SNOW COMPACTION SURVEY OF THE MEDICINE BOW - ROUTT NATIONAL FOREST

FINAL REPORT

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BACKGROUND

Snow compaction via recreation may impact forest resources such as vegetation, soils, water, and wildlife (e.g., Baiderin 1980, Emers et al. 1995, Hiemstra et al. 2002, Keddy et al. 1979, Marchand 1996, Walker et al. 2001). The Medicine Bow – Routt National Forest supports much winter recreation, including skiing and snowmobiling. In fact, it is one of the top snowmobile destinations in the United States, with over 325 miles of snowmobile trails on the Medicine Bow alone (Wyoming OSTW 2006). For example, a recent survey showed that the Snowy Range represented about 17% of all non-resident snowmobile trips to Wyoming, which is nearly double that of any other destination area in the state (McManus et al 2001). Despite the high level of winter recreation on the forest, no quantitative information was available regarding the extent or intensity of snow compaction. The need to quantify this impact was identified in both the Medicine Bow Forest Plan and the White Paper for amending the Routt Forest Plan's section on Management Indicator Species.

This project was designed to inventory snow compaction from anthropogenic recreational activities (i.e., skiing and snowmobiling) across the Medicine Bow - Routt National Forest. It was conducted by the Wyoming Natural Diversity Database in cooperation with the Forest Service (Modification Number 03 to Challenge Cost Share Agreement 02-CS-11020600-033). Field activities for this project were initiated in the spring of 2005 and completed in the spring of 2006. This was followed by a period of data analysis that culminated in drafting this report.

METHODS

We surveyed anthropogenic snow compaction in the Medicine Bow - Routt National Forest by observing and systematically recording evidence of compaction (e.g., ski tracks, snowmobile trails) from low-flying aircraft. Such flight-based surveys allowed us to cover relatively large areas where land-based study was financially and logistically prohibitive. We drew extensively from our knowledge of aerial wildlife track surveys in developing specific methods for this study. Aerial observation of wildlife is an established method of surveying, monitoring, and capturing large-bodied mammals. In recent years, aerial delineation of large carnivore tracks in the snow has become a recommended option for documenting the presence, abundance, and/or habitat use of large carnivores in the northern United States and Canada (e.g., Ballard et al. 1995, MELP 1998).

We conducted a pilot flight in April 2005, and began aerial surveys the following winter. These surveys were concluded in the spring of 2006. To ensure sufficient snow accumulation for recreationists to reach all accessible areas of the forest, we waited until late December to begin flights. Flights were only conducted in safe weather conditions once the following criteria were met:

1. There had been a weekend of recreational activity that was preceded by a measurable snowfall;

2. There was no measurable snowfall and minimal wind activity between the dates of use and the date of the survey flight; and
3. The weather on the flight dates was partly sunny or sunny.

This combination of criteria insured that *each flight captured an unbiased sample of compaction events that happened during one weekend*. Moderate snowfall can render tracks from compaction activities invisible (e.g., Figures 1 and 2), particularly when viewed from a plane, so criteria 1 specifically insured that the tracks observed were made over the weekend in question and were not remnant tracks from earlier compaction events. Similarly, criteria 2 and 3 insured that tracks from the weekend in question were not underrepresented in our surveys due to obfuscation from snowfall, blowing snow or poor lighting conditions (overcast skies create flat light that makes it difficult to distinguish tracks).

The primary survey effort involved flying the entire Medicine Bow - Routt National Forest along systematically predefined line-transects. Observations were made through a survey scope (Figure 3) at 20 second intervals. Compaction at each observation point was evaluated and recorded onto field datasheets using the protocol outlined in Appendix 1. Collecting data via a transect methodology allowed valid estimates of impact on a forest-wide scale. It was also systematic and replicable, thus allowing comparison of use intensity over time, if monitoring is eventually conducted.

We initially planned to conduct this detailed mapping across all high use areas and wilderness areas, after which we planned to replicate the transect process with remaining funds. Unfortunately, the accumulated costs of aborted flights and weather delays combined with unexpectedly large high-use areas and an unusually warm early spring prohibited us from completing mapping efforts and replicate transect flights. Instead, available survey points were analyzed using an environmental similarity index (e.g., Carpenter and Gillison 1993) and classification trees (e.g., Prasad et al. 2006) to compare sites of known compaction with sites of possible compaction. Sites were compared using a collection of geographic information system (GIS) data for environmental features that were deemed likely to influence compaction (Table 3). This resulted in a map of potential snow compaction across the entire Medicine Bow – Routt National Forest.

RESULTS AND DISCUSSION

Aerial Transects

Transect-based flights resulted in 980 survey points, 879 of which fell within the boundaries of the Medicine Bow Routt National Forest (Figure 4). Of the points on the forest, 31% contained human-caused snow compaction events (see Table 1 and Figure 5), which means that on a given weekend about 725,000 acres of the forest is compacted by winter recreation activities. Of the compacted area, 96.7% was from snowmobiles and more than half was classified as high-compaction. This means that on a single weekend of activity, 16.6% of the entire forest, or about 388,000 acres receives a high level of snowmobile activity. High, medium and low compaction events are defined in Appendix 1, and photographs providing examples of these levels are presented in Figures 6 – 8.

Data were collected on the cover type of survey points relative to the level of compaction received (Table 2). Across the forest, 68% of survey points had a primary cover type of conifer and 59% were classified as dense conifer. Many fewer survey points (17%) were classified as primarily open habitat, where "open" was defined as having little discernable vegetation evident above the snow surface (e.g., meadows). 27% of the conifer points showed some level of snow compaction, while 12% showed high compaction. In contrast, 64% of primarily open areas showed evidence of compaction. This translates into roughly 250,000 acres of primarily open land compacted on a given weekend, while 434,000 acres of conifer dominated land is compacted in the same period. Thus, although open areas receive proportionally more compaction than treed areas, compaction events are substantial in both cases and it does not appear that forest cover *per se* is a deterrent to compaction activities. Moreover, although the tree cover of compacted areas seems to be lower than non-compacted areas, the difference was not significant.

Mapping and Modeling

Given the extent of snow compaction on the forest (roughly 33% of forest area being compacted), mapping the compaction zones proved more difficult than expected. In addition to systematic survey points (Figures 4 and 5), we coarsely delineated a few high use areas while conducting aerial surveys, and collected photo-reference points for several areas (Figure 9). At this point, we were still far short of having confidently delineated compaction areas, but all flight time was expended and an unusually warm and dry spring caused a substantial reduction in snowpack, thus precluding further survey. However, we were able to use our existing points of known compaction and GIS information for the forest to develop a model of compacted areas.

Model output is detailed in Appendix 2. The final model (Figure 10) should be interpreted as *predicting area likely to be highly compacted by human recreation (primarily snowmobiles) over the course of a winter, if appropriate micro-site conditions exist.* It thus predicts a slightly larger area of compaction than the estimate from our point-based aerial surveys, which estimates compaction during one weekend. Considering all area predicted, 55% of the forest (1,283,502 acres) was predicted to be compacted during a winter of recreation. We have highest confidence in areas where both constituent models (see Appendix 2) predicted compaction (shown as darker shading in Figure 10). If only the area of model convergence is considered, about 29% of the forest (686,103 acres) was predicted to experience high compaction during a winter of recreational activity, which is slightly less than the point-based estimate.

At the scale of the forest, all area predicted by the models shown in Figure 10 is well within the reach of recreationists. However, it probably includes specific sites that experience little actual impact. This is due to the fact that there are factors acting at fine scales that are not adequately addressed at the scale of the models. For example, a dense stand of trees on a fairly steep, north-facing slope could retain deep, soft snow and be difficult for snowmobiles and skiers to traverse. Such micro-site conditions cannot readily be determined from available information at the scale of the entire Medicine Bow – Routt National Forest and thus do not readily influence the models.

