WILL DRONES REDUCE INVESTIGATOR DISTURBANCE TO SURFACE-NESTING BIRDS?

STEPHANIE B. BORRELLE & ANDREW T. FLETCHER

Institute for Applied Ecology New Zealand, School of Science, Auckland University of Technology, Private Bag 92006, Auckland 1142, New Zealand (stephborrelle@gmail.com)

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ABSTRACT

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Many colonial-nesting seabird species are highly threatened, and their conservation is a global priority. Yet long-term population data for many species are sporadic, given the location, physical nature of many colonies, and known negative impacts of investigator interaction. The low cost of unmanned aerial systems (UASs), or drones, has democratized access to remote sensing data with high spatial and temporal resolution. Although there are limitations and risks of employing drones for conservation and data-collection purposes, the benefits include the ability to monitor a greater number of colonies at higher spatial and temporal resolutions than traditional field methods. The establishment of drone-operation guidelines, however, is an important first-step in minimizing disturbance to surface-nesting birds, given that many surface-nesting birds are particularly vulnerable to disturbances that can reduce reproductive output and increase stress responses. Research on the disturbance to wildlife from drones is in its infancy, but here we briefly review whether and how studies have evaluated the impact of drones on their study species. We review as well the variability in physiological and behavioural responses observed, and whether the studies evaluated the risk of malfunction or crashes, common with off-the-shelf drone platforms. We found that attention to evaluating disturbance and risk assessments has been limited, but preliminary evidence suggests drones can reduce disturbance impacts on some species. On the other hand, in the face of widespread drone deployment, inexpensive and rapid data collection should not be put ahead of the potential risk and impact on species.

Key words: ethics, drones, investigator impact, monitoring, technology, unmanned aerial vehicle

Unmanned aerial systems (UASs or drones) are increasingly used for conservation and ecological applications (Linchant *et al.* 2015, Schiffman 2014). Advances in consumer electronics, open-source flight-control software, and data-transfer protocols are rapidly reducing the cost and expertise required to use drones for a range of disciplines (Crutsinger *et al.* 2016). The rapid deployment of drones in ecology has provided unique opportunities to advance our understanding of many systems and species (Grémillet *et al. 2012,* Hodgson *et al.* 2016). Conservation drones have been deployed to reduce poaching of Rhinoceros *Ceratotherium* spp. in South Africa by the Olifants West Conservancy (Bergenas *et al.* 2013), to survey elephants *Loxodonta* spp. in South Africa (Vermeulen *et al.* 2013), to survey orang-utan *Pongo obelii* nests in Sumatra (Wich *et al.* 2015), and to survey marine mammals (Koski *et al.* 2010, Smith *et al.* 2016). They have also been used in seabird research (e.g., Grémillet *et al*. 2012, McClellan *et al.* 2016; Table 1). Indeed, the application of such technology aligns well with conservationists' and ecologists' data requirements for seabird research; better, in fact, than alternative remote-sensing methods, such as satellite- or airplane-based sensors (Hodgson *et al.* 2016). Therefore, it is not surprising that there is an increase in research using drone-collected data and in publications on the subject (van Gemert *et al.* 2014). However, caution is needed with regard to potential adverse impacts of drone interactions for sensitive species (Vas *et al.* 2015).

The life-history strategies of many avian taxa are likely to make them differentially sensitive to investigator disturbances (Blackmer *et al*. 2004, Carey 2009). Long-lived species, such as seabirds, generally have high reproduction costs, and therefore breeders adjust their investment to balance the costs of survival and reproduction (Blackmer *et al*. 2004, Warham 1990). Seabirds are more likely to skip breeding in years when conditions are unfavourable or when they are highly disturbed (Blackmer *et al.* 2004, Warham 1990). The impact of investigators on the productivity of seabirds has long been of interest to the conservation community. Hickey (1955) stated that bird populations have a field reality and a paper existence. That is, colony productivity between observed seabird colonies and undisturbed colonies is likely inconsistent, and this subsequently affects our understanding of seabird population dynamics. Seabird species worldwide are under threat: 17 (5%) are listed as critically endangered, 101 (29%) as globally threatened, and another 35 (10%) as near-threatened, according to BirdLife International (2015, see also IUCN 2015). Conservation and monitoring activities that reduce breeding success increase the likelihood of continued decline and eventual extinction of vulnerable populations.

