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Evaluating changes in horse behavior as a response to small unmanned aerial vehicles

By Ryan G. Howell, Kaylee Draughon, Haley Johnston, Melissa Myrick, Val J. Anderson, Dennis L. Eggett and Steven L. Petersen

On the Ground

- The application of small unmanned aerial systems (sUAS) has expanded to include livestock management, however the effects of sUAS disturbance on domestic horses (*Equus calibus*) has not been well documented.
- We developed an ethogram to classify and record horse behaviors and changes in response to disturbance using a DJI Phantom 4 Pro sUAS by monitoring horse behavior at 5 second intervals from 3 m, 15 m, and 33 m above ground level (AGL).
- We found vigilance was the most common behavior after initial approach at all AGLs.
- Horses took evasive measures after approximately 20 seconds at lower AGL (i.e., <3 m).
- The recovery to the control behavior occurred sooner at higher AGLs and most horses recovered within 60 seconds.
- sUAS could be a valuable tool in horse management, including their potential use during domestic and free-roaming horse roundups.

Keywords: sUAS, drone, stimuli response, horse.

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Introduction

Small unmanned aerial systems (sUAS) are used in human societies to support a wide array of applications including, but not limited to, cadastral surveys, real estate estimates, mining operations, agriculture, military applications, emergency response, healthcare, recreation, and entertainment.[1-3] With relatively low costs and rising accessibility, sUAS incorporate the use of pilots, unmanned aircraft (commonly called "drones"), and sensors to meet human demands and opportunities with overwhelming capabilities.[4] Over the past decade, sUAS have also become an invaluable resource in remote sensing of the environment, for assessing ecological dynamics, to create conservation plans, for land monitoring and assessment, and in livestock and wildlife management.[5,6]

Various facets of wildlife research and livestock management throughout the world have benefited from the use of sUAS.[7] Examples include animal point-count surveys,[7,8] habitat analysis and monitoring,[9,10] and deterrence of animals from places of human/wildlife conflict.[11] Use of sUAS in farming and ranching is also becoming a common practice.[12] Research has attempted to quantify both behavioral responses[13-16] and physiological responses[17] of wildlife to drones. According to Ditmer et al.,[18] wildlife often respond to aircraft or other airborne vehicles with increased vigilance, aggression, or avoidance. They found in many cases wildlife would quickly become tolerant to these disturbances unless the vehicle remained close.[19] Similar studies have shown both terrestrial (mammals, reptiles) and aerial (birds, insects) species respond to drones with modified behavior.[20] Additionally, this behavioral response may be directly altered by differences in flight patterns such as flight height or distance from the animal.[21] For example, McIntosh et al.[22] found that fur seals exhibited little response to drones when flying overhead at 80 m, but exhibited an alarm response when flights were decreased to 60 m or lower.

Humans domesticated horses (*Equus calibus*) in Eurasia in approximately 3500 B.C.[23] Although domestication created a higher tolerance in horses to humans and human-related stimuli, horses have remained wary of external stimuli that approximate perceived threats such as predation.[24,25] Subsequently, drones may trigger a flight response in horses that would resemble similar assumed threats from predators that has been documented in other species of wildlife.[20,23] These perceived threats could create freeze and flight responses and

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Figure 1. Phantom 4 Pro drone used to detect horse responses to drones.

potentially a platform for herding animals with nontraditional methods.

The use of drones for managing livestock is intriguing to ranchers and farmers, however, data is limited on the efficacy and efficiency of using drone technology to accomplish animal management objectives.[26] Maeda et al.[27] was able to evaluate herd hierarchical structure in feral horses using drones, mentioning that behavioral response were at times influenced by drone interference. Inoue et al.[28] assessed the spatial positioning and social network dynamics of feral horses using drones and identified behavioral responses of horses to drones. Although horse studies provide important insight into the ecology and management of horses, the specific behavioral responses that are triggered by drones is poorly understood. The purpose of this research is to quantify horse behavior in response to drones, with consideration of horse group size and drone flight altitude. We believe this information can be used to inform private livestock managers and public agencies that manage horse populations about potential uses of drones.