The most important predictors of snow compaction were related to accessibility, most notably how close an area was to a posted snowmobile route, parking lot, or forest road. The single most important factor influencing whether an area was predicted to be compacted was its distance to a snowmobile route, where areas closer to routes were likelier to be compacted than more remote areas. At the scale of the whole forest, factors such as tree cover, slope, elevation, and precipitation were less influential in predicting compaction.

Wilderness Areas

Motorized compaction was documented in wilderness areas during our aerial surveys (Figure 12a-g). Given the structure of our data collection (see Methods), the intrusions shown in Figure 12 represent what might typically occur in one weekend of recreation. For some wilderness areas, we did not witness actual intrusion (e.g., Platte River, Savage Run, Never Summer, Encampment River), while for others numerous intrusions were documented (e.g., 5 in Flat Tops, 4 in Sarvis Creek, and 3 each in Mount Zirkel and Houston Park). However, all areas showed motorized activity proximate to their borders, which were sometimes quite intense, making it likely that additional and/or more extensive intrusions could occur over the duration of winter recreation activities. Aerial survey points, snowmobile routes, and output from snow compaction models are also shown in Figure 12 and help indicate wilderness areas that are most vulnerable to motorized compaction.

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Tables and Figures

Table 1: Summary of aerial survey points for snow compaction events by type and level of use. Data are number of survey points, which were placed systematically across the Medicine Bow – Routt National Forest (see Figure 7). There were 879 survey points in total, and this table represents the 286 survey points (33%) that were compacted (593 points, or 67%, were not compacted).

	Use Level			
Use Type	**High**	**Medium**	**Low**	**Total**
Count of survey points by use type and level of compaction				
Snowmobile Trail	38	38	18	94
Snowmobile Play Area	107	46	17	170
Ski Trail		4	4	8
Ski Slope	1			1
Natural (e.g., wildlife)	3	1	9	13
Total	149	89	48	286
Percent of compaction by use type				
Snowmobiles	97.3%	94.4%	72.9%	92.3%
Skis	0.7%	4.5%	8.3%	3.1%
Other	2.0%	1.1%	18.8%	4.5%
Percent of human-caused compaction by use type				
Snowmobiles	99.3%	95.5%	89.7%	96.7%
Skis	0.7%	4.5%	10.3%	3.3%

Table 2: Summary of land cover variables relative to snow compaction at survey points across the Medicine Bow – Routt National Forest. Data shown are number of survey points with the given cover type and use level combination.

Use Level	Primary Cover Type [a]							Total
	Aspen	Conifer-Dense	Conifer-Sparse	Devel-oped [b]	Open	Shrub [b]	Alpine [b]	
High	6	51	22		69		1	149
Medium	13	55	4		16	1		89
Low	6	26	5		9	1		47
None	62	390	47	3	52	19	21	594
Total	87	522	78	3	146	21	22	879
Compacted	29%	25%	40%	-	64%	-	-	32%
Highly Compacted	7%	10%	28%	-	47%	-	-	17%

(a) Primary cover type represents the land cover (evident from the plane during surveys) that covered the greatest percentage of the area viewed through the survey scope (Figure 3) at each survey point. Land cover types are defined as follows:

Aspen: Forest dominated by aspen trees.

Conifer – Dense: Forest dominated by conifer trees with little understory (i.e., snow) visible through the overstory canopy.

Conifer – Sparse: Forest dominated by conifer trees with understory (i.e., snow) clearly visible through the overstory canopy.

Developed: Dominated by human development, such as major roads, parking lots, or buildings.

Open: Areas with little vegetation clearly visible above the snow surface, typically meadows, riparian areas, or recent clearcuts.

Shrub: Areas where the primary vegetation visible above the snow surface was shrub-dominated, typically sagebrush, willows, sapling-stage clearcuts, or mixed montane shrubland.

Alpine: Areas above timberline that have no vegetation visible above the snow surface.

(b) Too few points were located in developed, shrub and tundra areas to draw meaningful estimates of the proportion of those areas that were compacted.

Table 3: List of variables used to predict the probability of high snow compaction occurring across the Medicine Bow – Routt National Forest. All variables and the resulting map (Figure 10) had a resolution of 30 meters and were limited to the forest boundaries.

Variable	Description	Source
Winter Precipitation (P8)	Precipitation of the Coldest Quarter. Derived from Daymet monthly precipitation data based on algorithm presented by Nix (1986).	Daymet surface weather and climatological summaries (http://www.daymet.org/).
Frost Days (TFA)	Mean number of frost days per year. A general biophysical parameter indicating the mildness/ harshness of the climate.	Daymet surface weather and climatological summaries (http://www.daymet.org/).
Elevation (DEM30)	Digital Elevation Models (DEMs) for Wyoming and Colorado based on 30 meter grid cells.	National Elevation Dataset (http://seamless.usgs.gov/).
Slope (SLOPE)	Slope of ground in degrees derived from the 30 meter DEM using standard ArcGIS® algorithms.	Derived from information from the National Elevation Dataset (http://seamless.usgs.gov/).
Tree Cover (PCTTRE)	Percent of land area covered by trees.	Region 2 Vegetation Database (R2Veg) Provided by the USDA Forest Service, Medicine Bow – Routt National Forest. Extracted from field "tree_cover_pct" in table "Reveg_species_calc".
Snow Routes (RTFS)	Euclidean distance from each cell to the nearest mapped winter recreation trail (snowmobile or ski trail).	Map of winter recreation routes provided by USDA Forest Service, Medicine Bow – Routt National Forest.
Access Points (ACSPT)	Euclidean distance from each cell to the nearest access point, where access points are generally parking areas and/or trailheads mapped by Forest Service staff.	Map of winter recreation access points provided by USDA Forest Service, Medicine Bow – Routt National Forest.
Roads (ROADFS)	Euclidean distance from each cell to the nearest road, including logging roads, mapped by Forest Service Staff.	Map of roads provided by USDA Forest Service, Medicine Bow – Routt National Forest.
Stream (STRM)	Euclidean distance from each cell to the nearest permanent drainage.	National Hydrography Dataset (http://nhd.usgs.gov/).

Figure 1. Partially obscured snow machine track after light snow, North of WY 130 in the vicinity of Snowy Range Pass.

Figure 2. Heavy use area, with tracks obscured by recent snowfall, North of WY 130 in the vicinity of Snowy Range Pass.

Figure 3: Calculation of field of view through the survey scope for aerial surveys in a) tabular form, b) graphic representation of the full extent of the system, and c) graphic representation of a close-up of the scope.

Figure 3a.

