Final Report: Grant #F19AP00029, *Madison Valley Pronghorn Movements Study*
Reporting Period: December 1, 2018 – November 30, 2023
State: Montana
Agency: Montana Fish, Wildlife and Parks

Background and Purpose

Recognizing the need to protect and conserve big-game winter range, stopover, and migration corridors for sustaining robust ungulate herds across Montana, Montana Fish, Wildlife and Parks (MFWP) initiated efforts to define ungulate seasonal ranges and migration corridors. Global positioning satellite (GPS) location data existed for more than 20 ungulate herds with different migratory habits and that inhabit vastly different landscapes across Montana. Our goal was to develop analysis tools to analyze existing and new GPS location datasets for mapping seasonal ranges and migration corridors for elk, mule deer, bighorn sheep, moose, and pronghorn.

As part of this effort, MFWP wildlife staff identified the Madison Valley as a priority area to collect pronghorn movement data with goals of delineating pronghorn seasonal ranges and migratory corridors. Although the Madison Valley supports one of the largest wintering pronghorn populations in southwest Montana with up to 2,480 animals counted during annual winter trend surveys, the seasonal ranges and migratory corridors of these pronghorn were largely unknown. A better understanding of pronghorn seasonal movements was needed to help public land management agencies and private landowners protect and improve migratory corridors and seasonal habitats through management decisions and project planning. Therefore, the objectives of this project were to:

1. Analyze existing ungulate GPS location data from across Montana to define seasonal ranges and migration corridors.
2. Collect seasonal movement data from pronghorn in the Madison Valley and define seasonal ranges and movement corridors.

Location

Elk, mule deer, bighorn sheep, and moose data from across the State of Montana were aggregated. The Madison Valley pronghorn data collection is focused within Madison and Beaverhead Counties, Montana.

Objective #1: *Aggregate and analyze elk, mule deer, bighorn sheep, and moose data to delineate seasonal range and migration corridors.*

Methods

We developed and implemented analytical methods to delineate and map ungulate seasonal ranges and migration corridors for elk, mule deer, bighorn sheep, and moose herds across Montana. The methods were created in program R and consist of 7 general steps, moving from data cleaning to final products deliverable to MFWP Geographic Data Services. Generally, we:

1) Cleaned and formatted the GPS location data obtained from MFWP databases using standardized methods,
2) Set up the appropriate file structure for a Migration Mapper project (Merkle et al. 2022),
3) Performed behavior classification and date selection using Migration Mapper,
4) Delineated migratory routes using herd-specific scripts with a standardized formatting,
5) Delineated seasonal ranges using a general script that applied the same analytical, procedures to each herd,
6) Generated herd-specific summary reports, and
7) Delivered final products to MFWP Geographic Data Services.

These methods are detailed below (sections 1-7):

1) Data cleaning and formatting

In general, we queried the respective databases for the GPS locations of each species, flagged herds with fewer than five collared individuals to be excluded from further analyses, aggregated neighboring herds where appropriate, formatted and standardized date and time fields, censored locations with an HDOP > 10, added a field for elevation, and identified and censored duplicate records and other erroneous locations (i.e. records of collar transport before capture or after being removed from the animal). Lastly, we saved cleaned .rds, .csv, and .shp files to be used in future analyses. The final file contained the following fields and associated formats:

- AnimalID: Animal ID formatted as a character.
- Herd: the herd formatted as a character.
- DateTime: Date and time stamp formatted as a POSIXct (i.e. "2011-02-15 10:00:00")
- Date: Date DateTime
- JDay: Julian day formatted as a number
- Month: Ordered factor w/ 12 levels Jan, Feb, etc...
- Year: the year of DateTime
- Latitude: Latitude as number
- Longitude: Longitude as a number
- UTME: UTM easting as a number
- UTMN: UTM northing as a number

2) File structure

We organized all documents related to the mapping effort within a “MappingProjects” parent directory with the following subfolders:

- ➔ aaa_MigrationMapperApplicationFiles: Containing the files associated with the Migration Mapper application (including previous versions) as well as the associated functions used in the migration route analysis that were obtained from the Corridor Mapping Team (CMT) GitHub site (see Delineating migratory routes).
- ➔ Data: Containing the processed data and related files that are needed for the migration analysis.
- ➔ Projects: Containing the herd-specific projects for all species and herds with a Species_Herd naming convention, for example Elk_Bangtails.

- ➔ RScripts_General: Containing general scrips used to delineate seasonal ranges and summary reports for each herd.
- ➔ Writing: Containing writing documents associated the mapping project, including the final report.

For each herd, we created a MigrationMapper folder (within the Projects -> Species_Herd folder) that contains Output and ShapeFiles subfolders (Figure 1.1).

MappingProjects: Parent directory for all migration route and seasonal range mapping.

- ➔ **Projects**: Main project folder that contains the projects for all herds.
  - ➔ **Elk_Bangtails**: Example project folder for the Bangtails elk herd.
    - ➔ **MigrationMapper** Parent folder for the migration analysis and mapping.
      - o **Output**: This folder is initially empty but later serves as the repository for output from Migration Mapper.
      - o **ShapeFiles**: Contains the shapefile of herd-specific GPS locations following the Species_Herd naming convention.

Figure 1.1. Example file structure for each herd project in Migration Mapper.

3) Migration Mapper

Overview

We used the Migration Mapper (v2.2; https://migrationinitiative.org/content/migration-mapper) application to classify migratory behavior and migratory periods (i.e., start and end dates) for each herd. Migration Mapper is a Shiny application that is written in R and generates a web-based graphical user interface (GUI) where users can visualize the GPS locations and associated net-squared displacement (NSD) curves (Bunnefeld et al. 2011) of each individual-year within a herd. The application has a series of tabs that walk users through importing and formatting data (tabs 1-4), date selection and behavior classification (tab 5), migration route delineation (tabs 6-7), winter range delineation (tabs 8-9), and final mapping (tab 10; Figure 1.2). Users can also set several analytical parameters in the Analysis Parameters tab. An exhaustive description of the Migration Mapper workflow is beyond the scope of this document. However, a detailed user guide for Migration Mapper can be found at the Wyoming Migration Initiative webpage (https://migrationinitiative.org/content/migration-mapper-user-guide). Moreover, our methods used only a small portion of the Migration Mapper (tabs 1-6) capabilities before moving into an R-based workflow.

In general, we used tabs 1–6 in Migration Mapper to perform the following tasks. In tab 1, we specified the data analyst, provided file paths to the Shapefiles and Output folders (i.e., Figure 1), set the starting date for NSD, and selected the field containing the unique animal ID. The default date from which to begin calculating NSD is 1-Feb in Migration Mapper. We changed this to 15-Feb for all species and herds as some individuals had not yet returned to their winter range by the

1-Feb default setting. In tab 1, it is also possible to resume an existing project by navigating to the Output folder of an existing project. In tab 2, we identified the date-time field(s). In tab 3, we identified the date-time elements and specified the time zone. Once this step was executed, Migration Mapper then performed several data checks in the background, the specifics of which are described in the user guide. Before continuing to tab 4, a warning page commonly appeared that described possible errors in the data, for example, the proportion of locations with > 8 hours between timestamps. In tab 4, we reviewed the summaries of the imported data. This tab was helpful to identify potential duplicates or other issues in the data that were flagged in the aforementioned warning page and missed in the cleaning process. If errors were discovered, we fixed the issues within the data cleaning script and reimported a new GPS location shapefile before restarting the project from tab 1. In tab 5, we classified the migratory behavior and identified the spring and fall migratory periods for each animal-year. These steps were a substantial part of the analysis and are further described in the respective sections below (see *Classifying migratory behavior* and *Migration date selection*). Lastly, in tab 6, rather than continuing with the migration route and seasonal range delineation in Migration Mapper, we exported the final migtime.csv and points shapefile. The migtime.csv contained the migratory behavior classification and spring and fall migration dates for each animal-year (Table 1.1). The exported shapefile was named pointsOut (by default) and contained the GPS locations as well as additional attributes specifying season, migratory behavior, and other metadata.

Table 1.1. Header of the migtime.csv output from tab 6 of Migration Mapper. The file contains the migration start and end dates migratory behavior classification of each individual-year.

id_yr	newUid	nsdYear	startSpring	endSpring	startFall	endFall	springMig	fallMig	moveType	fallMigDst	springMigDst
BT10001_2011	BT10001	2011	5/22/2011	5/30/2011	12/29/2011	1/7/2012	1	1	migrant	3816	17162
BT10020_2011	BT10020	2011	4/29/2011	6/6/2011	11/12/2011	12/15/2011	1	1	migrant	43559	94866
BT10023_2011	BT10023	2011	4/23/2011	5/28/2011	12/19/2011	1/4/2012	1	1	migrant	17287	40310
BT10028_2011	BT10028	2011	5/13/2011	5/29/2011	12/28/2011	1/8/2012	1	1	migrant	17794	41262
BT10029_2011	BT10029	2011	5/21/2011	6/4/2011	12/5/2011	12/22/2011	1	1	migrant	29390	60841
BT10033_2011	BT10033	2011	5/11/2011	5/19/2011	NA	NA	1	0	migrant	NA	23998
BT10035_2011	BT10035	2011	5/7/2011	6/15/2011	11/25/2011	12/6/2011	1	1	migrant	25571	70193

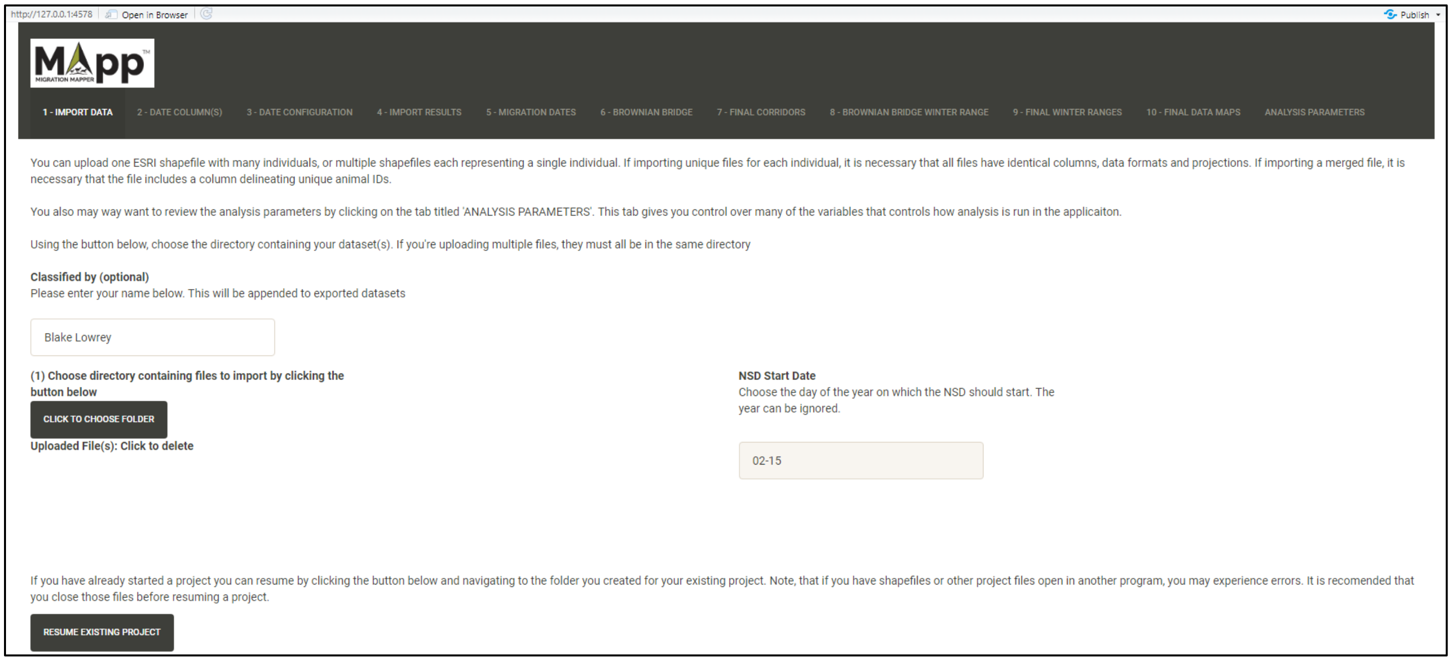

Figure 1.2. Screen shot of the Migration Mapper GUI for tab 1. The tabs are across the top of the page. Using the prompts on each page as well as the user guide, users can navigate the tasks on each tab to import data, conduct analyses, and export final spatial products. Tab 1 is also where users set the NSD start date as shown in the center of the page. Users can resume an existing project by navigating to the Output folder of an existing project after clicking on the prompt in the lower left side of the page.

