REVIEW

Assessment of known impacts of unmanned aerial systems (UAS) on marine mammals: data gaps and recommendations for researchers in the United States[1]

Courtney E. Smith, Seth T. Sykora-Bodie, Brian Bloodworth, Shalynn M. Pack, Trevor R. Spradlin, and Nicole R. LeBoeuf

Abstract: The development of advanced technologies to enhance conservation science often outpaces the abilities of wildlife managers to assess and ensure such new tools are safely used in proximity to wild animals. Recently, unmanned aerial systems (UAS) have become more accessible to civilian operators and are quickly being integrated into existing research paradigms to replace manned aircraft. Several federal statutes require scientists to obtain research permits to closely approach protected species of wildlife, such as marine mammals, but the lack of available information on the effects of UAS operations on these species has made it difficult to evaluate and mitigate potential impacts. Here, we present a synthesis of the current state of scientific understanding of the impacts of UAS usage near marine mammals. We also identify key data gaps that are currently limiting the ability of marine resource managers to develop appropriate guidelines, policies, or regulations for safe and responsible operation of UAS near marine mammals. We recommend researchers prioritize collecting, analyzing, and disseminating data on marine mammal responses to UAS when using the devices to better inform the scientific community, regulators, and hobbyists about potential effects and assist with the development of appropriate mitigation measures.

Key words: unmanned aerial systems, marine mammals, protected species, anthropogenic impacts, disturbance.

Résumé : Le développement de technologies de pointe pour améliorer la science de la conservation dépasse souvent les capacités des gestionnaires de la faune à évaluer de tels nouveaux outils et à assurer qu'ils sont utilisés sans risques en proximité des animaux sauvages. Récemment, les systèmes aériens sans pilote (UAS) sont devenus plus accessibles aux opérateurs civils et sont rapidement intégrés aux paradigmes de la recherche actuelle pour remplacer l'avion piloté. Plusieurs lois fédérales exigent des scientifiques l'obtention de permis de recherche pour approcher de près les espèces sauvages protégées telles que les mammifères marins, mais il est difficile d'évaluer et de mitiger les incidences possibles à cause du manque d'information disponible sur les effets des opérations de UAS sur ces espèces. Dans cette étude, nous présentons une synthèse de l'état actuel de la compréhension scientifique en matière des incidences de l'utilisation des UAS en proximité des mammifères marins. Nous déterminons aussi les données de base manquantes qui limitent actuellement la capacité des

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gestionnaires des ressources marines à développer des directives, des politiques et des règlements appropriés en matière d'opération sécuritaire et responsable des UAS près des mammifères marins. Nous recommandons que les chercheurs visent en priorité la collecte, l'analyse et la diffusion des données portant sur les réactions des mammifères marins aux UAS lorsqu'on utilise ces dispositifs afin de mieux informer le milieu scientifique, les autorités de réglementation et les amateurs á propos des effets potentiels et d'aider á l'élaboration de mesures d'atténuation appropriées. [Traduit par la rédaction]

Mots-clés : systèmes d'aéronef sans pilote, mammifères marins, espèce protégée, incidences anthropiques, perturbation.

Introduction

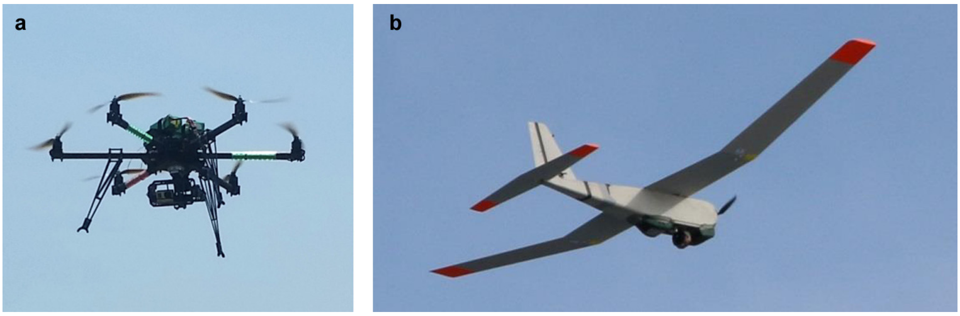
Aerial systems have long been integral to the monitoring and management of wildlife. Surveys and data gathering tools using aerial platforms can yield important information regarding habitat conditions, population size and demographics, as well as health and fitness for both terrestrial and marine species (Fearnbach et al. 2011; Vermeulen et al. 2013; Sweeney et al. 2015). However, as research budgets shrink and technology rapidly advances, scientists are looking to utilize unmanned aerial systems (UAS) as a safer and more cost-effective alternative for conducting low-altitude wildlife and ecological surveys (Koh and Wich 2012; Ogden 2013).