Methods

Small unmanned aerial system description

We employed a DJI (Shenzhen, China) Phantom 4 Pro quadcopter (Fig. 1) to monitor horse behavioral responses to the presence of drones. The Phantom 4 Pro has a maximum flight time of 28 minutes, which was sufficient to collect behavior responses of drone-horse interactions. The flight speed ranged between 8 and 16 km/hour (5-10 miles/hour), and the Phantom 4 Pro's maximum speed is 20 m/second (65.6 feet/second). The Phantom 4 Pro has a diagonal length of 350 mm (13.8 inches) with a 1,380 g (3 lb) takeoff weight and can operate in temperatures between 0°C and 40°C (32-104°F). Imagery used to assess horse behavior was collected with the on-board camera which shoots 4k 60 frames/second video, and 14 frames/second burst mode still photographs with 20-megapixel effective pixel size.

Study site and drone video data collection

The data was collected on private lands located in central Utah, with permissions received from land and horse owners to conduct this study. During each flight we measured horse behavior from individual horses and horse groups ranging in size from 1 to 10 individuals. During each data collection period, the drone was launched from over 200 m (656 feet) distance or from a position where horses could not observe the drone and remote pilot. These precautions were implemented to prevent the pilot and viewers from interacting with horses and potentially influencing their behavior throughout the sample period. When possible, observers would hide behind structures to prevent distracting horses. Preflight behaviors were collected by observers on the ground before launching the drone. This consisted of observing horses using binoculars and spotting scopes to minimize the potential of being seen and influencing horse responses.

Ground-based observations were also coupled with behaviors detected using video footage from the drone during the flight. The specification of the camera used to capture video included a 1-inch CMOS, effective pixel 20-megapixel sensor with a maximum video recording resolution of 4K 60 frames/second. The Phantom 4 Pro camera was directed to the experimental horses immediately after takeoff and continued to be directed at the study horse(s) through initial approach and all subsequent observation periods. We recorded horse behavior using predefined categories (walking, trotting, grazing, laying down, standing, and vigilance). Our efforts to acquire high resolution video imagery and recording ground-based observations were intended to work together in reducing error and bias when identifying horse behavioral response to drones

We monitored horse behaviors during the entire flight, searching for any obvious change in behavior and recording that change. The behavior horses exhibited before the launch of the drone was designated as the "control" behavior. Horse behavioral responses that occurred as the drone approached and was initially detected by the study horses was designated the "initial" response. As the drone reached approximately overhead, their behavior was recorded as the "arrival" response. After arrival, the drone was maintained as close to nadir to the study horse as possible by the drone pilot. We continued to measure horse behavior in subsequent 5-second intervals for 60 seconds. At the completion of the sample period, the drone was returned directly to the launch site at the same latitude as the last sample collected. Each flight targeted a single horse or group and remained over that group until the sampling period was complete. We only flew to a second group if they were distant enough to not detect the drone fight during the first flight sampling period. The drone was piloted by a Federal Aviation Administration (FAA) Part 107 certified remote pilot accompanied by a visual observer who helped maintain visual contact with the drone throughout each flight.

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Table 1
Summary of behaviors included in the ethogram used to assess horse behavior in response to drones

Horse Behavior	Behavior Description
Standing	Standing up, not moving
Laying down	Not in motion, laying on the ground
Grazing	Actively feeding
At Ease	Combined behaviors that occur when drones are absent
Vigilance	Actively monitoring, with rigid body posture and ears pointed forward
Walk	Slowly moving (either undisturbed or drone triggered flee)
Trot	Moving quickly (flee)
Gallop	Increased speed, all four legs off the ground at the same time (flee)
Evasive	Combined

Note: Behaviors were adapted from horse ethograms developed by Attman [22] and Ransom.[23]

