Preliminary study on nesting Adélie penguins disturbance by unmanned aerial vehicles

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Abstract

The importance of unmanned aerial vehicles (UAVs) in remote sensing is rapidly growing. However, knowledge about their potential impact on wildlife is scant, especially in Antarctica, where they are a new tool used in ecological research and monitoring.

In this preliminary study potential effects of wildlife disturbance by fixed-wing UAVs are investigated. In austral summer 2014/15, UAV overflights were conducted in the Adelié penguin (*Pygoscelis adeliae*) breeding colony at Point. Thomas (Western Shore of Admiralty Bay, King George Island, Antarctica, Subarea 48.1). The impacts of electric and piston engine UAVs flying at 350 m altitude above ground level (AGL) over the colony were compared to the undisturbed colony (control group), and to natural disturbance (skua – *Stercorarius* sp. flying over nesting penguins). Penguin behaviour was divided into: resting behaviour, comfort behaviour, vigilance/anxiety and aggression. Percentages of birds exhibiting different types of behaviour, time spent on each type of behaviour and number of different types of behaviour displayed by one bird during the observation periods were compared. No differences were found between the control group and overflights by electric UAVs. During the overflight by a UAV powered by piston engine, symptoms of vigilance were observed with penguins looking up and around for a few seconds when the UAV was overhead. Similar symptoms of vigilance were observed when skuas flew (approximately 5 m AGL) over penguin colony without trying to attack nesting birds. No increase in aggressive behaviour was observed during the overflights by either electric or piston engine UAVs. Plans for a systematic monitoring of UAV impact on wildlife, as well as preliminary guidelines for the next field season, were formulated.

Introduction

During the last decade, unmanned aerial vehicles (UAVs) have become an important tool in ecological research and monitoring, especially for inaccessible regions. UAVs can operate below cloud level and collect higher-resolution images at a lower cost than manned airplanes or satellites, and, therefore, offer ecologists a way of monitoring environmental phenomena that is responsive, timely and cost-effective (Anderson and Gaston, 2013).

Outside Antarctica, UAVs have been tested or used for surveys of numerous wildlife species such as African large mammals (Vermeulen et al., 2013; Mulero-Pazmany et al., 2014), marine mammals (Koski et al., 2009; Hodgson et al., 2013) and bird colonies (Sarda-Palomera et al, 2012; Chabot et al., 2015). Antarctic UAV-based surveys are in an initial development phase and include censuses of penguins (Trathan et al., 2014; Goebel et al., 2015; Ratcliffe et al., 2015; Rümmler et al., 2015) and leopard seals (Goebel et al., 2015).

Penguins are a key species group in Southern Ocean ecosystems. Their abundance and distribution has been used as one of the most important indication of ecosystem status and change (e.g. Jenouvrier et al., 2006; Trivelpiece et al., 2011; Lynch et al., 2009; Southwell et al., 2013).

The use of aerial survey methods, including small aircraft ‘Twin Otter’ and vertical take-off and landing (VTOL) platforms, to provide new estimates of krill-dependent penguin species population distribution and abundance within the framework of the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) Ecosystem Monitoring Program (CEMP) implementation has been recorded (Trathan et al., 2014; Goebel et al., 2015).

The rapidly growing use of UAVs in ecological research and monitoring is raising legitimate concerns over wildlife disturbance, especially as there is only limited information on the subject with almost no dedicated research to address it. During the Antarctic Treaty Consultative Meeting (ATCM XXVII) and the Committee for Environmental Protection meeting (CEP XVII) (Brasilia, 2014) both the advantages of using UAVs for research and monitoring, as well as potential safety, environmental and operational risks were discussed. In preparation for further discussions, the CEP requested papers providing members’ experience in this region. It is planned that further discussions at ATCM/CEP, the Scientific Committee on Antarctic Research (SCAR) and the Council of Managers of National Antarctic Programs (COMNAP) will help to formulate and adopt guidelines of safe UAV use, similar to the existing guidelines for the operation of aircraft near concentrations of birds in Antarctica adopted in 2004 (ATCM XXVII–CEP VII, Capetown, Resolution 2 (2004)). The aim of this study was to test the proposed methodology for monitoring the impact of electric and piston engine UAVs on Adelié penguins (*Pygoscelis adeliae*) on the western shore of Admiralty Bay (King George Island) and also to collect data enabling the formulation of preliminary guidelines for UAV overflights.

Methods

Study area

The study site was the breeding colony at Point Thomas (King George Island, South Shetland Islands, Antarctic Peninsula), which is located in Antarctic Specially Protected Area (ASPA) No. 128 – western shore of Admiralty Bay (Figure 1). This colony covers an area of approximately 43 400 m^2 and consists of approximately 5 700 pairs of all three *Pygoscelis* penguins, mostly Adélie penguins.