These systems can greatly benefit researchers and wildlife managers by reducing errors in aerial estimation of wildlife populations often caused by variation in survey path (Koski et al. 2015), increasing the time spent over the survey target (i.e., survey effort), minimizing the risk of potential disturbance, eliminating observer fatigue (Conroy et al. 2008; Hodgson et al. 2013), and maximizing the safety of wildlife researchers by negating the need to put people aboard aerial platforms (Wiegmann and Taneja 2003). In addition to the research benefits, UAS also can be an important tool to aid wildlife emergency responders and law enforcement officials in monitoring or investigating animals in distress and conducting safer rescue operations.

In recent years, UAS operations have been integrated into numerous field studies involving a variety of species: orangutans (*Pongo abelii*; Koh and Wich 2012), American alligator (*Alligator mississippiensis*; Jones et al. 2006), African elephants (*Loxodonta africana*; Vermeulen et al. 2013), black bears (*Ursus americanus*; Ditmer et al. 2015), as well as numerous avian (Chabot and Bird 2012; Rodríguez et al. 2012; Potapov et al. 2013; Chabot et al. 2014; Vas et al. 2015; Weissensteiner et al. 2015), ungulate (Barasona et al. 2014), and marine mammal species (Koski et al. 2009; Acevedo-Whitehouse et al. 2010; Selby et al. 2011; Martin et al. 2012; Schick et al. 2014). The research, conservation, and management applications of UAS vary widely, including the use of UAS to deter birds from feeding in commercially important agricultural areas (Grimm et al. 2012), monitoring habitat and biodiversity loss (Koh and Wich 2012), determining the health and fitness of large species where temporary capture is impractical (Hunt et al. 2013; Acevedo-Whitehouse et al. 2010), and monitoring illegal poaching activities (Olivares-Mendez et al. 2013; Mulero-Pázmány et al. 2014). There are also animal welfare applications; UAS are used to detect resting fawns at risk of fatal interactions with mowing machines (Israel 2011). UAS offer an effective means to obtain valuable information with minimal behavioral disturbance and (or) short-term, recoverable physiological responses (e.g., Ditmer et al. 2015) in many target species. Additionally, UAS cause significantly lower levels of disturbance than traditional aircraft when flown at comparable heights (Sleno and Mansfield 1978; Acevedo-Whitehouse et al. 2010; Mulaca et al. 2011; Moreland et al. 2015).

In the case of marine mammals, the data gathered from aerial platforms provides important information for the conservation and management of these species. Indeed, under the Marine Mammal Protection Act (MMPA), NOAA's National Marine Fisheries Service (NMFS) is tasked with integrating these data into annual stock assessment reports for cetaceans and pinnipeds, which supports the development of the regulatory frameworks needed to effectively manage these species. However, the relatively new use of UAS in marine mammal research presents additional challenges, particularly within the scope of their potential to impact marine mammals. Under the auspices of multiple statutes (e.g., the MMPA, Endangered Species Act (ESA), National Environmental Policy Act (NEPA)), several regulatory agencies are required to evaluate all reasonably foreseeable environmental consequences resulting from human activities. This can create a paradox, whereby the scientific research permitting process to obtain a permit for an action (including testing new technologies and methods) requires information from applicants regarding the disturbance thresholds of a proposed action. As a result, researchers and managers must infer known impacts from "surrogate" species, which may or may not occur within a comparable study area or similar study design. This can be

Fig. 1. Examples of two commonly used UAS platforms in marine mammal research: (a) a VTOL system (a HexaXL, by MikroKopter; photo by Courtney Smith, NOAA) and (b) a FW system (the Puma AE [All Environment], by AeroVironment, Inc.; photo publicly available from NOAA (see: http://response.restoration.noaa.gov/evaluating-oil-spill-response-technologies-arctic)).



especially challenging because marine mammal scientific research activities are generally required to be conducted in a manner that minimizes impacts and disturbances. Additionally, Federal Aviation Administration (FAA) requirements regarding UAS piloting and operations include limitations for the use of these platforms for research, which falls into the FAA category of commercial, rather than recreational, use. Thus, researchers using UAS must follow requirements for FAA permitting, which are currently evolving with few designated test sites to train and become experienced with UAS operations, and national airspace restrictions preventing their use (Watts et al. 2010; Hoppin 2014). As a result, there is little information available about UAS impacts on marine mammals.

