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Review

Environmental guidelines for operation of Remotely Piloted Aircraft Systems (RPAS): Experience from Antarctica

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ABSTRACT

Remotely Piloted Aircraft Systems (RPAS), or drones, are increasingly being used in close proximity to wildlife. RPAS can disturb animals in their natural environment, potentially causing stress or harm. However, research on the potential impact of RPAS on wildlife is preliminary and remains poorly understood. RPAS offer many benefits for research applications and other purposes, and can also help reduce wildlife disturbance that might otherwise occur. The Antarctic Treaty Parties recognised a need to develop environmental guidelines for RPAS use as a means to help avoid and/or reduce disturbance to wildlife in Antarctica while allowing for their beneficial use. To do so, a framework based on the Pressure – State – Response model was developed to provide a systematic means to consider relevant influences on RPAS and wildlife interactions. This framework was used as an aid to draft comprehensive environmental guidelines for RPAS use in Antarctica, which were adopted by the Antarctic Treaty Parties in 2018. The guidelines include recommendations for pre-flight preparations, on-site and in-flight protocols, and for post-flight actions and reporting. The guidelines were based on examples developed elsewhere in the world, on available scientific evidence for environmental impacts from RPAS, and through consultation among governments and scientific and technical bodies operating in Antarctica. The environmental guidelines adopted for RPAS operations in Antarctica could provide a model for application elsewhere in the world where there is a need to manage interactions between RPAS and wildlife and to avoid or reduce potential impacts.

1. Introduction

The use of Remotely Piloted Aircraft Systems (RPAS), or drones, is relatively new and growing rapidly. RPAS offer new capabilities for deployment of sensors for a wide range of applications, including science, logistics, education, reportage and recreation. Many of these applications are carried out in areas where wildlife is present, or in sensitive environments. Indeed, wildlife itself is often a subject of interest for RPAS use, for example for animal census (Vermeulen et al., 2013; Chabot et al., 2015; Moreland et al., 2015; McClelland et al., 2016; Borowicz et al., 2018; Callaghan et al., 2018; Canal and Negro, 2018; Hodgson et al., 2018), wildlife protection (Mulero-Pázmány et al., 2014; Sandbrook, 2015), or for recreational photography.

RPAS can disturb animals in their natural environment (Ditmer et al., 2015; Smith et al., 2016; Rümmler et al., 2018; Mulero-Pázmány et al., 2017; Weimerskirch et al., 2017; Barnas et al., 2017; Lyons et al., 2018), potentially causing stress, changes in behaviour, and/or impacts on breeding performance. In some cases, animals may be injured or killed by collisions with aircraft. On the other hand, deployment of RPAS may be safer and reduce or avoid environmental impacts that could be caused through more invasive methods of data collection such as personnel deployment to inaccessible field sites, or the use of manned helicopters or airplanes (Harris, 2005). Moreover, some studies have shown that wildlife counts using RPAS can improve survey accuracy compared to ground counts, at the same time as reduce potentially greater disturbance by ground surveys involving incursion into colonies (Ratcliffe et al., 2015; Hodgson et al., 2018). A number of researchers (e.g. Vas et al., 2015; Hodgson and Koh, 2016; Mulero-Pázmány et al., 2017) have suggested guidelines for RPAS operations to mitigate the potential for impacts on wildlife in a number of contexts globally.

The Antarctic Treaty Parties (Resolution 2 (2004)) adopted guidelines for the use of large conventionally piloted aircraft near birds in Antarctica in recognition that best-practice guidance was of great

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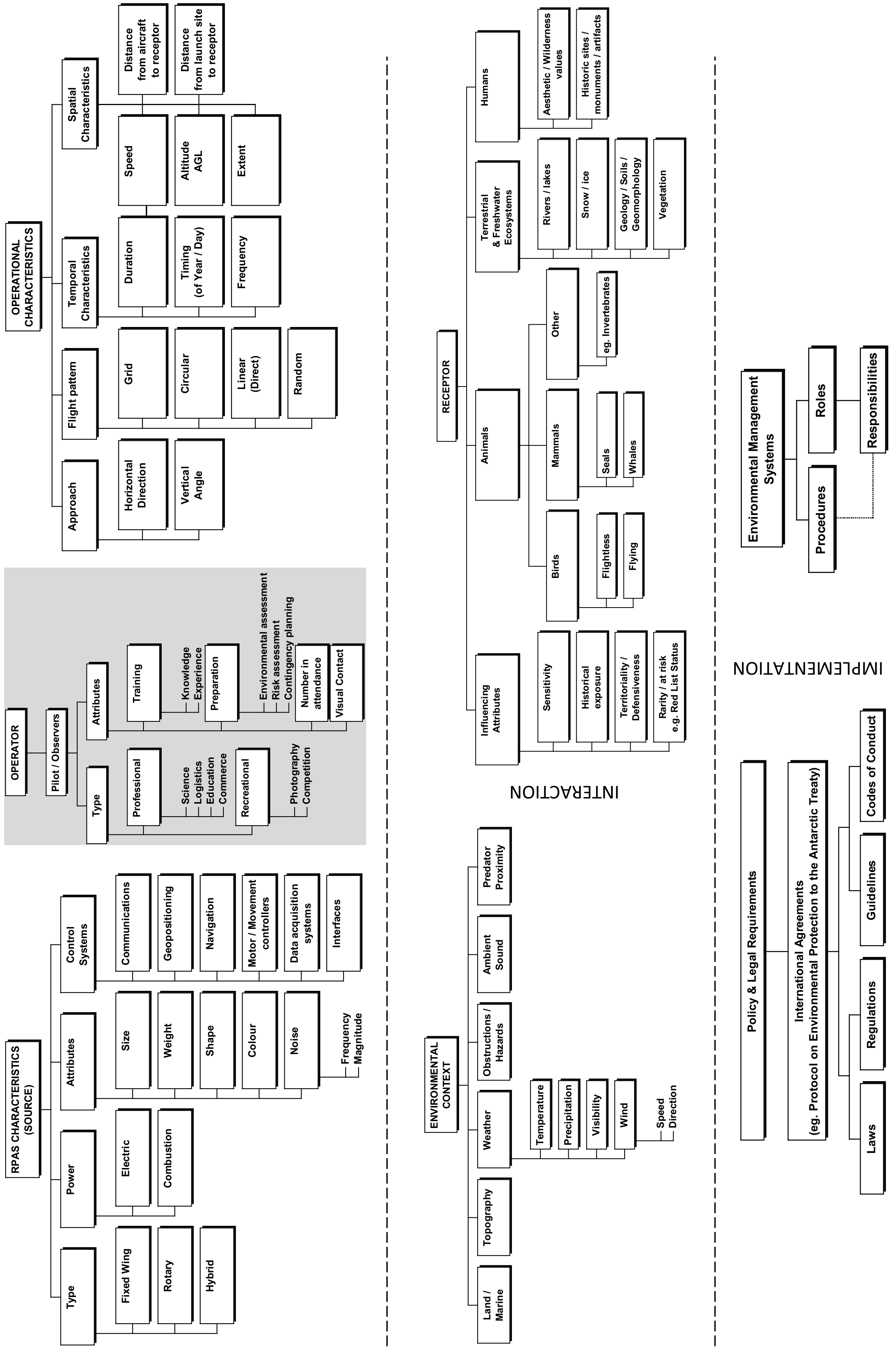


Fig. 1. Key factors influencing the risk of environmental impacts of Remotely Piloted Aircraft Systems (RPAS) in Antarctica.

practical utility to pilots for operations (Harris, 2005). Concerns about the growth in RPAS use coupled with their potential to cause environmental impacts, especially on wildlife, led the Antarctic Treaty Parties to initiate a process to develop environmental guidelines for use of RPAS in Antarctica (e.g. Germany, 2016, 2017, 2018; New Zealand, 2017a, 2017b; Poland, 2016, 2017a, 2017b; United States, 2014, 2015, 2017). Practical guidelines to address the operational and safety aspects related to RPAS were prepared by the Council of Managers of National Antarctic Programs (COMNAP, 2016), although these lacked detailed consideration of environmental aspects. The Antarctic Treaty Parties recognised the many benefits of RPAS for research, logistics and other purposes, and sought to ensure that potential impacts are minimized. This process involved several years of work considering the nature of the technology and how it is being used, examination of evidence for the type and magnitude of impacts of RPAS on wildlife (e.g. Rümmler et al., 2015, 2018; Weimerskirch et al., 2017; Mustafa et al., 2018), and considering the policy and legal context for regulating their use. Scientific, technical and logistics bodies were consulted through the process (COMNAP, 2017a, 2017b; IAATO, 2015, 2016; SCAR 2015a, b, 2017a, 2017b, 2017). A conceptual model was developed to organise and systematically consider the factors most likely to be influential in whether environmental impacts occur as a result of RPAS operations. This model, and the practical experience gained in the Antarctic context, may have more general application to RPAS operations elsewhere in the world. This may particularly be the case where there are also needs for practical guidelines to assist environmental managers, regulators and RPAS operators minimize the potential environmental impacts from RPAS.