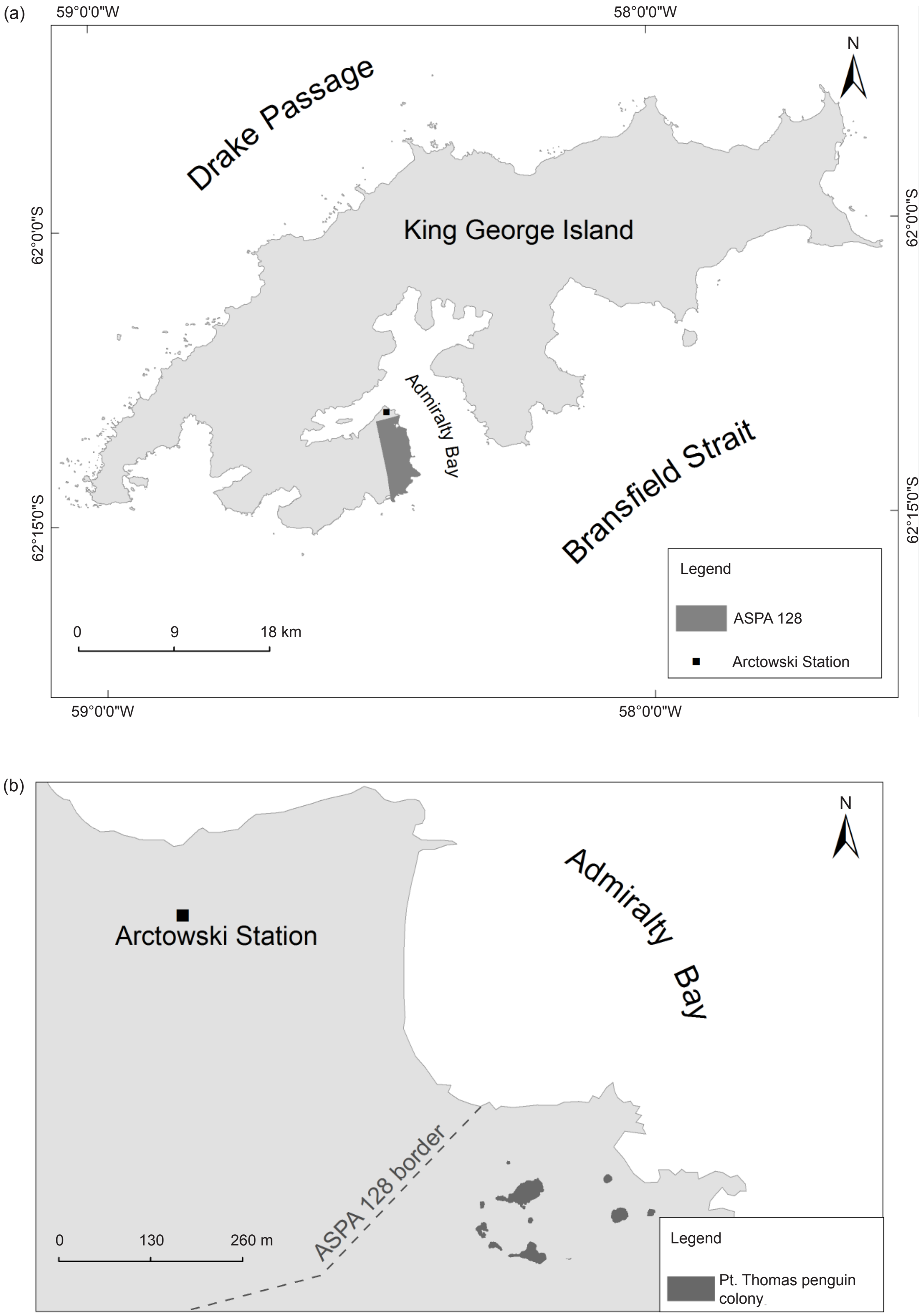

Figure 1: Study site located in Antarctic Specially Protected Area (ASPA) No. 128 western shore of Admiralty Bay, King George Island (A). Location of Point Thomas Adelié penguin colony breeding groups in the vicinity of Arctowski Station (B).

It is located approximately 700 m from Arctowski Station and is visited by observers monitoring breeding chronology and success of penguins, mapping breeding groups and nests in the colony, and collecting biological samples.

ASPA No. 128 is a site of long-term monitoring programs of bird and pinniped species conducted by the USA (Antarctic Marine Living Resources – AMLR) (e.g. Trivelpiece et al., 1987; Hinke et al., 2007) and Poland (Department of Antarctic Biology – IBB PAS) over the past 36 years (e.g. Jabłoński, 1984a; Chwedorzewska and Korczak, 2010; Korczak-Abshire et al., 2012). In the 2014/15 austral summer there were 5 879 breeding pairs of Adélie penguin, 484 breeding pairs of chinstrap penguin (*P. antarcticus*) and 5 442 breeding pairs of gentoo penguin (*P. papua*) (Korczak-Abshire, unpublished data) in the entire ASPA No. 128.

During the penguin incubation period in November 2014, the colony was overflown by two UAVs with different propulsion systems (electric engine powered by Li-Pol battery versus internal piston engine run on gasoline). The overflights were done at the altitude of 350 m AGL. Take-offs and landings were from Arctowski Station, approximately 500 m from the penguin colony. UAVs had pre-programmed flight plans that involved a series of parallel line transects above the penguin colony being monitored (Figure 2).

To determine a suitable flight altitude, preliminary test flights using penguin-like targets simulating the profile (shape, size) of penguins sitting on nests were conducted, with aerial photo images taken using an SLR Canon 700D camera with a 35 mm objective lens. On this basis it was determined that a flight altitude of 300–400 AGL allowed images to be taken with a ground sample distance (GSD) resolution of less than 5 cm, which enables satisfactory penguin species identification and nest counting.

UAVs

The following two fixed-wing UAVs were used in the study (Figure 3):

(i) CryoWing Mk1 (MTOW 35 kg, wingspan 3.8 m, max. flight distance 400 km, max. flight time 360 minutes, flight speed 105 km/h, fuel – 95 octane gasoline (piston engine))

(ii) Skywalker X-8 (MTOW 4 kg, wingspan 2.1 m, max. flight distance 40 km, max. flight time 30 minutes, flight speed 70–80 km/h, fuel – Li-Pol battery (electric engine)).

