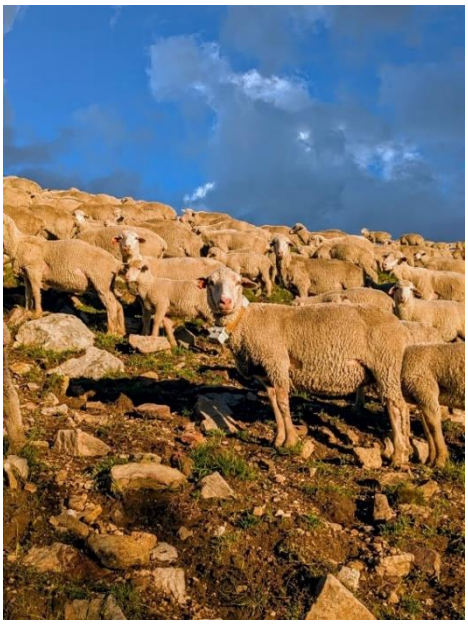
Coproducing Science to Evaluate Contact Risk Factors Between Wild and Domestic Sheep in Montana

Annual Report, September 1st, 2024



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Executive Summary:

Respiratory disease, specifically pneumonia caused by *Mycoplasma ovipneumoniae* (*M. ovi*), remains a limitation to bighorn sheep recovery in Montana. *M. ovi* can be transmitted among all members of the Caprinae family, including domestic sheep and goats, via direct contact (i.e., nose-to-nose) or via aerosols at distances up to 12-15 meters. The purpose of this study is to better understand how often, and under what circumstances, wild and domestic sheep contacts occur. This project aims to identify factors that contribute to a higher risk of contact, allowing managers to better predict when and where wild and domestic sheep and goats are likely to interact and how best to maintain physical separation between them. Optimizing our tools to reduce contact between bighorn sheep and domestic sheep and goats should reduce the risk of disease spillover, yielding benefits for both production agriculture and wildlife conservation.

This study is evaluating the probability of wild-domestic sheep contact as a function of individual, herd-level, and environmental covariates across eight study herds where existing Montana Fish, Wildlife and Parks' bighorn sheep research is planned or underway. Through producer surveys, local knowledge, and field investigations, a total of 48 domestic sheep and goat producers have been identified within 14.5 km of the bighorn sheep study herds. These operations have an estimated 11,826 domestic sheep, 271 domestic goats, and 35 livestock guard dogs. In the spring of 2024, GPS collars were deployed on participating domestic sheep operations that are herded, in large, fenced pastures, or that move frequently in temporary fencing. A total of 294 domestic sheep and 25 livestock guardian dog (LGD) collars were deployed across 5 operations and 10 bands/flocks within the vicinity of 3 bighorn sheep study herds. So far, GPS collars have been deployed on 38 bighorn rams and 124 bighorn ewes across 5 of the study herds. All collars are planned to last 2-3 years to capture seasonal and yearly variation in movements. Most bighorn sheep collars were programmed with a virtual fence to capture more frequent locations when they are within proximity to known domestic sheep or goat operations. A total of 51 close contact events, defined as collared bighorn sheep within 200 meters of domestic sheep or goats within a 24-hour period, were identified through GPS data (744 locations). These events involved 8 individual collared bighorn sheep across 2 study herds and each event involved an average of 2.08 individuals. The contact rate across all study herds was 0.15 contact events per collared bighorn sheep per month. Close contact events occurred in March, April, May, and June, 2024. An addition, 6 close contacts across 2 study herds were identified through ground observations by producers, landowners, comingling project staff, or FWP staff.

One full-time and one seasonal field technician joined the project in the spring of 2024. Efforts are underway to complete identification and ground-truthing of domestic sheep and goat operations within the study areas and to continue producer outreach to gather husbandry data on these operations. Ground-based survey protocol and observation tools are being explored and will be implemented in the fall of 2024. Collars on domestic sheep and LGDs will continue to be monitored and managed in coordination with sheep producers. Lastly, in the coming year, we plan to include the Thompson Falls bighorn sheep herd in northwestern Montana as another study area in this project; this report does not yet reflect that decision, but future reports will include this herd.

Project Background:

The risk of disease spillover has likely plagued the wildlife-domestic interface for as long as humans have managed domestic animals (Vicente et al. 2021). However, more recent global changes in wildlife populations, human development, land conversion, wildlife restoration efforts, and the intensification of agricultural and domestic animal operations have brought wildlife and domestics into more frequent contact, increasing the risk of disease transmission. Diseases shared at the wildlife-domestic interface have the potential for large social and economic costs, as exemplified by recent or historic outbreaks of bovine tuberculosis (Torgerson & Torgerson, 2008, Godfrey et al. 2018, Schmitt et al. 2002), highly pathogenic avian influenza (Ramos et al 2017), rinderpest

(Youde 2013), and brucellosis (Schumaker et al. 2012). Protecting wildlife populations and maintaining robust agriculture and livestock industries through sound science-based, collaborative management is vital to local economies and continued wild-domestic animal coexistence. Mitigating the risk of disease spillover at the domestic-wild interface is a complex endeavor involving multiple groups of people with different needs and interests, which necessitates co-produced problem solving and shared solutions that involve wildlife managers, domestic producers, and both wildlife and domestic advocates (Naugle et al 2020).