Antarctica is remote, extremely cold, subject to persistent and often strong winds, and has rugged and sometimes dangerous terrain. As such, the Antarctic represents one of the most challenging environments to operate RPAS. In these extremes RPAS may often be operating at or near performance limits, which increases the risk of unanticipated events, system failures, and aircraft loss. Thus, guidelines developed for practical operation of RPAS in this environment may represent a ‘worst-case’ scenario against which to consider adaptation of guidelines for use in other parts of the world.

A wide range of terms and acronyms have emerged to describe remotely piloted aerial vehicles and systems, such as Unmanned Aerial Vehicle (UAV), Unmanned Aircraft System (UAS), Remotely Piloted Aircraft Systems (RPAS), among others as well as drones. The term Remotely Piloted Aircraft Systems (RPAS) is used in this paper because it is consistent with terminology adopted by the International Civil Aviation Authority (ICAO) (2015), which defined RPAS as “A remotely piloted aircraft, its associated remote pilot station(s), the required command and control links and any other components as specified in the type design”. A Remotely Piloted Aircraft (RPA) is “An unmanned aircraft which is piloted from a remote pilot station”.

RPAS may be divided into three broad types: fixed wing, rotary and hybrid. Fixed wing RPAS usually have one pair of wings and may vary widely in size and shape; rotary RPAS may employ from two (traditional helicopter format with one main and one tail rotor) up to eight rotors (tricopters, quadcopters, hexacopters and octacopters, generically known as multicopters). Hybrids combine the Vertical Take Off and Landing (VTOL) capability of rotary aircraft with the more aerodynamically efficient design of fixed wings. RPAS may also be classified in accordance with whether they are propelled by electric or combustion engines, the latter often capable of greater height and range although typically generating more noise. RPAS are thus highly diverse, with many hundreds of both military and civilian manufacturers from > 64 countries and around 2650 models catalogued in Wikipedia (2018). More details on RPAS technology and models are available in Wich and Koh (2018).

2. Environmental impact of RPAS

A wide range of elements and interrelationships comprise RPAS activities and operations, so we designed a framework to structure our analysis and guideline development (Fig. 1). This framework organises important elements related to RPAS use into a model that indicates potentially causal interrelationships and pathways. The model aims to help develop systematic approaches to consideration of these factors both in the Environmental Impact Assessment (EIA) process prior to practical applications of RPAS, and for policy development.

The conceptual framework is broadly organised as a Pressure – State – Response model (OECD 2001), where elements related to human activity are considered the ‘Pressure’, which is a combination of the RPAS, Operator and Operational Characteristics. The ‘State’ refers to elements of the environmental context and components subjected to pressure, and ‘Response’ refers to the policy context, and regulatory and management responses. Influential factors are classified into seven categories: the RPAS Characteristics (Source), Operator, Operational Characteristics, Environmental Context, Receptor (ecological and other valued environmental components), the Policy and Legal Framework and Environmental Management Systems.

The conceptual model serves as a framework to identify and illustrate the key environmental considerations when operating RPAS. It is customised to the Antarctic context, especially the elements under ‘Receptor’. In other global contexts, the framework could be expanded to provide appropriate consideration of relevant animal classes. Under the ‘Response’ category, we have specified the Protocol on Environmental Protection to the Antarctic Treaty, which is the key international policy and legal instrument that sets environmental rules for all 53 countries that are parties to the Antarctic Treaty. In contexts elsewhere in the world, other multilateral environmental agreements (e.g. regional Conventions) and national laws to implement policies will be applicable.

3. Interactions between RPAS and environmental values

Several recent papers have reviewed literature on RPAS and animal interactions (Smith et al. 2016; Korczak-Abshire et al. 2016; Borrelle and Fletcher, 2017; Mulero-Pázmány et al. 2017; SCAR 2017b; Mustafa et al. 2018), and rather than repeat reviews *in extensis* the principal findings from these papers will be summarised.

Borrelle and Fletcher (2017) identified 11 studies that used RPAS to observe colonial-nesting bird species, and reviewed whether and how they evaluated the impact of RPAS on their study species. Four of the 11 studies evaluated the response of birds to RPAS (Chabot and Bird, 2015; Chabot et al. 2015; Rümmler et al. 2015; Vas et al. 2015), and the latter two were specifically designed to investigate the impact of RPAS on their study species. All of the studies reviewed, with the exception of McClelland et al. (2016), were also reviewed by the Scientific Committee on Antarctic Research (SCAR) (SCAR 2017b). This latter paper identified 23 peer-reviewed studies using RPAS that included some form of monitoring of wildlife response. All of the studies used behaviour as an indicator of response, while only one (Ditmer et al. 2015) measured physiological changes.

Twelve of the 23 studies reviewed by SCAR (2017b) identified a change in wildlife behaviour in response to RPAS. Responses, when they occurred, varied by species, RPAS type and flight parameters (e.g. distance, height, direction, speed). Lower RPAS flights generally evoked stronger behavioural responses in wildlife, and vertical, rather than angled or horizontal approaches, evoked stronger responses in birds. The SCAR (2017b) review noted that RPAS noise was a significant cause of behavioural reactions in animals, and cited evidence that launching RPAS > 100 m from bird colonies produced fewer reactions (Vas et al.

2015; Rümmler et al. 2015).

The systematic review by Mulero-Pázmány et al. (2017) of RPAS as a source of wildlife disturbance identified 54 publications that employed some form of RPAS over or near to wildlife, of which 36 explicitly reported on wildlife reactions. The analysis by Mulero-Pázmány et al. (2017) showed:

- The probability of RPA evoking a reaction in wildlife was greater when the flight pattern was linearly directed towards the receptor ('target-oriented'), as opposed to flight patterns that followed a grid ('lawn mower'), while reactions from random flight patterns ('hobby') were inconclusive.
- There was evidence that the intensity of reaction ('Alert' or 'Active') was also greater with 'target-oriented' flight patterns.
- RPA with combustion engines were more likely to cause reactions than electric, which typically operate more quietly.
- There are significant differences in reactions between species, with the least responsive being those living underwater, followed by terrestrial mammals, with the most responsive being birds. Flightless and large flying birds appeared to show stronger reactions than small flying birds, although these differences were not statistically significant.
- Animal life-history stage was an important determinant in how close RPA can approach before 'Active Reaction' occurs. Animals outside gestation or parental care periods exhibited reactions at greater heights or distances to RPA than animals in those breeding stages. Mulero-Pázmány et al. (2017) suggested this was because gravid or nurturing animals show more reluctance to flee than animals free from parental obligations. Nevertheless, there is some evidence such animals may react aggressively to RPAS when defending territories.
- 'Level of aggregation' was also influential in how close RPA can approach before 'Active Reaction' occurred, and animals also fled at longer distances when they were part of large aggregations rather than in small groups or solitary.
- Larger RPA caused 'Active Reaction' at higher elevations than smaller aircraft.

3.1. Interactions between RPAS and birds

Korczak-Abshire et al. (2016) flew an electric fixed-wing aircraft at 350 m Above Ground Level (AGL) over a penguin colony and observed bird behaviours no different to those in the control colony that was not overflown. In contrast, when flying a combustion-engine fixed wing aircraft overhead at the same altitude, an increase in 'Vigilance' and 'Aggression' behaviours by penguins was observed, with approximately 80% of birds displaying 'Vigilance'. This level of vigilance was considered similar to when predatory skuas overflew colonies without attacking at ~5 m AGL. Korczak-Abshire et al. (2016) attributed the elevated reactions to aircraft noise, and Korczak-Abshire (pers. comm. 2017) noted that the aircraft was difficult to see at that altitude. Neither type of RPAS flying over penguins at 350 m AGL evoked behavioural responses of 'Escape'.