While investigators may not pose a direct mortality risk, animals may still perceive human presence as a predation risk. Predation-risk responses may induce a physiological stress response, in which corticosteroids are released (Blackmer *et al.* 2004, Carey 2009). Such stress responses can affect reproductive output and long-term physiological condition if the disturbance is repeated (Blackmer *et al.* 2004), and some investigators have found direct effects on mortality rates (e.g., Feare 1976). Alternatively, animals may respond to investigator disturbance by fleeing the area, abandoning young or expending energy to relocate, which may reduce reproductive output (Carey 2009, Swenson *et al.* 1997). Disturbance from investigators

TABLE 1
Peer-reviewed studies employing off-the-shelf drone technology

Study	Purpose	Methods (platform, flight height, etc.)	Impact evaluation	Results (disturbance)	Risk evaluation
Sardà-Palomera *et al*. 2011	To monitor temporal changes in the breeding population of Black-headed Gull *Chroicocephalus ridibundus* in Catalonia, northeast Spain.	Fixed-wing drone, Multiplex Twin Star II model, Hitec/ Multiplex USA. Weight 1.5 kg, wingspan 1.42 m. Panasonic lumix camera.	Not measured	Not reported	No risk assessment reported
Chabot & Bird 2012	To test the application of small drone for monitoring Canada Geese *Branta canadensis* and Snow Geese *Chen caerulescens* at McGill University's MacDonald Campus farm fields, Quebec.	Cropcam, fixed-wing drone. Weight 2.7 kg, 2.5 m wingspan. Pentax Optio A20 camera.	Transects flown at 183 m altitude, repeated, and behavioural responses observed and recorded.	No geese were observed flushing or leaving during the drone surveys.	No risk assessment reported
Chabot *et al.* 2015	To determine the effectiveness of surveying a Common Tern *Sterna hirundo* colony using a small drone.	AI-Multi UAS fixed-wing electric aircraft, aerial insight. Weight 4 kg, 2.1 m wingspan. 12 flights across transects (multiple passes), 6 at 91 m altitude and 6 at 122 m altitude.	Disturbance responses were recorded for 10 flights and matched with 10 control periods (10 minutes after each flight). Observers recorded disturbance level (0 = none; 1 = moderate; 2 = high) at 30 second intervals from the flight commencement to termination. Disturbance scores summed to determine a single colony score. Paired *t*-test to compare difference between flights and controls.	No statistical difference between disturbance levels of the control and experiment. Eight uplifts from nests, or panic were recorded during flights compared to 4 during the control period. Uplifts also occurred while the the drone approached the colony for the initial flight. Authors noted that less disturbance was caused with the drone than with traditional in colony counts.	No risk assessment reported
Dulava *et al.* 2015	To investigate application of drones for waterbird identification (multiple species) at three locations in the continental US.	Honeywell RQ-16 T-Hawk, a gas-powered vertical take-off UAV, and AeroVironment RQ-11A UAS, a fixed-wing drone powered by lithium battery. Go-Pro camera.	38 flights at three locations, a range of altitudes from 15 m to 150 m above ground level. 583 images analysed for signs of flushing behaviour in 34 flocks of waterbirds. Not specifically designed to evaluate disturbance impact.	Flushing behaviour found in 38/583 images in 11 of 34 flocks. Highest flushing rate was at the low-altitude flights (16–27 m).	No risk assessment reported
Goebel *et al*. 2015	To conduct abundance counts of Gentoo Penguins *Pygoscelis papau* and Chinstrap Penguins *Pygoscelis antarctica* and compare with traditional in-colony counts at Cape Shirreff, Livingston Island, South Shetland Islands.	APQ-18 quadrocopter and APH-22 hexacopter, Aerial Imaging Solutions.	Acoustic sampling (measured in dB). Did not evaluate study species responses specifically.	No detection of drone sounds above ambient noise levels at 30 m. No physiological disturbance measured or reported.	No risk assessment reported
Ratcliffe *et al.* 2015	To develop protocol for monitoring Gentoo Penguins *Pgoscelis papau* on the Falkland Islands.	Hexacopter, payload maximum 2 kg. 30 m altitude for best resolution of the camera. 5 m/s speed, 5 m overlap	Not measured	Not reported	No risk assessment reported Noted malfunctions and crashes during an attempt to survey on Signy Island

