Unveiling the Impact of Drone Noise on Wildlife : A Crucial Research Imperative

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Afridi, Saadia; Hlebowicz, Kasper; Cawthorne, Dylan; Lundquist, Ulrik Pagh Schultz

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Unveiling the Impact of Drone Noise on Wildlife: A Crucial Research Imperative*

Saadia Afridi[1 2], Kasper Hlebowicz[3], Dylan Cawthorne[4], and Ulrik Pagh Schultz Lundquist[5]

***Abstract*— Unmanned Aerial Vehicles, commonly known as drones, have become integral across various industries, ranging from photography and surveillance to scientific research. While their applications offer numerous benefits, the noise generated by drones poses a potential threat to the well-being of wildlife. Using a systematic literature review, we examine a wide range of sources to gain insights into the current state of knowledge on the impacts of drones on wildlife, with a particular focus on noise. The literature review reveals a significant research gap and highlights the need for a more comprehensive understanding of the impact of drone-induced noise on animal and ecosystem behavior. This paper advocates for concerted efforts to address the issue of drone noise on animals. It raises a fundamental question: Can we design drones to minimize noise and responsibly incorporate them into wildlife research?**

I. Introduction

Unmanned Aerial Vehicles (UAVs) are becoming increasingly popular in wildlife research, providing unique opportunities for data gathering and observation. Recent applications of UAVs encompass a wide array of endeavors, from gathering biological samples [1], monitoring morphometric attributes [2], and collecting behavioral data [3, 4] to conducting census surveys [5], anti-poaching surveillance [6], and mapping species habitat use [7]. This technology has enabled researchers to access remote locations [8], study fine-scale wildlife movements, and employ automated analysis techniques for efficient species detection in imagery [9].

Despite the promising advancements and diverse applications, the growing integration of UAVs in wildlife studies has raised concerns about potential misuse and ecological disturbance. While in some cases, UAVs present a less disruptive alternative to traditional data collection methods [10], the media has highlighted instances of wildlife harassment captured in social media videos, fueling public apprehension [10]. The portrayal of UAVs as sources of disturbance in natural habitats has sparked discussions about the need to address the associated challenges [11]. The challenges associated with UAV use in wildlife monitoring include a lack of comprehensive research and clarity on disturbance issues. Concerns have led some countries to ban UAVs in national parks, underlining the urgency of addressing these environmental considerations [12].

Previous literature suggests that drone noise constitutes the primary and perhaps foremost factor influencing behavioral alterations in large terrestrial species subjected to drone encounters [13]. Furthermore, the auditory system of mammals exhibits a more rapid response than other sensory systems, triggering their neural circuits more swiftly and enabling a quicker fight or flight reaction [14]. While studies have delved into specific drone stimuli such as sound [15] and visual cues [16], understanding the distinct impacts of auditory and visual signals on animal disturbance caused by drones remains elusive. This paper seeks to address this gap by enhancing awareness of the impact of drone noise on animals within our technologically advanced era. Despite numerous studies exploring the effects of various factors on aerial, marine, and terrestrial animals, there is still a notable lack of understanding regarding the influence of drone-generated noise on animal behavior.

This paper seeks to bring attention to the often-overlooked issue of drone noise's impact on animals, highlighting its significance for both animal welfare and the pursuit of unbiased data. Emphasizing the dual perspective of the welfare of animals and the potential alteration of their behavior due to disturbances caused by drones, we argue that a comprehensive examination of the noise impact of drones is essential. This approach contributes to a more nuanced understanding of the field of wildlife research. Furthermore, the work proposes a concerted effort to address the impact of drone noise on animals, prompting a fundamental question to the engineering community: *Can we design drones that are less disturbing to minimize their impact on animals while complying with legislation that requires transparent drone operations?*

A. Drones

Within the drone landscape, three primary categories emerge fixed-wing, multirotor, and hybrid Vertical Take-off and Landing (VTOL) craft, as depicted in Fig 1. Fixed-wing drones, resembling small aircraft, are the workhorses of industrial applications, while multirotor drones such as quadcopters and hexacopters dominate the hobbyist realm [17]. A recent innovation, the hybrid drone, combines the take-off agility of a multirotor with the efficiency of fixed-wing flight. It is worth noting that fixed-wing, multirotor, and VTOL drones