Equus calibus ethogram and horse behavior data collection

We constructed an ethogram of potential horse behaviors using established criteria from previous studies.[29,30] During each flight we documented behavioral responses from each individual horse that occurred in relation to the drone flight (Table 1). We recorded all behaviors in 5 second intervals starting at the initial approach. We related these responses to the control behavior. In most cases, control behaviors (referred to generally as "at ease") were dominated by grazing, laying down, and standing while noncontrol were often characterized by vigilance and movement (referred to generally as "alarmed"). During each flight, we approached horse individuals or groups from one of three levels: 3 m, 15 m, and 33 m (9.8 feet, 49 feet, and 108 feet) above ground level (AGL).

Statistical analysis

We used chi-square analyses to identify whether horse behavior had changed between each time interval. The two variables used in the analyses were AGL of the drone (3 m, 15 m, and 33 m) and whether individual horses changed activities in response to the flight. We did not analyze differences in behavioral response due to the limited sample size when separating behaviors into specific activity type. With a low sample size, we selected an alpha of <0.1 as a measure of statistical significance. All analyses were conducted using SAS, version 9.4.

Results

Horses shifted behavior from an at-ease condition to an alarmed or evasive response (primarily vigilance) once they detected our drone (P = 0.075; Table 2). Grazing was the most common at ease behavior, however, once the drone approached, grazing declined sharply, replaced primarily by vigilance followed by walking (flee). No animals were ob-

Table 2
Comparison of horse response to drones at 3 m, 15 m, and 33 m in altitude during drone sampling periods, ranging from precontact (control) to 20 seconds after arrival overhead

	Drone Sampling Period											
	Control vs.	Initial Contact vs.	Arrival vs.	1-5 sec vs.	5-10 sec vs.	10-15 sec vs.						
		Initial Contact	Arrival	1-5 sec		5-10 sec				10-15 sec	15-20 sec	
	Change	No Change	Change	No Change	Change	No Change	Change	No Change	Change	No Change	Change	No Change
Height	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N(%)	N(%)
3 m	15 (88.2)	2 (11.8)	3 (17.7)	14 (82.3)	3 (17.7)	14 (82.3)	2 (11.8)	15 (88.2)	1 (5.9)	16 (94.1)	0 (0.0)	17 (100.0)
15m	11 (73.3)	4 (26.7)	2 (13.3)	13 (86.7)	1 (8.3)	11 (91.7)	0 (0.0)	8 (100.0)	7 (50.0)	7 (50.0)	0 (0.0)	13 (100.0)
33m	6 (50.0)	6 (50.0)	5 (41.7)	7 (58.3)	0 (0.0)	12 (100.0)	0 (0.0)	12 (100.0)	0 (0.0)	12 (100.0)	0 (0.0)	12 (100.0)
p-value	0.075	0.118	0.283	0.288	0.001	0.772						

Note: These data represent the initial contact only. The P value signifies a difference between change and no change in each sampling period where $\alpha < 0.1$. Variables being compared are the change in at-ease behaviors (grazing, laying down, standing, and nondrone associated walking) and alarmed behaviors (vigilance, trot, gallop, and drone-provoked walking).