Study	Purpose	Methods (platform, flight height, etc.)	Impact evaluation	Results (disturbance)	Risk evaluation
Rümmler *et al.*2015	To determine disturbance responses of Adélie Penguins *Pygoscelis adeliae* to drone activity on Ardley Island, South Shetland Islands.	MK ARF Okto XL octocopter, HiSystems. Weight 3.5 kg, 73 cm diameter, 52 dB at 40 m distance. No camera or sensor attached.	Vertical and horizontal flight schemes across 80 m transects at altitudes 50, 40, 30, 25 20, 15 and 10 m above the colony. Two replicates on three occasions. Response recorded with video and categorised using ethogram (Shuster 2010). Experiment stopped if other predators were nearby. Data analysed with binomial generalized linear mixed models and univariate analysis.	Significant impact on disturbance for both horizontal and vertical flight paths. Increased reactions at lower altitudes; habituation to the drone presence did not occur. Higher altitudes caused disturbance reactions with the drone, in contrast to predator species. Disturbance recorded at a take-off distance of 50 m.	No risk assessment reported
Weissensteiner *et al.* 2015	To determine utility of drones in assessing breeding status, age, fecundity of the hooded crow *Corvus* [*corone*] *cornix*	DJI Phantom 2 Vision, weight 1.4 kg, length 35 cm, 60 db noise at 2 m, built-in camera. No flight altitude reported, 6 m/s flight speed.	Not measured	Observed adults and juveniles reacting to the drone as though a predator were approaching, making alarm calls.	No risk assessment reported
Hodgson *et al.* 2016	Compare between UAV and ground-based counts of Frigatebirds *Fregata ariel* on Ashmore Reef Marian Reserve, Australia, Crested Terns *Thalasseus bergii* on Adele Island, Western Australia, and Royal Penguins *Eudyptes schlegeli* on Macquarie Island, Australia.	X8, 3D Robotics Octocopter, weight 6.2 kg, length 61 cm. 75 m flight altitude above seal level, 2–3 m/s speed. Macquarie Island survey – FX79 airframe.	Observers pre-flight and during flight. No specific parameter reported to measure behavioural response.	No response recorded	No risk assessment reported
McClelland *et al.* 2016	To estimate population of Tristan Albatross *Diomedea dabbenena* on Inaccessible Island, South Atlantic.	DJI Phantom 2, weight 1.4 kg, length 35 cm, 60 dG noise at 2 m, and Go-Pro camera attached. 20—150 m flight altitude (average 30 m), 5 m/s speed.	Not measured	Anecdotal note on Skua *Stercorarius antarcticus* interaction (not attempts to attack), and two Atlantic Yellow-nosed Albatrosses, one Sooty Albatross, no pursuance. No observed response of target species. Acknowledged that experiments testing impacts are needed, but did not conduct any evaluation.	No risk assessment reported
Vas *et al.* 2015	To test the impact of drones (colour, speed, flight angle) on semi-captive Mallard Ducks *Anas platyrhynchos,* Wild Flamingos *Phoenicopterus roseus* and Common Greenshanks *Tringa nebularia*.	Phantom drone (Cyleone, Montpellier, France); 35 cm, 1.03 kg, 60 dB noise level. Speed and angle altered 2, 4, 6, 8 m/s, angle altered 20°, 30°, 60°, and 90° from horizontal. Max 30 m altitude. Each method used for 3 drone colours — blue, white, and black. Replicated twice in greenshanks and 3–4 times in flamingos (total of 204 samples).	Observer watched the birds through binoculars, recorded responses as (1) no reaction, (2) brief head and tail movement, followed by moving away from the drone, (3) fly-off. Statistically analysed using variance analysis.	For all of the approaches for each species, mallards responded to 28%, flamingos to 22%, and greenshanks to 13%. Approach angle elicited responses in all species. Colour of the drone or approach speed had no effect on response from any of the species.	No risk assessment reported