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[1]Saadia Afridi, PhD candidate, University of Southern Denmark, Campusvej 55, 5230 Odense M, Denmark saf@mmmi.sdu.dk

[2]Saadia Afridi, Performance Engineer - Drone Noise Specialist, Avy B.V, Donauweg 21, 1043 AJ, Amsterdam saadia@avy.eu

[3]Kasper Hlebowicz, Wildlife Ecology and Conservation, Wageningen University and Research, Droevendaalsesteeg 3a, 6708 PB Wageningen, the Netherlands kasper.hlebowicz@wur.nl

[4]Dylan Cawthorne, Unmanned Aerial Systems Center, University of Southern Denmark, Campusvej 55, 5230 Odense M, Denmark dyca@sdu.dk

[5]Ulrik Pagh Schultz Lundquist, Unmanned Aerial Systems Center, University of Southern Denmark, Campusvej 55, 5230 Odense M, Denmark ups@mmmi.sdu.dk

all fall under the broader category of UAVs, but they differ significantly in various key aspects.

Fig. 1. Three categories of drones: with the fixed wing on the left (Skywatch), multirotor drone in the center (Yuneec), and a VTOL drone on the right (Avy)

A fixed-wing drone, resembling an airplane, is energy-efficient as it requires power only for forward propulsion, utilizing a single rigid wing for lift without vertical rotors. Fixed-wing drones are highly efficient and can cover large areas during extended flights. They are ideal for comprehensive mapping, infrastructure inspection, surveying, and agricultural monitoring over large geographical areas. VTOL drones efficiently perform vertical take-off and transition to horizontal flight, covering longer distances compared to multirotor drones, which primarily operate in short-range flights. Due to their aerodynamic efficiency during horizontal flight, VTOL drones exhibit longer endurance and range. They also boast higher payload capacity, making them suitable for missions requiring vertical take-off and longer-distance coverage, such as mapping, inspection, and drone delivery. Conversely, multirotor drones are ideal for tasks demanding agility and precision, like aerial photography, surveillance, inspection, and short-range deliveries, but they have limited endurance and range.

Drones, characterized by diverse designs that vary in size, propeller number, and arrangement, distinctly impact the noise generated during their operations. Table I illustrates the fluctuations in noise levels observed when analyzing drones at various Above Ground Level (AGL) altitudes.

TABLE I. Variations in Noise Levels Across Different Altitudes for Different Drones [18].

Various drones	AGL	Noise
Raven UAV	18 – 61m	70 – 60dB
Draganflyer	3 – 100m	60 – 30dB
Hexacopter APH-22	0 – 90m	57.8 – 31.3dB
Octocopter	10 – 50m	70dB
Phantom Cyclone	2m	60dB
ATLAS-T	120m	59dB
Skyeye	50m	52.5dB
Custom X8	50m	65dB

B. Material and Methods

The literature on the use of Unmanned Aerial Systems (UASs) for monitoring and studying wildlife, their interactions, and associated effects was extensively reviewed up to December 31, 2023. As a supplementary investigation, we conducted a targeted search for scientific literature that provided descriptions or analyses of drone noise and its impact on terrestrial wildlife. Employing keywords such as 'drone,' 'unmanned aerial vehicle,' 'unmanned aerial system,' 'remotely-piloted aircraft system,' 'unmanned aircraft,' 'UAV,' 'UAS,' and 'RPAS,' combined with terms like 'wildlife,' 'disturbance', 'animals,' 'birds,' 'marine,' 'reptiles,' 'terrestrial,' and 'megafauna' in the Google Scholar search and Web of Science engine, we identified relevant publications.

Initial investigations revealed a scarcity of published material specifically addressing the UAVs' noise impact on terrestrial animals. Consequently, our literature review was expanded to include drone visual impact studies on aerial and marine animals. To ensure a comprehensive review, scientific publications included peer-reviewed journal articles, university dissertations (including Master's theses), conference proceedings, and project reports. Additionally, we expanded our search by identifying relevant publications through citations in other publications. This broader scope yielded a total of 92 publications referencing noise impact, encompassing factors such as flight angles, approach distance, wind masking, and visual stimuli. Once we identified our potential studies through our database research, we began screening. Given our specific focus on drone noise and its impact on animals, publications limited to other aspects were excluded from our review. This integrated approach aimed to provide a comprehensive understanding of both the broader context of UAV utilization in wildlife studies, as well as specific insights into the drone noise on animals.

