An examination of trends in the growing scientific literature on approaching wildlife with drones

Matthew Mo and Katarina Bonatakis

Abstract: Drones or unoccupied aerial vehicles are rapidly being used for a spectrum of applications, including replacing traditional occupied aircraft as a means of approaching wildlife from the air. Though less intrusive to wildlife than occupied aircraft, drones can still cause varying levels of disturbance. Policies and protocols to guide lowest-impact drone flights are most likely to succeed if considerations are derived from knowledge from scientific literature. This study examines trends in the scientific literature on using drones to approach wildlife between 2000 and 2020, specifically in relation to the publication types, scientific journals that works are published in, purposes of drone flights reported, taxa studied, and locations of studies. From 223 publications, we observed a large increase in relevant scientific literature, the majority of which were peer-reviewed articles published across 86 scientific journals. The largest proportion of peer-reviewed research articles related to aquatic mammals or aquatic birds and the use or trial of drone flights for conducting population surveys, animal detection, or investigations of animal responses to drone flights. The largest proportion of articles were studies conducted in North America and Australia. Since animal responses to drone flights vary among taxa, populations, and geographic locations, we encourage further growth in the volume of relevant scientific literature needed to inform policies and protocols for specific taxa and (or) locations, particularly where knowledge gaps exist.

Key words: anthropogenic impacts, conference proceedings, project reports, research studies, university dissertations, unoccupied aerial vehicles, UAV.

Résumé : Les drones ou les véhicules aériens sans pilote (UAV) sont de plus en plus utilisés pour un éventail d'applications, y compris en remplacement des avions pilotés traditionnels comme moyen d'approcher la faune depuis les airs. Bien qu'ils soient moins intrusifs pour la faune que les avions pilotés, les drones peuvent tout de même causer divers niveaux de perturbation. Les politiques et les protocoles visant à guider les vols de drones afin d'avoir le moins d'impact sont les plus susceptibles de réussir si des considérations sont tirées des connaissances puisées de la littérature scientifique. Cette étude examine les tendances dans la littérature scientifique sur l'utilisation de drones pour approcher la faune entre 2000 et 2020, en particulier en ce qui concerne le type de publications et de revues scientifiques dans lesquels les travaux sont publiés, les objectifs de vols de drones signalés, les taxons étudiés et les lieux d'études. De 223 publications, les auteurs ont observé une forte augmentation de la littérature scientifique pertinente, dont la majorité étaient des articles évalués par des pairs et publiés dans 86 revues scientifiques. La plus grande proportion d'articles

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M. Mo. Department of Planning, Industry and Environment, Saving our Species program, Biodiversity, Conservation and Science, Parramatta, NSW 2150, Australia.

K. Bonatakis. University of Canberra, Bruce, ACT 2617, Australia.

Corresponding author: Matthew Mo (e-mail: matthew.mo@environment.nsw.gov.au).

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de recherche examinés par des pairs portait sur les mammifères aquatiques ou les oiseaux aquatiques, et l'utilisation ou l'essai de vols de drones pour effectuer des relevés de population, la détection d'animaux ou des études sur les réponses des animaux aux vols de drones. La plus grande partie des articles étaient des études menées en Amérique du Nord et en Australie. Étant donné que les réactions des animaux aux vols de drones varient selon les taxons, les populations et les emplacements géographiques, les auteurs prônent la croissance du volume de documentation scientifique pertinente nécessaire pour éclairer les politiques et les protocoles pour des taxons ou des emplacements précis, en particulier lorsqu'il existe des lacunes dans les connaissances. [Traduit par la Rédaction]

Mots-clés : incidences anthropiques, travaux de congrès, comptes rendus de projets, projets de recherche, mémoires universitaires, véhicules aériens sans pilote, UAV.

