness. *One Earth* [online]. 4 (1), pp. 114-123. [Accessed 15 March 2022].
- Zeller, K.A., Lewison, R., Fletcher Jr, R.J., Tulbure, M.G. and Jennings, M.K. (2020) Understanding the Importance of Dynamic Landscape Connectivity. *Land* [online]. 9 (303) [Accessed 22 June 2022].
- Zuur, A.F., Ieno, E.N. and Smith, G.M. (2007) *Analyzing Ecological Data* [online]. New York: Springer. [Accessed 23 June 2023].

Appendices

Appendix 1: Systematic Review Search String Iterative Design, Final Search Strings and Test List

Search String Iterative Design

Search String	Results	Test list Present (%)	Level of irrelevant studies
(drone* OR UAV* OR "Unmanned aer* vehicle*" OR "Unmanned air* vehicle*" OR UAS* OR "Unmanned aer* system*" OR "Unmanned air* system*" OR RPS* OR "Remote* piloted system*" OR RPAS OR "Remote* piloted air* system*" OR "Remote* piloted aer* system*")	96, 686	100	High
(drone* OR UAV* OR "Unmanned aer* vehicle*" OR "Unmanned air* vehicle*" OR UAS* OR "Unmanned aer* system*" OR "Unmanned air* system*" OR RPS* OR "Remote* piloted system*" OR RPAS OR "Remote* piloted air* system*" OR "Remote* piloted aer* system*") AND (conserv* OR reserve* OR preserv* OR monitor* OR manage* OR Wild* OR plant* OR animal* OR landscap* OR eco*)	38,667	100	High
(drone* OR UAV* OR "Unmanned aer* vehicle*" OR "Unmanned air* vehicle*" OR UAS* OR "Unmanned aer* system*" OR "Unmanned air* system*" OR RPS* OR "Remote* piloted system*" OR RPAS OR "Remote* piloted air* system*" OR "Remote* piloted aer* system*") AND (conserv* OR reserve* OR preserv* OR monitor* OR manage* OR Wild* OR plant* OR animal*	32,957	100	Medium

OR landscap* OR eco*) AND (experiment* OR “quasi experiment*” OR study OR studies OR control* OR “control group*” OR compar* OR contrast* OR “impact evaluation*” OR “impact analysis*” OR impact* OR differen* OR effect*)			
(drone* OR UAV OR UAVS OR “Unmanned aer* vehicle*” OR “Unmanned air* vehicle*” OR UAS OR “Unmanned aer* system*” OR “Unmanned air* system*” OR RPS OR “Remote* piloted system*” OR RPAS OR “Remote* piloted air* system*” OR “Remote* piloted aer* system*”) AND (conserv* OR reserve* OR preserv* OR monitor* OR manage* OR Wild* OR plant* OR animal* OR landscap* OR ecosystem* OR ecology) AND (experiment* OR “quasi experiment*” OR study OR studies OR control* OR “control group*” OR compar* OR contrast* OR “impact evaluation*” OR “impact analysis*” OR impact* OR differen* OR effect*)	24,455	100	Medium
(drone* OR “Unmanned aer* vehicle*” OR “Unmanned air* vehicle*” OR “Unmanned aer* system*” OR “Unmanned air* system*” OR “Remote* piloted system*” OR “Remote* piloted air* system*” OR “Remote* piloted aer* system*”) AND (conserv* OR reserve* OR preserv* OR monitor* OR manage* OR Wild* OR landscap* OR eco*) AND (experiment* OR “quasi	13, 160	100	Medium

experiment*" OR control* OR "control group*" OR compar* OR contrast* OR "impact evaluation*" OR "impact analysis*" OR impact*) AND NOT tropical OR subtropical OR tropics			

Final Search Strings

Science direct: (Drone OR "unmanned aerial vehicle") (conservation OR wildlife OR ecosystem) (experiment OR experimental OR compare OR control) NOT (tropical OR tropics)