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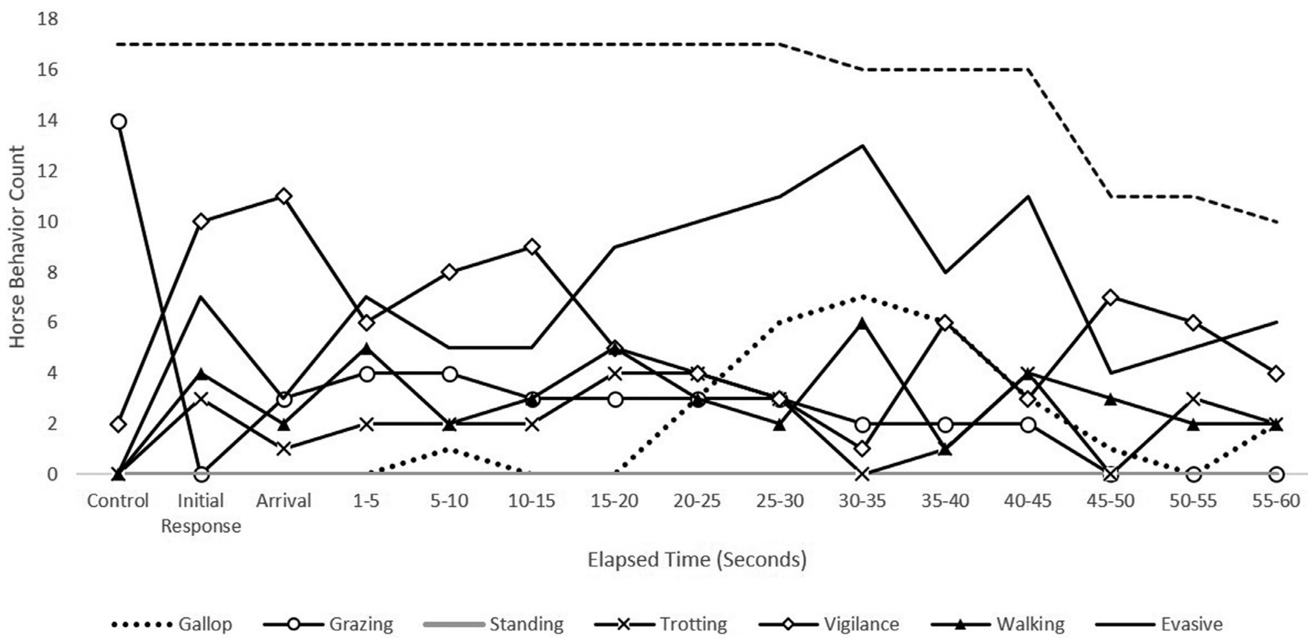

Figure 2. Count of individual horses that exhibited measured responses to drone disturbance over time at a 3 m approach. Individuals exhibiting gallop, trotting, or walking behaviors were also combined into an "Evasive" category. Total individuals monitored at the specified time is also indicated by a black dashed line.

served grazing after 50 seconds and did not return to grazing throughout the duration of the observation period. We observed more behavior changes when comparing the control period to all sample intervals than the comparison between the arrival period and those same sample intervals (Table 2). The percentage of horses that displayed altered behaviors was greatest for horses approached at low flight levels, which was particularly evident at 3 m and 15 m altitudes, where 88.2% (n = 15) and 73.3% (n = 11) of the horses changed from at-ease to an alarmed state, respectively. At 3 m AGL we observed a high level of vigilance (58.8%) or evasive behaviors (41.2%) occurring as the initial response compared with the control (11.8% and 0.0%, respectively). These behaviors remained high and continued throughout the assessment period (Fig. 2). The lowest occurring response was a gallop, with only two horses (5.2%) shifting to this behavior when the drone arrived overhead. At 15 m AGL, the horses initially shifted from at-ease behaviors to alarmed behaviors upon the drone's approach (initial response), primarily with vigilance and evasive behavior up to 35 seconds (Fig. 3). No horses shifted into a trot or gallop during the sample period at 15 m or 33 m. Only half of the horses responded with a change in behavior when the drone approached at 33 m AGL (Fig. 4).