Variable	Value	Units	Calculation Notes
Tube height	2.00	inches	Given
Total Tube Length	8.00	inches	Given
Extension Length	2.00	inches	Given
Cut Length	2.83	inches	Sqrt (TH^2 + EL^2)
Theta1	45.00	degrees	ArcTan (TH/EL)
Theta2	7.13	degrees	ArcTan ((TH/2) / TTL))
Theta3	37.87	degrees	Theta1-Theta2 = 45deg-Theta2
Theta5	9.46	degrees	ArcTan ((TH/2) / (TTL-EL))
Theta6	54.46	degrees	180-(90+Theta1)+Theta5
Plane Height	1,000.00	feet	Given
Da	777.78	feet	PlainHeight * Tan(Theta3)
Db	1,403.96	feet	(PlaneHight+CutLength)*Tan(Theta6)
DeltaDf	626.18	feet	Db - Da
DeltaDy	208.73	yards	Db - Da
DeltaDm	190.86	meters	Db - Da

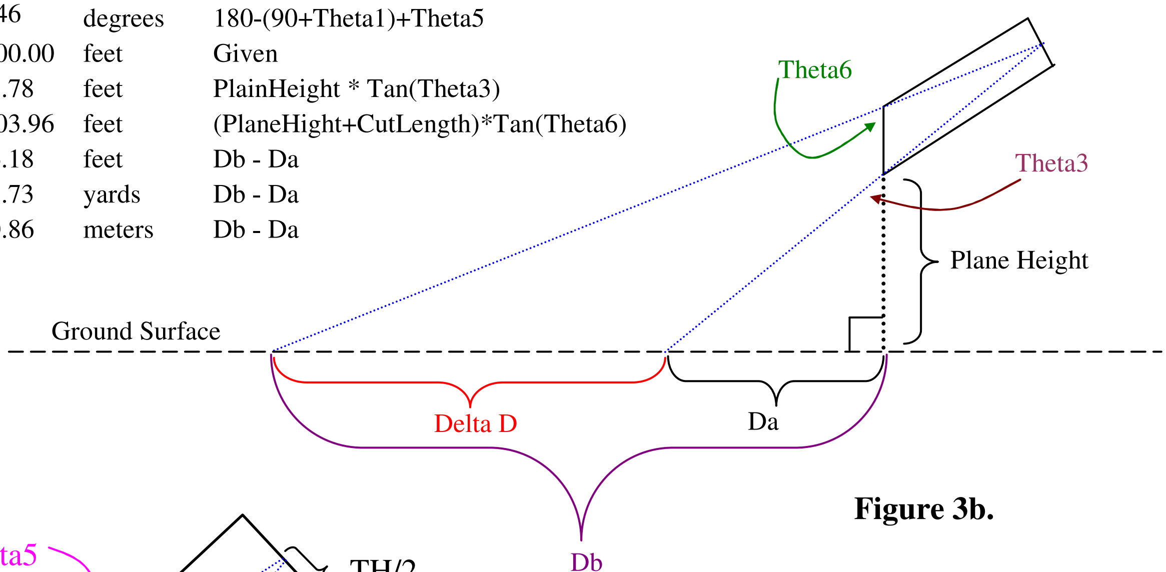


Figure 3b.

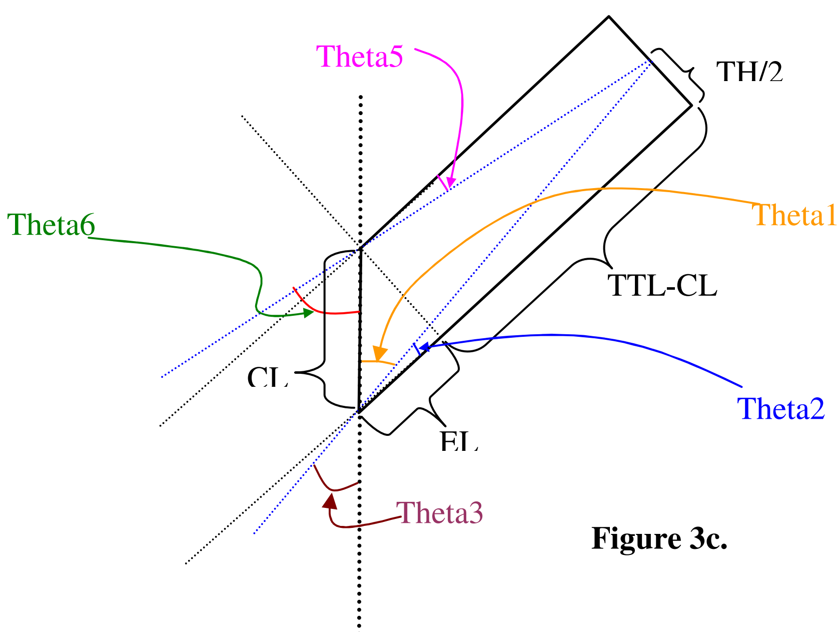


Figure 3c.

Figure 4: Map showing approximate location of aerial survey points in the Medicine Bow – Routt National Forest, with flight direction and view angle.

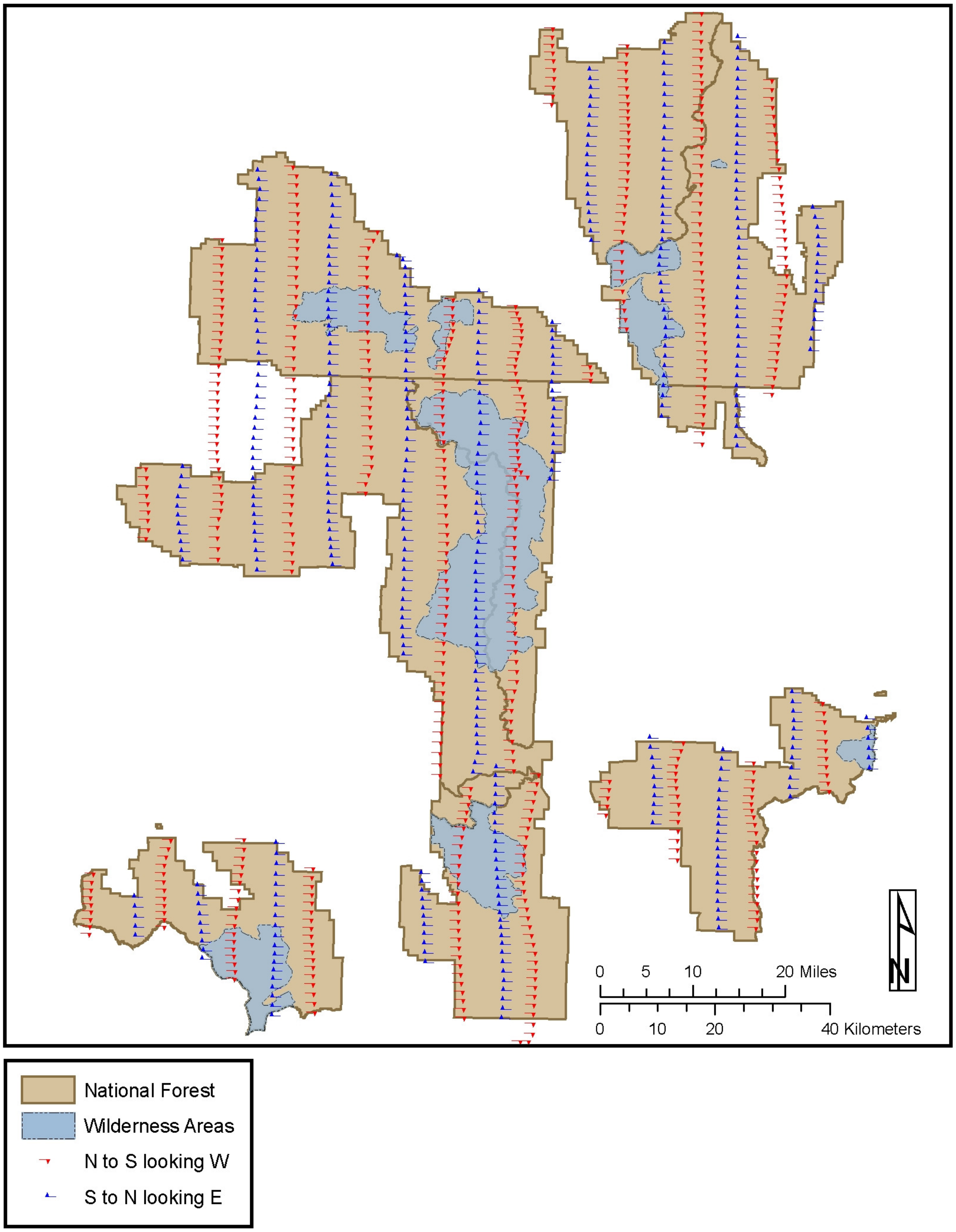


Figure 5: Map showing snow compaction events at aerial survey data points across the Medicine Bow – Routt National Forest. Summary tabulation of this data is show in Tables 1 and 2.

