Colegio de Postgraduados

Validation of the use of unmanned aerial vehicles for population assessment of the bighorn sheep (*Ovis canadensis mexicana* Shaw) in the Sonoran Desert

Lozano-Sifuentes, Ivan A.[1]; **Gastelum-Mendoza, Fernando I.**[2]; **González-Saldívar, Fernando N.**[2]; **Uvalle-Sauceda, José I.**[2]; **Cantú-Ayala, César**[2]; **Romero-Figueroa, G.**[4]; **Lozano-Cavazos, Eloy A.**[3*]

[1] Department of Rangeland, Wildlife and Fisheries Management, Texas A&M University, College Station, Texas.
[2] Universidad Autónoma de Nuevo León, Facultad de Ciencias Forestales. Linares, Nuevo León, México. C.P. 67700.
[3] Universidad Autónoma Agraria Antonio Narro. Saltillo, Coahuila, México. C.P. 25315.
[4] Universidad Autónoma de Baja California, Facultad de Ciencias. Ensenada, Baja California, México. C.P. 22860.
* Correspondence: alejandrolzn@yahoo.com

Citation: Lozano-Sifuentes, I. A., Gastelum-Mendoza, F. I., González-Saldívar, F. N., Uvalle-Sauceda, J. I., Cantú-Ayala, C. Romero-Figueroa, G., & Lozano-Cavazos, E. A. (2025). Validation of the use of unmanned aerial vehicles for population assessment of the bighorn sheep (*Ovis canadensis mexicana* Shaw) in the Sonoran Desert. *Agro Productividad*. https://doi.org/10.32854/x7gg2845

Academic Editor: Jorge Cadena Iñiguez
Associate Editor: Dra. Lucero del Mar Ruiz Posadas
Guest Editor: Daniel Alejandro Cadena Zamudio

Received: March 18, 2025.
Accepted: August 4, 2025.
Published on-line: October XX, 2025.

Agro Productividad, 18(9). September. 2025. pp: 151-161.

ABSTRACT

Objective: To evaluate the use of drones for population monitoring of the desert bighorn sheep in two Wildlife Management Units (WMUs) of the Sonoran Desert.

Design/methodology/approach: Fieldwork was conducted at El Tonuco and Chaparral Ranches, Sonora, during the summer seasons of 2020 and 2021. Direct observations of bighorn sheep were initially carried out, followed by the use of drones to record individual animals. Relative abundance was estimated according to sex and age class. To assess the effectiveness of drone usage, results were compared to those obtained through direct monitoring using the non-parametric Mann–Whitney U test, correction factor, and detectability percentage.

Results: Drone monitoring recorded 118 and 96 bighorn sheep in El Tonuco and Chaparral Ranches, respectively, representing 2.26 and 1.31 times more individuals than those detected through direct observations. Females constituted the most frequently recorded group. No significant differences were found in bighorn sheep abundance between the two monitoring techniques. At El Tonuco Ranch, the correction factor for population estimates based on direct observations, in comparison to drone data, was 62%, while at El Chaparral Ranch it was 24%. This factor varied significantly according to sex and age class ($P \leq 0.05$).

Study limitations/implications: It is recommended to complement the findings with geospatial analyses and to replicate this methodology in other key sites for the conservation of desert bighorn sheep.

Findings/conclusions: The use of drones proved to be a more efficient tool than direct transect observations for detecting bighorn sheep.

Keywords: Detectability, drone, correction factor, xerophilous scrub.

INTRODUCTION

In Mexico, three subspecies of desert bighorn sheep (*Ovis canadensis*, Artiodactyla: Bovidae) are recognized, inhabiting mountainous desert environments: *O. c. cremnobates* and *O. c. weemsi* in the Baja California Peninsula, and *O. c. mexicana* in Sonora, with reintroductions in certain mountain ranges of Chihuahua and Coahuila (Valdez & Krausman, 1999; Medellín *et al.*, 2005; McKinney & Villalobos, 2005; McKinney & Delgadillo, 2006). Due to unregulated hunting, habitat fragmentation, and disease transmission, the species is listed under Special Protection (Pr) according to NOM-059-SEMARNAT-2010 (SEMARNAT, 2019). From an ecological perspective, the desert bighorn sheep plays a key role in the structure and dynamics of plant communities by contributing to vegetation regulation in desert scrublands through grazing, which directly influences plant composition and diversity (Guerrero-Cárdenas *et al.*, 2016; Gastelum-Mendoza *et al.*, 2021, 2024). Economically, it is the most valuable game species in Mexico, with hunting prices exceeding USD 40,000 per specimen, thereby promoting its sustainable use through habitat and population management and conservation (Lee, 2011).