Respiratory disease among wild bighorn sheep and domestic sheep and goats in the western U.S. is one system in need of new solutions to minimize contact to prevent disease transmission between species. Prior to European settlement, North America was home to an estimated 1-2 million bighorn sheep (Buechner 1960). North American domestic sheep production peaked in the late 1800s at an estimated 51 million head (U.S. Department of Agriculture 2020). By the early 1900s, bighorn sheep populations were reduced to 20,000 due to unregulated market hunting, competition and disease from domestic sheep (Buechner 1960, Picton and Lonner 2008, Singer et al. 2000). Domestic sheep production has declined too, with more recent estimates of 5 million head in North America (U.S. Department of Agriculture 2020); however, the percentage of small operations has increased over time, and domestic sheep production remains an important source of livelihood for many producers, as well as a means for sustainable range management, in the western U.S. While both wild and domestic sheep populations in the U.S. are fractions of their historic highs, many domestic operations are located within current or historic bighorn sheep range, and respiratory disease remains a limitation to bighorn sheep recovery and a source of concern and contention between wild and domestic sheep advocates.

Mycoplasma ovipneumoniae (*M. ovi*), believed to be the primary causative agent involved in many of the cases of epidemic and endemic respiratory disease in wild sheep, is shed in respiratory droplets and is transmitted via direct contact (i.e., nose-to-nose) or via aerosols at distances up to 12-15 meters (Besser et al. 2014, Felts 2020). *M. ovi* damages the cilia of the cells lining the respiratory tract (Niang et al. 1998), which is believed to allow opportunistic or co-infecting pathogens to colonize the lungs and cause poly-microbial pneumonia (Johnson et al. 2022). *M. ovi* is widely distributed across domestic sheep herds (89% in a recent national survey across herd sizes), where it is carried amongst a large proportion (average of 60%) of individuals within flocks (Manlove et al. 2019). Clinical signs in domestic sheep vary from asymptomatic infections, to mild respiratory disease, to severe pneumonia and sudden death, and are assumed to be similar in domestic goats. *M. ovi* is also widely distributed among bighorn sheep herds across the west (Cassirer et al. 2018) and in Montana, where 78% (21/27) of sampled herds have had at least one *M. ovi* detection between 1991 and 2021 (Almberg et al. 2022). While less is known about the distribution of *M. ovi* in mountain goats, they too are susceptible (Blanchong et al. 2018, Wolff et al. 2019). In addition, all of Montana's sampled bighorn sheep and mountain goat herds have had detections of at least one Leukotoxin A-positive or hemolytic Pasteurella species, which are co-infecting agents suspected of influencing the severity of respiratory disease.

Spillover of *M. ovi* to wild sheep herds can happen from domestic sheep and goats or from chronically infected wild sheep and/or mountain goat herds (Kamath et al. 2019). Upon introduction into a bighorn sheep herd, *M. ovi* has been associated with all-age die-offs and herd declines ranging from 5-100% (Cassirer et al. 2018), followed by chronic infections that spark recurring lamb pneumonia that can depress lamb recruitment for many years. Where documented, immunity appears to be strain/variant-specific, such that new epidemics can be triggered by the introduction of new variants of the pathogen (Cassirer et al. 2017, Justice-Allen et al. 2016). In some cases, the presence of *M. ovi* and other coinfecting pathogens does not result in detectable die-offs or reduced adult or lamb vital rates (Butler et al. 2018, Paterson et al. 2021).

Currently, there are no treatment options to manage *M. ovi* infection in either wild or domestic sheep. So far, vaccine studies on domestic sheep have been unable to achieve significant immunity or pathogen clearance (Ziegler et al. 2014, Einarsdottir et al. 2018), and antibiotic treatment has been unsuccessful in eliminating *M. ovi*

infection (Johnson et al. 2021). At present, test and removal, and depopulation and reintroduction experiments in wild sheep are considered viable tools (although labor intensive) for pathogen management (Garwood et al. 2020, Montana Fish, Wildlife & Parks 2015, Almberg et al. 2021). Range expansion has also been explored as an option for increasing metapopulation structure and increased carrying capacity despite respiratory disease (Lula et al. 2020), although this potentially comes with increased risk of contact with neighboring herds or domestic flocks.

Because of limited options to date for pathogen management (Cassirer et al. 2018), much emphasis has been placed on maintaining effective separation between wild and domestic sheep to prevent contact. Current state, regional, and federal guidance suggests that optimal reintroduction sites or existing wild sheep herds should have ≥ 14.5 km of separation between domestic sheep and goats (Montana Fish, Wildlife & Parks 2010, Brewer et al. 2014, Wild Sheep Working Group 2012, US Forest Service 2015), a distance that is difficult to adhere to for existing herds, let alone for future wild sheep reintroduction sites. New tools, collaboratively developed between wild and domestic sheep interests, are needed for ensuring effective separation between wild and domestic sheep on shared landscapes to prevent transmission of *M. ovi* as well as other known diseases and future pathogens and parasites between species. Being able to better predict when and where wild and domestic sheep and goats are likely to interact and how best to maintain physical separation between them would help shift the focus from managing outbreak events to prevention, which has major implications for production agriculture and wildlife conservation. New tools for minimizing wild and domestic sheep contact could also expand options for reintroduction sites of bighorn sheep across Montana.

The goal of this project is to identify individual, herd/band-level, and environmental factors that influence the probability of wild and domestic sheep contact. These findings will identify situations where pathogen spillover is more likely, allowing wildlife and domestic sheep managers to focus on reducing the risk of epizootics in situations with a high risk of contact. Our specific objectives include:

1. Evaluate the probability of wild-domestic sheep contact as a function of individual, herd-level, and environmental covariates.
2. Collect detailed information about wild-domestic sheep contact events and document existing management strategies to maintain effective separation.

Methods:

Study Areas

Eight study areas in Montana that have wild and domestic sheep within 14.5 km of one another have been selected to capture replication and variability across key wild and domestic sheep herd-level and environmental covariates (Figure 1, Table 1). Study herds are areas where existing Montana Fish, Wildlife and Parks' (FWP) bighorn sheep research is planned or underway, where wild and domestic sheep are within 14.5 km, where producers are amenable to participation, and where project costs can be shared. Herds will be monitored for a minimum of 2-3 years, with herds entering the study on a staggered timeline. The Little Belts study herd will not have additional bighorn sheep collared during the study period and the probability of contact will be retrospectively evaluated using collar data from approximately 2020–2022.