II. UAVs and Wildlife

The initial instances of drone-induced disturbance behavior were first noted in studies primarily focused on utilizing aircraft for estimating population numbers [19]. As researchers recognized the potential negative impact of animals' aversive reactions on the accuracy of census data, investigations into this phenomenon gained direct attention [20, 21]. Analysis employing Generalized Linear Models revealed that wildlife reactions to aerial vehicles vary depending on the primary habitat type they inhabit [11] (see Fig. 2). Wildlife residing in both aerial and terrestrial habitats, including birds, insects, terrestrial mammals, and reptiles, demonstrated a higher likelihood of exhibiting behavioral changes in response to aerial vehicles. In contrast, wildlife in aquatic habitats, such as marine mammals and fish, exhibited a lower probability of behavioral responses.

While the primary focus of this paper is the examination of drone noise and its effects on wildlife, it is essential to acknowledge the broader context of drone-wildlife interactions, which includes visual disturbances. Several studies have highlighted the detrimental impact of drone presence on bird behavior due to both auditory and visual stimuli. For instance, a study demonstrated that the visual presence of drones near nesting sites caused significant stress responses in nesting birds, affecting their reproductive success [16]. Additionally, research has also highlighted that the combined visual and auditory disturbance of drones triggers increased vigilance, agonistic behavior, as well as instances of standing at or walking away from the nest, and escape behavior among nesting birds [22, 23]. These findings underscore the multifaceted nature of drone-wildlife interactions, where both noise and visual cues can contribute to behavioral changes in affected species.

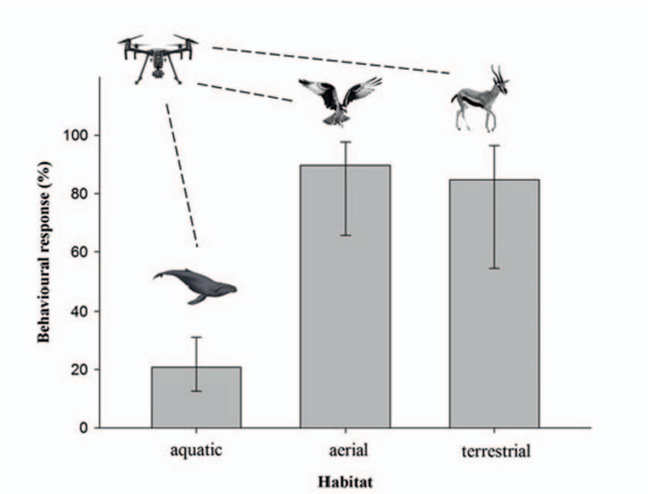

Fig. 2. Percentage of wildlife behavioral responses to aerial vehicles to their main habitat [11].

A. Aerial animals

From the perspective of birds, the presence of drones during overflights can affect their behaviors, as certain species may perceive drones as predatory birds, particularly those that are preyed upon by avian predators [24]. The shape and wing profile of certain drones have been identified as factors influencing the reactions of waterfowl, with profiles resembling raptors causing the most disturbance to wildlife [25]. Disturbance tends to occur more frequently during drone banking maneuvers, takeoff, or landing, especially when these actions happen over or near a flock, leading to the postulation that birds may interpret these movements as resembling the swooping of a predatory bird [25, 26].

For example, lekking prairie chickens display a heightened sensitivity to drone overflights within altitudes ranging from 25 to 100 meters. This heightened sensitivity may be attributed to the vulnerability of displaying birds to potential attacks by hawks [27]. In a research study investigating the responses of 22 avian species to drone flights, the researchers observed that birds typically did not react significantly to drone takeoffs when the drones were positioned more than 40 meters away from them [28]. Another source reported that drones could be flown within a 4-meter proximity to waterfowl, wild flamingos, and common greenshanks without causing notable disturbance, provided the drone avoided approaching the bird directly from above [29]. Minimal impact on waterfowl was observed when drones maintained speeds of 20–25 km/h, allowing the drone to pass the individual before it became aware of its presence [30]. Beyond evasive behaviors, some bird species were documented engaging in harassment, mobbing, or direct attacks on drones mid-flight [31]. A visual representation in Figure 3 depicts a raven attacking a delivery drone.