Effective management of desert bighorn sheep populations relies on accurate knowledge of their abundance and structure. In this regard, systematic monitoring is an indispensable tool for decision-making concerning the species' management and sustainable use, as it provides crucial information on population parameters such as abundance, age and sex structure, and harvest rate estimation (Romero-Figueroa *et al.*, 2024). Furthermore, monitoring allows for the identification of demographic trends, the detection of negative anthropogenic impacts, and the assessment of management and habitat restoration efforts (Lee & López-Saavedra, 1994; Lee, 2011; Romero-Figueroa *et al.*, 2024). The most efficient and widely used method for population monitoring of desert bighorn sheep in the Sonoran Desert is aerial helicopter surveys (Remington & Welsh, 1989; Lee & López-Saavedra, 1994). However, this method entails limitations related to high costs, complex logistics, and risks for involved personnel (Miller *et al.*, 1989). Ground-based monitoring, while safer and more cost-effective, only allows for coverage of limited areas, making it difficult to obtain representative population data (Norton-Griffiths, 1978). In this context, the use of unmanned aerial vehicles (UAVs) presents a technological tool that enhances human effort, reduces costs, and facilitates the implementation of standardized protocols for monitoring wildlife in hard-to-reach areas (Hodgson *et al.*, 2013; Martin *et al.*, 2012). This technology offers a systematic and replicable alternative for the continuous evaluation of the abundance and population structure of desert bighorn sheep, particularly in mountainous desert ecosystems where topographic and climatic conditions limit the application of traditional methods. Therefore, the aim of this study was to assess the abundance and structure of a desert bighorn sheep population in the Sonoran Desert using drone-based data, and to compare these findings with those obtained through direct observations. This analysis aims to generate valuable information for the species' management and conservation, and to support informed decision-making toward sustainable management.

MATERIALS AND METHODS

Description of the study area

The study area is located in the municipality of Hermosillo, Sonora, encompassing the ranches El Chaparral and El Tonuco, both registered as Wildlife Management Units (WMUs). El Chaparral Ranch lies 82 km northeast of Hermosillo city and covers an area of 6,515 hectares, while El Tonuco Ranch is situated 37 km in the same direction, spanning 1,560 hectares (Figure 1). According to the Köppen climate classification modified by García, the region corresponds to type BWhw(x′), characterized as very dry and semi-warm, with an average annual temperature ranging from 18 °C to 22 °C. During the coldest month, temperatures drop below 18 °C (García, 1998). The dominant vegetation type is microphyllous and sarcocaulescent desert scrub (INEGI, 2016; Figure 1). Precipitation is primarily concentrated in the summer, with a predominantly summer rainfall regime and a winter rainfall proportion ranging from 10.2% to 36% (CONAGUA, 2015). The topography of the sites varies in elevation from 0 to 1,056 meters above sea level. Slopes also differ according to terrain configuration, ranging from 0° to 2.7° in flat lowlands, 9° to 18° on hillsides, and 28° to 58° in the steepest mountainous areas.

Analysis of population abundance and structure

During July 2020 and August 2021, population monitoring of desert bighorn sheep was conducted. This period coincides with the hottest season in the Sonoran Desert, during which the monitoring and identification of the species are more effective due to increased predictability in their activity patterns and location. High temperatures force individuals to concentrate near permanent water sources and in shaded areas or elevated locations with better ventilation, significantly reducing their spatial distribution and facilitating detection (Adame *et al.*, 2017).