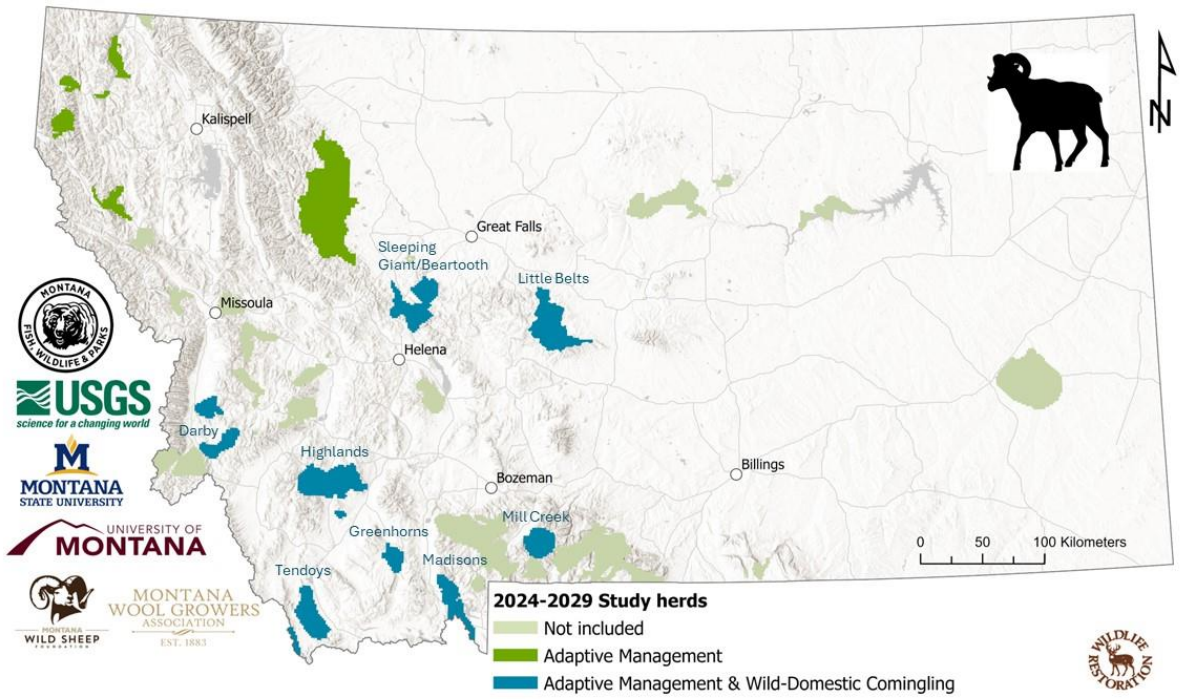

Figure 1. Bighorn sheep herds where wild-domestic sheep contact will be studied in coordination with FWP bighorn sheep research. Information on domestic sheep and goat operations will be collected within 14.5 km of the study herd distributions.

Table 1. Bighorn sheep study herds, classified by size, migratory status, and the type of domestic sheep herds within 14.5 km of bighorn populations, including size, whether they are herded or fenced, and whether dogs are used. Some sites have multiple domestic sheep herds of a given type within the vicinity of bighorn sheep, and this may be one way in which we build replication within and across study sites. The Sleeping Giant/Beartooth bighorn herd has both migratory and resident components.

			Bighorn Sheep Herd Type			
			Small (<150)		Large (>150)	
			Resident	Migratory	Resident	Migratory
Domestic Sheep Herd Type	Recreational (<20 head)	Fenced	Tendoys Highlands Little Belts	Greenhorns Mill Creek		Darby (Skalkaho & E.F. Bitterroot) Madisons (Taylor Hilgard & Beartrap Canyon)
		Dogs				Madisons (Taylor Hilgard & Beartrap Canyon)
		Herded				
	Small – Med (20-600 head)	Fenced	Highlands Little Belts Tendoys	Greenhorns Mill Creek	Sleeping Giant/Beartooth	Sleeping Giant/Beartooth
		Dogs	Highlands Little Belts Tendoys		Sleeping Giant/Beartooth	Sleeping Giant/Beartooth Madisons (Taylor Hilgard & Beartrap Canyon)
		Herded				Madisons (Taylor Hilgard & Beartrap Canyon)

	Large (600-1,200 head)	Fenced	Little Belts			
		Dogs	Little Belts			
		Herded	Little Belts			
	Very Large (1,200-12,000 head)	Fenced	Little Belts	Greenhorns		
		Dogs	Little Belts	Greenhorns	Sleeping Giant/Beartooth	Sleeping Giant/Beartooth
		Herded	Little Belts	Greenhorns	Sleeping Giant/Beartooth	Sleeping Giant/Beartooth

Objective 1: Probability of Contact Data Collection and Analysis

Domestic Sheep and Goat Producer Identification and Data Collection

Data is being collected on domestic sheep and goat operations within 14.5 km of the study herd distributions to capture variability in operation size, management practices, and agricultural settings. Operations have been identified through local knowledge (area biologists, MSU extension staff), mailed surveys, and ground observation efforts. To date, a total of 48 domestic sheep and goat producers have been identified within 14.5 km of the bighorn sheep study herds (Table 2, Figure 2). These operations have an estimated 11,826 domestic sheep, 271 domestic goats, and 35 livestock guard dogs. Project staff are contacting producers via mailings and phone calls to gather information on their animal numbers and husbandry practices. To date, we have collected information from 12 producers across 4 of the study herds, representing 1,984 domestic sheep and 94 domestic goats. Project staff will continue to identify and gather information on domestic sheep and goat operations within the study herd areas. If a producer cannot be reached or is unwilling to participate in the study, animal numbers and operation information will be estimated by field staff.