Classifying migratory behavior

Tab 5 allowed users to visually inspect the GPS locations and the respective NSD curves for each animal-year when classifying migratory behavior. We used a subset of the classifications available in Migration Mapper and broadly classified each animal-year as either Migrant, Resident, or None. We did not use the additional Migration Mapper classifications (e.g., Mixed-migrant, Nomad, Unsure, or Other). Animal-years classified as Migrant had a spring or fall migration between two distinct or semi-distinct seasonal ranges which were mostly non-overlapping. This included both long-distance migrations where individuals traversed broad (i.e., > 10 km) and complex landscapes as well as short-distance migrations, typically along elevation gradients, where individuals moved relatively short distances (e.g., < 10 km) between seasonal ranges (Figure 1.3). In the case of short-distance migrations, seasonal ranges were sometimes partially overlapping, yet two semi-distinct seasonal ranges were distinguishable. We entered abbreviations for short-distance migrant (SDM) or long-distance migrant in the comments section of Migration Mapper to distinguish the two migratory behaviors. Individual-years with only a single migration (i.e., only a spring or fall migration) were classified as migratory if they followed population patterns or seemed like a reasonable migratory movement (i.e., not wanderings) and ended at a clear seasonal range. The migrant classification also included dispersers (i.e., individuals that underwent a spring migration but did not return in the fall). We included these movements as migrations to highlight dispersal routes as migration routes. Individual-years classified as Resident had a sufficient monitoring period (i.e., were monitored through the summer period [end of July or August]) with no sign of a migratory movement or distinct seasonal ranges. Lastly, animal-years classified as None had insufficient data to determine their migratory behavior. This included animals that initiated a migration but were not observed establishing a clear seasonal range due to death or collar failure within the migratory period. This also included individuals with a clear migration that contained data gaps during the migratory sequence such that the arrival or departure dates could not be determined accurately (this situation was rare and mostly occurred in the Elkhorns elk herd where the collars recorded a single daily location and hid a high proportion of missed fixes). All animals classified as None, had 'Limited data' entered in the Additional notes section. When working in Migration Mapper, both the spring and fall migration boxes were checked by default when the respective slider bar was moved. If an animal-year was classified as Resident or None after moving the slider bars, both the spring and fall migration boxes needed to be unchecked. Conversely, these boxes were checked for the season in which a migration occurred for migrant individuals.

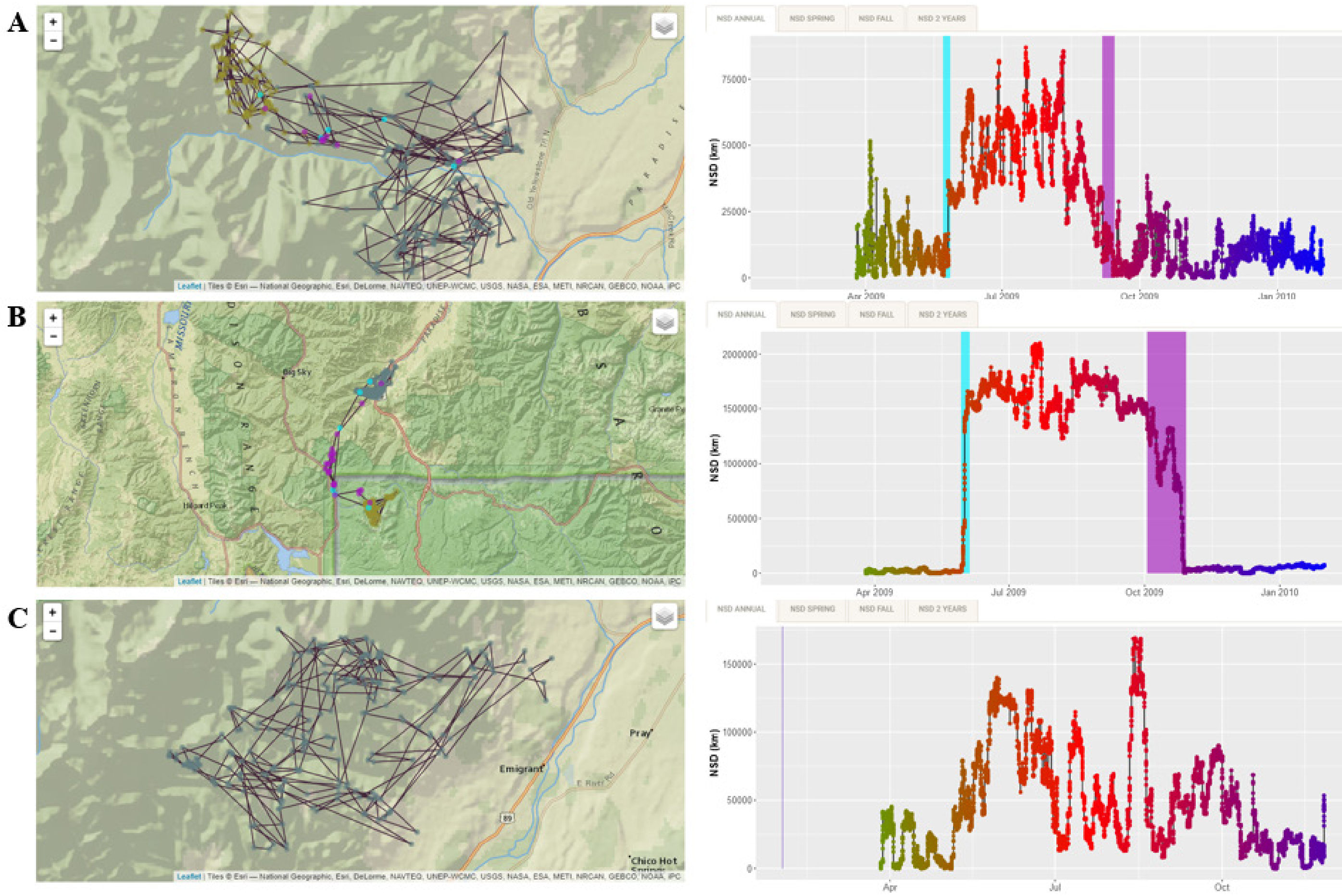

Figure 1.3. Examples of short-distant migrant (A), long-distant migrant (B), and resident (C) classifications as visualized in Migration Mapper (tab 5). While the seasonal ranges were partially overlapping for short-distance migrants (A), there are two semi-distance winter (grey) and summer (green) ranges separated by relatively short spring (light blue) and fall (purple) migrations. In contrast, long-distance migrations (B) had fully distinct seasonal ranges separated by relatively long migrations. The two behaviors were also characterized by differing NSD plots. While long-distance migrants (B) had a very clear delineation between the NSD values on each seasonal range, short-distance migrants had more overlap in the NSD values within the summer and winter periods. Residents (C) had no differences in annual use patterns when looking at either the map of GPS locations or NSD plot.

Migration date selection

We used the slider bars in tab 5 of Migration Mapper to identify migration start and end dates for each animal-year. We defined the start of migration as the date of the first linear sequence indicating movement away from a seasonal range towards a separate seasonal range after which the individual did not return until the following season. With this definition, spring exploratory movements in which an individual left the winter range but then returned a few days later were not included in the migration sequence. Stopover areas, where individuals slowed or paused their migration to forage or calve/fawn, were included in the migration sequence and were present in both spring and fall migrations (Figure 1.4). Depending on the position of the stopover site relative to seasonal range, stopover areas could look like steps in the NSD curve or have other appearances (Figure 1.4). A migration ended when an individual arrived at a new seasonal range where they stayed for > 30 days. For a movement to be considered a migration, individuals needed to stay on a seasonal range for a minimum of 30 days.

When using Migration Mapper, we first looked at the NSD plot to get the general date range. We then fine-tuned the dates by looking mainly at the map of GPS locations and stopped moving the date slider we there was a single point in or very near the summer or winter range. The dates selected with the slider bars were recorded by Migration Mapper and included in the final migtime.csv.

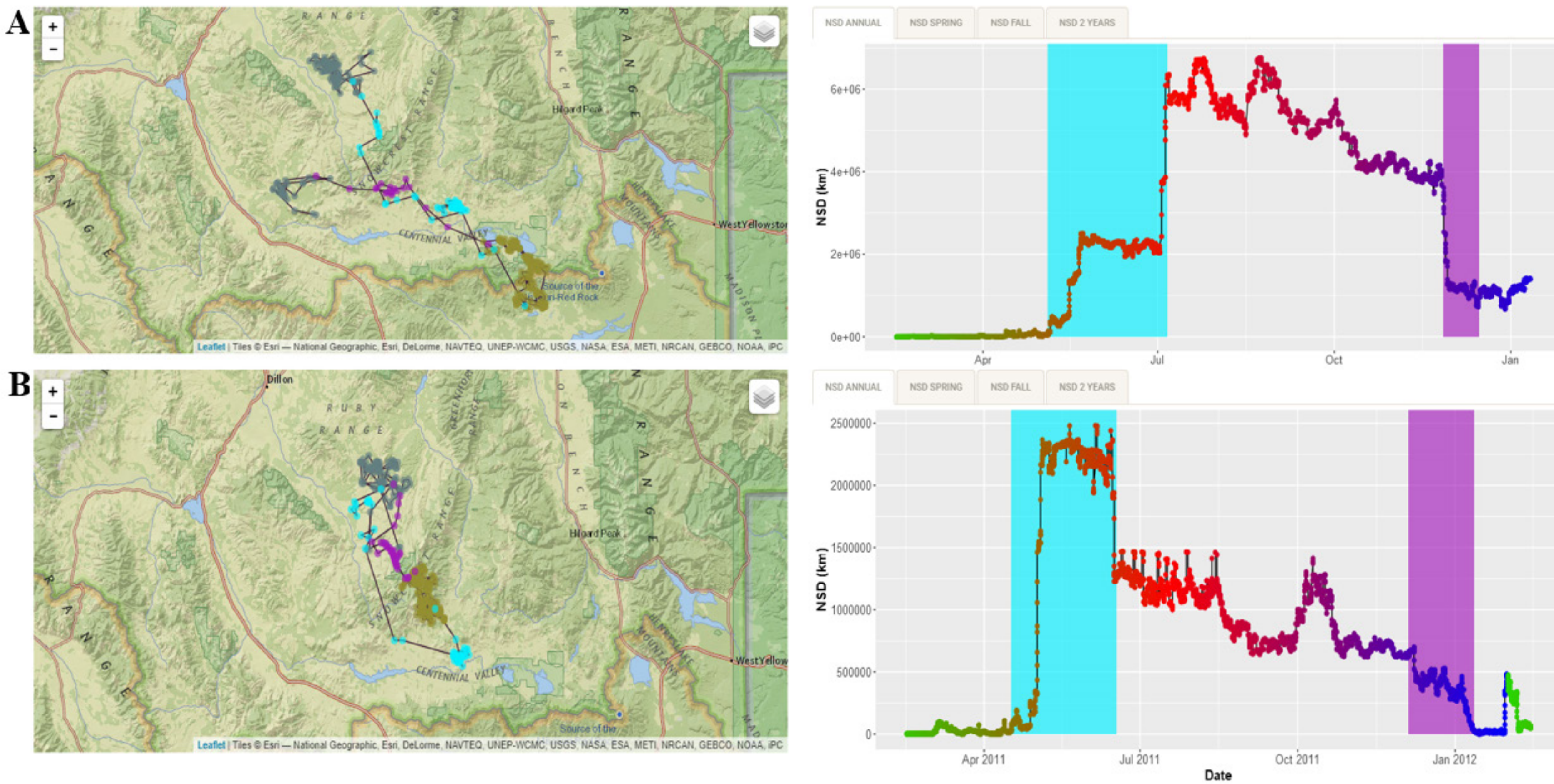

Figure 1.4. Two examples of stopover sites used by individuals in the Blacktail elk herd as visualized in Migration Mapper (tab 5). When the stopover was enroute to the final summer range, use of the stopover resulted in steps in the NSD curve (A). In contrast, when the stopover was beyond the final summer range, there was a high NSD plateau before moving to the summer range (B). Both examples were included in the migration sequence.

4) Delineating migratory routes

Once the migration periods were identified for each individual-year, we used two different variations of the Brownian Bridge Movement Model (BBMM; Horne et al. 2007) to delineate population-level migration routes. In general, the BBMM estimates the probability of where an animal could have traveled between two sequential GPS locations. When this process is conducted for all GPS locations in a migration sequence, the BBMM provides a utilization distribution (UD) estimate of the width of the movement path around the straight line between the successive locations, and can be used to identify migration routes (Sawyer et al. 2009) and stopover sites (Sawyer and Kauffman 2011). A key parameter of the BBMM is the Brownian Motion Variance (BMV), which provides an index of the mobility of the particular animal under observation (Horne et al. 2007). For animals with frequent re-locations, the BMV is generally less than 8000 and can be estimated with a traditional BBMM. However, for animals with one or two daily locations (i.e., life-cycle collars) the BMV can be extremely large (i.e., > 8000) and result in exceptionally large (i.e., wide) movement paths due to the increased uncertainty in the movement path between two GPS locations. These two situations required slightly different implementations of the BBMM when estimating migration routes for individuals with frequent or infrequent relocation schedules. In most cases, we used the traditional BBMM methods to calculate migration routes (see Traditional BBMM section). However, when GPS collars had missed fixes or a course fix frequency resulting in large breaks in the migration sequence, we used a modified Fixed Motion Variance (FMV) BBMM approach (see Fixed motion variance BBMM section).

Traditional BBMM

We used the traditional BBMM for all migration sequences with an estimated BMV < 8000. In this approach we applied a four-step process to calculate population-level migration routes which generally followed the approach outlined by Sawyer et al. (2009). We first estimated unique UDs for each migration sequence using a grid with 50-m resolution. When migration sequences had a data gap of ≥ 8 hours (i.e., an 8-hour time lag), we did not build a bridge between the two locations. Second, we averaged the UDs for a given individual's spring and fall migration sequences across all years to produce a single, individual level migration UD. We then rescaled this averaged UD to sum to 1. Third, we defined a migration route footprint for each individual as the 99% isopleth of the UD. Lastly, we stacked all the individual footprints for a given population and defined different levels of migration route use based on the number of individuals using a given pixel. We defined low-use migration route as areas traversed by ≥ 1 collared individual during migration, medium-use migration routes were used by ≥ 5 or 10% of collared migrants within the population, and high-use migration routes were used by ≥ 15 or 20% of collared migrants within the population. We then converted the migration routes from a grid-based format to a polygon format, while removing isolated use polygons of less than 20,000 m^2 (i.e., less than approximately five acres). When converting final migration route from grid to polygon data, all 50-m pixels were preserved in the final migration routes.

