DRONE USE FOR RAPTOR CONSERVATION AND MONITORING APPLICATIONS:
Review and best practices

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This report contributes to the Workplan of the Technical Advisory Group (TAG) of the Memorandum of Understanding on the Conservation of Migratory Birds of Prey in Africa and Eurasia (Raptors MOU).

The report and guidelines were prepared by the Science Division of the Israel Nature and Parks Authority to enable the essential use of drones while preventing disturbance and damage to protected nature values.

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Executive summary:

This document has been developed as a contribution to the Technical Advisory Group (TAG) supporting the Memorandum of Understanding on the Conservation of Migratory Birds of Prey in Africa and Eurasia (Raptors MOU), specifically in support of Tasks 16 and 22 of the TAG Workplan. It reviews the application of multirotor unmanned aerial vehicles (UAVs) for raptor conservation-related actions. The document introduces the subject, delineates pros and cons of UAV use, provides a list of best practices intended to standardise operations through all participating countries and provides useful digital resources for practitioners.

The introduction (Chapter 1) gives an overview of the subject, provides basic UAV related definitions, and places multirotor UAVs in context with available technologies used in high-altitude human operations. UAVs often outperform other methods in terms of budget, accuracy, and ease of application. However, their operation was shown to have negative impacts on wildlife, and any application should be considered against other alternatives and performed with caution.

The technologies' advantages are listed in Chapter 2, along with a concise list of optimal circumstances for application. Shortcomings and a list of non-optimal circumstances are given in Chapter 3. Chapter 4 describes successful examples of UAV use relevant to raptor conservation, dealing separately with distant UAV-wildlife interface and close-proximity operations. Chapter 5 contains detailed best practices for UAV application towards raptor conservation focusing on raptor safety through a pre-emptive approach. Future potential of novel UAV technologies is briefly discussed in Chapter 6 and the document is concluded (Chapter 7) and attached with an assemblage of useful resources including links to online material (Chapter 8), Useful templates for recommended tables (Chapter 9), and a list of valuable peer-reviewed publications cited throughout the document and related to the field.

Multirotor UAVs (drones) emerge as a promising prospect for raptor conservation actions. Used correctly, they can deliver rapid, accurate performance of high-altitude technical tasks like documentation, monitoring, pre-emptive deterrence, law enforcement or treatment administration. Practitioners must strive to minimise wildlife risk and maximise the impact of their work by diligently preparing for any UAV deployment to the aerial habitat whilst keeping in mind that any interference has disruptive potential. Adhering to best practices through

planning, execution and post-processing will set operations on the optimal path for successful human-raptor conservation interface.

Best practices for drone operation towards raptor conservation – Bullet points

The following best practices are all equally important and are ordered as they are presented in the main text (Chapter 5).

Objective and feasibility mapping: Understand and clearly state your needs, use a drone only if it is the optimal choice.

Choice of UAV platform: Study the market, learn about your options, choose the appropriate vessel. Seek expert advice and do not rely on "default" devices you may have available.

Task force: Operate in teams of minimum 2 people, ideally 3 – pilot, drone observer and trained ecological observer. Complex operation may require additional personnel.

Site inspection: Make a detailed preliminary site inspection well ahead of operation time, and a second inspection on the day of operation. Set decision rules for emergency cancellation.

Legislation: Understand local legislation about drone flight and your conservation subject, obtain necessary permits, maintain contact with authorities during operation, never fly illegally.

Disturbance minimisation, mitigation and disclosure: Minimise chances of disturbance by planning ahead, actively mitigate disturbances during operation, report incidents immediately.

Interacting with a species for the first time: Conduct preliminary sensitivity test, study responses, proceed with care and attention.

Pre-flight checklist: Prepare a written checklist detailing required equipment and preparations by all team members. Use it to make sure all components of your operation are in order.

In case of unplanned animal response: The ecological observer should look out for animal responses. Fly slowly away or ascend quickly if animals engage with the drone.

Yield handling: Collect and catalogue samples, SD cards or other output immediately after every landing. Do not fly with unsaved data, you may lose it.

Post operation report: Keep written documentation of the operation including achievements, incidents, and team member summaries. You may need it for various reasons.

Digital output: Keep a meta-data file describing your database. Long term storage of digital output should rely on failsafe methods like multiple backups or cloud services.

Biosecurity: Disease transmission endangers animals and humans. Minimize biological risk by maintaining strict hygiene, clean your equipment after each operation, use sanitary protection.

Mission file: Gather all operation related documents in a weather-proof folder and have it with you in the field. Keep the complete file for future investigation or regulatory requirements.

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1. Background

Unmanned Aerial Vehicles (UAVs), commonly known as drones, are battery powered, remote controlled airborne platforms capable of performing technical tasks at precise localizations in three-dimensional space. Common applications of drone capabilities include photography or other methods of documentation, cargo delivery, and use as carriers of tools meant to perform specific operations in otherwise inaccessible places (Emimi et al., 2023). Since the beginning of its widespread civilian use in the early 2000s, drone technology was integrated in many fields of human activity including multiple industries, government sectors, etc. (Tubis et al., 2024).

There are multiple types of UAVs, varying in size, shape, propulsion method and capabilities. The basic aspects characterising UAV systems are configuration and size (usually described in units of weight). There are three main configuration categories – Fixed wing UAVs have an airframe similar to that of regular aeroplanes, multirotor UAVs rely on several rotor engines to create vertical lift and manoeuvrability, and transitional UAVs combine properties of fixed-wing and multirotor systems (for a useful review see Johnston, 2019). Civilian UAV systems range from micro-drones (<2 kg) to large drones (>600 kg), the larger range currently occupied solely by fixed wing platforms (Yindee et al., 2024). This document focuses on the use of multirotor platforms in raptor conservation interface, as these are most suitable for related applications, and are usually the platform of choice (Fantin et al., 2024). Throughout the document the words "drone", commonly used by the general public, and "UAV" will be used intermittently to refer to multirotor UAV system, according to common jargon in the field (Edney et al., 2023).

A multirotor drone consists of several brushless motors, rotors, battery pack, variety of operational sensors, and either a set of integrated equipment or a rack for loading external payloads. Drones are wirelessly connected to a control unit which is usually handled by a pilot on the ground and includes a screen (in many cases a docking station for smartphones or tablets), joysticks, various control buttons and antennas. Vessels can either be remotely piloted in real time or preset to follow a course and perform specific tasks automatically. The designated activity of a drone usually involves carrying a tool to some specific high-altitude destination and keeping it there for the duration required to accomplish its task (Besada et al., 2018). Drones may be obtained as of the shelf products with set specifications, or via custom manufacturers that design and build drone platforms according to specific requirement (See useful resource table, Section 8.6, for a choice of companies and manufacturers).