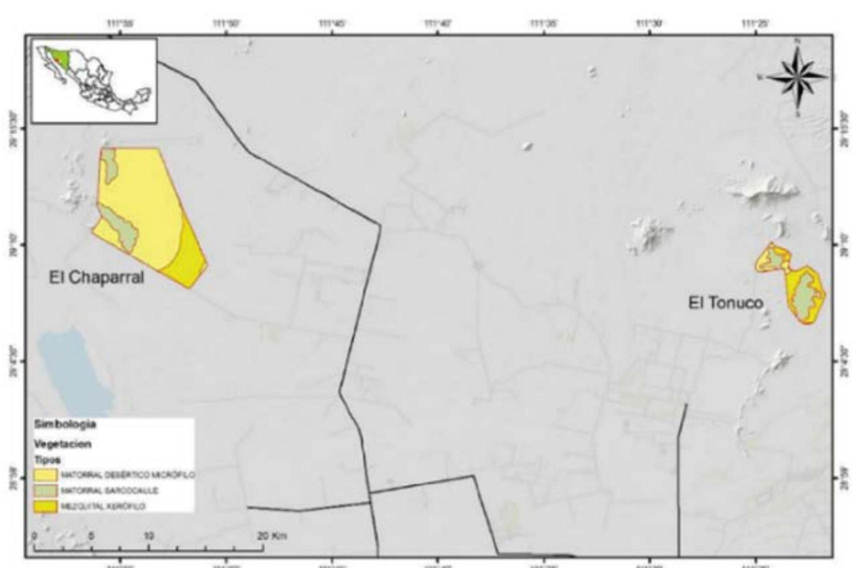

Figure 1. Location and vegetation types of El Chaparral Ranch and El Tonuco Ranch in the state of Sonora, Mexico.

Population monitoring was carried out using a network of roads adjacent to the bighorn sheep's escape terrain, primarily located in lowland foothill areas commonly explored during the legal hunting season. Based on these criteria, permanent observation points were established, spaced 1.5 to 2.0 km apart, to minimize the likelihood of pseudoreplication in individual recordings. Furthermore, due to the presence of permanent water sources in the area, the sheep did not frequently engage in local migrations, thus reducing the risk of overestimation in the observations. Sampling began 30 minutes before sunrise and continued until 11:00 a.m., or until wind speeds exceeded 25 kilometers per hour or drone operating temperatures risked overheating the devices.

At each sampling point, the start time was recorded, and observers searched for bighorn sheep for a period of 10 to 15 minutes, or until the professional guides (certified big-game hunting experts) identified the maximum number of individuals. This ensured accurate identification and detailed knowledge of the study area. At the end of the observation period, once the number of individuals by sex and age class was recorded (Figure 2), a drone flight was conducted over the locations where individuals were detected and surrounding areas to identify any not directly observed. A DJI Mavic 2 Pro drone was used for capturing aerial images and videos, equipped with a Hasselblad camera featuring a one-inch CMOS sensor and an effective resolution of 20 megapixels. The optical system has a 77° field of view and a 28 mm equivalent focal length, with an adjustable aperture ranging from f/2.8 to f/11, allowing optimization based on ambient lighting conditions. ISO sensitivity ranges from 100 to 3200 in automatic mode and up to 12800 in manual mode for photography, while for video, the range is 100-6400 (automatic) and 100-12800 (manual). Images were stored in JPEG and DNG (RAW) formats, and videos in MP4 or MOV using H.264/MPEG-4 AVC and H.265/HEVC codecs. The camera allows for 4K resolution recording (3840×2160 pixels) at 30 frames per second, providing high-quality footage for visual analysis of the observed wildlife. The drone was operated at an altitude between 20 and 40 meters above the mountainous terrain. This methodology yielded both total and relative abundance of the desert bighorn sheep population, where total abundance was defined as the number of individuals observed regardless of sex or age class. To calculate relative abundance, the proportion of individuals was determined for each category: females, young, class I

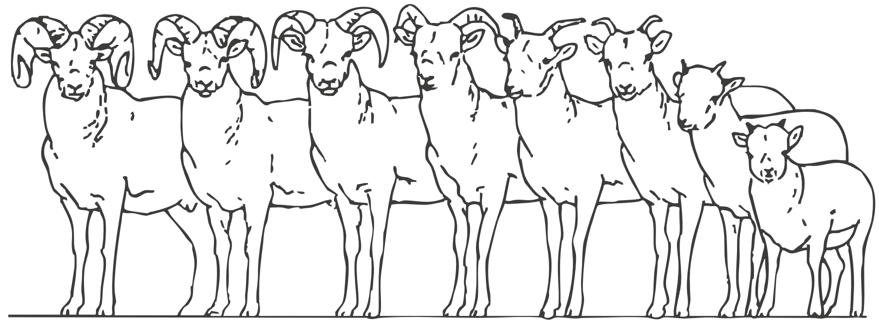

Figure 2. Sex categories and age classes of desert bighorn sheep according to the classification by Geist (1968).

males, class II males, class III males, and class IV males (Geist, 1968), relative to the total population abundance.

