WWF

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CONSERVATION TECHNOLOGY

DRONES FOR CONSERVATION

Drone technologies for conservation

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Cover image: Kandahalagala Island in the Huvadhu Atoll, The Maldives. Photo captured with a Ricoh GRII mounted on a 3DR Solo © James Duffy

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GLOSSARY OF TERMS

AGL	Above Ground Level
AOI	Area of Interest
ARF	Almost Ready to Fly
ATC	Air Traffic Control
BEC	Battery Eliminator Circuit
B-VLOS	Beyond Visual Line of Site
CAA	Civil Aviation Authority
CHDK	Canon Hack Development Kit
CMOS	Complementary Metal-Oxide-Semiconductor
CW	Clockwise
CCW	Counter-clockwise
DSM	Digital Surface Model
DJI	Da-Jiang Innovations
ESC	Electronic Speed Controller
FL	Flight Level
FLIR	Forward Looking Infrared Radar
FPV	First Person View
GIS	Geographical Information Systems
GPS	Global Positioning System
GNSS	Global Navigation Satellite System
IATA	International Air Transport Association
ICAO	International Civil Aviation Organisation
KAP	Kite Aerial Photography
LiDAR	Light Detection and Ranging
LiPo	Lithium Polymer
LRS	Long Range Systems
MP	Megapixels
NATS	National Air Traffic Services
NDVI	Normalised Difference Vegetation Index
NGO	Non-governmental Organisation
NOTAM	Notice to Airmen *(sic)*
OPTO	Optoisolators
OSD	On-screen Display
PfAW	Permission for Aerial Work
PNP	Plug and Play
PPK	Post Processing Kinematics
RC	Radio Controlled
RGB	Red, Green, Blue
RPAS	Remotely Piloted Aircraft System
RTF	Ready to Fly
RTH	Return to Home
RTK	Real Time Kinematics
RTL	Return to Launch
SfM-MVS	Structure-from-Motion Multi-View Stereo
TLS	Terrestrial Laser Scanner
TOW	Take-off Weight
UAV	Unmanned *(sic)* Aerial Vehicle
UTM	Unmanned *(sic)* Aircraft Systems Traffic Management
VFR	Visual Flight Rules
VLOS	Visual Line of Sight

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DRONES FOR CONSERVATION FAQ

What is a drone? (Chapter 5)

In the context of conservation and science, drones are lightweight aircraft platforms which can be purchased 'ready to fly' or be assembled & personalized by the user and equipped with integrated sensors, such as cameras or laser scanners. Less frequently, the platform is purchased with no integrated sensors, and adapted to carry sensors for different purposes, e.g. thermal imaging for detecting nocturnal animals, or multispectral/hyperspectral sensors for use in plant science applications. Drones come in all shapes and sizes and are manufactured by a wide range of suppliers. They are usually equipped with GPS and sophisticated autopilots and many models can be programmed to fly along 'waypointed' (GPS-guided) routes for executing robust aerial surveys, much like a piloted survey aircraft would do. The autopilots in most modern consumer drones allow the aircraft to be flown by non-expert pilots, since they provide excellent control and stability of the aircraft in flight. Drones may be multi-rotor or fixed wing. The application and the geographic setting for surveys dictates which type of platform is best for the job.

How are drone data collected?

The way that data are collected from drones varies from one application to another. Typically, a drone will be fitted with a sensor (a camera, a thermal imager or something more sophisticated such as a hyperspectral radiometer). The drone is then flown over the area of interest and the sensor captures data in flight. The data will usually be stored on a memory card within the sensor, or on the drone itself, depending on whether or how the sensor is integrated into the drone hardware. The way that the drone is flown and the type of sensor on board will affect the quality and spatial resolution of the data captured. In many cases, the sensor can be programmed to trigger an image capture at regular intervals during the flight (for stills) or as a video. The application will determine which of these trigger methods is most suitable. For survey applications, where a map or photogrammetry product is desired, the drone will often be flown in a 'lawnmower' pattern over the site of interest, going back and forth to cover the required survey area. The pilot can programme this survey flight to have different levels of overlap, depending on the desired quality of the output. For more bespoke applications, for example, sampling whale sputum onto a petri dish, or filming animal behaviour, the pilot may need to fly the drone manually using visual control either using line-of-sight operation or from the first-person-view camera on board. The latter gives the pilot a real-time view of the position of the drone relative to the subject of interest and allows the drone to be positioned precisely through manual pilot control.

What can drone data be used for? (Chapter 3)

This report details the wide variety of applications that scientists and conservationists have already implemented with drones. Reading about these examples may give you ideas about whether a drone is fit for your specific application. Broadly speaking, any application where imaging data can answer questions (e.g. about the spatial pattern in landscapes or temporal dynamics of an environmental phenomena) may be a suitable target for drone research. In non-imaging studies, the drone is an agile device that can be used to manoeuvre all kinds of payloads into difficult positions. With some ingenuity and careful planning, a drone can perform sampling functions not possible with other equipment.

Can drone data be used without any post-processing?

The conversion of data to information usually requires some data 'processing' but this does not always have to be computationally demanding. For example, an expert might view the raw video output from a camera mounted on a drone and use this to record species/population counts. In this case, the data would require minimal processing, but the time investment of the expert reviewing the video would be quite high. To produce photogrammetric products or to stitch together high quality orthomosaics requires detailed image processing workflows, and demands a capable desktop PC, or an on-demand cloud-based processing services. Processing of high quality radiometric multispectral or hyperspectral drone imaging products, or extracting information from drone-derived laser scanning data, will further add to the processing demands and will likely require bespoke software.

How are drone data processed? (chapter 8)

This depends on the data and the application. On a basic level, a single drone aerial photography survey of 10-20 minutes, with the camera triggering every 2–3 seconds can produce hundreds of geotagged photographs. On their own, each photograph may contain useful information, but the power of these data lies in combining the photographs to produce geographic layers (e.g. orthomosaics, GeoTIFFs, point clouds, digital surface models) that can be analysed rigorously using geospatial workflows. To generate such products requires access to software that can perform this image stitching. There are open-source options and commercial products for doing so, with varying levels of technical capability required to extract high quality outputs. Open-source tools can be more flexible in this regard but often require a higher level understanding of scripting/coding languages (Forsmoo et al., 2019). To execute these workflows a decent desktop PC is needed as the processing demands grow with greater numbers of photographs - although there are new options for processing becoming increasingly available for processing and storing big data in the cloud. For videographic analysis, equally, there will be requirements for video editing software and a good computer processor to allow the researcher to extract useful information from the drone video capture. More specialised research sensors, and thermal imagers will usually have their own software and workflows for extracting information.

How much area can a drone survey cover in a single flight? (Chapter 5)

The answer depends on various site-specific factors, data requirements and the platform being used. Concerning the platform, fixed wing aircraft are typically more aerodynamic than multi-rotor aircraft and have fewer motors to power, meaning less power required to travel the same distance, under the same conditions. Fixed wing aircraft are therefore more suitable for large surveys areas (>100 ha) because of their improved endurance. Beyond visual line of sight surveys also typically use fixed wing aircraft for the same reason, although these longer distance flights may require special permissions. Additionally, fixed wing aircraft are more prone to forces such as wind and therefore controlling the speed of the platform can be challenging in ceratain weather conditions. Multi-rotor aircraft on the other hand can achieve relative stability in position and constancy in speed even in high wind situations, making the data from these more reproducible and less prone to errors caused by such factors (e.g. image smear or blur if the platform is moving very fast or being buffered by wind). As a general rule the latest consumer grade multirotor platforms from leading manufacturers offer endurance of 18–25 minutes per battery (as of September 2020), which is considerably lower than the expected flight time of a similar grade fixed wing system. It is ultimately the battery life which limits the size of area that can be surveyed in a single flight. Second, site specific factors might dictate more complex flight plans being used (e.g. complex topography), and such issues can reduce endurance in the platform if the drone is having to ascend and descend regularly during the survey.

Third, the data requirements are a key consideration. Photogrammetric workflows may require high levels of image overlap between images, necessitating a denser network of flight lines. This means that the capacity to cover a larger area is reduced, and this becomes more extreme at lower flight altitudes. It can be addressed by increasing the flying height (since overlap increases as the camera is raised higher) but at the cost of reduced spatial resolution.

What spatial resolution can I expect from a drone survey?

This depends on flying height and the sensor being used. Expected ground sampling distance can be calculated with some simple equations. As a rule of thumb, drones fitted with high quality (>10 MP) cameras are expected to achieve around 1–2 cm spatial resolution at a flying height of 20–50 m. Climbing to 100 m, the resolution may coarsen to 2–5 cm. For more specialised sensors the spatial resolution capability will depend on the optics of the camera, and we advise users to consult specific user manuals since there can be considerable variability from sensor to sensor. Thermal cameras suitable for deployment on drones currently deliver data at a spatial resolution that is around an order of magnitude coarser than optical camera images (e.g. 1 cm RGB = 10 cm Thermal).

What are the ethical issues with drone surveys?

There are many ethical considerations that need to be considered before you take to the skies with your drone. The drone can be a democratic instrument in the right hands – it provides humans with access to airspace that otherwise lies outside of our gravitational capability. From this new viewpoint we can observe and measure things from a different perspective, but that perspective is a powerful one which should be used carefully and with an open view of the ethical issues in mind. Flying drones around human and non-human subjects can give rise to a range of emotional and physiological effects in your subjects, many of which are poorly understood in the case of non-humans. We discuss some of these considerations **in section 3.6** and **Figure 8** provides some bullet points for consideration prior to flights. Due to the fact that drones are synonymous with 'flying cameras' researchers must always consider issues around data protection and privacy – for which there are stringent national and international laws. Photographing people without their prior permission violates privacy laws in most countries. Flying over private property without obtaining permission is similarly problematic. Some people just don't like drones – this may be for unexplainable reasons, or it may be due to spiritual or religious beliefs; the latter particularly applies to the case of indigenous communities in some parts of the world (Sandbrook, 2015). We advise all researchers and conservationists to discuss and seek ethical approval for their operations from within their institutional structures.

What are the legal issues associated with drone surveys? (Chapter 7)

Similarly to ethics, legality of drone use is complex and varies spatially and temporally. At the time of writing, national and international aviation authorities are grappling with drone laws to decide how the aerial volume should be divided, and whether (and where) drones fit within the management of future airspace. Presently, there are some general guidelines that can offer some reassurance. Small drones with a total take-off-mass of less than 7 kg, are relatively free to explore the near-surface airspace up to around 100 m above ground level in most countries of the world, as long as these are in 'uncongested' zones free of other air traffic and away from densely populated areas. In doing so the pilot in command must maintain visual line of sight to the aircraft and typically, this means that the aircraft cannot travel more than 500 m away from its pilot. There are exceptions to this rule, most obviously in no-fly-zones around airports for example, where flying a drone of any size or type is strictly forbidden, and could lead to arrest and a fine, at the very least. The best course of action for any drone pilot would be to first check the aviation laws in the planned country of operation, ensuring first that there is no national ban on drones. In some countries there are special areas where drones may only be flown with a government permit (e.g. in the national park around mount Everest), and drone pilots should therefore prepare well in advance of any fieldtrip to ensure that they have the paperwork in place. There are nuanced rules globally about drone piloting and competence that we urge all pilots to be cautious and mindful of. For example, in the USA, drones can only be flown by pilots who have passed their Federal Aviation Authority Part 107 exam, and some national parks and state parks operate under drone bans. In many countries across Europe a different model exists for 'commercial operation' compared to 'research operation' of a drone. If you are being paid for the services you will deliver from your drone (e.g. aerial photography, or video capture) you will normally need to complete a government-approved course to register as a drone pilot, producing an operations manual and proving that you are sufficiently insured before you can legally fly (Cunliffe et al., 2017). For all these reasons, preparation is key – read up on what's allowed and what paperwork you need before travelling, and before you take off.

The online community diydrones.com offer a excellent forum for home built drones and related topics.

How much does a survey drone cost?

Highly capable lightweight (<7 kg take off weight) 'consumer' grade drones manufactured by the major brands are now very suitable for performing geospatial surveys. These can cost anywhere between €1,000 and €10,000 depending on capability and the sensors fitted. The more expensive end of the range would include drones fitted with differential GPS positioning (e.g. using RTK or PPK protocols to provide <2 cm spatial accuracy of products) or multispectral sensors. At the lower end of this range, you could expect to get a highly sophisticated multirotor system with all the necessary failsafes included (e.g. obstacle avoidance) as well as capabilities such as 'follow me', and a gimballed high quality RGB camera. Lidar-equipped drones are considerably more expensive and heavier machines – you could expect to pay up to €100,000 for one of these, and to fly them would require a special license in most countries owing to the size and take off weight of the drone (>20 kg in some cases). It is also possible to buy off-the-shelf 'hobbyist' drone platforms with no integrated sensors for considerably less than €1000. These would require a more 'grassroots' experimental approach (Anderson et al., 2016) and the user would have to modify the airframe to hold a sensor/sensors. It is likely that if you wanted to follow this route of 'build your own' you would need to take advice of radio-controlled aircraft experts. In this case, the online community diydrones.com provide excellent user forums with extensive information on a whole variety of relevant topics. You would also need access to basic electronics equipment to adjust wiring and add components (e.g. sensor triggers).

How are drone data different from other types of remote sensing data? (Chapter 6)

The main differences are spatial resolution and coverage. Drone data typically cover smaller spatial extents (10–100 ha per survey, typically) but provide finer spatial resolution data than those captured by survey aircraft or satellites. Drone surveys can be flown on demand providing a custom or finer temporal resolution than other remote sensing data. Drone data provide a localised picture of environments and ecosystems which can be useful for scaling up or validation experiments, or validating, calibrating coarser-grained satellite observations, for example. In many cases, drone data are useful on their own for studying individual animals or plants within a specific setting.

Can drone data be used with other geospatial datasets?

As explained above, yes. Once the drone data have been processed to generate a series of geospatial data layers (e.g. orthomosaic, multispectral map, point cloud or digital surface model) these layers can be imported into geospatial analysis software (e.g. GIS) and used alongside any other datasets of your choosing. Accuracy considerations are critical here – the GPS on board the drone will only have the same accuracy as a normal handheld GPS (nominally +/- 10 m, and potentially worse in the vertical domain than horizontal). If you wish to improve the spatial positioning of your drone data it is possible to do that using ground control points (localized features on the ground, which are visible in imagery and geo-positioned using high accuracy survey GPS) which constrain the bundle adjustment during processing. This requires additional equipment and processing effort.

Besides a drone, what other pieces of equipment necessary for drone surveys?

Survey drones equipped with cameras and in-built GPS have all you will need to generate basic mapping products. However, if you need enhanced accuracy or a means of validating the quality of the data you collect, you may also want to consider including the following in your field kit:

1. Targets can be deployed in the field to provide ground control, for improving the accuracy of the photogrammetric build (if applicable) and for validation. Usually these are 30 x 30 cm sprayed plastic targets, held in place with tent pegs. Ideally, you should deploy between 5 and 15 of these across the site for robust results, although this is debated in the literature (James et al., 2017a). Cunliffe and Anderson (2019) provide further details (**see section 7.4**).

2. A high accuracy GPS which exceeds that of the on-board GPS on the drone. This can be used to survey the ground control points to a higher spatial accuracy, and the arising data used to constrain the build within photogrammetric workflows.

3. Calibration targets, which are coloured in different shades, to provide a variety of surface reflectances across the visible and near infra red range, will be necessary/essential if using multispectral/hyperspectral fully radiometric sensors.

4. Field notebooks are essential for recording the details of each flight (take off/landing

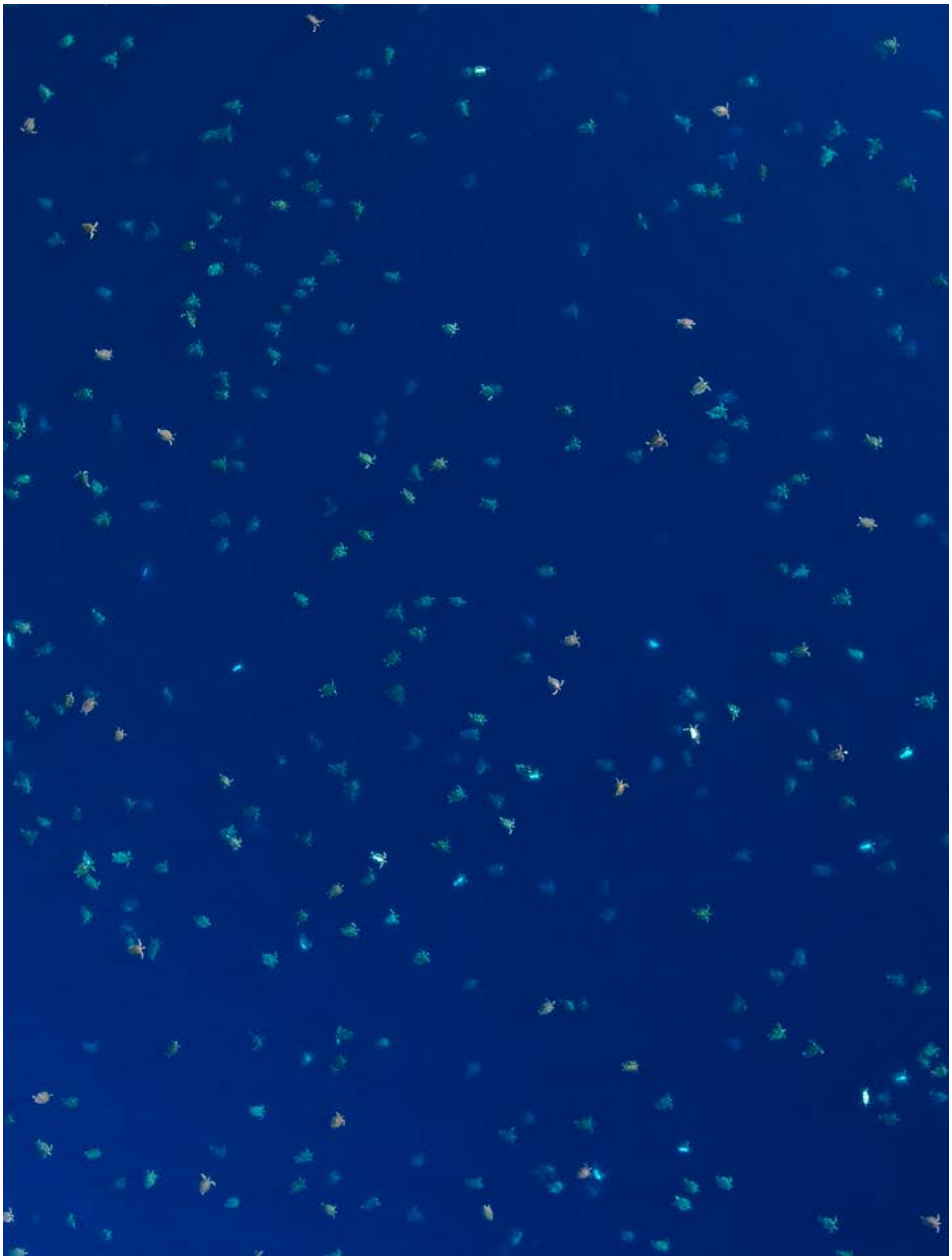
times, illumination conditions, issues encountered, battery number and drain).

5. A waterproof carry case is useful for sheltering the drone in case of unexpected wet weather.

6. Field spectroradiometers to measure the reflectance of objects *in situ* may be required if also using multispectral/hyperspectral fully radiometric sensors

7. Lens cleaning cloths are especially useful to ensure good image quality.

In specific field scenarios, there may be other pieces of kit you need. We recommend referring to Duffy et al. (2017) for insights into methodological pitfalls of working in challenging remote environments with drones, including various suggestions for extra items of field kit for use in high latitude, high altitude, wet tropical or dry desert climates.



Drones were used to assess the world's largest green turtle rookery on the Great Barrier reef.

1 PREFACE

1.1 Introduction

The Anthropocene – the current epoch in which we live in – defines the current geological time period of rapid global change (Steffen et al., 2011, Dirzo et al., 2014). Alongside the negative aspects of life in the Anthropocene (pollution, habitat loss and degradation, extinction, and rapid climate change) parallel positive developments are occurring – technology is rapidly evolving, and there are vast and expanding frontiers for exploration and observation. In this age of rapid technological and global change, humans face multifaceted challenges associated with managing and mitigating changes in climate, population growth, over-exploitation of natural resources and their subsequent impacts. Data (particularly spatial data) provide a crucially important underpinning to environmental decision-making for a sustainable future. As presented in previous issues of the WWF Conservation Technologies and Methodologies Series (Melin et al., 2017, Wearn and Glover-Kaepfer, 2017, Browning et al., 2017, Pettorelli et al., 2018a), remote sensing data (spatial 'imaging' data and products delivered by sensors on board satellites or aircraft) can provide a means by which ecosystems can be mapped at multiple scales to allow countermeasures to be planned and implemented at appropriate scales. Whilst data from satellites can provide a large-extent picture of contemporary change across continents and oceans, the spatial resolution (i.e. grain, or pixel size) of such data, or the timing of data collection, or quality due to clouds or atmosphere may not meet the needs for site-specific investigations. Many of the management issues relating to individual species or sensitive habitat areas require data at a finer spatial and temporal resolution for which sensors mounted on piloted airplanes can provide. However, such data can be expensive to acquire, they burn fossil fuels and require access to a suitably equipped scientific-grade aircraft, pilot and permissions, which may be out of reach for many researchers. Furthermore, survey flights over remote territories or unstable areas can be risky, placing conservationists and field staff at risk of injury and death.

Drones, or remotely piloted aerial systems, have now emerged into the consumer market and are of great utility for local-extent (1-100 ha per flight) surveys and observations, and are widely being used by researchers (Schiffman, 2014), following a long history of military use for surveillance and warfare. Conservationists have rapidly adapted consumer grade drone technology for 'proximal' sensing purposes and other applications (Sandbrook, 2015, Koh and Wich, 2012). At the time of writing, drone use is booming in conservation, with lightweight platforms being put to use in diverse fields, from sampling whale blow (sputum) samples (Geoghegan et al., 2018) to acquisition of aerial data for vegetation surveys (Dandois and Ellis, 2010, Zahawi et al., 2015), animal monitoring (Pomeroy et al., 2015), anti-poaching operations (Massé, 2018), and underwater coral reef habitats and species associated with them (Casella et al., 2017, Chirayath and Earle, 2016, Kiszka et al., 2016). After approximately a decade of experimentation with consumer drone technology, this report seeks to illuminate the opportunities that customized, low cost (generally €100-€2000) drone technology can deliver to conservation. With centimetre spatial resolution, proximal sensing products derived from drones overcome the spatial and temporal resolution and cost problem of their satellite counterparts, as well as the cost and safety issues associated with airplane surveys. Drones' self-service capability means that the timing, resolution, extent of surveys can be entirely user-controlled, offering considerable benefits over other remote sensing tools, particularly where environmental, climate variables hinder collection from space or airborne platforms. However, if drone methodologies were completely lacking any complexities,

Drones provide a self-service capability so the timing, resolution and extent of surveys are entirely user-controlled.

there would be no need for a user guide. Hence, we present a series of chapters that elucidate the key considerations associated with drone deployments specifically for conservation and ecology, and the emerging issues associated with drone-collected information.

1.2 Scope

This guide serves as an introductory text for the interested drone conservationist. We do not seek to provide a detailed introduction to remote sensing or proximal sensing principles, but through a series of informative chapters, conservation-based case studies and applications, the technical aspects of drone science or drone sensing will come to life. We assume that readers of this guide possess a basic background in ecology and/or conservation and an understanding of basic remote sensing principles (Pettorelli et al., 2018a). Good introductory texts covering drone methodologies in remote sensing and ecology and conservation include those by Anderson and Gaston (2013), Duffy et al. (2017), Sandbrook (2015), Koh and Wich (2012). Importantly, we seek to guide users towards critical, considered and ethical deployment of lightweight drone technology for answering a broad range of conservation questions. It is beyond the scope of this report to consider all types of drone technology, so we focus on lightweight systems, which are defined in most countries to not exceed a total take-off-weight (including sensors and all batteries) of 7 kg. The lowest weight class generally confers a low legislative hurdle for users in most regions of the world. The rules governing how, where and when such aircraft may be flown will change according to local, national and international policy (**Chapter 7**). All users are expected to read and abide by their country's civil aviation authority operational procedures before taking to the skies, regardless of their science or conservation mission.

1.3 The structure of this guide

Although this guide is aimed at those with little to no knowledge of, or experience with, lightweight drones, the content will address the ever-changing applications of conservation drones to a wider seasoned audience. The authors have made every effort to balance breadth, depth, and accessibility for more complex material. We cover a wide range of material starting with the evolution of the conservation drone (**Chapter 2**); a literature review summarising the state of the art in drones for conservation science, and key considerations for drone applications (**Chapter 3**). We then provide advice on executing a drone survey in 10 clear steps (**Chapter 4**), followed by details on drone anatomy (**Chapter 5**) and the wide range of sensor payloads now available (**Chapter 6**). Following this, we explore operational guidelines for flight planning and data collection (**Chapter 7**), and analysis (**Chapter 8**). We then shine a spotlight on how WWF are using drones in operational conservation research (**Chapter 9)**. We capture the technological limitations of current drone technology, caveats and solutions (**Chapter 10**); and then finish by summarising the future potentials and trends in the rapidly evolving drone industry and how these might benefit conservation scientists (**Chapter 11**).

A group of wild Sumatran elephants are tracked via drone in the community plantation in Musarapakat, Aceh, Indonesia. © Mahmud Yani/WWF-Indonesia

2 DRONE EVOLUTION

We begin this report by situating drones within their long history of military development and experimentation. We, alongside others, argue that this is an important consideration for drone users from all disciplines, because the emergence of drones from a military milieu can influence public perception of drone practices (Garrett and Anderson, 2017). For such reasons, the appearance of a drone in the field can give rise to a range of responses amongst the public, some positive, some less so. Indeed, in some settings, conservation drone deployments may be met with resistance, fear, animosity, demands for paperwork, and proof of pilot competence. Humle et al. (2014) argue that within conservation settings, drones may be considered by some to represent the "sinister technologies of surveillance or be associated with warfare and civilian casualties", with such negative perceptions potentially viewed as a return to "fortress conservation, reducing support for protected areas and undermining the relationships on which successful research and conservation projects are built". Some agencies will simply refuse to grant permission for drone flights, on various grounds. We propose that in understanding the drone's military history, conservationists will be better equipped to navigate these complex scenarios. Importantly this can allow for a more sensitive re-situation of conservation drones as positive forces for good, rather than, as may be seen by some stakeholders, an extension of surveillance technologies that could, in some contexts, be considered capable of delivering harm.

2.1 Military beginnings

The first pilotless aircraft were developed during the first world war and launched via catapult.

For more information visit:

https://www.iwm.org.uk/history/a-brief-history-of-drones

Consumer drone technology, like remote sensing and geographic information systems, has a military heritage (Garrett and Anderson, 2018). The first drones were developed during the first world war, and launched via catapult. These systems were very large compared to most modern day consumer drones and they were designed for use in reconnaissance missions or as aerial weapons. During world war II, the US radioplane company produced thousands of unpiloted 'drones' for use as gunnery targets. Military applications continued to be the primary focus for drones through the mid twentieth century, with large numbers being deployed during the Vietnam war for delivery of propaganda, and as military decoys. From this heritage modern drones have evolved to perform a much wider range of functions, and although the military still use drones widely, they are no longer the sole user of the technology in today's world. The word 'drone' itself is a simple descriptor that belies its complex origins and taxonomy – yet most drones possess a unifying capability, described succinctly by Wallace-Wells (2014): "Each of these machines gives its human operator the same power: it allows us to project our intelligence into the air and to exert our influence over vast expanses of space".

Every drone, if equipped with a camera, can provide a 'view from above', a capability long critiqued by human geographers in the context of the aerial characteristics of the drone gaze (Klauser and Pedrozo, 2015). Until the recent upsurge in consumer drone technology, the drone was best known for its role in exercising military/government power, across and within space; exerting superiority over humans (or non-humans) below. This connects the drone's view from above to a long history of subjugation through aerial spatial visualisation (Graham, 2016). Through this lens, drones can be considered part of an aerial assemblage that spans: aerial photography, warfare surveillance, aerial policing, photographic reconnaissance, satellite communications and spatial mapping; all of which have underlying, and associated "power dynamics" (Klauser and Pedrozo, 2015, Adey, 2010). The top-down view afforded by an aerial camera, if considered in a military context, can give the drone operator a sense of an "inherent superiority" over people or objects "beneath the gaze" (Graham, 2016, Garrett and Anderson, 2017). **Figure 1**, taken from Giones and Brem (2017) evidences the entwined strands of drone development, from military beginnings, to civilian applications.

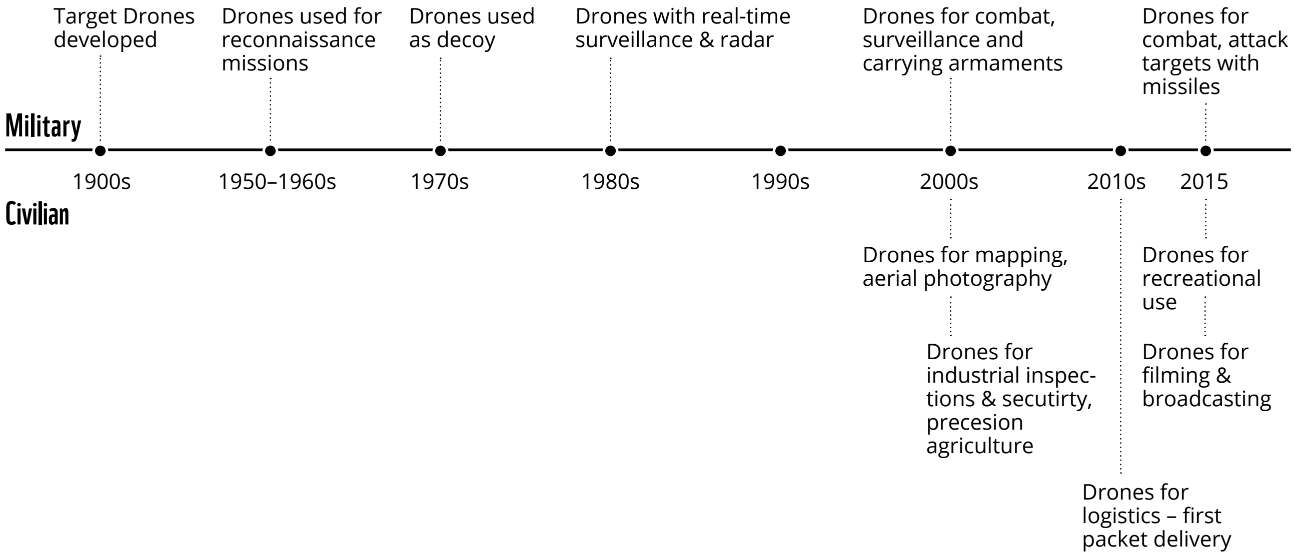


Figure 1: A timeline of military and civilian uses for drones – taken from Giones and Brem (2017).