The potential impact of RPA noise may in part depend on the ambient noise of the surrounding context. For example, Goebel et al. (2015) observed that the noise of a small electric hexacopter overflying Chinstrap penguins (*Pygoscelis antarctica*) during the egg-laying period at ~30 m could not be distinguished above the ambient noise of the colony, and there were "no signs of disturbance to the penguins caused by … overhead aircraft during any of the survey flights", which were flown between 30 and 60 m AGL.

In contrast, Rümmler et al. (2015) reported statistically significant increases in the percentage of Adélie penguins (*Pygoscelis adeliae*) exhibiting 'Disturbed' behavioural responses ('Vigilance', 'Agonistic', or 'Escape') when operating an electric octocopter 10–50 m AGL over two sub-colonies on Ardley Island, South Shetland Islands, during the breeding season. 'Disturbed' responses were elevated when the aircraft approached from both horizontal and vertical directions, with the latter causing 'Disturbed' responses in a significantly greater proportion of birds (Rümmler et al. 2015; Mustafa et al. 2017).

Rümmler et al. (2015) suggested that a higher level of disturbance than apparent in previous studies may be explained by the short distance (50 m or less) between the launch site and the colonies, possibly exacerbating bird reactions. Other factors such as ambient noise, local geography, the species, the time of season or of the day when experiments were conducted, and attributes of the RPA, among the many other factors illustrated in Fig. 1, may also have been influential. Prevailing windspeed was not found to be a significant factor influencing disturbance levels.

When operating a small electric octocopter over Gentoo penguins (*Pygoscelis papua*), Mustafa et al. (2017) reported no significant difference in the behaviour of birds in the control phase (without overflight) compared to when the colony was overflown at both 40 m and 50 m AGL. In contrast, a significant increase in 'disturbed' behaviour (i.e. 'Vigilance', 'Agonistic') was observed in Gentoo penguins when the aircraft overflew at lower altitudes, and also when the aircraft was flown vertically downwards towards the birds from above. There was no evidence of habituation occurring in the Gentoo penguins during the experiments. In the control phase, a higher percentage of Gentoo penguins displayed 'disturbed' behaviour than did Adélie penguins, indicating a naturally higher predisposition to behaviour classified as 'disturbed' among Gentoos. However, Adélie penguins displayed a more substantial shift in behaviour patterns between the control phase and when the RPA was operating (i.e. a higher percentage change in behaviour patterns), suggesting that the magnitude of change to Adélie behaviour as a result of the stimulus was greater than for Gentoo penguins. Mustafa et al. (2017) also found evidence that behavioural changes were strongest in these penguin species when RPA flights operated at altitudes of < 20 m, supporting the theory that RPA are perceived by the birds as a predatory threat when flown at this level and below. In summary, Mustafa et al. (2017) observed that Adélie and Gentoo penguins are likely to detect RPA operating overhead at 50 m, although behavioural changes at that level are relatively minor (mainly comprising an increase in 'Vigilance' – Rümmler pers. comm. 2017). Further work by Rümmler et al. (2018) reported behavioural reactions were evident in Adélie penguins when the RPA was operated at up to 50 m altitude AGL, although for Gentoo penguins reactions were only evident up to 30 m altitude. To minimize disturbance, it was recommended that RPA should be launched > 20 m away from Gentoo penguins (Rümmler et al. 2018) and at least > 50 m away from Adélie penguins (Mustafa et al. 2017), and generally should not be flown at 20 m AGL or less over either of these species.

Ratcliffe et al. (2015) surveyed a Gentoo penguin (*Pygoscelis papua*) colony using a hexacopter flown at 30 m AGL during incubation, with some chicks hatching near the end of the survey period. Incubating birds or those attending chicks did not leave nests in response to the aircraft, although non-nesting birds, and nearby King penguins (*Aptenodytes patagonicus*), moved away from the aircraft when it was overhead. The observations suggest that although birds did not leave nests, had they not been bound by parental obligations they are likely to have moved in response to the aircraft, and thus probably experienced stress that went unrecorded.

McEvoy et al. (2016) experimented with different types of RPAS when undertaking waterfowl surveys in Australia. They found little or no disturbance to wild waterfowl when operating RPA > 60 m above the water level (fixed wing models), or 40 m above individuals (multirotor models). At lower altitudes for all aircraft, and when fixed wing aircraft made direct approaches or rapidly altered direction, waterfowl would take avoidance action by swimming or flying away. The study also found that disturbance could be minimized by locating take-off and landing sites out of view of the birds, and by carrying out ascent/descent or sharp turning manoeuvres away from bird positions.

McClelland et al. (2016) conducted three flights using a quadcopter to count Tristan Albatross (*Diomedea dabbenena*), listed as Critically Endangered by the IUCN, at a breeding site on Inaccessible Island, Tristan da Cunha archipelago. Flying between 20 and 150 m AGL over the breeding site, the operator (with First Person View) and the observer (using binoculars) observed no obvious behavioural changes in the birds.

Weimerskirch et al. (2017) examined the behavioural responses of 11 species of seabird to a Phantom 3 quadcopter RPAS at the Crozet Islands, Southern Indian Ocean, including King, Macaroni (*Eudyptes chrysolophus*), Southern Rock-hopper (*Eudyptes chrysochome*), and Gentoo penguins, Wandering (*Diomedea exulans*), Sooty (*Phoebetria fusca*) and Light-mantled Sooty (*Phoebetria palpebrata*) albatross, Southern (*Macronectes giganteus*) and Northern (*Macronectes hallii*) Giant petrels, Imperial shag (*Phalacrocorax* [*atriceps*] *bransfieldensis*), and Sub-Antarctic skua (*Stercorarius antarcticus*). The aircraft was launched from a site at least 100 m from the birds to an altitude of 50 m AGL and then flown horizontally over the colony then descended to repeat the flight at 25 m AGL and again at 10 m AGL. Finally, the aircraft was flown on a vertical approach path from 10 m to 3 m AGL from overhead the birds. This procedure was repeated for all species and at different breeding stages, with a total of 1406 observations recorded. Behavioural reactions were classified as 'Resting' (0), 'Vigilance' (1), 'Take a look at the drone' (2), 'Agonistic' (3), and 'Escape' (4). In addition, physiological responses were recorded for five adult and five chick King penguins using external cardio-frequency meters measuring heart rate.

Overall, results from Weimerskirch et al. (2017) showed that behavioural responses intensified for all species as aircraft altitude decreased, although there were distinct differences by species and by breeding stage. The four species showing the strongest behavioural responses were Southern Giant petrel, Imperial shag, Sub-Antarctic skua and Northern Giant petrel, while the four species showing the least were Southern Rock-hopper penguin, Sooty albatross, Macaroni penguin and King penguin. When the aircraft was operating at 50 m AGL, no significant behavioural modifications were observed for all species except the Southern Giant petrel, some individuals of which (that were not already vigilant) changed from 'Resting' to 'Vigilance'. Sub-Antarctic skuas were already relatively vigilant prior to RPA flights, with evidence of a slight increase in vigilant behaviour displayed when the RPA made its first overflight at 50 m AGL. At 25 m AGL, 'Agonistic' behaviour increased among Light-mantled Sooty albatross and Sub-Antarctic skuas, suggesting these species are relatively sensitive to aircraft approach. At 10 m AGL, all species except Rock-hopper penguin and Sooty albatross showed increased 'Vigilance', while Macaroni penguins, Light-mantled Sooty albatross and Gentoo penguin showed a higher level of 'Agonistic' behaviour. All species showed their strongest behavioural reactions when the aircraft approached from above down to 3 m AGL.

Weimerskirch et al. (2017) observed behavioural reactions to intensify among King penguin chicks in response to increased aircraft stimulus and their heart rates to rise correspondingly, with increases of up to 30% on average above pre-approach levels. Chicks expressed signs of panic (rapid flipper flapping and escape reactions such as moving away) when the aircraft was at 25 m AGL. In contrast, incubating King penguin adults in the same situation showed little outward behavioural display in response to aircraft approaches at any distance, although average heart rates increased by up to 33% and 41% when approached to within 10 m and 2 m above the birds respectively. The peak heart rate values were similar to regular peak values observed during periods when the birds were exposed to natural interactions between congeners and/or predators, and were not being disturbed by the aircraft or humans. All birds returned to resting behaviour and basal heart rate levels within a few minutes after the experiment concluded, suggesting the elevated stress was transitory and limited principally to the time period over which the aircraft was operating in close proximity.