Behaviour observations

Data collection

The behaviour of breeding Adelié penguins was recorded on video camera (Samsung VP-DX 200 and Nikon D5100 (video mode)) placed on a tripod 5–10 m from the edge of a breeding group, with the cameraman sitting about 2 m further away. Each recording lasted 18 to 20 minutes. Control group data recording (breeding colony undisturbed by UAV overflights) was collected on 4 November while separate overflights by both UAVs took place on 6 November. The recordings were started when UAVs were in the air. In addition, a 3 minute recording showing a skua (*Stercorarius* sp.) flying at a constant height of5 m over the breeding penguins (but without mounting an attack) was recorded on 15 November for comparison with the non-UAV type of disturbance.

Data analysis

For each video sequence, 15 clearly visible breeding birds, not obscured by other individuals standing or passing through the group, were chosen. Therefore the same penguins were not always analysed for each test (control group, piston engine UAV, electric UAV, skua).

Bird behaviour was analysed for a 3 minute period during which the piston engine UAV was more or less directly overhead, and for another 3 minutes when the UAV was further away (up to 800 m) but still audible. In the case of the electric engine UAV, which cannot be heard or seen by human observers at 350 m altitude, one observation period was chosen randomly during the period when the UAV was engaged in flying parallel transects above the colony. In case of control group and skua overflight, the entire 3 minute period was analysed.

Behavioural responses of penguins were divided into five easily distinguishable types (Schuster, 2010; Hughes et al., 2008 with some modifications):

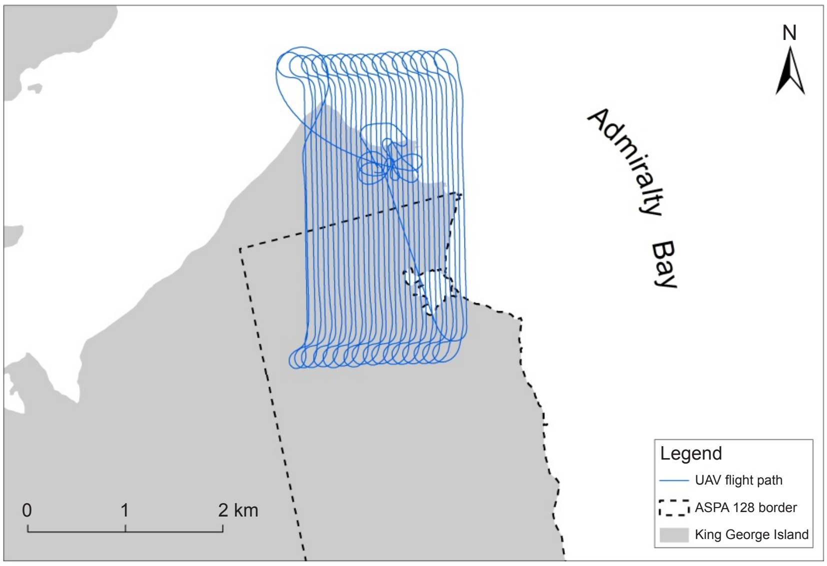

Figure 2: Example of GPS trajectory record of the flight plan carried out by the UAV above the Point Thomas penguin colony.

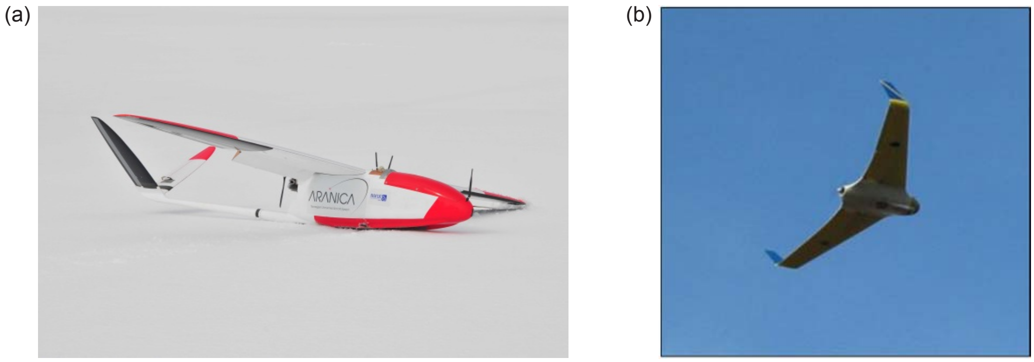

Figure 3: Fixed-wing UAVs used over ASPA No. 128: (a) CryoWing Mk1, (b) Skywalker X-8.

Type I – resting behaviour – birds motionlessly sitting/standing in nests, sleeping or looking at their neighbours.

Type II – comfort behaviour – birds cleaning and preening, changing position, stretching, interacting with their partners.

Type III – vigilance/anxiety – birds actively observing UAV/skua, standing up in their nests.

Type IV – aggression – birds posturing, gaping, pecking at individuals passing near their nest or at their neighbours.

Type V – escape – birds abandoning nests.

The number of birds exhibiting each behaviour type, the time (seconds) spent by each bird engaged in each type of behaviour and number of different types of behaviour displayed by one bird during the 3-minute periods were recorded. Data analysis was performed using the statistical package Statistica 5.5 (StatSoft). To establish the statistical significance of differences between datasets, ANOVA and Tukey HSD tests were used.

Results

In the control group data only three types of behaviour were observed – resting, comfort and aggression (Figure 4). Aggression occurred when non-nesting birds walked through the colony, violating the individual space of nesting birds. A similar situation was noted when the electric UAV flew above the colony.

Four types of behaviour (categories I – IV) were observed during overflights by the piston engine UAV, although no signs of anxiety (e.g. standing up) were observed. Therefore, behaviour type III was equivalent only to vigilance (active observation). No birds were observed abandoning their nests (type V behaviour).