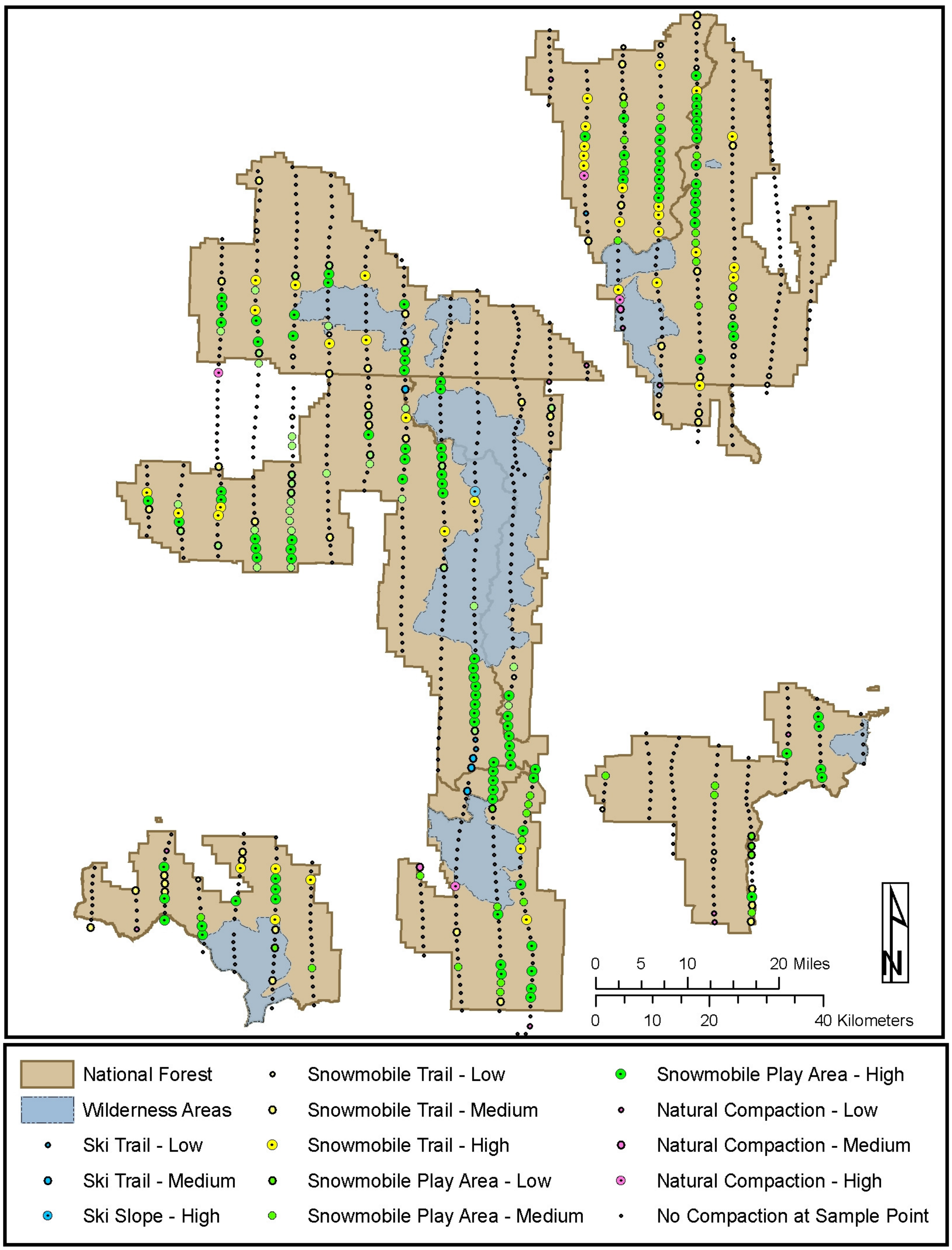
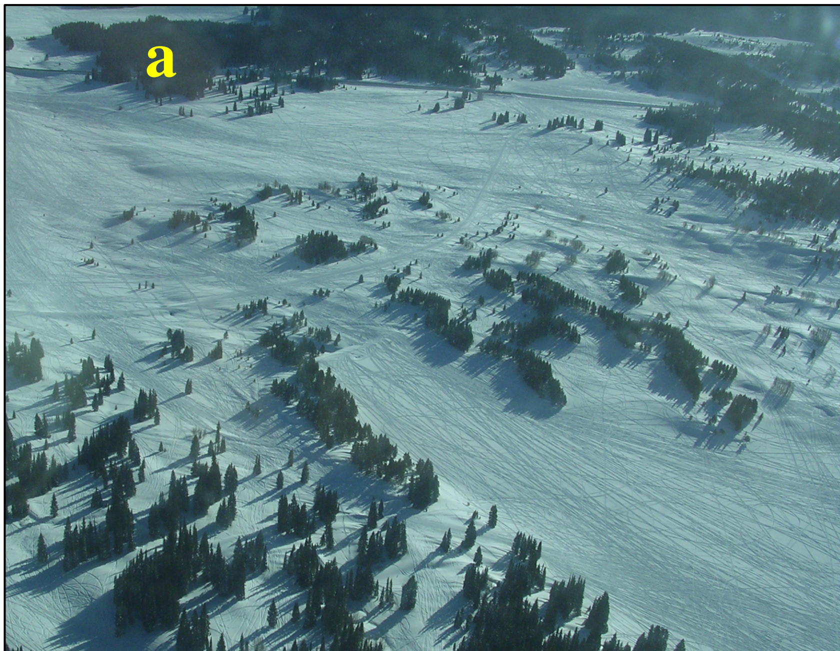


Figure 6. Aerial photographs of **high snowmobile use*:*** a) in open and sparse conifer habitat near Dumont Lake, central Routt; b) in open and sparse conifer habitat near Sand Lake, northern Medicine Bow; c) in open and sparse conifer by Walton Creek, central Routt; and d) in subalpine conifer by Medicine Bow Peak, central Medicine Bow.



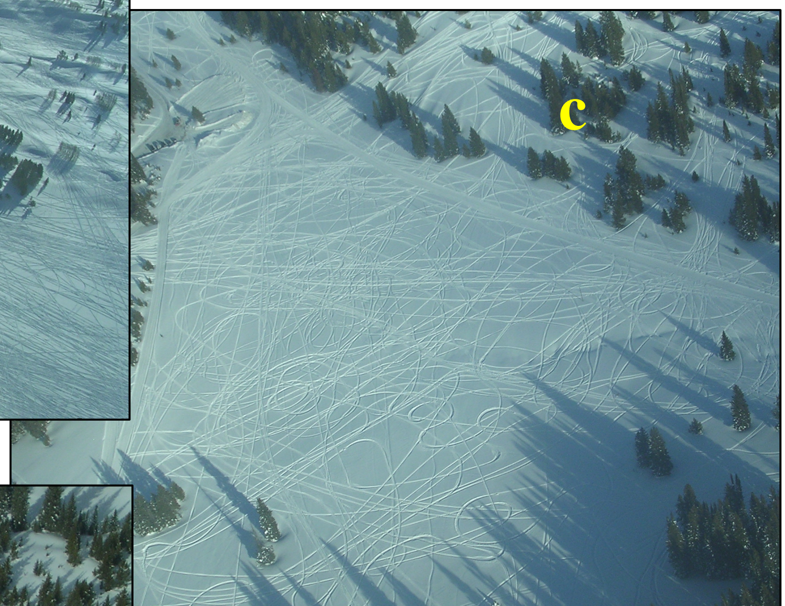


Figure 7: Aerial photographs of **moderate use:** a) a high use snowmobile trail and moderate use play area in open habitat (surrounded by sparse and dense conifer) near Buffalo Park, southern Routt; b) a medium use snowmobile area in open and sparse conifer habitat west of Sand Peak, southern Routt; and c) a medium use ski area in open habitat (surrounded by dense conifer) along Fishhook Creek, central Routt.