While we generated the three levels of migration route use, after further conversations among FWP staff, we chose to only display the low use areas on FWP maps and outreach materials. The medium and high use classifications were influenced by the number of collars deployed in a herd, the distribution of collars within a herd, and the migration patterns of collared individuals, and may not reflect true importance or relative use. For example, migration routes that appear to be used by only a single individual that was collared outside of the primary capture area may reflect the limited sample of collars in the immediate vicinity rather than the importance of a particular migration route or its relative use by the entire herd, inclusive of uncollared individuals. Rather than including potentially misleading classifications of importance, the classification of the single migration route footprint provided an equal weight for all mapped migration routes.

Fixed Motion Variance BBMM

We used the modified FMV BBMM approach to accommodate the increased uncertainty of migration sequences with an estimated BMV ≥ 8000. The FMV approach generally followed the traditional BBMM multi-step process to calculate population-level migration routes, however, instead of estimating the BMV empirically for each migration sequence, we fixed the BMV at a specified value. We used FMV values of 1,200 for elk and 1,100 for mule deer as suggested by Fattebert et al. (*In review*). These values were identified using simulation work to compare the overlap of migration routes generated with varying FMV values and a dataset that was subsampled to the 13-hour life-cycle fix rate, with migration routes generated using a full dataset (i.e., 2-hour fix rate) and the traditional BBMM (Fattebert et al. *In review*). Of the multiple FMV values that were evaluated, these resulted in the maximum overlap with the migration routes created with full dataset while minimizing the increased spatial extent (Fattebert et al. *In review*). Additionally, to accommodate the course fix schedules of life-cycle collars or other data gaps, we specified a time lag that was one interval greater than the collar fix rate when implementing the FMV approach. A smaller FMV value would generate a tighter migration route, while a larger maximum time would build Brownian bridges between successive locations farther apart in time.

Both methods were conducted within an R-based workflow using a series of functions that conducted the main procedures of creating the migration sequences, conducting the individual Brownian bridge analyses, calculating the population average Brownian bridge, and generating final polygon shapefiles. The functions were initially written by Jerod Merkle and are available via GitHub (https://github.com/hcopeland/CorridorMappingTeam). These functions also provided additional output files to the tabSixOutput folder, for example the metadata_migration.csv used to generate seasonal ranges (see *Delineating seasonal ranges section*). We changed function arguments to implement the traditional BBMM or FMV methods.

5) Delineating seasonal ranges

Our approach to delineate seasonal ranges differed from the Brownian Bridge methods used by the other western states (Kauffman et al. 2020). We opted for a kernel density estimate (KDE) approach after generating comparative maps of seasonal range estimates for multiple herds using KDE, autocorrelated kernel density estimation (AKDE), and BBMM (Figure 1.5). The KDE approach has a long history in ungulate spatial ecology, required relatively little processing time (in stark contrast to the ADKE), and provided an intermediate option in comparison to the BBMM which was relatively tight and the AKDE which was relatively broad (Figure 1.5). We used a R-based workflow that incorporated the cleaned .rds file containing the GPS locations obtained from FWP databases (see Data cleaning and formatting section), as well as the migtime.csv generated from Migration Mapper (Table 1) and the metadata_migration.csv which was created as an output file when building the individual migration sequences in the migration route analyses. For each herd we delineated 50, 95, and 99 percent home range contours for winter, summer, and annual periods. The contours represented the smallest areas where the probability of relocating an individual from the population was equal to the given percentages (i.e., 50, 95, and 99 percent). In general, we defined winter as the period between the 0.95th quantile of fall migration end dates and the 0.5th quantile of spring migration start dates, and defined summer as the period between the 0.95th quantile of spring migration end dates and the 0.5th quantile of fall migration start dates (Figure 1.6). For herds that were fully or predominantly resident, there were an insufficient number of migrants to define population-level seasonal dates. In these instances, we used set dates based on a calendar year (all moose and mule deer herds) or set dates estimated from the quantiles of migrant herds of the same species (resident elk and bighorn sheep herds). The set dates used for each species are below.

- Elk – Winter: 17-Nov to 06-May, Summer: 14-July to 17-October.
- Mule deer – Winter: 1-December to 31-March, Summer: 1-July to 1-September.
- Bighorn sheep – Winter: 23-December to 19-May, Summer 23-July to 7-November.
- Moose – Winter: 1-December to 31-March, Summer 1-July to 30-September.

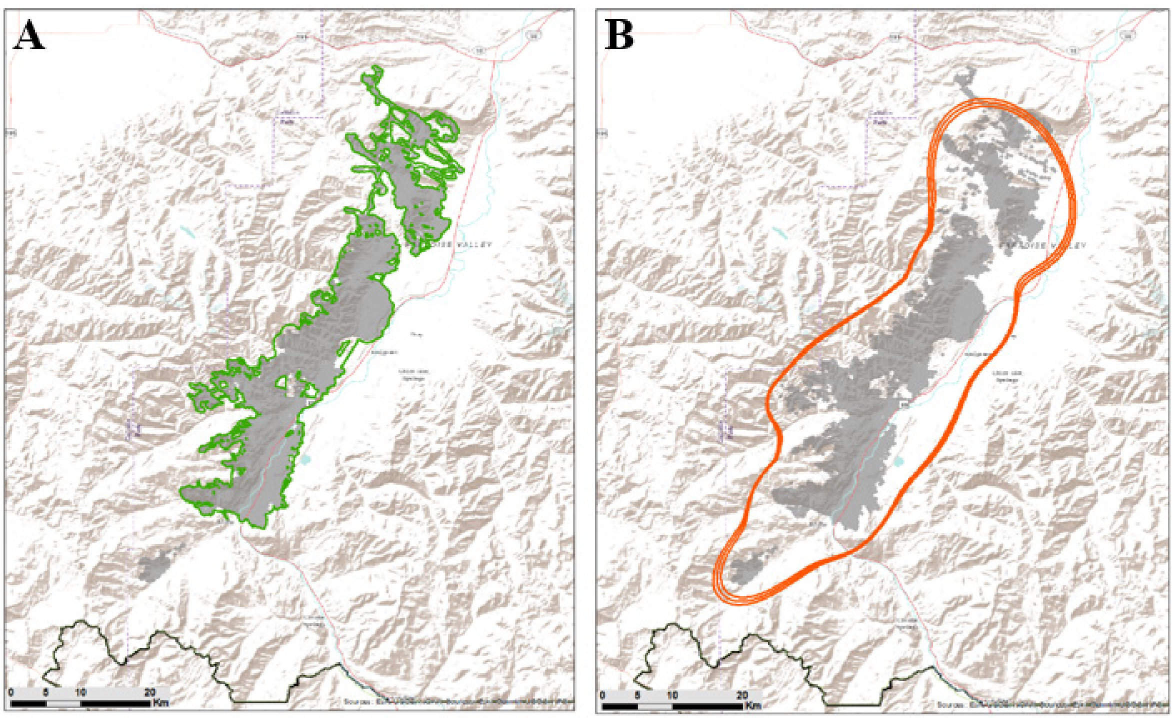

Figure 1.5. Ninety-nine percent BBMM (A) and AKDE (B) winter range estimates and associated GPS locations (grey) for the Big Creek elk herd. The BBMM methods produced a tight home range with linear features as seen in the northern portion of study area. The AKDE produced a broad winter range polygon and included areas well beyond the know distribution of the population, for example east of Hwy 89.

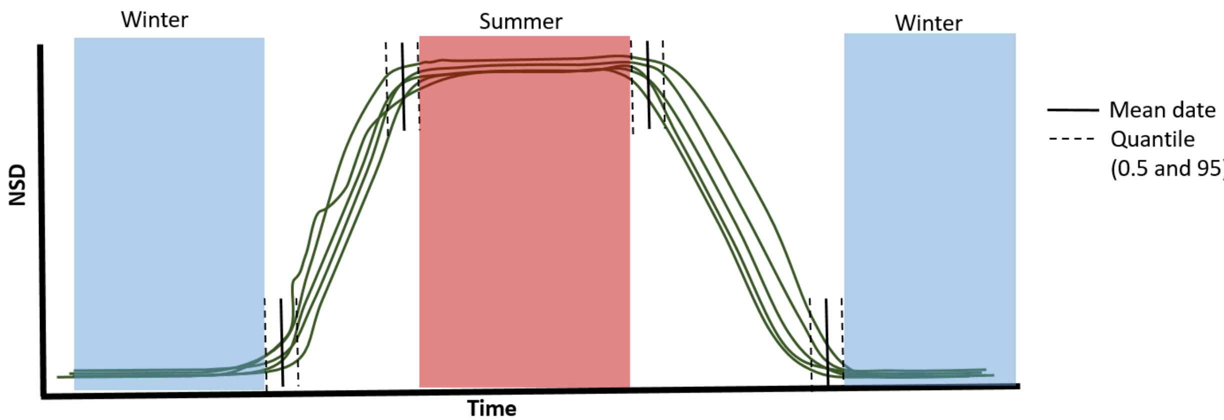

Figure 1.6. Five example NSD curves (green lines) and the resulting summer (red) and winter (blue) intervals. The solid and dashed vertical lines represent the mean and quantiles (0.5 and 0.95), respectively for the distribution of individual spring and fall migration start and end dates.

For each herd we used an iterative process that first subset the GPS locations to a single seasonal period (i.e., winter, summer, or annual). The winter periods generally started at the end of one year and continued through the beginning of the following year, for example Nov-2008 to May-2009. As a result, we set the annual period to begin at the end of the fall migration and terminate at the end of the spring migration the following year. For each seasonal period we further subset the data to a single year, randomly selected a single daily location for each individual, and censored individuals with fewer than 30 days of monitoring within a year. Using only one daily location helped to reduce auto correlation among the GPS locations for each individual-year. For each seasonal period and year, we generated individual KDEs across a common spatial extent using the href smoothing parameter. We then averaged 1) the individual KDEs within a year to estimate a population-level KDE for each year and 2) the resulting yearly population-level KDEs to estimate a single population-level KDE for each seasonal period. From each seasonal population-level KDE, we extracted the 50, 95, and 99 percent contours and included the contour percentile as a field in the metadata table (i.e., attribute table). The resulting polygons were saved with the Species_Herd_Season.shp (i.e., Elk_Blacktail_Summer.shp) naming convention.

6) Metadata

We output metadata pertaining to the general project (i.e., project start and end dates and number of animals sampled), migration (i.e., dates and distance), and the seasonal ranges (dates and sizes). The final metadata table contained the following fields. Date fields were summarized across individuals and years and represent the median if ≥ 3 individual-years were present and the mean if 2 individual years were present.

SPECIES: Species (i.e., Elk, Mule deer, etc.)
HERD: Herd name
SEASON: Annual, Summer, or Winter for the seasonal range analysis and Migration route for the migration route analysis.
PROJ_SAMPLE_TOTAL: Total number of collared animals in the population.
PROJ_FIX_RATE: The number of programmed fixes collected per day.
PROJ_Duration: the project duration in months
PROJ_Start: Month and day of the first GPS location.

PROJ_End: Month and day of the last GPS location.
PROJ_Duration: Difference (in months) between PROJ_Start and PROJ_End.
Use_Contour: Denotes the 50, 95, and 99 percent KDEs for the home ranges and Low, Medium, and High use for migration routes.
SEAS_Start_Date: The median start date (day-month) of the summer and winter periods for the home range analysis.
SEAS_End_Date: The median end date (day-month) of the summer and winter periods for the home range analysis.
SEAS_Data: The total number of animal-years used to generate the summer, winter, and annual ranges.
AREA_SQKM: Area (km^2) of the seasonal home ranges.
MIG_Data: Number of individuals and sequences used to delineate migration routes.
MIG_Spring_Start_Date: Median start date of spring migration.
MIG_Spring_End_Date: Median end date of spring migration.
MIG_Spring_Days_Migrating: The duration (in days) between the median spring start and end dates.
MIG_Fall_Start_Date: Median start date of fall migration.
MIG_Fall_End_Date: Median end date of fall migration.
MIG_Fall_Days_Migrating: The duration (in days) between the median fall start and end dates.
MIG_Spring_Mean_Distance: Mean distance (in kilometers) of spring migration.
MIG_Fall_Mean_Distance: Mean distance (in kilometers) of fall migration.
MIG_Spring_Median_Distance: Median distance (in kilometers) of spring migration.
MIG_Fall_Median_Distance: Median distance (in kilometers) of fall migration.
MIG_Spring_Max_Distance: Max distance (in kilometers) of spring migration.
MIG_Fall_Max_Distance: Max distance (in kilometers) of fall migration.
MIG_Spring_Min_Distance: Min distance (in kilometers) of spring migration.
MIG_Fall_Min_Distance: Min distance (in kilometers) of Fall migration.
DATA_Projection: GIS projection.

7) Summary report

We generated a pdf summary report for each herd that contained a project description, movement overview, the associated metadata for the project, migration routes and seasonal ranges, as well as figures depicting the seasonal use of public lands and the proportion of each migration behavior. The summary reports were generated using a ‘parent’ and ‘child’ relationship within an r-based workflow.