When the UAV with piston engine was flying directly above the penguins, approximately 80% of birds were displaying vigilant behaviour, looking up and around, as if trying to locate the source of the noise. When the piston engine UAV was further away, and the noise level decreased, only 20% of birds exhibited vigilance (type III).

A qualitatively similar situation was noted with the skua flying above the penguin colony. There was a synchronous head movement exhibited by all penguins coincident with the exact time of the skua overflight. This resulted in a mean duration of type III behaviour of 5.8 seconds (SD = 2.5). For the remainder of the 3-minute observation time type III behaviour was not noted and penguins behaviour was similar to the control group.

The mean number of activity types displayed by penguins ranged from 1.4 (SE = 0.16) during the electric UAV overflight to 2.6 (SE = 0.16) when the piston engine UAV was flying directly above the penguins (Figure 5). Statistically significant differences were observed between experiment variants (ANOVA $F_{70,4} = 7.31674$; $p < 0.0001$). A significant increase in the mean number of activity types was observed in birds during the overflight by a UAV powered by piston engine in comparison to the control group and electric UAVs (RIR Tukey test, $p < 0.05$).

In each variant of the experiment, resting behaviour occurred for at least 116 seconds (64% of the observation period). Vigilance, which was noted only during overflights by piston engine UAVs and by skua, did not exceed 9 seconds (4.6% of the observation period) (see Figure 6). In each variant, aggressive behaviour was noted only in single birds, with a mean duration time not exceeding 1.1 seconds.

Statistically significant differences were observed between experiment variants (ANOVA $F_{70,4} = 27.09831$; $p < 0.00001$) with significant increase in mean time spent on vigilance/anxiety behaviour in birds during the overflight by the UAV powered by piston engine and during the skua overflight (RIR Tukey test, $p < 0.05$) in comparison to the control group and electric UAV.

No statistically significant increase of time spent on aggressive behaviour was observed during the overflights (ANOVA $F_{70,4} = 0.40201$; $p = 0.80656$).

Discussion and conclusions

Data in this study allows for a preliminary conclusion that fixed-wing electric UAVs of the type used in this study flying at 350 m altitude AGL were not noticed by Adélie penguins. UAVs powered by piston engine were noticed (probably heard) by birds when directly overhead and elicited a detectable reaction (a few seconds of vigilance and a slight increase in activity level) that was similar to the reaction caused by natural disturbance (e.g. a skua flying overhead, but not attempting to attack penguins). Thus, although stimulus was different (auditory versus visual and a huge difference in altitude) the reaction intensity was similar.

Aggression in Adélie penguins colony during incubation period is a normal phenomenon, caused mostly by non-breeding birds moving through the colony, invading the territories of nesting penguins and being attacked by them or triggering agonistic interactions between nesting birds. No non-breeding penguins were seen running through the nesting group that was being filmed. Additionally, lack of increase in aggressive behaviour between nesting penguins during overflights suggests that non-breeding birds present in the colony (but outside the group being filmed) were not displaced by any of the UAV overflights. Such displacement would have precipitated their movement through the colony and increased the number of aggressive encounters with breeding birds, as well as between neighbouring breeding birds.

No other species of Antarctic wildlife were monitored but a single opportunistic observation was conducted during one overflight by a piston engine UAV at 350 m altitude AGL above a giant petrel (*Macronectes giganteus*) colony (Korczak-Abshire, personal observation). Although no nest were abandoned by breeding birds, which did not react to the disturbance in any easily visible way, a few of the

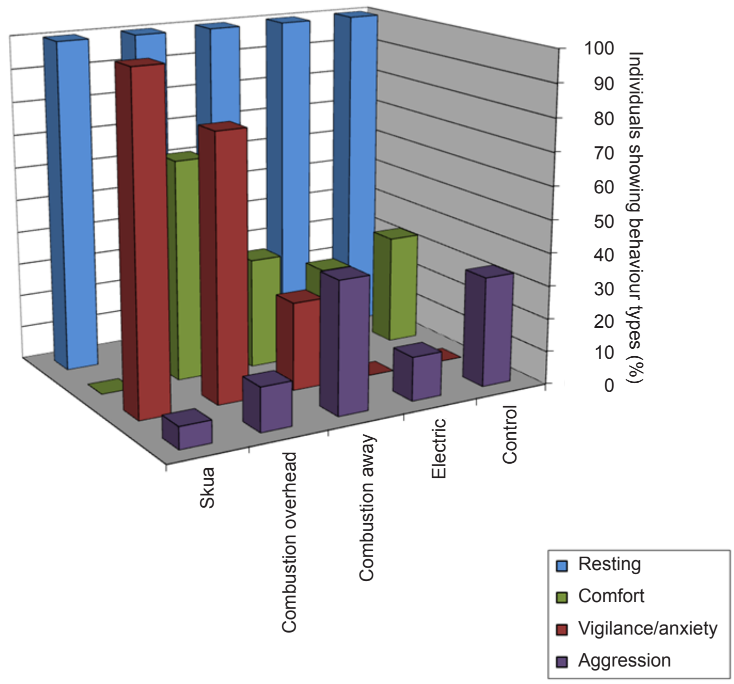

Figure 4: Percentage of nesting Adelié penguins exhibiting different types of behaviours: resting, comfort, vigilance/anxiety and aggression during control group monitoring; during overflights by UAVs with different types of propulsion; and during interaction with skuas.