2.1 The drone dichotomy in conservation

The dichotomy of the drone led Wallace-Wells (2014) to call for a more nuanced ecological taxonomy to be imposed on drone classification. There are now thousands of different kinds or 'species' of drone, with a diversity of uses for different settings (**see Figure 2**) – and Wallace-Wells (2014) argues that many of those used by scientists and conservationists could be classified in a separate family to military or police drones. Even within civilian applications, there is a great diversity of drone use – a conservation drone has different traits compared to a racing drone. Indeed the operational methods of flying and the underlying purpose for flying, are completely different across the examples shown here. Such classifications however, are confused by the fact that at the time of writing, widely available consumer-grade drones such as the DJI phantom, are being used in parallel by different groups: for example, within science and conservation (Rush et al., 2018), as well as by the military and police (Wall, 2016). Conservation ecology is in fact, a nexus of the spectrum of drone applications – with drones now widely used for surveying and inventory of 'at risk' animals (Wich et al., 2015, Linchant et al., 2013, van Gemert et al., 2015) and in reducing human-wildlife conflict (e.g. using drones to deter elephants from villages (Hahn et al., 2016). Alongside, drones are widely used by anti-poaching agencies (termed "green militarisation" by Lunstrum (2014) or "militarised"/"weaponised" conservation (Duffy, 2014, Wall and McClanahan, 2015), whilst there is new evidence emerging of a poaching 'arms race', where wildlife poachers themselves might engage lightweight drone technology to target their prey more effectively (Ecological Society of America, 2018).

Conservation and ecology provide a lens on the complex, sometimes, fuzzy boundaries between drone surveillance and drone science, giving rise to what Massé (2018) terms, "the multiple spatialities of conservation power". It is precisely for this reason that we emphasize the military beginnings of drones in this report. Most often, this blurring of definitions can generate confusion amongst stakeholders with whom practitioners may wish to build trust prior to deployment of drones for conservation-related activities. Such issues should be critically considered and discussed with stakeholders prior to aerial experiments. Whilst the temptation is often to consider just the methodological steps (e.g. how, where and when to fly) in relation to scientific questions, the history of the drone means that conservation drone practitioners should consider also the social, geopolitical and ethical implications of their praxes. Sandbrook (2015), in this frame, provides an excellent starting point from which ecologists can consider the ethical basis of planned drone deployments.

For further insight into this philosophical area, refer to Adey (2010), Garrett and Anderson (2018), and Chamayou (2015) to unpack this debate in more detail. Instead, we suggest there is a need to view the drone through a lens of environmental optimism. Like many geospatial technologies that have proven useful in ecology and conservation, drones are not alone in having military origins. Satellite data, geographic information systems and toolkits such as Google Earth, all have similar military beginnings, yet have been re-appropriated successfully to "socially productive ends" – allowing for more participatory and bottom-up democratic mapping approaches to emerge from a military genesis (Garrett and Anderson, 2018). In the past five years, drone metamorphosis has occurred to such an extent that there is a great diversity of drone activities around and above us and many imagined futures for what drone technology may deliver, both physically and philosophically, to the human race.

2.3 Hobbyist platforms for science and conservation

Figure 2: Zipline uses drone technology to deliver urgent medical supplies to local communities. © Sarah Farhat/World Bank

Modern consumer-grade platforms form the basis for most of the drone-based ecological or conservation research undertaken in proximal airspace (i.e. close to the ground, within which most conservation/ecology drones fly (<400 ft /120 m)). The miniaturization of electronic components, lighter and cheaper materials, increased computing power on ever smaller chipsets, alongside the miniaturization of digital camera sensor arrays, have made lightweight drones more affordable and accessible (Giones and Brem, 2017). Highly specialized 'surveying drones' are also on the market, e.g. from companies such as Leica[1], but their relatively higher cost and presumably, commercially closed-source capabilities, have precluded more widespread use within ecology and conservation applications. Amongst ecology and conservation groups there has been an upsurge in the deployment of commercial hobbyist systems over the past decade, either where drones are configured specifically for particular applications, or where systems are flown 'out of the box' to collect data (González-Jorge et al., 2017). In drone sensing there is something of a dichotomy between the rather low-cost data acquisition method, relying on affordable consumer grade aircraft to capture data, followed by the relatively high geospatial skillset needed to extract information from those data (e.g. using advanced software to generate point clouds, 2- or 3-dimensional datasets for mapping habitats or species). Arguably, this barrier is similar with many conservation technologies for example LiDAR (Melin et al., 2017) – the complexity lies in the stage where data are converted into information.

All the same, the workflow of drone science is new and different from well understood remote sensing methods of the past. Those data were more often captured by sensors flown on airplanes, navigated by skilled pilots; or from space-borne satellites operated by multi-national agencies and pre-processed for specific uses. Now, drone scientists are the data providers, the pilots and the data analysts, and with this, comes a need to understand the impacts of survey design, photogrammetry, image overlap, ground-control-point distribution, and camera settings on the quality of the data product generated.

California based photographer Chris Willis has integrated drones into his craft © snapchris.com

1 https://leica-geosystems.com/en-GB/products/uav-systems

Fixed wing drones can cover more area per survey, with a longer flight time, but require a larger space for take-off and landing.

Copters have shorter flight times, are noisier, but more maneuverable, can hover and require less space for take-off and landing.

Table 1 provides an overview of the most widely used drones with some highlighted scientific publications showing their use in ecology and conservation applications.
To summarise, there are two main families of lightweight drone available for use in ecology and conservation work – the fixed wing, and the multi-rotor system. Fixed wing systems offer considerably greater endurance (1–2 hours per battery in some cases) – allowing larger areal coverage per survey, since they are more aerodynamic. Where local legislation allows – beyond-visual-line-of-sight (BVLOS) surveys can be carried out effectively with these kinds of platforms. For this reason they have been put to good use in surveying remote areas of rainforest, for example. Multi-rotor or copter drones, on the other hand, are less aerodynamic, and deliver lower flight times per battery, but tend to be more stable and maneuverable, and more common on the commercial market than fixed wing systems, becoming the mainstay of most ecological and conservation drone research. Advancements in autopiloting software means that on the whole, multi-rotor and fixed wing systems can stabilize their flight with minimal need for pilot input. Multi-rotors are noisier than fixed wing drones, since they have more rotors and engines, and therefore can cause disturbance to wildlife, which may undermine the purpose of a survey. Hence, flight plans that are sensitive to these issues should be designed to generate minimal stress amongst target organisms. On the other hand, launch and landing for fixed wing drones requires more pilot skill, more space, and sometimes more infrastructure than multi-rotors which take off vertically. For example, some fixed-wing systems may be hand-launched while other requier propulsion such as a spring-loaded catapult. We explore these drone types in further detail in **Chapter 5**.

For more information visit:

Drones - Open Access Journal

Journal of Unmanned Vehicle Systems

Remote Sensing in Ecology and Conservation

Remote Sensing of Environment

Remote Sensing - Open Access Journal

There are a wide variety of academic papers that now summarise the capacities and capabilities of these 'lightweight' (sub 7 kg) drone systems for ecological and conservation work. We refer readers to a few key papers that provide useful insights, including Anderson and Gaston (2013), which provide a basis for understanding the capabilities of different drone platforms of varying sizes and payload capacities, with a particular focus on terrestrial ecology. Rees et al. (2018) provide a detailed account of the proven and potential uses of drone approaches for sea turtle survey. Woodget et al. (2017) similarly provide great insights on drone methods for fluvial habitat survey. Many of the approaches described therein, could be adapted readily to the monitoring of other species and their habitats: across terrestrial, aquatic, and coastal settings. There are also peer-reviewed journals focusing on drone-based research, for example 'Drones', and the 'Journal of Unmanned Vehicle Systems'; alongside broader remote sensing journals which feature articles employing drone methodologies, e.g. Remote Sensing in Ecology and Conservation, Remote Sensing of Environment, and Remote Sensing. Some of these journals have also featured special issues on drone applications in the past, see for example, the Remote Sensing in Ecology and Conservation special issue on "RPAS applications in conservation and ecology".

Table 1: Examples of lightweight drone systems used in ecological research

TYPE	MANUFACTURER AND MODEL	MAXIMUM OR TYPICAL TAKE OFF WEIGHT (TOW) INCLUDING BATTERIES AND SENSORS (IF APPLICABLE)	COST
MULTI-ROTOR	DJI Phantom (versions 1 to 4 and 'Pro')	Typical TOW is 1.4kg if fitted with standard DJI camera on gimbal.	€1–2,000
	3DRobotics Solo	Maximum TOW of 1.8kg but actual weight will vary depending on user-fitted sensor systems.	€400–800
	3D Robotics Y6	Maximum TOW of 1.8kg but actual weight will vary depending on user-fitted sensor systems.	<€500
	Draganflyer X6	Payload capacity 2.6kg	€10,000
	DJI Mavic Pro/Mavic Air	TOW when ready to fly, with built-in camera is 0.4kg (Air) – 0.725kg (Pro)	€700–€1,500
	Parrot Anafi	TOW 374 g with built-in camera	€1–2K
FIXED WING	Skywalker 2013	Variable depending on payload	€700–1,000
	Parrot Disco	700g, flying time of 45 minutes top speed of 80km/h	€800
	TBS Caipirinha	650g typically, if fitted with go-pro camera	€500
	SenseFly Ebee	700g	€15,000

BUILT-IN SENSOR?	COMMENTS	APPLICATIONS
Yes, Camera. Phantom 4 Pro includes a 1-inch 20-megapixel CMOS sensor suitable for still or video capture.	Ready to fly out of the box. Inbuilt camera with gimbal, and easy to use control software. Relatively closed-source compared to 3DR.	Bevan et al., 2015, McLelland et al., 2016, Kiszka et al., 2016, Marcaccio et al., 2015, McNeil et al., 2016
No but there are a wealth of camera mounts and gimbals than can be fitted to enable most cameras to be carried.	Ready to fly out of the box, but to fit sensors or gimbals requires some basic technical knowledge. Flies with a 3DR pixhawk autopilot which is fully open-source, so all flight parameters can be obtained easily. Open source Mission Planner software can be used to plan and execute autonomous flights.	Duffy et al., 2018b, Vattapparamban et al., 2016, Hogan et al., 2017, Crutsinger et al., 2016, Fernandes et al., 2018
No, camera mounts can be commercially purchased or 3D printed.	Typically must be built from a kit but is fully customizable. Uses a pixhawk (see notes for 3DR solo).	Cunliffe et al., 2016, Puttock et al., 2015
No, users report fixing ruggedized cameras to the underside using bespoke fixings.	Ready to fly system, but to fit sensors or gimbals requires some basic technical knowledge. Commercial	Woodget et al., 2017, Woodget et al., 2015
Yes	12 MP camera is integral to the drone	Fernandes et al., 2018
Yes	21 MP camera is integral to the drone	Borrelli et al., 2019
No, must be customized by the user. Consumer-grade cameras often used, e.g. Canon S100 operating 'canon hack development kit' (CHDK) for autonomous triggering.	Uses a HK 2.7 autopilot which is compatible with open-source Mission Planner software.	Wich et al., 2015
Built-in 14MP camera	Ready to fly out of the box, automated take-off and landing; Parrot FreeFlight Pro software for mission planning	Cerreta and Kiernan, 2019
No, but users report easy fitting of Go-Pro camera	Equipped with APM2 flight controller, compatible with open-source Mission Planner software.	Thapa et al., 2018
Yes – it can include the SenseFly S.O.D.A RGB camera or be fitted with a Parrot Sequoia for multispectral surveys	A relatively high-end version of a fixed wing aircraft but well supported by commercial suppliers.	Scobie and Hugenholtz, 2016

The Amoron'i Onilahy Protected Area in Madagascar is managed by local communities in partnership with WWF, who protect their natural wealth through ecotourism promoting biodiversity.
© Martina Lippuner/WWF-Africa

3 SO, YOU WANT TO USE A DRONE FOR CONSERVATION?

You are probably reading this report because you are interested in whether drone-based data might be useful for your ecology/conservation application. The chances are that some of the questions you need answering have already been addressed by others through experimenting with the technology, and in carrying out scientific or other investigations with drones. In this chapter we will:

- Summarise the current state-of-the-art in drone methodologies within ecology/conservation;
- Outline the key considerations that all drone operators must address before taking to the skies (**best practices, Figure 8**);
- Signpost to sections of this report providing details about the types of data that can be captured, and how;
- Briefly summarise the operational pitfalls and challenges facing drone operators in particular situations.

3.1 State-of-the-art drones in conservation

New research has shown that data from drones can deliver improved scientific measurements of natural phenomena compared to human observation. Hodgson et al. (2018), for example have evidenced more accurate animal counts from drone-based image data. Similarly, drones can deliver more accurate geospatial data at lower cost as compared to other surveying technologies (Glendell et al., 2017, Castillo et al., 2012) and are also often visually compelling and easy for non-experts to interpret and understand – so they can directly influence and inform policy change in a direct manner (Stark et al., 2018). Drone-captured data are therefore increasingly being used to support park managers and local communities to monitor and protect their areas in real-time (Ancin-Murguzur et al., 2020, López J, Mulero-Pázmány, 2019; **see section 3.7**). In the context of animal ecology, Koh and Wich (2012) argue that drones offer a non-technical approach for data acquisition at fine spatial and temporal resolutions. The following sections give a brief flavour of the breadth of scientific applications where drone data have contributed to an advanced understanding of ecology or conservation related issues.

3.2 Terrestrial flora

In the sphere of terrestrial ecology, drones have been used effectively for low-cost surveying of forest habitats for carbon assessment (Mlambo et al., 2017), and for spatial and volumetric assessment of forest structure (Dandois et al., 2015, Dandois and Ellis, 2010, Dandois and Ellis, 2013, Zahawi et al., 2015). In the Brazilian Amazon, d'Oliveira et al. (2020) have derived aboveground biomass (AGB) estimations as well as information on crown structure, leaf area density distribution from drone-mounted LiDAR. Baena et al. (2018) have shown how drone data can be used to inform terrestrial ecosystem assessment and also provide useful information for guiding management strategies for wildlife and plant communities (Lyons et al., 2018b). In drylands, early foundational work showed the promise of drone methodologies for mapping major vegetation types across landscapes – the fine spatial resolution of drone data revealed patterns hidden within coarser-scale satellite pixels (Laliberte and Rango, 2009, Rango et al., 2006). More recent work has shown that point clouds derived from drone-captured aerial photography can deliver crucial information about desert plant structures and above ground biomass (Cunliffe et al., 2016), leading to development of a new reproducible protocol for expanding such observations to a wide range of ecological systems (Cunliffe and Anderson, 2019). In low stature grassland ecosystems, new research has proven the capability of drone data to deliver information about grassland sward heights, crucial for understanding the spatio-temporal distribution of ecosystem services in systems where LiDAR would not deliver useful data on ecological structure (Forsmoo et al., 2018). Drones can also offer a new perspective – Liang et al. (2019) demonstrate the value of laser scanning data from drone platforms by showing how currently available off-the-shelf drone-based laser scanners can deliver “excellent tree height/tops measurement performance”. Although they demonstrate that the geometric accuracy of stem retrieval is less accurate than terrestrial laser scanning, the “high mobility and fast data acquisition” (ibid) offers benefits over TLS in forest systems.

Figure 3: A drone image showing dryland vegetation in the New Mexico Desert, taken by a DJI Phantom 4.
© Dr. Andy Cunliffe

MONITORING PLANT BIOMASS WITH DRONE PHOTOGRAMMETRY

Dr. Andrew Cunliffe, University of Exeter

Andy is a Research Fellow investigating the carbon dynamics of terrestrial ecosystems. He uses drone photogrammetry as a versatile tool to collect fine-grain observations of plants and landscapes at sites around the world.

Plants are critical components of most ecosystems, mediating exchanges of water and carbon between the land and the atmosphere, and forming the basis of most food webs. Conservation practitioners can use drones as tools to observe plants, looking for changes within and between ecosystems that inform understanding of plant health, forage availability, fuel loads, and ecological responses to environmental change.

Drones can acquire photographs of ecosystems from above in a reproducible and minimally invasive manner. These aerial photographs can be processed with photogrammetry techniques, generating geolocated mosaic images and 3-dimensional models. These images can be analysed to detect the presence of particular organisms, such as invasive species. The models also support extraction of canopy heights and associated attributes such as biovolume, which can be used to infer aboveground biomass. With repeated surveys, it is possible to monitor changes in vegetation cover, canopy height and biomass carbon storage through time.

Key advice for the new drone scientist:

1. Take the time to think about how the remotely sensed attributes relate to the properties you are interested in measuring.
2. When working with new approaches, undertake field trials to ensure that your data collection efforts will meet your needs.

Further information:

Andrew M. Cunliffe, Richard E. Brazier, Karen Anderson. 2016. Ultra-fine grain landscape-scale quantification of dryland vegetation structure with drone-acquired structure-from-motion photogrammetry, Remote Sensing of Environment, Volume 183, Pages 129–143.

3.3 Terrestrial fauna

Within faunal studies, drones have delivered novel data. For example, drone data have been used to understand more about the ecology of proboscis monkeys complementing satellite tracking and habitat mapping (Stark et al., 2018). Orang-utans (Wich et al., 2015) and chimpanzee nests (Bonnin et al., 2018), have been surveyed from drones where the fine spatial resolution data are essential for distinguishing the canopy characteristics associated with nesting sites. Thermal sensors on drones have been instrumental in monitoring canopy dwelling animals such as monkeys (Kays et al., 2019). Van Gemert et al. (2015) have pioneered the application of automatic counting systems to drone data for the purposes of population counts, whilst Weimerskirch et al. (2018) have used drones to advance understanding of animal behaviour and physiology. On the terrestrial – marine interface, emerging work by Nowlin et al. (2019) has begun to evaluate the role of drone data in monitoring human behaviour within conservation projects. Through this work they discuss the “legal and regulatory landscapes that scientists confront when people are their primary study subjects” and resultantly offer a useful set of guidelines for researchers studying human interactions with natural resources in the marine environment.

Figure 4: Orangutan nest spotted during aerial drone survey in Bukit Puton Forest Reserve. © WWF-Malaysia/Mazidi Abd Ghani

Figure 5: Fishing boats offloading their catches in Kayar, Senegal. © Aurélie Shapiro/WWF

3.4 Marine/coastal flora

In the near-shore coastal zone, seagrass surveys have been successfully delivered by drone (Duffy et al., 2018b). In sand-dunes, drones have been used to deliver spatial ecological data, and volumetric geomorphic information (Duffy et al., 2018a, Mancini et al., 2013). In marine turtle conservation Varela et al. (2019) have demonstrated the value of fine-grained coastal topographic models delivered from structure-from-motion photogrammetry workflows for assessing coastal squeeze and the impact of rising sea levels on turtle nesting beaches. Coastal assessment of vegetation zones using lightweight drones has also been carried out successfully by Ventura et al. (2018). Work by Gray et al. (2018) evidences that drone data are "highly effective" for training classification algorithms and validating fine-spatial resolution satellite data: in their example, they demonstrate this approach with regards to coastal habitat mapping products generated from coarser-grained satellite data.

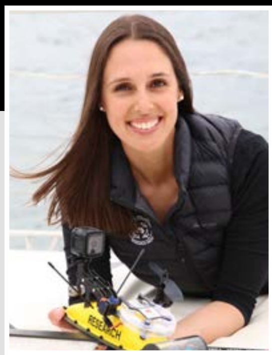
3.5 Aquatic systems

In aquatic systems the presence of water and spatial/temporally variant surface structures (e.g. waves, whitecaps) can create uncertainty in drone data making it difficult to stitch together images or generate high quality imaging products. There is cutting edge science being undertaken to try to address this problem, using 'fluid lensing' (i.e. "using water-transmitting wavelengths to passively image underwater objects at high-resolution by exploiting time-varying optical lensing events caused by surface waves" (Chirayath and Earle, 2016)) to overcome the problem. This technique relies on experimental complex algorithms to model the effect of surface motion on remotely sensed signals. It would probably be out of reach of most conservation practitioners at present, but in the future it is possible that it may form part of more standard marine processing workflows. On the other hand, if ideal conditions exist, with minimal wind, there are great opportunities for conservationists to benefit from drone data. Coral reef scientists have capitalised on the drone methodology because the shallow nature of many reefs, which means that in calm conditions, the reef structure can be effectively sensed from drones. For example, Casella et al. (2017) show how submerged reef morphology can be obtained by applying photogrammetric workflows to overlapping aerial images. Marine mammals have received much attention in this sphere – with surveys of dugongs (Hodgson et al., 2013), sharks and rays (Kiszka et al., 2016), seals (Pomeroy et al., 2015), jellyfish agglomerations (Schaub et al., 2018), cetaceans (Gray et al., 2019) and whales (**see case study, page 33**). Indeed, in the case of cetaceans, Gray et al. (2019) have demonstrated that in using state-of-the-art photogrammetric workflows and neural networks, it is possible to correctly classify whale species from drone imagery with 98% accuracy (57/58) for humpback whales, minke whales, and blue whales – meaning that automatic recognition of species from image data is a possibility in the future. Also in whales, recent work by Christiansen et al. (2019) has highlighted the capacity for 'weighing' marine mammals vicariously using photogrammetry techniques that describe the volumetric characteristics of individuals. In the freshwater domain, there are also studies which are starting to showcase the capability of drone technology for delivering new insights into the structure and function of rivers (Woodget et al., 2017, Husson et al., 2016, Husson et al., 2014).

Figur 6: Drone-based survey of Amazon river dolphins, Brazil. © Mauro/AFP

USING DRONES TO COLLECT WHALE LUNG SAMPLES

Dr. Vanessa Pirotta, Macquarie University



Vanessa Pirotta is a conservation biologist and science communicator who has recently completed her PhD at Macquarie University. Her research focuses on identifying conservation gaps for cetaceans : whales, dolphins and porpoises.

As part of Vanessa's PhD, waterproof drones were designed and built to sample whale lung microbiota for an assessment of whale health. Previously, sampling whale health was limited to whales that had either stranded, in which case their health was compromised or those that were hunted. The transition to sampling from live, free swimming whales originally included poles with petri dishes extended over whale blowholes from boats. This was and still is a successful method to collect lung microbiota however, this application requires close boat approaches to whales, which can be dangerous and invasive.

The application of drones to sample humpback whale lung microbiota off Sydney has been incredibly successful. In collaboration with industry (Heliguy Scientific), a remotely operated flip-lid mechanism on the drone allows a petri dish to be open and closed during flight to minimise sample contamination. From this, lung microbiota and viruses have been collected via this non-invasive method.

Key advice for conservation practitioners:

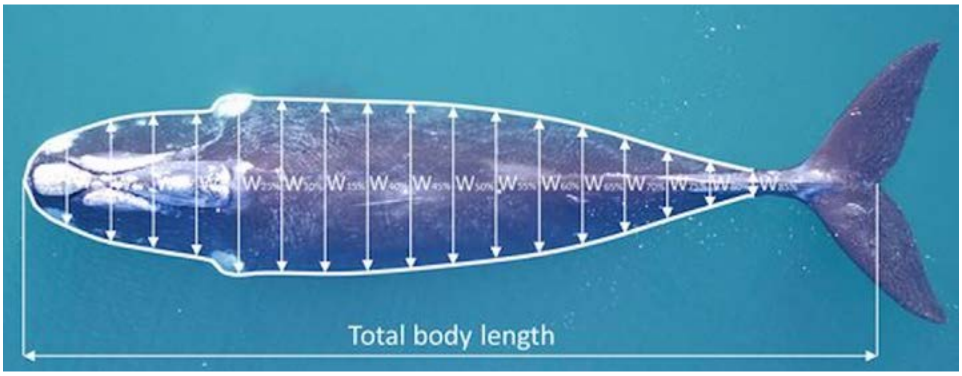
1. Collaborate with industry to develop tools for your research.
2. Go beyond your field of expertise and learn from others doing similar things in different environments.

Further information:

Pirotta, V., Smith, A., Ostrowski, M., Russell, D., Jonsen, I.D., Grech, A., et al. (2017). An economical Custom Built drone for assessing whale health. Frontiers in Marine Science, 4.

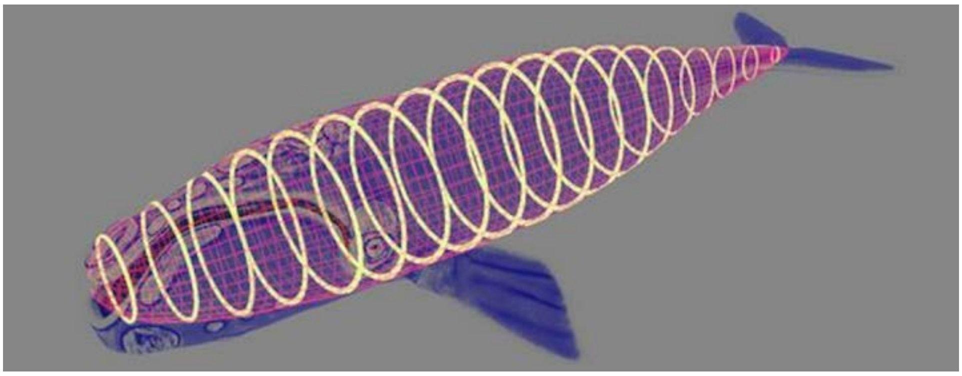
www.vanessapirotta.com

Whale lung sampling in action. Using drones to collect lung microbiota for a remote assessment of whale health off Sydney, Australia. © Vanessa Pirotta



Example aerial photographs of the dorsal surface of a southern right whale, used to measure body length and width (W) at 5 % increaments along the body axis from 5 % to 85 % body length from the rostrum (white arrows).

Lateral side of the same whale, used to extract body height (dorso-ventral distance) along the same measurement sites. The white solid lines indicate the location of the predicted girths (at 25,50 and 72 % BL from the rostrum) along the body axis (dotted white line).



A 3D model of the same whale, used to estimate body volume. The cross-sectional ellipses illustrate the variation in height-width ratio across the body of the whale.

Figure 7: Using drones to estimating body characteristics of cetaceans – from Christiansen et al. 2019.

3.6 Human-drone-wildlife nexus

Drone 'interference' has long been the concern of ecologists, because drones create visual and noise disturbance, and they occupy the same airspace as birds. Thankfully, there are a great many papers evaluating the ethical implications of drone operations near wildlife, or in 'wild' spaces. Lyons et al. (2018a) studied bird behavioral changes towards drones during the breeding season, as well as interactions with raptors, and effects on nesting birds in large colonies. They report that in more than 70 hours of flying they encountered no 'incidents' with birds, despite some aggressive behaviour from solitary breeding individuals. Our own experience from hundreds of hours of drone flights is similar – often birds (particularly large raptors or corvids) will notice the drone and find it of interest. We have not experienced any bird attacks on our drones, both multirotor and fixed wing. Corroborating this, Vas et al. (2015) showed that across 204 approach flights with quadcopter drone, 80% allowed approaches to within 4 m distance with no measurable behavioural effect of approach speed and drone colour on birds, with a slightly stronger reaction to drones approaching vertically. They recommended launching drones >100 m from any target organisms and "adjusting the approach distance according to species" (Vas et al., 2015). Amongst non-birds, the physiological response of large mammals to drone stimuli has been tested. American black bears showed raised heart rates when exposed to drones, with a declining physiological response with repeated exposure (Ditmer et al., 2019). Pomeroy et al. (2015) studied grey and harbour seals in the UK with drones and showed 'variable' responses to UAS flights, which they explained as being related to the animals' prior exposure to disturbance. In fur seal surveys, which would normally have to be undertaken on foot, McIntosh et al. (2018) showed that "with appropriate testing and ethical consideration; for many situations, RPAS can perform surveys with increased frequency, higher data resolution [sic] and less disturbance" than *in situ* methods. For those seeking general guidance about best practice for using drones around non-humans, we point readers to the work of Hodgson and Koh (2016) who provide a simple set of points (we have distilled these in **Figure 8**) for guiding all drone surveys. We argue that these guidance points are pragmatic for all drone users regardless of the survey type or target species. Further to Hodgson and Koh's (2016) guidance points, Mulero-Pázmány et al. (2017), and Sandbrook (2015), provide excellent critical reviews covering disturbance and ethics of drone surveys that all conservation and scientific practitioners would do well to read in advance of any airborne operation.

3.7 Protected area management

Well-managed protected areas (PAs), including sustainable use PAs with local traditional communities within, can play a great role in forest conservation, providing protection for biodiversity and serving as a reservoir for future restoration efforts. However, poorly governed and under-resourced PAs are unlikely to withstand the growing pressures they face, and while protected areas must be expanded it is imperative that they are also better managed and monitored. Monitoring and protecting vast PAs and wildlife, with limited resources and small teams, is a huge challenge in many tropical forest-rich countries, but conservation technologies such as drones can play an important role in assisting front-line conservationist and complementing resources to manage and protect PAs (Ancin-Murguzur et al., 2020, López J & Mulero-Pázmány, 2019).

ADOPT THE PRECAUTIONARY PRINCIPLE IN LIEU OF EVIDENCE.