Table 2. Domestic sheep (DS), domestic goats (DG), and livestock guard dogs (LGD) identified within 14.5 km of studied bighorn sheep herds. Data are based on producer surveys, local knowledge, ground surveys, and estimates. Numbers will be updated and refined as data is collected and additional bighorn sheep herds become collared.

Study Area	DS & DG Producers	# DS	# DG	# LGD
Highlands	16	721	88	5
Greenhorns	15	7390	94	14
Sleeping Giant/Beartooth	7	2950	25	12
Darby	5	55	43	0
Tendoys	5	710	21	4
Madisons	NA	NA	NA	NA
Mill Creek	NA	NA	NA	NA
Little Belts	NA	NA	NA	NA
TOTAL	**48**	**11,826**	**271**	**35**

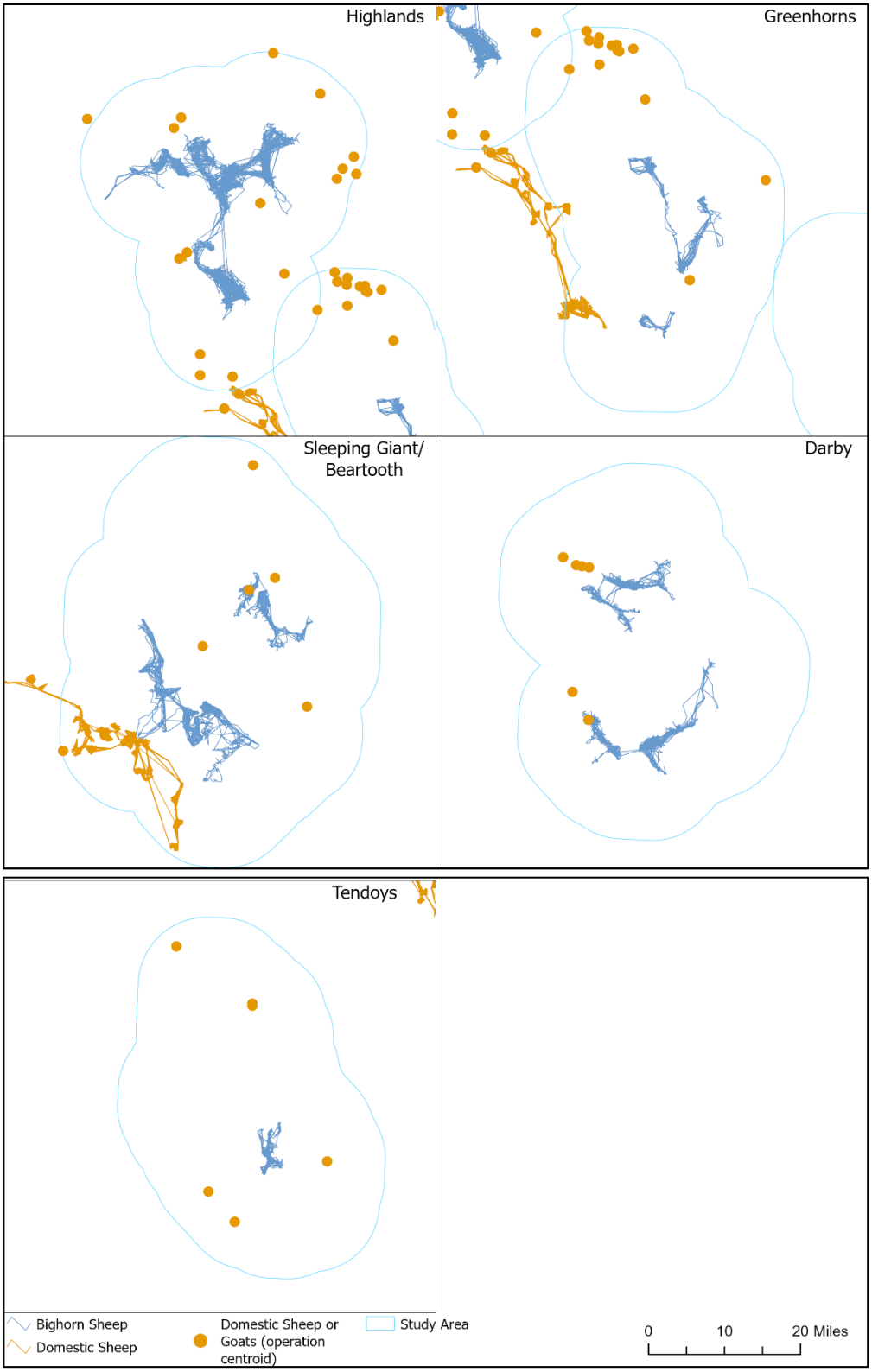

Figure 2. Collared bighorn and domestic sheep locations and known domestic sheep and goat operations within the study areas during July 1, 2023 – June 30, 2024. Data in the Madisons, Mill Creek, and Little Belts study areas have not been collected. Domestic operations are based on producer surveys, local knowledge, ground surveys, and estimates. Maps will be updated and refined as data is collected.

Domestic Sheep and Livestock Guard Dog Collaring

For participating domestic sheep operations that are herded, in large, fenced pastures, or that move frequently in temporary fencing, approximately 2.5% of the domestic ewes are fitted with Lotek LITETRACK Iridium 420+ GPS collars with a 2-hour fix rate. One to several domestic rams in each operation are also fitted with the Lotek collars with a 2-hour fix rate. In addition, 2-3 livestock guardian dogs (LGD) per band or flock are fitted with the Lotek collars with a 15-minute fix rate. Collars will remain deployed for approximately 3 years. During the reporting period, GPS collars were active on 294 domestic sheep and 25 LGDs across 5 operations and 10 bands/flocks within the vicinity of 3 bighorn sheep study herds (Table 3). A total of 260,059 domestic sheep GPS locations and 78,608 LGD GPS locations were collected during the reporting period (Dilution of Precision [DOP]<5, indicating good precision of the GPS location).