Up to the introduction and large-scale dissemination of drones, operations involving high-altitude activity required costly, dangerous, specialized human labour (climbing, parasailing, heavy equipment operation, helicopter piloting, even satellite communication), making many endeavours too expensive or risky to pursue (Höhrová et al., 2023). In other cases, capabilities offered by above-mentioned techniques are inadequate for delicate tasks due to disturbance or inaccessibility. Drone use revolutionised how human activity is conducted at high-altitude in many aspects. Compared with previously used alternatives, drones are affordable, safe to use, and require little training to handle properly (Madden et al., 2022). As such, drone application enables practitioners to achieve desired outcomes within budget and technical requirements of specialized tasks, offering an attractive alternative to other modes of high-altitude practice.

When choosing a drone platform while planning drone-based operations, prospective drone operators should consider several technical and legislative factors. First, the drone must be technically capable of carrying the relevant payload for the distance and duration required to complete the task. Second, the level of disturbance (noise, downdraught, etc.) and diameter of rotor swept area must be understood, and its potential impact on the subject of operation assessed. This aspect often contrasts the first one (drone dimensions required to carry the payload create impact risk), and the balance of both will usually determine which drone platform is suitable for an operation. Third, risk assessment should be made regarding the ground below an operation area, which may be exposed to falling debris or equipment. Finally, operators must be fully aware of, and adhere to legislative requirements in terms of licensing (both for pilot and equipment), legal restrictions on speed, altitude or flight in restricted areas, coordination with civil or military aviation control, permitting, and any other administrative measure required for legal operation of drones in the area of operation (Edney et al., 2023). See chapter 5 for a detailed list of best practices for drone operation in raptor conservation actions.

In operations involving wildlife interface, practitioners must also consider potential detrimental effects of drone operation on target animals and their environments (Mo and

Bonatakis, 2022a, 2022b; Rebolo-Ifrán et al., 2019; Sarasola et al., 2018). Physical impact is the first concern, and drones operating in vicinity of wildlife must maintain safe distance to avoid contact between drone and animals or related assets (nest, colony, etc.), which can prove extremely harmful and even lethal (Mo and Bonatakis, 2022b). Contactless detrimental effects, i.e. intimidation, deterrence, and increased physiological stress are all expected when drones operate in proximity to wildlife (Babic et al., 2023; Rebolo-Ifrán et al., 2019; Vas et al., 2015a). Accordingly, one must only execute drone operations in sensitive environments when actual necessity arises and maintain activity to the necessary minimum.

The use of drones for conservation, wildlife management and applied ecology purposes is widespread and constantly growing (Arona et al., 2018; Babic et al., 2023; Brisson-Curadeau et al., 2017; Mo and Bonatakis, 2022a). Drone activity ranges from monitoring for law enforcement or land management purposes to manipulations for experimental or conservation related objectives (Bondi et al., 2018; Ivosevic et al., 2015). Projects involving aerial wildlife particularly benefit from drone technologies, which greatly expand the toolbox available to partitioners interfacing with wildlife living in this challenging environment.

Raptor conservation revolves around avian species of the Accipitriformes and Falconiformes orders (Sarasola et al., 2018). Practitioners in this field direct their efforts towards conservation of birds of prey, related conservation assets (colonies, nests, habitat) and supporting ecological processes. Raptor conservation is a unique branch of avian conservation, requiring its own set of tools and methodologies due to particular nature and life strategies employed by raptors (Bird et al., 2024; Gallego and Sarasola, 2021). This document reviews drone employment towards raptor conservation and monitoring with an emphasis on raptor safety, ecological integrity, and maximisation of success. It specifies a list of best practices in drone operation for practitioners seeking to incorporate drone technology in their work (Chapter 5), and provides a list of useful online resources for practitioners (Chapters 8,9,10).

2. Drone use: Advantages and optimal circumstances

2.1 Advantages of drone use

Conservation practitioners encounter a unique set of challenges in fulfilling their duties (Balmford, 2003; Langford et al., 2011). On the one hand, conservation actions must be highly effective to justify involvement in natural processes. On the other hand, contact and disturbance to natural processes must be kept to the absolute necessary minimum. Furthermore, while the urgency of conservation actions is clear, funds are often limited. Aerial wildlife conservation activity in particular entails additional challenges (Tobias et al., 2013). Conservation assets (animals, nests, colonies) are often highly inaccessible, and any detrimental effect caused during operation can potentially span over enormous areas due to the large distances regularly covered by flying animals (Cryan, 2023). Given this state of affairs in the field, drone technology has several key advantages.

First, drones are largely affordable and their application is likely to fit the budget frame of even small conservation endeavours. Drone platforms range widely in terms of price, yet with a few thousands of US dollars and little overhead expenses in operation or maintenance one can get a sufficient drone for most daytime surveys. If licensed or expert piloting is needed for legislative reasons or due to the complexity of the task, a daily pilot fee (pilots usually operate their own equipment) would range between tens to hundreds of US dollars depending on the complexity of the operation and the required equipment. Such expert services may also be a wise choice for short term operations that require a limited number of flights. As mentioned previously, alternative methodologies capable of providing similar services to those provided by drone operation require specialised, high risk human labour or extremely costly equipment such as cranes, helicopters or satellites. Thus, affordability is an attractive aspect of drone operation (Höhrová et al., 2023).

Second, drones (even the larger commercially available alternatives) are relatively small, highly manoeuvrable, and agile. These are extremely important properties for operations that take place in sensitive aerial habitats or around conservation assets. A properly planned drone operation performed by qualified practitioners can result in centimetre-level precision of execution whether it involves monitoring, documentation, treatment administration or physical manipulation. This “surgical” level of aerial precision is hardly obtainable by any other means and is crucial when performing sensitive tasks such as in-nest feeding or other tasks

involving close contact with conservation assets. Even when an operation does not require close contact and immediate risk to conservation assets, precision in application ensures reliable results in surveys or various monitoring schemes (Edney et al., 2023). In this respect, the ability to repeatedly perform a task from the exact same location in three-dimensional space is highly beneficial, as it standardizes the effort across multiple repetitions and long periods of time ensuring reliable, accurate results (Chabot and Bird, 2015).
Third, even basic drone platforms can operate automatically based on preset flight tracks and task structures. This ensures reproducibility, standardized reporting (predefined task configurations can be attached to reports, manuscripts, etc.), and long-term consistency (Han et al., 2017). Automatic operation also eliminates the human factor from the equation and optimises resistance to winds during operation, both of which further improve operation accuracy.

Finally, drones operate completely independently from the ground environment immediately below their operation sites. This enables operation in otherwise inaccessible sites (above water for example, Joyce et al., 2019) and also minimises impact on terrestrial habitats below operation sites. While a solid, flat landing site is required, it can be flexibly located in a suitable area.