- Extra care should be taken if endangered species or sensitive habitats are involved.
- The range of animals and environments evaluated for drone sensitivity is limited – remember that your target organism's response may be unexpected. Seek expert advice if unsure.

UTILISE THE INSTITUTIONAL ANIMAL ETHICS PROCESS TO PROVIDE OVERSIGHT TO UAV-DERIVED ANIMAL OBSERVATIONS AND EXPERIMENTS.

- Ensure all drone methodologies are in accordance with approved institutional ethics permits.

ADHERE TO RELEVANT CIVIL AVIATION RULES AND ADOPT EQUIPMENT MAINTENANCE AND OPERATOR TRAINING SCHEDULES.

- Note local restrictions and national laws.
- Where rules are not clear, exercise extra caution.
- Regularly service drone equipment and keep maintenance/flight logs.
- Seek approval for flight from indigenous or local communities where appropriate.

SELECT APPROPRIATE UAV AND SENSOR EQUIPMENT.

- Choose the right drone to keep noise and visual stimulus to a minimum for both target and non-target organisms, considering motion type, shape, size and colour.
- Consider modifying drones if necessary to reduce noise or disturbance.
- Choose a sensor that enables sufficient data capture from a safe distance.

EXERCISE MINIMUM WILDLIFE DISTURBANCE FLIGHT PRACTICES.

- Locate site launch and recovery sites in advance and away from animals (out of sight if possible)
- Keep your distance from animals at all times during flight.
- Avoid threatening approach trajectories and sporadic flight movements.
- Develop protocols that minimise disturbance to your target species and others living around them.

CEASE UAV OPERATIONS IF THEY ARE EXCESSIVELY DISRUPTIVE.

- Monitor non-human and human behaviour during the drone flight.
- Cease drone operations if the response of subjects is adverse.

DETAILED, ACCURATE REPORTING OF METHODS AND RESULTS IN PUBLICATIONS.

- Ensure that you share your methodologies and experiences with others by undertaking reproducible, traceable research. Good practice will guide further good practice by others.

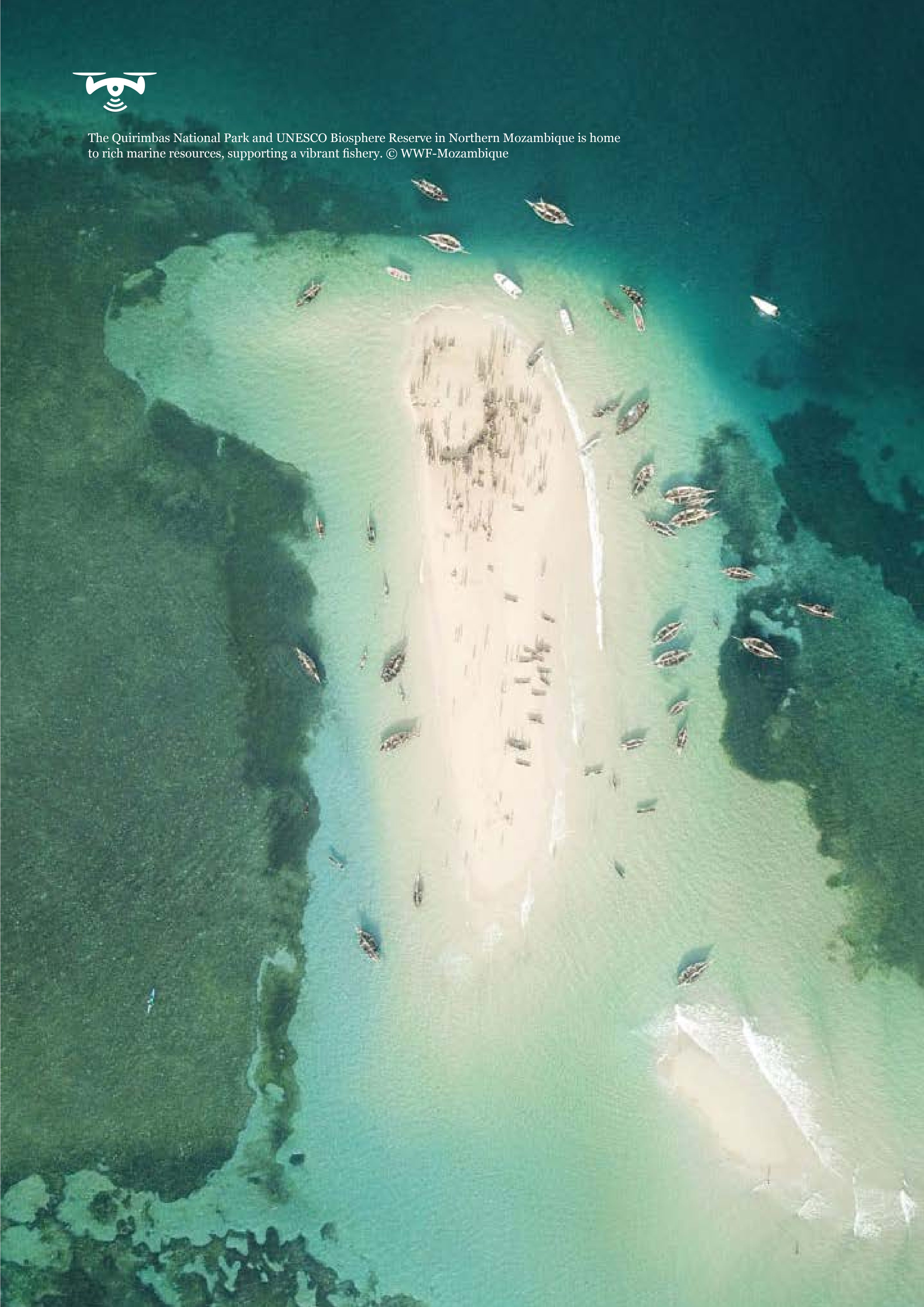
Figure 8: Seven points of good practice for drone operations – adapted from Hodgson and Koh (2016).

On top of being used for wildlife and vegetation studies, drones can be a great asset to assist park managers and local communities to monitor and protect their areas. In the context of PA management, drones have been used to assist a multitude of tasks such as anti-poaching patrolling (Hambrecht et al., 2019); forest fire detection and fighting (Ferreira et al., 2019, Merino et al., 2012); to document illegal logging and mining (Koh & Wich, 2012); to support search and rescue (Burke et al, 2019, Goodrich et al., 2008); public-use (Ancin-Murguzur et al., 2020, Sabella et al., 2017); mapping (Paneque-Gálvez, 2014, 2017, d'Oliveira et al., 2020), among other uses.

Nonetheless, the use of drones for PA management is restricted by many factors, such as cost and technological constraints, as well as practicality and ease of use. Often most commercial drones have an insufficient range and flying time to cover PA's vast areas, but technology has evolved rapidly, and localized use of drones has been promising. Legal and ethical implications of using drones for PA management also need to be carefully taken into account as, many countries have restrictions for flying drones beyond the visual line of sight or above a certain altitude, or there might be cultural, religious or political sensitivities with regards to traditional communities.

Despite the challenges, drones can increase the detail and efficiency of PA monitoring efforts, be a great tool to assist management, and help to monitor conservation impacts and threats. Furthermore, the low cost and time economy of applying drones for tasks such as mapping or forest inventory, as opposed to traditional fieldwork, can increase the detail and efficiency of data gathering and assessment, more comprehensively, on a larger spatial scale, appropriate temporal interval, and at a finer resolution. Drones can also be used paired with satellite images, which can previously detect early signs of disturbance, in areas where the drones can be rapidly deployed for further investigations and documentation.

Figure 9: Training Indigenous groups in the Amazon forest to monitor forest fires and deforestation with the help of drones. © Marizilda Cruppe/WWF-UK

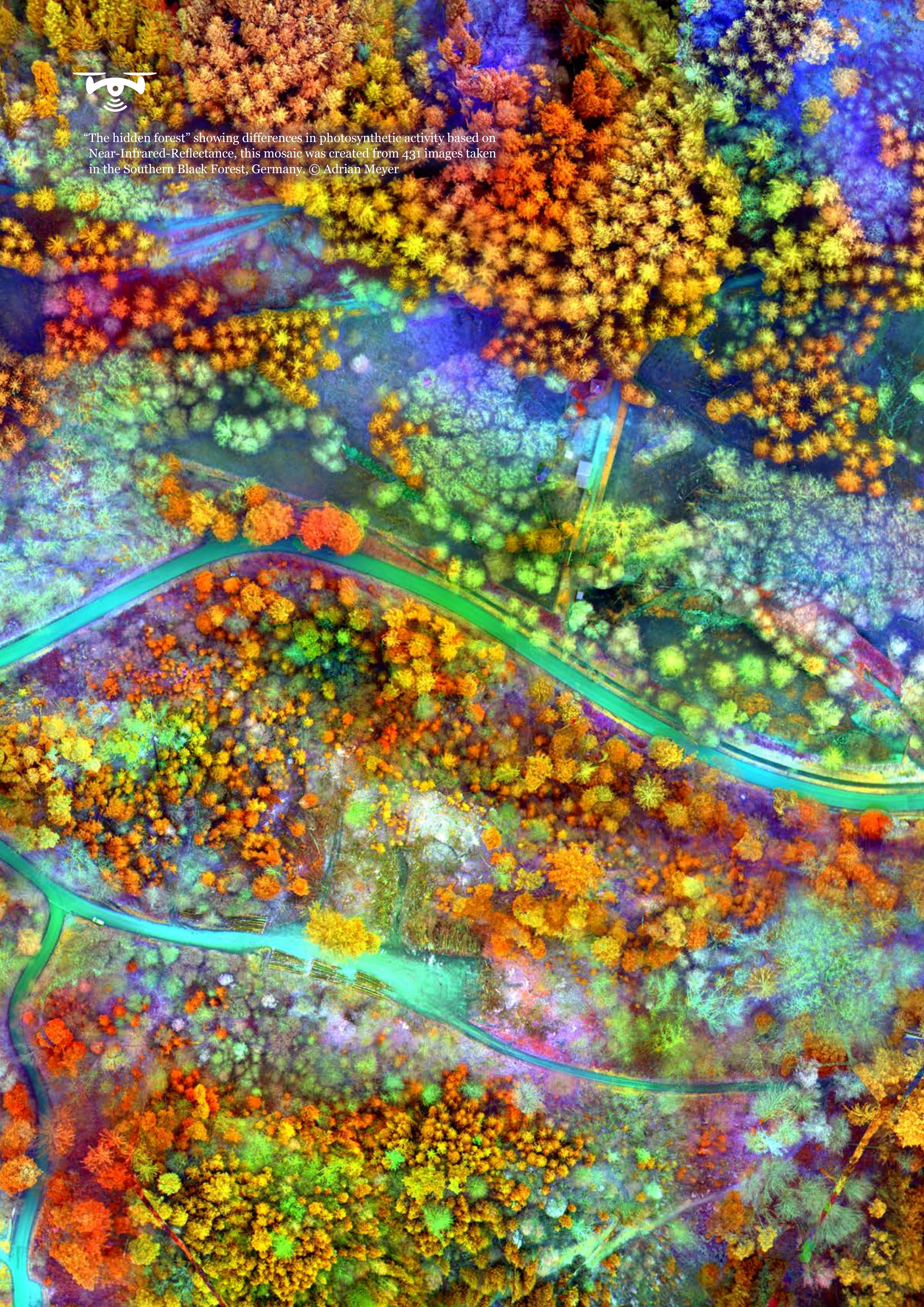


The Quirimbas National Park and UNESCO Biosphere Reserve in Northern Mozambique is home to rich marine resources, supporting a vibrant fishery. © WWF-Mozambique

4 EXECUTING A DRONE SURVEY IN 10 CLEAR STEPS

Here we present a typical workflow for successful execution of a drone-based landscape survey and the relevant chapter of this report to provide more information.

STEP	CONSIDERATIONS	CHAPTER
1. Form research question/select study site	Are drones the optimal tool for this task? Do you have access to equipment and relevant expertise? Are there any legislative hurdles or considerations, are permits required?	3, 5, 6 & 7
2. Equipment selection and preparation	Which type of drone is best suited to the data collection? Which sensor will capture data at desired scale/ wavelengths?	5 & 6
3. Test operation of equipment and sensor capabilities	Did you test the equipment in a 'safe' testing environment? Does the technology perform as expected? Does the sensor collect data suitable for your application?	5, 6, 7, 8 & 10
4. Study site assessment	Is a license or permit required to fly? How accessible is the site? Is there a safe spot for take-off and landing and do you have landowner permission to access this area? What hazards are present at the site? Can they be seen using satellite imagery or only in person? (e.g. telegraph cables). Are there any airspace restrictions?	3 & 7
5. Flight planning	What is the footprint of your sensor? Do you require redundancy in the data collected (e.g. double the number of photos)? Do you require redundancy in hardware? Check weather forecasts – implications for safety and data quality.	3, 6, 7 & 10
6. Survey Flights	Do you have the required personnel to operate safely? What are your emergency plans should something go wrong?	7 & 10
7. Backup data	Data should be backed up in the field if possible, or at least removed from the drone/sensor after each flight (if multiple flights are undertaken). Data should be backed up when out of the field (i.e. onto the cloud or external hard drives).	8
8. Clean data and pre-process if necessary	How are you going to organise and store the data for processing? Methods and workflow for removing unwanted data to streamline processing	8
9. Process data	Would a test run with a data subset help identify issues in processing? Do you have enough storage for the processed data? Do you have the necessary software and hardware?	8
10. Disseminate information	Processing software such as photogrammetry can produce a lot of information. Distil what information is critical to your project.	8



“The hidden forest” showing differences in photosynthetic activity based on Near-Infrared-Reflectance, this mosaic was created from 431 images taken in the Southern Black Forest, Germany. © Adrian Meyer

5 DRONE ANATOMY

Web search an image with the keyword “drone”, and you will likely be presented with pictures of commercial multi-rotor drones **(Figure 10)**. These have become synonymous.with the description and definition of a drone and probably justifiably so. Yet, there is an entire taxonomy of drones across the spectrum from military to civilian, research to recreation. Wallace-Wells (2014) writes, if you were developing “a taxonomy to describe all machines, these drones would not belong to the same species. They would probably not belong to the same phylum.” Drone technology has diversified so quickly, with over 1,500 different kinds of drones being manufactured, with so many applications, resulting in “a whole flying-robot ecology so vast that to call every one by the same name can seem absurd.” Multi-rotor drones have certainly inspired an entire consumer market, spawning new opportunities in science, commerce and play.

Figure 10: The consumer drone market is largely comprised of multi-rotor drones. © University of Exeter Drone Lab

As with all things, and despite the versatility and dominance of the multi-rotor within the drone world, there are flaws and limitations that may not make it the most suitable tool for a conservationist to capture the required data. An understanding of the typical abilities and limitations of each type of platform can help users make an informed decision in choosing the correct tool for the job, as part of any overall mission plan. Limited funds, difficult terrain, remote locations and inexperience are all problems that can be anticipated and mitigated (Duffy et al., 2017), whether fully or in part, with a small amount of drone anatomy knowledge going a long way in helping to secure the capture of the required data.

A fundamental reason to have a deeper understanding of the anatomy of drones, is one of safety. This is not just for the pilot, wider team or population at large, but also for the environment in which the operator(s) are working in. Without a working knowledge of how your drone functions, and therefore its limitations, accidents related to misuse can lead to injury and property damage, animal disturbance (adverse physical responses, stress events; (Ditmer et al., 2015, Ditmer et al., 2019, Hodgson and Koh, 2016, Mulero-Pázmány et al., 2017)), plastic pollution, noxious gases and even fires, all of which, depending on the local environment, could be potentially catastrophic.

There are a myriad of forum posts and other sources of information that discuss and debate the qualities and specifications of drone components, and the physics of flight is complex at best, especially for those not versed in mathematics, physics or engineering. The aim of this chapter is to synthesise this knowledge and introduce the reader to the various types of aircraft platform available for use. In this chapter we provide an insight into what can be expected from each type of platform with regards to its flying capabilities and limits, along with a dissection of the major components that come together to form a drone, for those with a non-technical background. We include essential elements of safety and law that are vital to successful operation and deployment.

5.1 Aircraft types

As described by DeBell et al. (2015), there are four main types of drone; fixed wing, multi-rotor, tethered (line flown) kite or balloon and lastly, blimp (the latter can be powered or tethered). More traditional helicopter-like aircraft (single large rotor, smaller stabilising tail rotor) can be used as drone platforms, but tend to be more of a niche product, with drone specific airframes (e.g. allowing accommodation for extra electronics required such as the autopilot) not being widely available. Traditional helicopters have their merits for surveying – they tend to be more stable and efficient than multi-rotors – but their mechanical complexity generally precludes them as a low-cost drone option, and hence we do not add further discussion of those platforms here. Whilst there has also been recent development with blimp drones, that focus has shifted towards either indoor use or systems that are beyond the budgets discussed in **Chapter 3** and as such the focus in this chapter will be placed on the other three major types of drone which are widely used within the environmental sciences.

The more complex a system is, the greater the chance of increased costs, reduction in long-term stability, and potential decrease in the reliability and robustness of the system itself. For a conservationist wanting to collect remotely sensed data, the most straightforward option is the one most likely to succeed, and this may mean that choosing a simple kite or balloon could in fact be the best option (Duffy and Anderson, 2016), especially when factors such as cost and transportation of equipment, remoteness, wind speeds, terrain and above sea level altitude are taken into consideration. It is also why simpler, low cost options may be favourable to expensive proprietary systems, which have replacement parts or entire components readily available, and in some instances flight controls that have been simplified with limited functionality for the novice pilot.

5.1.1 Tethered balloons and kites

The simplicity of these platforms is their strength. Tethered balloons and kites are mostly self-explanatory. Drone kites for aerial photography or Kite Aerial Photography (KAP) are fixed single line so they are easy to fly, and stable. They are usually constructed out of a lightweight and robust ripstop nylon material to create a simple airfoil. Tethered balloons can be constructed out of a number of different materials, but generally look exactly like the latex globes we are all familiar with. Balloons and kites don't require power supplies, meaning they can operate more consistently in remote locations, or in areas with limited access to power supplies or high capacity renewables. It is only the weather conditions that present limiting factors. The main difference between balloons and kites is their respective capabilities in wind. Whereas a kite needs wind to fly, balloons don't function well in windy conditions. Both systems are more suited to applications based on aerial photography, as opposed to data collection requiring video or motion sensitive devices (i.e. multispectral and hyperspectral sensors). Where location based data are required, utilising GPS enabled cameras or smartphones (Anderson et al., 2016) allows a balloon or kite user to collect geo-positioned aerial photos. Neither kites nor balloons are designed to carry heavy payloads, with typical balloons having a payload capacity of 0.2–0.3 kg, whereas kites can carry upwards of 1 kg. Despite their inherent limitations, kites and balloons can be effectively used in applications where other drones may not be viable due to wind conditions or terrain. Whilst kites and balloons can sometimes help in challenging environments, this can also potentially present personal hazards. As kites and balloons are tethered, they must be manually manoeuvred over the area of interest. Areas with difficult terrain or obstacles may not be conducive, or require extensive physical effort, to effectively manoeuvre the equipment during surveys.

Balloons and Kites can remain airborne as long as there is wind, affording the opportunity to cover large areas, but cannot be pre-programmed for surveys like drones.

Since neither kites nor balloons require power to remain aloft, the area they are able to survey is principally determined by the physical condition of the operator, and the ease of traverse of the terrain. However, as balloons are able to remain aloft for 2–4 days and kites are able to remain airborne as long as there is a suitable wind, both possess the potential to cover large areas. Static survey heights or exact repeated surveys are also difficult as, unlike with fixed wing or multi-rotors with autopilots, a defined flying height or flight path cannot be specified or programmed and is subject to wind conditions. As such, if repeat surveys with identical surveying methods are required, un-powered systems may not provide the requisite level of pilot control. For analyses involving photogrammetry derived products, such limitations can now be overcome with complex monte-carlo based modelling methods which allow the resultant survey-to-survey uncertainties to be accounted for (for details see Duffy et al., 2018a, James et al., 2017b).

5.1.2 Fixed wing

Fixed wing drones (e.g. **Figures 11, Figure 12**), are most recognisable by their visual similarity to piloted aircraft. They have a long body (fuselage), typically cylindrical or nearly cylindrical in shape, with rigid, immobile, wings extending from the fuselage at outward angles. Modern fixed-wing drones are not strictly limited to this shape alone, with a broad variety of forms and functions. These drones owe much of their development to the traditional radio control enthusiast community. Early research employed model aircraft equipped with 35 mm film cameras, but at the time wider adoption was limited by the high level of expertise required to build and fly these machines. As discussed in **Chapter 1**, and in large part due to the burgeoning First Person View (FPV) community, there are now numerous airframe designs available that offer excellent, low-cost, versatile platforms for collecting proximal remotely sensed data. Numerous examples of fixed-wing drones can be found at ConservationDrones.org along with detailed guides for purchasing

Numerous examples of fixed-wing drone models and detailed guides for purchasing or building them from scratch are available at ConservationDrones.org

and building them from scratch (**Figures 11, Figure 15**; Wich, Serge & Koh, Lian Pin, 2012). Aside from build-your-own options, there are a variety of more expensive, ready-to-fly fixed wing survey drones, equipped with a variety of built-in sensors. These include the Ebee survey drone (**Figure 12**), which can be flown straight out of the box, but the cost of these often exceeds €10,000 and thus is only a viable option for those with access to large budgets.

One of the key considerations when using fixed-wing drones is the amount of space available for take-off and landing. For novice users, linear take-off and landing must be into the wind. Creating a suitable area for linear take-off and landing requires enough excess space to accommodate necessary adjustment due to changes in wind direction, without introducing hazards such as bushes, trees, vehicles, or buildings. To identify the amount of area required, a simple formula can be used where a typical landing approach for a fixed-wing drone is utilised (a glide slope with the recommended maximum novice pilot value of 10 %; **Figure 13**). Applying this calculation from a flying altitude at last waypoint of 50 m, then the length of glide slope (or distance required for landing) would be 500 m.

Wind direction for take-off and landing, the need for space and, in some instances, a launch system that typically uses something akin to a catapult or bungee, also make fixed wing launches slightly more complex with regards to the overall autonomy when compared to other drone systems. Vertical take-off and landing (VTOL) fixed wing drones are now commercially available, and being tested for use by delivery companies such as Amazon (**Figure 14**). These are commercially expensive platforms but they offer the advantages of more controlled multi-rotor-like take-off and landing capabilities with the efficiency and glide of fixed wing systems in flight. At the time of writing these platforms tend to be more expensive than standard fixed wing systems and they are not widely tested within conservation science, so we do not discuss these further. Perhaps in the future these will become more widely available at lower cost as the technology develops.

Figure 11: Custom-built fixed wing drone. X-UAV Skua frame with 3DR Pixhawk autopilot, uBlox M8N GNSS, Purple Power PO-3548-1100 Professional Brushless Motor, 10x6 wooden propeller, 60A t-motor ESC, FrSky digital metal servos and 10000mAh battery. ©University of Exeter DroneLab

Figure 12: Commercial fixed-wing eBee survey drone. © Tegan Sampson

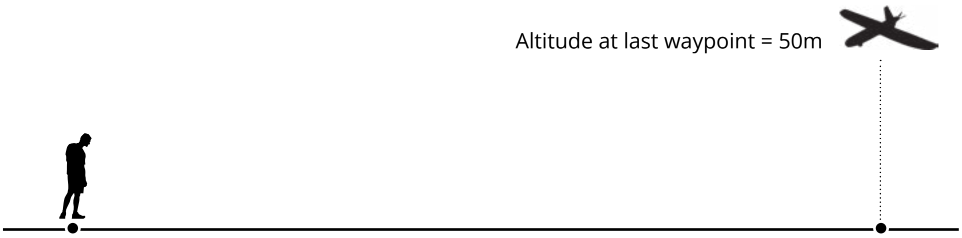


Figure 13: Calculating landing position for fixed wing drones.

Figure 14: Amazon Prototype Prime Air Drone. © Amazon

With regards to payload, most lightweight, fixed-wing drones can carry 0.5 kg off-the-shelf, but could be capable of carrying 1.5–2 kg if components are carefully selected or designed rather than relying on pre-made or almost ready to fly (RTF) systems. A flight time of at least 30 minutes should also be expected and up to an hour is easily achievable.

Typically a hobbyist-grade fixed-wing drone such as those used by the organisation "Conservation Drones" (**Figure 15**) is capable of covering from 10–100 ha in a single flight, when flying within the UK and EU-wide legal limits of 500 m line of sight and 120 m above ground level (AGL). Because the speeds at which fixed wings operate are generally much greater than that of other drone options, it is best to consider using these for larger area surveys. Consider that fixed wings also need to fly with more altitude to reduce any potential blur in data captured (for example, from a digital camera) due to the relative ground speeds. Fixed wings are manoeuvrable, but a change in direction needs to happen over a wider scale than that of a multi-rotor and flying at lower altitudes could potentially result in either unsafe turns or gaps in data.

Figure 15: A low-cost fixed wing system used by "Conservation Drones"

Wind is a major factor in any type of drone operation, and the type of airframe in a fixed-wing system is important to consider for successful operation in windier conditions. An aircraft with a dihedral wing (a wing that angles upward from the body towards the tip; **Figure 16**), can provide some inbuilt flight stability, exclusive of the autopilot. However, this design may be more susceptible to poor flight in higher wind conditions. The same can also be said of airframes that incorporate a large fuselage, since wind shear or gusts can act upon the body to render the aircraft unstable. Flying wing designs (e.g. see eBee design in **Figure 12**), which are popular in more expensive, proprietary drone systems, offer better performance in windy conditions due to their lower profiles, but tend to need to fly at higher speeds and may exhibit unstable behaviour when operated in manual mode. The level of manual control is worth consideration for inexperienced operators, and as per the discussion in Chapter 7, is an integral part of any safe operation.

One final consideration for fixed wing systems is the cost and fragility of the onboard sensors that are being used to collect data. In most instances, and certainly in the lower cost end of the drone market, fixed wing will offer more protection for the sensors in question. Many can be housed on top of a wing or within the fuselage for protection in the event of a propulsion failure, and there is the opportunity to bring a fixed wing down through a glide (as per a normal landing) or using a parachute deployment to slow the rate of fall. This greatly reduces the likelihood that fixed-wing sensors will experience the full force of a vertical fall from height. The QuestUAV 'data hawk' is a commercial fixed wing 'flying wing' style system that offers parachute landing capability for precisely this reason (**Figure 17**).

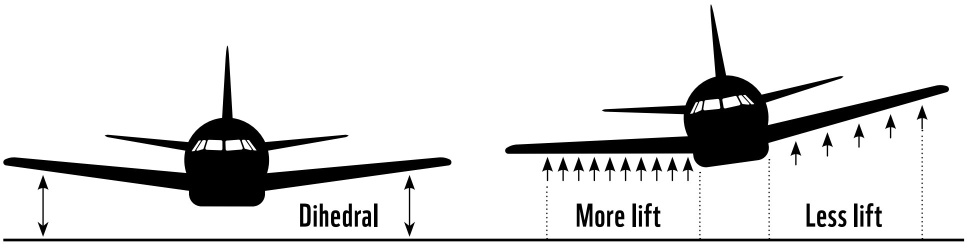


Figure 16: Depiction of wing dihedral - the upward angle of a wing in relation to its body/fuselage - is designed to have an impact on flight stability and impact on flight stability

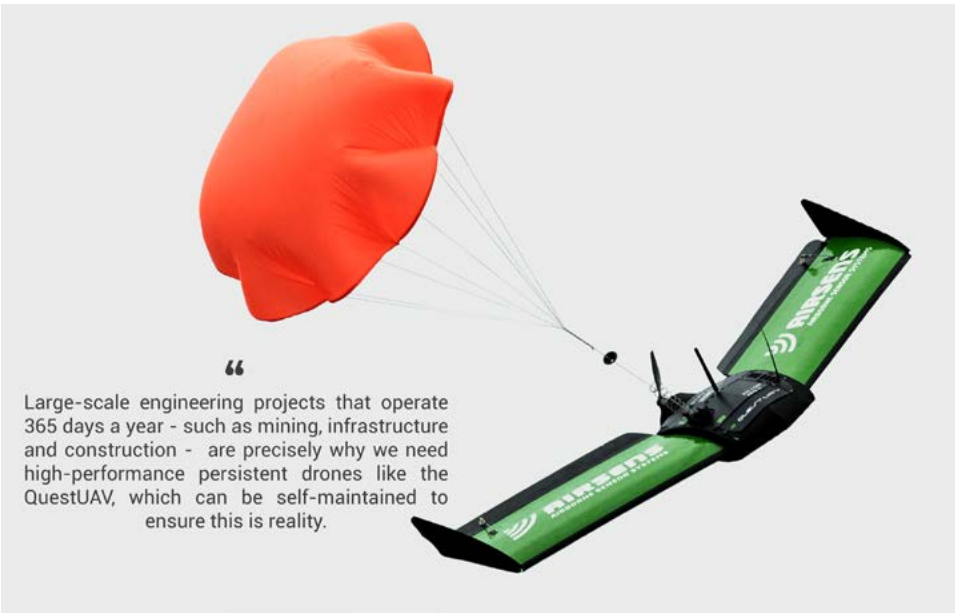


Figure 17: Parachute landing capability for a fixed wing drone © Quest UAV.

5.1.3 Multi-rotor drones

Multi-rotor drones come in all shapes and sizes, but are hallmarked by arms that protrude from a central body and house a motor and propeller on each (**Figure 18**). Arms are always even in number and range from four, six, or even eight on any given machine. If your objectives require capturing stabilised video, for wildlife monitoring or observation perhaps, then the multi-rotor is without doubt the best option available. Many commercial off-the-shelf systems now come complete with built-in gimbal mounted cameras, which are purposely designed for image stabilization and angle control. Within this market, the Chinese company, DJI have come to dominate the market by offering high quality products that are relatively affordable (from €700–€5,000 depending on capability) and simple to use. Even though the primary focus of DJI has been video, they have also become popular within the scientific community for their ease of flight, programming and the high quality of still image capture. Most of their systems now come ready equipped with auto take-off and landing, GPS failsafes, automatic geofencing and obstacle avoidance as standard. If you want to plan and collect fully autonomous flights using pre-programmed waypoints, DJI provide software for this (currently called 'ground station pro'). For other non-DJI systems, there are several options available such as droneDeploy, and Pix4D.