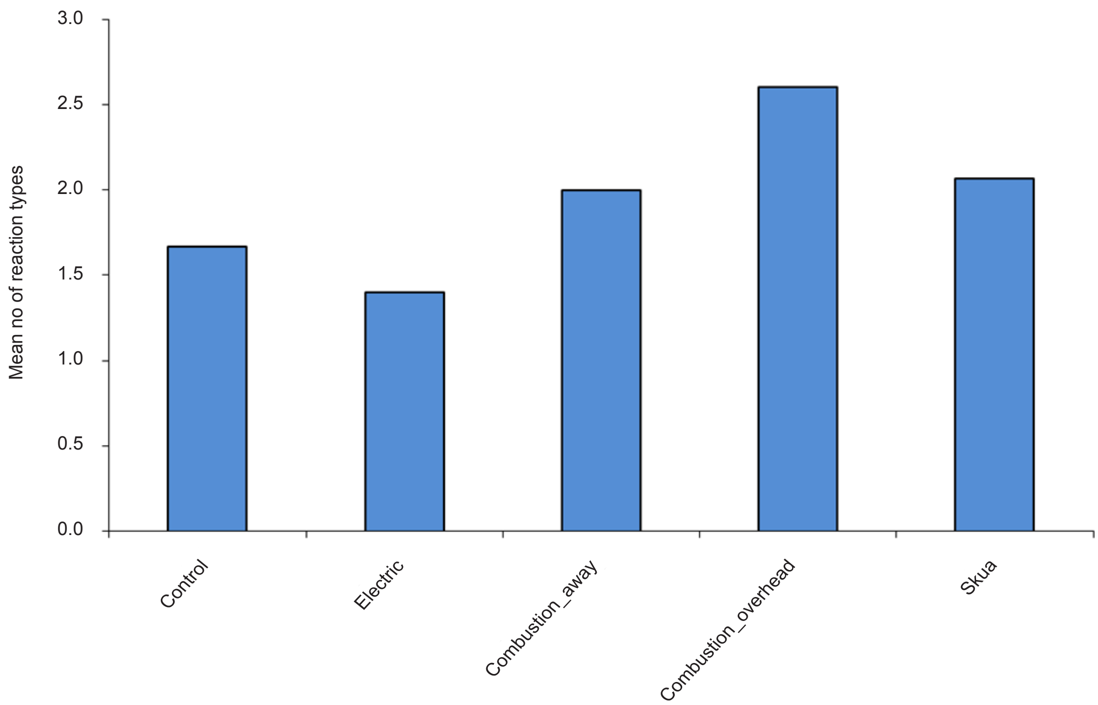

Figure 5: Mean number of reaction types exhibited by nesting Adelié penguins during control group monitoring, during overflights by UAVs with different types of propulsion; and during interaction with skuas.

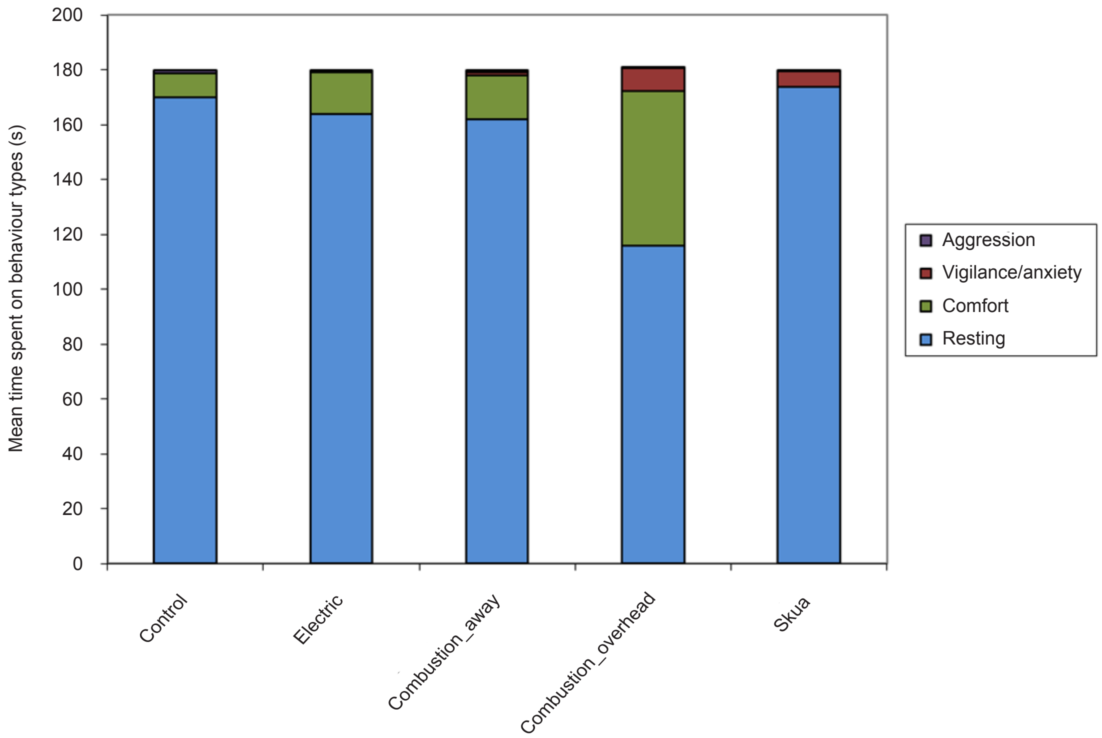

Figure 6: Mean time (seconds) spent by nesting Adelié penguins on different types of behaviour: resting, comfort, vigilance/anxiety and aggression during control group monitoring, during overflights by UAVs with different types of propulsion; and during interaction with skuas.

non-breeding petrels in the vicinity of the colony flew away and circled above the colony for up to 15 minutes before returning.

Based on the experience during the first season of these flights the following recommendations can be made:

- Trial control group recordings must be done a few days before UAV flights to find and test the best colony location, placement of the camera, time of day, number and location of nests etc.