2.2 Optimal circumstances for drone use in raptor conservation

Given their advantages, one can form a list of task characteristics in which drone use is an optimal solution for high-altitude technical operations. These are positive indications to drone utilization rather than strict requirements, and practitioners whose operations are characterised by one or more of the following are likely to benefit from drone incorporation.

- In limited budged circumstances requiring high-altitude operations.
- If an operation takes place in free airspace, like tasks requiring aerial footage or documentation.
- Conversely, if an operation takes place in tight space or around sensitive assets, both requiring delicate manoeuvring.
- If the same aerial procedure has to be carried out multiple times with high precision.
- When aerial tasks are required above sensitive terrestrial environments that are not to be compromised with terrestrial activity, equipment, or human presence.

- When aerial tasks are required above aquatic environments, which makes most available alternatives irrelevant.
- When precise documentation of the performed procedure is required.
- In countries and areas where drone transport legislation is permissive.
- When small payloads (food, medicine, animals) are to be transported to otherwise inaccessible, high places.
- When conservation assets involved were shown to react benignly to drones in their vicinity, or no detrimental reactions were ever observed (see section 5.7 for advice regarding the latter).
- In calm wind conditions, dry weather and good visibility (consult local weather services).
- When eye contact with the drone is constantly possible.
- In sparsely populated airspace with little animal traffic (consult local ecologists about best timing).

3. <u>Drone use: Shortcomings and non-optimal circumstances</u>

3.1 Shortcomings of drone use

The use of drones, especially in conservation-sensitive environments, is not problem free and should not be taken lightly. Operations may be detrimental or even hazardous, and local bureaucracy should be addressed prior to any planning or execution of drone-based schemes.

In terms of disturbance, drones have strong auditory and visual signatures, which were shown to be perceived by, and to detrimentally affect both terrestrial and aerial wildlife, specifically raptors (Lyons et al., 2018; Vas et al., 2015b). When planning drone operations, disturbing effects should be accounted for in several aspects. First, disturbance potential to targeted conservation assets must be understood prior to operation, and the desired effect should be weighed against possible detrimental consequences. This is especially true for operations requiring close-proximity to conservation assets like feeding, medicating or other forms of direct, individual-level support. Second, disturbing effects on other components of the habitat, which are not the designated conservation asset for a given operation, should also be considered in planning and execution. The integrity and health of a habitat is a basic requirement in any conservation scheme, and drone operation in a given airspace is liable to disturb natural processes (Vas et al., 2015b). Here as well, the benefits and drawbacks should be weighed and balanced to ensure optimal results. This holds for any airborne activity, as the aerial habitat is teeming with life and its inhabitants are mostly unaccustomed to anthropogenic presence (Diehl, 2013; Lambertucci et al., 2015).

Another, overarching aspect of disturbance accountability is the temporal scale of disturbance. The immediate effect drone activity has on surrounding wildlife is relatively clear and understandable and will most likely terminate upon the removal of a drone from the airspace (Werber et al., 2023). However, disturbances may have longer lasting effects caused by physiological stress or individual memory, which can cause behavioural changes (space use, scheduling, general apprehension) that can cascade to larger scale ecological changes in the environment. Furthermore, in operations involving repetitive drone activity in an airspace, the repeated nature of a disturbance may further exacerbate above mentioned effects and leave long term impacts on the habitat (Buma, 2015).

Drone operation also involves tangible physical hazards, especially if an operation involves flying in sensitive, populated aerial habitats. It has been repeatedly shown that aerial wildlife is unequipped to negotiate anthropogenic structures moving through the sky (drones, wind turbines, various aircrafts), which fly through the aerial habitat much differently than natural modes of flight (Chambert and Besnard, 2021; De Lucas et al., 2008; Loss et al., 2014). Fast, straight, noisy flight may either intimidate, or be completely unperceivable to wildlife, and may cause (usually lethal) collisions (May et al., 2020). In other cases, the novel stimulus created by artificial objects flying strangely through the sky may invoke curiosity, territoriality or aggression that could cause animals to actively engage drones mid-flight, to the detrimental effect of all parties involved (Lyons et al., 2018).

In operation involving tight spaces, delicate manoeuvring and close contact to conservation assets, the drones' main component of propulsion, its rotors, are a focal point of physical hazard. Drone rotors rotate extremely fast and are made of highly durable materials which easily cut through living tissue when coming in contact with it (Duma et al., 2021). Here, operating in close proximity to wildlife, operators must account for drone size, abrupt changes in wind regime, and movement potential (range, agility) of treated individuals, all of which may lead to direct, lethal contact between drone and conservation asset.

Potential physical impact on terrestrial habitats situated beneath drone-operated airspace is also a matter of concern. Falling debris or malfunctioning equipment and fire hazard originating from the combustible nature of lithium-polymer batteries may damage or destroy terrestrial components of the environment or injure operating personnel. Adequate precautions and safety arrangements must be made prior and during operations to contain such incidents as they arise (see sections 5.6, 5.8).

Finally, the legislative status of drones as aerial means of transport varies between countries, and within countries for different types of airspace (Tsiamis et al., 2019). Drone operation in ecologically sensitive airspace is likely to be prohibited or require special permit, and practitioners should be ready to face bureaucratic difficulties. This is especially true given the fact the drone traffic regulation is constantly evolving to keep up with rising prevalence and capabilities. An operation that was legal one year may become illegal the following year or require a different set of permits and arrangements with local authorities. Thus, drone operators should keep up with legislation as part of their routine and not expect this aspect to remain static. See section 5.5 for best practices in matters of legislation.

3.2 Non-optimal circumstances for drone use in raptor conservation

Given the limitations and hazards, one can list suboptimal circumstances for drone operation towards raptor conservation or monitoring. As with the list of optimal circumstances (section 2.2), these should not be regarded as strict prohibitions, rather as recommendations. If, during drone operation, one or more of the following circumstances occurs, extra care must be taken to avoid damage to involved parties (conservation assets, terrestrial habitat, involved and uninvolved persons, equipment) and the assistance of professional pilots is strongly encouraged.

- In environments which are unfamiliar to operators and were not previously surveyed.
- When an operation requires non-essential close-proximity to conservation assets or other environmental components.
- When conservation assets involved were shown to react detrimentally to drones in their vicinity.
- When noise is known to have adverse effects on the conservation asset or related processes.

- When engine generated winds are likely to compromise conservation assets (nests, small animals).
- In crowded airspace or during periods of intense aerial activity.
- Above crowded, sensitive or combustible terrestrial environments.
- In countries and areas where drone transport legislation is restrictive.
- In windy weather, during rain or in poor visibility.
- When eye contact with the drone and the organisms that may be disturbed is not constantly possible (flying without constant eye contact is currently illegal in most countries).
- Around airports or military facilities without prior approval and coordination.
- In areas with magnetic disturbance or low GPS reception.
- In areas with GPS spoofing.