was an important factor in the decreased reproductive success of Florida Brown Pelicans *Pelecanus occidentalis* and Double-crested Cormorants *Phalacrocorax auritus*, in which hatching success was negatively correlated to the frequency of investigators checking the nest sites (Anderson & Keith 1980). Beale & Monaghan (2004) found that nesting success in Common Murre *Uria aalge* and Black-legged Kittiwake *Rissa tridactyla* was negatively correlated with distance of visitors to nests (when the load of people was kept constant), and greater visitor numbers to the colony resulted in a 13% increase in nesting failure.

In the absence of observed behavioural changes, a number of species have shown physiological changes, including heart rate changes in Adélie Penguins *Pygoscelis adeliae* (Nimon *et al.* 1995), and hormonal responses in Magellanic Penguins *Spheniscus magellanicus* (Fowler 1999). Increased heart rates in disturbed birds have been linked to elevated metabolic rate, which may cause birds to decline in condition and, in turn, lead to higher rates of nest abandonment or breeding failures (Beale & Monaghan 2004, Cadiou & Monnat 1996). Further, investigations of nesting success between undisturbed colonies and disturbed colonies remain challenging, as disturbance is an inherent function of investigator presence. Such disturbance to vulnerable surface-nesting seabirds may exacerbate declines in populations, or influence the assessment of species' demographic parameters, which ultimately may lead to inappropriate conservation management actions or research programs (Blackmer *et al.* 2004).

The benefits of drones for collection of data on surface-nesting birds are compelling, including perceived reductions in impact and greater spatial coverage and frequency (McClelland *et al*. 2016). However, if used inappropriately, drones may scare birds away from nests, cause birds to abandon chicks, or chase away entire colonies, leading to significant breeding failures if the disturbance is severe (Grémillet *et al.* 2012). While behavioural changes in response to drones may not be observed immediately, delayed physiological responses, as seen in penguin species, may be triggered, leading to behavioural changes later (Beale & Monaghan 2004). In this case, nesting success may be reduced, or nest abandonment may increase. The extent and severity of these effects will be influenced by the sensitivity of the species in question, intensity of disturbance caused by drone use, and the time at which surveying is conducted (e.g., when birds are prospecting for nests, or during chick provisioning). Therefore, investigators would ideally plan drone-surveying activities for periods when impact is minimised. However, it is likely that worst period for the birds may be the ideal period for data collection.

We searched Google Scholar and Web of Science using the terms "*drone*", "UAV*", "UAS*",* and "*birds"* or variations of these terms, for published studies using drones with colonial-nesting bird species (Table 1). We selected only those studies that used off-the shelf drone platforms (i.e., not those that need to be flown by trained pilots). Of the few studies published to date that use drones for collection of data on surface-nesting birds, four of 11 studies specifically described methods for recording and evaluating species' responses to drone activity (Table 1). Two of these (Rümmler *et al.* 2015; Vas *et al*. 2015) were specifically aimed at evaluating the impact of drones on their study species. Ratcliffe *et al.* (2015) found that drone presence did not affect behavioural responses in Gentoo Penguins *Pygoscelis papua*, when certain heights and distances were maintained. Similarly, McClelland *et al.* (2016) observed no behavioural response in Tristian Albatrosses *Diomedea dabbenena* after use of a small, low-cost drone platform. Rümmler *et al.* (2015), however, detected distinct behavioural responses in Adélie Penguins, even at the highest altitude they assessed. This suggests that some species or colonies may be more sensitive to drone presence than others (A. Bond, pers. comm. 2017). For instance, in the case of Adélie Penguins, which nest in the open, their main outside threat to breeding success comes from the air in the form of avian predators (Young 1994), and therefore it is not surprising that they would be sensitive to anything flying over them. While a number of studies provided anecdotal evidence of disturbance responses, or lack thereof, none of the studies reported a risk assessment, and only one (Ratcliffe *et al*. 2015) acknowledged the risk of malfunctions or crashes in collecting data with the use of drones. Although limited, the evidence thus far suggests that drones reduce disturbance to surface-nesting birds compared with traditional in-colony data-collection methods, at least for some species (Table 1).