Results

We delineated and mapped ungulate seasonal ranges and migration corridors for 21 elk (Figure 1.7), 12 mule deer (Figure 1.8), 10 bighorn sheep (Figure 1.9), and 4 moose (Figure 1.10) herds across Montana (Table 1.2).

Table 1.2. Summary of ungulate herds used to delineate and map seasonal ranges and migration corridors.

			Spring migration		Fall migration	
Species	Herd	No. individuals	Start	End	Start	End
Elk	Bangtails	16	8-May	16-May	29-Sep	24-Oct
	Big Creek	43	7-Jun	12-Jun	5-Oct	10-Oct
	Blackfoot Clearwater	18	24-Apr	23-May	--	--
	Blacktail	27	29-Apr	22-May	26-Nov	17-Dec
	Clark's Fork	9	29-May	6-Jun	27-Jan	29-Jan
	East Fork Bitterroot	64	8-May	21-May	2-Nov	28-Nov
	Elkhorns	59	21-May	28-May	30-Oct	04-Nov
	Gallatin	23	6-May	18-May	23-Oct	26-Oct
	Greeley	20	25-Apr	8-May	19-Oct	26-Oct
	Madison	87	13-May	31-May	29-Oct	15-Nov
	Mill Creek	22	4-May	12-May	2-Oct	7-Oct
	Missouri Breaks	47	30-Apr	1-May	13-Sep	15-Sep
	Northern Madison	21	23-Apr	29-Apr	18-Oct	19-Oct
	Northern Sapphire	139	1-May	7-May	16-Oct	24-Oct
	Northern Yellowstone	108	13-May	2-Jun	8-Oct	11-Nov
	Pioneers	30	21-May	2-Jun	25-Sep	20-Nov
	Sage Creek	28	31-Mar	1-May	20-Nov	23-Dec
	Silver Run	20	5-May	30-May	16-Nov	19-Nov
	Tendoys	50	26-Apr	7-May	13-Oct	24-Oct
	Tobacco Roots	22	8-Jun	9-Jun	5-Nov	6-Nov
	West Fork Bitterroot	46	27-Jun	4-Jul	27-Sep	28-Sep
Mule Deer	Boxelder	17	22-Mar	23-Mar	29-Nov	30-Nov
	Cabinet-Salish	40	7-May	17-May	7-Oct	12-Oct
	Culbertson	31	17-May	19-May	28-Dec	29-Dec
	Devils Backbone	17	14-Mar	15-Mar	23-Apr	28-Apr
	Glendive-Sidney	36	12-May	18-May	15-Sep	18-Sep
	Lodge Creek-Milk River	24	--	--	--	--
	Philipsburg	31	17-May	5-Jun	27-Nov	28-Nov
	Rocky Mtn Front	49	22-May	28-May	9-Oct	17-Oct
	Sapphire North	28	--	--	--	--
	Sapphire South	21	4-May	10-May	6-Oct	9-Oct
	Sweetgrass	25	--	--	--	--
	Whitefish	44	20-May	28-May	13-Oct	4-Nov
Bighorn sheep	Castle Reef	27	18-May	29-May	31-Oct	4-Nov
	Fergus	25	23-May	26-May	1-Oct	2-Oct
	Lost Creek	26	6-May	12-May	23-Nov	26-Nov
	Middle Missouri	18	--	--	--	--
	Paradise	24	--	--	--	--
	Petty Creek	23	--	--	--	--
	South Madison	52	22-May	30-May	26-Nov	2-Dec
	Spanish Peaks	12	22-May	31-May	5-Nov	10-Nov
	Stillwater	20	24-May	31-May	17-Oct	21-Oct
	Upper Yellowstone	6	11-May	15-May	1-Nov	3-Nov
Moose	Cabinet-Salish	39	18-Apr	30-Apr	22-Dec	29-Dec
	Mount Haggin	10	24-Apr	11-May	11-Oct	14-Oct
	Rocky Mtn Front	41	5-Jun	15-Jun	2-Oct	13-Oct
	Upper Big Hole	35	23-Apr	28-Apr	20-Nov	8-Dec

Migratory behaviors varied within and across species and herds, and ranged from herds that were fully resident to those that were largely migratory (Figure 1.11 and 1.12). We also observed notable variation in the proportion of GPS locations on public lands with some herds almost completely on public lands for both summer and winter seasons, while other herds were predominantly on private lands annually (Figure 1.13 and 1.14).The final seasonal ranges, migration routes, and summary report was provided to MFWP Geographic Data Services for inclusion in the strategy for wildlife movement and migration.

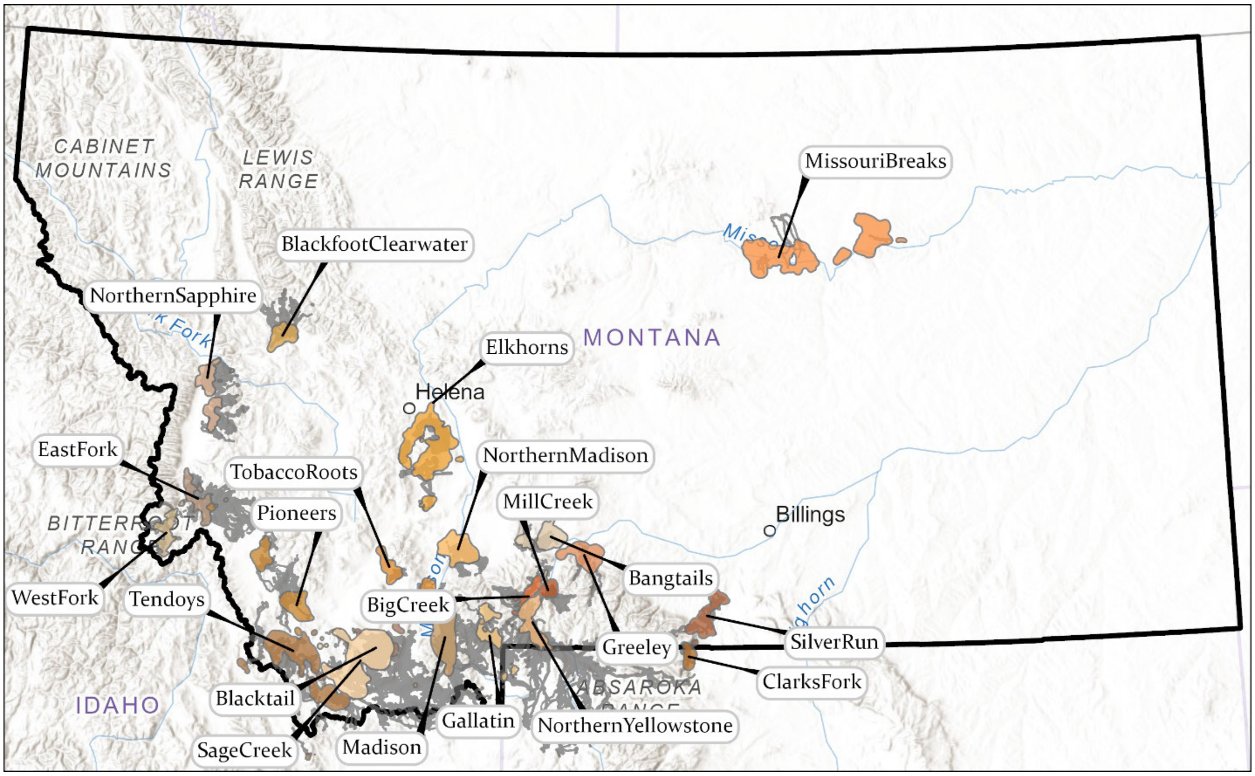

Figure 1.7. Ninety-five percent home range contours representing winter ranges (orange) and migration footprints (gray) for elk herds included in the state-wide mapping effort.

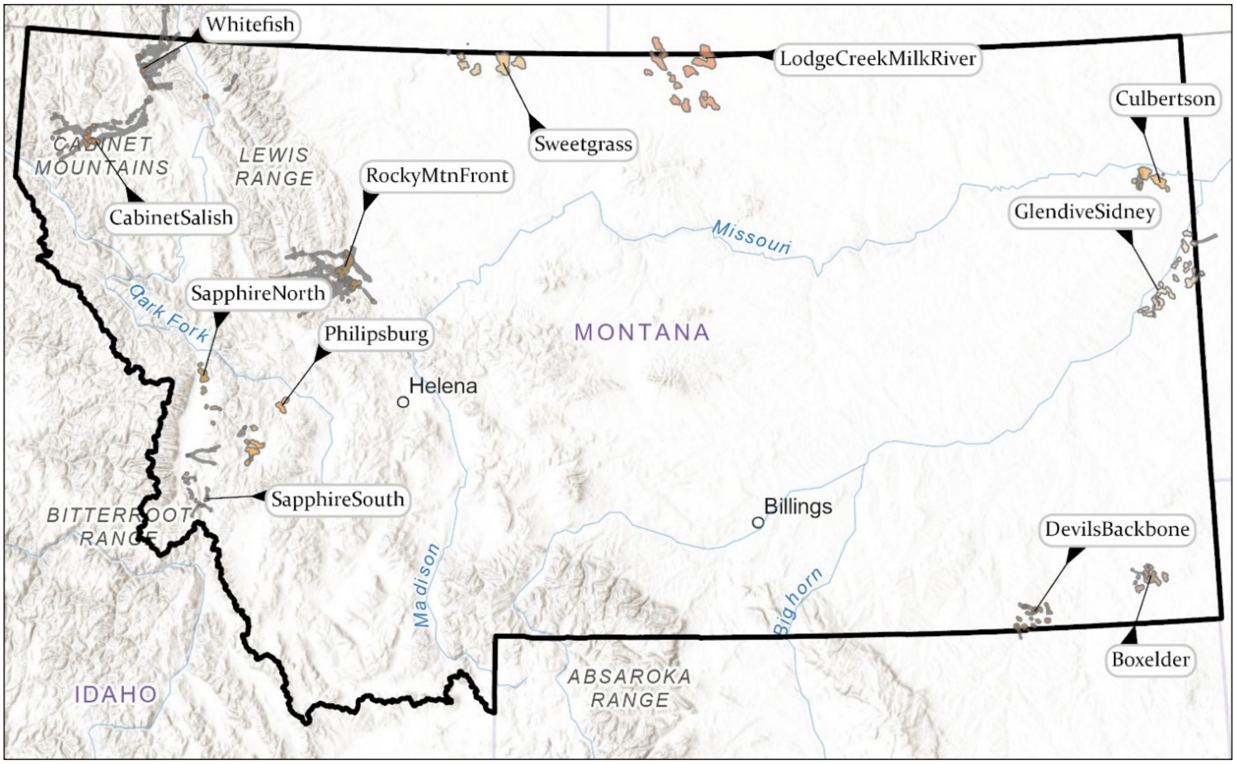

Figure 1.8. Ninety-five percent home range contours representing winter ranges (orange) and migration footprints (gray) for mule deer herds included in the state-wide mapping effort.

Figure 1.9. Ninety-five percent home range contours representing winter ranges (orange) and migration footprints (gray) for bighorn sheep herds included in the state-wide mapping effort.

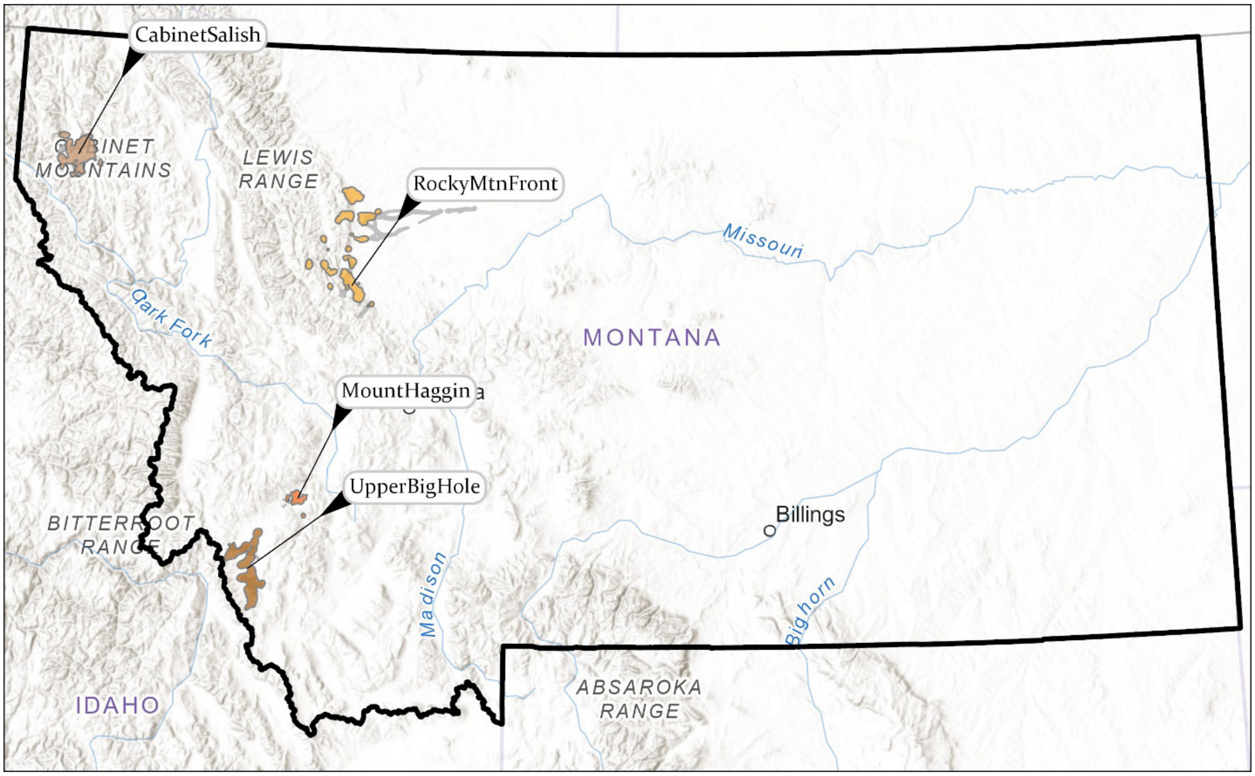

Figure 1.10. Ninety-five percent home range contours representing winter ranges (orange) and migration footprints (gray) for moose herds included in the state-wide mapping effort.