Pubmed: (((drone OR "Unmanned aerial vehicle" OR "Unmanned air vehicle" OR "Unmanned aerial system" OR "Unmanned aircraft system") AND (conserve OR conservation OR reserve OR preserve OR preservation OR monitor OR manage OR Wildlife OR landscape OR ecosystem)) AND (experiment OR experimental OR "quasi experimental" OR control OR "control group" OR compare OR comparison OR contrast OR "impact evaluation" OR "impact analysis" OR impact)) NOT (tropical OR subtropical OR tropics)

Scopus: (drone* OR "Unmanned aer* vehicle*" OR "Unmanned air* vehicle*" OR "Unmanned aer* system*" OR "Unmanned air* system*" OR "Remote* piloted system*" OR "Remote* piloted air* system*" OR "Remote* piloted aer* system*") AND (conserv* OR reserve* OR preserv* OR monitor* OR manage* OR Wild* OR landscap* OR eco*) AND (experiment* OR "quasi experiment*" OR control* OR "control group*" OR compar* OR contrast* OR "impact evaluation*" OR "impact analysis*" OR impact*) AND NOT tropical OR subtropical OR tropics

Google Scholar: (drone* OR "Unmanned aer* vehicle*" OR "Unmanned air* vehicle*" OR "Unmanned aer* system*" OR "Unmanned air* system*" OR "Remote* piloted system*" OR "Remote* piloted air* system*" OR "Remote* piloted aer* system*") AND (conserv* OR reserve* OR preserv* OR monitor* OR manage* OR Wild* OR landscap* OR eco*) AND (experiment* OR "quasi experiment*" OR control* OR "control group*" OR compar* OR contrast* OR "impact evaluation*" OR "impact analysis*" OR impact*) NOT tropical OR subtropical OR tropics

Test List

- Ancin-Murguzur, F.J., Munoz, L., Monz, C. and Hausner, V.H. Drones as a Tool to Monitor Human Impacts and Vegetation Changes in Parks and Protected Areas. Remote

Sensing in Ecology and Conservation. 2020:6(1): 105-113. Available from: https://doi.org/10.1002/rse2.127

- Arona, L., Dale, J., Heaslip, S.G., Hammill, M.O. and Johnston, D.W. Assessing the Disturbance Potential of Small Unoccupied Aircraft Systems (UAS) on Gray Seals (Halichoerus grypus) at Breeding Colonies in Nova Scotia, Canada. PeerJ. 2018:6: Available from: https://doi.org/10.7717/peerj.4467

- Chrétien, L., Théau, J. and Ménard, P. Visible and Thermal Infrared Remote Sensing for the Detection of White-tailed Deer Using an Unmanned Aerial System. Wildlife Society Bulletin. 2016:40(1): 181-191. Available from: https://doi.org/10.1002/wsb.629

- Forsmoo, J., Anderson, K., Macleod, C.J.A., Wilkinson, M.E. and Brazier, R. Drone-based Structure-from-motion Photogrammetry Captures Grassland Sward Height Variability. Journal of Applied Ecology. 2018:55(6) 2587-2599. Available from: https://doi.org/10.1111/1365-2664.13148

- Getzin, S., Wiegand, K. and Schöning, I. Assessing Biodiversity in Forests Using Very High-resolution Images and Unmanned Aerial Vehicles. Methods in Ecology and Evolution. 2012:3(2): 397-404. Available from: https://besjournals.onlinelibrary.wiley.com/doi/10.1111/j.2041-210X.2011.00158.x [Accessed 21 June 2020].

- Gonçalves, J.A. and Henriques, R. UAV Photogrammetry for Topographic Monitoring of Coastal Areas. Journal of Photogrammetry and Remote Sensing. 2015:104: 101-111. Available from: https://doi.org/10.1016/j.isprsjprs.2015.02.009

- Hodgson, J.C., Holman, D., Terauds, A., Pin Koh, L. and Goldsworthy, S.D. Rapid Condition Monitoring of an Endangered Marine Vertebrate Using Precise, Non-invasive Morphometrics. Biological Conservation. 2020:242. Available from: https://doi.org/10.1016/j.biocon.2019.108402

- Inoue, T., Nagai, S., Yamashita, S., Fadaei, H., Ishii, R., Okabe, K., Taki, H., Honda, Y., Kajiwara, K. and Suzuki, R. Unmanned Aerial Survey of Fallen Trees in a Deciduous Broadleaved Forest in Eastern Japan. PLoS One. 2014:9:(10). Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4184894/ [Accessed 21 June 2020].