4. <u>Drone applications to raptor conservation – Successful examples</u>

Drone capabilities enable practitioners to document, interact and even come in contact with raptors and raptor-related assets. Some of the applications mentioned below were mostly implemented on non-raptor avian species, but their applicability and productivity in raptor systems (after proper inspection was conducted, see section 5.7) is highly plausible.

4.1 Distant operations and remote interface

<u>4.1.1 Drone use in high altitude infrastructure proofing for raptor safety</u>

Electrocution is a major cause of anthropogenic related death for many raptor species, specifically larger species or those that interact with power structures for perching, nesting etc. (González et al., 2007; Lehman et al., 2007; Manville, 2016; Sarasola et al., 2018). Electrocutions are recognized as a major conservation concern worldwide, and many countries regulate power grid development towards their prevention (Biasotto et al., 2022). Electrocution often causes power outages and damages the power grid, so conservationists, developers and governments are largely on the same side. Much of the actions taken to prevent electrocution and collisions involve upgrade and maintenance to existing infrastructure. Drones are increasingly used for these proposes in all stages of the process from inspection to installation of insulation gear or bird diverters (Schofield et al., 2020; Kathryn et al., 2024; Zhai et al., 2024).

4.1.2 Drone-based wildlife deterrence

Further on the subject of human-wildlife interface, drone-based deterrence is another developing field of application (Egan, 2018; Hornain and Rosely, 2024; Werber et al., 2023). The encounter between avian wildlife and some types of infrastructure, these days mainly wind turbines, may be lethal to animals and hazardous to humans, like in airports and other aviation facilities (Hunt and Watson, 2016; Matyjasiak, 2008). As mentioned in the case of electrocution and collisions, governments in many parts of the world now regulate the development of these types of infrastructure for wildlife conservation, human safety and infrastructure integrity. The task of deterring flying animals from approaching an airspace is complicated (Rivadeneira et al., 2018; Lukas et al., 2020; Garcia-Rosa and Tande, 2023). Relevant airspace is usually large, animals manoeuvre through three-dimensional space (requiring altitude adjustment of deterrence), and the terrestrial environment below often contains sensitive or dangerous equipment and infrastructure. Drones may provide an attractive solution for deterrence (though not free of limitations) of particular species, specifically large, non-flocking species like many raptors. The ability to accurately pilot a drone to specific locations in three-dimensional space enables fast, accurate response to immediate collision risks, and technical abilities are being developed these days towards a variety of related applications (Werber et al., 2023).

4.1.3 Population monitoring

Population monitoring is perhaps the optimal mode of drone application in wildlife and conservation management (Brisson-Curadeau et al., 2017; Lyons et al., 2019; Edney et al., 2023). Raptor population counts, nesting surveys and related activities require observation of extensive areas and counting of large amounts of individuals. This often has to be done repetitively across long time ranges, and accurately to ensure comparability of results. Many raptor species aggregate in remote, inaccessible areas for communal activities like nesting and colonising. These ecological focal points are crucial indicators of population integrity and health due to the large amount of gathered individuals, repetitiveness across time and importance of performed activities (breeding, feeding, fledging) in the life histories of monitored species. Thus, raptor monitoring and inspection are important conservation actions and considerable effort is being made to perform them.

Drones feature an array of capabilities that streamline monitoring and surveying, make it minimally disruptive to the subject, and maximally efficient to the operator (Gallego and Sarasola, 2021; Edney et al., 2023) . Many drones carry documentation equipment (cameras, sensors, audio recorders etc.) capable of providing high-quality input from far enough to bring drone related disturbance to a minimum, and their use makes human presence on the ground around monitored areas largely redundant. A drone can repetitively and accurately document the same area over extended periods of time, enabling dynamic monitoring schemes and standardized frames of reference to study population trends on the long term (Junda et al., 2015). Another attractive aspect of drone application relates to post-processing of monitoring and survey input. Many commercial drone platforms are integrated with advanced software capable of automizing tasks like counting, composite photography (often required for large areas), and identification of differences between iterations of a documentation task (Srivastava et al., 2022). These capabilities, along with affordability and ease of operation, have brought significant changes to wildlife monitoring, increasing its prevalence, scientific impact, and applicative, conservation significance. Please refer to (Brisson-Curadeau et al., 2017) for a selected list of drone based population monitoring campaigns.

4.1.4 Habitat management and surveying

Another aspect indirectly related to raptor conservation is land or habitat management and surveying. The prosperity and prevalence of any raptor species closely depends on the integrity of its habitat across all aspects. Water availability, vegetation status, animal community structure, and many other habitat characteristics can be surveyed using drones with high efficiency and accuracy (Giambastiani et al., 2020; Monteiro et al., 2021; Jordan, 2023). These activities form another layer of interface with raptors, enabling their preservation through ecological interactions with different environmental components.

4.1.5 Law enforcement

A developing field of drone application, drone-assisted law enforcement is relevant for conservation in general and particularly in raptor protection. Law enforcement actions can benefit from drone use in documenting illegal activity, securing sensitive areas, collecting proof to substantiate cases against offenders etc. (Bondi et al., 2018; Ericksen, 2019; Fish and Richardson, 2022). Raptors are sensitive as conservation assets for many reasons. In many societies they are coveted as pets, hunting assistants or trophies and their nests and colonies are exposed to theft (Abensperg-Traun, 2009; D'Cruze and Macdonald, 2016). Drone-based security and enforcement is likely to prove useful in protecting raptors against these and other malignant activities. Raptors, being apex predators or scavengers, are also highly sensitive to poisoning, which may have devastating effects on their populations (Murn and Botha, 2018; Ogada et al., 2012). By enabling efficient, automated measures for monitoring and surveying large areas, drones are likely to play a protective role in this respect as well.

4.2 Close contact and individual level interface

Operations requiring close contact with raptors or related conservation assets (colonies, nests) can also potentially benefit from some aspects of drone application. Practitioners intending to implement close-proximity interface with any type of wildlife should do so with utmost caution and optimally engage professional pilots, local ecologists and weather services. Drones of all types are potentially lethal if they come in contact with conservation assets and all measures must be taken to avoid such incidents. In cases where potential benefits (or potential harm from other methods) outweigh the risks, drone application should be chosen.

<u>4.2.1. Individual level surveys</u>

Individual level surveying activities, like nesting success monitoring which involves frequent, repetitive visits to specific nesting sites, can be made more efficient and potentially less disruptive using small drones operated efficiently with high precision (Junda et al., 2015; Bird et al., 2024). Such individual nesting surveys can also provide live stream output to practitioners, that can choose to intervene in sensitive situations related hatchling health, poisoning, immediate predation risk, etc.

Another related aspect of this type of action is general-public engagement. Video output of nests and nestling is highly engaging, and if surveyed individuals get habituated to close-proximity drone flight, their consecutive footage can provide valuable content for practitioners to broadcast to the public and receive support for their causes (Bonney et al., 2016).