If your objective is to capture stabilised video, a multi-rotor is the best option

If you wish to attach third-party sensors to drones there are a range of options. A California-based company called MAPIR[2] offer high quality, low cost upgrades like post-market mounts for near-infrared cameras for DJI multi-rotor systems. Unfortunately, due to market forces, DJI's competitors who previously offered multi-rotors with more flexible and open-source features are not so widely available, as both 3D Robotics and Hobby-King have discontinued their open source Arducopter-based products. However, there are still pre-built options available from small manufacturers such as Drotek in France[3]. For the more adventurous, and because of their mechanical simplicity, it is also relatively simple to build your own multi-rotor easily within a €500–1,000 budget that will offer stable, fully automated, repeatable missions with the ability to carry custom payloads – **Figure 19** is one such self-built example, costing <€500 (without sensor).

You can also build your own multi-rotor within a 500–1,000€ budget that offers stable, repeatable missions with the ability to carry custom payloads.

Figure 18: Commercial drones: left is the 3DR Solo and right is the DJI Phantom 4. Both include gimballed cameras, weigh <2kg take-off weight and can fly for 15–25 minutes on a single battery (<1,500€). © University of Exeter DroneLab

2 https://www.mapir.camera/
3 https://drotek.com/

Figure 19: Modified Tarot 650 fram quadcopter with 3DR pixhawk autopilot, multistar motor and propellors, ublox M8N GNSS and 1000mAh battery.
© University of Exeter DroneLab

There are overall fewer factors for a pilot to consider in conducting a safe and successful mission with a multi-rotor drone. One of the key advantages of the multi-rotor is the VTOL capability. It is not uncommon for a pilot to find themselves in an environment that does not provide the necessary space for take-off and landing with a fixed-wing drone (Duffy et al., 2017). Multi-rotors are also not affected by wind direction in the same way that fixed wing systems can be, and therefore provide more flexible use cases. The design of the multi-rotor also means that manoeuvrability is very precise. Relative to their fixed-wing counterparts, multi-rotor systems are capable of changing direction in small areas. The ease with which multi-rotors can be manoeuvred also results in fully automatic missions being much more straightforward to execute, and in some cases, once the pre-programmed mission has been uploaded to the multi-rotor, pre-checks completed and the motors started, only a single tap of a button or flick of the switch can allow the machine to complete its task with virtually no pilot input.

As with fixed-wing drones, the typical payload capacity of a lightweight, off-the-shelf multi-rotor tends to be up to 0.5 kg. However, custom multi-rotors can be built with relative ease, increasing payload capacity to 2.5–3 kg if you carefully select components rather than relying on pre-made systems. A typical flight time of 15–25 minutes can be expected although multi-rotor flight time is affected much more by factors such as payload and wind speed by comparison to fixed wing, and an operator could quite easily find that only 10-15 minutes is available for the safe, conservative completion of a mission. It may be necessary to experiment with airspeeds to establish a “sweet spot” for maximising distance, while maintaining data quality.

Expect to achieve 20–30 ha of coverage during one multi-rotor flight at the typical legal limit of 120 m AGL.

Pilots should expect to achieve 20–30 ha of coverage when flying at the typical legal limit of 120 m AGL with a low-cost, lightweight multi-rotor. However, the precision of multi-rotors also means that, as is the case with tethered kites and balloons, the altitude that they can fly at to collect data is much more flexible than that of fixed wings, which must fly at a greater altitude in order to reduce blur. Because of relative ground speed and the blur it causes to image data, the lower an aircraft flies, the slower it must also fly. Which means fewer ha may be covered within a single mission due to the slower speeds and lower altitude. This is particularly the case when collecting precision data with required overlap, for photogrammetry or 3-dimensional mapping.

Flight control software is dependent on the drone and piloting device (laptop, phone or tablet).

For a list of common flight planning and control software, see table 5, chapter 8.

5.2 Flight control

There are two main components for drone flight control: the autopilot and the Global Navigation Satellite System (GNSS). The autopilot is a combination of both hardware and firmware that functions as the machine brain, controlling a range of functions, from simple stabilisation to fully automated missions, including the triggering of the sensor payload. The autopilot communicates with associated software, enabling remote control of the drone, typically via a laptop or tablet. The GNSS, whilst not entirely necessary for flight, provides the location information to the autopilot, thereby facilitating autonomy, and can associate sensor-collected data (e.g. aerial imagery) with temporal and spatial coordinates, as well as providing real-time tracking of the drone for the pilot.

Physical hardware options (autopilots) at the low-cost end of the self-build drone market are varied, but the firmware and associated software that goes with them is limited. DJI does offer a stand-alone autopilot, however the firmware is proprietary and locked, preventing a user from amending certain programs and is far less customizable than those of other manufacturers. Furthermore, DJI's autopilot is specifically for multi-rotors whereas autopilots that run the PX4/Ardupilot firmware allow for conversion of any type of radio-controlled vehicle. The PX4/Ardupilot can also communicate with a wider variety of sensors and associated software allowing a greater level of customization, which makes them especially popular in the self-build community. There are other types of flight controllers which provide some basic features and allow for an on-screen display (OSD) but these are squarely aimed at the FPV community and aren't as much use for survey purposes.

Figure 20: Assembling low cost multi-rotor drones using a Pixhawk autopilot in the Brazilian Cerrado. © WWF-Brazil

Because drones are capable of flying beyond radio control and/or falling out of the sky, it's important to have an autopilot that can provide assistance in the form of failsafes. Some common failsafes include: providing a return to launch/home function (RTL/RTH) at the press of a button, creating a predefined geofence defined by specific height or distance, which serves as a virtual boundary for a particular drone flight, ensuring that it doesn't stray too far or too high, or low battery warnings which trigger specific events such as RTL/RTH or an immediate landing. Other events that can trigger failsafes include loss of radio control and loss of GNSS.

For remote sensing applications, an important functionality is the triggering of a sensor at predefined times or locations, giving the pilot the ability to control data collection in time and space. Autopilots such as the Pixhawk, and variations upon this flight controller, allow for this. There are also autopilots utilising a Raspberry Pi (RPi) via an arduino hat, such as that made by Emlid[4]. These utilise PX4/Ardupilot firmware, and allow for the use of the typical array of sensors. These also allow the utilisation of the RPi as an onboard Linux computer to control sensors, collect, and process data in ways that aren't possible from any other autopilot in this price range.

5.3 Batteries

From smartphones and laptops, to hybrid or fully electric cars and trucks, and all the way up to home and industrial energy storage, lithium-ion (Li-ion) and more recently, lithium-polymer (Li-Po or LiPo) batteries have been key to their successes and evolution, and the same is true of drones. The power to weight ratio offered by new generation batteries have made electronics more mobile, but also, because of this same energy density and the chemical compounds involved, these need to be treated with caution and recycled responsibly. Although LiPo batteries are generally safe (Wang et al., 2012), mishandling, misuse or accidents with lithium batteries can have unintended consequences that aren't easy to deal with, such as unexpected combustion that cannot be extinguished with water. There are a number of precautionary measures that can be taken to lessen the risk of serious accidents allowing an operator to safely utilise lithium batteries, which we discuss in the following sections.

5.3.1 Safety of LiPos

The most commonly used battery type within drones is the Lithium Polymer battery (LiPo). Some LiPo batteries, such as those manufactured by DJI or 3DR, are considered to be "smart", whereby the charge and discharge rates, and current status are monitored by the battery itself so the battery health can be relayed back to the drone and pilot. Some batteries, including the Parrot Anafi, discharge automatically after a period of inactivity. The majority of LiPo batteries however, do not have these features, but the basic principles of LiPo batteries apply to all.

Voltage (V) is an important indicator to be aware of and can be used to trigger a failsafe automated drone response. Each cell in a LiPo battery is rated at 3.7 V (its nominal voltage) and a given storage capacity rated in amp-hours (Ah), or more frequently with drone batteries, milliamp-hours (mAh – note, there are a 1000 mAh in 1 Ah). The amp-hours rating indicates the number of amps that can be drawn constantly to provide power for one hour. These individual cells are combined into packs, either in series or parallel (sometimes both) to produce desired power outputs. These combinations are labelled on the LiPO battery packs, with an 'S' representing the number of cells in 'series' or 'P'

4 https://emlid.com/

to indicate the number of packs in 'parallel', followed by the total nominal voltage. The other indicator of note on LiPo batteries are the 'C' ratings, whereby C is the multiplier of the mAh capacity in the LiPo to indicate the maximum number of amps available at a safe constant discharge. To recap with an example; a 3S1P 3,000 mAh 20 C battery = a 11.1 V single pack 3,000 mAh battery, that can provide 3A (1C) of power for one hour, or can provide a maximum constant safe discharge of 60 A (20C).

Thermal runaway, or spontaneous heating is the major safety concern with lithium batteries and can be caused by a number of different catalysts, including overcharge/discharge, physical damage, overheating or short circuits (Wang et al., 2012). Lithium batteries that undergo thermal runaway can give off toxic gases, cause fires and, in some cases, explode. Lithium battery fires are also difficult to extinguish at source due to the potential for the battery to generate its own oxygen and hydrogen.

When powering drone launches, all LiPo batteries will experience some form of 'battery sag' which will typically display as a voltage drop of approximately 0.2–0.3 V per cell (S). For safe flying, it is recommended to only fly until you have a minimum charge of 3.5 V per cell, at which point the drone should have already, or be very close to having, landed. Under load during flight, and even more so with multi-rotors, once a LiPo has dropped to 3.4 V per cell, voltage undergoes a relatively rapid exponential drop in power that can very quickly lead to a crash or thermal runaway. In smart LiPo battery systems the drone will often have failsafes set up, so that once the battery reaches a low threshold, the controller will beep to notify the pilot of the need to bring the drone to land (25% remaining energy) or will automatically return to home and land (10% remaining energy).

Always check your LiPo battery for signs of damage before every flight to prevent dangerous accidents. Indications a battery is no longer flight safe include puffing or distortion.

While LiPo batteries can quickly become unsafe if improperly cared for, being acutely aware of any early warning signs of damage or overuse can drastically reduce potential accidents. Knowing when a battery should be deemed unusable is paramount to their safe function. An early warning sign of a LiPo becoming unsafe is when it becomes 'puffy' or distorted from its original shape. Internally, the battery has begun to produce gas, expanding the container and should be retired from use. Any visible signs of damage to the exterior of the battery should also be considered as having rendered the battery unusable and, in the event of an accident or crash with a drone, even without puffing or visible damage, a LiPo battery should be treated as unusable until it has been thoroughly checked for signs of deterioration or visible puffing.

There are a myriad of 'proper disposal' techniques discussed in forums and blog posts on the internet, should a battery be deemed unusable. The only advice that can be given here is that of following the manufacturer's guidelines and, where possible, finding an appropriate, local e-waste or hazardous waste disposal facility. If working in a location where this is not viable, research the disposal method prior to undertaking fieldwork. Decide on an appropriate solution should the disposal need arise and prepare for the worst. Make sure you are fully aware of the potential hazards involved with any given method and have adequate mitigation protocols in place. Disposal methods are an individual choice and responsibility falls upon every drone user. Some municipal recycling centres will accept LiPO batteries for recycling.

5.3.2 Charge, discharge and battery life

If not using a manufacturer supplied charger, it is important to use one that has a specific function for LiPo batteries, including a dedicated 'balancing' port that can handle the equivalent number of cells as your LiPo (S value). Typical charging rates should not exceed 1C of the battery and so using our example from the previous section, that battery should be charged at a maximum of 3 A and to a maximum of 12.6 V. Most LiPo battery chargers will automatically control the maximum voltage of a given battery based on the S value input into the charger, but the input amperage can normally be adjusted, and it is possible to charge at a rate lower than 1C which may help to extend the life of the battery. In addition to the general advice above, always read the LiPo manufacturer's instructions and guidance as that should always supersede what is written here or elsewhere. Improper charging can lead to charge/discharge internally between cells (balance), or over/under charge of the entire pack, and both can subsequently lead to thermal runaway, and potentially, a drone crash.

Always read the LiPo manufacturer's instructions and guidance for the proper use, and disposal of batteries.

Whilst LiPo batteries are considered to have a relatively long lifespan (Scrosati and Garche, 2010), typically lasting 300 charge cycles, this lifespan is based upon usage where the draw on the battery is low relative to its capacity (≤ 1C). In drone operation, this is rarely achievable, and batteries undergo stress that decreases their lifespan, with some lasting as few as 20 or 30 flights. Because LiPos possess a higher comparative C rating to the drone's amp draw, they tend to be less stressed and hence exhibit longer lifespans. For example, if your drone typically draws 15 A during normal flight, and your two 3000 mAh batteries are rated at 10 C and 20 C respectively, then it is likely that your 20 C battery will have a longer lifespan. For batteries that aren't 'smart', it is worth considering keeping a battery logbook, recording each charge/discharge/flight, logging amp values and flight times. As the fully charged amp rate starts to diminish, or the flight times start to shorten, then it is likely that the battery is becoming worn and replacement should be considered.

For batteries that aren't 'smart' i.e do not assess their charge and discharge, it is worth considering keeping a battery logbook, recording each charge/discharge and log flight amp values and flight times.

When the fully charged amp rate starts to diminish, or flight times shorten, consider replacing the battery.

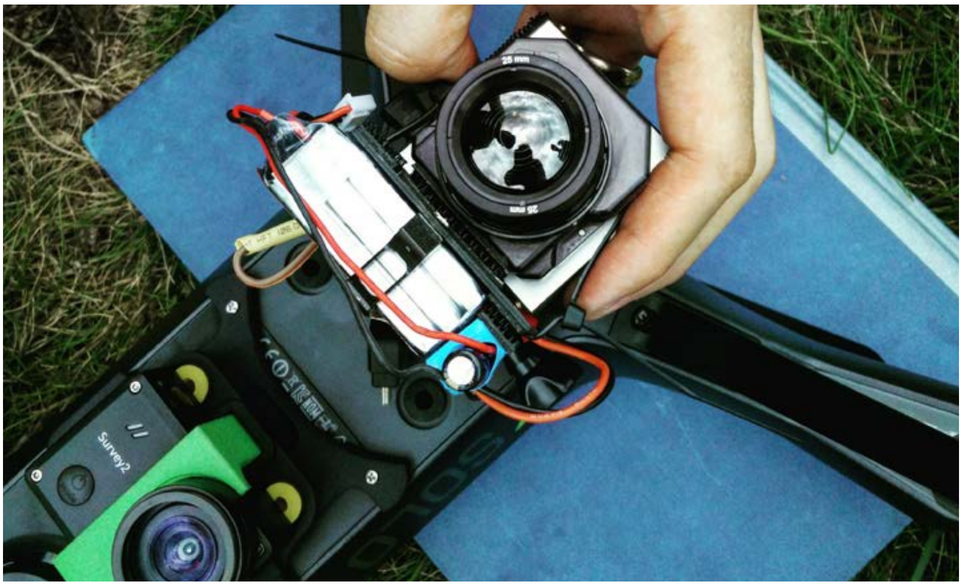


Figure 21: A 3DR Solo drone is equipped with several cameras and extra batteries, which are checked before every flight. © University of Exeter DroneLab

5.3.3 Travelling with LiPo batteries

If you are travelling by airplane with your drone it is vital that you check the rules about carrying drone batteries with your airline, prior to travel.

There are strong restrictions preventing check-in or carry-on for Lithium-based batteries.

Travelling with LiPo batteries has become more complicated in recent years with most airlines tightening restrictions on the transport of these batteries. These restrictions don't just apply to airline passengers either, many postal and delivery services are now limiting the size of batteries they will transport or ship. As a result, it may be necessary to use more specialist certified services for transport of hazardous materials, although these can be relatively costly. Airlines now specify the total energy density a passenger is allowed to carry, with this normally being described in watt-hour (Wh). Wh can be calculated by multiplying the number of volts in the battery by the Ah of the battery (if working in mAh divide by 1000). These guidelines are provided by most national aviation authorities but always check with your airline for exact Wh and individual item limits before travel.

It is important to remember that when travelling with LiPo batteries, they should always be charged/discharged to the nominal voltage level, stored in LiPo safe bags at all times and where applicable, terminal ends should be protected with electrically insulated tape or covers. We recommend carrying an official letter detailing the contents of your LiPO bags with you whilst travelling to defuse confrontations at security.

Figure 22: This custom-built drone has 6 rotors to carry an SLR camera for professional photography. © Chris Hunkeler/Creative Commons

5.3.4 Summary

- Always transport and store batteries in a LiPo safe bag or fire-safe locker.
- Keep batteries cool and never leave in direct sunlight. Room temperature is normally sufficient but in hotter climates, a cooler, shaded space may be required.
- LiPo cells have an absolute minimum discharge level of 3 V per cell and never should never be charged beyond 4.2 V per cell.
- Check battery voltages before charging/discharging to ensure within normal limits.
- If possible, charge/discharge batteries within a LiPo safe bag but ensure that the battery is visible to check for excessive heat build-up, puffing or smoke.
- Charge away from any flammable materials or liquids, and where possible, on top of non-combustible surfaces such as concrete or marble.
- Do not leave charging/discharging batteries unattended.
- Keep a class D fire extinguisher at hand. In remote locations or where this is not feasible, a bucket of sand. Never try to extinguish with water.
- Do not leave batteries fully charged for extended periods of time. If a battery has been charged for use but is not utilised within a few days, it is best to discharge to storage capacity.
- Allow batteries to cool before charging (post flight) or after charging (pre-flight).
- Another useful option for transportation, charge/discharge and storage (alongside or in conjunction with LiPo safe bags) is an ex-military ammunition box. It is essential to drill holes into the ammunition box though so as to allow any gas build up to dissipate in the unlikely event of thermal runaway.
- Finally, NEVER post, dispatch or carry a damaged, puffy, or a suspected defective LiPo on an airplane (and be cautious if transporting by any other means).
- For transportation on commercial airliners, check the service providers regulations with regards to LiPo batteries. The Federal Aviation Authority in the US give a good example of the general rules[5] but these will vary from country to country and airline to airline.

5 https://www.faa.gov/about/office_org/headquarters_offices/ash/ash_programs/hazmat/passenger_info/media/Airline_passengers_and_batteries.pdf

5.4 Motors, Propellers and Electronic Speed Controllers

Too much payload leading to an underpowered aircraft can quickly lead to an accident. Understanding of electronic speed controllers (ESCs), brushless motors and propellers and their relationship to the basic principles of drone flight can help minimize the chance of accidents prior to take-off.

At their most basic, ESCs, motors and propellers use the chemical energy of a LiPo battery as electricity, and then convert it into mechanical energy and finally thrust. The ESC is responsible for regulating the power supplied to the motor(s). The motor(s) in turn, provide(s) a combination of speed and torque to the propeller(s), and these then generate the thrust required for flight.

In order to calculate required thrust, you must consider the type of drone you are using, as the calculations vary for each machine. In comparison to fixed-wing drones, calculating the thrust required for multi-rotors to fly is fairly straightforward: a sum greater than 100% of the aircraft's mass is needed for flight, meaning that whatever an aircraft weighs, you'll need motors and propellers capable of generating thrust greater than that of the machine's weight. A general principal for any multi-rotor is that it will ideally create twice the mass in thrust at 100% throttle. For example, a multi-rotor that weighs 2 kg will generate 4 kg of thrust at full throttle. Representing an overall thrust to weight ratio of 2:1. It is essentially aviation by brute force.

For fixed-wing drones, the amount of thrust required to achieve flight is based upon watts (W) per unit of mass (e.g. kg) and can vary depending on the airframe and type of flying style required. Factors such as lift generated from the wings, and the drag of airframe play an important role. It's also important to be aware that the thrust required to sustain flight will likely be lower than that required for take-off. Fixed-wing drones with an autopilot in control of the flight are incredibly stable and almost static in their flight patterns by comparison to the nuanced control of manual flying. However, they tend to be heavier than multi-rotors, and are likely to require a bungee/catapult or hand launch to take off. Hand launching requires a co-pilot to physically throw the drone into the air, whereas a bungee/catapult take-off is achieved by using a thick elastic cord to fire the drone forward. If not using an off-the-shelf drone, much of the more detailed information available for selecting the correct motor can be confusing. Airframe kits that come "ready-to-fly" (RTF), or "plug-and-play" (PNP) are considered "off-the-shelf" and can simplify the selection process. If it's an "almost ready-to-fly" (ARF), then follow the manufacturers guidelines but be aware of the additional weight of any extra electronics or sensors that need to be added.

5.4.1 Motors

While there are two distinct types of motors – brushed and brushless – brushed motors are an older technology that are now obsolete within the drone community, with brushless motors now the preferred and most commonly used. Brushless motors all follow a nomenclature system that denotes their name, size, and the revolution per minute per volt (Kv) rating that allows for quick selection based on a manufacturer's guidelines. The first 4 numbers are essentially two pairs of measurements in millimetres, the first pair is for the motor diameter, but can either be the full external diameter (outside edges of the rotor, the moving part of the motor) or the diameter of the internal stator (the fixed part of the motor). The second pair of numbers indicate the height of the motor, again either of the internal stator, or the external rotor. Next is the Kv rating (not the same as kV – kilovolts), which is the motor rpm (revolutions per minute) per volt applied, (i.e. its constant velocity). The Kv rating is also an indicator of the size of propeller a motor can spin. Higher Kv ratings will spin a smaller propeller, faster, a lower Kv rating will spin a larger propeller, slower. It is essentially a torque versus speed offset.

To select the right motor and propeller combination it is important to know a set of information about the motor. Manufacturers will also provide details on the minimum/maximum input voltage, maximum amps and with more recent changes for multi-rotors, specification sheets to advise on the various battery voltage, motor and propeller combinations and their subsequent power demands and outputs in amps (A), watts (W), and thrust in grams (g). This can be a significant help when trying to select the right motor and propeller combinations, but most motors specifically designed for fixed wing airframes forgo the additional data on thrust (g). They normally provide only battery voltage and propeller combination with the subsequent amps and watts. It is also becoming more common for multi-rotor motors to be specified as either CW (clockwise) or CCW (counter-clockwise) as multi-rotors rely on equal paired numbers of each (2CW and 2CCW for a quadcopter). If this information is missing, then the motor can easily be made to spin in either direction simply by swapping the positive and negative connections to the ESC (it is also possible to specify the direction of turn within the firmware of the ESC but is more complex than just switching the positive and negative connections).

5.4.2 Propellers

Propellers are a type of airfoil, not unlike wings on an aircraft except that they are not static in relationship to the body of the aircraft. When a propeller turns/spins, it's airfoil is designed to screw the blade through the air, with changes in air pressure generated by the propeller providing the thrust. It is akin to using a corkscrew to open a bottle of wine, or inserting a screw into wood – a propeller "screws" into the air. With multi-rotors, it is also possible to gain some transitional lift from the propellers when in forward motion, whereby the propellers act as both a fixed wing and a propeller at the same time. If you notice your multi-rotor drawing less power than expected at a given forward velocity, it's likely to be transitional lift (a sweet spot for efficiency).

As with the motors on a multi-rotor, propellers are required in equal paired numbers of CW and CCW and need to be fitted to their corresponding motor (CW propeller onto CW motor). In fixed-wing terminology, the CCW is known as either a normal or tractor and the CW as either reverse or pusher. Propellers are sized in inches, with the overall diameter proceeding the blade pitch. Essentially, the blade pitch is the distance the propeller will screw through the air with each revolution. As thrust and lift both relate to the overall surface area of the propeller, and propeller efficiency increases with size, it could be tempting to always choose large, high-pitched propellers. However, both an increase in pitch and an increase in the diameter of the propeller will increase the required torque and subsequent amps drawn (and relates to the motor Kv mentioned earlier) and a poorly matched set up can quickly overheat and burn out components.

Generally, multi-rotors tend to utilise pitches from 8 to 12 cm, with lower pitches allowing for quicker acceleration, and then rely on increasing the diameter of the propellers to generate any extra thrust required. They have also evolved to include a flatter, wider blade profile. Fixed wing drones are the opposite, with pitch playing a bigger role because they equate to a greater top speed, which is more important in the forward velocity needed by the aircraft.

Plastic propellers are cheaper, but more flexible. Wooden propellers provide a more environmentally friendly option with the added bonus of being quieter in operation

Propellers come in a range of materials including plastic, carbon fibre, plastic/carbon fibre hybrids and wood. Weight of the propeller generally has a marginal impact on power draw, whereas the material's flexibility can have a greater impact. Propeller tips that are too flexible can bend upwards at high speeds because most of the thrust/lift is generated towards the tip, causing a difference in force at either end of the blade that will deform the propeller. If this happens then there will be a reduction in propeller efficiency and may – in the case of overburdened multi-rotors – result in instability and ultimately, a crash. Propellers are one of the components most likely to be damaged during general use. As such, because they are less expensive, users may be tempted to use plastic propellers, but because of their flexibility and non-recyclable properties, other propeller types, especially wooden, should be considered as an environmentally friendly option.

For most drone users, drone noise is of limited importance, but when utilizing drones for conservation or ecological research purposes, especially where animal welfare is concerned, it is an important consideration, as drones can disturb or stress the subjects of interest (**see section 3.6**). Lowering the Kv of the motor and choosing to fly with larger propellers with a stiffer material can reduce the overall noise generated by the aircraft.

Always check propellers for damage such as nicks, chips or cracks before flight, and replace if needed.

In addition to propeller size and material, balance is also an important consideration when discussing propellers at large. Propeller balance can affect flight efficiency and stability, as well as the quality of data recorded by onboard sensors. Improperly balanced propellers will be less efficient in flight, and will also result in vibrations that can negatively affect sensor-gathered data. One of the reasons DJI has become so successful is due to the stability of their camera gimbals. However, where sensors aren't mounted on a gimbal, vibration remains an issue. At a minimum, propellers should always be cleaned and checked for damage such as nicks or chips. Light scratches can be counter balanced using a propeller balancer or light sanding, the application of masking tape or light brushes of correction fluid. If a propeller is chipped or cracked then it needs to be replaced.

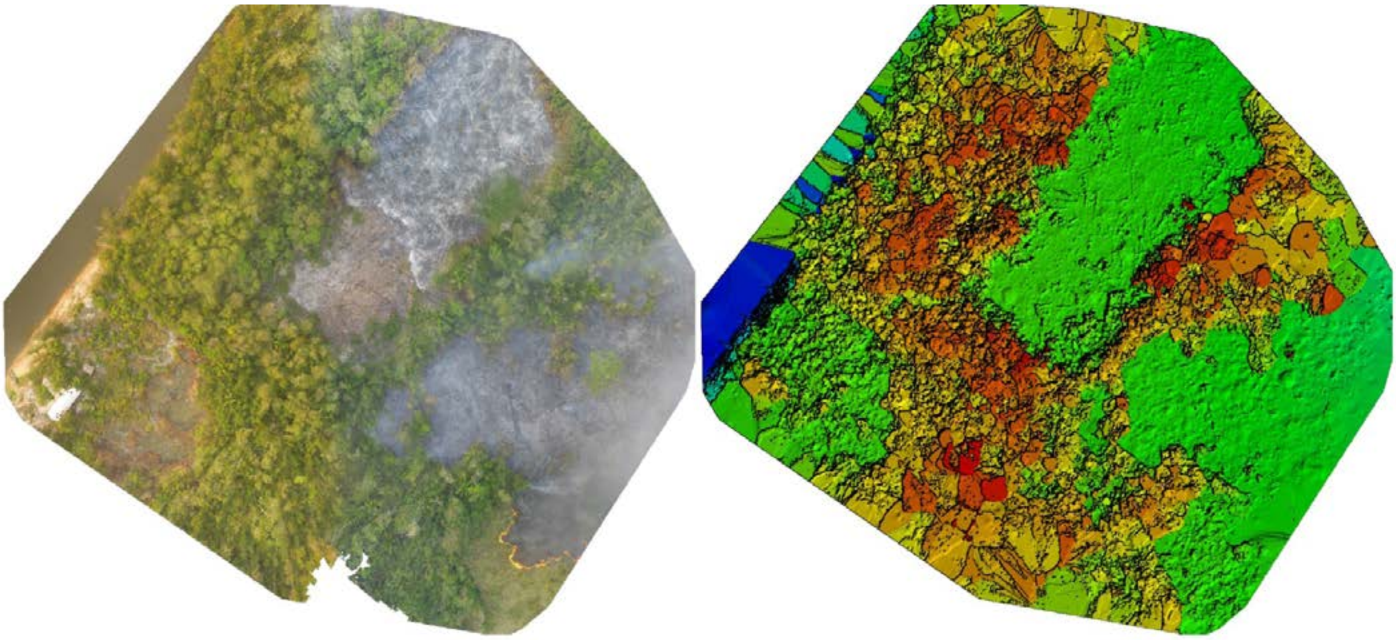


Figure 22: Ortho-mosaic and DSM over an illegally burned forest in a Brazilian Amazon protected area. © Felipe Spina Avino/WWF Brazil

5.4.3 Electronic Speed Controllers (ESCs)

ESCs function as a regulatory system that is initiated by the autopilot as a mechanism to control the amount of energy the motor is supplied from the battery. The autopilot tells the ESC how much energy is required by the motor, in turn, the ESC regulates the flow of energy from the battery to the motor accordingly.

Although uncommon, some motor and ESC combinations don't work well together and, where possible, users constructing their own drones should select an ESC that's recommended by the motor manufacturer. A good rule of thumb when choosing an ESC, whether for a multi-rotor or a fixed wing, is to have an ESC that has an amp rating at least 20% higher than what is expected to be required by the motor and propeller combination. ESCs can generate a lot of heat when under load and excessive heat can be damaging, leading to an ESC failure and possible crash.