Introduction

In wildlife management and research, drones or unoccupied aerial vehicles are rapidly replacing traditional occupied aircraft as a means of approaching wildlife to undertake detection, population counts, and aerial observations (Anderson and Galston 2013). Drone use is preferred over occupied aircraft in terms of being compact, cheaper to operate, easy to deploy, and therefore less time-consuming and requiring fewer qualifications and skills to operate (Aniceto et al. 2018; Koh and Wich 2012). Being unoccupied also means that collisions are substantially less of a human safety issue (Chabot and Bird 2015) since collisions involving occupied aircraft were a leading cause of work-related deaths in wildlife biologists (Sasse 2003). Drones have also been purported to be less intrusive to wildlife than occupied aircraft owing to their smaller size and lower noise emissions (Chabot and Bird 2012; Sardà-Palomera et al. 2012). However, these characteristics also mean that drone pilots may attempt to approach wildlife at closer distances than within occupied aircraft (Mo and Bonatakis 2022).

Anthropogenic disturbances have the potential to cause animals to sustain physiological stress, expend energy escaping, or abandon their offspring temporarily or permanently (Frid and Dill 2002; Houston et al. 2012). These impacts may subsequently have population-level impacts or affect local distributions of species if disturbances occur over broad expanses of time and space (Marion et al. 2020). Observable impacts on animal behaviour have been documented from both civilian (Rebolo-Ifrán et al. 2019) and professional drone flights (Wallace et al. 2018). There is therefore a need for government agencies to develop regulatory frameworks to manage risks associated with the increasing use of drones (Clarke and Moses 2014). This sentiment has been expressed in terms of drone impacts on public safety, privacy, and security (Reid 2014; Rao et al. 2016), as well as for minimising impacts on wildlife (Rebolo-Ifrán et al. 2019).

There is a growing body of scientific literature considering the effects of drone flights on different vertebrate taxa as well as reviews synthesising this information (Christie et al. 2016; Colefax et al. 2018). Scientific literature to date has shown numerous factors that influence animal responses to drone flights (Mo and Bonatakis 2022), which include drone characteristics such as their shape (McEvoy et al. 2016), size (McIntosh et al. 2018), colour and patterning (Mapes et al. 2020), and noise emissions (Weston et al. 2020). Flight practices are also important considerations, such as take-off distances from animals (Bech-Hansen et al. 2020), approach distances (Mustafa et al. 2018), angles of approach (Weimerskirch et al. 2018), and airspeed (Schroeder et al. 2020). Managers seeking to develop policies and protocols to guide lowest-impact drone flights are most likely to succeed if considerations are derived from knowledge of the above factors. However, effects of drone flights vary among taxa, populations, and geographic locations (Bennitt et al. 2019; Jarrett et al. 2020),

and managers may find deficiencies in information relating to specific taxa and locations of their concern.

In this study, we examine trends in the scientific literature on using drones to approach wildlife. Specifically, we examine trends in (i) publication types, (ii) scientific journals that publish peer-reviewed articles, (iii) purposes of the drone flights, (iv) taxa studied, and (v) locations of studies. We limited our review to relevant publications between 2000 and 2020.

Methods

Scientific literature was searched using Google Scholar, Web of Science, and Scopus databases for publications describing or providing commentary of practices involving drones approaching wildlife from 2000 to 2020. Keywords used in the search were combinations of “drone”, “unoccupied aerial vehicle”, “unoccupied aerial system”, “unmanned aerial vehicle”, “unmanned aerial system”, “remotely-piloted aircraft system”, “unoccupied aircraft”, “unmanned aircraft”, “UAV”, “UAS”, and “RPAS” with “wildlife”, “animals”, “birds”, “mammals”, “reptiles”, “amphibians”, “fish”, and “vertebrate”. Additional publications were sourced by querying relevant citations in other publications. This study concerned drone flights approaching animals; therefore, publications were excluded if drones were solely used for aerial radiotelemetry or locating indirect signs of wildlife such as nests.

Publications from the literature search were examined by their type (articles in peer-reviewed journals (research articles, review articles, commentary articles), conference proceedings, university dissertations, project reports), and year of publication. Articles published in peer-reviewed journals were examined by journal. Research articles in peer-reviewed journals were examined for their main purposes for using drones (e.g., using or trialling drones for animal detection or investigating animal responses to drone flights), specific taxa, and the country the fieldwork was undertaken in.

Results

The literature search found 223 publications that described or provided commentary involving flight practices of drones approaching wildlife between 2000 and 2020 (see [Table A1](#)).