While multiple reviews have been published on the applications, capabilities, and inventory of UAS platforms, the effects of their operations on wildlife are under-reported in the literature. Additionally, there has not yet been a comprehensive analysis of UAS impacts on wildlife. Given the limited published literature on the effects of UAS operations on marine mammals, particularly when flown at lower altitudes, more information is needed to assist with shaping guidelines for safe and responsible operation of UAS near marine mammals. Here, we briefly describe commonly used UAS, provide an overview of published studies that include known effects of UAS flown in proximity to marine mammals, and present an analysis of the largest information gaps. We also highlight how the current state of scientific understanding presents challenges to managers as they permit important research and provide guidelines to the general public to ensure the health and safety of marine mammals.

Commonly used UAS

Various designs of UAS platforms are in operation, which have been divided into multiple classification schemes based on device weight, propulsion methods, payload capacity, altitude and range capabilities, and general application (e.g., Mackenzie 2009; Watts et al. 2012; Anderson and Gaston 2013). For the purposes of our analysis, this paper focuses on two broad classes that are commonly used in marine mammal research: vertical takeoff and landing (VTOL) and fixed-wing (FW) systems (Fig. 1). The designs and functionality of these two UAS types yield a wide range of applications and support various research objectives.

Vertical takeoff and landing systems (VTOL)

As the name implies, VTOL systems are those that have the ability to take off and land vertically, eliminating the need for a runway. The propulsion mechanisms involve rotors affixed to the top of the system (as seen in larger, manned helicopters) or those extending horizontally with arms from the main UAS housing. The number of rotors varies, depending on the design, but generally ranges from four (quadcopter) to eight (octocopter). Because VTOLs have the ability to maintain a stationary position, they can be ideal for photography and videography, monitoring slow-moving wildlife or real-time events, such as whale entanglements, and can easily be operated and maneuvered in areas that conventional aircraft cannot access.

Such systems used in marine mammal research are generally lightweight (under 5 kg), inexpensive (relative to other manned survey platforms), easily portable, and readily available from numerous commercial manufacturers. The systems are remotely operated, using toggle-based hand controllers, and can be monitored visually by the naked eye and kept within visual line-of-sight of the operator, using smaller, portable ground control stations. The applications for VTOLs in marine mammal

Table 1. Summary of known published impacts of UAS on marine mammals.

Species group	Species	UAS design	Model	Lowest altitude	Behavioral response details	Source
Cetaceans						
Mysticetes	Humpback whale (*Megaptera novaeangliae*)	VTOL	Mini- helicopter 'Birdy'	~9 m	No behavioral responses observed. (Permit No. 716-1705-01, 2008 annual report).	NMFS (2008)
	Bowhead whale (*Balaena mysticetus*)	FW	TD100E	120 m	No behavioral responses reported.	Koski et al. (2015)
Mysticetes and odontocetes	Blue whale (*Balaenoptera musculus*), humpback whale (*Megaptera novaeangliae*), gray whale (*Eschrichtius robustus*), and sperm whale (*Physeter macrocephalus*)	VTOL	Radio-controlled helicopter	13 m	Large whales showed no additional avoidance behaviors when approached by UAS than observed during vessel-based research activities.	Acevedo-Whitehouse et al. (2010)
Odontocetes	Beluga (*Delphinapterus leucas*)	FW	Senior Telemaster (fuel powered)	150–200 m	No abnormal behaviors observed during or after flights.	Sleno and Mansfield (1978)
	Killer whale (*Orcinus orca*)	VTOL	APH-22 (battery powered)	35 m	No behavioral responses observed.	Durban et al. (2015)
Sirenians						
Sirenia	Florida manatee (*Trichechus manatus*)	FW	FoldBat (fuel powered)	100–150 m	No behavioral responses observed.	Jones et al. (2006)
	Dugong (*Dugong dugon*)		ScanEagle (fuel powered)	~150–300 m	Unlikely to have behavioral responses when flown at 300 m.	Hodgson et al. (2013)
Pinnipeds						
Ottariids	Steller sea lion (*Eumetopias jubatus*)	FW	Puma AE (All-Environment) (battery powered)	60 m	No behavioral responses observed.	Fritz (2012)
	Steller sea lion (*Eumetopias jubatus*)	VTOL	Aeryon Scout (quadcopter; battery powered)	~15–30 m	At >30 m, 1% were alert; at 20–30 m, 1.6% were alert; at 15–20 m, 20.8% alert and 2% entered the water.	Fritz (2012)

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Table 1 *(continued)*.