Researchers may assume that, in addition to providing more accurate observations, drones may reduce investigator impact, with consequent improvement in long-term reproductive output, compared with traditional in-colony monitoring. However, it is difficult to test this assumption in the absence of comparative

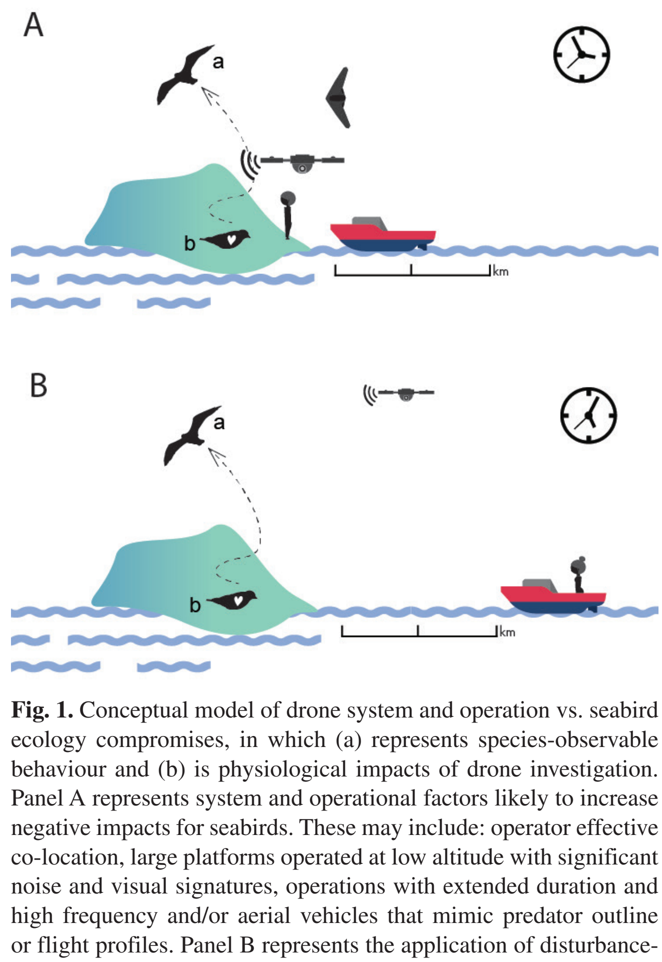

Fig. 1. Conceptual model of drone system and operation vs. seabird ecology compromises, in which (a) represents species-observable behaviour and (b) is physiological impacts of drone investigation. Panel A represents system and operational factors likely to increase negative impacts for seabirds. These may include: operator effective co-location, large platforms operated at low altitude with significant noise and visual signatures, operations with extended duration and high frequency and/or aerial vehicles that mimic predator outline or flight profiles. Panel B represents the application of disturbance-minimisation measures. These may include: standoff distances for operators, increased platform standoff enabled by telephoto lenses and sensors (e.g., Kemper & Vasel 2016), smaller low-visibility air vehicles with low audio signatures.

disturbance assessments. Furthermore, there are risks to species because of platform malfunctions, or operator and signal errors (Sanz Muñoz *et al.* 2012), which may result in a drone crashing into a colony or environmentally sensitive area. The choice of platform and the skills of the operator will dictate the level of risk to species or site, but researchers should not overlook this when choosing to use drones for data collection.