Types of publications

Articles in peer-reviewed journals comprised the largest proportion of publications from the literature search, the majority of them research articles ($n = 169$) as well as 22 review articles and four commentary articles ([Fig. 1a](#)). Seven of the review articles concerned specific taxa, all of which were aquatic animals ([Smith et al. 2016](#); [Borrelle and Fletcher 2017](#); [Fiori et al. 2017](#); [Mustafa et al., 2018](#); [Rees et al. 2018](#); [Schofield et al. 2019](#); [Raoult et al. 2020](#)). There were also 10 conference proceedings, 10 university dissertations, and eight project reports.

More than 85% of publications were published between 2015 and 2020 ([Fig. 1b](#)). The earliest publication was a university dissertation completed in 2003 ([Jones 2003](#)). The majority of other university dissertations found in the literature search were completed from 2016 onwards. The earliest conference proceedings from the literature search were published in 2011 ([Israel 2011](#); [Selby et al. 2011](#)), with subsequent conference proceedings published every year to second year.

Fig. 1. (a) Publication types describing or providing commentary of flight practices of drones approaching wildlife ($n = 223$). (b) Temporal distribution of articles in peer-reviewed journals comprise of research, review and commentary articles represented in (a).

Scientific journals

Peer-reviewed articles were published across 86 scientific journals, 63 of which published only one article (Table 1). The highest number of articles were published in the *Journal of Unmanned Vehicle Systems* ($n = 22$; renamed to *Drone Systems and Applications* in 2022), *PLoS ONE* ($n = 15$), *Drones* ($n = 14$), *Scientific Reports* ($n = 9$), *Polar Biology* ($n = 8$), *Biological Conservation* ($n = 6$), and *Frontiers in Marine Science* ($n = 6$). Articles appearing in these seven journals were first published in 2012 (Fig. 2). The *Journal of Unmanned Vehicle Systems*, established in 2013, published eight articles in 2015 and has maintained publication of two to four articles in each subsequent year. *PLoS ONE*, established in 2006, has steadily published between one to three articles in most years since 2012. *Drones*, established in 2017, published two to six articles annually from 2018 to 2020.

Taxa

Of the 169 peer-reviewed research articles from the literature search, all but one (Erbe et al. 2017) concerned specific taxa (Fig. 3). A large proportion of these articles concerned mammals ($n = 94$), in particular aquatic mammals ($n = 53$). The few articles concerning sire-nians were some of the earliest articles concerning aquatic mammals. Articles concerning cetaceans and pinnipeds were first published in 2009 and 2013, respectively, and increasingly published between 2015 and 2020 (Fig. 4a). There was only one article concerning hippopotamuses, which was published in 2019 (Inman et al. 2019).

Nonaquatic mammals were represented in 42 peer-reviewed research articles. Articles concerning terrestrial ungulates ($n = 17$) and carnivorans ($n = 11$) were particularly prominent, first appearing in peer-reviewed literature in 2012 (Koh and Wich 2012) and 2013 (Koski et al. 2013), respectively (Fig. 4b). Articles concerning primates were distributed between 2012 and 2020, increasingly published more recently. Similarly, articles concerning nonaquatic carnivorans and marsupials were increasingly published in the more recent years. The three articles concerning elephants were distributed between 2013 and 2019 (Vermeulen et al. 2013; Hahn et al. 2017; Bennitt et al. 2019).

Birds were also represented in a large proportion of research articles ($n = 67$). Between 2005 and 2012, these articles exclusively concerned aquatic birds, which included water-fowl, waders, penguins, and other seabirds (Fig. 4c). Aquatic birds ($n = 53$) continued to be

Table 1. Scientific journals identified in the literature search that published only one article describing or providing commentary of flight practices of drones approaching wildlife.