Species group	Species	UAS design	Model	Lowest altitude	Behavioral response details	Source
	Steller sea lion (*Eumetopias jubatus*)		APH-22 (hexacopter; battery powered)	~45 m	Over 4 h of flight time, only one instance of disturbance, five animals flushed into water (0.3% disturbance rate, as compared to 5% disturbance rates from amanned aircraft)	Sweeney (2014)
Otariids and phocids	Antarctic fur seal *(Arctocephalus gazella)*, leopard seal *(Hydrurga leptonyx)*, Weddell seal *(Leptonychotes weddellii)*,	VTOL	Quadrocopter model md4-1000 (from Microdrones, GmbH)	23 m	No observations that any pinnipeds were responding to the aircraft at altitudes over 23 m.	Perryman et al. (2014); Goebel et al. (2015)
Phocids	Harbor seal (*Phoca vitulina*)	VTOL	Cinestar 6 (Hexacopter; battery powered)	30–50 m	Little to no behavioral reactions at 30 m altitude on frequently disturbed haulout. Seals on more remote haulout site observed flushing with UAS at 50 m.	Pomeroy et al. (2015)
			Skyjib (Octocopter; battery powered)			
Phocids	Gray seal (*Halichoerus grypus*)	VTOL	Cinestar 6 (Hexacopter; battery powered)	5–30 m	For breeding seals: Animals were alert, lifted heads with UAS at 30 m; shuffling and changes in position were observed when UAS at 15 m.For molting seals: Animals were alert, lifted heads with UAS at 30 m; shuffling and changes in position were observed when UAS at 30 m; seals observed to flee from UAS at 5 m.	Pomeroy et al. (2015)[a]

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Table 1 *(continued)*.

Species group	Species	UAS design	Model	Lowest altitude	Behavioral response details	Source
			Vulcan 8 (Octocopter; battery powered)	30–50 m	For breeding seals: Animals were alert, lifted heads with UAS at 50 m; locomotion of seals was observed when UAS was at 30 m.For molting seals: Animals were alert, lifted heads with UAS at 50 m; shuffling, changes in position and fleeing behavior were observed when UAS at 50 m	
Phocids	Ice seals: ribbon seal (*Histriophoca fasciata*); spotted seal (*Phoca largha*)	FW	ScanEagle (fuel powered)	90–200 m	Comparison with manned aircraft surveys showed marked reduction in disturbance during UAS operations.	Moreland et al. (2015)
Phocids	Ice seals: bearded seal (*Erignathus barbatus*); ribbon seal (*Histriophoca fasciata*); ringed seal (*Pusa hispida*); spotted seal (*Phoca largha*);	FW	ScanEagle (fuel powered)	~90–300 m	UAS was small, relatively quiet, and did not seem to disturb the seals as much as a manned vehicle.	NMFS (2009); Mulaca et al. (2011)

[a]Additional information regarding lateral distance thresholds for behavioral reactions are included in Pomeroy et al. (2015), but were not included in this table as it was the only reference to do so.

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research are not as well documented as FW systems (e.g., Koski et al. 2009; Hodgson et al. 2013). However, the growing availability of off-the-shelf technology has facilitated numerous research efforts (Table 1). Generally, the hovering capability and system design of VTOLs provides a unique and effective vertical platform for aerial photography and videography, thus facilitating great potential for counting species for population assessments (Hodgson et al. 2013), conducting photogrammetric studies and determining body condition (Hunt et al. 2013; Durban et al. 2015; Goebel et al. 2015), and developing remote means for collecting biological samples, such as breath exhalate to monitor disease (e.g., Acevedo-Whitehouse et al. 2010). Future applications already in place with other marine species may be expanded to include outfitting UAS with payload components, such as telemetry devices, which could be remotely deployed on animals to assist with tracking individuals (Jensen et al. 2014). Employing UAS in this manner may likely mitigate the need for close approaches by vessels, thereby reducing impacts of vessel-based systems (Stark et al. 2003; M. Moore, pers. comm., 20 March, 2015).

Fixed-wing (FW) systems

FW systems are generally much larger in size (with wingspans up to 3 m), sometimes requiring a runway for launch and landing or retrieval. However, once airborne, FW UAS require very little control from the operator because of integrated autopilot capabilities, which enable the FW UAS to fly between predetermined waypoints. Likewise, altimeters as part of the payload enable geofencing to maintain the UAS at specific altitudes (Hardin and Jensen 2011). FW UAS generally travel at higher altitudes and at faster speeds than VTOL systems, although slower speeds are usually necessary to ensure that measurements are accurate (e.g., clear images from vertically placed cameras). Finally, these systems can range hundreds of kilometres from the launch site, often beyond the visual line-of-sight of the UAS operator, making it an ideal platform for use in remote locations that may be unsafe or inaccessible for observers aboard manned aircraft surveys (NMML 2008; Koski et al. 2010). However, geographic locations for beyond-line-of-sight UAS operations may be limited due to currently proposed FAA regulations and, outside of designated testing ranges, are only permitted within certain Arctic areas (FAA 2012). Overall, the capabilities of FW UAS make this platform suitable for many of the same marine mammal applications as that of VTOLs, with the exception of research that would require a low-altitude, fixed position, such as breath sampling.