ESCs can be classified into one of two types based on whether they possess a battery eliminator circuit (BEC) or not. BECs allow for the ESC to power other electronics in conjunction with motor(s). ESCs without a BEC are referred to as optoisolators, or OPTO for short, and cannot power additional electronics. For fixed-wing drones, having an ESC with an incorporated BEC can reduce the amount of electronics required because the BEC can provide a stable 5 V to the servo rail of the flight controller, and can also act as flight controller backup power supply. The same is possible with multi-rotors, but only one ESC should be used as a BEC, with the others having the power supply pins removed from the connector to the flight controller. This is necessary to avoid interfering signals from each of the 4 BEC power supplies to the flight controller causing what is known as a "brown out" (confusion within the system caused by competing signals), which can result in issues with the motor's power delivery. The downside to this is that one ESC will be working harder and generating more heat than the others, and subsequently is at greater risk of failure. If one ESC fails on a quadcopter, there's a much higher likelihood of a crash than with a hex/octocopter or fixed wing. As such, choosing a dedicated 4in1 ESC for a quadcopter can be a good choice as these have smaller footprints, are easy to incorporate, and typically come with a dedicated BEC that has less of an impact on the ESC's workload. Post installation of ESCs and before the first test flight of a new drone, it is very important to follow the flight controller guidelines for the calibration of ESCs. This is to ensure that the signal processing and power delivery are synchronised so that all motors are working correctly.

5.4.4 Radio control (Rx/Tx) and telemetry

Radio control and telemetry facilitate radio communications between the pilot, drone, and co-pilot, making them an essential system within any drone design. Off-the-shelf drones typically come with systems that use the Wi-Fi frequencies of 2.4 or 5.8 GHz (gigahertz). These are excellent for carrying multiple data streams such as high definition video, telemetry, and control all within a wide bandwidth on a single frequency. However, it's important to note that these Wi-Fi systems are not ubiquitous amongst all drone set-ups. In most use cases when flying across areas of 1–100 ha, 2.4 or 5.8 GHz should provide sufficient range for continuous connectivity, but in areas with potential obstacles (e.g. trees) that could interfere with signals, these frequencies may not be optimal. The right frequency for a given situation depends on balancing transmission distance, obstacles, and the type/volume of data needing to be transmitted. Higher frequencies, such as those used by Wi-Fi, are able to transmit a high volume of data across short distances, but are not particularly suited to penetrating obstacles, whereas lower frequencies are able to transmit across long distances and penetrate obstacles, but are limited in the amount of data they can transmit. Common alternative frequencies options are 433, 868, 915 MHz (megahertz) and 1.2/1.3 GHz.

Radio control and video systems consist of two units, the transmitter (Tx) and the onboard receiver (Rx). The frequencies of 433, 868, and 915 MHz, and 2.4 (5.8 is less useful here because of its limited range) GHz, are typically used for control and telemetry, whereas the 1.2/1.3 and 2.4 or 5.8 GHz are used for video transmission. Most ready to use handheld radio control units now come as standard with 2.4 GHz Tx's and Rx's but many can be swapped out for long range systems (LRS) that utilise 433, 868 or 915 MHz and can potentially control drones over 10's or even 100's of kilometres.

Importantly, the use of radio frequencies is governed by national and governmental laws, and this must be given due constraint when purchasing a drone for use in a particular country. A couple of important points with regards to radio frequencies are that national laws govern their use. This includes bands and associated power supply (**see Chapter 7**). The frequency of 2.4 GHz is a common and widely used band due to Wi-Fi infrastructure, and while this is unlikely to be an issue when operating in remote areas, it is still important to switch off other sources of Wi-Fi on mobile phones, in some cases activating flight mode, to avoid interference from Wi-Fi enabled sensors being carried by the drone such as GoPro cameras. Signals can easily become swamped and a drone control can be lost due to these competing signals. If trying to utilise a video relay system or FPV, it is important to use control and telemetry frequencies that are different to the video relay. Because all of these frequencies are sine waves, using 2.4 for control and 1.2 for video will result in interference when the two sine waves synchronise.

Table 2: Summary of different drone capabilities

	Fixed Wing	Multi-Rotor	Balloon	Kite
Takeoff/landing space	Large	Small	small	medium
Endurance	30–60 mins	20 mins	2–4 days	hours
Payload	0.5–2 kg	0.5–3 kg	0.3 kg	0.5 kg
Agility	Medium	High	Low/Low	Low
Manoeuvrability	Medium	High	Low/Low	Low
Autonomy	Full	Full	Camera	Camera

EMPOWERING TRADITIONAL COMMUNITIES AND FRONT-LINE STAFF TO USE DRONES FOR CONSERVATION.

Felipe Spina Avino, WWF-Brazil

Felipe Spina Avino is a Brazilian Conservation Biologist who has worked in South America, Africa, and Europe. Currently, he leads the work on Conservation Technologies at the WWF-Brazil Science team, where has been building the capacity of local communities, Rangers, and PA managers to use Conservation Technologies, including drones, to monitor and protect their landscapes.

Felipe and colleagues have been promoting drones as a powerful way to involve traditional communities, combining traditional knowledge, technology, and science to assist in monitoring and combating deforestation and fires in protected areas in the Amazon and Cerrado.

Key advice for conservation practitioners:

1. Before you decide to buy a drone, learn from others through research, for example, the review by Paneque-Gálvez et al. on Small Drones for Community-Based Forest Monitoring, and the online platforms: Wildlabs and ConservationDrones.

2. To be more effective, especially in larger areas, drones should be used in combination with other technologies, such as satellite data, to provide near-real-time data on deforestation and forest-fires.

3. If you are working with community members, it is critical to engage them in all project phases to enable them to work independently to protect and monitor their territories. Ensure they are skilled in all project aspects, including flying and maintenance skills, the capacity to effectively gather data, and analyze it.

Further information:

Ferreira, Manuel Eduardo et al. “Zoning the Fire-Risk in Protected Areas in Brazil with Drones: A Study Case for the Brasília National Park.” IGARSS 2019 - 2019 IEEE International Geoscience and Remote Sensing Symposium (2019): 9097-9100. DOI:10.1109/IGARSS.2019.8900421

Training traditional communities and PA’s managers to use drones to assist with Cerrado conservation and Non-timber forest products sustainable management. © Paulo Henrique-Funatura/WWF-Brazil

The Little Wild Horse & Bell Canyon is a remarkable hiking area in the desert landscape of Green River, Utah, USA. © Michael Tuszynski/Unsplash.com

6 DRONE SENSORS

6.1 Introduction

There are a wide variety of sensors available for drones and, while it's not possible to cover them all here in detail, we review some of the typical constraints and considerations when trying to incorporate an after-market sensor into a drone system. The following points cover some of these major considerations:

- Understanding how the data need to be collected and whether the sensor can facilitate this is important. Blindly purchasing a sensor to do so without these considerations can quickly lead to owning a device that can't deliver and will likely not meet expectations. The user must carefully consider whether a sensor needs to be triggered remotely. If not, the sensor may need to be triggered to record data prior to take-off, which will require additional data storage capabilities and the editing of extra data, post flight. Alternatively, some sensors will provide a time-lapse or intervalometer function via internal firmware/software (allowing users to capture data at set time intervals), while others won't. In some cases behaviour can be modified via firmware hacks such as the Canon Hack Development Kit[6]. Some sensors may also be activated via a hot-shoe (the metal contact point found on top of some sensors) or a dedicated control port (via a cable connecting to the sensor), or possibly even via dedicated servo acting as a finger (a physical mechanism used to push the shutter button), all of which can be controlled via the autopilot.

- Sensor sensitivity relative to the flight characteristics of the drone is worthy of consideration to assure high quality data are collected. With more sensitive sensors, the vibrations produced from the motors and propellers on drones can distort images or introduce aberrations into the data. Velocity or unstable flight can cause issues and is why gimbals or other forms of stabilisation are so important for recording video from drones, or using cameras with adjustable shutter speeds.

- For most types of sensor, weight isn't as much of a factor as it used to be. In recent years, an increasing number of devices have been adapted for drone use (mainly through miniaturisation of parts), but the overall physical size of the sensor still needs to be considered. If the sensor cannot be housed securely on, within or onboard the drone platform, then it should not be used.

- Cost is also a factor as many sensors may be more valuable than the drone itself, and as discussed in Chapter 3, choosing the sensor may determine which drone to use, simply from a sensor-protection standpoint.

- One final point is the use of position data (e.g. from an onboard GPS or GNSS) and whether it needs to be used or merged into the data collected from the sensor, for example via a camera that incorporates latitude and longitude in the EXIF data of collected photos. Again, some may come with simple GNSS built in that is sufficient, but in cases where GNSS is needed, working out how that can be achieved may play a role in which sensor to choose.

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6 http://chdk.wikia.com/wiki/CHDK

6.2 Overview of drone sensors

Drones can be equipped and customized with a variety of sensor types, depending on the data requirements for your survey or study area, and the weight capacity of your drone. Here we showcase the different types of drone sensors, their costs, advantages and some common examples. The references provide more specific applications and uses.

MULTISPECTRAL — LOW-COST

AGROCAM

Example Models	Agrocam, MAPIR Survey2
Typical Price Range	€200–500
Typical Weight Range	50–150 g
Example Applications	Plant health, landcover classification
Notes	Usually flown in pairs or as part of an array
References	Koucká et al. 2018

MULTISPECTRAL — FULL RADIOMETRIC

PARROT SEQUOIA

Example Models	Tetracam Mini-MCA, Parrot Sequoia, Micasense Altum
Typical Price Range	€2,000–8,000
Typical Weight Range	500–1,500 g
Example Applications	Plant health, landcover classification
Notes	Full radiometric could allow for better integration with other RS products
References	Ahmed et al., 2017

OPTICAL — ACTION CAMERAS

GOPRO HERO 3+

Example Models	GoPro, Yi Action Camera
Typical Price Range	€100–500
Typical Weight Range	100–150 g
Example Applications	Filming animal movements, creating films, orthomosaics, point clouds
Notes	Can provide live feed to pilot; beware of wide angle views which distort data
References	Ventura et al. 2016

OPTICAL — COMPACT CONSUMER GRADE CAMERAS

CANON S110

Example Models	Ricoh GR II, Canon S110
Typical Price Range	€200–500
Typical Weight Range	200–400 g
Example Applications	Orthomosaics, point clouds
Notes	Look out for manual modes, RAW and intervalometers which will allow more flexibility
References	Jensen & Mathews 2016

OPTICAL — SINGLE LENS REFLEX (SLR)

NIKON D 700

Example Models	Nikon D3000, Canon 5D
Typical Price Range	€400–3,000
Typical Weight Range	750 –1,500 g
Example Applications	Orthomosaics, point clouds
Notes	Tend to require larger drones to carry the heavier payload
References	Hodgson et al. 2013

OPTICAL — MOBILE PHONES

SMARTPHONE

Example Models	iPhone, Android phones
Typical Price Range	€50–500
Typical Weight Range	100–200 g
Example Applications	Orthomosaics, point clouds
Notes	Need to use an app to automatically collect sensor data
References	Anderson et al. 2016

HYPERSPECTRAL

SENOP HSC-2

Example Models	Senop HSC-2, Optronics Hyperspectral
Typical Price Range	>€30,000
Typical Weight Range	600 g-1000 g
Example Applications	Forestry, plant health, landcover classification
Notes	Can involve complex radiometric and geometric processing
References	Nezami et al., 2020; senop.fi

LIGHT DETECTION AND RANGING (LIDAR)

YELLOWSCAN VX-20

Example Models	RIEGL VUX-1UAV, YellowScan Vx, Velodyne puck
Typical Price Range	€6,000-€30,000
Typical Weight Range	1kg - 3.5 kg
Example Applications	Point clouds
Notes	May not come with inbuilt inertial measurement unit or GNSS
References	www.yellowscan-lidar.com

THERMAL

FLIR VUE PRO

Example Models	FLIR Vue Pro
Typical Price Range	€2000-€5000
Typical Weight Range	100–300g
Example Applications	Population counts, cryptic feature detection
Notes	Beware of differences between radiometric and relative measurements
References	Kays et al. 2018

UAS4ECOLOGY: DRONES FOR ECOLOGICAL RESEARCH

Urs A. Treier & Signe Normand, Ecoinformatics & Biodiversity,
Aarhus University, Denmark.

Urs A. Treier and Signe Normand are ecologists using drone-based remote sensing to address questions in ecology and conservation. They are running the UAS4Ecology Lab founded and led by Signe Normand and managed by Urs Treier.

They apply UAS technology to understand vegetation changes in Arctic environments under global change by combining extensive ground-based sampling with information derived from drone-based remote sensing. They use simple consumer-based cameras, multispectral sensor or LiDAR carried by rather light quad- or octocopters. Besides documenting field sites before sampling, they aim to quantify vegetation cover, productivity, and other site-specific parameters that can be derived from the point-clouds, spectral information or ultra-high spatial resolution. Drones provide the link between the highly valued field-based observations, and the large-scale earth observations from satellites, ultimately allowing to up-scale information important for nature conservation and management. Applying drones in Arctic environments is challenging. Harsh conditions and remote field sites only reachable by helicopter, boat and foot demand robust, ultra-light, and modular equipment. Furthermore, when spending longer periods of time at a remote field camp they must produce power with solar panels to recharge batteries. Even though the drone industry has developed quickly in recent years, new solutions need to be engineered and optimized for specific needs.

Key advice for the new drone scientist:

1. Make your data collection as easy, simple, light, and cheap as possible - be question driven. Consider the objective and hypothesis, data collection and processing, and results before starting your drone endeavour.

2. Reference and standardise your drone data with independent ground control, ground truth and reflectance data, especially if your aim is monitoring or change detection.

Further information:

https://twitter.com/UAS4Ecology

Fixed-wing drones are being used in Malaysia to monitor orangutan nests. Using a drone is not only cost-effective, but more accurate than surveys from the ground or helicopter.

7

FLIGHT PLANNING AND OPERATIONS

7.1 Introduction

When planning drone flights, it is very important that drone operators consider the complex volumetric 'airspace' within which flight operations will occur. Knowing the rules of this airspace is an essential part of becoming a drone pilot, and for countries with national regulations, commercial drone pilots must sit examinations to prove that they know and understand these basic rules. For scientific researchers, or those working within non-profit organisations, many countries have no requirement for pilots to obtain a special license from the aviation authorities since research-type flights in remote areas are often classified separately to those undertaken for commercial operations. However, keep in mind licensing is rapidly changing, and familiarizing oneself with the following basic information about airspace is essential for drone operations.

Understanding the capabilities of drones when operated in specific modes is also critical, as these factors and settings will define the drone's mobility, and the pilot's control of the aircraft within the airspace. With increased availability of drone technology worldwide, users must be aware that there are a wide variety of legislative responses that individual governments have implemented to control, or police, drone use. Being aware of these variations in national policy is critical, since in some countries, or areas, the legislation will completely preclude drone use. This chapter provides a relatively brief, but critical overview of these key issues, framing them for the conservation practitioner, concluding with some key recommendations for 'best practice'.

7.2 Airspace

Airspace should actually be considered as 'air volume'. Airspace is a broad term that defines the complex invisible volumetric infrastructure that controls aircraft movements in the atmosphere above our heads. Airspace globally is generally classified into volumetric blocks labelled with the letters 'A' to 'G'. These volumetric zones vary in their level of use from one country to another, but include two important extremes of airspace:

- Class A (very tightly controlled: reserved for high speed jets and for 'instrument flight rules' flights)
- Class G (uncontrolled: where aircraft must only follow simple rules)

In between classes A and G exist a series of other airspace zones, where pilots must maintain some level of radio contact with air traffic controllers. Airspace zones can extend to different heights above ground level, depending on the types of operations that they are designed to control. The best source of information on permanent air traffic zones is a formal airspace map, which can be obtained from national civil aviation authorities – but note, these can be changed regularly, so users should consult the most up-to-date information sources. Temporary air traffic zones can be set up to support certain types of military civilian operations, and these tend to use a 'NOTAM' (notice to airmen (sic)) route. Information about NOTAMs can be obtained online[7] (**Figure 24**) – and the maps shown also include permanent NOTAMs as well as temporary ones. Temporary NOTAMs can include activities as diverse as military exercises, air shows, parachute jumps, firework displays and the presence of cranes extending into useable airspace.

7 https://notaminfo.com/ukmap,
https://skyvector.com/

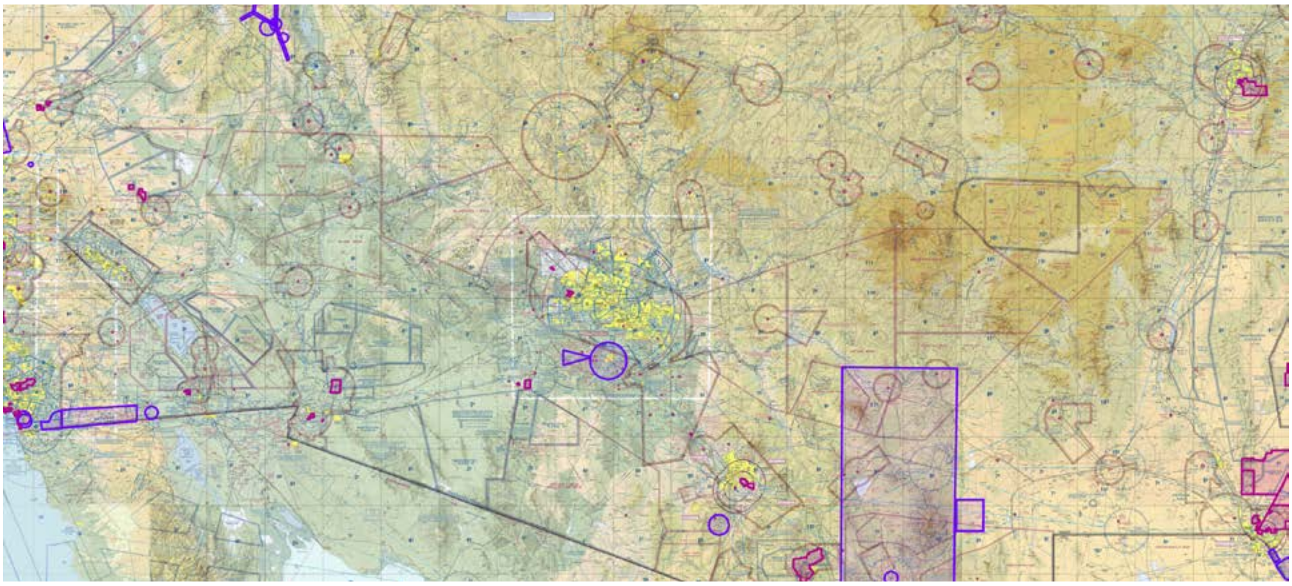

Figure 24: Example NOTAM map for the south-west United States on September 9, 2020. NOTAMS in red and purple are restricted UAV airspace, due to military or other planned activities. Circles contain information denoting other airspace restriction to certain heights above ground level.

It pays to think of these airspace designations volumetrically as a series of conical segments extending towards the upper atmosphere, as often there will be a series of concentric airspace designations extending outwards from major airports at different heights to allow for holding patterns and ascent/descent trajectories for large jets (**Figure 25**).

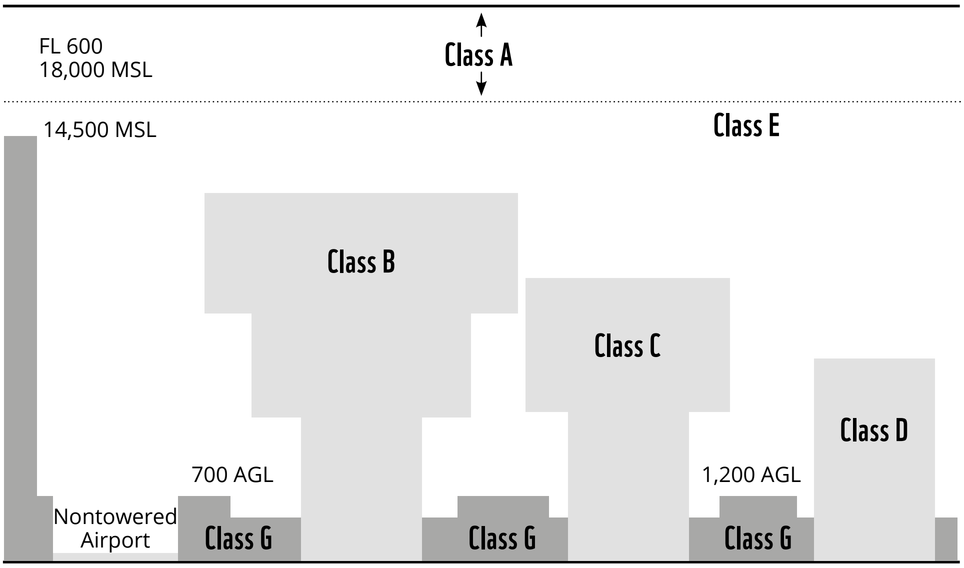

Figure 25: The complex volumetry "airspace" designations that broadly apply globally. AGL = above ground level. FL = flight level (= height above ground level/100). MSL = mean sea level

For the most part, this user guide relates to the use of lightweight (<7 kg) drones, which themselves have operational limits related to battery life and restricted operational distance from pilot (imposed by radio control, wi-fi or visual line of sight limits). Also, given that it is illegal to operate drones within close proximity of major airports (and a terrible idea to do so), and that most key conservation and ecology priority areas are situated far from such infrastructures, we assume that such drones will mainly be operating within class G airspace (Garrett and Anderson, 2018). If we follow the UK Civil Aviation Authority Guidance (which is common to many other countries with drone regulations in place), we find that the following rules of flight apply:

As a general rule, all drones must fly within line of sight of the operator, and below 120 m.

The aircraft must stay within **line of sight** of the operator, and must **not fly above 400 ft (120 m) from the ground level at take-off point.** The maximum distance for a single line-of-sight flight is **500 m from the pilot** in command.

“Although operators of drones weighing 7 kg or less are **not required to have the permission of Air Traffic Control** (even when flying within controlled airspace or within an aerodrome traffic zone), the Air Navigation Order requires that any person in charge of a small drone **may only fly the aircraft if reasonably satisfied that the flight can safely be made;** and must maintain **direct, unaided visual contact** with the aircraft”[8]

Further, the **responsibility “lies with the operator** to determine if the area he (sic) has chosen to fly in is suitable”

Importantly, for drones equipped with cameras – those who do not have an additional permission from the CAA, are “restricted to **remaining at least 150 metres** from **congested areas or any organised, open-air assembly of more than 1,000 people.** Drone operators **must not fly camera fitted drones within a distance of 50 metres of any person, vessel, vehicle or structure that is not under the control** of the person in charge of the said aircraft (during take-off and landing this distance may be reduced to 30 metres). This means that each flight will carry a ground ‘footprint’ below the aircraft, within which there should be no uninvolved members of the public.”

The term ‘bringing under control of the pilot’ is ambiguous, and cannot be interpreted as simply requiring ‘notification’, since a person notified of your flight and potentially interfering with it may not be under your control. If you cannot keep your drone more than 50 m from subjects (volumetrically), you should not fly. Furthermore, any images captured that compromise the privacy of non-consensual people should be deleted from the camera memory immediately after landing and never shared.

8 https://www.caa.co.uk/Consumers/Unmanned-aircraft/Our-role/Airspace-restrictions-for-unmanned-aircraft-and-drones/

These rules are provided by civil aviation authorities around the world, an example from Singapore shown in **Figure 26**. Importantly, the requirement to fly within 'visual flight rules' where the drone is always within the pilot's line of sight is very pertinent to those flying small drones – the smaller the drone, the shorter the distance from the pilot (vertically or horizontally) that the pilot will lose sight of the aircraft, so the smaller the area that can be surveyed per-flight.

Figure 26: Drone recommendations from the civil aviation authority of Singapore
© Civil Aviation Authority of Singapore

In the UK, there is now a mobile phone application called 'NATS assist' which is expressly designed for drone users. It is free to download and provides pilots with up-to-date NOTAM information for their current location. It can also be used to raise NOTAMs – so that once a pilot arrives at a site, they can drop a pin and enter a few details that are then released as a temporary NOTAM to notify other air users of the drone operation. **Figure 27** shows a screenshot from this app, with the blue dot as the location of the user. Airspace restrictions are shown as yellow or red circles. In the USA, B4UFLY[9] is an app that checks for local flight restrictions and permissions around a selected location.

Perhaps the best advice we can provide on airspace is that pilots should both check air-space prior to, (desk-based, and *in situ*) and during flights, and then make every effort to notify other users of their intended flight operations, no matter how low the flights will be, and even if short in duration. In Class G airspace, any air user can enter and fly through the volume using visual flight rules, which means that these uncongested zones are often the places where military forces may perform unexpected low flight operations or practice missions, or emergency aircraft such as helicopters will operate. For these reasons a good suggestion is to also make a courtesy phone call to any near-by air traffic control towers to notify them of your location, time window of operations, maximum flight height and type of aircraft. As long-term operators of drones we can say that information is power – air traffic operators would rather know that you are there, they do not have the powers to stop you from flying and they can notify other air users of your presence.

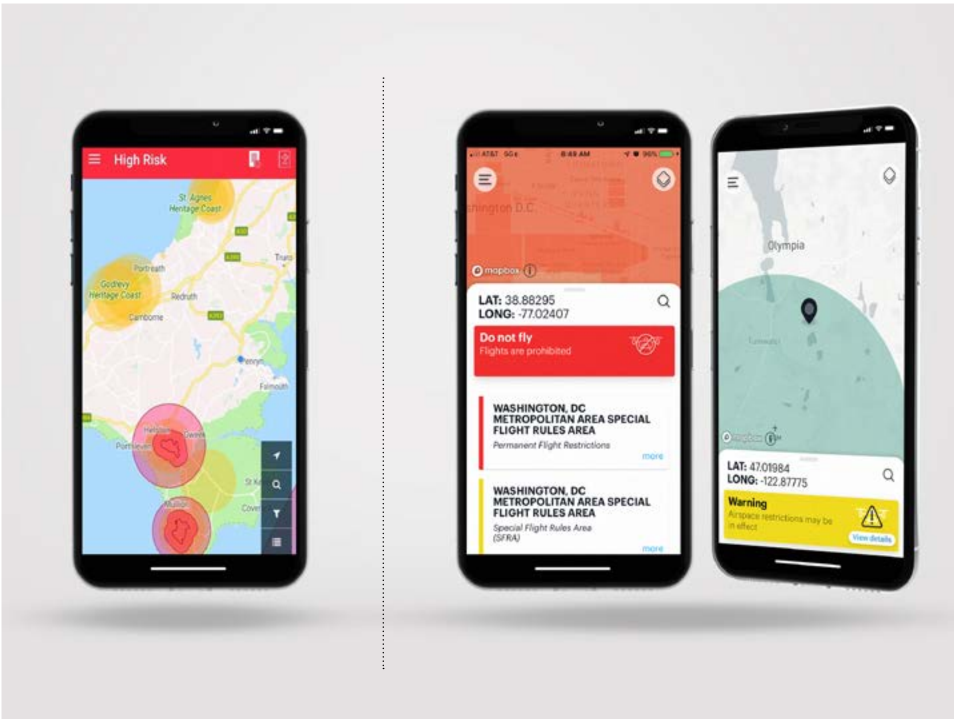

Figure 27: Left: Screenshot from the NATS-Assist app on 20 December 2018, in the UK. The blue dot shows the drone operator's location, and the coloured circular areas are those places where airspace restrictions exist. Using this app, users can raise NOTAMs for drone operations. Right: Screenshots from the B4UFLY app.

9 https://www.faa.gov/uas/recreational_fliers/where_can_i_fly/b4ufly/

7.3 Flight modes

The increasing number of drones on the market means that a full digest of the variations in flight modes available is impossible. However, we have summarised the major types of flights that can be operated from many consumer drones on the market in **Table 3**. These settings apply to multi-rotors for the most part, but some can also be used with fixed wing systems.

Table 3: A summary of operational modes for most lightweight consumer-grade drones

MODE	FIXED WING OR COPTER?	WHAT IT DOES	WHEN TO USE IT
Stabilised or 'positioning' mode, also called hover or loiter	Copter	All drone's sensors (including GPS) will be active, ensuring self-stabilisation of the drone in the air. If the pilot lets go of the controller's sticks, the aircraft should stop and hover over a fixed position. Flight can then be controlled in x,y,z directions by manual control on the radio controller. For some DJI drones this function includes automatic obstacle avoidance	For manual surveys, reconnaissance, following individuals, targeting specific areas or sampling things like whale sputum (see case study page 33)
Attitude hold or 'ATTI' (A) mode	Both	This mode holds the drone at a fixed altitude, but can drift in x,y. This mode can kick in if GPS hold is lost during stabilised flight. The pilot is in control of all other commands	This is a sub-standard control compared to stabilised mode, but it can be useful for surveying complex areas, or remaining above tree canopy, if an experienced pilot is in charge. Best avoided for beginners.
Sport mode	Copter	This is a relatively new option available on many DJI drones. It uses GPS for positioning but disables forward and downward vision systems so there is no obstacle avoidance capability. The sensitivity on the controls is enhanced in ATTI (attitude mode) making the drone responsive to pilot input compared to stabilised mode	This is a faster velocity mode designed to give pilots a thrill ride, and not ideal for surveying. Images captured in this mode are likely to be blurry. It may only be useful if you need to get your drone somewhere fast, or bring it back to a landing spot quickly in the event of an emergency.
GPS-waypoint mode	Both	This mode allows the pilot to pre-plan a way-pointed route that the drone will follow. An automatic take off and landing point can be defined, and the drone can be programmed to complete a fully autonomous flight. Camera parameters can sometimes be used to define the flight settings on the basis of desired overlap and sidelap (e.g. for photogrammetric purposes). The pilot must be able to take control of the aircraft and interrupt the autonomous flight in the event of an emergency	This is a widely used method for capturing reproducible survey data for mapping, orthomosaic generation or structure-from-motion photogrammetric workflows.
Fully manual	Both	Many of the drone's sensors are disabled and the pilot must control everything. In reality most drones will not permit full manual control since it is risky for all but most advanced pilots	Probably best avoided unless you are a professional drone racer or have extensive experience.
Return to launch (RTL) or Return to Home (RTH)	Both	This is a common feature of most GPS-controlled consumer drones. The take-off site is stored in the drone's memory and the drone can return to hover over this position if RTL mode is triggered. RTH returns to a pre-defined location or the loaction of pilot/controller	This is useful at the end of a GPS-guided survey, or if the battery becomes drained and a rapid landing sequence is required. The drone will usually fly back quickly to a RTL or RTH position at a pre-determined height
Air brake	Copters	This is a recent feature in some multi-rotor drones. It allows the pilot to interrupt a GPS-waypoint mission and pauses the drone in mid-air by starting ATTI or stabilised mode. The GPS waypoint route can be re-started from the paused position	This is very useful if something strange happens mid-survey. E.g. an obstacle is encountered, wind speed suddenly picks up, a bird shows interest in the drone or a mob of crows appear overhead. It can give the pilot some time to decide on whether it is safe to continue with the survey or RTL or RTH to land.