Journal title	
<i>Acta Theriologica Sinica</i>	<i>IOP Conference Series: Earth and Environmental Science</i>
<i>Animal Conservation</i>	<i>Journal of Applied Ecology</i>
<i>Animals</i>	<i>Journal of Ecology and Environment</i>
<i>Annual Review of Marine Science</i>	<i>Journal of Ecotourism</i>
<i>Aquatic Conservation: Marine and Freshwater Ecosystems</i>	<i>Journal of Environmental Planning and Management</i>
<i>Aquatic Mammals</i>	<i>Journal of Ethology</i>
<i>Ardea</i>	<i>Journal of Fish Biology</i>
<i>Australian Field Ornithology</i>	<i>Journal of Neuroscience Methods</i>
<i>Australian Mammalogy</i>	<i>Journal of the Japanese Society of Agricultural Machinery and Food Engineers</i>
<i>Australian Zoologist</i>	<i>Journal of Wildlife Management</i>
<i>Biodiversity Observations</i>	<i>Latin American Journal of Aquatic Research</i>
<i>Biology Letters</i>	<i>Mammal Research</i>
<i>Bird Conservation International</i>	<i>Marine Pollution Bulletin</i>
<i>Bird Study</i>	<i>Marine Turtle Newsletter</i>
<i>Bollettino del Museo di Storia Naturale di Venezia</i>	<i>mSystems</i>
<i>CCAMLR Science</i>	<i>Ocean and Coastal Management</i>
<i>Conservation Physiology</i>	<i>Paladyn, Journal of Behavioral Robotics</i>
<i>Crop Protection</i>	<i>Raptors Conservation</i>
<i>Current Zoology</i>	<i>Remote Sensing in Ecology and Conservation</i>
<i>Ecological Applications</i>	<i>Royal Society Open Science</i>
<i>Ecological Informatics</i>	<i>Surveying and Land Information Science</i>
<i>Endangered Species Research</i>	<i>The Auk</i>
<i>Environmental Conservation</i>	<i>Tropical Conservation Science</i>
<i>Environmental Practice</i>	<i>Unmanned Systems</i>
<i>Folia Primatologica</i>	<i>Viruses</i>
<i>Food Webs</i>	<i>Waterbirds</i>
<i>Functional Ecology</i>	<i>Wetlands Ecology and Management</i>
<i>Global Ecology and Conservation</i>	<i>Wildlife Biology</i>
<i>Herpetological Review</i>	<i>Wildlife Research</i>
<i>Ibis</i>	
<i>ICES Journal of Marine Science</i>	
<i>Integrative Zoology</i>	
<i>International Journal of Environmental Research and Public Health</i>	

the most represented bird taxa in articles from 2013 to 2020. Articles concerning birds of prey were distributed between 2013 and 2018. Articles concerning passerines and galliforms were first published in the scientific literature in 2015 (Weissensteiner et al. 2015) and 2016 (Scobie and Hugenholtz 2016), respectively. In 2020, articles concerning parrots, pigeons (Weston et al. 2020), and swifts (Mesquita et al. 2020) also appeared in peer-reviewed literature.

Reptiles were represented in 15 research articles, all of which concerned aquatic taxa (Fig. 4d). The earliest articles concerning crocodilians were research studies published in 2006 and 2012 that trialled drone techniques on a selection of varied taxa (Jones 2003; Martin et al. 2012). More recent articles concerning crocodilians have been ecological or behavioural studies of crocodilian species incorporating drone flights (Bevan et al. 2018; Ezat et al. 2018; Gallagher et al. 2018; Thapa et al. 2018). The earliest article concerning sea turtles was published in 2015 (Bevan et al. 2015), which has been accompanied by one to two additional articles each year from 2016 to 2020.

Fish were represented in 17 research articles, the majority of which concerned elasmobranchs ($n = 15$). Three articles involved detections of bony fishes through drone flights (Colefax et al. 2019; Jech et al. 2020; Kelaher et al. 2020).

Fig. 2. Temporal distribution of peer-reviewed articles published in seven scientific journals ($n = 80$).

Fig. 3. Broad taxonomical classifications represented in peer-reviewed research articles ($n = 169$). Note that some research studies were conducted across more than one taxon.

Purposes of drone flights

The main purposes of the 169 peer-reviewed research articles were examined, some of which had more than one main purpose. Large proportions of these articles related to the use or trial of drone flights to conduct population surveys ($n = 52$), undertake animal detection ($n = 50$), or conduct investigations of animal responses to drone flights ($n = 40$). Animal detection and population surveys through drone flights appear in the scientific literature as early as 2005 and 2010, respectively, progressively increasing in the volume of

Fig. 4. Taxonomical classifications of animals represented in peer-reviewed research articles: (a) aquatic mammals ($n = 52$), (b) nonaquatic mammals ($n = 43$), (c) birds ($n = 64$), and (d) reptiles ($n = 15$).

research articles (Fig. 5). Research articles on investigations of animal responses to drone flights have been published since 2015.