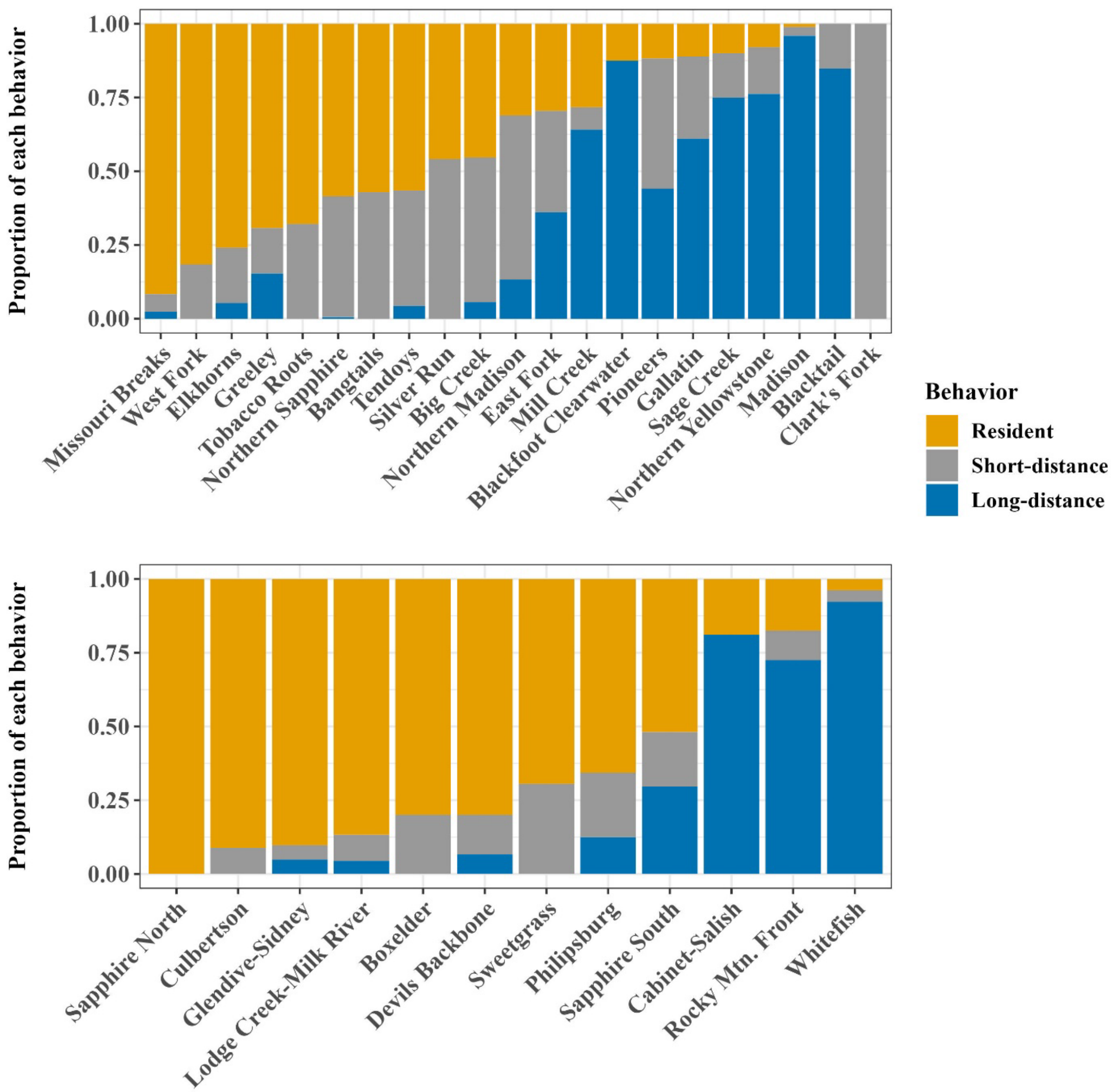

Figure 1.11. The proportion of resident, short-, and long-distant migrant individuals in each of the elk (top) and mule deer (bottom) herds included in the statewide mapping effort. Refer to the "Classifying migratory behavior" section for migratory behavior definitions.

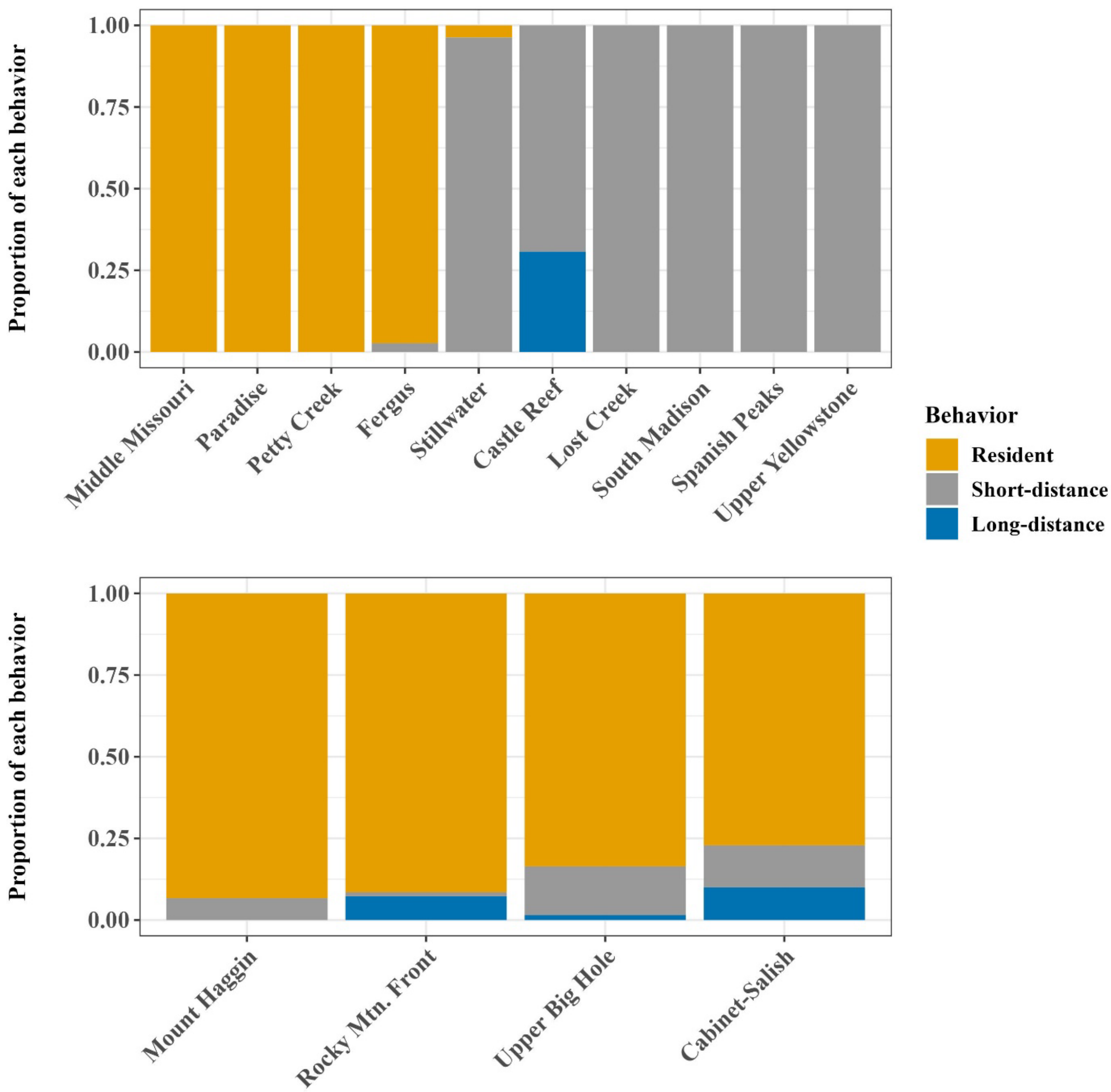

Figure 1.12. The proportion of resident, short-, and long-distant migrant individuals in each of the bighorn sheep (top) and moose (bottom) herds included in the statewide mapping effort. Refer to the "Classifying migratory behavior" section for migratory behavior definitions.

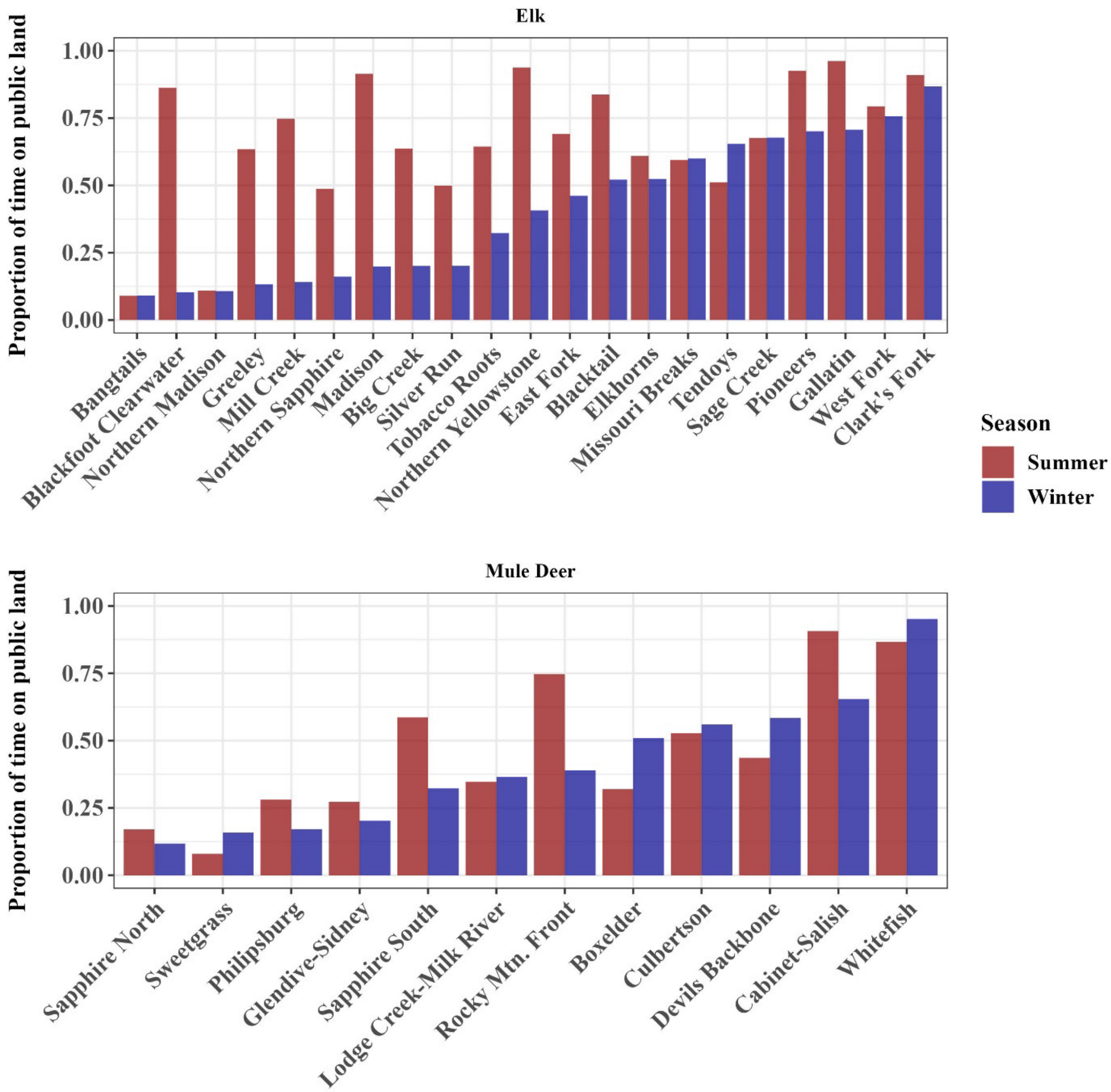

Figure 1.13. The proportion of elk (top) and mule deer (bottom) GPS locations on public lands for the summer and winter periods for all herds included in the state-wide mapping effort.