Known effects of UAS on marine mammals

Despite the increasing use of UAS in marine mammal research, relatively few studies have systematically documented their effects on various species of marine mammals (Table 1). However, two main effects of disturbance were identified, regardless of platform or target species: disturbance from noise versus visual cues from the UAS (or its shadow). In many of the cases where information is available, it is largely anecdotal with cursory observations briefly mentioned within the context of other (i.e., non UAS impact-focused) research. Most of the relevant research reviewed in this paper tested the utility of UAS as a research platform for data collection (e.g., Koski et al. 2009, 2013; Perryman et al. 2014), and have therefore not collected primary, empirical data on the behavioral responses of marine mammals to UAS. As a result, the current literature is biased towards reporting observed behavioral responses, as opposed to situations in which no behavioral response was observed. Thus, little is known empirically about the responses of individual marine mammals or populations or species as a whole to the presence or absence of UAS.

Based on the existing information, it appears that flight altitude is an important factor. However, there is no conclusive information to distinguish between disturbance from noise versus disturbance by visual cues from the UAS or its shadow as a function of altitude. Many researchers reported that UAS elicited fewer disturbance and avoidance behaviors than would a traditional manned aerial survey (Sleno and Mansfield 1978; Acevedo-Whitehouse et al. 2010; Mulaca et al. 2011; Moreland et al. 2015), likely because noise levels were far less than those observed from manned aircraft and are often diminished by ambient noise levels from various environmental factors (Jones et al. 2006; van Polanen Petel et al. 2006; NMFS 2008, 2014; Hodgson et al. 2013; Goebel et al. 2015; Pomeroy et al. 2015). For example, two types of VTOL systems (the APH-22 hexacopter and Aeryon Scout quadcopter) were measurably quieter at altitudes greater than 23 m than the traditional manned aerial survey platform (Twin Otter) at an altitude of ~200 m (700 ft) (NMFS 2014). Additionally, these two systems at lower altitudes (<23 m) were found to be even quieter than ambient sound levels of coastal sampling sites. The Puma AE (a FW UAS) was found to be even quieter than either of the two VTOL systems (NMFS 2014). It should be reiterated, however, that ambient environmental conditions factor largely in determining acoustic effects.

VTOLs that hover at low heights over animals during research (e.g., for breath sampling of cetaceans) may generate more noise and should be monitored for behavioral reactions; however, this did not appear to be the case during breath sampling of several species of large whales (Acevedo-Whitehouse et al. 2010). In general, cetaceans and sirenians do not appear to be acoustically disturbed by UAS, which can be attributed to the loss of acoustic energy at the air–water interface. Minimal, or no, disturbance was documented at ~150 m for beluga whales (Sleno and Mansfield 1978), 13 m for blue, gray, humpback, and sperm whales (Acevedo-Whitehouse et al. 2010), and ~30 m for killer whales (Durban et al. 2015). Florida manatees did not seem to be disturbed by the noise of FW UAS flying near 100 m (Jones et al. 2006), and researchers believe that dugongs and other marine fauna would not be disturbed by the noise of a FW UAS flying ~300 m (1000 ft) above the water (Hodgson et al. 2013).

Indeed, as altitude decreases, the triggers for behavioral responses most likely shift from purely acoustic modalities to acoustic and visual ones. Cetaceans, in general, may be more sensitive to behavioral disturbance the lower a UAS is operated. For example, bottlenose dolphins (*Tursiops truncatus*) have been observed chasing the shadows of a VTOL operated at ~20 m (R. Cassof, pers. comm., 29 October, 2014). Conversely, dolphins from the same population were shown to sporadically, yet briefly (<10 s), avoid shadows cast from a tethered airship that hovered over focal animals; however, the altitude of the airship during this encounter was not reported (Nowacek et al. 2001).

In this respect, marine mammals that spend considerable time on land, such as pinnipeds, may be especially sensitive to both visual and acoustic cues of the UAS, and thus, more prone to disturbance than cetaceans or sirenians. As a frame of references, the silhouettes of an APH-22 (VTOL UAS) at 6 m, an eagle at 23 m, and a Puma AE (FW UAS) at 33 m are identical in size to the silhouette of a manned Twin Otter aircraft at ~200 m altitude (NMFS 2014). These types of visual cues can trigger multiple behavioral responses. For example, the hovering behavior of a VTOL resembles known predators (e.g., bald eagles) and may elicit flushing behavior as observed in harbor seals (Olson 2013). However, even in this case, behavioral responses to avian predators were shown to vary based on the level of habituation to human disturbance at each haulout site (see also Pomeroy et al. 2015).