- Sources of natural disturbances (frequency of skua attacks, inter-colony paths most commonly used by non-breeding birds etc.) must be analysed, in order that a suitable base-line can be included in analysis and will not influence the outcome of the planned UAV experiments.

- Control group observation must be done immediately before UAV overflight to allow for a reliable comparison. If done a day before or after the overflight, the margin of error increases as penguin behaviour can be influenced by other factors, for example weather or skua attacks. The best option is a 20–30 minute recording with the overflight around its midpoint.

- Noise measurements should be done in conjunction with the filming, so that the relationship between noise level and changes in wildlife behaviour can be determined.

Review of available literature

The consequences of human disturbance on wildlife are not always directly visible. Even seemingly unaffected (no observable behavioural reaction) animals might undergo physiological changes in response to disturbance. Increased heart rate in response to different types of anthropogenic disturbance (human presence, handling, aircraft flights) was observed in yellow-eyed penguins (*Megadyptes antipode*) (Ellenberg et al., 2013), Adélie penguins (Wilson et al., 1991), Humboldt penguin (*Spheniscus humboldti*) (Ellenberg et al., 2006), magellanic penguins (*S. magellanicus*) (Walker et al., 2005) and king penguins (*Aptenodytes patagonicus*) (Viblanc et al., 2012). American black bears (*Ursus americanus*) showed consistently strong physiological responses (elevated heart rates) with rather infrequent behavioural changes when exposed to the presence of a multicopter (Ditmer et al., 2015). However, incubating American oystercatchers (*Haematopus palliatus*) showed only minimal changes in heart rate in response to human activity ranging from pedestrians to military and civilian aircraft; only low-altitude, high-velocity military overflights caused significant (12%) heart rate increase (Borneman et al., 2014). The difference between species reaction to disturbance is also seen in the habituation process, with Humboldt penguins showing little habituation potential (Ellenberg et al., 2006) in comparison to king penguins (Viblanc et al., 2012) or magellanic penguins (Walker et al., 2005).

Quantitative information on potential UAV disturbance of wildlife is rather scarce – observations on species ranging from Antarctic penguins to African elephants (Table 1). Three of them were specifically aimed to study multicopter impacts on Adélie penguins (Rümmler et al., 2015), American black bears (Ditmer et al., 2015) and three species of waterfowl (Vas et al., 2015). Data on distance thresholds of disturbance of grey seals was reported by Pomeroy et al. (2015).

Ten publications contain information on potential disturbance resulting from different types of multicopters, the other six deal with fixed-wing UAVs. All except one (heart rate measurements on black bears done by Ditmer et al., 2015) concentrate on behavioural impact, which was observed either from the ground or analysed from collected video material.

Multicopters have the ability to maintain a stationary position and are easily maneuvered in areas inaccessible to fixed-wing UAVs (e.g. among trees), but have limited flight time and distance and are best suited to monitor small areas which must be surveyed from low altitudes (e.g. nests on trees, slow moving animals, single bird nests). Behavioural disturbance reported from multicopters suggests that UAVs can approach animals up to relatively short distances (5–50 m depending on species) without eliciting strong behavioural reactions. Approach mode (horizontal or vertical) was an important factor for waterfowl (Vas et al., 2015) and Adélie penguins (Rümmler et al., 2015), with birds probably interpreting vertical approach as a raptor attack. Launching UAVs no closer than 100 m from the birds was recommended (Vas et al., 2015) and supported by Rümmler et al. (2015), who reported a level of disturbance considerably higher in contrast to previous studies on birds (Hanson et al., 2014; Goebel et al., 2015; Vas et al., 2015) and hypothesised that it might have been caused by the short distance (50 m) between penguin colony and the take-off place.

Environmental factors, such as wind speed and ambient noise, may also play an important role. Ditmer et al. (2015) observed that heart rate increases in American black bears were positively correlated with wind speed, suggesting that stress responses were stronger when UAV flights involved an element of surprise (bears could most likely not hear the approach of the UAV in windier conditions, so they were more startled). However, ambient noise near a chinstrap penguin colony during the egg-laying period was so high that the sound of a hexacopter hovering at an altitude of 30 m was lost in the background (Goebel et al., 2015).

Pomeroy et al. (2015) also reported that groups of grey seals may have different reactions depending on their age, sex and biological state (breeding or moulting), and probably also on their experience of previous disturbance. Such observations are especially important as multicopters are becoming widely used both for scientific research and monitoring, as well as recreational purposes.

Fixed-wing UAVs can travel at higher altitudes and speeds than multicopters, which coupled with their longer flight duration and autopilot mode of control makes them especially useful for surveying large areas.

All published research on fixed-wing UAVs except one (Moreland et al., 2015) deal with UAVs equipped with electric engines flying at altitudes ranging from 10 to 260 m AGL. Only in two cases of African elephants (Vermeulen et al., 2013) and African rhinoceros (Mulero-Pazmany et al., 2014) no behavioural impact was observed. In other cases observed impact ranged from non-significant (colony of black-headed gulls by Sarda-Palomera et al., 2012) to initial disturbance (upflights) followed by rapid habituation (common tern colony by Chabot et al., 2015).

While UAVs with electric engines are reportedly to make less noise than UAVs with piston engines, they have lower flight endurance (limited battery capacity), less total weight and are not suitable for long-distance missions covering large target areas. This latter issue is especially important in the harsh and unpredictable weather conditions of the South Shetland Islands, where using a piston engine UAV would be more practicable.

Moreland et al. (2015) detailed a survey of spotted (*Phoca largha*) and ribbon (*Histriophoca fasciata*) seals in Bering Sea pack-ice using a piston engine UAV. During flights at 91–200 m altitude some significant impacts ('heads up' or 'foreflippers extended') were observed in 42% of seals, although no seals diving from floes were noted; however, the authors reported a large reduction in disturbance in comparison with helicopter surveys.