Figure 8: Aerial photographs of **low use*:*** a) snowmobile play in sparse conifer west of Sand Peak, southern Routt; and b) snowmobile play in open habitat (flanked by aspen and sparse conifer) near Cyclone Park, southern Routt.

Figure 9: Map showing location of photographs taken while conducting aerial surveys of snow compaction across the Medicine Bow – Routt National Forest. Representative photos are shown in Figures 6 - 8.

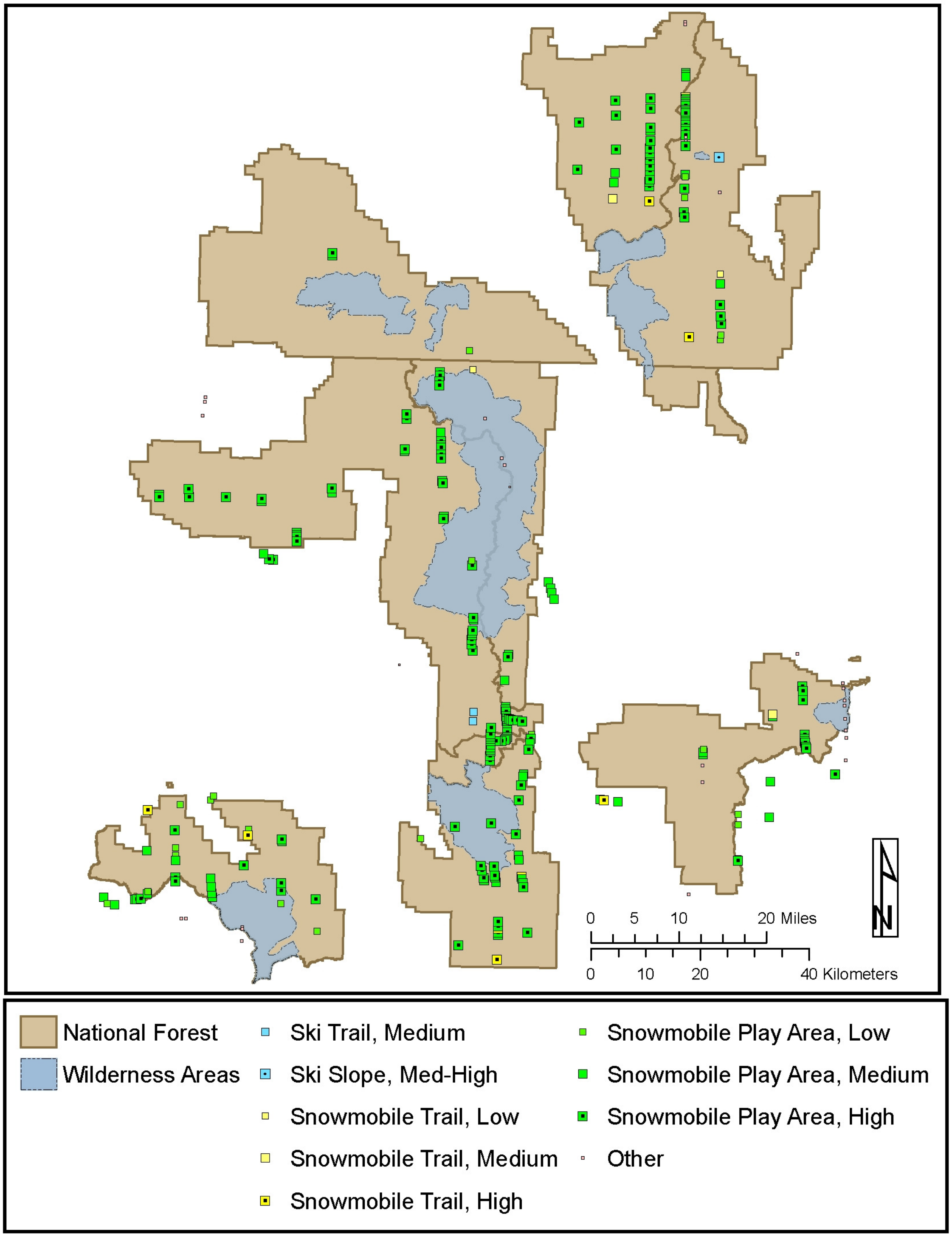


Figure 10: Map of potential high-compaction areas in the Medicine Bow – Routt National Forest based on models described in Appendix 2.

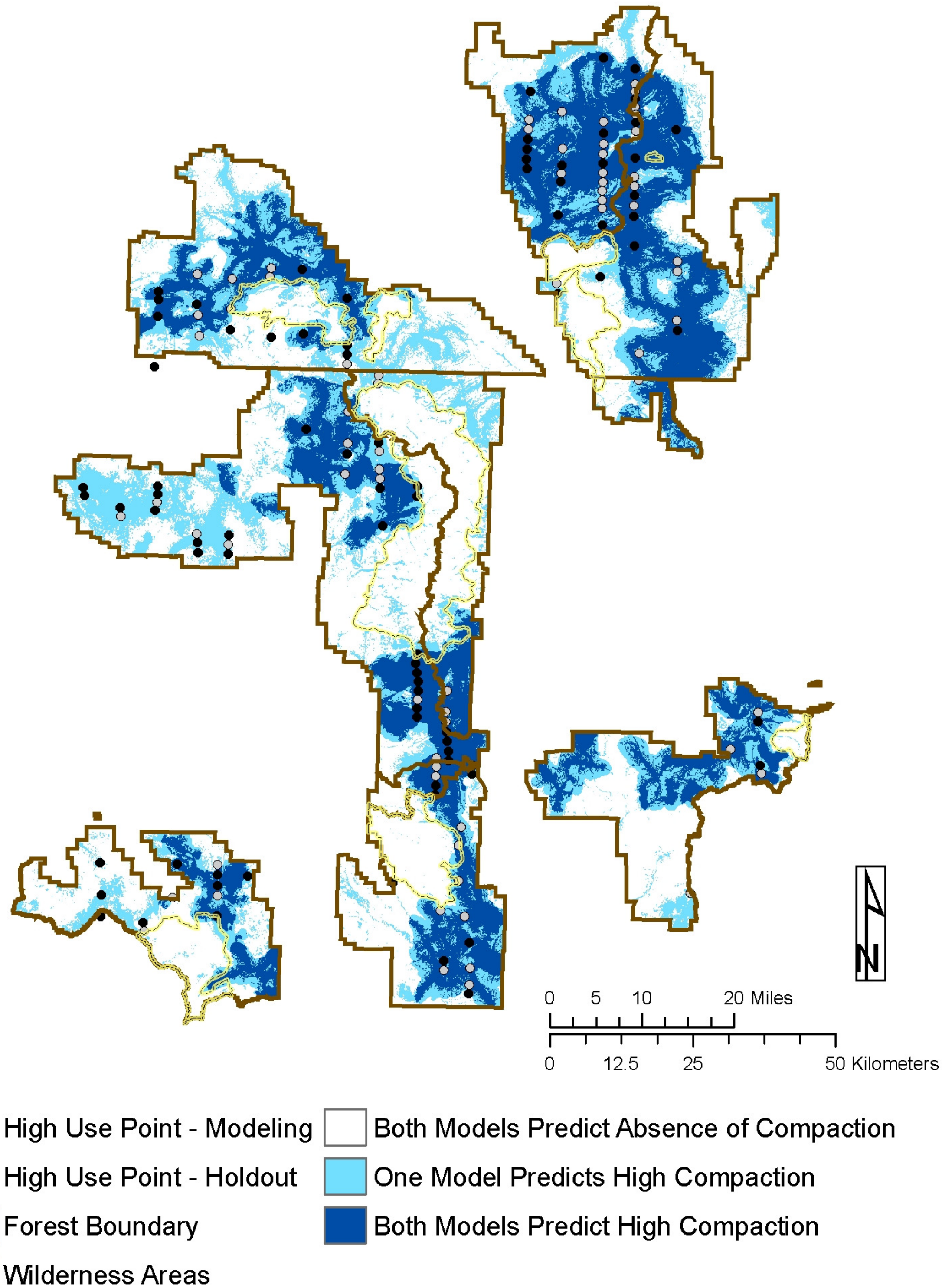


Figure 11: Predictive snow compaction model (see Figure 10 and Appendix 2) overlaid with winter recreation routes provided by the Forest Service.