Considering the change in horse behaviors between sample periods, we found that horses either shifted their behavior from an at-ease condition to an alarmed response ($P < 0.003$) or experienced no change across all flight levels (Table 3). No horses transitioned from an alarmed state to at-ease during initial contact. We consistently recorded the highest number of behavior change counts at 3 m and 15 m than at 33 m. This pattern continued when comparing the initial response of horses with horse behavior at each of the arrival times and each subsequent interval. Between the control and initial arrival at 3 m altitude, horses that changed their behavior (n = 15, 88.2%) shifted from at-ease behaviors including grazing (n = 14, 93%) or laying down (n = 1, 7%) to alarmed and evasive behaviors that include vigilance (n = 8, 53%), walking (n = 4, 26.7%), or trotting (n = 3, 20%; Table 3, Fig. 2). At 15 m, a similar response was observed, where most horses (75%) changed behaviors from grazing (n = 6, 50%), standing (n = 3, 25%), or being alert (calm vigilance; n = 3, 25%) to becoming vigilant and alarmed (n = 6, 50%) or evading the drone by walking or trotting (n = 4, 33%; Table 3, Fig. 3.). In comparison, at 33 m only half of the horses responded with a behavior change to the drone flight, shifting from grazing (n = 3, 50%) or unalarmed walking (n = 3, 50%) to alarmed vigilance (n = 3, 50%) or evasive walking and trotting (n = 3, 50%; Table 3; Fig. 4.).

Discussion

Our results indicate horses respond to drones with altered behavior starting at the initial time of arrival and extending >60 seconds in duration. In comparison to our control group, horses modified their behavior from a relaxed state into an alarmed response, which was demonstrated by increased vigilance and eventual flight. Horses shifted from standing, grazing, and initially vigilant behavior into walking, trotting, and galloping, particularly when the drone was operating at the lower AGL (3 m). Horses responded to drones upon initial approach, which is a behavior observed in large ungulates.[30] Our research suggests individual horses will primarily display vigilant behavior in response to drones rather than immedi-

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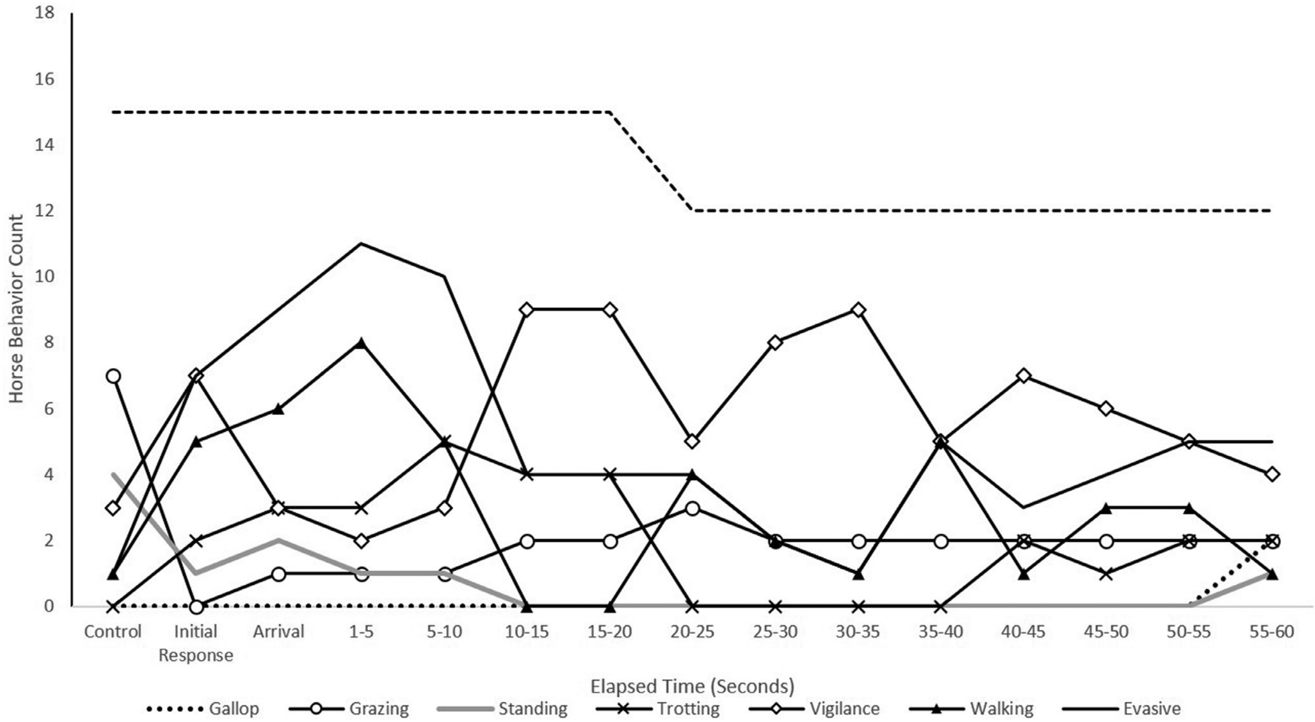