- Moloney, J.G., Hilton, M.J., Sirguey, P. and Simons-Smith, T. Coastal Dune Surveying Using a Low-cost Remotely Piloted Aerial System (RPAS). Journal of Coastal Research. 2018:34(5): 1244-1255. Available from: https://doi.org/10.2112/JCOASTRES-D-17-00076.1

- Oosthuizen, W.C., Kruger, L., Jouanneau, W. and Lowther, A.D. Unmanned Aerial Vehicle (UAV) Survey of the Antarctic Shag (Leucocarbo bransfieldensis) Breeding Colony at Harmony Point, Nelson Island, South Shetland Islands. Polar Biology. 2020:43: 187-191. Available from: https://link.springer.com/article/10.1007/s00300-019-02616-y [Accessed 21 June 2020].

- Rush, G.P., Clarke, L.E., Stone, M. and Wood, M.J. Can Drones Count Gulls? Minimal Disturbance and Semiautomated Image Processing with an Unmanned Aerial Vehicle for Colony-nesting Seabirds. Ecology and Evolution. 2018:8(24): 12322-12334. Available from: https://doi.org/10.1002/ece3.4495

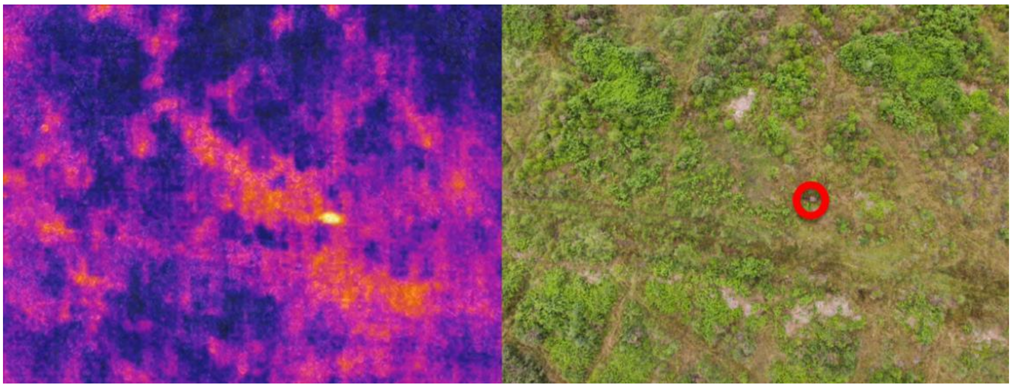
- Tedstone, A.J., Cook, J.M., Williamson, C.J., Hofer, S., McCutcheon, J., Irvine-Fynn, T., Gribbin, T. and Tranter, M. Algal Growth and Weathering Crust State Drive Variability in Western Greenland Ice Sheet Ice Albedo. The Cryosphere. 2020:14: 521-538. Available from: https://tc.copernicus.org/articles/14/521/2020/ [Accessed 21 June 2020].