We found 12 research articles related to using drones to observe natural animal behaviour, mostly from 2018 onwards. All but one of these research articles (Inoue et al. 2019) concerned aquatic taxa (Raoult et al. 2018; Adams et al. 2020) such as elasmobranchs (Lea et al. 2018; Rieucan et al. 2018; Tucker et al. 2019; Dines et al. 2020; Frixione et al. 2020; Porter et al. 2020), crocodilians (Gallagher et al. 2018), turtles (Bevan et al. 2016), and cetaceans (Torres et al. 2018).

In 17 research articles, drone flights were used to collect biological data, which were body condition in pinnipeds (Allan et al. 2019; Hodgson et al. 2020) and cetaceans (Christiansen et al. 2016; Krause et al. 2017); individual markings (Durban et al. 2015) and biochemical vital signs in cetaceans (Horton et al. 2019); morphometric measurements in

Fig. 5. Temporal distribution of peer-reviewed research articles in which drone flights were used for different purposes ($n = 170$).

pinnipeds (Pomeroy et al. 2015), cetaceans (Christiansen et al. 2018, 2019), and bony fishes (Jech et al. 2020); vocalisations in bats (Fu et al. 2018; Kloepper and Kinniry 2018); and nest contents and survival in birds of prey (Potapov et al. 2013; Junda et al. 2015), aquatic birds (Sardà-Palomera et al. 2017; Lachman et al., 2020), and passerines (Weissensteiner et al. 2015). A further seven research articles involved drone flights to collect samples from animals, which all related to blow sampling from cetaceans (Acevedo-Whitehouse et al. 2010; Apprill et al. 2017; Pirotta et al. 2017; Geoghegan et al. 2018; Nelson et al. 2019; Raudino et al. 2019; Centelleghé et al. 2020).

Only three research articles involved drone flights conducted to deliberately disturb and disperse animals from certain areas. These publications concerned agricultural crop protection from elephants (Hahn et al. 2017) and passerines (Nakajima et al. 2019; Wandrie et al. 2019).

Research locations

The largest proportion of peer-reviewed research articles were studies conducted in North America ($n = 64$) (Fig. 6). These studies were conducted across 10 countries, particularly in the United States of America ($n = 25$, with an additional 7 in Alaska) (Fig. 7a). Studies in the United States of America were published as early as 2005 (Abd-Elrahman et al. 2005) and up to eight were published annually between 2015 and 2020. The earliest studies in Mexico ($n = 8$) and Canada were published in 2010 (Acevedo-Whitehouse et al. 2010) and 2012 (Chabot and Bird 2012), respectively; however, the majority were published between 2015 and 2019. North American studies published in research articles were also conducted in Costa Rica (Sykora-Bodie et al. 2017; Gray et al. 2019), Greenland (Bröker et al. 2019; Lee et al. 2019), Belize (Ramos et al. 2018), Panama (Kays et al. 2019), the Bahamas (Hensel et al. 2018) and Guatemala (Warembourg et al. 2020).

Fig. 6. Continents represented in peer-reviewed research articles ($n = 169$). Note that some research studies were conducted across more than one continent.

Fig. 7. Temporal distribution of peer-reviewed research articles conducted in (a) North America ($n = 64$), and (b) Australia ($n = 39$). Note that some research studies were conducted across more than one country.

The second largest proportion of research articles were studies conducted in Australia ($n = 39$). The earliest Australian article was published in 2013 (Hodgson et al. 2013) and subsequent articles were published between 2016 and 2020 (Fig. 7b).

Table 2. Temporal distribution of peer-reviewed research articles of studies conducted in European countries.