At the end of each sampling period at each observation point, the number of individuals detected through direct observation and the number recorded via drone were documented. The population detectability percentage was expressed as the difference between detections obtained through direct observation and those recorded using drones. Additionally, the total population correction factor (regardless of sex or age classes) was calculated using the following formula:

$$Correction\ factor\ (\%) = \left(\frac{Total\ number\ of\ observations\ with\ direct\ observation \times 100}{Total\ number\ of\ observations\ using\ drone} \right) - 100$$

For relative detectability by sex and age class (females, young, class I, II, III, and IV males), the following formula was used:

$$\begin{matrix} Correction\ factor\ for \\ sex\ and\ age\ class\ (\%) \end{matrix} = \left(\frac{\begin{matrix} Number\ of\ observations\ of\ each\ sex\ and\ age\ class \\ by\ direct\ observation \times 100 \end{matrix}}{Number\ of\ observations\ of\ each\ sex\ and\ age\ class\ using\ drones} \right) \times 100$$

Finally, the non-parametric Mann-Whitney U test ($\alpha \leq 0.05$) was applied to identify differences in bighorn sheep population abundance based on the two monitoring techniques used.

RESULTS AND DISCUSSION

Although no significant differences were identified in the number of bighorn sheep recorded using the two monitoring techniques, direct observation at El Tonuco Ranch yielded 45 individuals, whereas drone monitoring detected 118, representing a 2.26-fold increase in population abundance compared to direct observation. Similarly, at El Chaparral Ranch, 73 individuals were recorded through direct observation, while drone monitoring identified 96, equating to a 1.31-fold increase in abundance (Table 1).

The use of drones for wildlife and habitat monitoring is still considered emerging, although it is steadily developing as a valuable tool for ecological studies. Several investigations have demonstrated the utility of this methodology in the population assessment of wildlife. Michel *et al.* (2014) validated the use of drones to monitor penguin colonies in the Shetland Islands, Norway. Additionally, drone technology has been successfully applied to monitor other terrestrial mammals, with studies on the abundance and distribution of elk (*Cervus elaphus*) (USGS, 2014), fallow deer (*Dama dama*) (Barasona *et al.*, 2014), and elephants (*Loxodonta africana*) (Vermeulen *et al.*, 2013). In Mexico, Mandujano *et al.* (2017) designed a drone-based methodology for monitoring white-tailed deer (*Odocoileus virginianus*) and their habitats in Actopan, Veracruz, the Tehuacán-Cuicatlán Biosphere Reserve in Puebla, and certain regions of Oaxaca. More recently, Valencia-Maldonado (2021) applied this

Table 1. Comparison of desert bighorn sheep population abundance using direct observation and drone monitoring at El Tonuco and El Chaparral Ranches, Sonora, Mexico.

Sex and age classes	**Direct observation**		**Difference in observation****
	Rancho El Tonuco (*U*=11*, *P*=0.3)		
Females	16	57	3.56
Offspring	5	25	5
Class I Males	2	3	1.5
Class II Males	4	4	0
Class III Males	6	13	2.16
Class IV Males	12	16	1.33
Total	45	118	2.26
Rancho El Chaparral (*U*=15.5*, *P*=0.75)			
Females	31	41	1.32
Offspring	22	31	1.4
Class I Males	14	17	1.21
Class II Males	2	2	0
Class III Males	4	5	1.25
Class IV Males	0	0	0
Total	73	96	1.31

* Mann-Whitney U test; number of times greater.

technology to assess the abundance of mule deer (*Odocoileus hemionus eremicus*) in the Sonoran Desert. Contrary to the results of the present study, no differences were reported between direct transect observations and drone-based monitoring.

These findings suggest that the effectiveness of population monitoring techniques drone-based or direct observation depends on habitat characteristics and species ecology (Mandujano *et al.*, 2017). For instance, mule deer are primarily distributed across lowlands and gently rolling hills covered by desert scrub in the Sonoran Desert, where relatively flat terrain and sparse vegetation enhance visual detection and facilitate transect counts (Mackie *et al.*, 2003). In contrast, desert bighorn sheep are associated with rugged mountainous habitats, steep slopes, sparse vegetation, and difficult terrain, which limits the efficiency of direct observation and complicates the application of transect-based sampling (Valdez & Krausman, 1999). Under such conditions, the use of drones offers clear advantages by enabling efficient monitoring in remote areas and facilitating the detection of individuals in complex habitats.

The results of this study suggest that drones are more effective than direct observation in estimating the sex structure of desert bighorn sheep populations (Table 1). Drone-based evaluations more effectively identified the locations of females and young, which are generally more difficult to observe than adult males (Valdez & Krausman, 1999). This is primarily due to the species' sexual segregation behavior. During the non-breeding season, females and young tend to remain in hard-to-reach highland areas of the mountain ranges, using such locations as an anti-predator strategy (Bleich *et al.*, 1997). In contrast, males, after the breeding season, tend to move randomly across the mountain strata in search of high-quality forage to replenish the energy lost during reproduction (Main *et al.*, 1996), which typically spans from July to December, peaking between August and November.