7.4 Navigation and accuracy

GPS capabilities on board drones are typically basic consumer-grade systems, which means that users can expect spatial accuracy in x,y,z to be typically +/-2-5 m or as low as +/- 10 m. For this reason, the positional accuracy of your drone in volumetric space is at best, approximate within these limits. For these reasons it is essential for the pilot (and preferably a co-pilot or spotter) to maintain eye contact with the drone as it flies in order to be able to take prompt action if the drone comes closer than one would wish to a feature (e.g. building). Some drone companies give full access to the flight logs (such as 3DR or self-built), others make accessing this information more difficult (DJI), but even if you retrieve these flight logs they will only provide a general idea of position within those abovementioned accuracy limits.

For improved accuracy of the location of the drone, one needs on-board high accuracy GPS, known also as real-time-kinematic (RTK) GPS. This is where the drone will communicate with a base station whose position is known to within a few cm in x,y,z. The differential correction to this base station will allow a much more precise location of the drone to be determined. Whilst most consumer drone systems do not include RTK capabilities, in Spring 2019, DJI released a Phantom 4 RTK-capable system, although the cost remains relatively high (at the time of writing the cost for the drone plus base station was in excess of €8,000). PPK (post-processing kinematic) GNSS solutions are also available which deliver similar accuracy to RTK, but require post-processing of flight logs.

Without RTK capabilities on the drone, geo-positional information about features within the scene can only be obtained via independent reference to ground control points deployed within the scene and referenced using a differential GNSS system (**Figure 28** shows such a methodology in operation). For many applications this level of accuracy will not be necessary – such detail is only needed if the absolute position of objects on the Earth's surface is needed. For some applications hand-held GPS survey of such markers can provide useful validation of drone products, for example, markers can be used to constrain the location of pixels within a geospatial workflow (e.g. orthomosaic generation) or to check the quality of resultant builds relative to an independent measurement (e.g. compare the location of a pixel in the model build vs. its position measured on the ground).

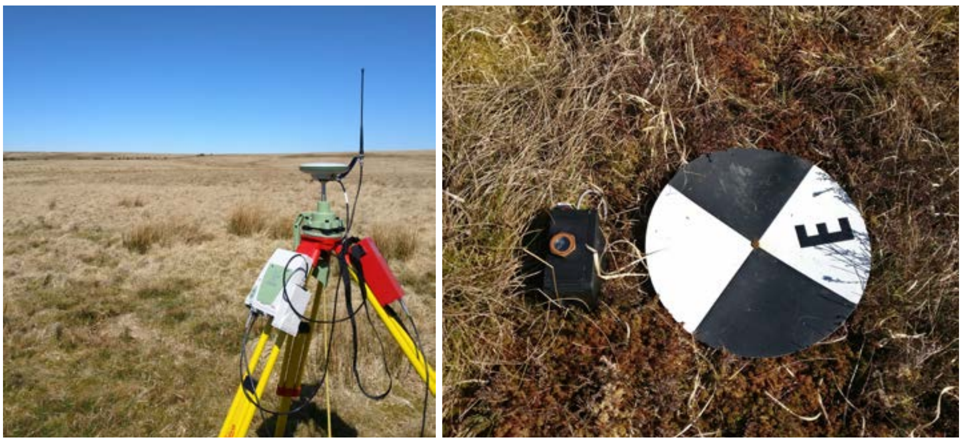

Figure 28: The use of a ground-based RTK survey system includes a base station (left) and ground control points reference markers deployed within the survey area (right).

7.5 Legal issues and permits

All countries have some form of legislation covering aviation practice and airspace management, however there is variability in the strength of legislation as it applies to different types of drone operations. **Table 4,** from DeBell et al., (2015), evidences the diversity of drone legislation across some regions of the world.

Table 4: UAV industry and legislation for the major economic regions of the world. From DeBell et al. (2015), but note this information was published several years prior to the publication of this WWF report, so some information may now have changed.

	UAV RELATED INDUSTRY	REGULATED?	COMMERCIAL UAV FLIGHTS PERMITTED?	HOBBYIST UAV FLIGHTS PERMITTED?	OTHER NOTES
Australia	Y	Y	Y	Y	2 kg defines "small" UAV (including payload); license required.
Canada	Y	Y	Y	Y	UAV flights permissible under license.
China	Y	N[b]	Y[b]	Y	
Europe[a]	Y	Y[c]	Y	Y	Variation in definitions across different EU member states see (Silverburn 2013)
India	Y	N	N	?[d]	
Mexico	Y	N	Y	Y	Liberal attitudes to UAV use (Garcia 2013)
USA	Y	Y	N	Y	Commercial use currently under revision y the FAA. No fly zones implemented in certain regions.
Brazil	Y	Y	Y	Y	Currently a complete ban on commercial UAV use

Note: data collated in January 2015.

a Europe has been included as a single entity due to its unified trade and legislation.

b China appears to allow operation by authorization at a provincial or town planning level but has nothing in place at a national level.

c While there are overarching EU guidelines, it is also stated that each member state is responsible for applying their own law relating to UAV use.

d There are competitions involving UAVs and plenty of hobbyists flying, but regulation relating to hobby pursuits has been difficult to find.

To provide an example of the diversity of international regulations: in the UK, research or recreational flights with small drones weighing less than 7 kg TOW require an online exam, drone registration with a unique identifier[10] **(see Figure 26**). Research pilots should also obtain permission from the landowner from whose land the drone will take off and land prior to flights. In the USA, all pilots must be registered with the Federal Aviation Authority and hold a current drone pilot's license[11]. To obtain this license pilots undertake a theory and practical test, preceded by several days of classroom teaching. The USA also requires all drone users to register with the FAA and fit their drones with a

10 https://www.caa.co.uk/Consumers/Unmanned-aircraft-and-drones/

11 https://www.faa.gov/uas/

license plate and ID. Similar rules are being implemented in Europe[12]. Permits may also be required depending on the location of surveys, with tighter controls on federal land and in National Parks, for example. Much like the fast-paced technological changes (e.g. B-VLOS, swarm flying and, detect and avoidance technology (**Chapter 11**)), the associated regulation is struggling to keep apace of drone developments, therefore it is critical that all pilots themselves obtain timely information on the rules within their operating country prior to flying.

Some websites to check for drone regulations:

Australia:
https://www.casa.gov.au/drones

USA:
https://faadronezone.faa.gov/

Europe:
https://www.easa.europa.eu/domains/civil-drones/naa

Drone bans:
https://uavcoach.com/drone-bans/

Compiled list of regulations by country and state:
https://uavcoach.com/drone-laws/

7.6 Best practice

We provide here a set of key recommendations and actions that drone pilots can follow to help ensure that operational problems do not arise.

- If travelling, be mindful that large drones attract attention at customs and you should always carry appropriate official paperwork with you to ensure smooth entry into the country. This also includes receipt of purchase, insurance information and import permits. Smaller drones or fold-up models concealed within carry-on bags attract less attention, but still require proof of ownership and permits where needed. Do not transport a drone battery (typically LiPo) in checked luggage (see **Section 5.3.1)**.

- Check the drone laws for the operating country prior to flights.

- If a licence to fly a drone is required, leave plenty of time to fill paperwork and obtain permits, since this can sometimes be a lengthy process, depending on the country.

- Notify, and where necessary, obtain permission from landowner/s prior to operations.

- Notify other airspace users of your intention to fly, operational flight plans and on completion of your survey, repeat the same.

- Use geofences within your flight planning software to ensure that you do not encroach into unauthorised airspace in both height and lateral bounds.

- Be aware of privacy issues and remove all images of non-consenting people from your image sets.

- If you encounter resistance or conflicts during your drone operations, land your drone before discussing.

- Carry all your paperwork with you to site.

- Wherever possible, when you fly take a co-pilot or a spotter along with you to watch out for aerial and terrestrial hazards and manage inquisitive bystanders while you focus on flying.

12 https://www.easa.europa.eu/domains/civil-drones-rpas

A polar bear leaps across the ice in Nunavut, Canada. The 2018 winner of the "Drone Awards Photographer of the Year" © Florian Ledoux/Drone Awards/Art Photo Travel

8 DRONE DATA

8.1 The drone's niche

Drones unlock the potential to capture data at finer spatial and temporal resolutions than satellite or airborne remote sensing platforms offer. Information about a particular environment, individual, or group of organisms can be collected in greater detail, meaning smaller features can be detected, comprising a larger number of pixels at finer resolution. Drone-based data can also be collected more frequently (i.e. surveys could be conducted at varying frequencies, from daily to multiple times or specific times of day). To help describe the drone's niche, the following sections will compare proximal sensing technology to existing remote sensing platforms, such as satellites and light aircraft, and also to *in situ* monitoring techniques.

Some satellite data sources:

Copernicus Sentinel Hub:
https://www.sentinel-hub.com/

NASA Landsat Science:
https://landsat.gsfc.nasa.gov/

Planet:
https://www.planet.com/

MAXAR (DigitalGlobe):
https://discover.digitalglobe.com/

Airbus Geostore:
https://www.intelligence-airbusds.com/geostore/

Satellite platforms currently offer a broad suite of data products which can be of use to scientists, environmental managers and conservation practitioners alike (Pettorelli et al., 2018b). Some satellite programs (e.g. Landsat and Copernicus) offer freely available data, whereas commercial operators of higher resolution imagers/sensors (MAXAR, Planet, Airbus) charge for access to their data. Satellite platforms carry a variety of sensors that operate both actively and passively, sensing across the electromagnetic spectrum. For example, some platforms such as Worldview-3 or Sentinel-2 carry multispectral sensors, spanning the visible part of the spectrum, as well as a near-infrared band (Ferreira et al., 2016). Some sensors offer spectral capabilities in the near-, short-wave and thermal infrared part of the spectrum. Information captured within these individual bands (or combinations of them) can provide rich information about various characteristics of the Earth's surface (Pettorelli et al., 2018b). While a wide range of sensors exist, they are pre-determined by the organisations which design and run the satellite systems. It may be the case that particular sensors do not collect sufficient information to answer some research questions.

The freely available data archive of the Landsat satellite program makes it a powerful tool for analysis on multi-decadal scales, for example investigating habitat change in response to storm events over time (Douglas et al., 2018). The ability to investigate change over such large temporal extents makes satellite based remote sensing useful for research, management and conservation purposes. Satellite data can be acquired on temporal resolutions of single days or weeks. With the regular addition of new systems and constellations, revisit times (i.e. how often images over a given area will be captured) are being significantly reduced (e.g. Sentinel platforms are expected to deliver revisits of between 1 and 6 days (Berger et al., 2012). Regardless of the expected revisit times, the orbits of most satellite image capture are timed to occur at the same time of day, every day, and useable data cannot always be guaranteed. For optical sensors cloud cover and atmospheric haze is a significant obstacle, either obscuring features, or creating altered brightness in areas of cloud or cloud shadow (Zhu and Woodcock, 2012). Furthermore, other features such as the presence of water in intertidal areas or shadows at the beginning or end of daylight can reduce the quality of, or invalidate, the data acquired. The inability to adjust the time of data acquisition from satellite platforms is significant drawback of this type of remote sensing technique. This leads to potential uneven sampling regimes and gaps in datasets.

Airborne platforms can be used to collect remote sensing data at specific times and places. The advantages of using light aircraft include the finer spatial resolution data and better control over the timing of data collection. Therefore, dynamic processes can be captured during times that are most suited to the application in question. Airborne campaigns can be undertaken at low tide states when intertidal environments are exposed and not obscured by the water column, for example, or animal behaviours or movements captured when they are most likely to occur. Airborne surveys can also cover significant areas, e.g. 10–100 km^2, which is suitable for studies at the landscape or regional scales. The major drawbacks of airborne operations however are mainly linked to their logistical complexity. They require a team of trained individuals (e.g. pilots, sensor operators) to undertake successful flights, as well as a suitable aircraft, fuel, infrastructure and the associated authorisations. These factors make it an expensive and somewhat exclusive form of data capture, where it is limited to those that have the necessary resources to launch such a campaign.

In situ monitoring with specialized sensors such as terrestrial laser scanners (TLS) offers very fine-grained data measuring structural and physical variables of environmental features at a specific point in time. Examples of TLS applications within the environmental sciences include sand dunes (Feagin et al., 2012), cliff faces (Westoby et al., 2018) and the monitoring of landscape processes such as river catchment development (Kociuba et al., 2014). The data outputs from this technology are typically ultra-fine resolution, dense point clouds, which if used effectively can produce a 3D representation of the landscape or features. Compared to drones, this is a very useful approach, given the situations where drones are unable to capture data of features hidden from the nadir viewpoint. However, this technology remains expensive (laser scanners can cost over €20,000) and are cumbersome, making it difficult to transport in the field, while the spatial coverage is limited to relatively small range (up to 1 ha per scan). This immobility could be detrimental to data acquisition, especially if time-limited by a specific process, environmental conditions or the presence of an individual or group of individuals. Other *in situ* remote sensing approaches for ecological and environmental monitoring include ground-based photography, such as movement triggered camera traps or time-lapse photography. As with the other techniques highlighted here, each of these are beneficial when used in particular circumstances (e.g. time-lapse to monitor the evolution of shorelines over time), but the lack of perspective, due to the ground-based positioning, limits the spatial extent at which data can be captured.

Drones are a self-service data capture method, allowing the user to collect information when it is best suited to their research.

In contrast to the aforementioned approaches, drone technology democratises the remote sensing workflow – allowing individuals to collect data when they want and where they want. Drones can be described as a self-service data capture methodology, allowing the user to time the acquisition of data when it is best suited in relation to environmental conditions or the position of features of interest (such as landscape structures of organisms). For example, within intertidal coastal zones, the timing of data acquisition is crucial, due to the presence of water during the tidal cycle. Scenarios such as these are well suited to drone-based data collection, and it has been demonstrated through the mapping of spatial heterogeneity within intertidal seagrass meadows (Duffy et al., 2018b).

Figure 29: A drone-based survey of gharials in Nepal, a critically endangered crocodile species known for their significant length. © G. Jung Thapa/WWF-Nepal

Drones are also highly flexible, both in their design and the types of sensors that can be attached to them (**see Chapter 5 and Chapter 6**). This means that drone users can capture remote sensing data in the formats they require, containing the information most useful to their desired applications or research questions. As has been shown within the spotlight features in this report, the types of sensors are wide ranging, spanning optical and sonic data capture, as well as the acquisition of biological samples from the natural environment. The flexibility in airframe design also opens opportunities to attach various types of sensors and execute flights in a variety of manners (e.g. hovering to collect data at the same location over a defined period of time, or flying at a faster speed to image the largest area as possible in a single flight).

8.2 Available software and costs

Software associated with drone-based data collection and processing can broadly be split into three categories (when considering data from optical sensors).

- mission planning software
- ground station software
- data processing and analysis software

8.2.1 Mission planning software

Mission planning software is used to set up the drone system and plan flights (if automated with the use of GPS onboard the drone). This software can also be used to change parameters on the drone, such as default speeds, sensor calibration onboard the autopilot and program default behaviours (e.g. return-to-launch routines), and failsafes. Some autopilot systems, and associated software, will even let the user manipulate how the hardware performs (such as power output to the motors) or logging information from specific sensors inside the autopilot.

8.2.2 Ground station software

Ground station operations which control the drone in flight are often run on a phone or tablet, but can also be executed on a laptop computer (depending on the software and associated autopilot). The key features of these software packages are to aid in the launch, landing and operation of the drone whilst airborne. In some cases, these features are bundled with mission planning capabilities into one software package. Some of these software packages are drone manufacturer specific, some work for multiple models, and they are a mixture of free and paid for (**Table 5**). Examples include ground station Pro (for DJI models) and Solex for the 3DR Solo quadcopter. Autopilots in custom made drones will often have compatible ground station software available, although it's best to check this with the manufacturer/supplier to be sure.

Table 5: Available third-party drone planning software and apps

NAME	OPERATING SYSTEM	DESCRIPTION	WEBSITE
B4UFLY	Android and iOS	The Federal Aviation Administration (FAA) has produced this app to make it very easy to know where in the US you can, and cannot, fly your drone.	https://kittyhawk.io/b4ufly/
Airmap	Android and iOS	A comprehensive flight planning app that also includes regulations for more than 20 countries. Can be used to program DJI drones.	www.airmap.com
DroneDeploy	Android and iOS	Flight planning app and cloud-processing platform for 3D models and vegetation indices (NDVI). Also offers an enterprise platform	www.dronedeploy.com
Mission Planner	Mac and Windows	Computer based open source planning software and image geo-positioning. Oriented towards custom built drones running Ardupilot software	www.ardupilot.org/planner
DJI go	Android and iOS	Planning software designed for all models of DJI drones	www.dji.com/de/goapp
Litschi	Android and iOS	Open source mission planning software designed for DJI drones	www.flylitchi.com
Maps made easy	Web and iOS	Web system for cloud processing of drone data, and an integrated planning app for DJI drones	www.mapsmadeeasy.com

8.2.3 Data processing and analysis software

The most common way to process and obtain tangible outputs from optical and multispectral data captured from drones is by using photogrammetric approaches – namely Structure-from-Motion Multi-View Stereo (SfM-MVS). Software offering this sort of processing typically allows the user to output a variety of spatial products produced from their inputs. These include, but are not limited to, orthomosaics, 3-dimensional models, digital elevation models and point clouds. Each of these detailed datasets can be used either individually or in tandem for a variety of ecological and environmental applications. **See Chapter 3** for examples of drone data usage in conservation and ecology. Photogrammetry software packages are highly varied, and each is unique in terms of the features that it offers. Careful consideration is required before choosing which software package to use for processing your drone data. Many of the proprietary programs offer a free trial for a limited period of time. This may serve as a good to test to see if your particular processing needs can be met with it. **Table 6** shows a selection of typically used free and commercial software packages. The software used to process the data is rarely able to perform remote sensing or spatial analyses e.g. for image classification or topographic analysis. Users must export products (e.g. orthomosaics, surface models) from these processing softwares and undertake such higher level processing elsewhere. There are an infinite number of possible workflows for post-hoc handling of geospatial datasets, including open source toolkits such as R and QGIS.

Table 6: A non-exhaustive list of photogrammetry software packages. Adapted from Forsmoo et al. (2019)

NAME	SOURCE	GUIDE PRICE
Agisoft Metashape	www.agisoft.com	$179 (standard) $3499 (professional)
Pix4D	www.pix4d.com	$4400 dollars (standard) $240 monthly
3DFlow Zephyr Pro	www.3dflow.net/3df-zephyr-pro-3d-models-from-photos/	Free to $4300 depending on version/features
MICMAC	github.com/micmacIGN/micmac	Free
GRAPHOS	github.com/itos3d/GRAPHOS	Free
Autodesk Recap	www.autodesk.com/products/recap/overview	$310 yearly
ESRI Drone2Map	www.esri.com/en-us/arcgis/products/drone2map/overview	$2500 yearly
Photomodeler Premium	www.photomodeler.com	$995 (standard) $49 monthly
RealityCapture	www.capturingreality.com	Pay per input pricing options available
OpenDroneMap	www.opendronemap.org	Free
DroneDeploy	www.dronedeploy.com	$99 per month

8.3 Data processing approaches

For data processing approaches, the planning, flying procedure and the research goal, will impact what type of method, or processing pipeline, will be required to achieve the desired result. For some applications minimal or no processing may be required, as individual images may provide the information required. But where multiple images, or multiple types of data need to be combined, processing may become slightly more complex.

Starting with our first example, it is easily possible to capture one hectare with a single image utilising a wide-angled lens on a camera or smartphone flown at ~100 m altitude. If this image was captured with complimentary position data (e.g. from GPS or GNSS), the latitude and longitude could be inserted via the Exif information of the image, or added via a GIS software, which may be enough to provide a simple base map on a local scale. However, one of the key benefits of using proximal sensing technology is the larger extent that can be covered with a single mission where overlapping aerial photographs, or other images, are captured in sequence as the drone moves across the area.

Should larger areas need to be covered, or 2.5D data is required (surface or volumetric data), if there is a need to fly at a lower altitude or flying above an object of height (for example flying at 100 m altitude but over a tree canopy of 40 m height), then multiple images may need to be "stitched" together, or mosaicked, to produce the desired output. The previous section highlighted SfM-MVS as one of the most popular ways to process drone data of this type and there are a multitude of specialist software available that perform the SfM-MVS process.

Some of the most popular software options include Agisoft Metashape (formerly Photoscan), Pix4D and DroneDeploy, all of which are commercial products; the latter two cases also include cloud-based options. There are many other commercial options available[13], as well as an evolving open-source option: OpenDroneMap[14] (see **Section 8.2.3**). There are many examples in the literature that detail SfM workflows for mosaicking image data obtained from proximal sensing platforms. The software packages listed above also often provide tutorials and sample data. Furthermore, thorough descriptions of the technique's application in a variety of fields can be found in the literature (Burns et al., 2015, Smith et al., 2016, McDowall and Lynch, 2017).

Aside from the above, it is also useful to have a plan in place for the managed storage of any data collected, for example flight logs and their associated images. If flying multiple missions on a regular basis, it can be easy to either lose track of which flight log corresponds to which data set, or accidentally overwrite the autopilot with logs from more recent missions. In addition, large capacity USB sticks or external hard drives are essential assets in the field, as data collected can quickly grow to the 10's and possibly even 100's of GB.

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13 https://geo-matching.com/photogrammetric-imagery-processing-software
14 https://www.opendronemap.org/

MAPPING HABITATS OF THE GREAT BARRIER REEF

Karen Joyce, James Cook University

Karen is a remote sensing researcher and educator in Queensland, Australia, who loves using satellites and drones to map, measure, and monitor from above to help look after our environment.

Karen has been working on the Great Barrier Reef since the late 1990's, mapping the different corals, algae, and other underwater habitats. Initially she used a lot of satellite data to create maps, but now more and more is being done with drones. One of the biggest challenges for mapping the reef is that the water gets in the way of being able to clearly see the coral. But drones allow us to be flexible in terms of selecting the time to capture data to align with low tide to be able to see the reef with less interference from the water column. Karen and colleagues have collected several years' worth of drone data over the Heron Reef study site, so that they can now quantify changes that are occurring at very fine spatial scales. This level of detail was only previously possible by conducting in-water surveys, which often have limited coverage.

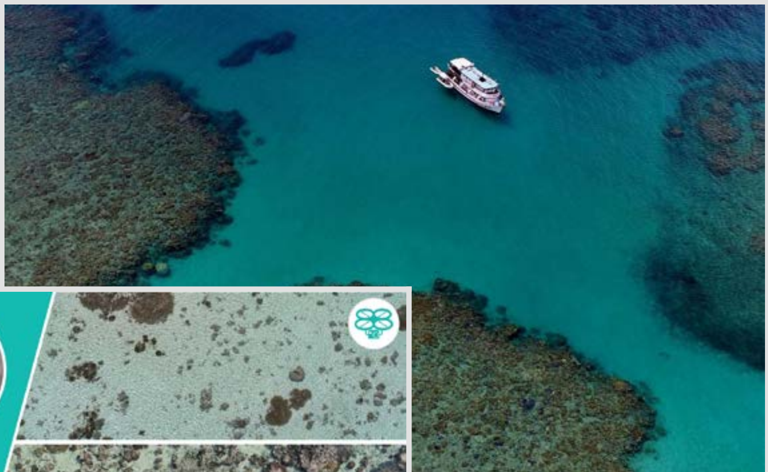
Key advice for conservation practitioners:

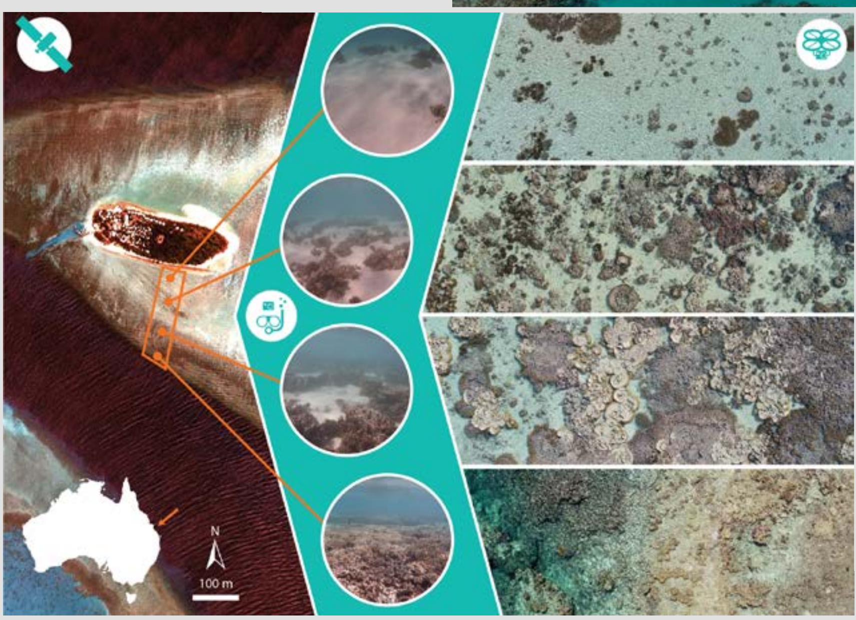
1. Figure out the minimum characteristics of the data that you need to answer your question BEFORE you select your geospatial tool. That is, don't buy the drone until you are sure that it will serve your purpose!

2. Remember to include software, data storage devices, and sufficient training (for software and drone flying) into your drone start up budget.

Further information:

www.kejoyce.com





Drones are just one tool that we use to unlock the habitat secrets of the Great Barrier Reef. We also use satellites to cover large areas, and in-water surveys for calibration and validation.

The mangroves of Mahafaly, Southwester Madagascar are known for their exceptional beauty, intactness and biodiversity, but are under increasing pressure from human activities. © Martina Lippuner/WWF-Africa

9 HIGHLIGHTS FROM WWF'S CONSERVATION ACTIVITIES

As the largest international conservation NGO on earth, the World Wide Fund for Nature (WWF) applies new technology to mitigate pressing environmental issues affecting humans and wildlife alike. In addition to the more straightforward advantage of using drones for anti-poaching, which started with the Wildlife Crime Technology Project[15], the other applications of high quality, high spatial and temporal resolution data and remote access in a variety of environments via drones, afford flexibility and innovation to meet the needs of conservationists working to tackle issues such as climate change, sustainable resource use, species conservation and the fight against wildlife crime.

Drones are facilitating better interactions between scientists and species. Observation and studies of wild animals in their habitats may involve dangerous access by scientists, or, on the contrary, distance is limited by laws and regulations, limiting the impacts of the studies. With advancing drone technology, including more powerful sensors, quiet motors, scientists can get up close and personal (albeit while following best practices; **Chapter 7**) with the species of interest. In Romania, WWF is using drones to deal with the delicate nature of rehabilitating bear cubs **(see case study on page 97)**. In the Bear Orphanage in Romania, bear cubs must learn to forage for their food, and managers need to avoid as much human interaction as possible. A custom drone has been developed to bring food to the animals and replicate their wild foraging activities, while avoiding any human scents, not to mention saving time and effort on transport.

In the western US, a similar project using customized drones has been developed by the US Fish and Wildlife Service and WWF-US to widely inoculate prairie dogs against a deadly plague – which is meant to help endangered black footed ferrets, who prey on them (Ditmer et al., 2015). An octocopter drone, outfitted with a customized hopper is used to drop vaccine-laden peanut-butter pellets into prairie dog burrows. The prairie dogs eat them and then become immune to the sylvatic plague, a non-native disease they have little natural immunity against. The vaccine delivery method by drone is as effective and practical, and more affordable, than manual delivery via all-terrain vehicles, or vaccination of captive raised and released animals.

Nevertheless, drones may still have impacts on wildlife, and there is an increasing need for assessment, and development of best practices, to minimize physiological stress from scientific study via drones. The selection of fixed-wing drones, like those being used by WWF-Malaysia to quantify orangutan nests in Borneo, are an improvement over helicopters, which are not only costly, but loud, disruptive and not very environmentally friendly.

In terms of mapping, surveying and collecting geo-spatial data, drones are multiplying the efficacy of conservation field campaigns. In eastern Africa, the use of drones is providing extensive information on mangroves, which are swampy forests established in intertidal zones and deep unstable mud, which are inaccessible, difficult and dangerous to access. There is little one can do to avoid crocodiles, snakes and aggressive hippos, or virtually impenetrable tree stands, other than choose to not survey an area. These are common deterrents which tend to bias wetland field plots and measurements. In Tanzania, WWF-Germany and WWF-Tanzania have deployed quadcopter drones outfitted with visible and infra-red cameras to assess mangrove forest stands. The drone data are being used

15 https://www.worldwildlife.org/projects/wildlife-crime-technology-project

to identify canopy species, as well as canopy density, heterogeneity, and at fine spatial resolution, vegetation indices to assess forest health (Tian et al., 2017). Ultimately, these surveys provide the perfect dataset at intermediate scale between field plots and satellite, and can be integrated into satellite workflows for biomass estimation, as in Navarro et al. (2019) or applicable to forest health in the context of certification activities.[16]

Also in East Africa, WWF-Germany and WWF-Mozambique have used airborne drones to assess underwater coral reef ecosystems, which are otherwise difficult to observe at large scales, requiring dive and snorkeling gear and methods, boats, all complicated by water depth, tides, and currents. Some areas are often too dangerous or remote even to access, and a drone can easily overcome this, and in these environments is less hindered by terrain or vegetation. The approach delivers fine spatial resolution geo-located images, which can be used to identify benthic habitats and provide extensive field information for calibrating and validating satellite-image derived maps (see figure). There are however, other elements to consider when surveying marine habitats, notably to reduce the effects of sun glint on the ocean surface (Joyce et al., 2019).