Both Moreland et al. (2015) and this study show that flights of piston engine UAVs must be planned at considerable altitudes if more unwarranted impacts are to be avoided. New innovative technology has clearly outpaced our ability to assess its impact on wildlife and to provide regulatory guidelines. These gaps in knowledge must be addressed quickly to ensure the safe use of UAVs in ecological monitoring and research. Different types of UAVs (multicopter, fixed-wing UAVs with electric or piston engines) must be chosen depending on flight purpose and after careful consideration of potential environmental consequences of their use, also comparing them to the existing methodologies (e.g. monitoring by people on the ground, use of helicopters, people climbing trees to look into bird nests).

Based on the first season Poland formulated the following preliminary guidelines for the future use of UAVs in Polish Antarctic research:

- overflights of Adelié penguin colonies by both types of UAVs at the altitude of 350 m are deemed safe
- if overflights of Adelié penguin colonies at lower altitudes are planned – UAVs with electric engine are recommended
- overflights of giant petrel colonies must be kept to a minimum, and then only with electric UAVs.

It is hoped that these Polish guidelines will be developed as more research is conducted and will contribute to the overall development of a suite of broader guidelines for the safe use of UAVs in Antarctic research.

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Table 1: Impact of UAVs (unmanned aerial vehicles) on wildlife. UAS – unoccupied aircraft system.

Species	Location	UAVs	Altitude, noise level, impact observation method	Impact	References
		Multicopters (quadcopters, hexacopters, octocopters)			
Hooded crow (*Corvus cornix*)	Sweden (tree groups in and around Uppsala) Nesting status survey	Quadcopter: Phantom 2 Vision (DJI) Weight: 1 160 g Dimensions: 29 × 29 × 18 cm Flight time: 25 min	Altitude: <5m above nest Impact measurement: ground observer	Moderate (alarm calls, cowering), lower than caused by monitoring by people	Weissensteiner et al., 2015
Mallards (*Anas platyrhynchos*), wild flamingos (*Phoenicopterus roseus*), common greenshanks (*Tringa nebularia*)	France (semi-captive and natural settings) UAS bird impact study	Quadcopter: Phantom (Cyleone) Diagonal length: 350 mm Weight: 1 030 g Max. speed: 15 m/s	Altitude: <30 AGL Noise level: 60 dB at 2 m Impact measurement: experiments designed to study impact of UAS color, speed and approach angle, ground observer	Approach speed, UAS colour and repeated approaches: no significant impact Approach angles: marked impact (head, tail movements, moving away) during vertical approach	Vas et al., 2015
Gentoo penguin (*Pygoscelis papua*), Adélie penguin (*Pygoscelis adeliae*)	South Georgia, Signy Island (Antarctica) Developing aerial survey methods	Hexacopter: Cinestar 6 (FreeFly Systems) Diameter: 1 204 mm Weight: 2 650 g	Altitude: 15 m AGL Impact measurement: ground observer	No impact	Trathan et al., 2014
Adélie penguin (*Pygoscelis adeliae*)	Ardley Island (Antarctica) UAS bird impact study	Octocopter: MK ARF Okto XL (HiSystems) Total weight: 3.5 kg Dimensions: 73 × 73 × 36 cm	Noise level: 70 dB at a distance of 5 m 10–50 m AGL Impact measurement: experiments designed to study impact of vertical and horizontal flights, video recordings of breeding penguins behaviour	Visible reaction (vigilance) of penguins increasing with lowering altitudes. Short-term habituation absent. Flight mode (horizontal or vertical) impact: significant at altitudes below 20 m	Rümmler et al., 2015
American black bears (*Ursus americanus*)	northwestern Minnesota (USA) Measuring behavioural and physiological response to UAS	Quadcopter: 3DR IRIS (3DR) Motor-to-motor dimension: 550 mm Total weight:1 282 g Flight time: 16–22 min	Altitude: 21 m AGL Distance between UAV and target bear: 43 m Impact measurement: cardiac biologgers and GPS collars	Consistently strong physiological responses (elevated heart rates), infrequent behavioural changes. Magnitudes of heart rate spikes correlated with wind speed and proximity of UAV	Ditmer et al., 2015

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Table 1 (continued)