Adult males, particularly class III and IV, were more frequently recorded via drone in both El Tonuco and El Chaparral Ranches; however, no class IV males were recorded at El Chaparral (Table 1; Figure 3). The low detectability of adult males may be attributed to their low abundance or to the possibility that, during the study period, they were located in the uppermost parts of the mountain ranges or near female groups as they attempted to establish dominance for the upcoming breeding season (Bleich *et al.*, 1997). Moreover, in August one of the hottest months in the Sonoran Desert bighorn sheep tend to reduce activity to conserve energy.

The greater detectability of adult males using drones (Figure 4) reinforces the notion that this technology is effective in identifying individuals dispersed across large areas. These findings align with those of Anderson *et al.* (2018), who concluded that drones overcome the limitations of direct observation, especially in detecting species in open and inaccessible environments. However, while drones increase individual detection rates, the lack of significant differences in the observation of class II males suggests that habitat characteristics or behavior of specific age classes may influence the effectiveness of this technology. Compared to previous studies that reported variability in drone efficacy

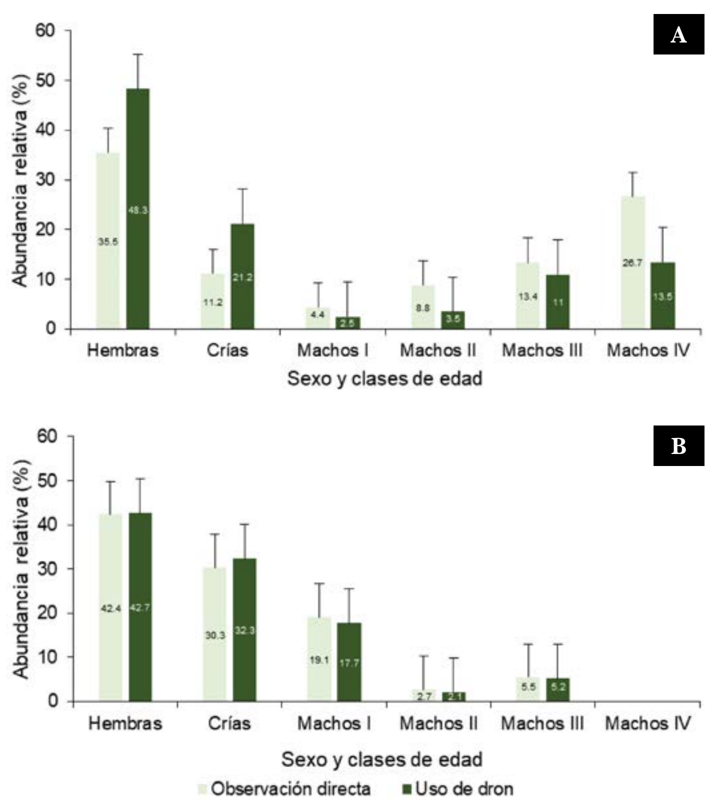

Figure 3. Relative abundance of desert bighorn sheep records by sex and age class, according to the classification proposed by Geist (1968), obtained through direct observation and drone use at El Tonuco Ranch (A) and El Chaparral Ranch (B), located in Hermosillo, Sonora, Mexico (vertical lines on the bars indicate the standard error of the mean).

Figure 4. Desert bighorn sheep specimen classified as a class III male, according to Geist's (1968) criteria, detected using a drone at El Chaparral Ranch at an approximate altitude of 20 meters above ground level (photograph taken by the first author).

depending on species and environment (Wehausen & Bleich, 2007), the present study underscores the importance of integrating multiple monitoring methods to achieve more accurate population estimates.

At El Tonuco Ranch, the overall correction factor for the population estimated through direct observation compared to drone-based monitoring was 62%. This indicates that direct observation underestimates approximately 62% of the population recorded via drones. At El Chaparral Ranch, the correction factor was 24%, suggesting that direct observation underestimates about 24% of the population detected using drones (Figure 5). Additionally, the correction factor was influenced by sex and age classes (Figure 3; $P \leq 0.05$). These results indicate that drone technology enables more efficient detection of bighorn sheep, suggesting that, while useful, direct observation may not be sufficient to obtain accurate population estimates in open and hard-to-access environments.