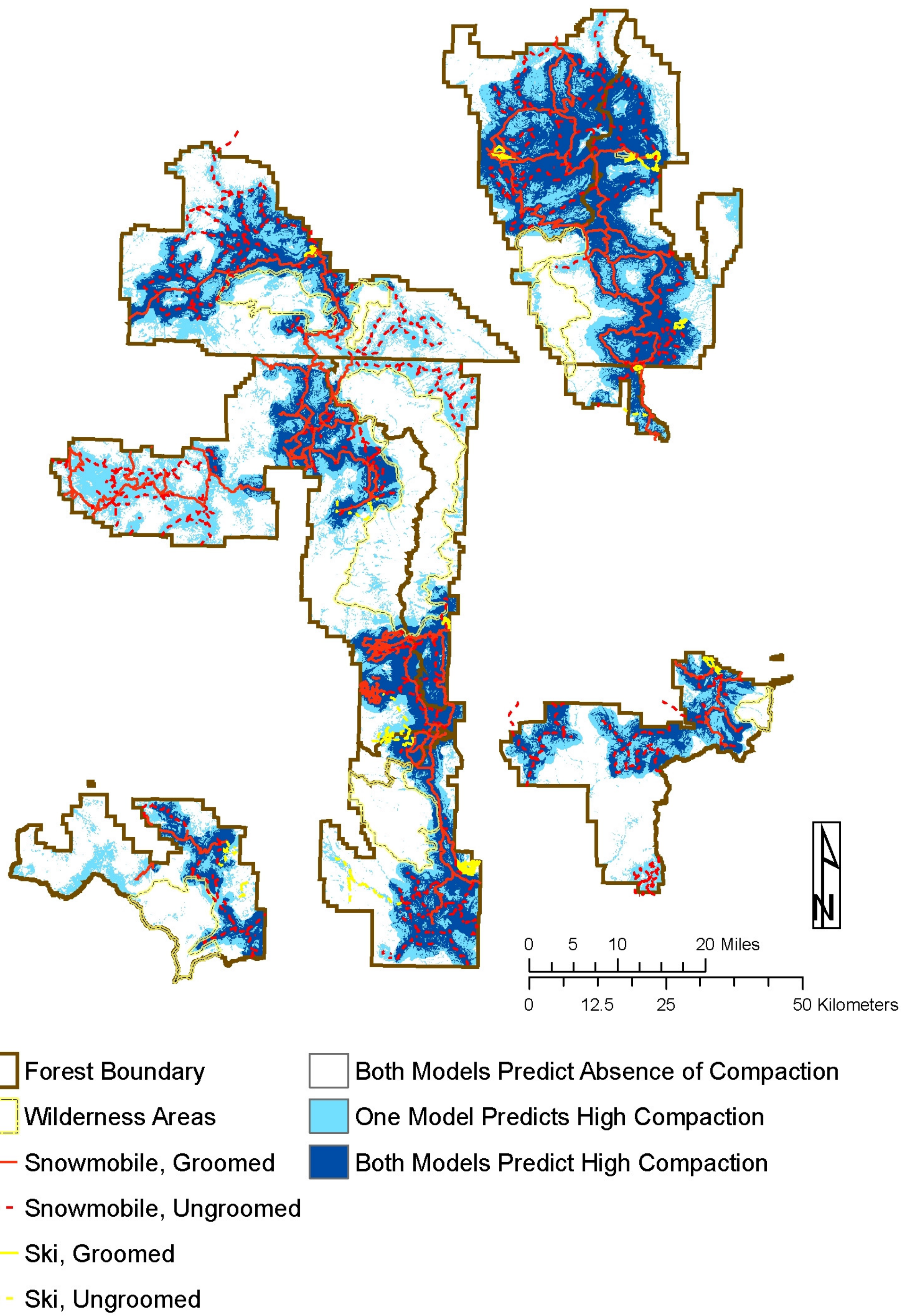


Figure 12: Documented snow compaction relative to wilderness area boundaries for a) the Platte River and Savage Run Wilderness, b) the Snowy Range Research Natural Area, c) the Encampment River and Houston Park Wildernesses, d) the Mount Zirkel Wilderness, e) the Sarvis Creek Wilderness, f) the Flat Tops Wildnerness, and g) the Never Summer Wildnerness. All images use the following legend.