<u>4.2.2. Close contact wildlife interface</u>

Another aspect of close-proximity drone application involves actual interface with the conservation asset. Drones capable of carrying payloads can deliver medicine, food, or other forms of intervention in extreme cases concerning individual survival. In one such case, Israeli conservation authorities intervened to aid in-nest feeding of a Eurasian griffon vulture (*Gyps fulvus*) hatchling after his mother died of collision. Practitioners delivered food to the cliff-hanging nest, and together with its father, facilitated successful fledging. Such operations should only be considered during cases of immediate danger to the individual studied, which makes drone related hazards comparably tolerable.

5. <u>Best practices list for drone operation in raptor conservation</u>

The following is a detailed list of best practices for practitioners applying drone methodologies in raptor conservation actions. The list was compiled from literature (Junda et al., 2015; Vas et al., 2015b; Joyce et al., 2019; Madden et al., 2022; Srivastava et al., 2022; Edney et al., 2023) and expert experience and adapted to the purposes of raptor conservation. All practices are equally important regardless of their place in the list. Practitioners seeking to utilise drones in their interface with raptors should closely adhere to practices in the list throughout planning, execution and post-processing to maintain human and wildlife safety and maximise chances of success. A shortened, bulletin list of best practices is given in page 4.

5.1 Objective and feasibility mapping

Start operation planning by clearly mapping and stating objectives. Based on the resulting objective layout, compare costs, time frames and expected disturbance of all potential methods. If drone methodology proves to be the optimal one, proceed with planning a UAV-based operation.

5.2. Choice of UAV platform

If objective and feasibility mapping (section 5.1) indicate drones as the optimal mode of operation, UAV platform choice should be the next stage. Practitioners can independently perform market survey and pick suitable vessels from the huge variety available, but expert opinion should optimally be sought. If practitioners already possess a UAV, they should not be tempted to use it as “default” if it doesn’t suit the task. UAV flight time in sensitive ecological context is precious and should be exploited to the fullest by using the optimal equipment. In cases where available, of the shelf UAVs do not suit practitioners’ needs, contacting costume UAV manufacturers should be considered (See section 8.6).

Drone variety is very extensive and choosing the optimal platform is imperative for successful, safe, minimally disruptive application. For operations not requiring high proximity (>5 m) to asset (monitoring, surveying, law enforcement etc.), main considerations include size of area to be covered (which will determine required battery life, flight altitude, desired speed and manoeuvrability), required documentation method (which will determine required payload size and affect power consumption), and local legislation (which may prohibit the use of certain kind of vessels in specific ways like flight altitude or operation in sensitive environments, see section 5.5). For close-proximity operations one must primarily consider asset safety, and would usually prefer the smallest, most manoeuvrable, least disruptive platform (especially regarding noise and silhouette) and capable of executing the task safely.

5.3. Task force

Any UAV based operation should minimally rely on a crew of two-a pilot (preferably trained and licenced) and a visual observer following the vessel as it operates in the airspace. In ecologically sensitive circumstances one should not operate UAVs without close inspection of a local ecologists informed in the nature of the task and sensitivities of the asset and its environment. In close-proximity operations an additional “asset observer” should be included in the team, whose role is to verify asset safety. One must be aware that a territorial raptor can surprise and attack the drone arriving from a “blind spot”. Therefore, asset observers should be positioned as close as possible to the field of close-proximity operation without disrupting the asset, compromising the operation, or putting themselves in risk of drone strike. One of the team members should also take on the role of operation manager, in charge of bureaucracy, documentation, post-processing and other management tasks.

5.4 Site inspection

Once an initial work plan is prepared a preliminary site inspection should be executed, preferably by the entire team (each responsible for inspecting site components relevant to their part of the operation). Inspection should be done in person, and should supply the following information:

- Terrestrial environment: terrain type, topography, land cover, human presence, infrastructure on site, ecological sensitivity.
- Airspace: Obstructions, visibility, wildlife or human presence.

- Access to operation site: ensure safe path to operation site, preferably for vehicular transport. In relevant cases, access to emergency personnel or equipment should be verified.
- Meteorological conditions: Wind regime, temperature, precipitation.
- Ecological circumstances: Inspection of ecological processes taking place around the site (on the ground or in the airspace), important for ecological risk assessment and timing of operation.
- Required legislative measures (see section 5.5).

Once a preliminary site inspection is completed, practitioners should adjust their plan to conform with on-site conditions.

An additional inspection should be made on the day of operation to validate the preliminary one and make sure immediate environmental and ecological conditions are permissive. Here, practitioners should optimally prepare a clear, simply written list of thresholds and prohibitions to enable clear-cut decision making for execution. The list should be based on technical capabilities of the vessel and ecological circumstances, and contain thresholds for weather variables and ecological decision rules (For instance, if an unrelated critically endangered species is present on site, abort operation). If one or more of these a priori made decision rules is not met, practitioners should strongly consider aborting the operation and preparing for another deployment when conditions are ripe.

5.5 Legislation

UAV related legislation is a complex topic to address. Rules vary by site (country, proximity to infrastructure, ecologically sensitive area, etc.), type of drone, and over time as regulation of the field takes shape. Inappropriate use of UAVs can lead to legal actions against operators, damage or loss of equipment, and in extreme cases damage to conservation assets. Law enforcement may be done remotely or automatically by electronic measures which take control of the vessel or bring it down. Such incidents should be strictly avoided in close-proximity operations by maintaining awareness of and strictly abiding with local legislation.

Drone operation may be legally restricted at a given locality in the following respects: flight altitude, flight speed, payload size, lighting on board, drone model or size (usually weight), battery type, battery size, flight mode (automatic, manually operated), time of day, etc. Any operation planning phase (Section 5.1) should include an in-depth inspection of the legal situation in the planned operating area. Operators should contact local aviation authorities, preferably after the initial operation plan is laid out, confirm the legal feasibility of the plan and optimally obtain written approval to operate. If the designated airspace is under special status definition (nature reserve, private land, military facility, civil aviation related land, etc.) operators should also contact relevant authorities and obtain clear, written approval for their specific task.

A further stage of legal validation, not always required by authorities but highly recommended, is real-time coordination with relevant authorities during operation. For this purpose and others, it is useful to have an individual contact to whom details of the operation are disclosed and live updates are given when airspace use commences and terminates. Airspace use is highly regulated in most parts of the developed world and adherence with regulations is crucial for successful, streamlined application.

The legal status of target species and other species likely to be affected should also be ascertained, as operating drones in vicinity of endangered conservation assets may be illegal or considered legally unethical in various places. To this effect, practitioners should address wildlife and conservation management officials ahead of time and obtain necessary permits according to operative requirements. Most raptor species are protected by local laws and international treaties, and practitioners seeking to interface with raptors using drones must do so in coordination with local environmental authorities.