The dichotomy between conservation research and the impact of investigators on wildlife can present unexpected challenges for conservation efforts, particularly for management of threatened species. Wildlife are bound to interact with investigators and their tools, potentially causing stress, harm, or death to animals (Götmark 1992). There are trade-offs for all conservation actions, whether they are explicitly known or unintentional (Hirsch *et al*. 2011). Effective long-term conservation of a species requires ecological understanding, and, therefore, interactions of investigators with populations or specimen collection are warranted (Nisbet & Paul 2004, Winker *et al*. 2010).

Minimally invasive remote sensing of seabird-colony status is possible with intelligent selection of drone systems. Remote sensing fundamentals, including minimum target-feature dimensions, colour, shape, and texture, will inform the maximum appropriate spatial resolution. Current flexibility in drone configuration, sensor specification, and data telemetry affords researchers a range of options to reduce potential behavioural and physiological impacts of investigation (Fig. 1, panel A vs. panel B). Perceived predation risk may be reduced by minimising platform size, outline and flight profile, speed, proximity, and colour (Fig. 1, panel B). Standoff distance can be increased by using stabilised telephoto lenses and high-resolution cameras, as smaller and higher-quality cameras become available (Altena & Goedemé 2014). Selection of propulsion systems to reduce noise signatures may further reduce perceived threat (Sinibaldi & Marino 2013). Timing, duration, and frequency of data capture should be considered in conjunction with drone-system specification to optimise the trade-off between ideal data collection and minimal disturbance. This optimisation process can be informed only by an understanding of the ecology and biology of the study species, or, in the absence of such knowledge, by taking a precautionary approach. Importantly, the desire to capture data quickly or cheaply should not be placed ahead of employing drone systems that minimise potential impact on the species of concern.

Studies have shown empirically that there are negative impacts associated with investigator presence at study colonies. Therefore, drones provide an alternative means of collecting important demographic and environmental data. For surface-nesting birds, drone technology can provide a more accurate method of collecting population data because of its ability to take large-scale images of colonies, which can be counted carefully in the lab and compared through time, therefore reducing the uncertainty of estimates in traditional observer counts (Hodgson *et al*. 2016, van Gemert *et al*. 2014). However, the disturbance of colonies from impulsive drone deployment may affect some species in much the same way as traditional in-colony data collection methods.

Field biologists have an obligation to evaluate their impact on the species and system that they study, and to minimise any adverse effects (Nisbet & Paul 2004). As with any study, investigators employing drone technology for monitoring surface-nesting seabirds should carefully consider the question being asked and the potential gains in knowledge, and weigh them against the consequences of disturbance (Nisbet & Paul 2004). Further testing of the impacts on study species and non-target species, as well as assessments of risks of using drones, are an important priority (Grémillet *et al.* 2012). The development of drone-operation guidelines for wildlife will help address and minimise potential disturbance on wildlife; however, it may not be a case of "one size fits all" for surface-nesting birds.

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REFERENCES

ALTENA, B. & GOEDEMÉ, T. 2014. Assessing UAV platform types and optical sensor specifications. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences* II-5: 17-24. doi:10.5194/isprsannals-II-5-17-2014.

ANDERSON, D.W. & KEITH, J.O. 1980. The human influence on seabird nesting success: conservation implications. *Biological Conservation* 18: 65-80.

BEALE, C.M. & MONAGHAN, P. 2004. Human disturbance: people as predation-free predators? *Journal of Applied Ecology* 41: 335-343.

BERGENAS, J., STOHL, R. & GEORGIEFF, A. 2013. The other side of drones: saving wildlife in Africa and managing global crime. *Conflict Trends* 3: 3-9.

BIRDLIFE INTERNATIONAL. 2015. *Global Conservation Strategy*. [Available online at: http://www.birdlife.org/worldwide/partnership/global-conservation-strategy. Accessed 24 June 2015].

BLACKMER, A.L., ACKERMAN, J.T. & NEVITT, G.A. 2004. Effects of investigator disturbance on hatching success and nest-site fidelity in a long-lived seabird, Leach's storm-petrel. *Biological Conservation* 116: 141-148.

CADIOU, B. & MONNAT, J.Y. 1996. Parental attendance and squatting in the kittiwake *Rissa tridactyla* during the rearing period. *Bird Study* 43: 164-171.