Figure 3. Count of individual horses that exhibited measured responses to drone disturbance over time at a 15 m approach. Individuals exhibiting gallop, trotting, or walking behaviors were also combined into an "Evasive" category. Total individuals monitored at the specified time is also indicated by a black dashed line.

Figure 4. Count of individual horses that exhibited measured responses to drone disturbance over time at a 33 m approach. Evasive is represented by walking only at 33 m AGL. Total individuals monitored at the specified time is indicated by a black dashed line.

ately evade the drone. Additionally, grazing behavior ceased as the drone approached suggesting that foraging and diet can be affected by drones.

Horse behaviors exhibited during the time between initial approach and the arrival of the drone to an overhead position were similar for all three flight altitudes ($P = 0.178$; Table 1). However, when comparing the number of horses that changed behaviors between initial approach and arrival of the drone overhead to those that maintained the same behavior, most (82.4%, 86.7, and 58.3%) continued in the alarmed or evad-

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Table 3
Comparison in the change or lack of change in horse responses to drones flying during 6 sampling periods, ranging from control to the 15- to 20-second interval post initial contact

Sample Period	Height	Response of horses to drones: Change from at-ease to alarmed	No change in at-ease condition	Change from alarmed to at-ease	No change in alarmed condition	*p*-value
Control to Initial Contact	3m	N=15 (88.2%)	N=0 (0.0%)	N=0 (0.0%)	N=2 (11.8%)	0.003
	15m	11 (73.3%)	1 (6.7%)	0 (0.0%)	3 (20.0%)	
	33m	6 (50.0%)	6 (50.0%)	0 (0.0%)	0 (0.0%)	
Initial contact to arrival	3m	0 (0.0%)	0 (0.0%)	3 (17.6%)	14 (82.4%)	0.007
	15m	0 (0.0%)	1 (6.7%)	2 (13.3%)	12 (80.0%)	
	33m	5 (41.7%)	1 (8.3%)	0 (0.0%)	6 (50.0%)	
Arrival to 1-5 seconds	3m	1 (5.9%)	2 (11.8%)	2 (11.8%)	12 (70.6%)	0.641
	15m	1 (8.3%)	1 (8.3%)	0 (0.0%)	10 (83.3%)	
	33m	0 (0.0%)	1 (8.3%)	0 (0.0%)	11 (91.7%)	
1-5 seconds to 5-10 seconds	3m	1 (5.9%)	3 (17.6%)	1 (5.9%)	12 (70.6%)	0.777
	15m	0 (0.0%)	1 (12.5%)	0 (0.0%)	7 (87.5%)	
	33m	0 (0.0%)	1 (8.3%	0 (0.0%)	11 (91.7%)	
5-10 seconds to 10-15 seconds	3m	1 (5.9%)	3 (17.6%)	0 (0.0%)	13 (76.5%)	0.016
	15m	2 (35.7%)	0 (0.0%)	2 (14.3%)	7 (50.0%)	
	33m	0 (0.0%)	1 (8.3%)	0 (0.0%)	11 (91.7%)	
10-15 seconds to 15-20 seconds	3m	0 (0.0%)	3 (17.6%)	0 (0.0%)	14 (82.4%)	0.772
	15m	0 (0.0%)	2 (15.4%)	0 (0.0%)	11 (84.6%)	
	33m	0 (0.0%)	1 (8.3%)	0 (0.0%)	11 (91.7%)	