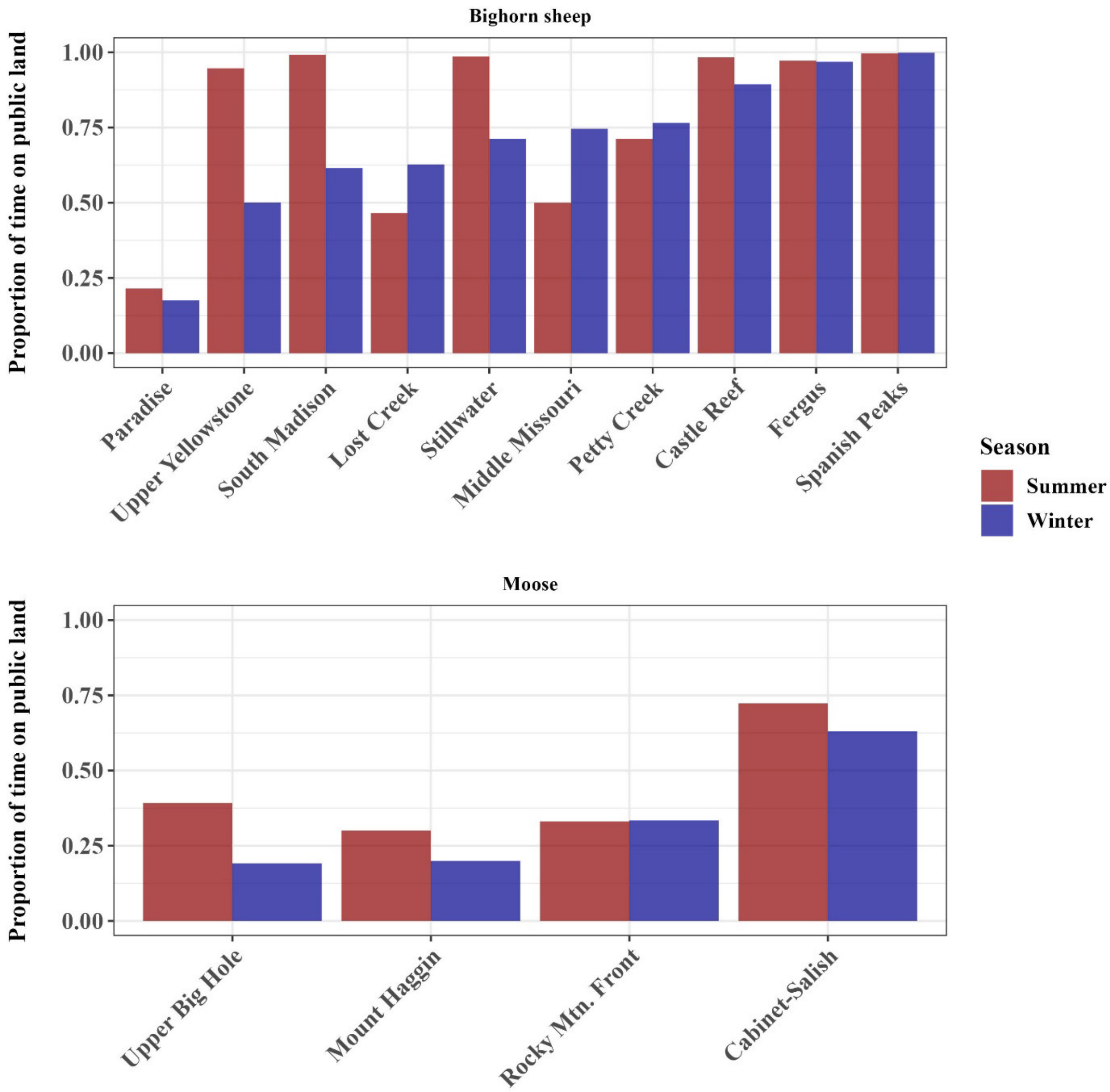

Figure 1.14. The proportion of bighorn sheep (top) and moose (bottom) GPS locations on public lands for the summer and winter periods for all herds included in the state-wide mapping effort.

Objective #2: ***Collect seasonal movement data from pronghorn in the Madison Valley.***

During Jan and Feb of 2019, 2020, and 2021, we captured and collared a total of 82 adult female pronghorn (40, 20, and 22, respectively). Collars were programmed to record locations every 2 hours (2019 collars) or every hour (2020 and 2021 collars) and transmit locations and mortality alerts through the Iridium satellite network. Of the 82 collared animals, 10 (12%) had collar malfunctions and 55 (67%) died (Figure 2.1). Mortality investigations were completed as soon as possible after receiving the mortality alerts. Of the mortalities, causes included 15 (27.3%) predation from coyote, 13 (23.6%) unknown cause, 7 (12.7%) predation from unknown predator, 7 (12.7%) natural (includes starvation and injury), 5 (9.1%) legal harvest, 2 (3.6%) disease, 1 (1.8%) predation from wolf, 1 (1.8%) predation from mountain lion, 1 (1.8%) illegal take, 1 (1.8%) vehicle collision, 1 (1.8%) train collision, and 1 (1.8%) capture-related. We ended collection of GPS collar data on July 24, 2023, at which point 17 collared animals were still alive (21% of the total captured).

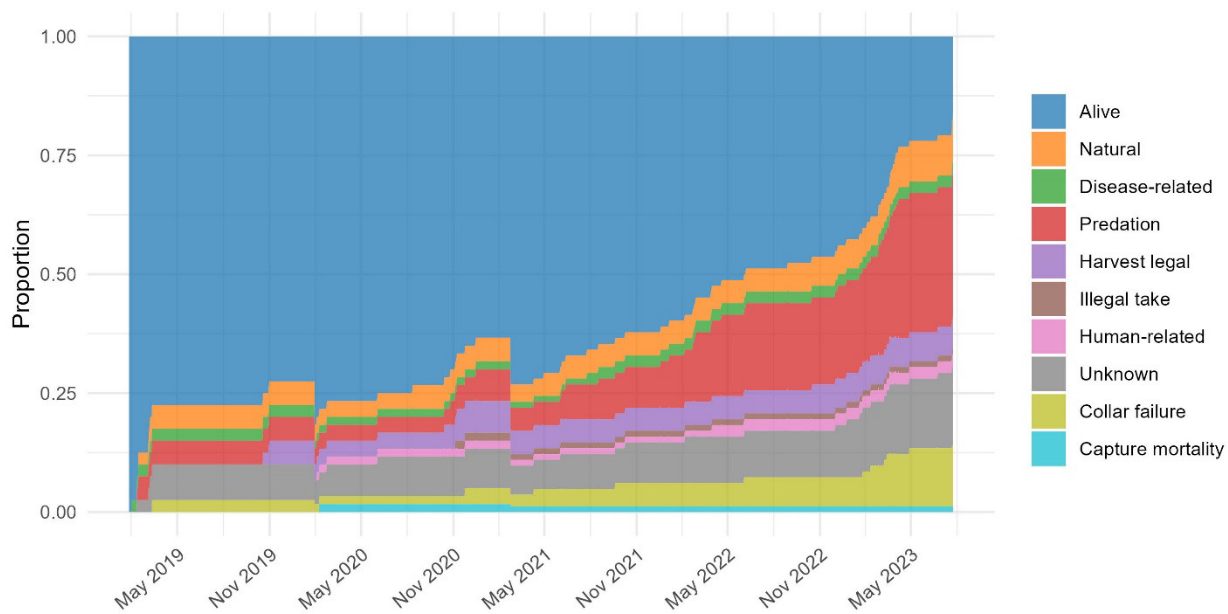

Figure 2.1. Proportion through time of collared adult female pronghorn remaining alive (dark blue), with a malfunctioned collar (gold), or dead (colored by cause of death) in the Madison study area from January 2019 to July 24, 2023. Cause of death was determined by field investigations.

We collected 1,547,258 GPS locations from 82 animals, averaging 18,869 (range: 60 – 38,683) locations per individual. We used the GPS data to define seasonal ranges and migration corridors for this population (Figures 2.2 – 2.6). To calculate seasonal ranges (Figure 2.7), we randomly sampled 4 locations per day per individual and estimated a 95% kernel utilization distribution (KUD) for each season and study area (i.e., population-level). The 95% KUD represents the area in which the probability of relocating an animal is equal to 0.95. We defined spring as April 1 – June 30, summer as July 1 – Aug 31, fall as September 1 – November 30, and winter as December 1 – March 31. To estimate migration corridors (Figure 2.6), we identified migration periods for each individual-year using Migration Mapper and used Brownian Bridge Movement

Model (BBMM; Horne et al. 2007) methods to define population-level migration routes, similar to the methods described in Objective 1. The BBMM estimates the probability of where an animal could have traveled between two sequential GPS locations. When this process is applied to all GPS locations in a migration sequence, the BBMM provides a utilization distribution (UD) estimate of the width of the estimated movement path around the straight line between the successive locations and can be used to estimate migration routes (Sawyer et al. 2009) and stopover sites (Sawyer and Kauffman 2011). Because we were interested in classifying migration strategies and migratory periods for full "migratory years," which we defined to span 01 Feb – Jan 31, individuals with movement data occurring after 01 Feb 2023 were incomplete and not included in this analysis. In general, we applied a four-step process to calculate population-level migration routes which generally followed the approach outlined by Sawyer et al. (2009). We first estimated unique UDs for each migration sequence using a grid with 50-m resolution. Second, we averaged the UDs for a given individual's spring and fall migration sequences across all years to produce a single, individual level migration UD. We then rescaled this averaged UD to sum to 1. Third, we defined a migration route footprint for each individual as the 99% isopleth of the UD. Lastly, we stacked all the individual footprints for a given study area and converted the migration routes from a grid-based format to a polygon format, while removing isolated use polygons of less than 20,000 m^2 (i.e., less than approximately 5 acres) and clipping to the boundary of Montana. When converting final migration route from grid to polygon data, all 50-m pixels were preserved in the final migration routes. Thus, the mapped migration routes represent areas used by ≥1 migrant during spring and/or fall migration periods.

Movement patterns of individuals were diverse across the study area and the seasons, demonstrating that the population includes both migratory and resident animals (Figure 2.2). Pronghorn movement data collected suggest at least 3 semi-distinct herds are present in the Madison Valley, providing important information on herd structure that will be helpful in future management decisions. These herds include 1 herd east of the Madison River and 2 herds west of the river, separated north to south by Wigwam Creek and Shining Mountains Estates. Migratory animals primarily winter on the east side of the Madison River and migrated south to higher elevation summer ranges as far as Island Park, ID (Figures 2.2 – 2.8). In 2019, one animal migrated through the Centennial Valley to spend summer in Idaho, and then moved to the Camas Creek winter range in Idaho to spend winter 2019-2020. This animal was killed on railroad tracks near Dubois, ID in February 2020. In 2021, another animal migrated to spend summer in the Centennial Valley and then wintered east of Clark Canyon Reservoir and I-15. She spent both 2022 and 2023 at her Centennial Valley summer range and Clark Canyon Reservoir winter range and did not return to the Madison Valley. Resident animals primarily winter on the west side of the Madison River and used similar areas on the west side of the Madison Valley during both summer (Figure 2.4) and winter (Figure 2.6).

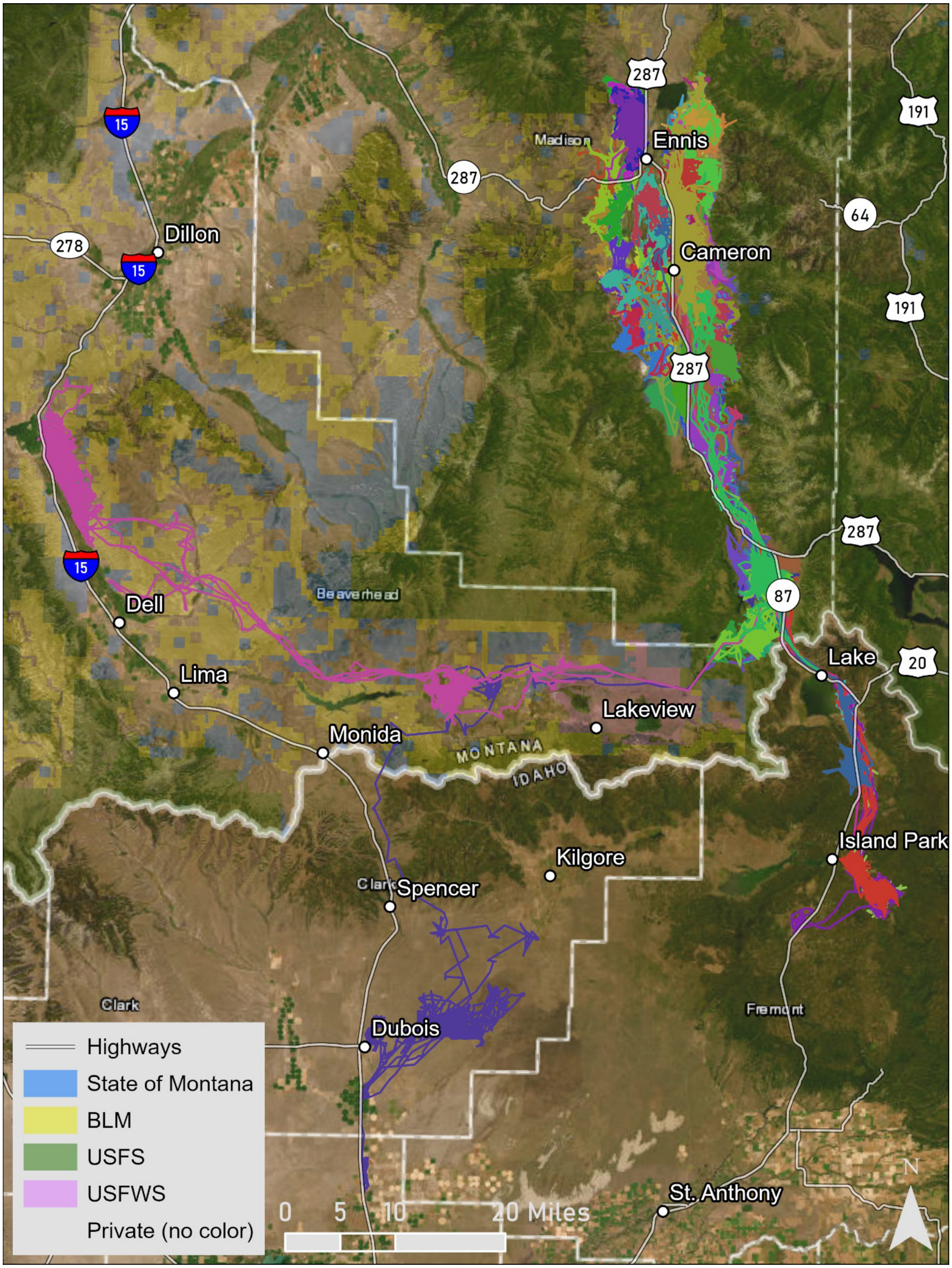

Figure 2.2: GPS tracks (colored by individual) from collared pronghorn in the Madison Valley. Data from January 2019 to July 24, 2023 are displayed.