Appendix 2: R Script for Processing of Thermal Imagery

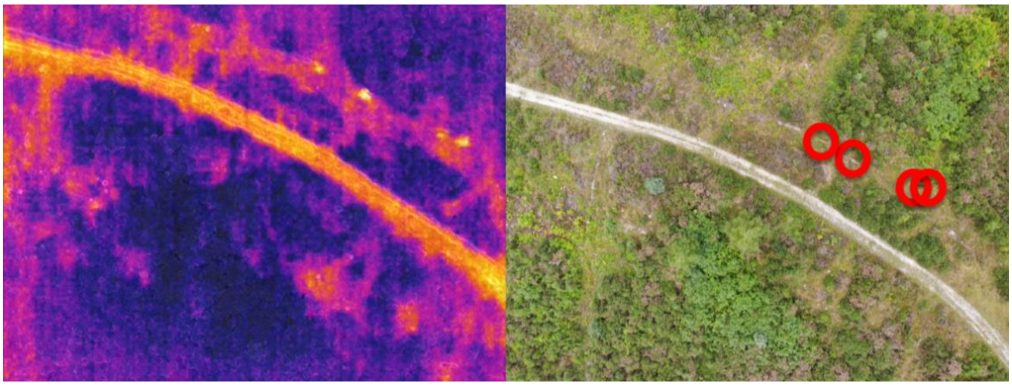
```
library(raster)
library(tidyverse)
library(terra)
getwd()
setwd("FILE LOCATION HERE")

l<-list.files(, recursive = T, pattern = "JPG", full.names = T)
l

thresh<-1.8

for (i in 1:length(l)){
  r<-raster(l[i])
  r<-0.04 * r - 273.15
  r<-scale(r)
  r[r<=thresh]<-NA
  writeRaster(r,filename=paste0("Scaled",str_split(l[i],"/")[[1]][2],".jpg"),
          format= "GTiff", overwrite=T)
  }
```

Appendix 3: Thermal Imagery of Livestock and Non-livestock animals

Thermal and RGB Imagery of three Ponies at Crabtree Hill on the 5th of August (Ponies circled Red).

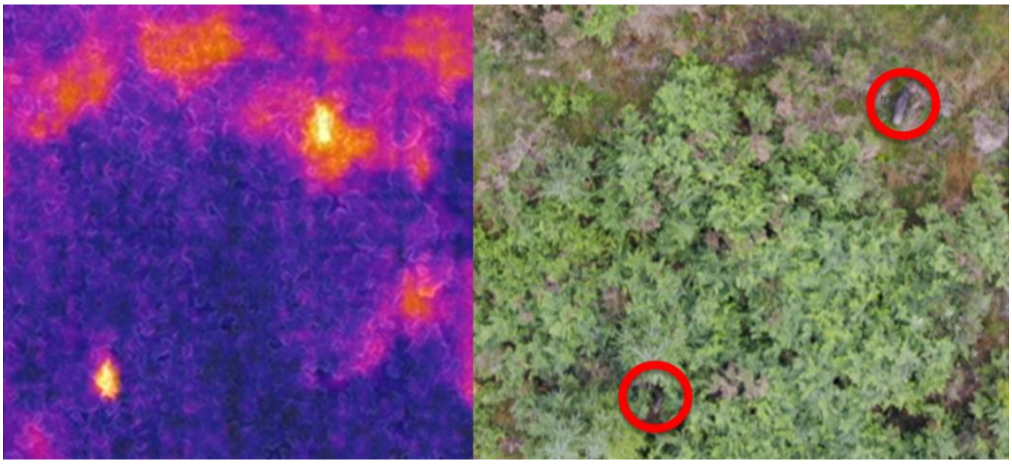


Thermal and RGB Imagery of one Pony at Crabtree Hill on the 5th of August (Pony circled Red).

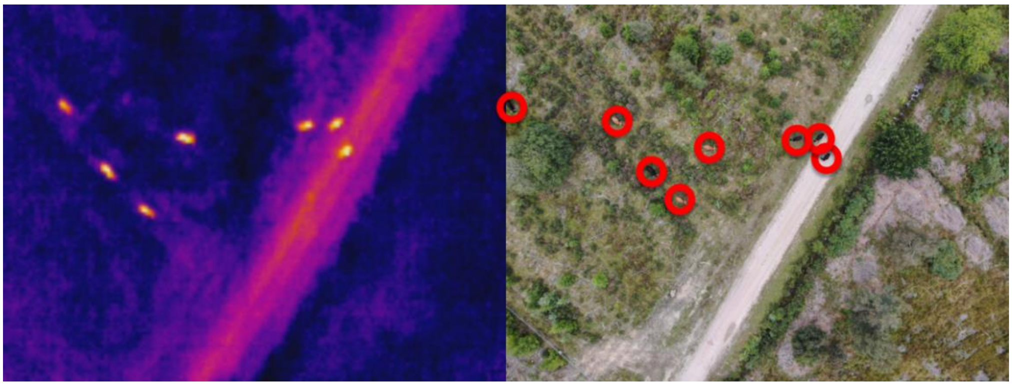


Thermal and RGB Imagery of four Deer at Crabtree Hill on the 5th of August (Deer circled Red).