Domestic sheep and LGD location data is transmitted via satellite every 3-4 hours to allow field staff to identify and respond to close contact events. Producers participating in the collaring efforts will also have access to their animal's location data through an online mapping platform, EarthRanger. Frequent location updates will allow producers to use the information for their day-to-day sheep management.

Two bands across two operations are collared at an approximately 6% domestic sheep collar rate with up to 4 LGDs collared. For these bands, we will capture band spatial distribution across seasons and years using very-high-resolution satellite imagery and/or unmanned aerial vehicle imagery and compare it to the locations of the GPS collars. This analysis will provide insight into the collar rate needed to accurately estimate flock or band distribution on the landscape.

Table 3. Summary of active domestic sheep (DS), livestock guard dog (LGD), and bighorn sheep (BHS) GPS collars during July 1, 2023 – June 30, 2024. The number of DS ewe collars reflect a minimum collar rate of 2.5% of the flock.

		Active Collars				
Study Area	**Producer**	**DS - ewe**	**DS - ram**	**LGD**	**BHS – ewe**	**BHS - ram**
Highlands	-	-	-	-	52[1]	5
	A	3	1	2	-	-
Greenhorns	-	-	-	-	11	5
	B	168	4	10	-	-
	C	44	2	4	-	-
Sleeping Giant/Beartooth	-	-	-	-	29	14
	D	68	3	6	-	-
	E	0	0	0	-	-
	F	0	0	0	-	-
	G	1	0	3	-	-
Darby	-	-	-	-	25	13
Tendoys	-	-	-	-	7	1
Madisons	-	-	-	-	0	0
Mill Creek	-	-	-	-	0	0
Little Belts	-	-	-	-	0[2]	0[2]
TOTAL		**284**	**10**	**25**	**124**	**38**

[1] *Bighorn ewes in the Highlands study area are collared with Advanced Telemetry System (ATS) collars with a 4-hour fix rate.*

[2] *Historic GPS collar data from the Little Belts bighorn sheep herd will be explored in our contact risk analysis.*

Bighorn Sheep Collaring

Bighorn sheep capture and collaring efforts were carried out by Montana FWP as part of their Statewide Adaptive Management of Bighorn Sheep and Mountain Goats research project. Bighorn ewe collars were programmed to record locations at 2-hour intervals and are set to drop-off in 3 years. Ram collars were programmed to record locations at 2-hour intervals from January to September and 30-minute intervals from October to December in order to capture fine scale movement during the breeding season. Ram collars are set to drop-off in 2 years. In addition, collars deployed in the Darby, Tendoys, Greenhorns, Highlands, and Sleeping Giant/Beartooth study herds were programmed with virtual fences of an approximately 0.5 mi boundary around known domestic sheep operations (as of December 2023). To better capture wild-domestic sheep interactions, programmed collars that cross into or out of a virtual fence boundary will send an alert and will record locations at 15-minute intervals while within the virtual fence. During the reporting period, GPS collars were active on 38 bighorn rams and 124 bighorn ewes across 5 of the study herds (Table 3). A total of 62,638 ram locations and 154,845 ewe locations were collected during the reporting period (DOP<5). Bighorn ewes in the Highlands study area are collared with Advanced Telemetry System (ATS) devices as part of FWP's Highland Bighorn Sheep Population Management Evaluation research project and have a 4-hour fix rate with no virtual fences. These collars are included in our reporting and will be used for animal tracking and further contact risk analysis. FWP does not plan to collar bighorn sheep in the Little Belts herd as part of the wild-domestic sheep contact risk study or adaptive management project, so historic collar data will be explored in our contact risk analysis. Refer to FWP's bighorn sheep research project reports for more information about bighorn sheep capture, collaring, and management efforts.

Close Contact Analysis

For this investigation, we will characterize both the frequency and duration of contact events across a diversity of landscapes. We define a direct contact event as a minimum of one 2-hour fix rate GPS location of a collared bighorn sheep within 200 meters of a band of, or pasture holding domestic sheep, within a 24-hour period. The duration of contact will be defined as the sum of all 2-hour GPS locations within 200 meters of a band of, or pasture holding domestic sheep, per day.

While the overlap between wild and domestic sheep in space and time may be most relevant for describing the probability of direct transmission for pathogens like *M. ovi*, spatial overlap over a season may be a better metric for indirectly transmitted pathogens that persist in the environment. Our metric of indirect contact is defined as the percentage of overlap between 95% kernel density home range estimates for collared bighorn sheep and neighboring domestic sheep/pasture over a 6-month season (e.g. May – October; November – April). Contacts will be measured at the collared-individual level (wild and domestic).

The response variable of interest is the frequency and duration of direct and indirect contacts, as defined above, during a 3-year study period per herd. While numerous factors may influence the probability of contact, we have prioritized those covariates likely to have the largest influence on contact, such that we ensure replication of these covariates across study areas to maximize statistical power. Individual covariates include sex and age of the collared individual. Herd and flock covariates include timing of the breeding season (for both wild and domestic sheep), resident versus migratory status, herd size and density, domestic herd type (herded vs. fenced), wild sheep age and sex ratios, and time since introduction/augmentation. Environmental covariates include bighorn sheep habitat quality within domestic sheep and bighorn sheep home ranges, point attractants including water sources, cultivated crops, and salt/mineral licks, and point deterrents including fences or structural barriers and other separation strategies already in place (e.g. guard dogs, fladry, etc).