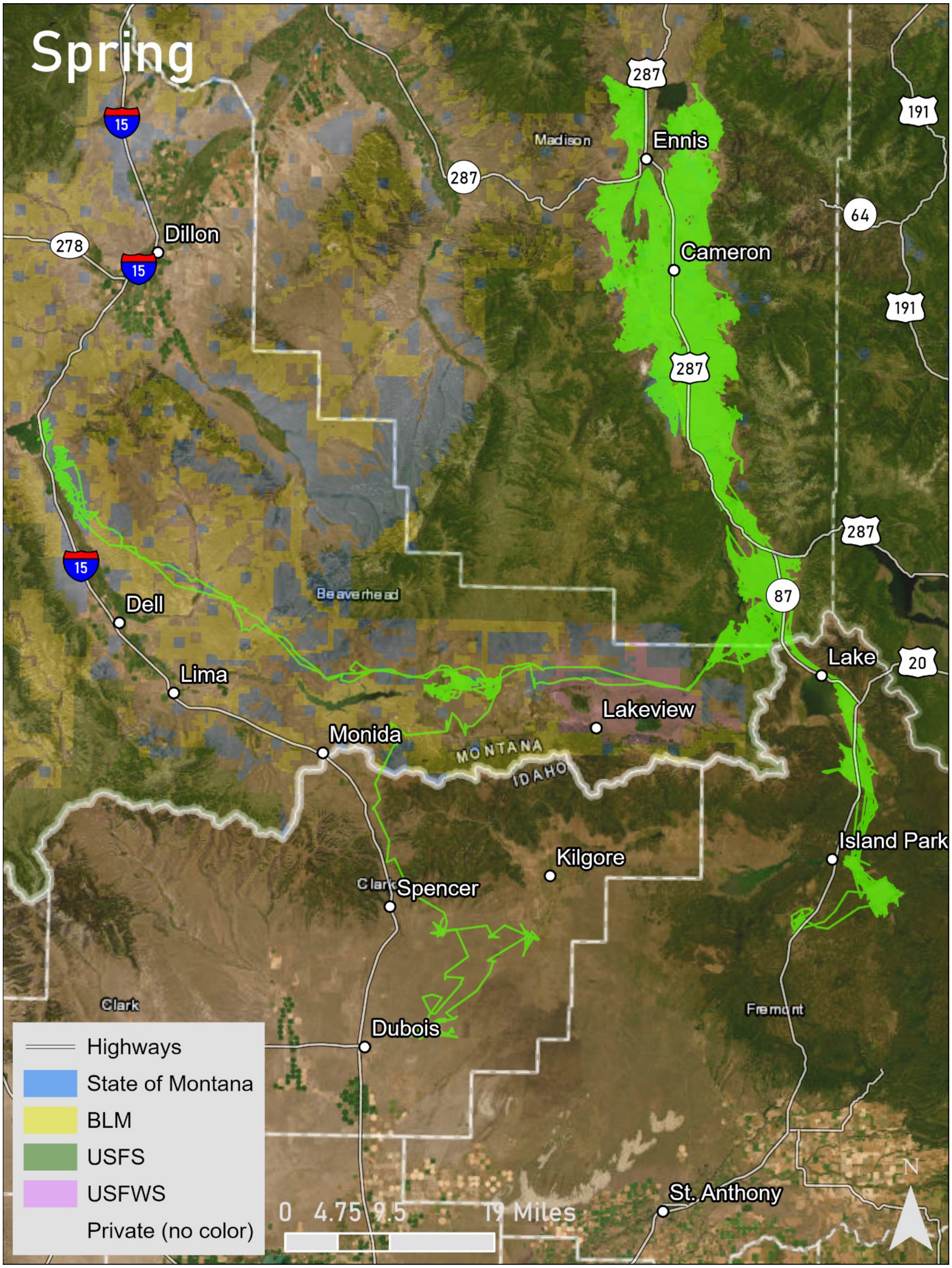

Figure 2.3: Spring (1 April – 30 June) GPS tracks from collared pronghorn in the Madison Valley. Data from January 2019 to July 24, 2023 are displayed.

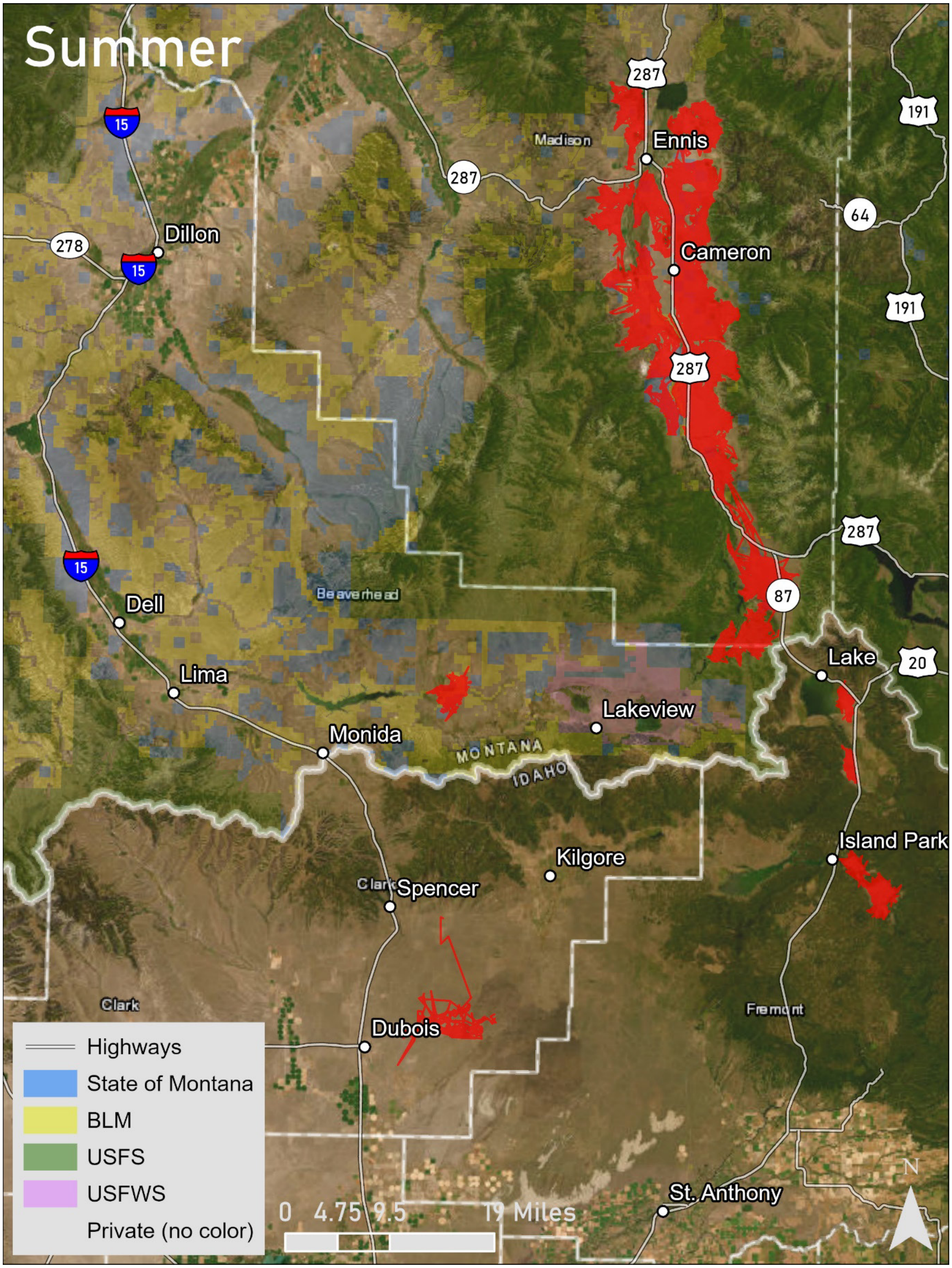

Figure 2.4: Summer (1 July – 31 August) GPS tracks from collared pronghorn in the Madison Valley. Data from January 2019 to July 24, 2023 are displayed.

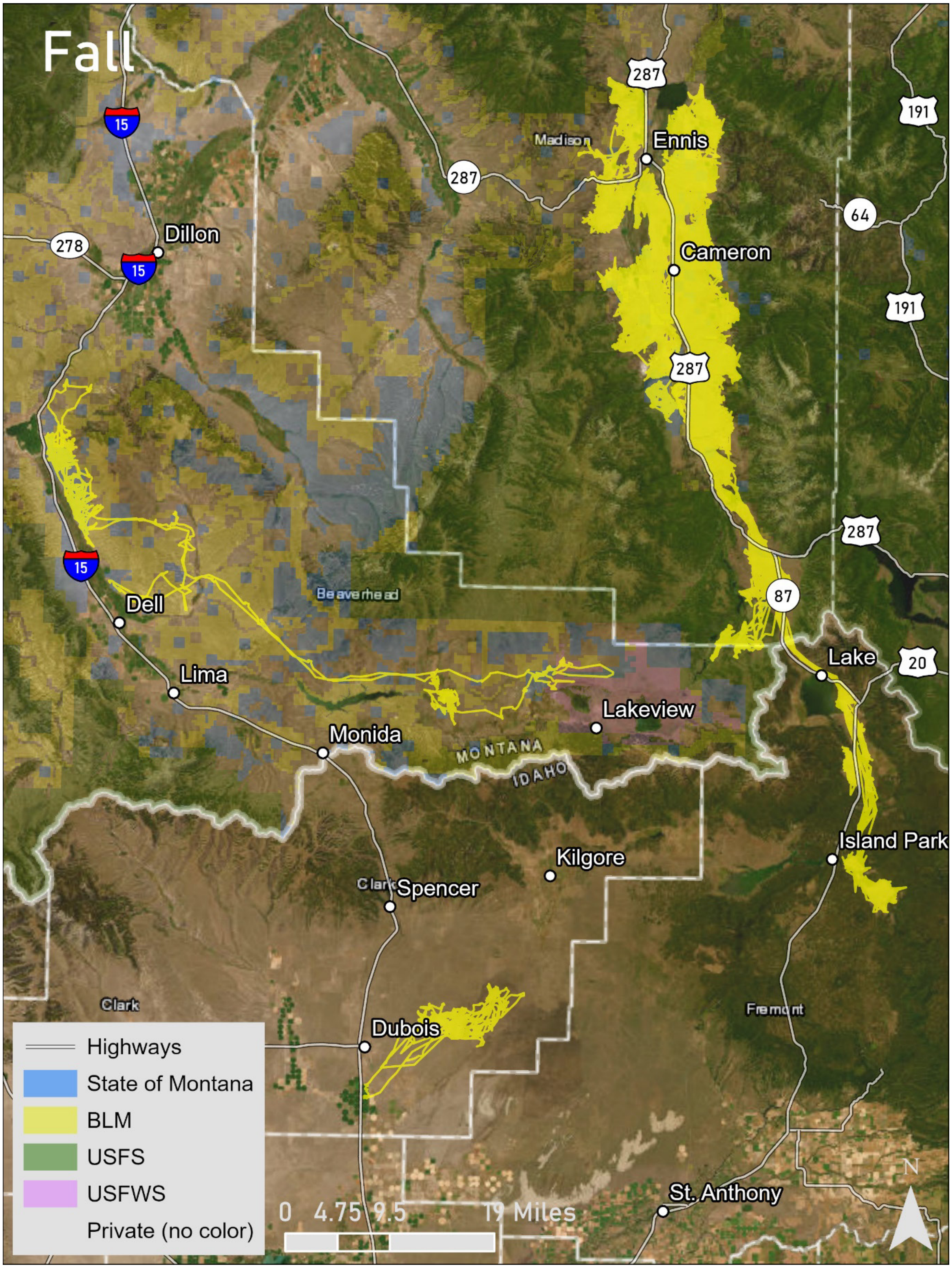

Figure 2.5: Fall (1 September – 30 November) GPS tracks from collared pronghorn in the Madison Valley. Data from January 2019 to July 24, 2023 are displayed.