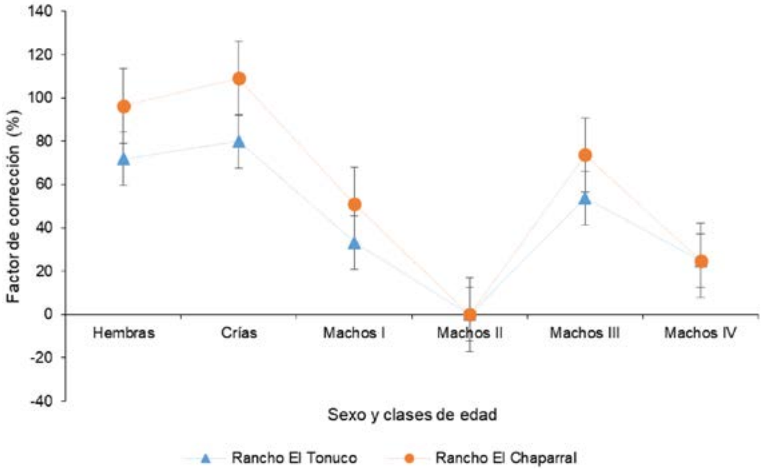

Figure 5. Variation in the correction factor comparing direct observation with drone use, based on sex, age classes, and study site in the Sonoran Desert (vertical lines on the data points indicate the standard error).

The use of drones for regional-scale population assessments of desert bighorn sheep must consider key factors for estimating abundance from aerial surveys, including the number of animals observed, detectability value, the area surveyed, and the total available habitat for the species. Detectability is defined as the probability of observing an animal within the observers' field of view (Steinhors *et al.*, 1989). Unlike drones, this parameter has been calculated for aerial bighorn sheep surveys conducted via helicopter (Romero-Figueroa *et al.*, 2024). For instance, in the Baja California Peninsula, population censuses of bighorn sheep have assumed that only 35% to 60% of the total population is sighted (De Forge *et al.*, 1993; Martínez *et al.*, 2010). This estimation is based on the work of McQuivey (1978) and Hervert *et al.* (1998), who reported that the probability of detecting a group of sheep during a helicopter survey ranged from 0.37 to 0.55. Although drone use in wildlife studies has proven to be an effective tool for obtaining population and behavioral data, its potential limitations are often insufficiently addressed (Ajanic *et al.*, 2020). For example, some animals may alter their behavior or avoid the drone's presence, potentially affecting the representativeness of the observations (Adame *et al.*, 2017). Additionally, the limited battery autonomy restricts flight duration and coverage, especially in extensive or hard-to-reach areas. Further challenges include potential errors in identifying individuals or species from video footage, due to image quality, drone speed, or lighting conditions (Jones *et al.*, 2023). These limitations must be considered when interpreting results and designing more robust methodological protocols. Drone-based wildlife monitoring may present biases in shaded areas or regions with dense vegetation, where visual or thermal detectability of animals may be significantly reduced. For example, in closed-canopy forests, tree cover may conceal animals in both RGB and thermal imagery, thereby lowering count accuracy and increasing the likelihood of missing individuals under foliage (Koh & Wich, 2012; Chrétien *et al.*, 2016). Similarly, Burke *et al.* (2018) noted that thermal interference from the ground and vegetation obstruction may hinder detection with infrared cameras mounted on drones, especially in densely vegetated areas. On the other hand, studies using LiDAR sensors indicate that even advanced systems struggle to penetrate multiple vegetation layers and detect wildlife or understory features without very high point densities (Torresan *et al.*, 2017). Collectively, these findings suggest that shaded or densely vegetated areas may introduce undercounting biases in drone-based projects, thereby affecting data representativeness and validity.

Therefore, it is essential to calibrate drone use to accurately determine the proportion of the bighorn sheep population that can be detected using this technology. Furthermore, drone effectiveness is closely linked to technological aspects. In this regard, integrating thermal and topographic sensors is important to enhance animal detectability and improve habitat assessment efficiency. The findings presented in this study underscore the value and advantages of using drones as a tool for monitoring desert bighorn sheep populations in the Sonoran Desert. However, it is crucial to replicate this research in other regions within the species' natural range in northern Mexico. Additionally, this methodology could significantly contribute to the Conservation, Repopulation, and Sustainable Use Program for Desert Bighorn Sheep in Sonora, by complementing helicopter-based aerial monitoring through training of authorities, WMU landowners, and wildlife technicians in drone technology applications.