Objective 2: Ground-based Observations of Close Contacts

In a subset of study sites where close contacts occur (based on incoming GPS data or visual observations) and where producers and landowners will allow project activities, a field crew will respond to close contact events with ground-based surveys to capture detailed information about the event. Descriptive data collected will include the number and demographics of wild and domestic sheep involved, location details, duration of contacts, LGD behavior, and other attractants or detractants. These visual observations will also provide a dataset against which the GPS data can be compared in terms of accuracy. The ground-based survey protocol is being developed and data will be collected through visual observations and camera traps during the next reporting period.

Results:

Objective 1: Probability of Contact Data Collection and Analysis

During the reporting period 9 GPS-collared bighorn sheep across 2 study herds and a total of 4,452 locations were within 1,000 meters of domestic sheep or goats (Table 4, Figures 3 & 4). These totals are based on GPS locations of bighorn sheep relative to collared domestic sheep or to domestic sheep and goat property boundaries if no animals are collared. For bighorn sheep with virtual fences programmed, a total of 3,339 GPS locations among 12 bighorn sheep across 3 study herds were collected at a 15-min fix rate within virtual fences. Several of these sheep entered a virtual fence around a property, but remained more than 1,000 meters from any collared domestic sheep on the property. A total of 51 close contact events, defined as at least one GPS-collared bighorn sheep within 200 meters of domestic sheep or goats within a 24-hour period, were identified through GPS data (744 locations; Table 4, Figures 3 & 4). These 51 events involved 8 individual collared bighorn sheep across 2 study herds and each event involved an average of 2.08 GPS-collared individuals. The average individual bighorn sheep contact rate across all study herds was 0.15 contacts per GPS-collared bighorn sheep per month (106 individual contacts/162 collared bighorn sheep/4.3 month average air time). The average contact rate for the Sleeping Giant/Beartooth herd was 0.07 contacts per bighorn sheep per month (15 individual contacts/43 collared bighorn sheep/4.8 month average air time) and the average contact rate for the Darby herd was 0.53 contacts per bighorn sheep per month (91 individual contacts/38 collared bighorn sheep/4.5 month average air time). Close contact events occurred in March, April, May, and June, 2024. An addition, 6 close contacts across 2 study herds were identified through ground observations by producers, landowners, comingling project staff, or FWP staff during the reporting period.

Table 4. Bighorn sheep (BHS) observations in proximity to domestic sheep (DS), domestic goats (DG), and livestock guard dogs (LGD) during July 1, 2023 – June 30, 2024. The number of GPS locations (locs) include those in proximity to collared DS and LGDs and to mapped property boundaries of non-collared DS and DG. GPS locations of BHS, DS, and LGDs only include fixes with DOP<5. Distances between BHS and DS/DG/LGD are estimated and categorized accordingly.

	BHS Observations within 200 m of DS/DG/LGD							**BHS Observations within 1,000 m of DS/DG/LDG**				
Study Area	**GPS Locs**	**Collared BHS**	**Contact Events**	**Contact Rate (events/BHS/ month)**	**Camera Trap[1]**	**Visual[1]**	**Uncollared BHS[2]**	**GPS Locs**	**Collared BHS**	**Camera Trap[1]**	**Visual[1]**	**Uncollared BHS[2]**
Highlands	0	0	0	0	0	4	4	0	0	0	4	4
Greenhorns	0	0	0	0	-	0	0	0	0	-	0	0
Sleeping Giant/Beartooth	50	3	10	0.07	0	2	4	855	4	0	4	13
Darby	694	5	41	0.53	-	0	0	3,597	5	-	0	0
Tendoys	0	0	0	0	-	0	0	0	0	-	0	0
Madisons	-	-	-	-	-	0	0	-	-	-	0	0
Mill Creek	-	-	-	-	-	0	0	-	-	-	0	0
TOTAL	**744**	**8**	**51**	**0.15**	**0**	**6**	**8**	**4,452**	**9**	**0**	**8**	**17**

[1] An observation is defined as a visual or camera trap observation made by producers, landowners, comingling project staff, or FWP staff within a 24-hour period.

[2] Uncollared bighorn sheep numbers include all individuals seen during a contact observation and the same individuals may be counted multiple times across observations.