Species	Location	UAVs	Altitude, noise level, impact observation method	Impact	References
		Multicopters (quadcopters, hexacopters, octocopters)			
Gentoo penguin (*Pygoscelis papua*), Adélie penguin (*Pygoscelis adeliae*), fur seals (*Arctocephalus gazella*), leopard seals (*Hydrurga leptonyx*)	Livingston Island, (Antarctica) Testing VTOL platform, estimating abundance, colony area and density of krill-dependent predators	Hexacopter: APH-22 (Aerial Imaging Solutions) Length: 82.3 cm Total weight: 2.72 kg	Altitude: penguin colonies: 15 and 45 m AGL, fur seals: 45 m, leopard seals: 15–45 m Noise level: 31.3–57.8 dB at altitudes 0–90 m AGL Impact measurement: ground observers, comparing VTOL-generated noise to ambient and penguin generated sound	No signs of disturbance, sound of a hexacopter at an altitude of 30 m was lost in the background (penguin noise)	Goebel et al., 2015
Osprey (*Pandion haliaetus*), bald eagle (*Haliaeetus leucocephalus*), ferruginous hawk (*Buteo regalis*), red-tailed hawk (*B jamaicensis*)	Montana (USA) Testing rotary-winged UAV for surveying raptor nests in boreal forest and prairies	Quadcopter: Draganflyer X-4 (Draganfly Innovations) Dimensions: 64.5 × 64.5 × 21 cm Weight with payload: 770 g	Altitude: 3–6 m above nest Noise level: 60 dB at 3m, 30 dB at 100 m Impact measurement: ground observers	Adult birds reacted with aggression against UAV, no lasting disturbance (quick return to pre-survey behaviour), recommendation: no UAV use during late-nesting stage (nestlings prone to jumping from nest)	Junda et al., 2015
Gray seals (*Halichoerus grypus*), harbor seals (*Phoca vitulina*)	Outer Hebrides, Tayside, Firth of Forth, Sutherland (UK) Trial flights to survey grey and harbor seals using a range of different platforms	Quadcopter: DJI 450 (DJI) Max payload: 750 g Hexacopter: Cinestar 6 (FreeFly Systems) Max payload: 1.5 kg Octocopter: Skyjib (Horizon AP) Max payload: 5 kg Octocopter: Vulcan (Vulcan UAV) Max payload: 1.75 kg	Altitude: 30–60 m AGL Minimum distance: 200 m Impact measurements: live first-person view (FPV) video feed, analysis of video recordings from the ground	Variable responses (from alert to fleeing), possibly related to the animals' experience of previous disturbance. Precautionary guideline: adjustments to flying patterns made when reactions for >10% of the animals were greater than head-up alerts	Pomeroy et al., 2015

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Table 1 (continued)

Species	Location	UAVs	Altitude, noise level, impact observation method	Impact	References
Multicopters (quadcopters, hexacopters, octocopters)					
Steller' sea eagle (*Haliaeetus pelagicus*)	Magadan State Reserve (Russia) Testing application of UAV for Steller's sea eagle nest surveys	Quadcopter: Arducopter (3DRobotics) Quadcopter: X468 Traveler	Impact measurement: ground observer	No reaction of adult birds in general, one individual was curious and made a fly-by to see the UAV at a close distance	Potapov et al., 2013
Common gull (*Larus canus*)	Baltic Sea coast (Germany) Testing UAVs for survey of common gull colony	Multicopter: Falcon 8 (Ascending Technologies) Max take-off weight: 2 kg Multicopter: MD 4-1000 (Microdrones GmbH) Max take-off weight: 5 kg	Altitude: 50 m AGL Impact measurement: ground observer	No reaction at >15 m	Grenzdörffer, 2013
Fixed-wing UAVs					
Elephants (*Loxodonta africana*), buffon kob (*Kobus kob kob*), baboon (*Papio anubis*)	Burkina Faso (shrub and woody savannah) Mammal survey	Gatewing X100 (Trimble UAS) Wingspan: 100 cm Weight: 2 kg Engine: Electric propulsion	Altitude: 100 m AGL Impact measurement: additional test flights with ground observer	No flight or warning behaviour was recorded	Vermeulen et al., 2013
Black-headed gull (*Chroicocephalus ridibundus*)	Inland lagoon in Catalonia (Spain) Testing aerial survey methods in easily disturbed and difficult-to-access colony	Multiplex Twin Star II model (Hitec/Multiplex) Wingspan: 1.42 m, Flight speed: 30–40 km/h Engine: Electric propulsion	Altitude: 30–40 m AGL Impact measurement: calculating percentage of flying gulls in each photo of breeding colony	No significant impact. Only 1.25% of gulls flying	Sarda-Palomera et al., 2012
Common tern (*Sterna hirundo*)	Tern Islands (Canada) Census of large breeding colony	AI-Multi UAS (Aerial Insight) Wingspan: 2.1 m Weight: 4 kg Flight time: 45–60 min Flight speed: 60 km/h Engine: Electric propulsion	Altitude: 91–122 m AGL Impact measurement: ground observer	Terns were initially disturbed by the UAS flying overhead, but rapidly habituated. No evidence of sustained disturbance to the colony	Chabot et al., 2015

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Table 1 (continued)

Species	Location	UAVs	Altitude, noise level, impact observation method	Impact	References
		Fixed-wing UAVs			
Spotted seals (*Phoca largha*), ribbon seals (*Histriophoca fasciata*)	Bering Sea Evaluation of a ship-based UAV for monitoring of marine mammals	ScanEagle (Boeing) Length: 1.2 m Wingspan: 3 m Payload: 6 kg Speed: 25 m/s Flight endurance: >20 h Engine: Internal combustion	Altitude: 90–200 m AGL Impact measurement: analysis of collected aerial images	Disturbance (head up or foreflippers extended) in 42% of seals, much less than in helicopter surveys	Moreland et al., 2015
Black rhinoceros (*Diceros bicornis*), white rhinoceros (*Ceratotherium simum*)	South Africa Evaluating UAV to monitor for poaching activities in open grassland and forest	Easy Fly St-330 (St-models) Wingspan: 1.96 m Max take-off weight: 2 kg Max range: 10 km Flight endurance: 50 min Engine: Electric propulsion	Altitude: 10–260 m AGL Impact measurement: analysis of collected aerial video material	No alarm or discomfort reactions during flights. Further investigation needed for repeated (continuous) use of UAV	Mulero-Pazmany et al., 2014
Greater sage-grouse (*Centrocercus urophasianus*)	Colorado (USA) Evaluation of UAV to detect and monitor greater sage-grouse leks	Raven sUAS (Aero Vironment) Wingspan: 1.38 m Weight: 1.9 kg Engine: Electric propulsion	Altitude: 37–91 m AGL Noise level: 60–70 dB at altitudes 18–61 m Impact measurement: ground observers	No long-term response or reaction to the flights, some males momentarily paused or crouched when UAS flew over or near the leks	Hanson et al., 2014