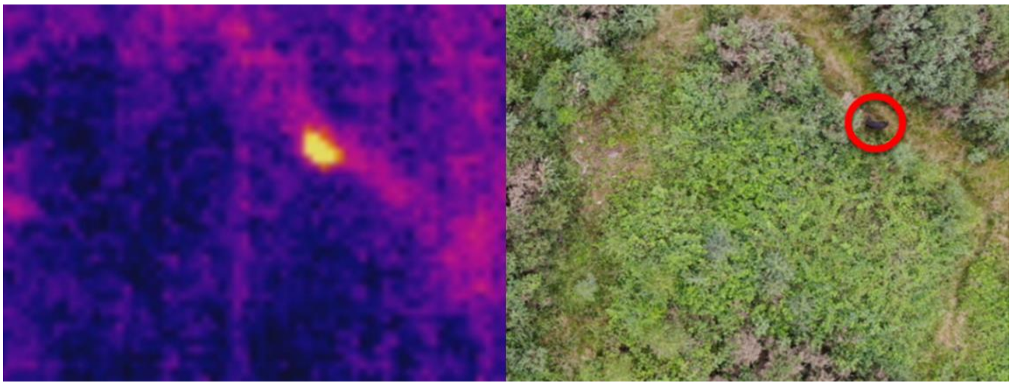
Thermal and RGB Imagery of one Deer at Crabtree Hill on the 5th August (Deer circled Red).



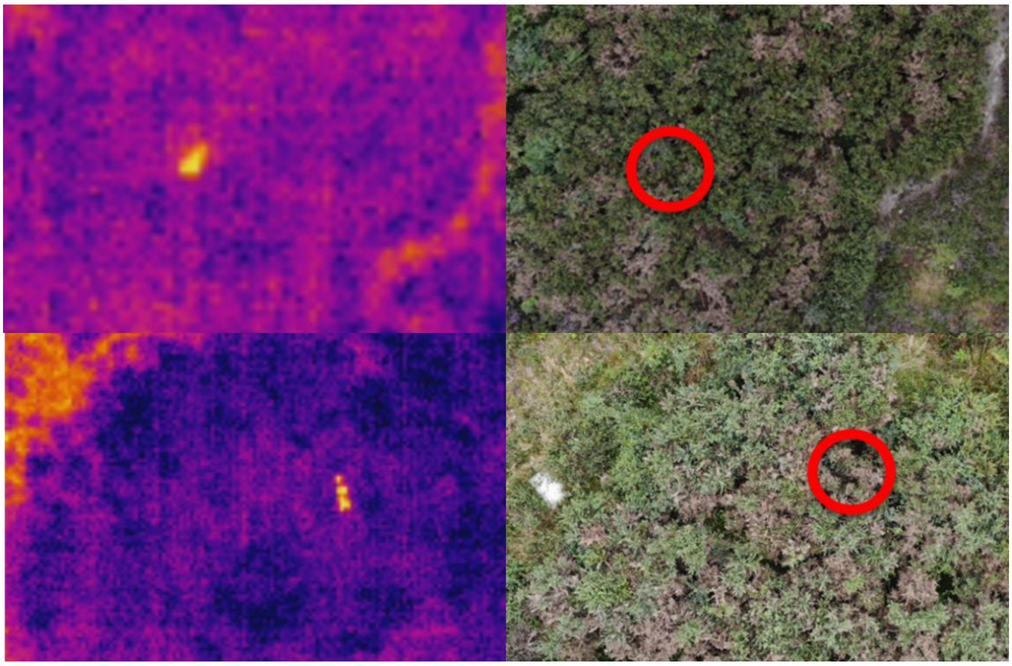
Thermal and RGB Imagery of two Deer at Edgehills Bog on the 5th August (Deer circled Red).