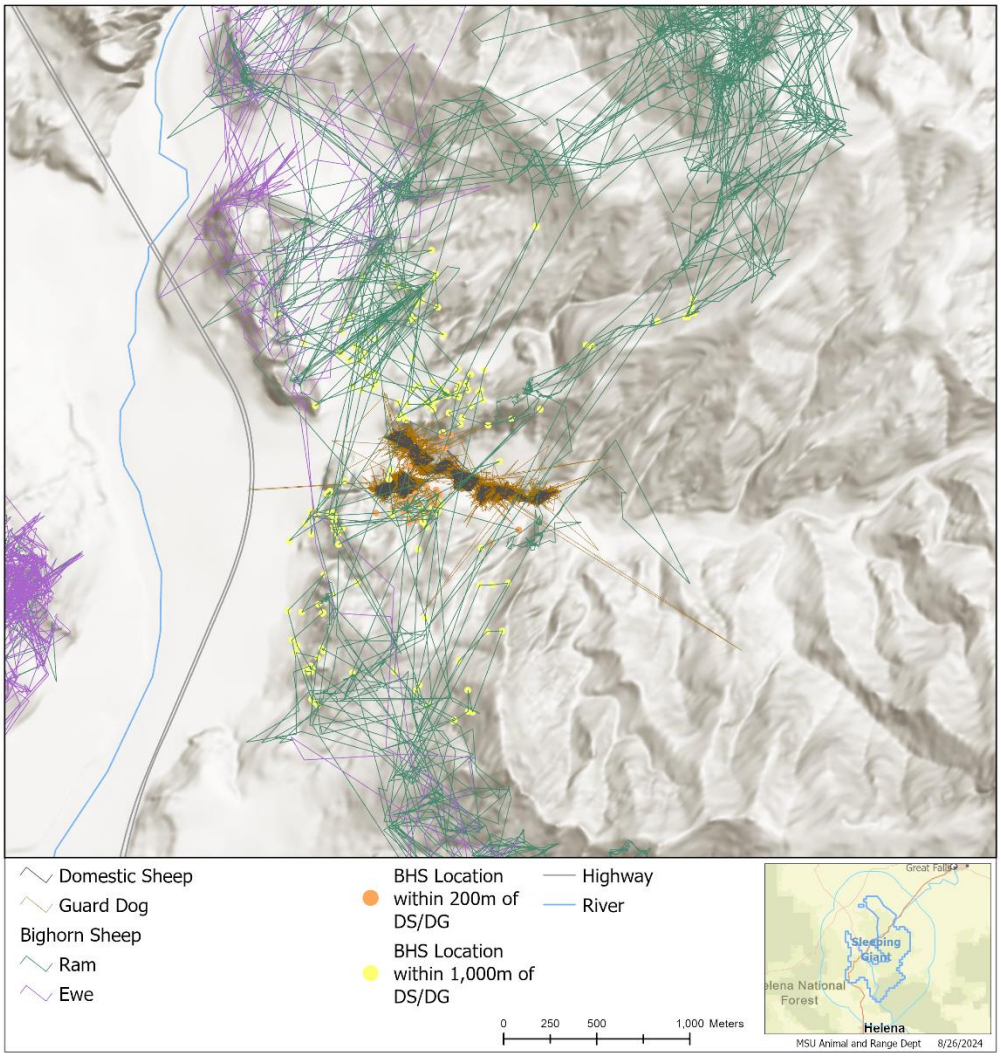

Figure 3. Bighorn sheep (BHS) GPS collar locations in proximity to domestic sheep (DS), domestic goats (DG), and livestock guard dogs during July 1, 2023 – June 30, 2024 in the Sleeping Giant/Beartooth study area. GPS locations only include fixes with DOP<5.

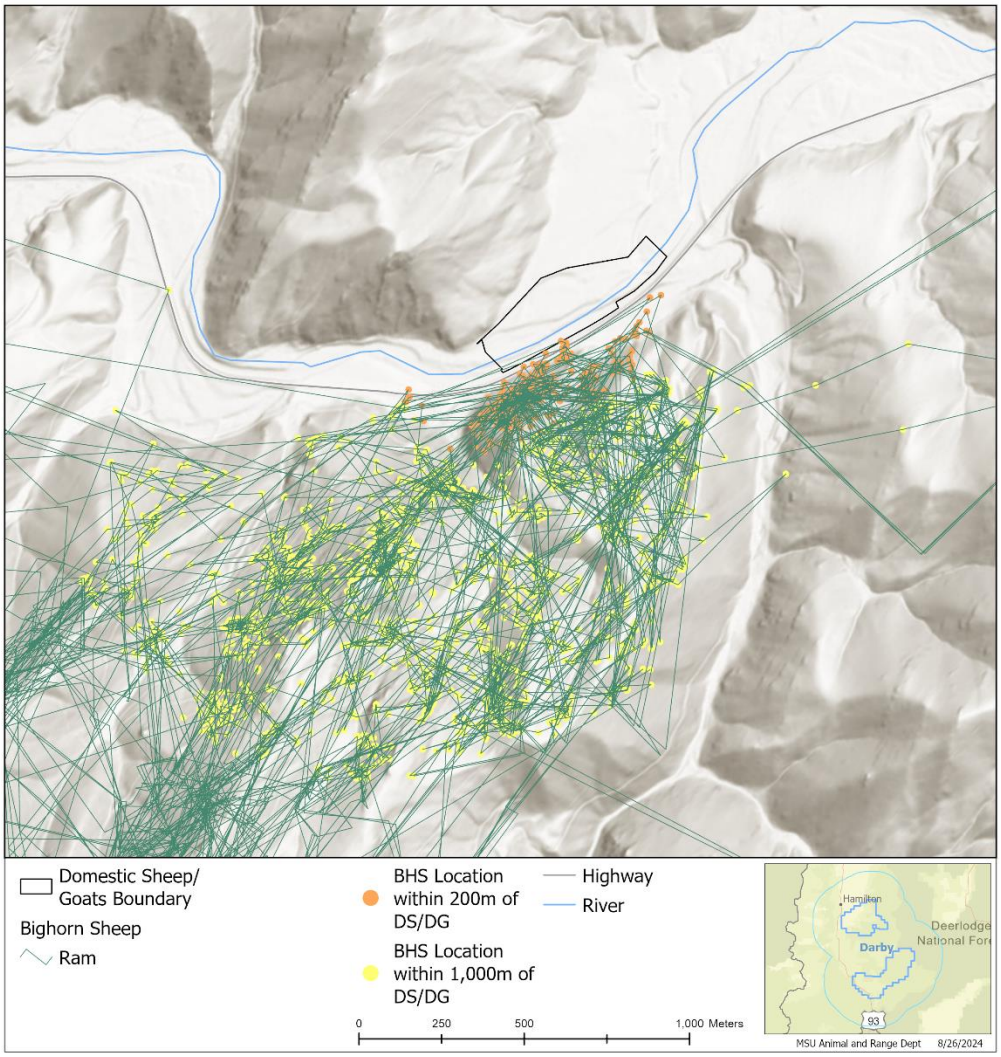

Figure 4. Bighorn sheep (BHS) GPS collar locations in proximity to domestic sheep (DS), domestic goats (DG), and livestock guard dogs during July 1, 2023 – June 30, 2024 in the Darby study area. GPS locations only include fixes with DOP<5.