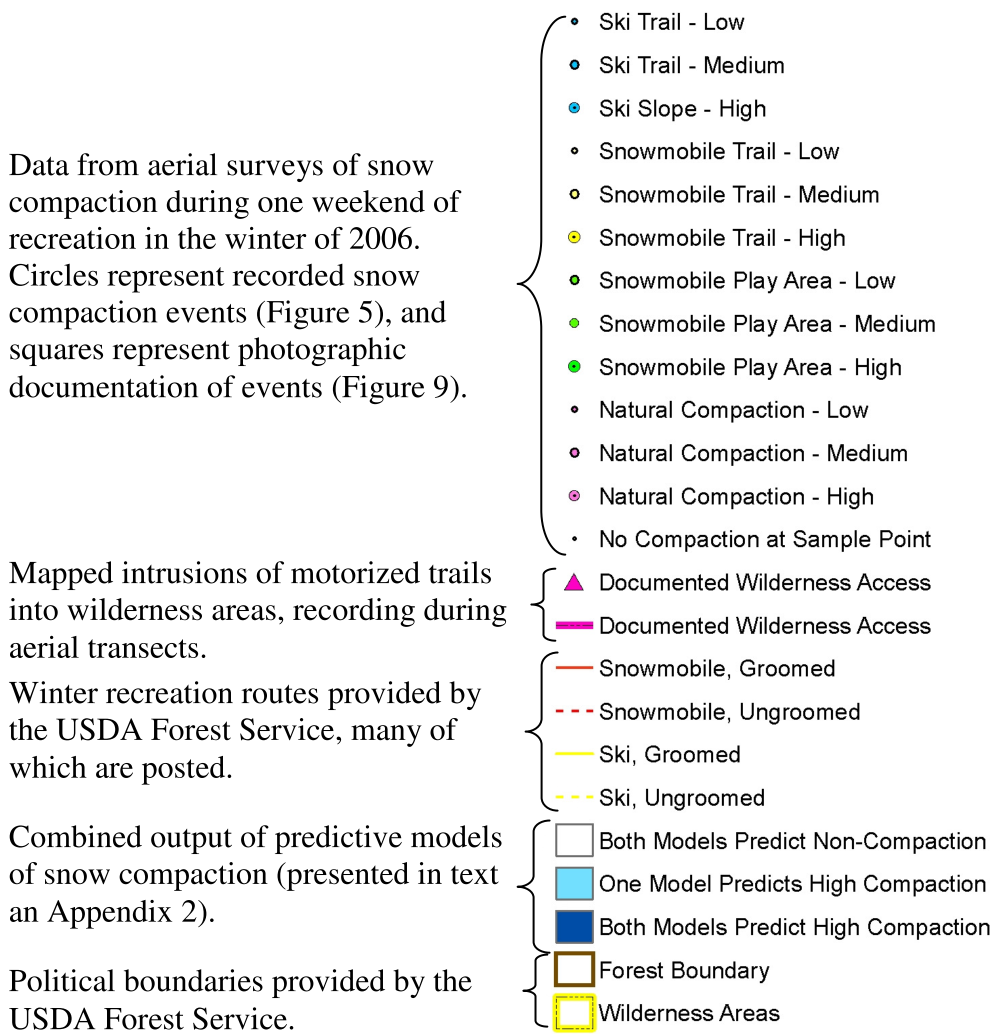


Figure 12a: Platte River and Savage Run Wilderness

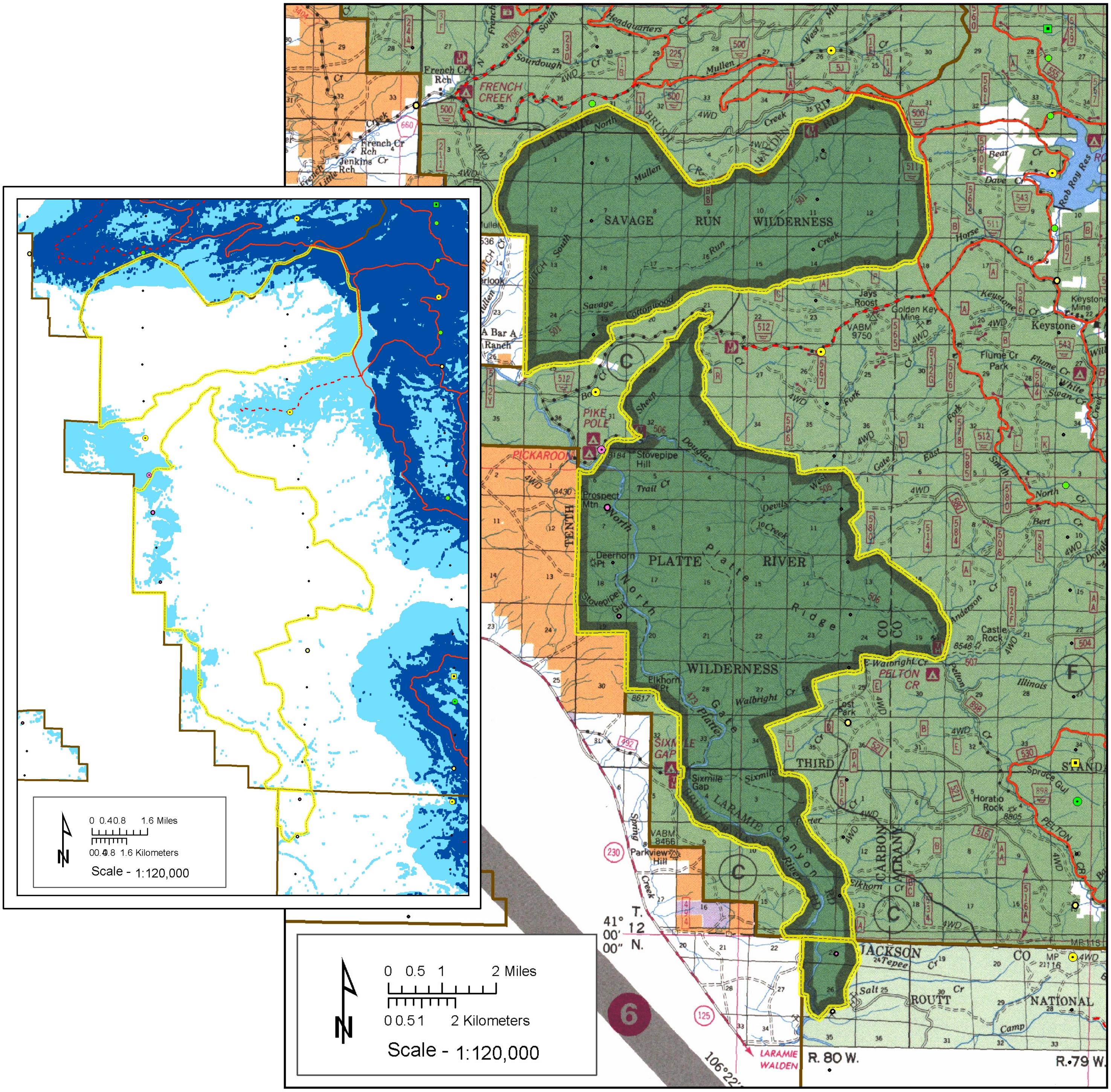
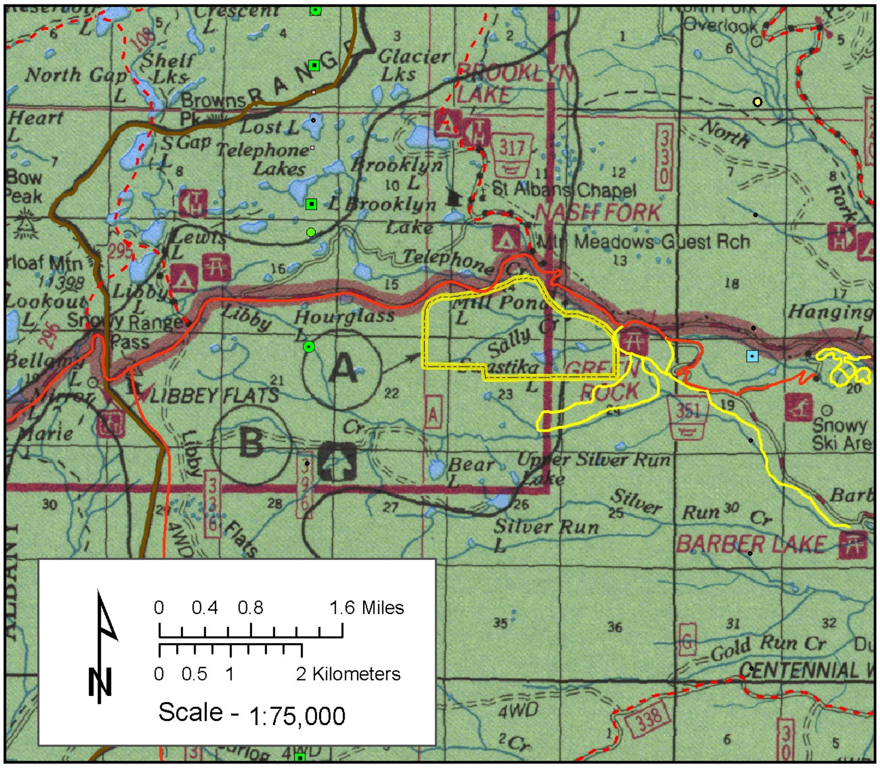