Although limited in sample size, these results suggest caution should be exercised when interpreting outward behaviour as an indicator of stress levels in King penguins, as also found in other species (Ditmer et al. 2015). However, for King penguins, even the closest approaches of the aircraft (to within 2 m) by Weimerskirch et al. (2017) evoked responses comparable to common natural sources of disturbance, and on cessation of the stimulus bird recovery times appeared to be rapid. More research is required to determine the extent to which these observations hold true for other species.

A summary of the most recent scientific knowledge of Antarctic wildlife responses to RPAS was made in SCAR (2017) based on the workshop on 'Drones in Antarctic Biology' held in 2017. The report noted that most Antarctic researchers working in this field agreed that changes in RPA noise intensity (e.g. as occurs at take-off or when an RPA needs to compensate for wind gusts or makes other sudden movements) and vertical altitude changes by RPA in the direction towards animals induce the strongest wildlife reactions. The report also noted that habituation to RPA by wildlife had not yet been observed. While recognising these general observations are yet to be statistically proven, the report suggested that, based on a general consensus among scientists working in the field, they should be taken into account when formulating guidelines.

At the SCAR (2017) workshop, Vieira et al. (2017) reported their experience operating a small fixed-wing RPA near wildlife on the Antarctic Peninsula over four summer seasons. When operating between 90 and 120 m AGL, they observed skuas (*Stercorarius* sp.) often flew from some distance (~200 m) to investigate their RPA, following it for some time without attacking, presumably to establish whether the RPA represented a threat. They noted that at least one attack occurred when the RPA flew at a lower altitude (50 m), damaging the RPA wing, suggesting skuas will aggressively defend their territory when they perceive the RPA is approaching too close.

Separation distances that could be used as the basis for further consideration in the development of guidelines for RPAS use near Antarctic wildlife were presented in SCAR (2017) and later published in Mustafa et al. (2018) (Table 1), noting that these initial distances are not based on a precautionary approach. Table 1 presents distance thresholds for RPAS operation beyond which 'disturbance' of wildlife is considered – based on currently available evidence – unlikely to occur. In compiling the table, 'disturbance' has been defined as any detectable change in animal behaviour or physiological functioning. Thus, the criteria used for the thresholds in Table 1 are not those at which a change is considered to have a 'significant' impact on individuals or populations (e.g. impairing ability to survive or reproduce), but rather those at which some change, however minor, has been detected. The question of the significance of disturbance is not addressed in SCAR (2017) or Mustafa et al. (2018), although is identified as an item in need of further elaboration.

There remains considerable uncertainty surrounding these thresholds, as they do not necessarily indicate the distance at which 'disturbance' of wildlife might lead to significant impacts on either individuals or populations. However, the table provides at least first indications of the approximate distances at which animal reactions, at some level, might be anticipated to occur and as such this should aid planning and implementing RPAS operations in a manner that minimises the potential for disturbance that could lead to significant impacts. More research is needed to provide more definitive threshold distances.

In the meantime, Table 1 provides indicative threshold distances for various species, although given the uncertainties and complexities, SCAR (2017) and Mustafa et al. (2018) concluded that species-specific guidelines were not useful given the current state of knowledge. Nevertheless, SCAR (2017) also concluded that "A vertical and horizontal limit to animal aggregations should be defined beyond which disturbance can be excluded", supported by Mustafa et al. (2018), recognising that there are practical benefits to providing some guidance,

Table 1
Minimal flight distances with no proved disturbance by RPAS by species based on studies reviewed (adapted from Mustafa et al. 2018).

Group	Species	Multicopter / electric[1]	Fixed wing / electric[1]	Fixed wing / gas fueled[1]
Penguins	Gentoo penguin	50 m [a]	n.a.	n.a.
	Chinstrap penguin	50 m [b]	n.a.	n.a.
	Adélie penguin	> 50 m [b]	< 350 m [b]	> 350 m [b]
	King penguin	> 50 m [b]	n.a.	n.a.
	Macaroni penguin	50 m [b]	n.a.	n.a.
	Southern rock-hopper penguin	50 m [b]	n.a.	n.a.
Mammals	Fur seal	50 m [c]	n.a.	n.a.
	Weddell seal	50 m [c]	n.a.	n.a.
	Leopard seal	50 m [c]	n.a.	n.a.
Other birds	Kelp gull	30 m [c]	30 m [c]	n.a.
	Antarctic Tern	n.a.	> 100 m [c]	n.a.
	Southern Giant petrel	200 m [b]	200 m [b]	n.a.
	Northern giant petrel	≥ 50 m [c]	n.a.	n.a.
	Brown skua	100 m [b]	200 m [b]	n.a.
	South Polar skua	100 m [b]	200 m [b]	n.a.
	Wandering albatross	> 50 m [b]	n.a.	n.a.
	Sooty albatross	50 m [b]	n.a.	n.a.
	Light-mantled sooty albatross	> 50 m [b]	n.a.	n.a.
	Imperial cormorant	> 50 m [b]	n.a.	n.a.

1. State of knowledge: a = 'well founded', b = 'data poor', c = 'extremely data poor', n.a. = not available.

even if generalised and even where there remain acknowledged uncertainties.

Barnas et al. (2017) evaluated the behavioural responses of nesting lesser snow geese (*Anser caerulescens caerulescens*) to RPAS surveys carried out in Wapusk National Park, Canada. Using a fixed wing RPA, they found that snow geese showed elevated levels of vigilance when overflown at an altitude of ≥75 m AGL, with the proportion of time birds displayed vigilant behaviour increasing during overflights. Most of the behavioural change was accounted for by increased nest maintenance and 'low scanning' (observation without craning heads), with few birds moving off nests as a result of the stimulus. Flights were launched between 325 and 2100 m from the subject birds, and launches did not provoke significant changes in behaviour. Birds in the control group > 500 m distant also displayed an increase in vigilance when the aircraft was airborne, suggesting that aircraft noise was responsible for at least some of the behavioural changes, or that the birds were visually aware of the aircraft even at that distance. Further work is needed to separate the visual versus auditory components in the stimulus leading to behaviour changes. Flight altitude was not found to be an important influence on behavioural changes in this study, although the authors noted that this may be because the elevations selected for the experiments were already above a threshold below 75 m at which changes in behaviour would be more strongly provoked. This observation prompted the recommendation that RPAS flights above an altitude of 75 m should result in relatively minimal disturbance for this species at least.

Behavioural responses of thick-billed murres (*Uria lomvia*) to a small (< 2 kg) rotary RPA were investigated at Coats Island and Digges Island, Canada, by Brisson-Curadeau et al. (2017). RPA launches were made either above or below and at a distance of 15–30 m from the target birds, and the aircraft was then flown slowly towards the birds to a horizontal distance of 15 m or 30 m, at which a photograph was taken. The study found that on average 8.5% of birds flushed from the nest site, almost all of which were non-breeders (> 99%) and returned to the nest within 10 min. The angle of approach was not a substantial influence on whether birds took flight, indicating that for cliff-dwelling species a vertical approach may not be as important to reactions as it is for nesting waterbirds in a wetland (Vas et al. 2015). No eggs were lost at this colony, and RPAS operations had no impact on breeding success. The authors considered it surprising that no breeding birds flew off their nests, as the species typically shows an elevated sensitivity to human presence. Supplementary observations were also made of several other species of Arctic seabirds (Common murre (*Uria aalge*), Glaucous gull (*Larus hyperboreus*), Iceland gull (*Larus glaucoides*)), with the finding that more breeding Common murres flushed during RPAS surveys when in the presence of aerial predators, resulting in several eggs being lost. When such aerial predators were absent, no breeding murres flushed in response to the RPA and no eggs were lost. During the surveys Glaucous gulls appeared unresponsive to the RPA, while in contrast most Iceland gulls took flight when the RPA approached within ~30 m, although returned to nests within a few minutes. There was little evidence for habituation to RPA by murres, although gulls seemed to become habituated to the presence of the RPA after about 3 min. The way in which different bird species react, and the conditions leading to avoidance behaviour in response to RPA, thus vary. Brisson-Curadeau et al. (2017) found RPAS surveys to be faster, more practical, cheaper and more accurate than ground surveys, although to mitigate potential disturbance they recommended:

- Carry out baseline tests to witness behaviour patterns on-site and immediately prior to full survey, especially when avian predators are present;
- Allow a 5-min habituation period when operating RPAS near gulls to yield the most accurate counts;
- Near murres, maintain a separation distance of at least 20 m when using small rotary RPAs and conduct take-off and landings outside of the hearing range of the colony, although flushing of most non-breeding birds remains likely.