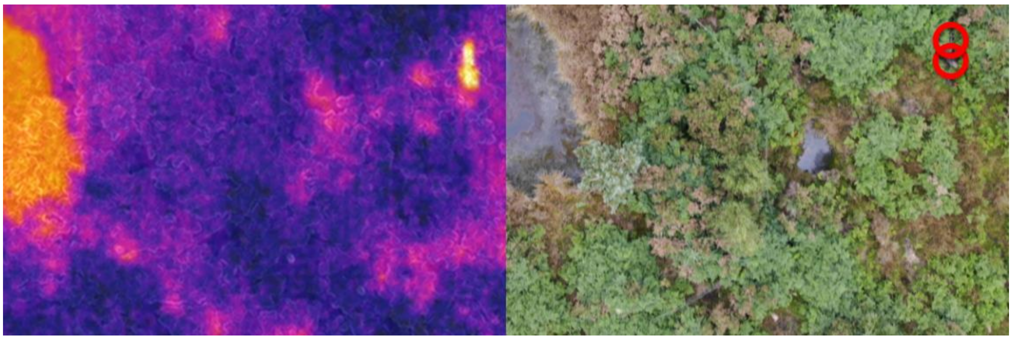
Thermal and RGB Imagery of eight Cattle at Crabtree Hill on the 25th August (Cattle circled Red, 8th Animal Visible only on RGB Image).



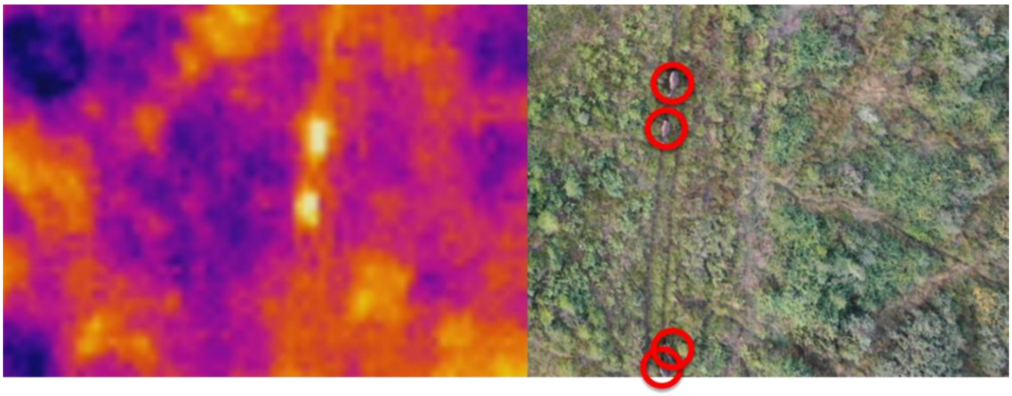
Thermal and RGB Imagery of a Deer at Crabtree Hill on the 25th August (Deer circled Red).



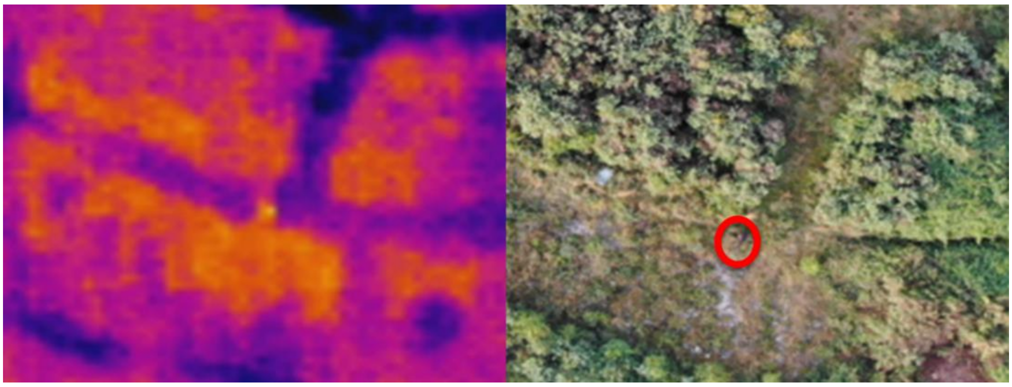
Thermal and RGB Imagery of two Deer at Crabtree Hill on the 25th of August (Deer circled Red).