CAREY, M.J. 2009. The effects of investigator disturbance on procellariiform seabirds: a review. *New Zealand Journal of Zoology* 36: 367-377.

CHABOT, D. & BIRD, D.M. 2015. Wildlife research and management methods in the 21st century: Where do unmanned aircraft fit in? 1. *Journal of Unmanned Vehicle Systems* 3: 137-155.

CHABOT, D., CRAIK, S.R. & BIRD, D.M., 2015. Population census of a large common tern colony with a small unmanned aircraft. *PloS One* 10: e0122588.

CROXALL, J.P., BUTCHART, S.H., LASCELLES, B., ET AL. 2012. Seabird conservation status, threats and priority actions: a global assessment. *Bird Conservation International* 22: 1-34.

CRUTSINGER, G.M., SHORT, J. & SOLLENBERGER, R. 2016. The future of UAVs in ecology: an insider perspective from the Silicon Valley drone industry. *Journal of Unmanned Aerial Systems* 4: 161-168.

DULAVA, S., BEAN, W.T. & RICHMOND, O.M. 2015. Environmental reviews and case studies: applications of unmanned aircraft systems (UAS) for waterbird surveys. *Environmental Practice* 17: 201-210.

FEARE, C. J. 1976. The breeding of the Sooty Tern *Sterna fuscata* in the Seychelles and the effects of experimental removal of its eggs. *Journal of Zoology* 179: 317-360.

FOWLER, G. S. 1999. Behavioral and hormonal responses of Magellanic penguins (*Spheniscus magellanicus*) to tourism and nest site visitation. *Biological Conservation* 90: 143-149.

GOEBEL, M.E., PERRYMAN, W.L., HINKE, J.T., ET AL. 2015. A small unmanned aerial system for estimating abundance and size of Antarctic predators. *Polar Biology* 38: 619-630.

GÖTMARK, F. 1992. The effects of investigator disturbance on nesting birds. In: POWER, D.M. (Ed.) *Current Ornithology.* Springer. pp. 63-104.

GRÉMILLET, D., PUECH, W., GARCON, V., ET AL. 2012. Robots in ecology: welcome to the machine. *Open Journal of Ecology* 2: 49-57.

HICKEY, J.J. 1955. Some American population research on gallinaceous birds. In: WOLFSON, A. (Ed.) *Recent Studies in Avian Biology.* Urbana, IL: University of Illinois Press. pp. 326-396.

HIRSCH, P.D., ADAMS, W.M., BROSIUS, J.P., ET AL. 2011. Acknowledging conservation trade-offs and embracing complexity. *Conservation Biology* 25: 259-264.

HODGSON, J.C., BAYLIS, S.M., MOTT, R., ET AL. 2016. Precision wildlife monitoring using unmanned aerial vehicles. *Scientific Reports* 6: 22574.

INTERNATIONAL UNION FOR CONSERVATION OF NATURE. 2015. *IUCN Red List of Threatened Species* [Online]. [Available online at: www.iucnredlist.org. Accessed 14 September 2016].

KEMPER, G. & VASEL, R. 2016. Multi sensor and platforms setups for various airborne applications. *International Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences* XLI-B1: 217-220. doi:10.5194/isprs-archives-XLI-B1-217-2016.

KOSKI, W., ABGRALL, P. & YAZVENKO, S. 2010. An inventory and evaluation of unmanned aerial systems for offshore surveys of marine mammals. *Journal of Cetacean Research and Management,* 11: 239-247.

LINCHANT, J., LISEIN, J., SEMEKI, J., ET AL. 2015. Are unmanned aircraft systems (UASs) the future of wildlife monitoring? A review of accomplishments and challenges. *Mammal Review* 45: 239-252.

McCLELLAND, G., BOND, A., SARDANA, A., ET AL. 2016. Rapid population estimate of a surface-nesting seabird on a remote island using a low-cost unmanned aerial vehicle. *Marine Ornithology* 44: 215-220.

NIMON, A.J., SCHROTER, R.C. & STONEHOUSE, B. 1995. Heart rate of disturbed penguins. *Nature* 374: 6521.