5.6 Disturbance minimisation, mitigation and disclosure

Drones operating in the airspace generate multiple layers of disturbance. It Is important to acknowledge that disturbance goes beyond the immediate presence of a drone in space, may have prolonged cumulative effects, and can cascade to other components of the ecosystem. Thus, disturbance treatment should be properly executed with the notion that proper planning and avoidance is far preferable to mitigation and remediation.

Practitioners should address the issue of wildlife disturbance by maintaining a three-layered best practice approach:

- *Minimisation*: The likelihood and scale of disturbance to target individuals and surrounding ecosystem should be minimized during the planning phase. Season, time of day, drone model, flight path, ground activity and any other aspect of an operation should be designed to minimise wildlife exposure to drone activity whilst maintaining the desirable outcome.
- *Mitigation*: This refers to actions taken during operation to minimise disturbance or likelihood of wildlife-drone contact. This aspect should be conducted by the residing ecologist in the field during operation, who should visually monitor the drone and gage asset and ecosystem response to the operating vessel. The ecologist should also oversee natural processes taking place in the vicinity of the operation. If unacceptable levels of disturbance occur during operation (mass movements, inter-species interactions, etc., optimally these were defined in advance during the threshold planning phase, see section 5.4) the ecologist should use his professional judgment and decide whether the operation should be changed, aborted to resumed.
- *Disclosure*: In cases where acute effects of disturbance are witnessed, it is the practitioners' duty to immediately abort the operation, remove the drone from the airspace, report the incident to local authorities and fully cooperate with any necessary actions taken to contain the effect. Here also, resident ecologist discretion should be the base for any decision making. Practitioners should be prepared with relevant contact information in case of acute disturbance and address the contact without delay, keeping ecological integrity as their first priority.

5.7 Interacting with a species for the first time

In operations involving species whose reaction to drones was never documented or studied, practitioners should conduct a preliminary "sensitivity test" before attempting to execute their mission. The vessel should be piloted to make a gradual approach to the asset (colony, individual, nest, etc.) starting from far enough to contain any unexpected response. Wildlife responses should be studied and susceptibility to drone related disturbances balanced with operational needs and final objectives. Some research suggest that this can also help habituate animals to the stimulus, which might mitigate acute disturbing effects. However, habituation responses are species specific, and this should not be taken as a given.

5.8 Pre-flight checklist

It is the pilot's duty to perform any pre-flight checks or protocols according to drone manufacturer's instructions. These should include inventory checks for all necessary equipment (including spares and sufficient stock of perishables to carry through the mission), software updates, drone calibration, personnel check-up and authority notification. Below is a suggested check-list form for generic surveying operations, which could be adapted to facilitate other types of missions as well (Table 1).

In close-proximity operations, the team should be prepared to administer emergency treatment to conservation assets in the field in case of emergency or accident. At least one team member should be trained in trapping and administering treatment to individuals from the target species, and any necessary equipment should be present on site. This includes trapping equipment (cages, ropes, bags, face covering, protective clothing for handler), first aid necessities, and enough fuel or other means to enable rapid evacuation. Such a first response kit should be prepared in advance with the help of a veterinary doctor and at least one member of the team should be closely acquainted with the kit's content and order.

5.9 In case of unplanned animal response

If conservation assets show signs of detrimental response to drone presence, the team should execute a disengagement manoeuvre meant to distance the drone from the animal quickly and without causing more stress. It is the asset observers' role to look out for signals of engagement or response by the animal. Some species were shown to mob, attack or otherwise engage flying drones, which is hazardous to all parties and highly undesirable. In cases of response, pilot should either fly slowly away from the animal and its home env/ironment or immediately increase altitude to the maximum permitted legally in the operation area. This manoeuvre should be executed in coordination with the entire team, who should optimally train for such circumstances in advance.

5.10 Yield handling

Many drone operations are executed with the prospect of obtaining some type of yield. In survey or monitoring operations this would usually be one or more SD cards containing data collected during operation. In close-proximity operations yield may take the form of biological samples or even living individuals. Practitioners must remember that obtaining this yield was the main purpose of their operation (and related disturbance affected on the asset) and treat it with maximal care.

5.10.1 Electronic yield: Any electronic material should immediately be stored and backed-up. SD cards should be cleared and formatted before each operation and retrieved every time the drone lands. The information is valuable and may be lost if equipment breaks down.

5.10.2 Biological yield: Operators performing drone-based biological sampling should be prepared in advance with all equipment and capabilities necessary to obtain and secure samples upon completion of the operation. This includes biosecurity measures for minimising chances of disease spread, equipment required to meet sterility requirements and freshness of samples, and means for proper storage of samples for the commute to a laboratory. Again, these samples are invaluable and were obtained at a cost of disturbance and risk to conservation assets. Take great care to ensure their integrity.

5.11 Post-operation report

Post operation reports are often required by permitting authorities and are also useful for documentation and follow-up procedures away from the field. The report should contain a description of the operation, species monitored and species' reactions to the drone, measures of success or failure, description of yield (SDs used, food administered, etc.), unexpected occurrences, and a short contribution from each team member disclosing their aspects of the operation. A post-operation report template is given in Table 2.

5.12 Digital output

For operations involving electronic documentation, a standardized protocol for data handling and storage should be established and maintained during the entire campaign. On site, data should be handled as specified in section 5.9.1. On the long run, a meta-data file should be used to keep track of operations and data storage. A basic meta-data template is attached below (Table 3). Data should optimally be stored in a way that ensures its long-term availability in a failsafe manner (multiple backups, cloud storage).

5.13 Biosecurity

Biosecurity is a major issue when dealing with wildlife, especially in avian systems. Disease vectors can be transmitted by contact and lead to zoonotic outbreaks, inter-species or inter-colony infection and other unwanted situations. In regard to birds, in the case of an outbreak of highly pathogenic avian influenza in the area of operation, special precaution measures should be considered. All precautions should be taken to avoid biological contact between conservation assets, and between conservation assets and humans. Practitioners should maintain personal hygiene, avoid arriving on site while sick and wear masks if coming in close contact with animals. Equipment should be cleaned and sterilised, optimally after each flight. If biological material is collected, it should be handled according to stringent protocols. Biosecurity is an important topic, and proper attention will keep operators healthy and conservation assets safe.

5.14 Mission file

Consistency and reproducibility are key for long term conservation efforts. For these to exist throughout a project, practitioners must maintain a well-ordered record of their actions and resulting output. Operation managers should keep a mission file (hard copy or digital) for every individual flight to gather all documents related to the operation. Doing so will maintain order, enable streamlined communication with authorities (which may require different bits and pieces of information), and facilitate long term improvement based on accumulated knowledge. The file should contain all documents and tables mentioned so far (Table 5), relevant literature, and any other related document. Practitioners are likely to benefit from having their mission file in the field with them during operation for unexpected situations.