Fig. 3. Raven attacks drone delivering coffee in Australia. From [32].

Instances of severe behavioral responses may lead to the abandonment of young birds and increased energy expenditure, ultimately resulting in breeding failures [33]. Additionally, disturbances can elicit physiological responses, including heightened heart rate and hormonal fluctuations, associated with increased metabolic rates that may contribute to declines in condition [33]. The overall impact of these adverse outcomes depends on the extent and severity of the disturbance, as well as the sensitivity of the nesting bird species.

B. Marine animals

Many marine species heavily rely on sound for essential activities such as orientation, foraging, communication, and threat detection [34], exposing them to potential harm from human-induced noise associated with activities like shipping [35], offshore wind farms [36], seismic exploration [37], and military sonar [38]. The consequences of anthropogenic noise on marine mammals include behavioral changes (e.g., avoidance), physiological impacts (e.g., stress and hearing impairment), disruption of communication and echolocation signals, and modifications in vocalizations [39]. Conventional understanding suggests that small- and medium-sized UAVs generate minimal underwater noise, seemingly causing little disturbance to marine life [40]. It has also been discovered that the UAV sounds do not propagate effectively from the air into the water. The noise generated by drones closely matches the background noise level in shallow water habitats [41, 42]. Upon comparing recorded drone noise levels with the established hearing thresholds of dolphins and whales, it became evident that, for the majority of these marine mammals, drones operate beneath their auditory thresholds [43]. A traditional investigation centered on southern right whale mother-calf pairs in Australia utilized UAV tracking and acoustic tag measurements and found no observable behavioral reactions to close UAV approaches [44]. Other studies, albeit anecdotal, have reported similar outcomes for various baleen whale species, including gray whales [45], humpback whales [46], bowhead whales [47], and blue whales [48].

In the case of toothed whales, a study [49] disrupts this presumption, revealing heightened signs of discomfort, including increased reorientation and tail slapping in bottlenose dolphins when a UAV operated at a 10m altitude. Intriguingly, these effects dissipate at higher altitudes of 25m and 40m, prompting a reevaluation of the presumed harmlessness of UAVs near cetaceans. Another study [50] also showcased the behavioral responses of bottlenose dolphins to UAVs, as depicted in Fig 4. This emphasizes the necessity for comparable studies on toothed whales with different hearing thresholds and frequencies to assess their reactions to UAV approaches. Additionally, it is essential to consider potential physiological responses, such as stress, in cetaceans exposed to UAVs, as noted in terrestrial mammals [51].

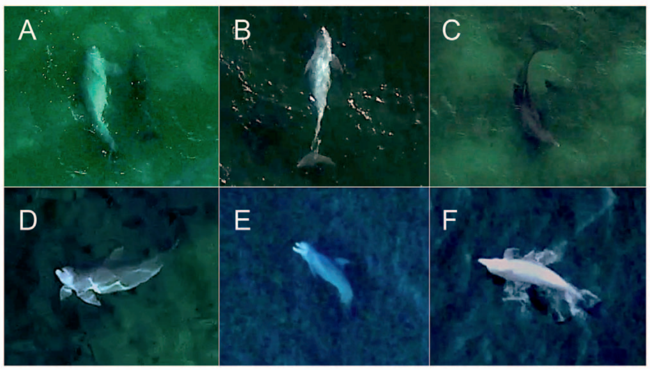

Fig. 4. Instances of bottlenose dolphin reaction to the presence of drone comprised (A) side-roll, (B) belly-up, (C) circular swim (left), (D) spin-and-orient, (E) side-roll (open-mouth), and (F) breach (inverted). From [50].