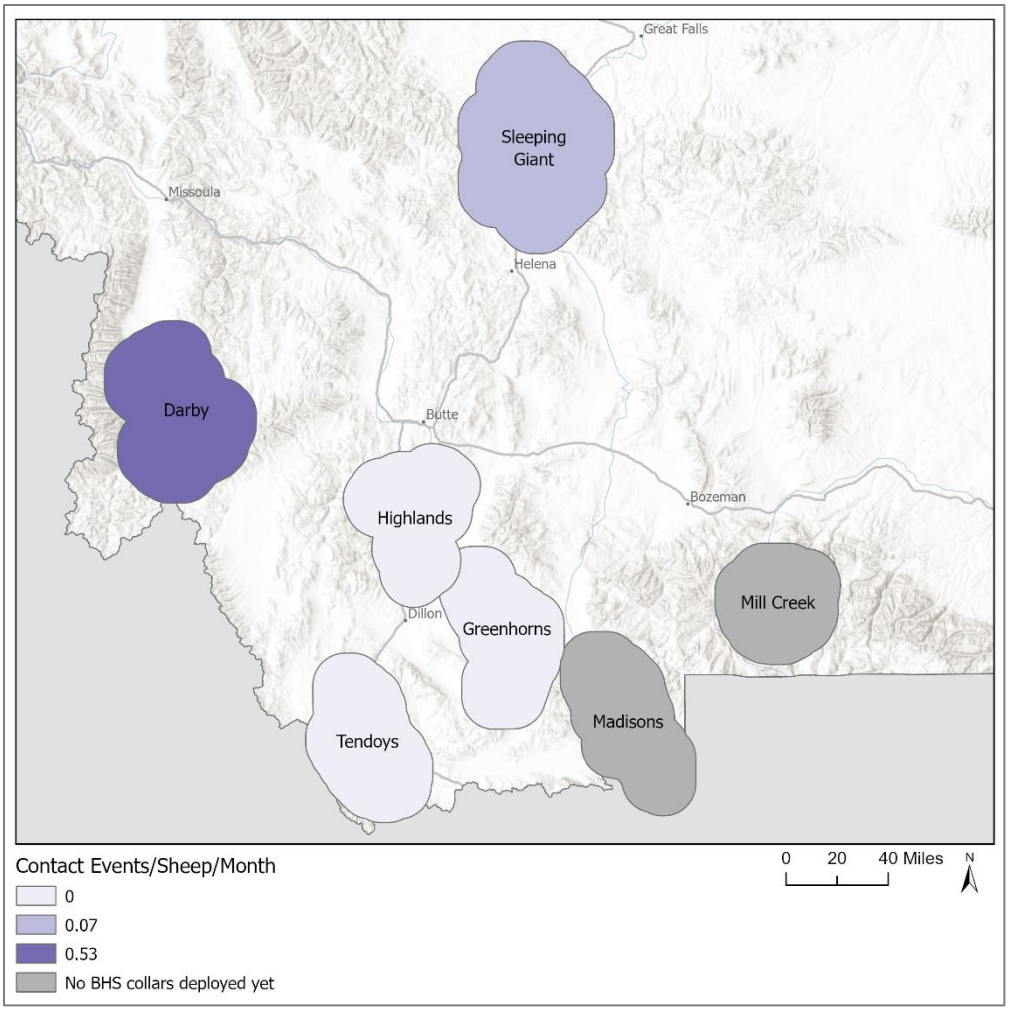

Figure 5. Bighorn sheep (BHS) close contact rate by study area during July 1, 2023 – June 30, 2024. The contact rate is calculated as the total number of individual BHS contacts with domestic sheep and goats, per the total number of BHS collared, per the length of time collars are active.

Discussion:

The purpose of this study is to better understand how often and under what circumstances wild and domestic sheep contacts occur, thereby allowing wildlife and domestic sheep managers to develop new strategies to reduce the risk of contact. We intend to use the preliminary data from this observational study to develop an expanded set of potential mitigation strategies for reducing rates of contact in situations that have a high probability of comingling that can be tested experimentally.

By understanding how contact probability is influenced by domestic flock characteristics, bighorn herd attributes, shared landscape, water and range resources, and the use of fencing, dogs, or other management tools, we may be able to better predict contact risk, better understand the relative effects of manipulating different covariates, and develop better interventions to prevent contact and therefore pathogen spillover. Even for covariates over which we may have no control (certain landscape features or distances between existing wild and domestic sheep herds), understanding the associated risks for contact may provide guidance on the most important places to implement other mitigation measures and improve our assessments of suitable sites for bighorn sheep reintroduction or population expansions. Our goal is to ultimately provide practical guidance and tools for reducing wild and domestic sheep contact beyond a line on the map. By bringing together diverse stakeholders early in the development of this project, we aim to incorporate local, generational, social, and scientific knowledge and perspectives from sheep producers, landowners, sportspeople, and wildlife managers into our evaluation of wild-domestic sheep comingling. The products of this study will be presented to and vetted by these stakeholders throughout the project's duration.

While our study will provide valuable insight into the characteristics of wild-domestic sheep contact events, there are some limitations. Battery life limits the resolution of the GPS monitoring, and the window of 200 m used to define a contact event is somewhat subjective, relatively imprecise, and may reflect either true nose-to-nose contact between animals or merely the presence of a bighorn sheep near of domestic flock. Additionally, it will be impossible to place collars on all animals in a bighorn herd or domestic sheep flock, which may lead to missed contact events. Some of these limitations will be mitigated in a subset of data, where ground observations will be used to more closely assess the nature of a close contact. Because this is an exploratory study with limited prior information, we have selected a large number of covariates that may impact the frequency and nature of contact events. This will reduce the statistical power of the data analysis to identify the most important predictors of the probability of comingling. However, we anticipate that our initial analyses will enable us to select the most relevant covariates for future in-depth analyses. Lastly, while we hope to infer the likelihood of disease transmission from these contact data, this study was not designed to investigate pathogen transmission, and it will generally not be possible to determine whether a specific contact event may have led to the transmission of a certain organism from one animal to another.

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