Country	2012	2014	2015	2017	2018	2019	2020
Italy	—	—	—	—	Valle and Scarton (2018)	Valle and Scarton (2019)	Centelleghé et al. (2020); Valle and Scarton (2020)
Spain	Sardà-Palomera et al. (2012)	Barasona et al. (2014)	—	Sardà-Palomera et al. (2017)	Afán et al. (2018)	—	—
England	—	—	Pomeroy et al. (2015)	—	Rush et al. (2018)	—	—
Greece	—	—	—	Schofield et al. (2017)	—	—	Centelleghé et al. (2020)
Denmark	—	—	—	—	—	—	Bech-Hansen et al. 2020
France	—	—	Vas et al. (2015)	—	—	—	—
Poland	—	—	—	—	Witczuk et al. (2018)	—	—
Portugal	—	—	—	—	—	Inoue et al. (2019)	—
Scotland	—	—	—	—	—	—	Jarrett et al. (2020)
Sweden	—	—	Weissensteiner et al. (2015)	—	—	—	—

Seventeen research articles were studies conducted in Europe (Fig. 6), distributed across 10 countries (Table 2). The earliest European articles were two studies conducted in Spain, published in 2012 and 2014. The largest proportion of European articles were studies conducted in Italy ($n = 4$) and Spain ($n = 4$), mostly between 2018 and 2020.

Fifteen research articles were studies conducted in Asia (Fig. 6), distributed across seven countries. The earliest Asian articles were studies conducted in Indonesia and Russia, published in 2012 and 2013, respectively (Table 3). The largest proportion of Asian articles were studies conducted in China ($n = 5$), Indonesia ($n = 3$), and South Korea ($n = 3$), mostly published between 2017 and 2019.

Eleven research articles were studies conducted in Antarctica (Fig. 6). The earliest of these articles was published in 2010 (Table 4). The remainder were published between 2015 and 2020, with one to two of these articles published each year within this period.

Thirteen research articles were studies conducted in Africa (Fig. 6). These studies were distributed across eight identified countries, two of them island countries east of the mainland. Each country was only represented in one article, except for Botswana ($n = 3$) and South Africa ($n = 3$). The earliest African articles were studies conducted in Burkina Faso and South Africa, published in 2013 and 2014, respectively (Table 5).

Only four articles were studies conducted in South America (Fig. 6), two in Brazil (Mesquita et al. 2020; Oliveira-da-Costa et al. 2020) and two in Argentina (Christiansen et al. 2019; Schroeder et al. 2020).

Eight research articles were studies conducted in six island countries that are not part of any continent (Fig. 6). These articles were all published between 2015 and 2019 (Table 6). Studies conducted in French Polynesia and New Zealand comprised half of these eight articles.

Discussion

The volume of scientific literature relating to approaching wildlife with drones had exponentially increased between 2003 and 2020, particularly in the last five years. This reflects the growing popularity of drones and how they will likely be increasingly used and readily adopted for a spectrum of applications (Anderson and Gaston 2013). The largest proportion of peer-reviewed articles were concerning drone-based population surveys as an alternative to traditional methods using occupied aircraft (Chabot and Bird 2015; Borrelle and Fletcher 2017). Drones have subsequently appeared in the scientific literature as a means of undertaking aerial animal detection and more recently extended to innovative techniques for observing natural animal behaviours, collecting biological data, and even collecting samples from animals or deliberately disturbing animals from agricultural areas. However, our review found that population surveys and animal detection have consistently remained the predominant drone applications amongst newer innovations.

Outside of wildlife management and research, drones are also increasingly being adopted in a wide range of applications such as land surveillance (Tripicchio et al. 2015), traffic monitoring (Coifman et al. 2006), disaster management (Restas 2015), agricultural practices (Frankelius et al. 2019), defence and law enforcement (Reid 2014; Floreano and Wood 2014), and cinematography (Cheng 2015). Drones are also available as off-the-shelf products and are used for civilian activities by recreationalists (Siyuan 2015). The expansion in drone applications notionally increases the chances of wildlife coming into contact with drones. This raises the importance of managers developing adequate regulatory frameworks to minimise risks (Weston et al. 2020). In particular, the uptake of commercially available drones for civilian recreation poses the potential for a wide array of medium- to large-bodied animals to come into contact with drones beyond the taxa traditionally monitored by aerial surveys. The significant increase in relevant scientific literature therefore

Table 3. Temporal distribution of peer-reviewed research articles of studies conducted in Asian countries.