6. Future potential of emerging technologies

Two decades ago drones were large, cumbersome aerial vehicle mainly used by security forces (Hossain, 2022). Rapid development in multiple fields including power storage, computation, communication and remote sensing pushed drone technology forward. Today drones operate across many fields of human activity, from construction to emergency services, providing quick response and extended outreach. This accelerated dissemination and demand for UAV capabilities drives development further still, and future developments are expected to herald new, exciting implementations.

6.1 Improvements in basic specifications

Practitioners should expect increased flight ranges, speeds, payload capacity and battery life as drone industries embrace novel technologies (Doornbos et al., 2024). Such improvements in basic specifications should enable longer missions and extended ranges. Monitoring and documentation operations are expected to become practical for assets (colonies etc.) situated further away from practitioners, and to include larger areas. Increased payload capacity is likely to enable more sensors to be carried on board, increasing scope and efficiency. Close-proximity operators are likely to benefit from the ability to use smaller vessels for missions that used to require capabilities of larger ones, and increased speed and manoeuvrability will reduce collision hazards and minimize disturbance duration.

6.2 Data processing and artificial intelligence (AI)

Increased onboard computing power will allow drones to implement novel software aimed at independent operation and decision making (Buchelt et al., 2024; Caballero-Martin et al., 2024; Nwankwo Constance Obiuto et al., 2024). Artificial intelligence tools will enable automatic identification of natural components (individuals, structures, environmental conditions) in the field, opening an exciting range of opportunities. Operators could use such capabilities to automatically scan and search through vast expenses of unfamiliar space, extending their reach efficiently and reliably. Advanced systems could also be "taught" to identify threats, alert authorities in cases of need (criminal activity, wildlife emergencies, other specific circumstances) and even provide automatic deterrence when needed.

6.3 Swarm intelligence

A major direction in cutting edge UAV development, swarming involves the use of multiple vessels in unison towards a joined objective (Zhou et al., 2020; Abdelkader et al., 2021). Drone swarms can significantly increase scope and range for existing implementations and introduce new possibilities. Centrally operated swarms have potential for large scale deterrence of aerial wildlife from infrastructure, an important aspect of responsible human development into aerial habitats. Many deterrence missions are impractical for single drone operations due to the size of restricted areas, heterogeneity of threats, and limitations of range and battery life. Swarms are likely to solve most aspects of this issue by operating multiple vessels in unison and providing digital resource allocation. Swarms are also likely to be incorporated into survey and monitoring operations, providing greater coverage, multiple vantage points, central control of extensive missions, and live documentation of ecological processes in multiple sites.

6.4 Integration with other technologies

A prospect with interesting logistical implications. Operators will be able to automatically deploy drones based on sensor input from the field, shortening response time and increasing efficiency (Tuyishimire et al., 2017). Another option, soon to be operational, is the use of drone as "data mules" for distant data collection from remote stations such as field cameras, acoustic recorders, etc. Here, communication components in both devices will interact to deliver collected data to storage space in the drone, which will subsequently deliver it to operators at the back end. This is an exciting prospect for environmental practitioners, who often deploy long term stationary devices for data collection and subsequently make costly, disruptive, significant effort to retrieve collected information.

Drone capabilities are constantly improving. Practitioners relying on drones for their duties or considering drone use for specific operations should stay up to date with available technologies via online sources (see chapter 8) and expert consultation. Practitioners requiring capabilities which are commercially unavailable from major distributers should consider custom drone manufacturers, who are often capable of delivering drones with extended abilities.

7. Conclusion

Raptor conservation actions can significantly benefit from harnessing UAV technologies to interface with raptors or study them from afar. Environmental professionals dealing with raptor conservation are operating with sensitive creatures in challenging environments. Challenges arise from raptor ecology (behaviour, reproduction strategies, home ranges, nesting habits), the variety of threats, human-wildlife conflicts and irresponsible human conduct. These days, as human expansion up to the aerial habitat is accelerating, high-altitude technologies supply us with energy, transportation routes, living space and other basic necessities. Bringing cutting-edge drone-based solutions to the field of raptor conservation increases productivity, efficiency and safety of operators and wildlife.

Drones are useful throughout the entire range of raptor conservation activity from remote monitoring, habitat surveying and environmental law enforcement to close-contact biological sampling and rescue interventions of individual animals. In many cases, the use of drones is likely to be more affordable, less time and human labour consuming, less disruptive and safer. As such, drones are expected to integrate across the field and become fundamental to the way we interface with raptors and their environment.

As this integration unfolds in pace with technological development and growing conservation needs, practitioners must acknowledge their role as gate keepers to the delicate world of aerial habitat interface. Along with great technical potential, drones introduce a novel type of presence to the airspace and its long-term effects are poorly understood. Their use should be done in strict precautionary manner, with a clear understanding that harm prevention is far preferable to cure. As long as practitioners maintain this mindset an operate professionally and responsibly, drone related hazards will gradually be contained and raptor species throughout the world will substantially benefit from these man-made “allies in the sky”.

8. <u>Online resources</u>

The following is a non-exhaustive list of drone related online resources meant to provide practitioners with a first step for online surveys towards drone operation. The list contains freely accessible resources (for academic, peer reviewed resources see bibliography), and was compiled so that it addresses a wide international audience.

8.1 Drone manufacturers and suppliers

A list of major drone manufacturers world-wide compiled by Wikipedia, containing access links to information and homepage of each company.

https://en.wikipedia.org/wiki/Category:Unmanned_aerial_vehicle_manufacturers

DJI homepage: DJI is currently the largest drone company and global leader of civilian drone innovation. The site features available cutting-edge technologies, product reviews and an international list of outlets.

https://www.dji.com/global

DroneNerds: A major US distributer of leading drone brands. The site features a great variety of platforms and related content written by professionals in the field.

https://www.dronenerds.com/collections/drones-enterprise-drones-quantum-systems

Copters: A major EU distributer of drones and related equipment.

https://www.copters.eu/58-outlet

8.2 Legislation

Drone regulation database: A useful resource supplying practitioners with legislative information across most countries:

https://www.droneregulations.info/

EASAs (European Union Aviation Safety Agency) comprehensive website for drone legislation and regulatory aspects:

https://www.easa.europa.eu/en/the-agency/faqs/drones-uas

The US Federal Aviation Administration's homepage for drone users, containing up to date regulations, administrative resources, and useful information:

https://www.faa.gov/uas

8.3 Conservation

Conservation drones: An international cooperation of drone operators and conservationists working towards conservation improvement via drone technologies. The site contains useful information for practitioners, success stories, drone construction guides and other useful material.