Note: These data represent the initial contact only. The P value signifies a difference between the three heights in relation to a change or no change in horse condition when the $\alpha < 0.1$. Variables being compared are the change in at-ease behaviors (grazing, laying down, standing, and nondrone associated walking) and alarmed behaviors (vigilance, trot, gallop, and drone provoked walking).

ing behavior at all three altitudes, respectively ($P = 0.007$, Table 2). A similar pattern was observed between the overhead arrival and the subsequent sample periods (Table 1). In the first 20 seconds of the disturbance at 3 m altitude, individuals tended to decrease vigilant behavior and slightly increase slow evasive behavior, however, after 20 seconds, a larger portion of individuals began galloping to evade the drone disturbance (peak at 30-35 seconds, $n = 7$; Fig. 2.).

Recovery from an altered behavior was more rapid when drones were flying at 33 m and at 15 m to a lesser extent, indicating horses may rapidly acclimate to an incoming drone if the flight pattern is not threatening. Previous research also found negligible behavioral response to drones approaching at a high altitude and minimizing movement.[31] We found that evasive behaviors were less prevalent at 15 m and 33 m compared with 3 m AGL. Horses demonstrated a change in behavior (became more vigilant) as horizontal proximity of drone to horse increased. Inoue et al.[26] similarly found that horses demonstrated a lack of avoidance behavior (i.e., rapid, evasive moment, and panic), when drone flights exceeded 25 to 80 m (80-260 feet) in altitude. For repeat flights, our data indicated horses may acclimate to drones from repeated exposure with a delayed recovery time.

Our study provides insight into the use of drones as a tool to modify domestic horse behavior and movement patterns. This could be applicable to improved management protocols for owners of domestic horses. As commercially available drones become more prevalent, easier to fly, and less expensive, they can be more readily deployed by farmers and ranchers. One behavior we observed was a downward trend in grazing and subsequent increased tendencies toward evasive movement and vigilance demonstrated by our study horses. This may suggest that horse foraging can be impaired with drone activity, and overall heath, stress, and diet could be compromised by fear induced from drone activities and their flight patterns. Laporte et al.[32] found that livestock responded to the fear of predation (wolves) with higher stress levels, reduced reproduction, and reduced weight gain. This may be most important when fear inducing activities are prolonged or frequently repeated. Horses exhibiting high fear and stress levels when being herded, especially when prolonged, would potentially experience immediate and long-term health impacts such as impacts to their diet and elevated stress levels. Managers should consider these health impacts when conducting drone flights to manage livestock herds, including domestic and free-roaming (wild) horse herds.

Although our study has focused on domestic horses, our research could provide insights into management of free-roaming horses by federal land management agencies (i.e., Bureau of Land Management wild horse managers). In 2019, the Bureau of Land Management spent approximately $3.5 million on horse management issues.[33] Although we did not assess the use of drones to herd animals in a directional manner, our results suggest horses respond to drones, typically with movement away from the drone's position. More re-

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search is needed to determine the effects of drones on free-roaming horse movement patterns; however, our data indicate that drones can trigger behavioral responses and movement in horses, potentially offering a safer and more cost-effective method of performing free-roaming horse management practices compared with occupied aircraft.[34] These activities could include moving horses away from sensitive areas (i.e., riparian areas), facilitating contraception applications, improving monitoring efforts, and supporting roundup operations.

The advancement of drone technology, though still relatively new, has proven invaluable for countless industries. As technology and regulations continue to progress, their utility in land management (including management of domestic horses) will become more pronounced. At present, using drones in management of horses is severely hampered by the requirement to operate within the visual line of sight in the United States and elsewhere. We expect this limitation to be eased as technology allows for more confidence in the drone's ability to sense and avoid hazards and operate with increased reliability. More reliable drone technology will further unlock their potential as a management tool for domestic and free-roaming horses, as well as other livestock species.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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