Offering practical advice for RPAS operations, Duffy et al. (2017) emphasised the importance of pre-flight planning and preparation to avoid mishaps. For example, they recommend measures such as selection of robust aircraft, extensive site reconnaissance prior to flight operations, including mapping and simulations, site risk assessments and developing pre-agreed flight protocols to anticipate problems, ground surveys on foot or initial high-level reconnaissance flights to identify potential hazards, equipment testing, and they emphasise the need for communication with other airspace users. They also recommend both a pilot and an observer to operate RPAS. For in-flight operations, they caution against the impact that wind, dust and excessive heat or cold can have on flights. While not concerned with environmental considerations specifically, mission success avoids aircraft losses that could cause environmental impacts such as disturbance to, or collisions with, wildlife, or pollution or depreciation of aesthetic or wilderness values if the aircraft cannot be recovered.

3.2. Interactions between RPAS and mammals

Physiological measurements made by Ditmer et al. (2015) indicate that outward animal behaviour may be limited as a predictor of stress levels in animals. They found that wild American black bears responded to RPAS flights with elevated heart rates, rising by up to 123 beats per minute above the pre-flight baseline, even when outward behavioural changes were infrequent. Ditmer et al. (2015) concluded that, given the widespread increase in RPAS, it is critical to quantify and understand the impact of RPAS as stressors to wildlife, including physiological changes, and to take this into account when developing regulations and best scientific practices. When operating a small (2.5 kg) fixed-wing RPA at 75 m AGL and 120 m AGL over polar bears (*Ursus maritimus*), Barnas et al. (2018) observed vigilant behaviour increase, which was comparable to the increased polar bear vigilance previously witnessed in response to tourist tundra vehicles operating in proximity. It was surmised that these particular bears were likely to be habituated to some extent to anthropogenic disturbances. However, since none showed flee responses the authors noted that RPAS survey caused less disturbance than would typically occur using traditional mark-recapture methods.

Smith et al. (2016) reviewed the impacts of RPAS on marine mammals, noting that data gaps constrained the development of guidelines, regulations and policies for safe and responsible operations. Summarising observations from seven studies that used a variety of RPAS (fixed-wing and multicopter, combustion and electric powered) with cetaceans or sirenians, no behavioural changes were reported when aircraft were operated at elevations between 9 and 300 m. Durban et al. (2015) operated a small hexacopter UAV 35–40 m over killer whales with no observed disturbance. Christiansen et al. (2016) concluded that UAV noise profiles were close to ambient noise profiles in shallow waters, are largely below the low-frequency hearing thresholds of toothed whales, are likely above the hearing thresholds of baleen whales and pinnipeds, and that even if heard the underwater noise effect is likely to be small, even for animals close to the surface. Erbe et al. (2017) measured underwater sound levels of commonly used small electric RPAs to show they were tens of dB lower than those of small motorcraft and below levels considered in environmental regulations for underwater noise. Noise attenuation by water reduces substantially the potential for significant RPAS impacts on animals at sea.

Acevedo-Whitehouse et al. (2010) used a remote control combustion engine helicopter (3 kg) to sample exhaled breath condensate from Blue (*Balaenoptera musculus*), Humpback (*Megaptera novaeangliae*), Gray (*Eschrichtius robustus*) and Sperm (*Physeter macrocephalus*) whales. At the reported operating sampling altitude of 13 m (~40 ft), these large cetaceans did not display any more avoidance behaviour (actively moving away from the collection device) when approached by the model helicopter than is commonly observed during close approach by small boats. It was concluded that distress caused by this helicopter was minimal, despite the combustion engine being relatively noisy.

Behavioural responses were more evident in pinnipeds on land, with three of six studies operating RPAS between 5 and 60 m AGL recording variable reactions (Fritz 2012; Sweeney 2014; Pomeroy et al. 2015). When RPAS were operating above 30 m AGL, alert reactions were generally observed in 1% or less of animals, although on several occasions small numbers of individuals took to water (Sweeney 2014; Pomeroy et al. 2015). Pomeroy et al. (2015) observed reactions to vary by species, whether seals were breeding or molting, and by the noise level of specific aircraft models. Pomeroy et al. (2015) observed molting Gray seals moved away from an electric octocopter when it operated 50 m overhead, and breeding Gray seals (n = 21), on the other hand, moved away when the aircraft was 30 m overhead. These distances reduced to 10 m vertically and 15 m horizontally for molting Gray seals (n = 20) using an alternative octocopter that produced less noise. There was a greater propensity for Harbor seals (*Phoca vitulina*) to move at a more remote and less-frequently disturbed site, suggesting habituation may be a factor for this species.

When aircraft were operating at < 30 m, several studies reported more animals reacting or stronger reactions such as body movement or taking to water (Fritz 2012; Pomeroy et al. 2015). However, Goebel et al. (2015) reported no behavioural reactions by Antarctic seals when their quadcopter was operated at 23 m AGL or above.

Several studies (Mulac et al. 2011; Moreland et al. 2015) operating fixed-wing combustion powered RPAS at elevations > 90 m reported significant reductions in disturbance among several species of ice seals compared to manned aircraft surveys.

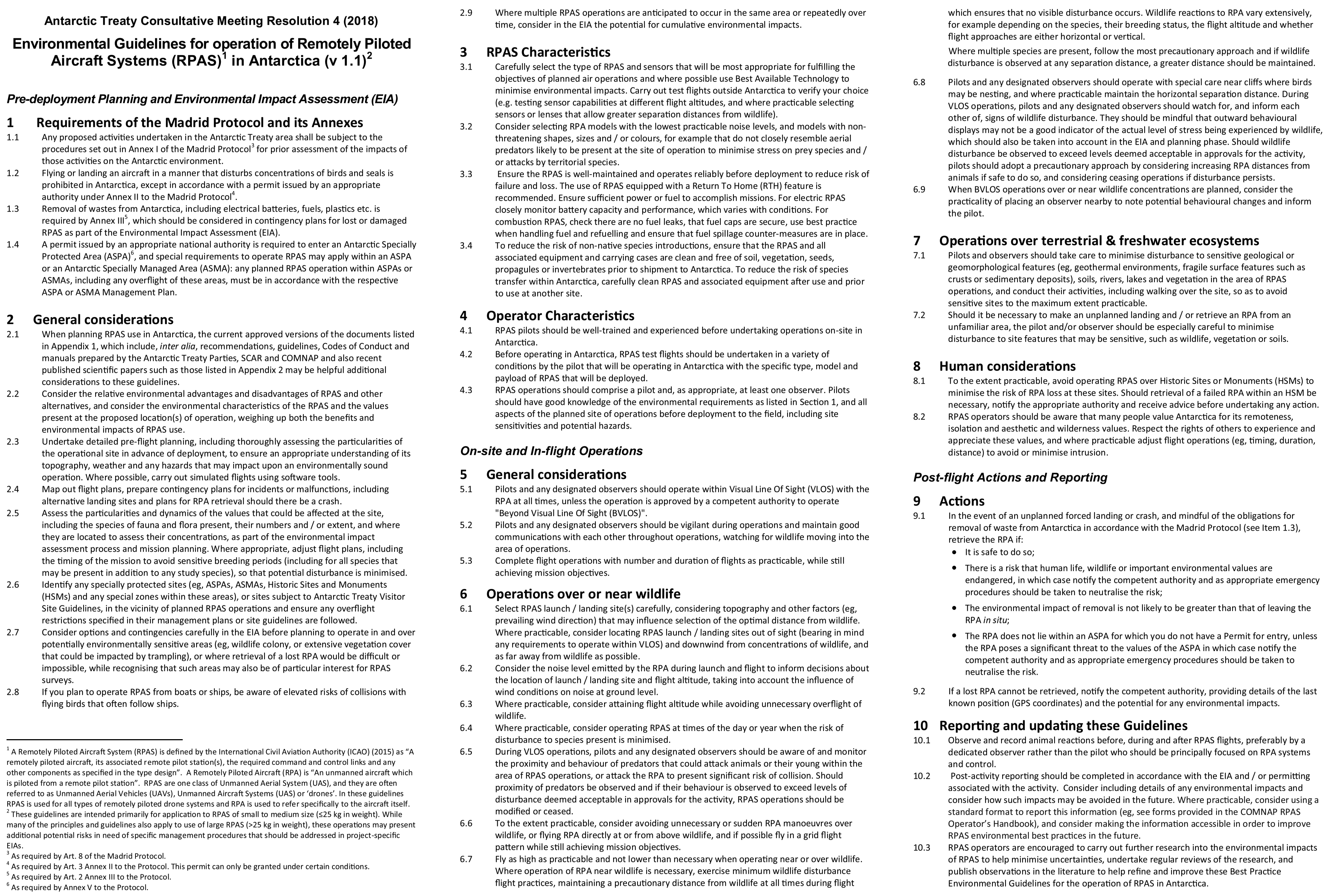
As noted by Smith et al. (2016), the literature is biased towards reporting situations where a behavioural response has been observed, as opposed to no response, although even then there is "a general lack of marine mammal response to UAS presence when the aircraft are operated above a certain altitude … However, caution should continue to be used when operating the aircraft at any altitude, because important details about the nature of the exposure are opportunistic".