https://conservationdrones.org/our-story/

WWF Techhub: A WWF resource for conservation practitioners involved in drone operations or those considering it.
https://techhub.wwf.ca/technology/drones-uav-monitoring-surveying/

Drones.gov.au: Operated by the Australian government, the site contains useful information for local users, good advice and successful example of drone use in environmental management.
https://www.drones.gov.au/benefits-and-use-cases-drones/environmental-management

8.4 Operation

DJI pre and post flight checklists for pilots:
https://www.d1store.com.au/lounge/content/drones-pre-and-post-flight-checklist?srsltid=AfmBOorpM9NFK0C2brY5VVa4JI8jHh9wGQEOrwPDALS8sA7pjnyo7DL2

DARTDrones: A drone training platform featuring thousands of pages of free and paid content including courses for all levels.
https://www.dartdrones.com/resources/

A Drone Industry Insights review and meta-analysis of drone markets, operation, and expert opinions.
https://droneii.com/free-drone-resources?srsltid=AfmBOor_dNOQFuIQqLq8oVDIWQm0FuxBMs9C9mpWgxxRcAPqBJrdlfff

8.5 Software

Autopilot software:
https://px4.io/
https://ardupilot./
https://www.jouav.com/products/software/
Flight planning software:
https://www.sphengineering.com/flight-planning/ugcs
https://www.djiflightplanner.com/
https://www.droneharmony.com/

Mapping and surveying:

https://www.drone.io/

https://www.dronedeploy.com/

https://www.pix4d.com/

Others:

Online calculator for drone output and specification.

https://www.ecalc.ch/xcoptercalc.php

Basic flight time calculator.

https://www.omnicalculator.com/other/drone-flight-time

8.6 Custom drone manufacturers

Luminier: A versatile company working in multiple industries.

https://www.lumenier.com/

INDEX Drones: A company specializing in in affordable, customised drone manufacturing.

https://indexdrone.com/product/customized-drone-manufacturing/

Robotican: A robotics company specializing in cutting edge, independently built drones from tiny documentation platforms to huge, combustion powered carriers.

https://robotican.net/

8.7 DIY drones

DIYDrone: Distributer of DIY drone kits, site has relevant content, forum and community discussions.

https://diydrones.com/

A detailed, illustrated guide for DIY drone construction.

https://www.instructables.com/The-Ultimate-Guide-to-Building-a-Quadcopter-From-S/

9 Template tables

Table 1: Pre-flight checklist adapted from (Edney et al., 2023)

Planned survey date:		
Survey objectives:		
Location:		
Team members:		
Permit number:		
Emergency contact:		
Checklist:	**Notes**	**Completed?**
Equipment and set-up		
Recommended equipment list	• Drone x1 (a spare drone is an advantage) • Batteries x3, properly stored (1 for use, 2 spare) • Charger, if field conditions permit • SD cards – twice the expected needed memory space • Controllers x2 (1 for use, 1 spare), fully charged • Landing platform • Sanitation equipment (alcohol, detox wipes) to clean drone between iterations and maintain biosecurity • Spare parts (propellors, motors, etc.) • Safety equipment for team (glasses, gloves, proper clothing, shade, rain shelter) • Handheld anemometer • Fire extinguisher/fire blanket and lipo-safe bags (in case of battery failure) • Fully charged cellphone or other means of communications • Sustenance for team according to team size and expected mission duration • Built-in software is up to date • Maps downloaded for cases of communication lost and offline operation	
Set-up	• Batteries intact, fully charged and inserted in drone • SD card empty and inserted in drone • Payloads securely attached • Remote controller has an empty cache • Team members fully able to immediately communicate with each other • Trapping equipment • Operative emergency evacuation vehicle and route • First response treatment kit	
Close-proximity emergency equipment	• Flat surface for emergency treatment administration, and means to sterilize it • All the above should be adapted to target species based on veterinary advice. In operation where non-target species presence is dense, preparations should be made to handle relevant emergencies as well.	

Personnel	
Know your team – ask the following questions	• Any illness? • Any medications? • Causes of stress? • Alcohol or drug consumption in last 24 hours? • Sufficient sleep? • Sufficient sustenance? • Ready to operate?
Drone settings	
Suggested setting pre-flight check up Consult user manual and manufacturer resources for checkups relevant to your particular vessel	• Calibrate Compass and IMU. • Strong, consecutive GPS reception (metals and unrelated electronics may interfere with signal). • Drone home point set as controller, not take-off location. • 'Return to home' failsafe appropriately set e.g., fly vertically up then horizontal, rather than shortest possible route (a diagonal line). • Documentation scheme set according to plans and requirements (functional documentation equipment, operation regime, resolution). • Capture RAW images unless battery life is an issue.
1) Flying	
Take-off	• Take-off and landing position (TOLP) should be even and far from rock/ice walls. • Area downwind of the drone should be clear. • TOLP set at least 100 m from conservation assets to minimize disturbance. • Make sure drone is facing away from the pilot and that gimbal and documentation equipment are not in contact with the substrate.
During flight	• Grid flight pattern with 70-80% forward/backward overlap and 60% sideways overlap is advised for count operations. • Altitude and speed alterations should be made at least 50 m away from conservation assets. • Pilot, observer and asset observer should maintain constant contact as long as the vessel is airborne.
Landing	• Land when battery falls below 30% • Set landing site at least 100 m away from conservation assets. • Make sure team members are all informed the vessel is approaching. • Sanitise equipment • Remove and secure SD card

Table 2: Post-operation report template

Operation date:	
Survey objectives:	
Location:	
Team members:	
Permit number:	
Operation summary:	
Main findings:	
Authority reports:	
Electronic output description:	
Biological output description:	
Unexpected events:	
Team member summary:	Mission manager: Pilot: Drone observer: Asset observer: Ecologist: Other:

Table 3: Meta-data

Ord.	Campaign	Operation date	Location	Flight number	Manager	Data type	Storage location	Owner	Contact
1									
2									
3									
4									
5									

Table 4: Biological sampling form

Ordinal biological sample number:	
Operation date:	
Survey objectives:	
Location:	
Team members:	
Permit number:	
Mode of sampling:	
Samples taken (species, tissue, size):	
Field storage conditions:	
Required laboratory storage conditions:	
Required analysis:	
Suspected contamination:	
Abnormal incidents:	
Contact at laboratory facility:	

Table 5: Mission file cover page

Operation date:	
Survey objectives:	
Location:	
Team members:	
Permit number:	
File content	
Literature:	
Maps:	
Risk threshold list:	
Permits and licenses:	
Contact lists:	
Checklists:	
Emergency kit description:	
Manuals:	
Team details:	
Digital resources:	
Other	

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The document was referenced with an intention to supply readers with useful material for further enquiry rather than to prove or substantiate claims in a scientific fashion. References focused on recent publications to reflect the fields' current technological position.

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