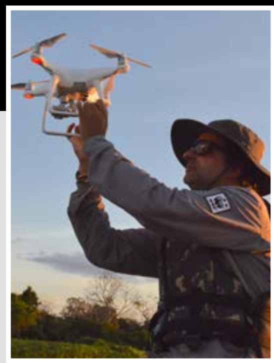
The use of drones in conservation projects is also a powerful way to involve local communities. Between 2018 and 2019, WWF-Brazil trained more than 100 people including protected areas managers, traditional communities, as well as local associations, to increase involvement and combine traditional knowledge with science to detect and prevent forest fires and deforestation. There are similar efforts around the world as NGOs involve local communities in monitoring and patrolling efforts, particularly in the context of reducing emissions from deforestation and degradation (REDD+) projects (Paneque-Gálvez et al., 2014). Involving more people in data collection, while educating them in safety measures, best practices, and providing guides like this one, will ensure that conservation will continue to evolve and improve along with the dynamic drone technology we use.

Figure 30: Training indigenous groups in the Amazon forest to monitor fires and deforestation with the help of drones. © WWF-Brazil/Osvaldo Gajardo

16 https://www.worldwildlife.org/stories/drones-provide-an-up-close-look-at-the-health-of-forests

SURVEYING RIVER DOLPHINS IN THE AMAZON

Marcelo Oliveira, WWF-Brazil



Marcelo is a conservation biologist with 19 years of experience in protected areas management and wildlife conservation projects in different biomes in Brazil. After finishing the Master's in Conservation Leadership at the University of Cambridge, he started his career in the Amazon working mainly on habitat connectivity, the links between habitat and human health, and social engagement in conservation.

Quantifying abundance of wildlife is key for sound management and conservation. Much effort has been invested into freshwater dolphin surveys in the Amazon basin. However, river dimensions and complex logistics limit replication of such studies across the region. WWF evaluated the effectiveness of using Unmanned Aerial Vehicles (UAVs) for surveying two Amazon dolphin species, tucuxi and pink dolphin, in tropical rivers. Compared to estimates derived from visual surveys, the use of UAVs could provide a less expensive and more accurate estimate of Amazon River dolphins.

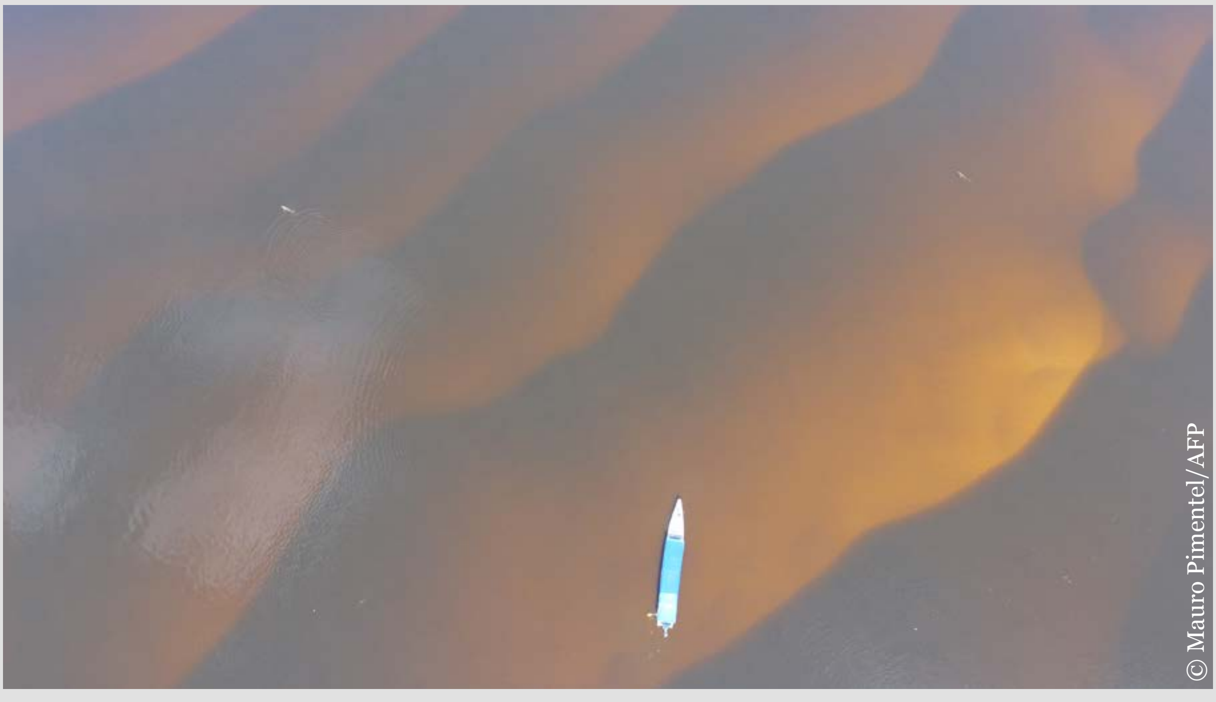
Key advice for conservation practitioners:

1. Experienced pilots are a necessity. The small multi-rotor off-the-shelf UAVs were chosen because of vertical take-off and landing capability required to operate from a boat in movement, and their stability in flight. However, under strong wind situations, the take-off and landing operations were challenging.

2. Follow well-defined operational protocols, including the best practice described in the literature (Hodgson and Koh 2016), and ensure minimal disturbance to wildlife, and the safety of operators and researchers.

Further information:

Oliveira-da-Costa, M., Marmontel, M., Da-Rosa, D., Coelho, A., Wich, S., Mosquera-Guerra, F., & Trujillo, F. (2019.). Effectiveness of unmanned aerial vehicles to detect Amazon dolphins. Oryx, 1-3. doi:10.1017/S0030605319000279



© Mauro Pimentel/AFP

The communal conservancy of Spitzkoppe, Namibia, empowers local communities with the rights to manage and benefit from wildlife, strengthening rights, livelihoods and stewardship of these unique landscapes. © Martina Lippuner/WWF-Africa

10 TECHNOLOGICAL LIMITATIONS, CAVEATS AND SOLUTIONS

10.1 Platform Limitations

Drone platforms can be divided into two types – multi-rotor and fixed wing (as described in **Chapter 5**). There are some limitations shared by both types of airframe, as well some aircraft specific drawbacks. In this section we will deal with each in turn.

Multi-rotor platforms are generally easier to operate than fixed-wing.

Fixed wing drones are generally more challenging to operate than multi-rotor platforms. Firstly, they often require more space to land and take off, and a more involved pilot or co-pilot for launch. Some larger fixed wings can require infrastructure such as a catapult or scaffold ramp for launch, whereas some can be launched with a bungee. Small fixed wings such as the eBee or Parrot Disco can be launched by hand. For drones that do require extra equipment, careful consideration is required as to whether it is feasible to transport this extra kit to survey areas. Secondly, for landing, fixed wings typically require open spaces where they can glide to the ground. This requirement is a key consideration during flight planning. Also, landings can be rough, so designs that protect sensors (e.g. by either embedding them in a recess within the fuselage or installing a servo activated cover plate) are recommended. Next, fixed wing drones generally fly faster and remain constantly moving once in the air. This requires more experienced and confident pilots that are comfortable with the notion that the drone cannot hover over a position as multi-rotors can. Some autopilots may offer a loiter mode which instructs the drone to circle at a given diameter from a GNSS-guided position, which leaves the drone undertaking a predictable behaviour while the pilot makes their next decision. In relation to obstacle avoidance and safe flying, the quick speeds and inability to hover require more advanced piloting skills and quick reaction times. Due to their airframe design and typically single motor setups, fixed wing drones are more sensitive to wind, especially gusty conditions. This means that their operating range tends to be narrower (in terms of weather, wind speeds) than multi-rotors. Wind can also have more of an affect during gridded survey flights, where the drones speed will be affected on 'up-wind' and 'down-wind' legs. Survey design can alleviate this issue to a certain extent, by flying 90 degrees to the prevailing wind direction. Finally, because fixed wings fly longer, they can operate over larger areas, which means they tend to be flown beyond the line of sight, meaning certain legislative challenges may need to be overcome prior to flying **see Chapter 7**).

Fixed wing drones may cover a greater distance beyond line-of-sight, but not exclusively. Check flight permissions.

Multi-rotor platforms are easier to operate due to their ability to vertically take-off, land and hover or loiter in a fixed position. The take-off and landing space required is much smaller, and for more advanced pilots can also be from a moving platform such as a boat. However, they do have several limitations which need to be considered when planning their use for research or conservation purposes. Due to the multiple motors inherent in their design, these types of drones use a lot more battery power during flight and therefore have much shorter flight times than a typical fixed wing drone. This can limit the aerial coverage in a single flight and require surveys to be split into multiple missions. Careful planning of flights, with the possibility of different landing locations to take-off, could aid in covering greater areas in a shorter amount of time. Another drawback of multi-rotor drones is the exposure of components to the elements. Self, or custom-built, multi-rotor drones tend to have more wiring and electronics openly exposed on the frame. While this is useful for maintenance and modification purposes, it also means that, along with the motors, they are vulnerable to ingress from water (salt, fresh and rain), humidity, sand and

Multi-rotor platforms are easier to operate due to their ability to vertically take-off, land and hover or loiter in a fixed position

dust particles (Duffy et al., 2018a). Some 'off-the-shelf' models, such as the DJI phantom, have a plastic shell which helps protect most components from these environmental conditions. Furthermore, it is recommended to have spare components at all times to replace any parts that have been damaged by exposure (e.g. rotors, batteries, propellers). Multi-rotor drones produce a loud buzzing noise from their motors. This can be disruptive or even harmful to wildlife (**see section 3.6**), and is, therefore, a major limiting factor in survey design and operations that involve the surveying of wildlife, or planned in environments with sensitive animals in close proximity. Also, if sensors such as microphones are being used on the drone then (**see case study, page 103**), the noise from the motors needs to be accounted for in sensor design, mounting and/or analysis. Noise is seen as one of the key areas in which the consumer market can be advanced and, as a result, drone manufacturers are working on reducing it in newer versions of their products.

10.2 Sensor Limitations

Regardless of the type of sensor, the weight of the payload is a major limiting factor when it comes to deciding what type of sensors to mount on board a drone platform. The amount of thrust available from the on-board electric motors, size and design of the airframe, will determine how much weight can be safely carried on-board a drone. For commercially available platforms, this limit is usually stated by the manufacturer, whereas for custom made platforms, some calculations will need to be made, given the power of on-board motors. It is also important to note that, alongside the weight of the sensor itself, a mount or gimbal may also have to be considered to stabilize image capture. We advise that, prior to any actual survey flights with a new sensor configuration, tests should be conducted with a 'dummy' weight (e.g. bags of rice) equal to the weight of proposed sensors, so that the pilot can observe the performance of the drone without the risk of losing a valuable sensor should a crash occur.

When using a self-build drone where the sensor is not integrated, the biggest challenge is creating a harmonious and reliable link between sensor and drone, or enabling a sensor/payload to operate independently at desired times or time intervals. The most simple solution is to operate a sensor autonomously, for example by using a camera with a built in intervalometer that takes photos at regular intervals without relying on any cues from the autopilot. This can be achieved with cameras, such as the Ricoh GR II or GoPros, flashing firmware onto an SD card to increase the functionality of a camera (e.g. Canon Hack Development Kit (CHDK) on Canon Powershot D30), or by using a cable to send pulses from the autopilot to the sensor to trigger the shutter (e.g. Canon S110). Alternatives include pre-determined triggers, linked to the autopilot and/or the Tx/Rx system operated by the pilot. This means that sensors can be triggered when certain criteria are met (e.g. distance travelled, position in space, or sufficient overlap; e.g.(Anderson et al., 2016)), or by the pilot remotely activating a switch on their controller/ground station. These types of links and set-ups are crucial for successful data capture with drones. Drone operators should ensure that their sensors operate as desired in different scenarios, and that the link between platform and sensor is reliable.

Consumer grade cameras have become a sensor of choice for many researchers and conservation practitioners due to their affordability, consistency and ease-of-use. To effectively be utilised on a drone platform, a few operational limitations must be overcome or considered. Firstly, in 'auto' mode, many cameras will vary some, or all of, the shutter speed, aperture and ISO settings between photos, in order to obtain a well exposed photograph. While this tends to result in the creation of well exposed photos (especially useful if weather conditions are variable), it means that the images are not as useful for

ASSESSING MANGROVES IN THE RUFIJI DELTA, TANZANIA

Aurélie Shapiro, WWF-Germany

Aurélie is a remote sensing specialist for WWF in Germany, with an increasing interest in collecting data herself using commercial multi-rotor drones.

She has equipped a 3DR Solo drone with a visible and near-infrared camera, enabling it to map high resolution vegetation indices in Tanzanian mangroves, as well as deriving 3-dimensional canopy structure. The mangroves of the Rufiji Delta have a long history of human impact, resulting in changing species compositions, and degradation, which has resulted in an invasive liana establishment, which, in some cases, has completely covered the remaining trees. She uses drones to evaluate the composition and structure of the mangrove forests to determine specific indicators which we can connect and monitor from satellite.

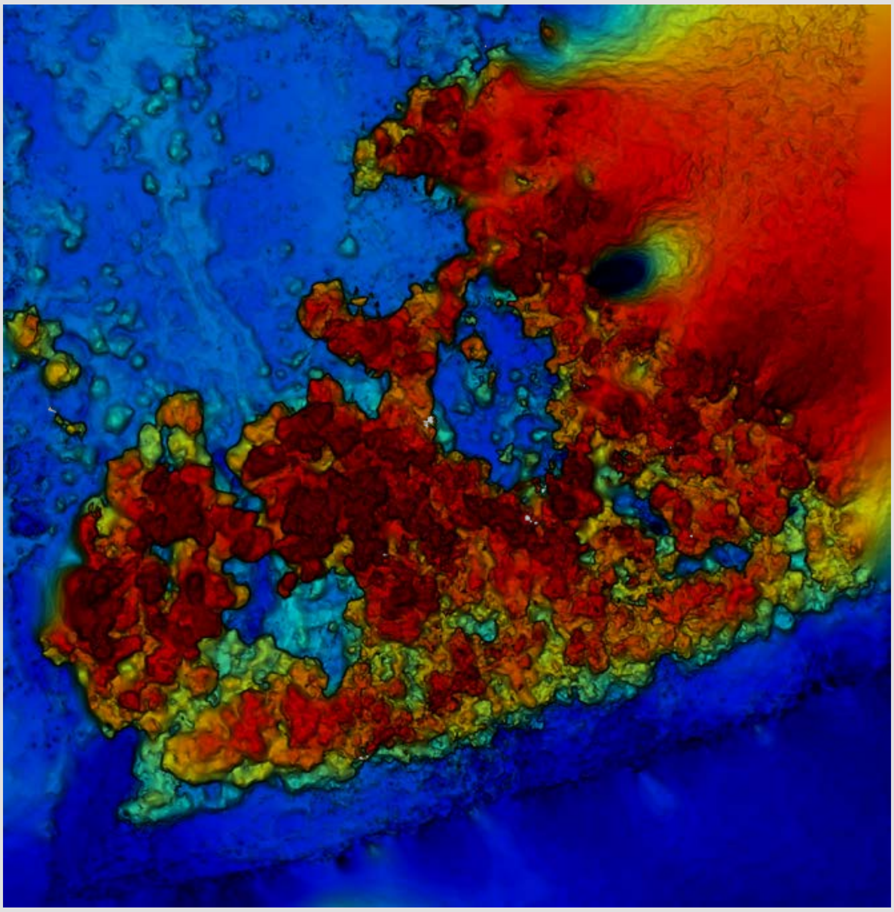
Key advice for conservation practitioners:

1. The addition of a near-infrared camera has provided a whole new aspect of forest remote sensing via drone, with a richer dataset than visible information alone.

2. Launching drones from boats can be a tricky endeavour, so we looked for sand banks exposed at low tide.

Further information:

https://arcg.is/0eXPOm



3D structure of a mangrove stand created from aerial photos taken from a 3DR Solo drone. Darker reds indicate higher canopy.

remote sensing analysis or image mosaicking further down the line, because the exposure varies in space and time. Two ways to help mitigate against this issue include fixing the camera settings in a 'manual' mode, to ensure that settings such as shutter speed and aperture are kept consistent, and/or to enable the recording of RAW images alongside compressed image formats such as JPEGs. RAW files are digital negatives which allow modifications to exposure post capture with fewer negative effects on image quality. With a complimentary set of RAW images, modifications can be made to try and correct exposure differences between images, which is beneficial when compositing images into a mosaic. Lens focus is another issue which can result in a whole dataset being rendered unusable. Ideally, sensors with manual control of focal distance should be used for optical data capture. We recommend that the lens is focussed to infinity, as once at altitude, everything at distance from the drone will be in focus.

Kites are capable of providing aerial data for environmental and ecological research purposes, particularly in inaccessible or difficult environments, or where weather may be too extreme for a motor powered drone.

Thermal sensors also require careful consideration prior to successful deployment for data capture. Firstly, the resolution of image data produced by thermal sensors tends to be much lower than typical optical sensors. For example, the FLIR Vue Pro R has a sensor resolution of 336 × 256 pixels. Ultimately this means that features of interest for which the sensor is intended to image need to be big enough in extent to be picked up by the sensor. Another limitation relates to the type of data being captured by the sensor – are the values fully radiometric (real calibrated measures of thermal emissivity) or relative values. Again, depending on the application, relative values may suffice, but in some cases realistic measures of temperature may be required (for example checking the health of an animal). Fully calibrated sensors are also more expensive, with the FLIR Vue Pro R costing ~50% more than the FLIR Vue Pro.

Figure 31: Humpback whales, honorable mention Wildlife category, 2018 Drone Awards.
© Anders Carlson/Drone Award/Art Photo Travel

10.3 Legislative Limitations

Drone use has rapidly increased around the world, while the legislation has in places struggled to keep pace. Fortunately, progress has been made with regards to obtaining relevant permission from organisations such as the International Air Transport Association (IATA) and the United Nation's International Civil Aviation Organisation (ICAO) working together to formulate best practice and regulation guidelines for nation states, alongside a database of existing regulations from around the world (see the ICAO safety report[17]). It is important to remember that legal drone operations in one country may be illegal in another. Close attention should also be paid to the legality of flying, not just in a given country, but also in a given location. Flying in a rural environment might be OK, but in a national park, or other designated land use, it may be prohibited.

Further legislative barriers to be aware of include those pertaining to privacy, data and radio frequencies. Capturing images of people or private property, and flying in proximity to government installations, should all be taken into consideration and the relevant governing bodies should be contacted for advice. Even data laws should now be considered, with extreme examples, such as that recently passed in Tanzania, having the potential to land anyone collecting unauthorised data in prison[18]. Often overlooked is the fact that, radio frequencies are used by a wide number of different sectors including telecommunications, transport, medical, industrial and scientific, therefore legislation around these tends to be robust and can come with heavy penalties. Some frequencies such as 433MHz, 868MHz or 915MHz are country, or continent, specific based on the particular region's use for telecommunications, whereas frequencies used for WiFi, 2.4GHz and 5GHz, are globally ubiquitous and free to use. It is also worth noting that even if a given frequency such as 2.4GHz can legally be used, there may still be restrictions on the amount of power allowed for transmission.

10.4 Alternative proximal sensing approaches

Kites, balloons and blimps offer an interesting twist on proximal sensing…they are tethered! Therefore, they are often considered piloted as opposed to unpiloted, presenting different methodological and legislative opportunities and challenges. It is useful to consider these alternative proximal sensing platforms, especially when the aforementioned limitations with drone platforms and associated legislation can hinder your ability to undertake proximal data capture. The following section will give an overview of each of these three alternatives.

The technological boom (including lower cost, easily obtainable electronic components) that has helped fuel the uptake of drones has also benefitted other proximal platforms. Kites in particular, are capable of providing aerial data for environmental and ecological research purposes, particularly in inaccessible or difficult environments, or where weather that may be too extreme for a motored drone. For a review of this technology and associated published work see Duffy and Anderson (2016). Kites are well suited to aerial operations in windy conditions that would otherwise be adverse for drones. Suitable levels of wind, combined with kites designed to be stable (e.g. kite aerial photography or KAP kites), provide a useful platform for sensors which one can use to acquire data. Kites are also relatively inexpensive, easy to transport and easy to operate. Compared to lightweight drones, kites excel in all of these areas, making them a feasible methodological choice when resources and logistical capabilities are restrictive (e.g. in remote polar regions (Fraser et al., 1999)). As aforementioned, the tethered nature of kites can reduce

17 https://www.icao.int/safety/Documents/ICAO_SR_2018_30082018.pdf
18 https://www.theeastafrican.co.ke/news/Tanzania-passes-new-draconian-data-law/-/2558/2667678/-/11ywry9z/-/index.html

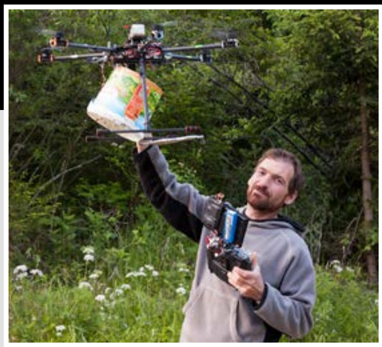
the level of legislative complexity when using them for data capture. This also makes them a potentially safer alternative, especially when considering operations involving animals. It is important to consider these alternative proximal sensing platforms as back-ups for drones. Kites fit this remit well due to their portability and ease-of-use.

Balloons and blimps are similar to kites, in that they can also be tethered. However, they both require helium (of differing volumes) in order to launch and achieve an airborne position. This makes them stable platforms and ideal for data capture in fixed positions, or where variation in sensor position during a given survey is not required. They are also sensitive to wind so have a restricted operational envelope, much like lightweight drones, where high winds make them unsafe and likely unusable for the collection of high-quality data. The need for helium does make them less portable and more logistically challenging proximal sensing platforms. Although the tethered option could result in a reduction in potential legislative hurdles, the risk of transporting and using compressed gas in the natural environment adds complexity to operations using balloons and blimps.

Figure 32: The Skyrunner is a polish UAV Blimp made by sky&you. © Princo85/Wikimedia Commons

BEAR CUBS: YOUR LUNCH IS IN THE AIR

Leonardo Bereczky and Alexandra Dumitrescu, WWF-Romania



Alexandra coordinates the individual fundraising efforts from WWF Romania side to support the Bear Orphanage - the only facility in Europe that deals with orphan bear cubs and their rehabilition to be released in the wild. Leonardo Berecsky built the center 15 years ago and handles the facility, and has adapted a drone to fit the needs of the rehabilitation center. The center is fully supported through charitable support.

Feeding the bears at the Bear Orphanage has always been a difficult process, in order to ensure that contact with humans is kept to a minimum. Food has to be snuck in and hidden in different areas of the enclosed forest so that the cubs have a similar experience to foraging in the wild.

This process has meant that Leonardo Bereczky had to carry large quantities of food on a regular basis up a steep hill and wait for the right time in order to sneak in the enclosure undetected to provide the cubs with all they need.

Fortunately, this is no longer the case as Leonardo has made some modifications to a drone in order to fly in food and release it from high above in the heart of the forest where the bears are located.* A plastic container with a metal lid and an electric remote release can carry up to 1.5 kilograms of food at over 100 km/h. The two kilometer round-trip is flown in just a few minutes, and the flying feeder is quickly ready for another round.

This device has great advantages. The cubs now have almost no contact with humans, nor do they pick up Leonardo's scent, which would have lingered during the prior feeding process, meaning that the only Rehabilitation Center for Orphan Bears in Europe is a major step closer to perfectly replicating life in the wild for the cubs and thus ensuring they have better chances of survival after they are released into the wild.

Feeding the cubs is one of the most important steps in the rehabilitation process. It's not only what they are given, or how much, but the when and how, which can be controlled via drone and is essential to limit the interference of humans into the bearcubs lives.

Key advice for conservation practitioners:

1. Invest in customized drones that can carry multiple functions – not just imaging.
2. be creative

Further information:

1. Support the bear orphanage via WWF Romania Patreon: www.patreon.com/posts/wwf-starts-for-6724158
2. More stories: www.patreon.com/wwfromania
3. And to view more about the bear cubs, and the orphanage, follow WWF Romania on YouTube.

* note that in some countries, releasing things from drones is illegal, so as always, check national laws and regulations.

"Responsible Daddy the Gharial with Babies", runner-up 2018 Drone Awards, Wildlife Category

11 FUTURE TRENDS AND POTENTIALS

Drone technology is advancing apace. Even in the time it has taken us to write this report, technology has changed and adapted. There are a great number of companies and experts working on the next innovation, so here we highlight some of those potential future advancements and frame them in the context of what they could deliver to conservation science.

11.1 First Person View (FPV) flying

First person view (FPV) technology, where pilots typically wear specialized FPV goggles, allows the pilot to be 'in the drone' through a live video feed from a small camera on board the aircraft. Within hobbyist drone groups there has already been an upsurge in the use of FPV technology, particularly for drone racing, since FPV shortens the synapse between the pilot's hand controls and the motion of the aircraft, creating a more immersive flying experience. There are several potential benefits that could be gained within conservation projects if FPV were to become widely employed:

- For longer missions beyond visual line of sight (BVLOS), FPV offers a means of navigating airspace, should legislation allow.
- To capture information about specific target species FPV may be the only feasible way to target sampling (either image-based or physical sampling (e.g. whale sputum sampling, **see case study page 33**))
- For footage to inform conservation actions on the ground (e.g. mark/recapture type studies), the immediacy of information gained through FPV facilitates more efficient capture of target organisms by a ground team.
- FPV is a highly suitable to monitoring the safety of an area quickly – for example, undertaking a rapid reconnaissance flight over an area that is to either be surveyed on the ground, or from the air later on.
- FPV allows for rapid pilot intervention in the event of an unexpected hazard, for example, emergent trees in a canopy that could not be seen during flight planning, or the arrival of a curious raptor.

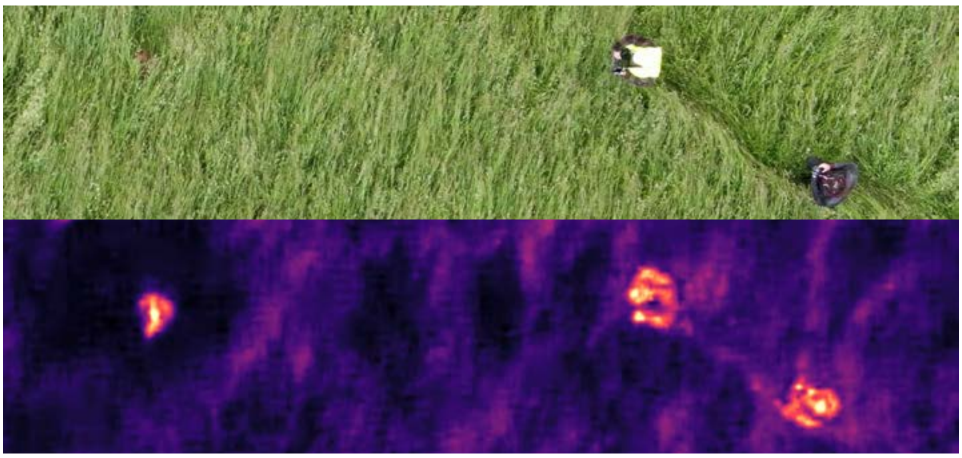


Figure 33: A visible RGB drone image (top) and the thermal vision appraoch for detecting hidden fawns in spring meadows, automatically detected by AI software and rescued before mowing operations. © Adrian Meyer/FHNW

11.2 Caged drones

As has been discussed in Chapter 7, ensuring the safety of pilots and other subjects (humans, animals or infrastructure) is paramount during drone operations. A major cause of concern, and indeed perhaps the largest cause of injury from drones is that propeller sets that can lead to lacerations if flown dangerously. One innovation to mitigate the risk from drone propeller injuries, or damage, involves caging the aircraft in such a way that flight is not interfered with. The Elios drone, for example was designed with civil engineering inspections in mind – the cage allows it to navigate tight tunnels and enclosed spaces without fear of damaging the drone or the infrastructure being inspected. We suggest that beyond delivering enhanced safety functionality, these cages open up new territories for ecologists and conservationists to survey. For example, caged drones could deliver helpful data in underground ecosystems such as caves, or in confined areas where safety is paramount, such as in urban areas. Similarly, if flying in areas of challenging topography, or in highly structured ecosystems, the caged drone could deliver data where other drones cannot go.

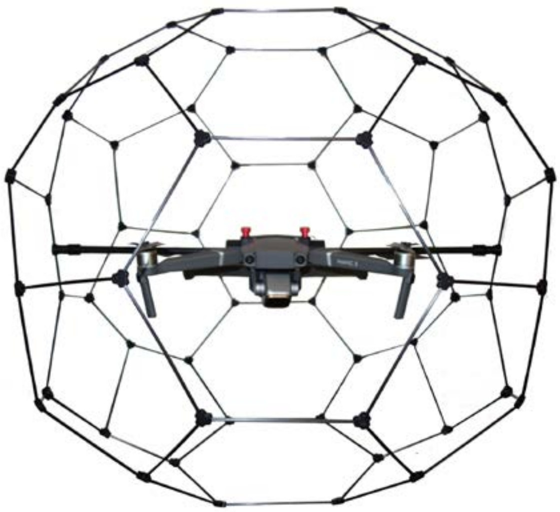


Figure 34: Protective cage for DJI Mavic 2. © Multinnov

11.3 Autonomous guidance

Most modern consumer-grade drone technology now contains autonomous guidance systems, particularly for automatic take-off and landing and detect-and-avoid capabilities. For example, most DJI drones include, as standard, some form of obstacle avoidance technology, and automatic take-off and landing capabilities. In the future, the trend for including such capabilities is set to continue, since legislators place pressure on drone manufacturers to hold some responsibility to ensure that customers cannot undertake reckless flights, or accidentally cause damage to other people or property. Aside from the safety case, these autonomous guidance systems may be useful, or unhelpful, to ecologists depending on the application area concerned. Of benefit is the greater reliability and reduced chance of accidental damage to hardware. However, in certain settings drone pilots may find these control systems to be problematic – for example if data are required in close proximity to features such as trees the system over-ride could preclude data collection. In rough terrain, automatic landing can prove difficult if a flat surface cannot be found, and over-riding the autonomous control is harder in some systems than in others.