3.3. Impacts of RPAS on other environmental values

Research to date has focused on the interactions of RPAS with animals and no studies have been identified that have investigated potential impacts on other environmental values, such as on terrestrial or freshwater ecology, wilderness or other aesthetic values, or historic sites, monuments or artefacts. Most publications on use of RPAS in wilderness areas (other than those related to animal ecology) focus on Search and Rescue applications. One paper was identified that considered the impact of RPAS on people as a result of their use for conservation purposes often in remote or semi-natural environments (Sandbrook 2015), and one that considered social and ethical aspects of RPAS use, such as privacy and annoyance issues (Duffy et al. 2017), although neither of these papers considered impacts on wilderness experience or other aesthetic values. The US National Park Service banned recreational use of RPAS within National Parks in 2014 (Sandbrook 2015) on the grounds of negative impact on the wilderness experience of visitors, potential impacts on wildlife, and the risk of aircraft loss in sensitive areas (e.g. hot springs in Yellowstone National Park). In the United States, the Wilderness Act 1964 prohibits 'motorized equipment', 'landing of aircraft' and other forms of 'mechanical transport' in designated Wilderness Areas, and this policy is interpreted by agencies such as the US Forest Service and US Bureau of Land Management to include a ban on RPAS use in these areas. Other countries, for example Germany and Switzerland, also ban the use of RPAS in National Parks and nature reserves except by permit. While impacts on human values such as 'isolation', 'solitude', 'remoteness', and 'pristineness' have received little consideration in the scientific literature, some policy-makers are anticipating the problem and implementing regulations on RPAS use in sensitive areas such as National Parks and wilderness reserves.

4. Environmental guidelines for operation of RPAS

A Committee for Environmental Protection (CEP) is established under the Protocol on Environmental Protection to the Antarctic Treaty (the Environmental Protocol) for the purpose of providing advice and formulating recommendations on environmental matters to Antarctic Treaty Consultative Meetings, which are held annually. The Antarctic Treaty Parties began formally considering environmental aspects of the operation of RPAS at the CEP in 2014 (Germany/Poland 2014; United States 2014). COMNAP (2015) and SCAR (2015a, 2015b) reported to the CEP in 2015 on the risks and benefits of RPAS, and IAATO noted it was developing RPAS guidelines for application to tourists travelling with their members (IAATO 2015). The CEP established an intersessional contact group in 2017 to review the latest scientific research and information from operators with a view to develop, on the basis of a



Antarctic Treaty Consultative Meeting Resolution 4 (2018)

Environmental Guidelines for operation of Remotely Piloted Aircraft Systems (RPAS)[1] in Antarctica (v 1.1)[2]

Pre-deployment Planning and Environmental Impact Assessment (EIA)

1 Requirements of the Madrid Protocol and its Annexes

1.1 Any proposed activities undertaken in the Antarctic Treaty area shall be subject to the procedures set out in Annex I of the Madrid Protocol[3] for prior assessment of the impacts of those activities on the Antarctic environment.

1.2 Flying or landing an aircraft in a manner that disturbs concentrations of birds and seals is prohibited in Antarctica, except in accordance with a permit issued by an appropriate authority under Annex II to the Madrid Protocol[4].

1.3 Removal of wastes from Antarctica, including electrical batteries, fuels, plastics etc. is required by Annex III[5], which should be considered in contingency plans for lost or damaged RPAS as part of the Environmental Impact Assessment (EIA).

1.4 A permit issued by an appropriate national authority is required to enter an Antarctic Specially Protected Area (ASPA)[6], and special requirements to operate RPAS may apply within an ASPA or an Antarctic Specially Managed Area (ASMA): any planned RPAS operation within ASPAs or ASMAs, including any overflight of these areas, must be in accordance with the respective ASPA or ASMA Management Plan.

2 General considerations

2.1 When planning RPAS use in Antarctica, the current approved versions of the documents listed in Appendix 1, which include, *inter alia*, recommendations, guidelines, Codes of Conduct and manuals prepared by the Antarctic Treaty Parties, SCAR and COMNAP and also recent published scientific papers such as those listed in Appendix 2 may be helpful additional considerations to these guidelines.

2.2 Consider the relative environmental advantages and disadvantages of RPAS and other alternatives, and consider the environmental characteristics of the RPAS and the values present at the proposed location(s) of operation, weighing up both the benefits and environmental impacts of RPAS use.

2.3 Undertake detailed pre-flight planning, including thoroughly assessing the particularities of the operational site in advance of deployment, to ensure an appropriate understanding of its topography, weather and any hazards that may impact upon an environmentally sound operation. Where possible, carry out simulated flights using software tools.

2.4 Map out flight plans, prepare contingency plans for incidents or malfunctions, including alternative landing sites and plans for RPA retrieval should there be a crash.

2.5 Assess the particularities and dynamics of the values that could be affected at the site, including the species of fauna and flora present, their numbers and / or extent, and where they are located to assess their concentrations, as part of the environmental impact assessment process and mission planning. Where appropriate, adjust flight plans, including the timing of the mission to avoid sensitive breeding periods (including for all species that may be present in addition to any study species), so that potential disturbance is minimised.

2.6 Identify any specially protected sites (eg, ASPAs, ASMAs, Historic Sites and Monuments (HSMs) and any special zones within these areas), or sites subject to Antarctic Treaty Visitor Site Guidelines, in the vicinity of planned RPAS operations and ensure any overflight restrictions specified in their management plans or site guidelines are followed.

2.7 Consider options and contingencies carefully in the EIA before planning to operate in and over potentially environmentally sensitive areas (eg, wildlife colony, or extensive vegetation cover that could be impacted by trampling), or where retrieval of a lost RPA would be difficult or impossible, while recognising that such areas may also be of particular interest for RPAS surveys.

2.8 If you plan to operate RPAS from boats or ships, be aware of elevated risks of collisions with flying birds that often follow ships.

2.9 Where multiple RPAS operations are anticipated to occur in the same area or repeatedly over time, consider in the EIA the potential for cumulative environmental impacts.

3 RPAS Characteristics

3.1 Carefully select the type of RPAS and sensors that will be most appropriate for fulfilling the objectives of planned air operations and where possible use Best Available Technology to minimise environmental impacts. Carry out test flights outside Antarctica to verify your choice (e.g. testing sensor capabilities at different flight altitudes, and where practicable selecting sensors or lenses that allow greater separation distances from wildlife).

3.2 Consider selecting RPA models with the lowest practicable noise levels, and models with non-threatening shapes, sizes and / or colours, for example that do not closely resemble aerial predators likely to be present at the site of operation to minimise stress on prey species and / or attacks by territorial species.

3.3 Ensure the RPAS is well-maintained and operates reliably before deployment to reduce risk of failure and loss. The use of RPAS equipped with a Return To Home (RTH) feature is recommended. Ensure sufficient power or fuel to accomplish missions. For electric RPAS closely monitor battery capacity and performance, which varies with conditions. For combustion RPAS, check there are no fuel leaks, that fuel caps are secure, use best practice when handling fuel and refuelling and ensure that fuel spillage counter-measures are in place.

3.4 To reduce the risk of non-native species introductions, ensure that the RPAS and all associated equipment and carrying cases are clean and free of soil, vegetation, seeds, propagules or invertebrates prior to shipment to Antarctica. To reduce the risk of species transfer within Antarctica, carefully clean RPAS and associated equipment after use and prior to use at another site.