CONCLUSIONS

The use of drones enabled the detection of a greater number of bighorn sheep compared to direct observation, with the most notable difference observed at El Tonuco Ranch. Due to their gregarious habits and ethology, adult females were the most frequently detected individuals. The results demonstrate that drone technology is an effective methodology for monitoring desert bighorn sheep populations in desert scrub habitats. Therefore, it is recommended that this approach be replicated in other areas within the species' natural range in the Sonoran Desert. Lastly, a portion of the photographic and video material obtained during this study is available on the first author's social media platforms (Instagram: @ivanlzns and @wildlifeoldmexico).

ACKNOWLEDGMENTS

We extend our gratitude to Jorge and Jacobo Artee for their logistical support at El Tonuco Ranch, as well as to Roberto Garrobo for his assistance at El Chaparral Ranch.

REFERENCES

Adame, K., Pardo, M. A., Salvadeo, C., Beier, E., & Elorriaga-Verplancken, F. R. (2017). Detectability and categorization of California Sea lions using an unmanned aerial vehicle. *Marine Mammal Science*, 33, 913-925. https://doi.org/10.1111/mms.12403

Ajanic, E., Feroskhan, M., Mintchev, S., Noca, F., & Floreano, D. (2020). Bioinspired wing and tail morphing extends drone flight capabilities. *Science Robotics*, 5, eabc2897. https://doi.org/10.1126/scirobotics.abc2897

Anderson, K., & Gaston, K. J. (2013). Lightweight unmanned aerial vehicles will revolutionize spatial ecology. *Frontiers in Ecology & Environment*, 11, 138-146.

Barasona, J., Mulero-Pázmány, M., Acevedo, P., Negro, J. J., Torres, M. J., Gortázar, C., & Vicente, J. (2014). Sistema de aviones no tripulados para estudiar la abundancia espacial de ungulados: relevancia para la epidemiología espacial. *MÁS UNO*, 9, e115608.

Bleich, V. C., Bowyer, R. T., & Wehausen, J. D. (1997). Sexual segregation in mountain sheep: resources or predation. *Wildlife Monographs*, 134, 1-50.

Burke, C., Rashman, M., Wich, S., Symons, A., Theron, C., & Longmore, S. (2018). Thermal drones as a solution to detect animals in the wild: Identification of limitations and possibilities. arXiv preprint arXiv:1812.05498. https://arxiv.org/abs/1812.05498

Chrétien, L. P., Théau, J., & Ménard, P. (2016). Wildlife multispecies remote sensing using visible and thermal infrared imagery acquired from an unmanned aerial vehicle (UAV). *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XLI-B1, 873-879. https://doi.org/10.5194/isprs-archives-XLI-B1-873-2016

Comisión Nacional del Agua [CONAGUA]. (2015). Red de consulta sobre precipitaciones anuales en el estado de Sonora, México.

De Forge, J., Osterman, S., Toweill, D., Cyrog, P., & Barrett, E. (1993). Helicopter survey of peninsular bighorn sheep in northern Baja California-1993. *Desert Bighorn Council Transactions*, 37, 24-28.

Gastelum-Mendoza, F. I., Lozano-Cavazos, E. A., González-Saldívar, F. N., Uvalle-Sauceda, J. I., Romero-Figueroa, G., Serna-Lagunes, R., Tarango-Arámbula, L. A., & Cantú-Ayala, C. M. (2024). Estrategias forrajeras del borrego cimarrón (*Ovis canadensis mexicana*) en el noreste de México. *Ecosistemas y Recursos Agropecuarios, 11*(1), e3921. https://doi.org/10.19136/era.a11n1.3921

Gastelum-Mendoza, F. I., Tarango-Arámbula, L. A., Olmos-Oropeza, G., Palacio-Núñez, J., Valdez-Zamudio, D., & Noriega-Valdez, R. (2021). Diet and sexual segregation of the bighorn sheep (*Ovis canadensis mexicana* Merriam) in Sonora, Mexico. *Agroproductividad, 14*(6), 31-39. https://doi.org/10.32854/agrop.v14i6.2043

Geist, V. (1968). On the interrelation of external appearance, social behaviour, and social structure of mountain sheep. *Zeitschrift für Tierpsychologie*, 25, 119-215.

García, E. (1988). Modificaciones al régimen de clasificación climática de Köppen, México. Instituto de Geografía. Universidad Nacional Autónoma de México.

Guerrero-Cárdenas, I., Gallina, S., Corcuera, P., Álvarez-Cárdenas, S., & Ramírez-Orduña, R. (2016). Diet composition and selection of the bighorn sheep (*Ovis canadensis*) in Sierra El Mechudo, Baja California Sur, Mexico. *Therya, 7*(3), 423-437. https://doi.org/10.12933/therya-16-394

Hervert, J., Henry, R., Brown, M., & Kearns, R. (1998). Sighting rates of bighorn sheep during helicopter surveys on the Kofa National Wildlife Refuge, Arizona. *Desert Bighorn Council Transactions*, 42, 11-26.