Group size has also been reported to modify animals' response toward UAVs with larger group sizes exhibiting increased avoidance. In larger groups, Beluga species were reported to exhibit increased avoidance responses and were prone to sudden dives during low-altitude flights, especially below 23m [52]. Larger groups, in particular, experience a higher likelihood of sudden dives (shown in Fig. 5), particularly when a drone initially approaches the group.

Fig. 5. Beluga exhibits avoidance reactions to drones when in large groups. From [53].

Behavioral responses can also be season-dependent which adds another layer of complexity. For instance, harbor seals showcase variability in reactions, with a threshold distance of 80m during the pre-breeding period and heightened agitation at 150m during the molting season. This variability underscores the multifaceted nature of UAV disturbance on marine mammals, influenced by temporal factors and prior disturbances [54]. In the aerial domain, concerns arise from the noise levels produced by UAVs, falling within ranges known to disturb sea otters and pinnipeds [55]. This prompts concerns regarding the potential adverse impacts of operating low-altitude UAVs on marine life. While it is believed that underwater noise may not significantly affect marine mammals [40], the noise generated by UAVs in flight introduces a new dimension to consider, raising concerns about the potential negative impact of using drones at low altitudes on marine life.

C. *Terrestrial animals*

Ecologists studying terrestrial animals traditionally use aerial surveys to quantify abundance, distribution, and habitat [56]. UAS have become instrumental in performing these tasks and gathering data that was once logistically challenging to obtain via manned aircraft. While drones are extensively researched concerning megafauna [57] and recreational filming [58], our comprehension of their impact on animal behavior is incomplete. A study examining seven herbivore species—African elephant, giraffe, impala, red lechwe, tsessebe, blue wildebeest, and plains zebra—revealed negative responses to approaching drones, as depicted in Fig. 6. The drones used for observation were the Phantom

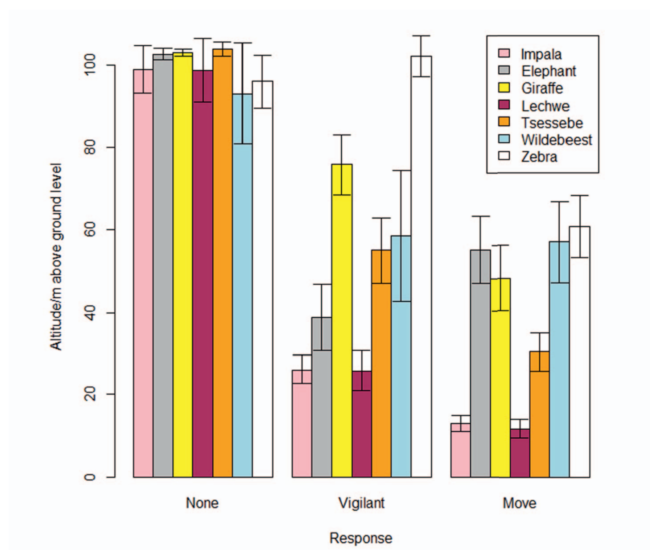

Fig. 6. The reactions of seven African herbivore species to vertical UAS approaches assessed at different altitudes above ground level. From [59].

III Professional and the Inspire I from DJI at varying altitudes. The vigilant threshold varied across the different species. Elephants, giraffes, wildebeest, and zebras avoided UAVs at around 50–60m AGL, tsessebe at 30m AGL, while impala and lechwe only moved when UAVs were about 15m AGL [59]. Additionally, guanacos spotted drones at 180m above ground level, beyond their usual visual range [60]. Exploring the potential broader impacts of drone disturbances on wildlife, it is worth noting that these disruptions might also manifest through metabolic and physiological reactions in animals. Moreover, this can be dependent on the reproductive status and social environment, including the presence of conspecifics, youngs, and more generally, group size. Research on hibernating Black bears, depicted in Fig. 7, showed elevated heart rates in response to overhead VTOLs [51]. Additionally, the female American black bear with at least two cubs exhibited the fastest recorded movement, relocating 576.3m away within 40 minutes of drone exposure.