4 Operator Characteristics

4.1 RPAS pilots should be well-trained and experienced before undertaking operations on-site in Antarctica.

4.2 Before operating in Antarctica, RPAS test flights should be undertaken in a variety of conditions by the pilot that will be operating in Antarctica with the specific type, model and payload of RPAS that will be deployed.

4.3 RPAS operations should comprise a pilot and, as appropriate, at least one observer. Pilots should have good knowledge of the environmental requirements as listed in Section 1, and all aspects of the planned site of operations before deployment to the field, including site sensitivities and potential hazards.

On-site and In-flight Operations

5 General considerations

5.1 Pilots and any designated observers should operate within Visual Line Of Sight (VLOS) with the RPA at all times, unless the operation is approved by a competent authority to operate "Beyond Visual Line Of Sight (BVLOS)".

5.2 Pilots and any designated observers should be vigilant during operations and maintain good communications with each other throughout operations, watching for wildlife moving into the area of operations.

5.3 Complete flight operations with number and duration of flights as practicable, while still achieving mission objectives.

6 Operations over or near wildlife

6.1 Select RPAS launch / landing site(s) carefully, considering topography and other factors (eg, prevailing wind direction) that may influence selection of the optimal distance from wildlife. Where practicable, consider locating RPAS launch / landing sites out of sight (bearing in mind any requirements to operate within VLOS) and downwind from concentrations of wildlife, and as far away from wildlife as possible.

6.2 Consider the noise level emitted by the RPA during launch and flight to inform decisions about the location of launch / landing site and flight altitude, taking into account the influence of wind conditions on noise at ground level.

6.3 Where practicable, consider attaining flight altitude while avoiding unnecessary overflight of wildlife.

6.4 Where practicable, consider operating RPAS at times of the day or year when the risk of disturbance to species present is minimised.

6.5 During VLOS operations, pilots and any designated observers should be aware of and monitor the proximity and behaviour of predators that could attack animals or their young within the area of RPAS operations, or attack the RPA to present significant risk of collision. Should proximity of predators be observed and if their behaviour is observed to exceed levels of disturbance deemed acceptable in approvals for the activity, RPAS operations should be modified or ceased.

6.6 To the extent practicable, consider avoiding unnecessary or sudden RPA manoeuvres over wildlife, or flying RPA directly at or from above wildlife, and if possible fly in a grid flight pattern while still achieving mission objectives.

6.7 Fly as high as practicable and not lower than necessary when operating near or over wildlife. Where operation of RPA near wildlife is necessary, exercise minimum wildlife disturbance flight practices, maintaining a precautionary distance from wildlife at all times during flight which ensures that no visible disturbance occurs. Wildlife reactions to RPA vary extensively, for example depending on the species, their breeding status, the flight altitude and whether flight approaches are either horizontal or vertical.

Where multiple species are present, follow the most precautionary approach and if wildlife disturbance is observed at any separation distance, a greater distance should be maintained.

6.8 Pilots and any designated observers should operate with special care near cliffs where birds may be nesting, and where practicable maintain the horizontal separation distance. During VLOS operations, pilots and any designated observers should watch for, and inform each other of, signs of wildlife disturbance. They should be mindful that outward behavioural displays may not be a good indicator of the actual level of stress being experienced by wildlife, which should also be taken into account in the EIA and planning phase. Should wildlife disturbance be observed to exceed levels deemed acceptable in approvals for the activity, pilots should adopt a precautionary approach by considering increasing RPA distances from animals if safe to do so, and considering ceasing operations if disturbance persists.

6.9 When BVLOS operations over or near wildlife concentrations are planned, consider the practicality of placing an observer nearby to note potential behavioural changes and inform the pilot.

7 Operations over terrestrial & freshwater ecosystems

7.1 Pilots and observers should take care to minimise disturbance to sensitive geological or geomorphological features (eg, geothermal environments, fragile surface features such as crusts or sedimentary deposits), soils, rivers, lakes and vegetation in the area of RPAS operations, and conduct their activities, including walking over the site, so as to avoid sensitive sites to the maximum extent practicable.

7.2 Should it be necessary to make an unplanned landing and / or retrieve an RPA from an unfamiliar area, the pilot and/or observer should be especially careful to minimise disturbance to site features that may be sensitive, such as wildlife, vegetation or soils.

8 Human considerations

8.1 To the extent practicable, avoid operating RPAS over Historic Sites or Monuments (HSMs) to minimise the risk of RPA loss at these sites. Should retrieval of a failed RPA within an HSM be necessary, notify the appropriate authority and receive advice before undertaking any action.

8.2 RPAS operators should be aware that many people value Antarctica for its remoteness, isolation and aesthetic and wilderness values. Respect the rights of others to experience and appreciate these values, and where practicable adjust flight operations (eg, timing, duration, distance) to avoid or minimise intrusion.

Post-flight Actions and Reporting

9 Actions

9.1 In the event of an unplanned forced landing or crash, and mindful of the obligations for removal of waste from Antarctica in accordance with the Madrid Protocol (see Item 1.3), retrieve the RPA if:

- It is safe to do so;
- There is a risk that human life, wildlife or important environmental values are endangered, in which case notify the competent authority and as appropriate emergency procedures should be taken to neutralise the risk;
- The environmental impact of removal is not likely to be greater than that of leaving the RPA *in situ*;
- The RPA does not lie within an ASPA for which you do not have a Permit for entry, unless the RPA poses a significant threat to the values of the ASPA in which case notify the competent authority and as appropriate emergency procedures should be taken to neutralise the risk.

9.2 If a lost RPA cannot be retrieved, notify the competent authority, providing details of the last known position (GPS coordinates) and the potential for any environmental impacts.

10 Reporting and updating these Guidelines

10.1 Observe and record animal reactions before, during and after RPAS flights, preferably by a dedicated observer rather than the pilot who should be principally focused on RPA systems and control.

10.2 Post-activity reporting should be completed in accordance with the EIA and / or permitting associated with the activity. Consider including details of any environmental impacts and consider how such impacts may be avoided in the future. Where practicable, consider using a standard format to report this information (eg, see forms provided in the COMNAP RPAS Operator's Handbook), and consider making the information accessible in order to improve RPAS environmental best practices in the future.

10.3 RPAS operators are encouraged to carry out further research into the environmental impacts of RPAS to help minimise uncertainties, undertake regular reviews of the research, and publish observations in the literature to help refine and improve these Best Practice Environmental Guidelines for the operation of RPAS in Antarctica.

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[1] A Remotely Piloted Aircraft System (RPAS) is defined by the International Civil Aviation Authority (ICAO) (2015) as "A remotely piloted aircraft, its associated remote pilot station(s), the required command and control links and any other components as specified in the type design". A Remotely Piloted Aircraft (RPA) is "An unmanned aircraft which is piloted from a remote pilot station". RPAS are one class of Unmanned Aerial System (UAS), and they are often referred to as Unmanned Aerial Vehicles (UAVs), Unmanned Aircraft Systems (UAS) or 'drones'. In these guidelines RPAS is used for all types of remotely piloted drone systems and RPA is used to refer specifically to the aircraft itself.

[2] These guidelines are intended primarily for application to RPAS of small to medium size (≤25 kg in weight). While many of the principles and guidelines also apply to use of large RPAS (>25 kg in weight), these operations may present additional potential risks in need of specific management procedures that should be addressed in project-specific EIAs.

[3] As required by Art. 8 of the Madrid Protocol.

[4] As required by Art. 3 Annex II to the Protocol. This permit can only be granted under certain conditions.

[5] As required by Art. 2 Annex III to the Protocol.

[6] As required by Annex V to the Protocol.

Fig. 2. Environmental Guidelines for operation of RPAS in Antarctica (Introduction and Appendices omitted).

precautionary approach, guidance for the environmental aspects of RPAS use in Antarctica, taking into account different purposes (e.g. scientific, logistic, commercial and leisure) and the type of RPAS, including site- and species-specific conditions. All members of the CEP and relevant scientific and technical bodies were invited to participate in the group, chaired by Germany. Eleven countries, including Argentina, Australia, France, Germany, Republic of Korea, The Netherlands, Norway, Poland, Spain, the United Kingdom and the United States actively participated in the group, plus the technical and scientific bodies COMNAP and SCAR. The underlying issues and drafts of environmental guidelines for RPAS were considered by the group over 2017–18 (Germany 2018).