In further developments, there are great innovations happening in research and commercial areas that exploit gesture-based control of drone platform movement – in some cases this can remove the need for a controller, since the drone responds to image-based cues within the scene. This relies heavily on computer-vision based algorithms to detect desired subjects, and then gestures (arm movements, facial expressions) before implementing pre-defined manoeuvres. This technology has been designed to anthropomorphise robotic technology to increase the usability of drones and remove the need for complicated joystick-based control (Monajjemi et al., 2016).

New miniaturised hardware is now allowing near real-time image processing to take place on the drone in near real-time, meaning that drones can, for the first time, be responsive in human timescales. The machine learning algorithms that have driven this advancement hold great potential within conservation fields – for example, the method of allowing a waving subject to be identified, and followed, could also be tuned to respond to natural movements of animals to track them autonomously in real time, to enable the drone to respond to certain types of animal behaviour (mating, hunting), or to perform in-flight classification of animal species from real-time video.

11.4 Differential GPS PPK/RTK

Ground based surveying has made widespread use of high accuracy GPS, particularly real-time kinematic (RTK) correction systems which enhance the precision of positional information derived from satellite data, yielding, typically centimetre precision in three dimensions. With drone workflows the traditional approach to achieve such levels of precision with survey data is to calibrate models using RTK-GPS surveyed ground control points during post-processing (Cunliffe et al., 2016, Duffy et al., 2018). This can be a time-consuming activity and therefore reducing/removing the need for ground control is desirable if high geospatial accuracy workflows are desired from drones. This is particularly true when environments are inaccessible or budgets are tight, since the RTK method requires users to have access to expensive GNSS equipment (costing up to €20K). There are now methods for achieving high accuracy ground-based data for a fraction of the above stated cost, exploiting open-source lightweight GNSS receivers such as PiKSI[19] (Varela et al., 2019) however, a preferable method would be to do so in-flight using an on-board RTK-type system. Until recently the issue was the speed with which the GPS sensor on the drone could communicate with the base station to deliver a positional solution in three dimensions. There are now systems available on the market that are beginning to offer workable solutions to this challenge. One example is the Ebee RTK system: a fixed wing drone equipped with RTK-GPS which claims to deliver sub-decimeter accuracy data without the need for ground-control. It does of course, still require a base station to achieve in-flight accuracies to the stated level. Forlani et al. (2018) used this system and showed that, with the inclusion of just one additionally-surveyed ground control point to the workflow, the vertical error (which is usually larger than the x,y error) could be constrained to within 3 cm. The continued issue is that drones equipped with RTK technology remain much more expensive than standard consumer drone systems (perhaps as much as 30 times more expensive per unit), so there is no real cost saving in hardware terms with these systems over a traditional workflow (where a drone + RTK-GPS on the ground are used in combination). However, there would be considerable data processing time savings.

19 https://www.swiftnav.com/piksi-multi

As an alternative to RTK, post-processing kinematic (PPK) GPS solutions are also available on some drones. They differ from RTK systems by not explicitly requiring a dedicated base station in some regions of the world (e.g. the USA where there is a good network of public base stations that can be used to post-process the data ex situ). RTK corrects data in flight, whilst PPK data are corrected after the flight. These are emerging systems and it is not clear where the best benefits for the conservation community lie. However, within a few years we expect that the availability of such systems for drones will be more widespread since high positional accuracy is required for accurate navigation, surveying and safety.

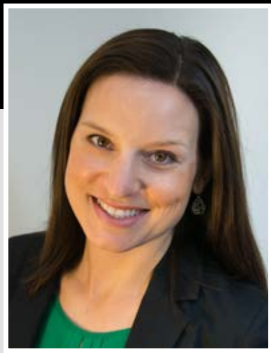
11.5 Swarms

Swarms are multiple drones in simultaneous operation. Operationally, swarm applications tend to be limited to performance or military applications – for example the record breaking performance of 1374 drones over the City Wall of Xi'an (**Figure 35**) or the 2019 Super Bowl. Even within the military, swarms are a relatively new capability, and so it will likely be some time before civilian technology develops to the same level of function. Despite the fact that legislation in many areas of the world precludes the general use of drone swarms, there are potential various benefits within ecology and conservation that can be imagined should swarm operations become possible, and the law be relaxed in future. From a mapping perspective, swarms can be deployed to map larger areas more efficiently than is possible with a single aircraft. For example, from a single launch point, several co-operating drones could fly outwards to collect aerial photography data; allowing improved spatial coverage as compared to a single drone within the same time-window. If such a system could be created, it would also have potentially valuable use for anti-poaching scenarios where rapid response data are needed over potentially large areas. Another imagined application would be collecting data remotely from dynamically moving targets (e.g. tagged wild animals), where cooperating aircraft could hunt for roaming creatures. To realise this, hardware capabilities would need to include within-swarm communication (drone-to-drone, and drone-to-base) and tools to optimise coverage and avoid collision.

Figure 35: Drone swam over the city wall of Xi'an. source: Youtube

DRONES, SOUND, AND ANIMALS

Dr. Laura Kloepper, Notre Dame, USA



Laura Kloepper is an Assistant Professor in the Department of Biology at Saint Mary's College in Notre Dame, Indiana. Her research focuses on understanding the sensory and behavioral processes underlying echolocation in toothed whales and microchiropteran bats, two suborders of mammals that convergently evolved echolocation.

Laura uses drones to record the acoustic and flight behaviour of groups of bats. By equipping the drone with microphones and thermal imaging cameras, the drone can be manoeuvred in 3D space to understand how bats use their echolocation and modify their flight to avoid collisions while flying at very high speeds. An off-the-shelf drone was modified for the research, which was a solution to record high-quality sound without compromising flight performance of the drone.

Key pieces of advice for conservation drone practitioners:

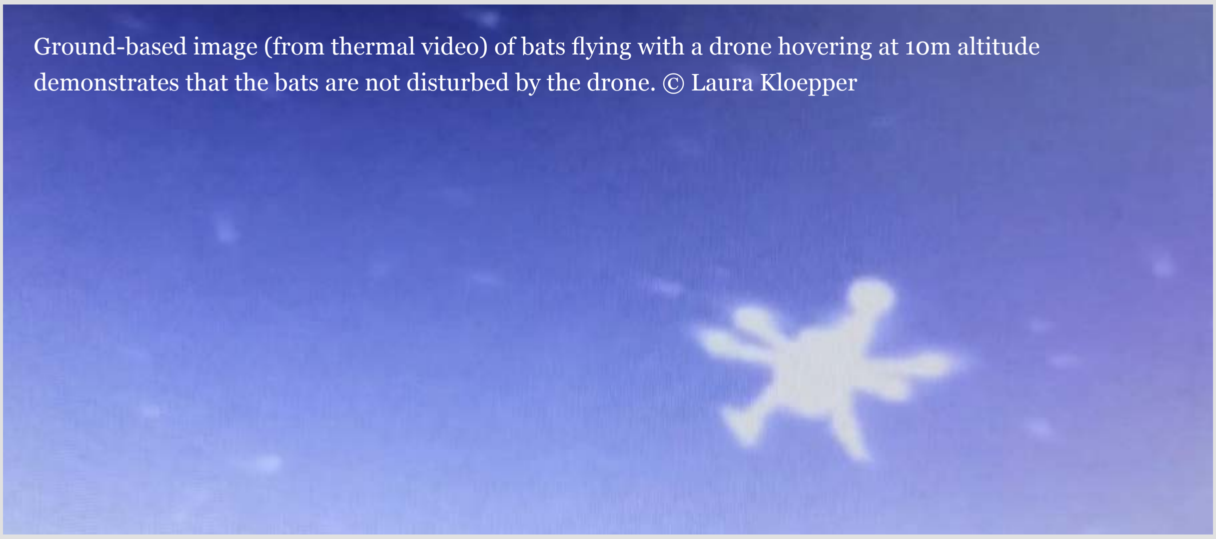
1. It is important to understand that noise disturbance from drones can have a large effect on animals, and that the noise profiles of drones vary wildly by manufacturer. Many animal species hear very differently than humans, so it's crucial to characterize the noise profile of your drone of interest while also considering the hearing range of your target species. Even if you're just photographing animals with a drone, noise disturbance can have negative effects on the behaviour of animals including feeding, social, and reproductive behaviour.

2. When studying a species that has yet to be recorded with a drone (such as we did with bats), it's crucial to develop a conservative plan to both assess the species response to the drone and minimize behavioural effects of the drone on the animal.

Further information:

1. Fu, Y, Kinniry, M, Kloepper, LN. The Chirocopter: A UAV for recording sound and video of bats at altitude. Methods Ecol Evol. 2018; 9: 1531–1535.

2. Kloepper, L.N. and Kinniry, M. 2018. Recording animal vocalizations from a UAV: bat echolocation during roost re-entry. Scientific Reports.



Ground-based image (from thermal video) of bats flying with a drone hovering at 10m altitude demonstrates that the bats are not disturbed by the drone. © Laura Kloepper

11.6 Autonomy in power and charging

One of the most restrictive harwdare features in modern consumer drone technology is battery life (**see section 5.3**), where LiPo battery life tends to fall within the 15 minute to 45 minute boundary for most multi-rotor aircraft (fixed wings may have longer endurance given their enhanced aerodynamics). In the last years, the industry has made strong steps towards improving efficiency and battery longevity per unit weight, with many systems now having 'smart batteries' that deliver a longer life-span and improved information about state and, in some cases, improved energy delivery rates. To realise long endurance missions there is a recognition that drones must move towards more autonomous power systems, e.g. self-powered through solar technology or autonomous charging capabilities. Current science and technology investigations are advancing these threads, for example by:

- Evaluating alternative fuel sources such as hydrogen fuel cells which have greater endurance per unit weight than current lithium-based sources. An example is the B-shark Narwhal 2 multi-rotor system which claims to deliver 2 hours flight time from a single battery. Hydrogen cells are also likely to be less damaging environmentally than lithium batteries which are currently difficult to dispose of sustainably.

- Autonomous charging capabilities are being investigated whereby drones could potentially re-charge themselves when battery levels drop too low. This is already being achieved through landing pads (skysense.co) which charge the battery once the drone has landed, requiring minimal pilot intervention. Simic et al. (2015) proposes a method for resonance-based wireless energy transfer which would allow a drone battery to charge when proximal to a power pylon.

- Equipping drones with solar charging capabilities directly offers another method for improving autonomy. Examples of this so far have been trialled in large concept wing-based models, such as NASA's Helios drone (**Figure 36**) and the new concept Ordnance Survey drone. These systems are, by necessity, much larger than standard off-the-shelf multi-rotors and they are expensive to build and operate. The addition of solar panels increases weight resulting in there being a fine balance between size and energy requirements.

Figure 36: Example of solar-powered wing drone. © NASA

11.7 Upscaling, data assimilation, remote sensing workflow

Whilst there is a plethora of studies using drones in isolation, there remain untapped opportunities to synthesise drone data into wider remote sensing workflows. Typically, drone studies present themselves as improvements upon other remote sensing datasets by virtue of the finer grained data, but as we have discussed, operational issues prevent drones from delivering regional or global extent coverage. Data fusion approaches are already emerging in the precision agriculture and environmental science sectors – using fine-scale drone data to improve the quality of land cover mapping retrievals from satellite data. In these cases, the fine-scale information from the drone is highly useful for resolving spatial patterns in land cover which are particularly useful in complex environments. There remain as yet untapped opportunities for assimilation of drone data into broader RS workflows. We propose that drone data using a variety of sensors (**Chapter 6**) can deliver:

- Information for calibration or validation of satellite data. Vicarious calibration campaigns tend to rely on point-based observations of land or sea surface spectral properties, and drones could improve the spatial representation of such data by allowing sensors to be moved quickly across small portions of the scene. Puliti et al. (2018) have shown the validity of drone data for validating forest stock estimates obtained from sentinel-2 data, for example.

- In data assimilation schemes, fine-grained observations from drones could prove valuable for improving model outputs. To provide one example, Hill et al. (2011) explain that "the use of coarse-scale observations in ecological data assimilation schemes is complicated by spatial heterogeneity and nonlinear processes" and by combining frequent coarse-resolution observations (e.g. from satellites) with temporally sparse fine-resolution measurements (e.g. we suggest from drones), the data assimilation scheme has the potential to provide less biased results. So far, this approach has not been tested with drone data, but we suggest it could be a useful way forward.

- Models of radiative transfer which are used frequently within RS science to predict surface radiative properties from top-of-atmosphere measured signals (e.g. from satellite data) are usually driven in forward mode using synthesised estimations of spatial landscape structure. Inclusion of real data from drone-based SfM for example, into these RT schemes could potentially improve the quality of inversion results, delivering higher quality data to users.

- Fluid lensing approaches are high-tech methods for deriving cm-resolution multispectral 3D maps of submerged aquatic systems, which allow the adverse refractive distortions from ocean waves to be removed (Chirayath and Earle, 2016, Chirayath and Instrella, 2019). Fluid lensing relies on robust physics and requires specialised equipment, but shows great promise for 'seeing through waves' to map benthic substrates.

The above innovations have not yet been realised operationally, and there will need to be significant scientific and technical investment to deliver meaningful products that can be used by those in the ecology/conservation field. We propose that these represent useful foci for future remote sensing work, downstream of which will be benefits for all who use data and products from satellite systems.

11.8 Legislative framework – better integration of drones into airspace

Airspace is a complex, invisible, three-dimensional infrastructure. Until civilians had access to low-cost drones, access to airspace was the privilege of those with a pilots' license and access to expensive aircraft. Drones disrupt access to airspace to some extent, although we argue that there is an airspace stratification that applies to lightweight drone operators and pilots of other aircraft, by virtue of the technological and safety limits applying to the operations of small drones.

Rules of airspace access are controlled by aviation authorities, and there are clear, internationally-accepted, rules that pervade airspace management and access globally – **Figure 37** depicts these generalised rules. Broadly speaking lightweight drones, if operated according to widely accepted protocols (**see Chapter 7**; e.g. <100 m above ground height and line-of-sight-operations) can be used without issue in Class G airspace (**Figure 37**), which allows pilots to operate according to 'visual flight rules' (VFR). VFR are where the drone is kept within the pilot's sight, and action is taken to watch for other air users and maintain a safe distance from them.

We argue that in the majority of cases in ecology/conservation settings operations will take place in Class G airspace, and so operations operations should not be unduly restricted in many areas. Most of the other airspace classes listed in **Figure 37** relate to airspace above the 100 m height limit and are typically found in close proximity to airports or landing strips used by other air traffic (e.g. parachuters or gliders). Of course, national and local rules may restrict drone deployments – such as within national parks and over private property, so drone pilots should check before flying.

Figure 39: Urban Density (2014). © Mark Lehmkuhler

In the future, it is likely that airspace management systems will have to change to accommodate drones of all sizes. New models are being drawn up that would allow for integration of drones into current airspace management systems. For example, **Figure 38** shows a conceptual model being developed by a Californian start-up (AirMap) that will use a software system to keep drones in their own airspace by allowing them to communicate with other aircraft. The future legislation and management of airspace will undoubtedly be decided by federal/national authorities. To provide an example, a new five-year US-based Federal Aviation Authority “Reauthorization Act of 2018” was signed into law on 5th October 2018. This law confirmed some of the controversial rules that the FAA considers critical to its ability to regulate drone traffic. Moreover, it paved the way for funding for drone-specific air-traffic control systems capable of tracking both traditional aircraft and commercial drones.

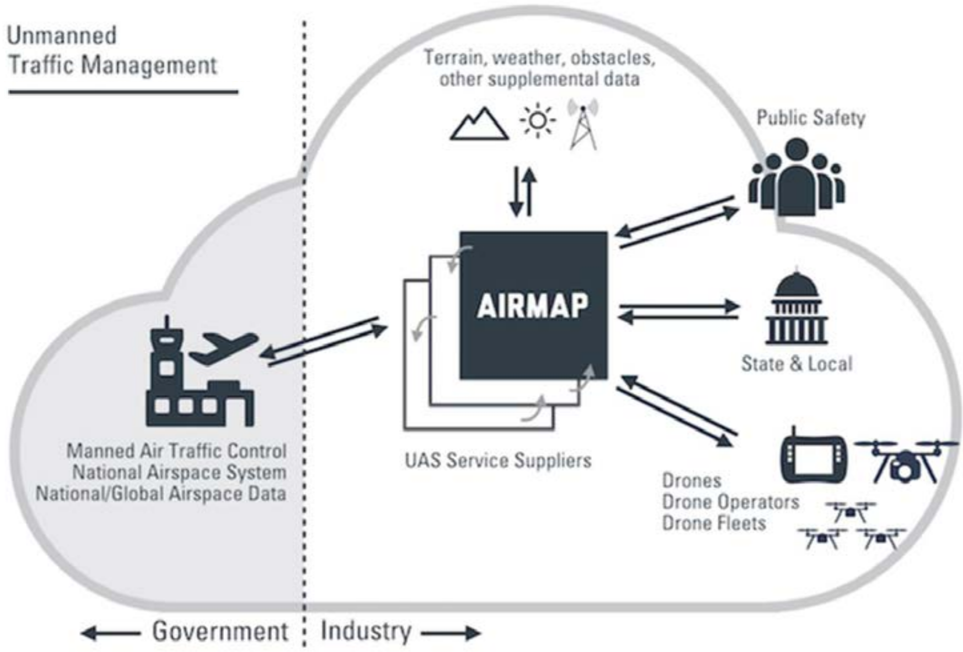


Figure 38: Airspace management system that incorporates lightweight drones.
© www.flyingmag.com/atc-for-drones

The proposed goal of this legislation was to "provide safe, low-altitude operations for both drones and manned (sic) aircraft. The longer-term goal is to accommodate what is expected to be enormous growth in the use of commercial drones, in an efficient way". It uses a NASA-designed system for tracking drones called the unmanned aircraft systems traffic management (UTM) system (**Figure 39**). The plan is that the UTM will be a central point of contact for all drone users including hobbyists, air traffic control, law enforcement and anyone else interested in drone traffic. Similarly, to the generalised airspace classification (**Figure 37**), the UTM divides the aerial volume into discrete airspace classes, defined according to their height and proximity to other hazards and air traffic. The UTM will identify aircraft in each zone, and "communicate with, or influence them to move in a direction that is safe for all aircraft". As a concept, this offers a relatively simple way to manage the flow of drones into airspace, but in practice the complexities of doing so, particularly with respect to prioritising particular airspace users and communicating with drone pilots, would require significant advances in drone-to-drone and drone-to-other airspace and UTM communications. These systems are not operational yet, but give a flavour of how future airspace access may be governed. This could either benefit or hamper ecology/conservation drone operations depending on the level of mandate afforded to lightweight drones over other aerial operations.

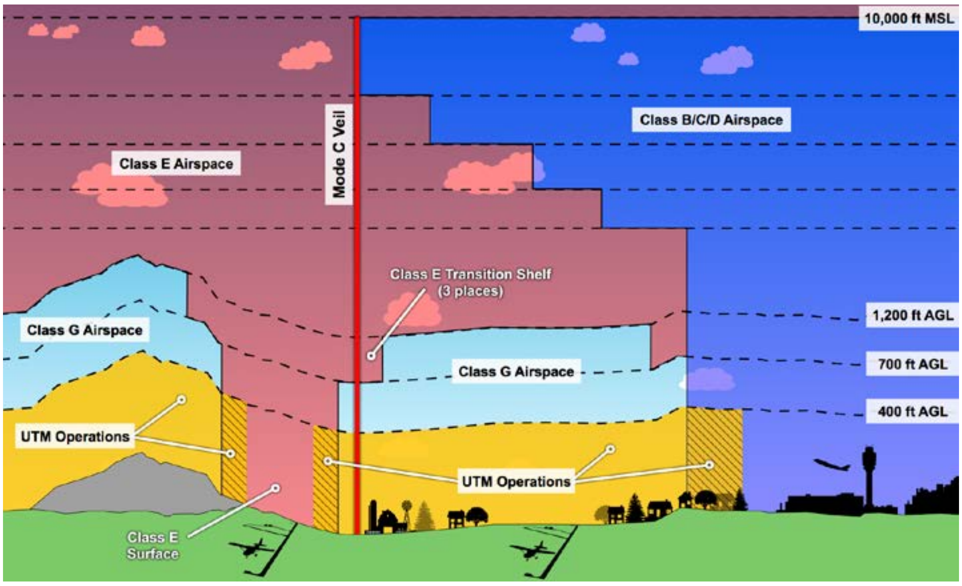


Figure 39: Unmanned Traffic Management System being explored by the FAA. © NASA (https://semiengineering.com/faa-traffic-management-anticipates-flying-cars/)

LOCAL-SCALE IMPACTS OF BOAT ANCHORAGE ON SEAGRASS MEADOWS

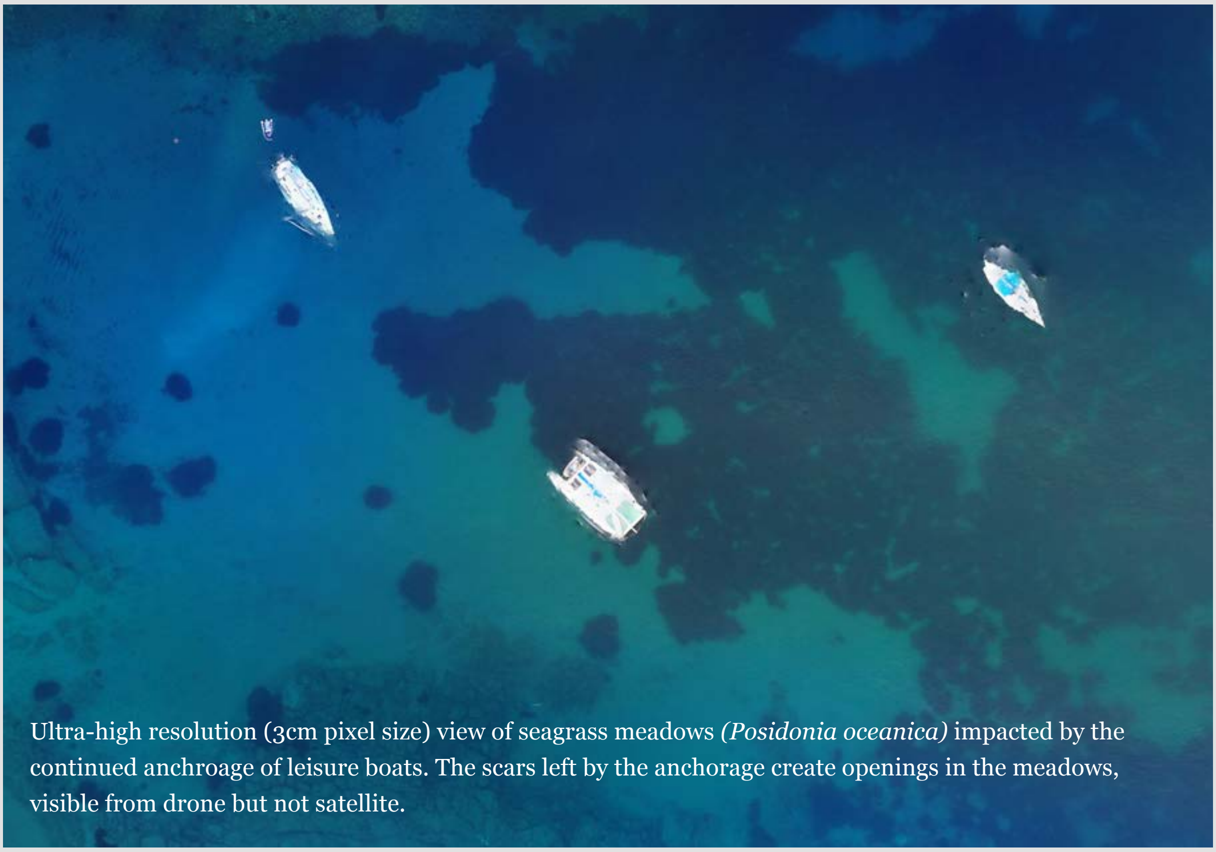
Dimitris Poursanidis, Foundation for Research and Technology – Hellas, the Remote Sensing lab

Dimitris is an Earth Observation Data Analyst, and Marine ecologist, who loves to combine new technologies with field data, trying to provide useful information for conservation activities.

Fine scale assessment of the ecological (health) status of the seagrass meadows, in the National Marine Park of Alonissos and Northern Sporades in Greece, is conducted by means of SCUBA diving and applying non-destructive methods, such as drone surveys. During the surveys, which produce data at the scale of centimeters, information related to shoot density, the compactness of the meadows, the impacts of human activities and the occurrence of litter/debris, is evaluated. The use of drone allows the collection of data at the scale of the bay, or cove, and the post processing of the collected information can provide useful insights on the number of scars at each cove, the spatial location and the size. As such, targeted measures and activities can be implemented in order to minimize the impacts. This information supplements the satellite remote sensing data, which can be used for the location of areas with high densities of boats during the summer period.

Key advice for conservation practitioners:

1. Understand the limitations of the drone in the area you will work and tailor the flight time based on the position of the sun (e.g. avoiding sun glint).
2. Avoid midday flights in order to minimize moving obstacles on the sea surface (boats, swimmers, etc).



Ultra-high resolution (3cm pixel size) view of seagrass meadows *(Posidonia oceanica)* impacted by the continued anchroage of leisure boats. The scars left by the anchorage create openings in the meadows, visible from drone but not satellite.

Seaweed farming in Ankilimionga in the Mahafaly land- and seascape in the Southwest of Madagascar.
© Martina Lippuner/WWF-Africa

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“Great Immigration Birds Eye View” by Thomas Vijayan. Highly commended, Drone Awards 2018, Wildlife Category. © Thomas Vijayan /Drone Awards/Art Photo Travel

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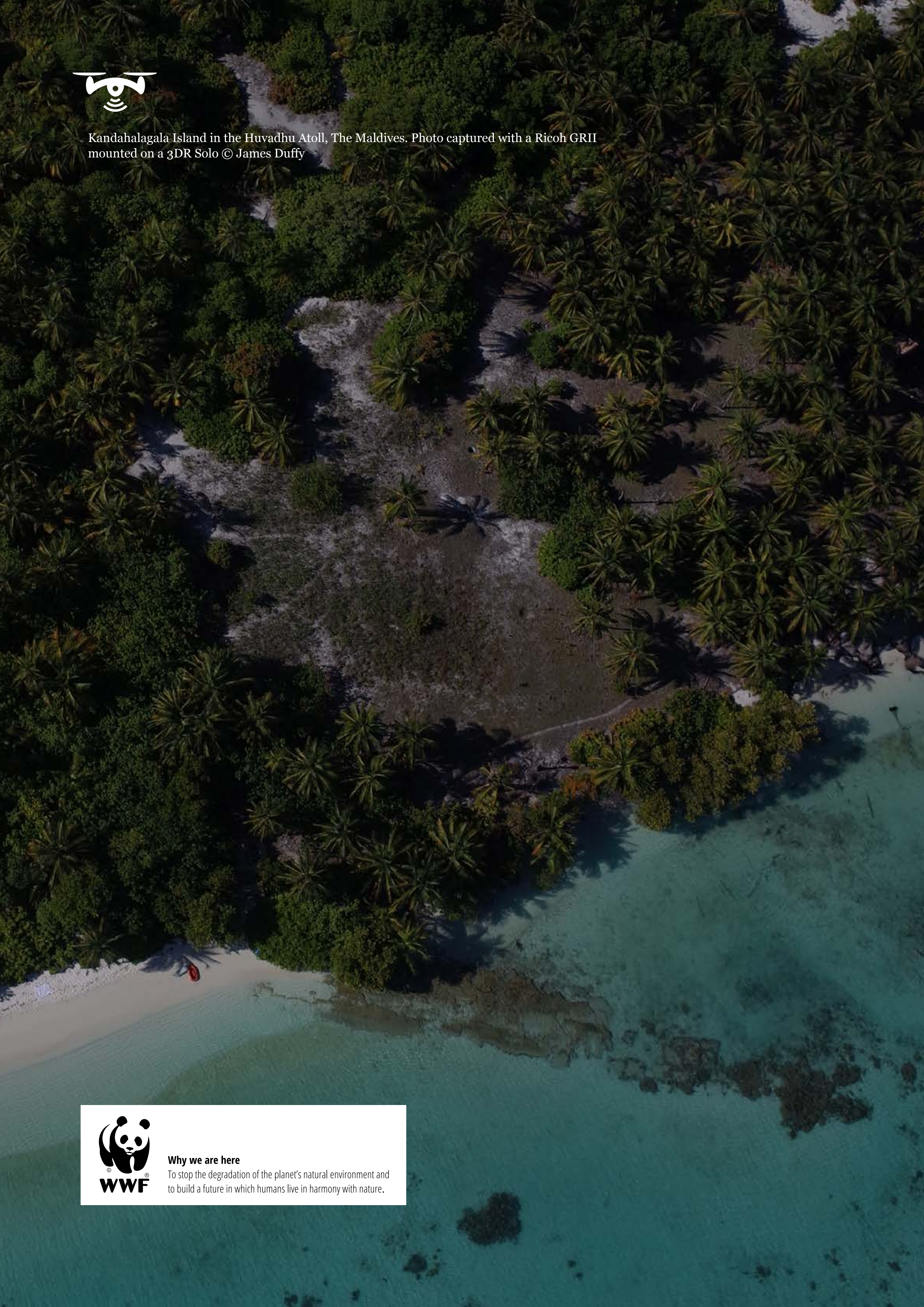

Kandahalagala Island in the Huvadhu Atoll, The Maldives. Photo captured with a Ricoh GRII mounted on a 3DR Solo © James Duffy