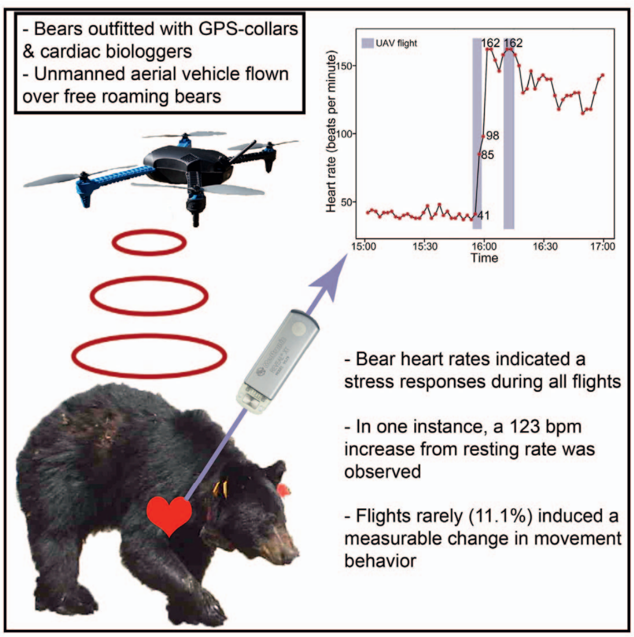

Fig. 7. Bears showed elevated heart rates in response to UAV flights, with minimal behavioral reactions. From [51].

Elephants also quickly move away from VTOLs due to their bee-swarm-like sounds [61]. Asian elephants are reported to exhibit disturbance by drones above 100m AGL. This heightened sensitivity is attributed to their ability to detect low-frequency sounds and effectively propagate such noises [13]. These findings corroborate the observations in [62] that emphasize the reliance of elephants on their auditory, for environmental interaction and communication with peers. In addition to the Asian elephant, the giraffe was also affected by the drone when flown above 100m AGL [13]. In African reserve regions, it has been documented that elephants display increased vigilance in response to drones at a distance of 50m, while giraffes exhibit a similar response from drones at 80m AGL [59]. Among the unexamined species without audiograms, the giant anteater, which is both an endangered species and the largest in the Pilosa order, was introduced to drone studies for the first time. Given its limited auditory and visual capabilities [63], it was - as predicted - the least responsive to drones, demonstrating a high tolerance for sound pressure before exhibiting behavioral changes.

D. *Challenges in Wildlife Responses to Drones*

Conducting wildlife research using drones presents a myriad of challenges, with a primary focus on understanding and addressing species-specific responses. The literature underscores the existence of diverse behavioral disturbance thresholds across various taxa, necessitating tailored methodologies to minimize the impact of drone-based studies on wildlife behavior [64, 65]. Notably, nesting species, such as Adélie and Gentoo penguins, showcase variable sensitivities to drone activities, emphasizing the importance of species-specific considerations in the deployment of drone technology for ecological studies [66]. Additionally, the correlation between biological states, particularly the responses of species engaged in parental nest defense, adds a layer of complexity that researchers must address to accurately interpret drone-induced effects on wildlife behavior [67]. The impact of drones during critical periods like breeding and molting seasons further underscores the need for targeted investigations to comprehend the specific challenges posed during these crucial life stages [68]. Furthermore, age-dependent reactions, as witnessed in varying responses between adult and younger age classes, contribute to a nuanced understanding of the differential stressors imposed by drones at different life stages [69].

In the realm of group dynamics, the reactions of herds during drone flights add another layer of complexity to wildlife research. This was evident in large groups shifting from foraging to vigilance and locomotion during UAS scanning behavior flights [70]. These findings emphasize the importance of considering collective responses versus those of lone individuals when utilizing drones in ecological studies [71]. Overall, the challenges posed by species-specific responses, combined with the complexities of group dynamics and the biological state, highlight the need for a comprehensive and nuanced approach to wildlife research utilizing drone technology.

III. Discussion

In the context of technological innovation intersecting with conservation needs, this study examines the impact of drone noise on animals. This research highlights an opportunity to advance ethical drone use, emphasizing the importance of minimizing disturbances during wildlife monitoring.