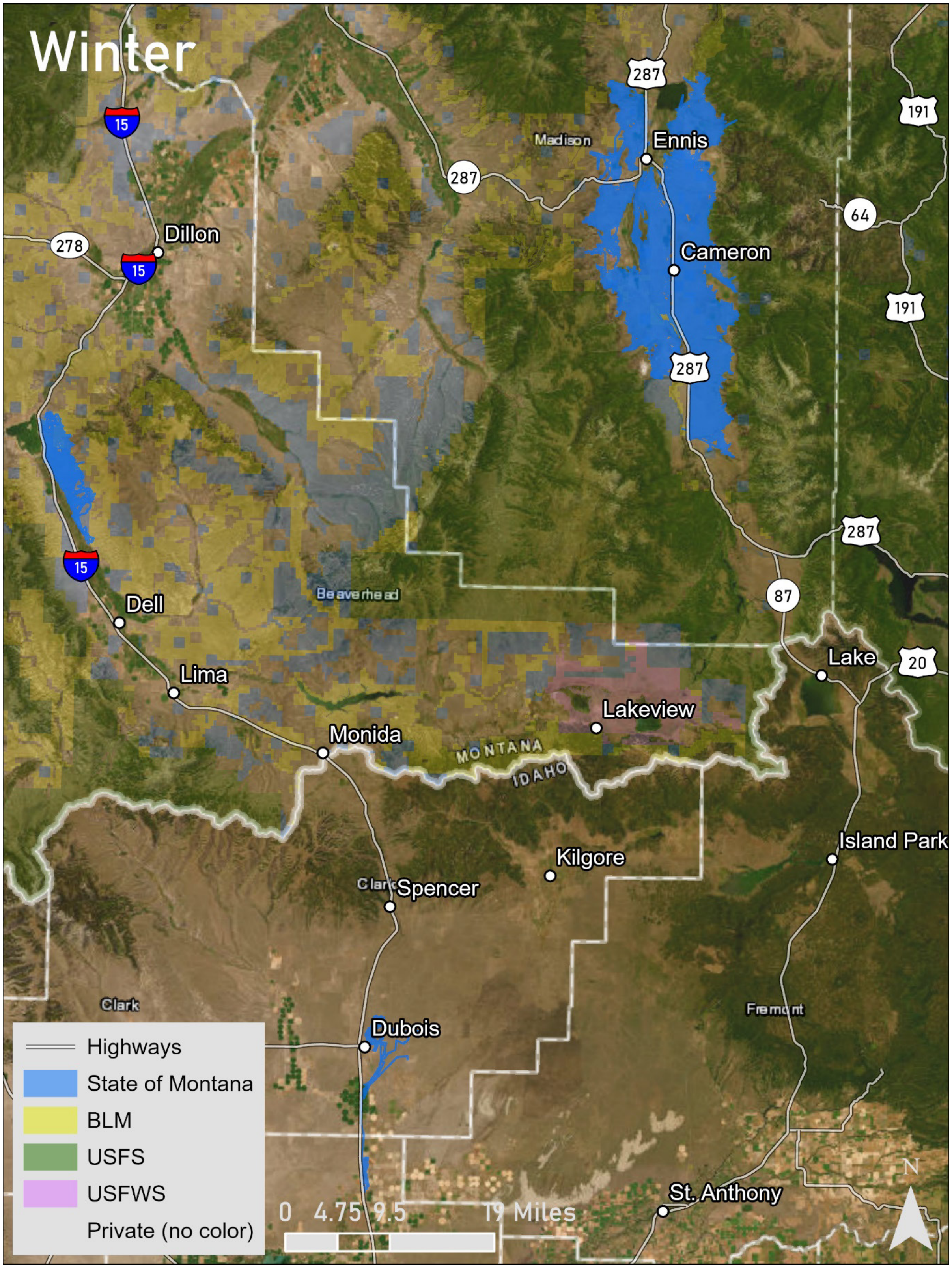

Figure 2.6: Winter (1 December – 31 March) GPS tracks from collared pronghorn in the Madison Valley. Data from January 2019 to July 24, 2023 are displayed.

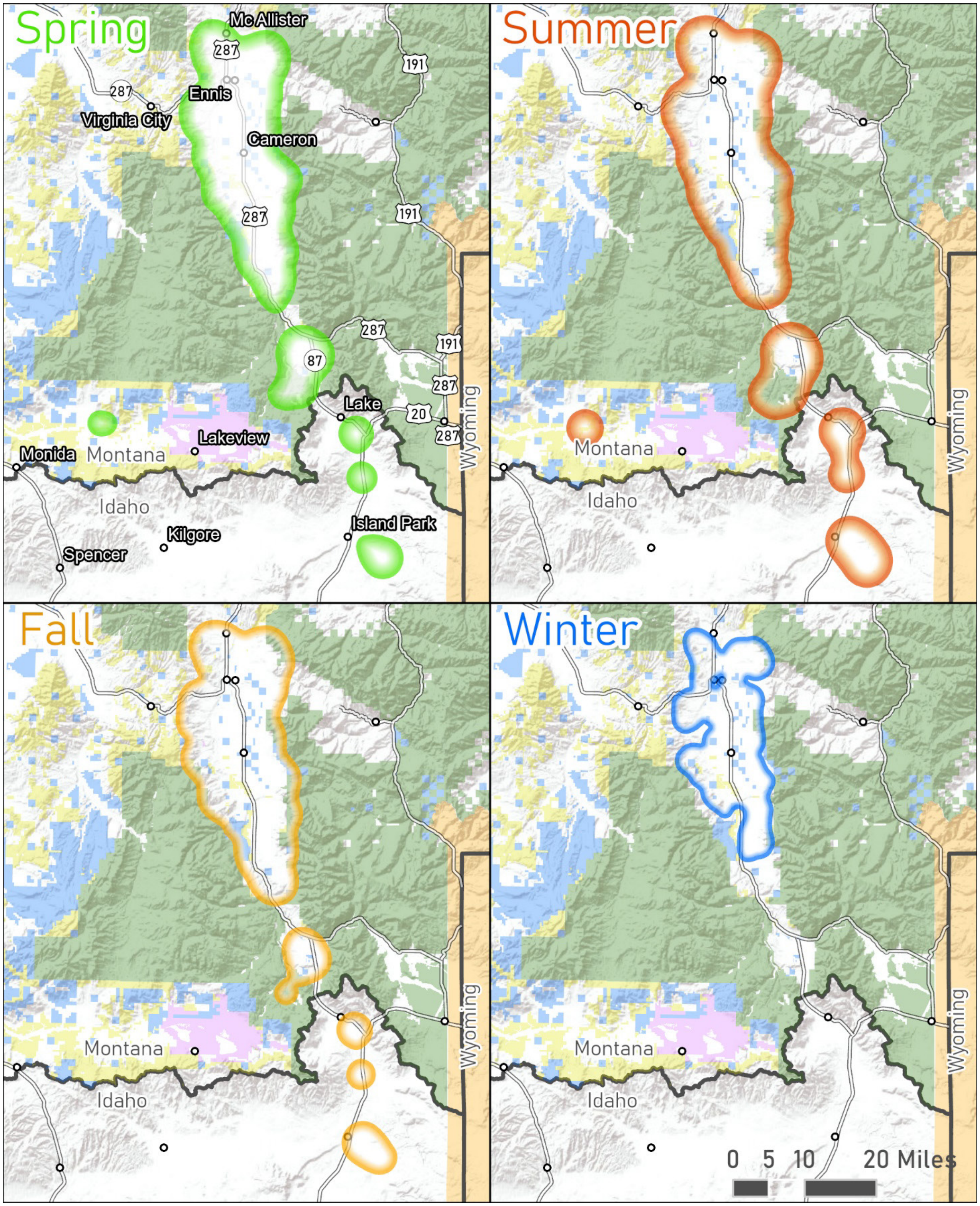

Figure 2.7. Seasonal ranges of collared adult female pronghorn in the Madison study area. Spring: Apr 1 – Jun 30; Summer: Jul 1 – Aug 31; Fall: Sep 1 – Nov 30; Winter: Dec 1 – Mar 31. Data from January 2019 to July 24, 2023 are displayed.

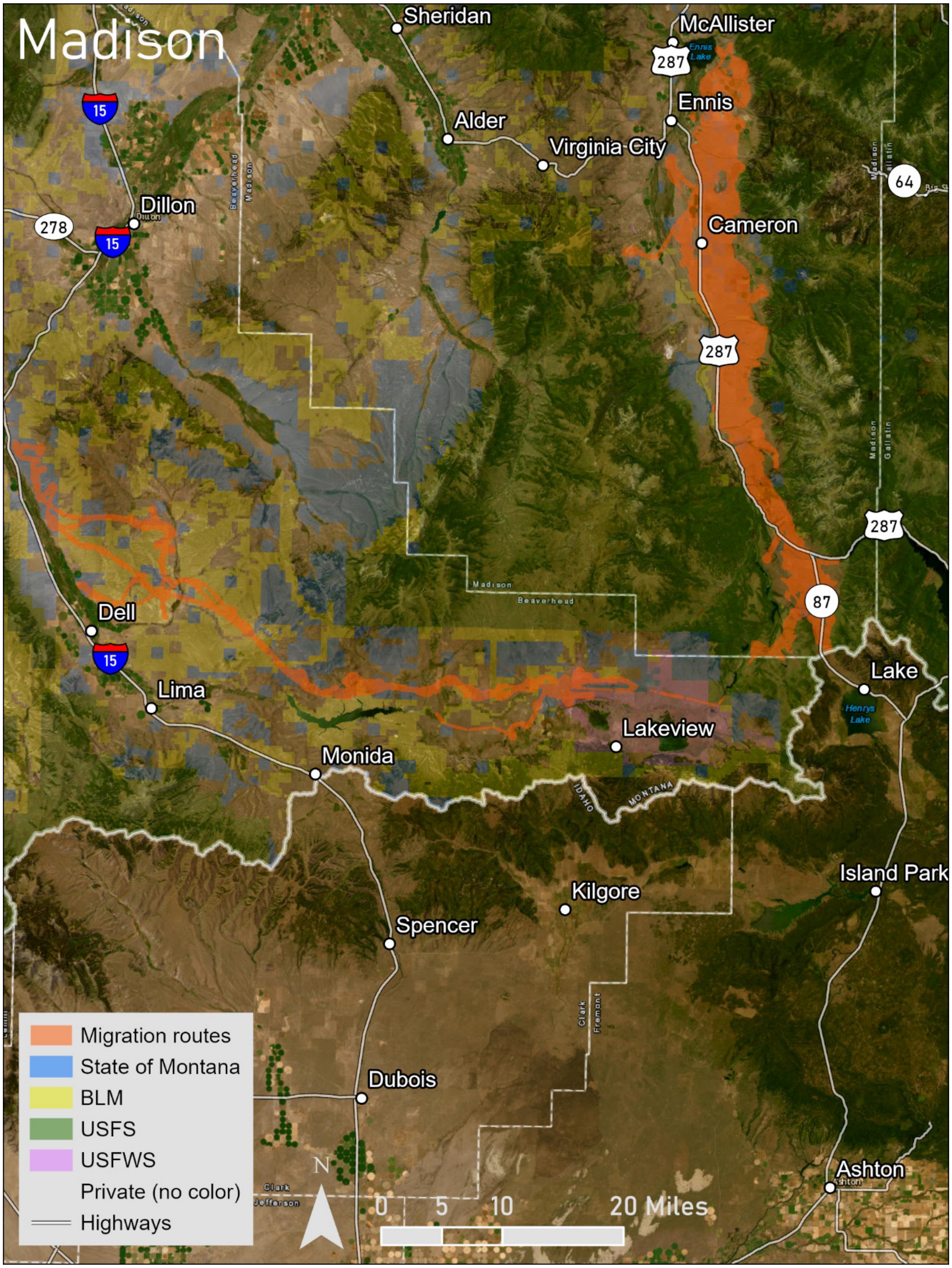

Figure 2.8. Estimates of migration routes of migrant collared adult female pronghorn in the Madison study area. Migration routes represent areas used by ≥1 migrant during spring and/or fall migration periods and are clipped to Montana only. Individuals with movement data occurring after 01 Feb 2023 are not displayed.

Movement data indicated that barriers to pronghorn movement are present on the landscape and informed multiple mitigation efforts to improve landscape permeability for pronghorn. In summer 2019, a problematic fence located between Highway 287 and the Madison River on BLM and private land was identified by the movement data. This fence, a jack-leg fence with woven wire (Figure 2.9), had barred the southward spring migration of collared pronghorn and was modified to pronghorn-friendly post and wire fence with 18" high smooth bottom wire (Figure 2.10). In addition, the Greater Yellowstone Coalition has worked to remove and/or modify fences to wildlife-friendly standards along the Highway 287 corridor. The National Parks Conservation Association has worked with various private landowners to replace 5-strand barbed fences with approximately 8 miles of pronghorn-friendly fences with smooth bottom wires. Movement data continues to be used to understand the success of fence modifications, identify additional problematic barriers, and collaborate with numerous NGO partners to facilitate fence modifications and promote safe wildlife passage.

Figure 2.9. The problematic fencing barrier between Highway 287 and the Madison River. The jack-leg fence and wire combination resulted in a fence impassible to pronghorn. Photo credit: BLM

Figure 2.10. Collaborative fence modification project in the Madison Valley to improve pronghorn movements, informed directly by the GPS collar data collected during 2019-20.

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