Hodgson, A., Kelly, N., & Peel, D. (2013). Unmanned aerial vehicles (UAVs) for surveying marine fauna: a dugong case study. *PLoS ONE, 8*(11), e79556.

Instituto Nacional de Geografía y Estadística [INEGI]. (2016). Conjunto de datos vectoriales de Uso del suelo y vegetación. Escala 1:250 000. Serie VI. Conjunto Nacional.

Jones, L.R., Jared, A.,Elmore, B., Santhana, K., Sathishkumar, S., Kristine, O. E., Morgan, B. P., Bradley, F. B., & Raymond, B. I. (2023). Controllable factors affecting accuracy and precision of human identification of animals from drone imagery. *Ecosphere, 14*(9), e4657. https://doi.org/10.1002/ecs2.4657

Koh, L. P., & Wich, S. A. (2012). Dawn of drone ecology: Low-cost autonomous aerial vehicles for conservation. *Tropical Conservation Science, 5*(2), 121-132. https://doi.org/10.1177/194008291200500202

Lee, R. (2011). Economic aspects of and the market for desert bighorn sheep. *Desert Bighorn Council Transactions*, 51, 46-49.

Lee, R. M., & López-Saavedra, E. (1994). A second helicopter survey of Sonora, México. *Desert Bighorn Council Transactions*, 38, 12-13.

Mackie, R. J., Kie, J. G., Pac, D. F., & Hamlin, K. L. (2003). Venado Bura (*Odocoileus hemionus*). En B. C. Thompson, G. A. Feldhamer, & J. A. Chapman (Eds.), Mamíferos salvajes de América del Norte. Biología, Manejo y Conservación (2da ed., pp. 889-905). University Press.

Main, M. B., Weckerly, F. W., & Bleich, V. C. (1996). Sexual segregation in ungulates: new directions for research. *Journal of Mammalogy*, 77, 449-461.

Mandujano, S., Mulero Pazmany, M. C., & Rísquez-Valdepeña, A. (2017). Drones: una nueva tecnología para el estudio y monitoreo de fauna y hábitats. *Agroproductividad, 10*(10), 79-84.

Martínez, R., Alaníz, J., Guevara, A., & González, S. (2017). Monitoreo poblacional del borrego cimarrón (Ovis canadensis) en Baja California en el año 2010. En R. Eatón, A. Guevara, & J. Tapia (Eds.), Estudios Sobre el Borrego Cimarrón en el Noroeste de México (pp. 57-73). Universidad Autónoma de Baja California.

McKinney, B. R., & Villalobos, J. (2005). Desert bighorn sheep reintroduction in Maderas del Carmen, Coahuila, México. *Desert Bighorn Council Transactions*, 48, 46-49.

McKinney, B. R., & Delgadillo, V. (2006). Desert bighorn reintroduction in Maderas del Carmen, Coahuila, México. *Desert Bighorn Council Transactions*, 48, 46-49.

Medellín, R., Manterola, C., Valdez, M., Hewitt D. G., Doan-Crider, D., & Fulbright, T. E. (2005). History, ecology, and conservation of the pronghorn antelope, bighorn sheep, and black bear in Mexico. En J. L. E. Cartron, G. Ceballos, & R. S. Felger (Eds.), Biodiversity, ecosystems, and conservation in northern Mexico.

Servicio Geológico de EE. UU. [USGS]. (2014). Servicio Geológico de EE. UU. Sitio web del Proyecto Nacional de Sistemas de Aeronaves No Tripuladas. http://rmgsc.cr.usgs.gov/UAS

Torresan, C., Berton, A., Carotenuto, F., Di Gennaro, S. F., Gioli, B., Matese, A., & Wallace, L. (2017). Forestry applications of UAVs in Europe: A review. *International Journal of Remote Sensing, 38*(8-10), 2427-2447. https://doi.org/10.1080/01431161.2016.1252477

Valdez, R., & Krausman, P. R. (1999). Mountain sheep of North America. University of Arizona Press.

Valencia-Maldonado, C. (2021). Uso de dron para el monitoreo de venado bura (*Odocoileus hemionus eremicus*) en desierto sonorense. Tesis de Maestría, Universidad Estatal de Sonora.

Wehausen, J. D., & Bleich, V. C. (2007). Influence of aerial search time on survey results. *Desert Bighorn Council Transactions*, 49, 23-29.