Multiple pinniped species have been observed flushing into the water as a result of very low-level UAS overflights (Fritz 2012). For species that haul out in large congregations at rookeries (such as otariids), a flushing event can quickly escalate into a stampede, which has resulted in serious injuries or mortalities in the past (Wilson et al. 2012). On the other hand, other species may not react at all. Northern fur, Weddel, and leopard seals did not appear to be disturbed by FW UAS flying at least 23 m above them (Goebel et al. 2015). However, gray seals showed responses (heads-up) with an altitude as low as 50 m for one system (the Vulcan 8) and movement towards the water when the UAS was at this same altitude above the haulout (Pomeroy et al. 2015; Table 3). Based upon observations during manned aerial surveys (including large, low-flying aircraft systems), Hawaiian monk seals very rarely react to aircraft and when they do, typically just raise their heads momentarily (NMFS 2014). As such, managers must be aware that a “one-size-fits-all” disturbance threshold from UAS impacts may not be applicable to all species. Factors that need to be considered for determining accurate thresholds of behavioral disturbance due to UAS include the type of device used, its capabilities, and the situational circumstances of the research, such as the species, habituation levels, and behavioral context observed during the flight.

These studies imply a general lack of marine mammal response to UAS presence when the aircraft are operated above a certain altitude (despite the bias towards over-reporting disturbances in studies not focused on assessing behavior responses). However, caution should continue to be used when operating the aircraft at any altitude, because important details about the nature of the exposure are opportunistic, given that these data were leveraged from research activities not intended for studying or eliciting behavioral responses. Finally, it is important to note that in addition to the limited published studies on UAS impacts to marine mammals, there is significant anecdotal information about their response to UAS operations in the form of personal communications, blogs, photographs, and videos (e.g., on YouTube). However, due to the recreational or commercial nature of how such information was obtained, any interpretation of behavioral responses from anecdotal sources should be treated with caution.

UAS impacts on other wildlife species

To facilitate effective reporting of marine mammal behavioral responses to UAS operations, we present three case studies of UAS research involving other taxa, where the potential impacts were documented and critically analyzed to address issues of concern. Our hope is that these case studies will provide a basic foundation for researchers establishing novel methods that are scientifically robust, and that they will also provide others with potential scenarios in which the use of UAS is appropriate. We highlight these studies as examples of methodologies that would be useful to systematically assess UAS impacts on marine mammals.

UAS impacts on waterfowl

As mentioned earlier, potential stressors, such as the size, shape, or noise of a UAS may be more or less significant under different circumstances. Proximity and color are additional factors that need to be considered, and Vas et al. (2015) designed a study to specifically address them. The authors varied the color as well as speed and angle of approach of a UAS to test the impact these characteristics had on the behavioral responses of mallards, flamingos, and common greenshanks. Over the course of hundreds of trials, the authors identified some characteristics as being significant in leading to a behavioral response, while others elicited no response. Specifically, they found that while UAS color and approach frequency had no impact on bird response, the birds responded strongly to the vertical approach angle. The authors took one additional step to explain why some factors seemed to be impactful; in this case, the birds may be interpreting the vertical approach as a raptor attack. The authors recommend launching UAS from a safe distance away from wildlife and adjusting the approach distance according to the species. Such an approach certainly establishes circumstances for when and how to use UAS technology in studying these specific species consistent with robust scientific methods, but it also aids in establishing biological rationales for managers to understand how UAS usage may cause disturbance to some marine mammal species (i.e., those that may expect a predator approach from above), and develop appropriate mitigation measures to minimize impacts on some species. This is further supported by the findings of Pomeroy et al. (2015), who determined lateral distance thresholds of disturbance for gray seals at various haulout sites.

UAS impacts on birds of prey

The method of assessing impacts in an experimental situation is important in accurately determining their significance. Grubb and Bowerman (1997) used a classification and regression tree (CART) analysis of several thousand observations of various airborne platforms on multiple populations of a single species (bald eagles), which is known to be particularly sensitive to behavioral disturbance, displacement, and reproductive failure when approached by aircraft. Although this study did not involve UAS specifically, the analytical approach to assessing impacts can be robustly applied to varied UAS types and characteristics, as well as different biological categories of individuals exposed (e.g., response severity, baseline behavioral state, reproductive or age status, social context, previous exposure, etc., and combinations thereof). The analysis can also estimate the frequency of responses expected based upon specific factors (e.g., distance of the exposed individual from the stressor), which is important for managers to know when determining the status of an activity (e.g., go/no-go scenarios). We believe the CART approach can be successfully applied to evaluate marine species research using UAS; it can supplement other approaches. The CART analyzes robustness of the UAS methods, helps identify or allay concerns about the impact of the research, and enhances productivity of research programs.