Papers that have suggested environmental guidelines for use of RPAS in other parts of the world (Vas et al. 2015; Hodgson and Koh 2016; Mulero-Pázmány et al. 2017) and for operations in Antarctica (Goebel et al. 2015; United States 2015; IAATO 2016; SCAR, 2017, 2017a, 2017b) were evaluated for the consistency in their recommendations, and this also provided input to the draft guidelines.

Development of the environmental guidelines needed to strike a balance between the complexity implicit in the wide range of interacting factors represented in Fig. 1 and the need for practical application by RPAS operators in the field. From a practical point of view, there are three main phases at which guidelines are likely to be helpful: 1) pre-deployment planning, 2) on-site/in-flight operations, and 3) post-flight activities and reporting. For example, steps taken during the pre-deployment phase can significantly influence activities and outcomes at the on-site/in-flight phase, and these are further likely to influence the post-flight phase (which could include RPA recovery and clean-up). It was therefore decided to structure the guidelines around the practical process of RPAS planning and deployment, rather than directly map them from the conceptual model. Fig. 1, however, was important as a framework against which to consider whether the guidelines being developed were comprehensive in capturing the important elements and interactions relevant to environmental performance.

In summary, the environmental guidelines for operation of RPAS in Antarctica were based on available scientific evidence for environmental risks and impacts arising from RPAS use, technical aspects of RPAS technology, the theoretical framework in Fig. 1 summarising the most important elements and interactions to consider, practical experience in use of RPAS in the field by operators, existing models of guidelines for RPAS use suggested elsewhere in the world and in Antarctica, and the practical need for a document structure that users would find easy to implement. The draft environmental guidelines for operation of RPAS so developed were submitted for consideration by the CEP in 2018 (Germany 2018) and, following discussion and amendments at that meeting, the final environmental guidelines were adopted by the Antarctic Treaty Parties through Antarctic Treaty Consultative Meeting Resolution 4 (2018) (Fig. 2).

5. Discussion

The guidelines adopted are intended to apply mainly to RPAS operations within Visual Line of Sight (VLOS) and using small to medium sized aircraft (≤25 kg), which are likely to account for the majority of non-military RPAS activity taking place. RPAS operations Beyond VLOS (BVLOS) and with larger aircraft (> 25 kg) pose additional risks, and while most of the guidelines may apply, these operations are in need of additional specific environmental and safety management measures. For example, operating BVLOS may limit the capacity of operators to observe directly the surrounding context of an RPA in flight, and in particular the effects it might be having on wildlife. In addition, larger aircraft have greater potential to be lethal should a malfunction occur.

During development of the guidelines, there was considerable debate over whether or not specific guidance on separation distances between the RPA and wildlife should be adopted. Those in favour of defining separation distances, even if indicative, argued there is a need by pilots to have some practical guidance on separation distances at which wildlife would be likely to be disturbed by RPAS. For example, there is some evidence to suggest that some penguin species tend to experience some level of disturbance only when an RPA is operating closer than 50 m (Rümmler et al. 2015). It was noted that specific separation distance guidance is available to pilots operating conventional fixed-wing or helicopter aircraft near wildlife, and that this was considered practical and operationally useful (Harris, 2005; Antarctic Treaty Resolution 2 (2004)). On the other hand, there is evidence showing that the distances at which some level of disturbance is apparent varies across species (Weimerskirch et al. 2017; Brisson-Curadeau et al., 2017; Rümmler et al. 2018). For practical operations, it could be useful for pilots to be aware of indicative distances at which certain species might experience some disturbance, such as set out in preliminary findings in Table 1, although this could make the guidelines more complicated to follow, especially where multiple species are present. The variability across species, as well as the preliminary nature of scientific evidence that has so far been assembled, led Mustafa et al. (2018) to conclude that at present species-specific guidelines are not yet practical. The Antarctic Treaty Parties took the decision to omit specific separation distances from the guidelines adopted (Fig. 2), at least until more comprehensive and robust evidence can be gathered.

In the context of Antarctica, the Environmental Protocol requires in Article 3.1 that protection of the environment shall be a fundamental consideration for conduct of all activities in the region, and Article 3.3 accords priority to scientific research over other activities such as leisure or commerce. A further debate was therefore held over whether the RPAS environmental guidelines should be customised to particular user groups, in particular whether guidelines should be more restrictive on recreational uses of RPAS than on scientific or logistic applications. At first, this approach seemed appealing because recreational uses were considered ‘unnecessary’, and therefore more constraints on RPAS operation could be justified given an over-riding objective to protect the environment. Mulero-Pázmány et al. (2017) also recommended that RPAS flights over wildlife be discouraged for leisure purposes. However, based on the principle enshrined in the Environmental Protocol that environmental protection considerations should apply to the planning and conduct of *all* activities (Article 3.1), the decision was taken that the guidelines should apply to *all* users of RPAS and that limits to recreational uses, if warranted, should be regulated through other provisions and processes such as Environmental Impact Assessment, or perhaps by means of voluntary limits implemented by tour operators such as has been the case to date (IAATO 2016).

The definition of ‘disturbance’ was also recognised as presenting difficulties, since the majority of research to date has been based on behavioural indicators of disturbance. There is evidence to suggest that outward behaviour is not necessarily a clear indicator of the stress level experienced by animals, and therefore may not be reliable as a guide to ‘disturbance’. For example, the behaviour of birds when exposed to disturbance may suggest those that remain on nests are less stressed than those that fly off or move away because they are more static. Typically flight or flee behaviour has been classified to indicate a higher level of stress being experienced by the animal than if the animal remained static (e.g. Rümmler et al. 2015, 2018; Weimerskirsch et al. 2017). However, the reverse may be true, because even though the powerful instinct to remain on the nest may prevail over the desire to escape, stress levels being experienced by the animals may actually be higher than if they were free to flee. Physiological changes, however, are more difficult to measure, and it would seem that behavioural indicators of disturbance – while imperfect – may be more practical to use for guidance at least until more physiological research provides a better understanding of the true stress levels experienced by wildlife as a result of RPAS operations.

The question of the significance of certain levels of ‘disturbance’ by RPAS has barely been addressed in research to date. For example, does an increased level of 'vigilance' translate into any significant impact on the animal, such as its health, reproductive success or life-span, as a result of the disturbance? Long-term studies are needed to develop a better understanding of what level of disturbance might be significant, and this will vary across species and also according to particular contexts, and Mustafa et al. (2018) identified this as an important priority for further research. Improved understanding of the physiological changes induced by certain forms and levels of disturbance may help, although even then proving causative links to impacts on animals such as declines in health or reproductive performance and life-span, as well as changes to the animal population, may prove challenging when considered against the wide range of other influential variables acting in the environment. For example, the significance of disturbance resulting from RPAS operations may be difficult to separate from factors such as prey availability, natural predation, local pollutants, and changing conditions as a result of climate change.

6. Conclusion

Given the preliminary nature of research into disturbance of wildlife by RPAS, the difficulties of assessing actual levels of stress being experienced by animals, and the uncertainties over the significance of consequential impacts for individual animals and populations as a whole, it is particularly important that a precautionary approach is taken to RPAS operations. Mulero-Pázmány et al. (2017) noted that recreational uses of RPAS are rising rapidly, and that some authorities have already put in place regulations based on the precautionary principle to prevent potentially negative consequences on fauna. At the same time, the many benefits of RPAS for wildlife research and a wide range of other applications, and their potential to reduce environmental impacts that might otherwise occur using alternate methods, should also be taken into consideration. There is a need for a balance between use and protection, and the non-mandatory guidelines adopted by the Antarctic Treaty Parties through Resolution 4 (2018) represent an attempt to strike that balance by providing RPAS operators and regulators with practical advice that, according to the best evidence currently available and if followed, should allow RPAS to be used in proximity to Antarctic wildlife with relatively low levels of environmental impact. The Antarctic Treaty Parties also agreed to consider further the circumstances under which recreational uses of RPAS should, or should not, be allowed in Antarctica.

The Antarctic Treaty Parties recognised that the RPAS technologies themselves and scientific understanding of their potential impacts are rapidly evolving. As such, it was considered important to review recommended best practices regularly in the light of advances in scientific knowledge and technical developments. There remain numerous gaps in understanding of RPAS and wildlife interaction, and further research is needed both in the Antarctic and elsewhere in the world. In the meantime, the environmental guidelines for RPAS operations in Antarctica could provide a model to be adapted for use elsewhere in the world wherever there is a need to manage interactions between RPAS and wildlife.

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Declaration of competing interest

The authors have no conflicts of interests to declare.

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