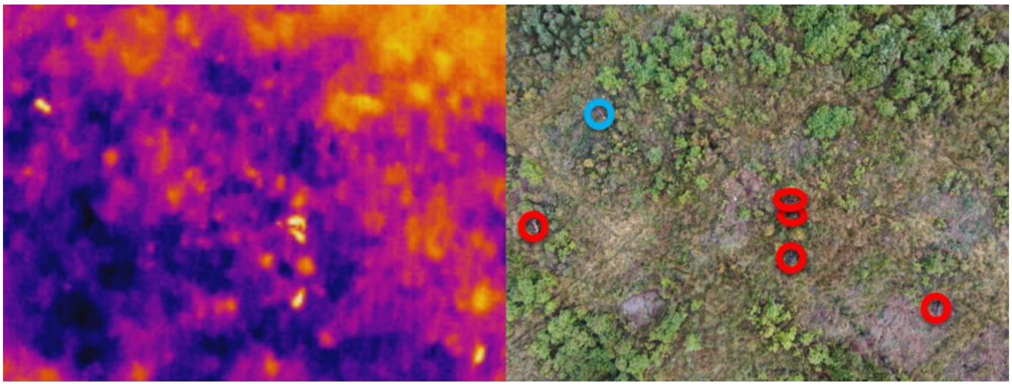
Thermal and RGB Imagery of two Deer at Edgehills Bog on the 25th August (Deer circled Red).



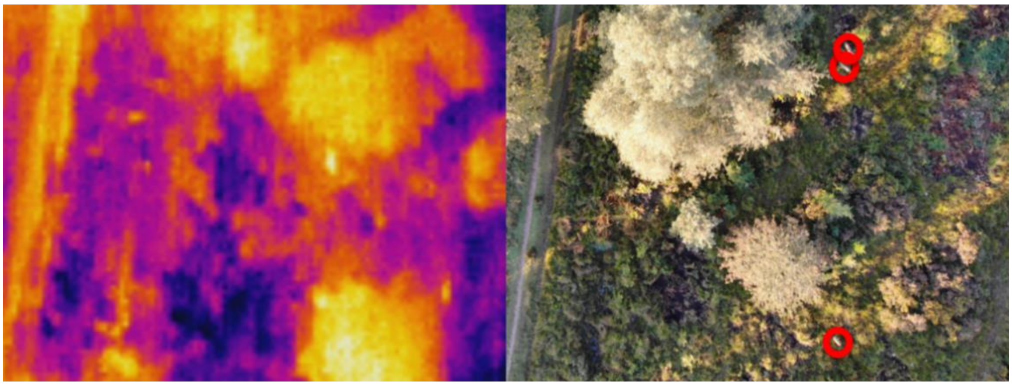
Thermal and RGB Imagery of four Ponies at Crabtree Hill on the 18th September (Ponies circled Red, two Ponies Visible only on RGB Image).



Thermal and RGB Imagery of a Deer at Crabtree Hill on the 18th September (Deer circled Red).



Thermal and RGB Imagery of five Ponies and a Deer at Crabtree Hill on the 8th October (Ponies circled Red, Deer circled Blue, Left Pony Visible only on RGB Image).



Thermal and RGB Imagery of three Deer at Crabtree Hill on the 8th of October (Deer circled Red).

Appendix 4: List of Equations

Percentage cover of feature of interest: **(Size of feature (m^2)/Total Ground Cover (m^2)) x 100**

Directional Change in Scrub Cover: $\mathbf{X_{(Change)}=X_{(2021)} - X_{(2015)}}$