Country	2012	2013	2015	2017	2018	2019	2020
China	—	—	—	—	Guo et al. (2018); Su et al. (2018)	Wu et al. (2019); Yang et al. (2019) Burke et al. (2019)	He et al. (2020)
Indonesia	Koh and Wich (2012)	—	—	Radiansyah et al. (2017)	—	—	—
South Korea	—	—	—	Han et al. (2017)	—	Hong et al. (2019); Lee et al. (2019) Nakajima et al. (2019)	—
Japan	—	—	—	—	—	—	—
Nepal	—	—	—	—	Thapa et al. (2018)	—	—
Russia	—	Potapov et al. (2013)	—	—	—	—	—
Taiwan	—	—	Liu et al. (2015)	—	—	—	—

Table 4. Temporal distribution of peer-reviewed research articles of studies conducted in Antarctica.

Year	No. articles	References
2010	1	Gardner et al. (2010)
2015	1	Goebel et al. (2015)
2016	2	Korczak-Abshire et al. (2016) ; Rümmeler et al. (2016)
2017	1	Krause et al. (2017)
2018	2	Rümmeler et al. (2018) ; Zmarz et al. (2018)
2019	2	Korczak-Abshire et al. (2019) ; Pfeifer et al. (2019)
2020	2	Bird et al. (2020) ; Oosthuizen et al. (2020)

provides a valuable evidence base to managers to leverage from in developing policies and protocols to guide lowest-impact drone flights. This growing body of knowledge helps to inform principles and considerations that policies and protocols should consider, such as incorporating specific drone systems and flight practices to minimise disturbance ([Mo and Bonatakis 2022](#)).

A range of studies highlight substantial variations in animal responses to drone flights among taxa, populations, and geographic locations ([Mulero-Pázmány et al. 2014](#); [Jarrett et al. 2020](#)). This presents a challenge for developing intuitive policies and protocols, which means that managers will often require taxa- and (or) location-specific literature. Our review found substantial variation in the volume of scientific literature between vertebrate taxa and continents. The scientific capacity of countries within the range of different species is a likely variable influencing these disparities, as well as the body mass and threat status of different species ([dos Santos et al. 2020](#)). Amongst peer-reviewed articles involving drone approaches of wildlife, aquatic mammals and aquatic birds were the most studied taxa, which corresponds with these taxa having been historically monitored through aerial surveys ([Angliss et al. 2018](#); [Colefax et al. 2018](#); [Wang et al. 2019](#)). In contrast, there were notable deficiencies such as an absence of studies on taxonomical groups that could potentially be susceptible to drone-induced disturbances such as rodents, xenarthrans, and lizards. Furthermore, there are few relevant studies on diverse taxonomical groups such as bats, marsupials, passerines, and other birds. We therefore encourage future studies investigating animal responses to drone flights for underrepresented taxonomical groups.

Based on trends observed in this review, we project that the volume of scientific literature on drone applications for wildlife research and management will likely continue to grow substantially in the near future. The majority of scientific literature identified in our review was published in peer-reviewed journals, which provides a level of quality control and confidence in managers deriving implications from research findings ([Sizo et al. 2019](#)). The requirement of certain university degrees to undertake research projects presents a convenient pathway for accelerating research ([Schopf et al. 2014](#)), and some of the dissertations we found were subsequently also published in peer-reviewed journals (e.g., [Chabot 2009](#); [Chabot and Bird 2012](#)). We found that peer-reviewed articles were published across a broad range of scientific journals, most frequently in two focused journals, the *Journal of Unmanned Vehicle Systems* and *Drones*, both of which were established relatively recently. The establishment of such focused journals reflects our projection of substantial growth in this research area.

[illegible]

Table 6. Temporal distribution of peer-reviewed research articles of studies conducted in island countries not part of any continent.

Country	2015	2016	2018	2019
French Polynesia	—	Kiszka et al. (2016)	Rieucan et al. (2018)	—
New Zealand	—	—	Gooday et al. (2018)	Fettermann et al. (2019)
Cook Islands	—	—	—	Horton et al. (2019)
Falkland Islands	Ratcliffe et al. (2015)	—	—	—
French Southern Territories	—	—	Weimerskirch et al. (2018)	—
Tristan da Cunha	—	McClelland et al. (2016)	—	—

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Appendix A

Table A1. List of scientific publications describing or providing commentary of practices involving drones approaching wildlife from 2000 to 2020.

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