Multi-taxa studies

Although dedicated experiments addressing the impact of UAS on a single target species are valuable, they are not always practical given time, staff, space, or funding limitations in field studies of marine protected species. Given these practical considerations, finding cost-effective methods to collect, analyze, and report conclusions on the impacts of UAS methods on marine mammal species is critical to regulating UAS use in the vicinity of marine mammals. Studies reported in Vermeulen et al. (2013) provide an example of how data collected for one purpose can also benefit non-target species. The authors, while questioning the feasibility of UAS technology to the study of elephants, simultaneously assessed the potential for UAS disturbance to non-target species by using ground observers to corroborate all animal reactions as documented by the images captured by the UAS. However, given that the UAS transects were designed for detecting elephants, not all non-target species were detected in the images. Although not as informative as dedicated studies, the potential for concurrent disturbance assessments of multiple species can cumulatively lead to a better understanding of how different methodologies can benefit other species by answering questions that may not otherwise attract the necessary funding or attention.

Discussion

Unmanned aircraft systems can offer an effective method for scientific researchers, emergency responders, and law enforcement officials to collect data that supports the conservation and recovery of marine mammals or other protected species (Hood et al. 2010). In addition, they can potentially provide the public with a unique way to view and appreciate wildlife in ways that would not be possible otherwise. Despite these benefits, UAS also have the potential to be highly disruptive to wildlife if they are not used in a safe and responsible manner. Wildlife managers and researchers are becoming increasingly aware that either acute or chronic disturbances of wildlife can significantly impact individual, population, and species health and fitness by disrupting migratory patterns, breeding, feeding, and sheltering (Fair and Becker 2000). Caution must also be taken given that the lack of an observed behavioral response does not indicate a lack of impact. For example, black bears were found to increase their heart rates (a stress response) when small UAS (VTOLs) were hovering above. It is possible that other species, including marine mammals, exhibit the same physiological response.

As the scientific community continues to assess the impacts of UAS on marine mammals and other species of wildlife and to address the dearth of information available on this subject, we encourage researchers and members of the public to be conscious of the potentially negative effects that these systems can have on wildlife and to take a precautionary stance on using UAS around animals to avoid harassment or injury (NMFS 2015).

Data gaps

To some degree, the current lack of research focused on investigating the effects of UAS on marine mammals and other species is the natural result of an innovative technology that is evolving faster than regulatory authorities can develop a new management framework (Watts et al. 2012; Ditmer et al. 2015). From a research perspective, investigating the effects of UAS on marine mammals is paradoxically challenging because obtaining the necessary permits requires submitting an application that includes information on known disturbance thresholds — the very data being sought in the proposed study. UAS also pose management challenges because they require that researchers navigate multiple jurisdictions to obtain all of the necessary permits and certifications (Rango and Laliberte 2010; Watts et al. 2012).

A review of the relevant literature has revealed limited research and analysis to date on the impacts of UAS on marine mammals. The majority of recent projects have focused on evaluating the methodological application of UAS in studies on population demographics (Hodgson et al. 2013; Sweeney 2014) and health and fitness (Durban et al. 2015; Goebel et al. 2015). In only a handful of instances — often in studies of the use of UAS as deterrents for so-called nuisance species (Grimm et al. 2012) — have researchers explicitly monitored behavioral responses. Moreover, increasing anecdotal evidence demonstrates that UAS have the potential to disturb marine mammals and other wildlife species if not used responsibly. Because these data take the form of personal accounts, blogs, photographs, and videos posted by the general public, the evidence is not robust enough to provide a sound basis for taking management actions. However, they certainly provide enough evidence to highlight both our concern about misuse of UAS by the public and uncertainty regarding impacts on marine mammals, and thereby further demonstrate the need for scientific and empirical research to inform management.

Additionally, the rapid advancement of technology must also be considered when referencing behavioral responses documented in earlier literature, which may provide limited data. In many cases, previous generation technologies incorporating GPS and altitude sensors were not nearly as accurate as technologies have become in recent years, reducing the confidence in older data. Likewise, the information collected from studies using older UAS models can often be considered obsolete because of the rapid technological evolution that may disallow certain data comparisons. Finally, historic studies of target species or populations may not be accurate proxies for assessing present-day impacts. For example, the Arctic has experienced environmental shifts attributed to climate change and an increase in anthropogenic activities, such as shipping and oil and gas exploration. As a result, the cumulative effects over time may lead to changes in how individual animals perceive and respond to potential novel stressors (like UAS) in their environment.