NISBET, I.C. & PAUL, E. 2004. RE: Ethical issues concerning animal research outside the laboratory. *ILAR Journal* 45: 375-377.

RATCLIFFE, N., GUIHEN, D., ROBST, J., ET AL. 2015. A protocol for the aerial survey of penguin colonies using UAVs 1. *Journal of Unmanned Vehicle Systems* 3: 95-101.

RÜMMLER, M.C., MUSTAFA, O., MAERCKER, J., ET AL. 2015. Measuring the influence of unmanned aerial vehicles on Adélie penguins. *Polar Biology* 39: 1329-1334.

SANZ MUÑOZ, D., PEREIRA VALENTE, J.R., CERRO GINER, J.D., ET AL. 2012. Risk analysis for UAV safe operations: a rationalization for an agricultural environment. In: PERRUZZI, A. (Ed.) *Proceedings of the First International Conference on Robotics and Associated High-Technologies and Equipment for Agriculture: Applications of Automated Systems and Robotics for Crop Protection in Sustainable Precision Agriculture (RHEA-2012).* Pisa, Italy: Pisa University Press. pp. 235-240.

SARDÀ-PALOMERA, F., BOTA, G., VINOLO, C., ET AL. 2012. Fine-scale bird monitoring from light unmanned aircraft systems. *Ibis* 154: 177-183.

SCHIFFMAN, R. 2014. Drones flying high as new tool for field biologists. *Science* 344: 459-459.

SINIBALDI, G. & MARINO, L. 2013. Experimental analysis on the noise of propellers for small UAV. *Applied Acoustics* 74: 79-88.

SMITH, C.E., SYKORA-BODIE, S.T., BLOODWORTH, B., ET AL. 2016. Assessment of known impacts of unmanned aerial systems (UAS) on marine mammals: data gaps and recommendations for researchers in the United States 1. *Journal of Unmanned Vehicle Systems* 4: 1-14.

SWENSON, J.E., SANDEGREN, F., BRUNBERG, S., ET AL. 1997. Winter den abandonment by brown bears *Ursus arctos*: causes and consequences. *Wildlife Biology* 3: 35-38.

VAN GEMERT, J.C., VERSCHOOR, C.R., METTES, P., EPEMA K., KOH L.P. & WICH, S. 2015. Nature conservation drones for automatic localization and counting of animals. In: AGAPITO L., BRONSTEIN M. & ROTHER C. (Eds.) *Computer Vision – ECCV 2014 Workshops. ECCV 2014.* Lecture Notes in Computer Science, volume 8925. Springer. pp. 255-270. doi:10.1007/978-3-319-16178-5 17.

VAS, E., LESCROËL, A., DURIEZ, O., BOGUSZEWSKI, G. & GRÉMILLET, D. 2015. Approaching birds with drones: first experiments and ethical guidelines. *Biology Letters* 11: 20140754. doi:10.1098/rsbl.2014.0754.

VERMEULEN, C., LEJEUNE, P., LISEIN, J., ET AL. 2013. Unmanned aerial survey of elephants. *PloS One* 8: 1-7.

WARHAM, J. 1990. *The Petrels: Their Ecology and Breeding Systems.* London, UK: Academic Press.

WEISSENSTEINER, M.H., POELSTRA, J.W. & WOLF, J.B. 2015. Low-budget ready-to-fly unmanned aerial vehicles: an effective tool for evaluating the nesting status of canopy-breeding bird species. *Journal of Avian Biology* 464: 425-430.

WICH, S., DELLATORE, D., HOUGHTON, M., ET AL. 2015. A preliminary assessment of using conservation drones for Sumatran orang-utan (*Pongo abelii*) distribution and density 1. *Journal of Unmanned Vehicle Systems* 4: 1-8.

WINKER, K., REED, J. M., ESCALANTE, P., ET AL. 2010. The importance, effects, and ethics of bird collecting. *Auk* 127: 690-695.

YOUNG, E. 1994. *Skua and Penguin: Predator and Prey.* Cambridge UK: Cambridge University Press.