A. *Ethical Drone Use*

Ensuring responsible and sustainable wildlife monitoring practices requires a robust ethical framework. Value-sensitive design (VSD) emerges as a pivotal approach, embedding ethical considerations into the drone technology design process [72, 73]. VSD integrates environmental preservation and animal welfare values from the inception of technological development [74, 75]. Striking a delicate balance between technical efficiency and ethical imperatives, this approach necessitates interdisciplinary collaboration among technical UAV experts, biologists, and ethicists.

An intriguing facet of ethical drone use involves a crucial decision: should drones be silent or adopt a biomimetic approach to integrate seamlessly with wildlife? This pivotal question sparks a profound discussion bridging technological innovation and ecological harmony.

The debate over whether drones should be completely silent or embrace biomimicry introduces a fascinating realm within ethical drone use. Silent drones may reduce disturbances, but biomimetic design could offer a more integrated and ecologically sensitive approach. This nuanced discussion invites technical UAV experts to delve into the intricacies of designing drones that align with both scientific objectives and ethical considerations.

The optimization of drone noise levels is not merely a technical challenge; it evolves into an ethical imperative. This optimization is about not only enhancing data collection efficiency but, more crucially, minimizing potential disturbances to the subjects of study.

Viewing flying drones in close proximity as an invitation to partnership rather than intrusion fosters a deeper appreciation for animal lives, translating into more effective conservation strategies. The objective is to infuse knowledge pursuits with heightened ethical consciousness

The core argument is rooted in the need for a comprehensive understanding of the issue. Beyond scientific rigor, a compassionate lens is advocated, recognizing the behavioral intricacies of wildlife. In presenting this case, we advocate for an approach that not only broadens the scope of our understanding but actively integrates the principles of respect and empathy into our scientific pursuits.

In conclusion, this study underscores the importance of integrating ethical principles into the design and operation of drone systems for wildlife monitoring. By prioritizing responsible stewardship of the environment, we aim to ensure that technological advancements in drones align with the preservation of natural habitats and wildlife. This approach not only enhances the effectiveness of scientific exploration but also contributes to a more sustainable coexistence between technology and the natural world.

B. Future Directions and Recommendation

In moving forward, several key areas warrant attention for the advancement of ethical drone-assisted wildlife conservation. The following recommendations outline future directions to enhance the effectiveness and ethical considerations of drone use in this domain.

1) Innovations in Drone Technology: Moving forward, the evolution of ethical drone use in wildlife conservation prompts a focus on continuous innovation. Advancements in drone technology should prioritize the development of quieter propulsion systems, adaptive flight algorithms minimizing disturbance, and specialized sensors enhancing data collection with minimal impact. Biomimicry, drawing inspiration from nature's designs, could play a crucial role in developing drone propulsion systems that mimic the quiet and non-intrusive characteristics of certain wildlife. Collaborations between engineers, biologists, and conservationists remain pivotal for pushing the boundaries of drone design and tailoring future iterations to minimize ecological footprints.

2) Tailoring Guidelines for Diverse Ecosystems: Recognizing ecosystem diversity, future efforts in drone-assisted wildlife conservation should concentrate on crafting guidelines tailored to the specific needs of aerial, terrestrial, and marine environments. Recommendations must account for unique sensitivities within each habitat, suggesting altitude and noise thresholds that respect wildlife behavioral intricacies and acoustic requirements. A nuanced approach to guidelines ensures adaptability across diverse ecosystems.

3) Global Collaboration and Standardization: The envisioned path forward emphasizes fostering global collaboration and standardization in ethical drone use for wildlife conservation. Cross-disciplinary partnerships among researchers, conservationists, and policymakers are crucial for sharing best practices, harmonizing ethical standards, and establishing a framework for responsible drone-assisted wildlife monitoring globally. Standardization guarantees consistent prioritization of ethical considerations, irrespective of geographic location or ecosystem type.

4) Development of Testing Standards for Drones: Shaping the future of ethical wildlife monitoring requires establishing testing standards for drones. Rigorous assessments of noise levels, flight altitudes, and impact on animal behavior should be part of a standardized testing framework, ensuring adherence to predefined ethical criteria and fostering accountability in wildlife conservation practices. Biomimicry concepts could also be explored in testing protocols to evaluate the drone's ability to minimize disturbance by drawing inspiration from natural behaviors observed in wildlife.

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