In addition to an overall lack of directed studies by researchers on the effects of UAS on marine mammals, an omission from the literature is the consideration of multiple stressors and related impacts from multiple UAS devices targeting animals, or UAS being used concurrently with other activities that may impact wildlife. Much in the same manner that researchers will regularly place multiple tags (e.g., suction cup, implantable, etc.) on a single whale, it is not unreasonable to consider multiple UAS targeting a single individual or group of individuals. This is particularly relevant as recreational UAS operators are not required to have pilot certifications, have vague guidelines in place for responsible use, and are increasingly targeting marine mammals. The combination of these factors make a potentially injurious interaction inevitable between a UAS and marine mammal; as evidenced by systems being crashed regularly into ecologically important areas or animals being chased by aircraft (Morley 2013; Prettyman 2013; Berwyn 2014; Palermo 2014; Kelly 2015). This risk dramatically increases with multiple UAS platforms being operated remotely and within a small airspace. Even well-managed research activities are not exempt from UAS malfunctions; for example, the engine of a remote airplane failed while on autopilot directly above a manatee wintering site and crashed into Tampa Bay (Jones 2003).

As a result, we have two main recommendations for the marine mammal scientific research community:

1. Evaluate the behavioral responses of different taxa exposed to different types of unmanned aircraft at various altitudes. Information about distance thresholds at which visual or acoustic impacts (with reference to measures of received sound levels) elicit behavioral responses is especially warranted.
2. Evaluate various factors that could elicit or modulate behavioral response by marine mammals, such as (*i*) acoustic features of the study area (ambient masking noise levels, blocking visual elements, such as cliffs and trees); (*ii*) species and age class of study animals; (*iii*) behavioral state of study animals; (*iv*) presence and type of other nearby anthropogenic activities; (*v*) UAS acoustic and visual properties (size, number of engines, sound output magnitude and frequency characteristics); and (*vi*) UAS approach angle (vertical, acute, horizontal), speed, and number of experimental presentations.

Such information will enable NMFS and other federal or state agencies to develop appropriate and useful guidance or regulations to manage the use of UAS near protected species.

Future development of appropriate policies, guidelines, or regulations

UAS user groups are evolving and now include scientific researchers, emergency responders, law enforcement officials, and recreational hobbyists, so it will be necessary to develop appropriate standards of conduct for each because their purposes, needs, and legal authorities to approach marine mammals are vastly different. Currently for scientific researchers in the United States, the FAA requires special airworthiness certificates, operator certifications, and other authorizations, while NMFS requires permits for work conducted on species protected by the MMPA and ESA. The general public (e.g., hobbyists) are not eligible for permits to closely approach marine mammals and therefore are expected to adhere to existing guidelines to avoid disturbing (i.e., "harassing") marine mammals[2].

In February 2015, the FAA published a proposed rule (FAA 2015: 80 FR 9543) that is intended to provide some of the regulatory clarity sought by the public about UAS usage. The proposed rule presents a potential new regulatory framework for the commercial use of UAS in certain situations, which would apply to research activities and businesses (e.g., tourism), but not hobbyists. The rule proposes operators obtain certification, keep aircraft within visual line-of-sight, stay well clear of airports, and fly at speeds less than 100 miles per hour and below 500 ft. While this rule only addresses certain types of uses, the FAA has been clear that it is only the first in a series of potential regulations or policies that will build upon each other to establish a comprehensive management framework for UAS use (FAA 2015: 80 FR 9543).

Several wildlife conservation agencies are also in the process of evaluating the needs for additional guidance regarding UAS operations near wild animals by the diverse suite of user groups. NMFS is specifically evaluating the needs unique to marine mammals and plans to provide information in the near future on best practices for UAS operations near cetaceans and pinnipeds to help scientific researchers, emergency responders, law enforcement officials, and hobbyists minimize their potential impacts on the animals.

Conclusion

There are numerous factors that make it difficult for government agencies and scientific researchers to evaluate the potential impacts of UAS usage near marine mammals. Information is needed to help address this challenge, and researchers can assist by collecting, analyzing, and disseminating data about UAS impacts to provide the foundation for sound management strategies, and help agencies realize the full potential of UAS to assist efforts to protect and conserve living marine resources.

[2]Under the MMPA, Section 3(16 U.S.C. 1362), it is illegal to "harass" marine mammals in U.S. waters. The MMPA defines the term "harassment" as: "any act of pursuit, torment, or annoyance which – (1) has the potential to injure a marine mammal or marine mammal stock in the wild, (Level A harassment), or (2) has the potential to disturb a marine mammal or marine mammal stock in the wild by causing disruption of behavioral patterns, including, but not limited to, migration, breathing, nursing, breeding, feeding, or sheltering (Level B harassment)." The ESA provides additional protections to species that are listed as threatened or endangered.

Thus, accurately and scientifically reporting behavioral responses to UAS within an empirical context (i.e., publishing in peer-reviewed journals) is important to better inform the scientific community, regulators, and hobbyists about potential effects, as well as assist with the development of appropriate mitigation measures.

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