Figure 12b: Snow Range Research Natural Area



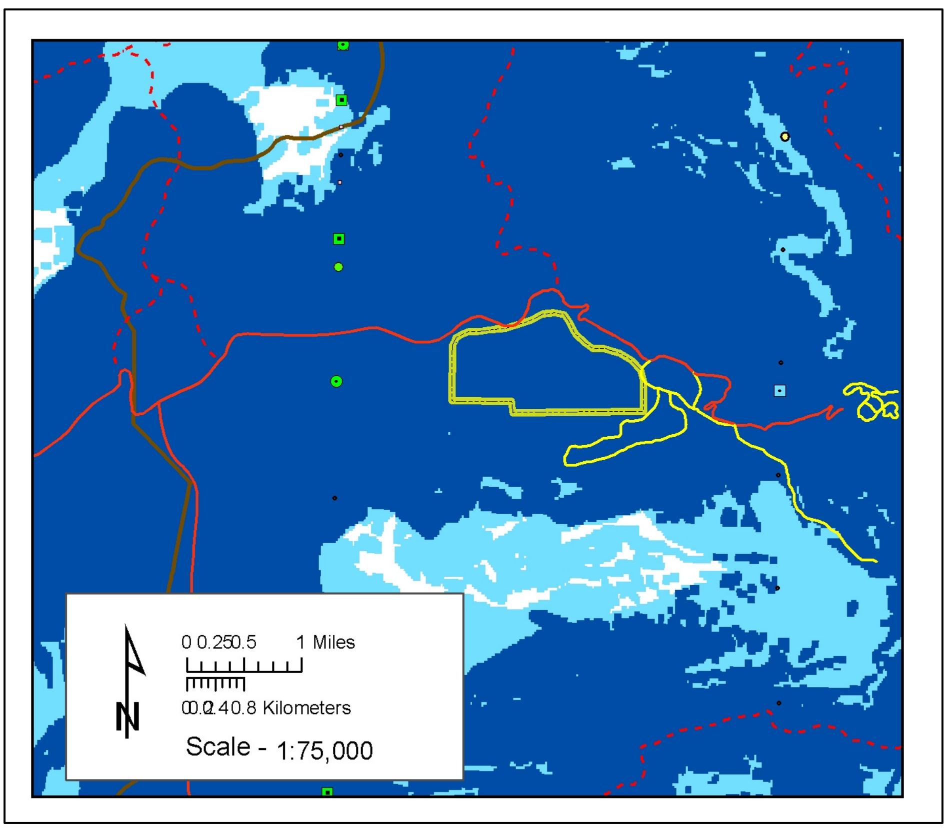
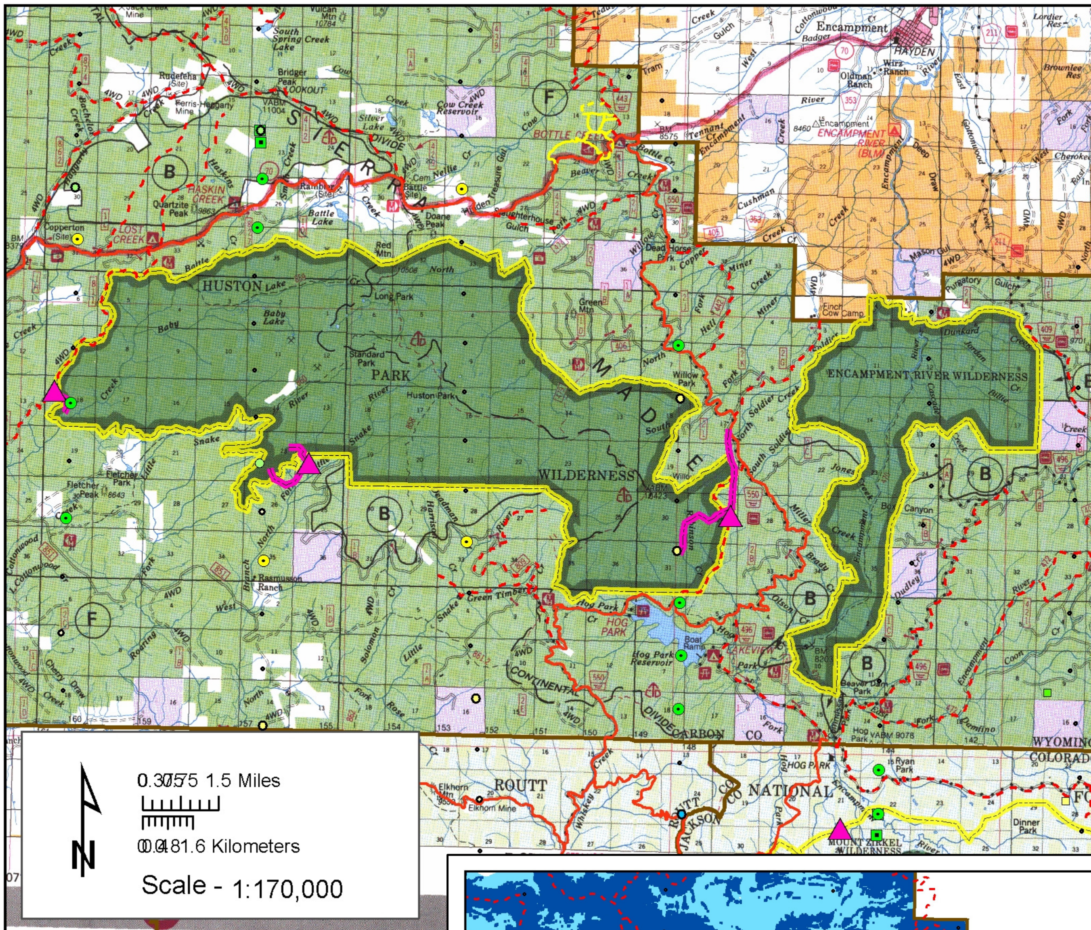


Figure 12c: Encampment River and Houston Park Wilderness



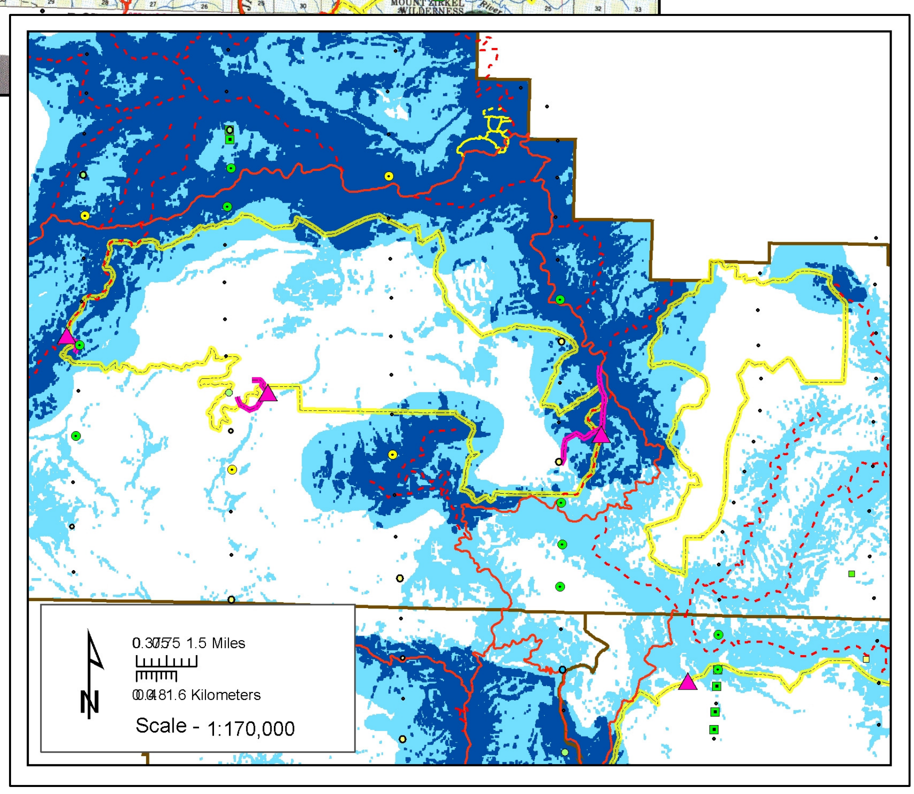


Figure 12d: Mount Zirkel Wilderness

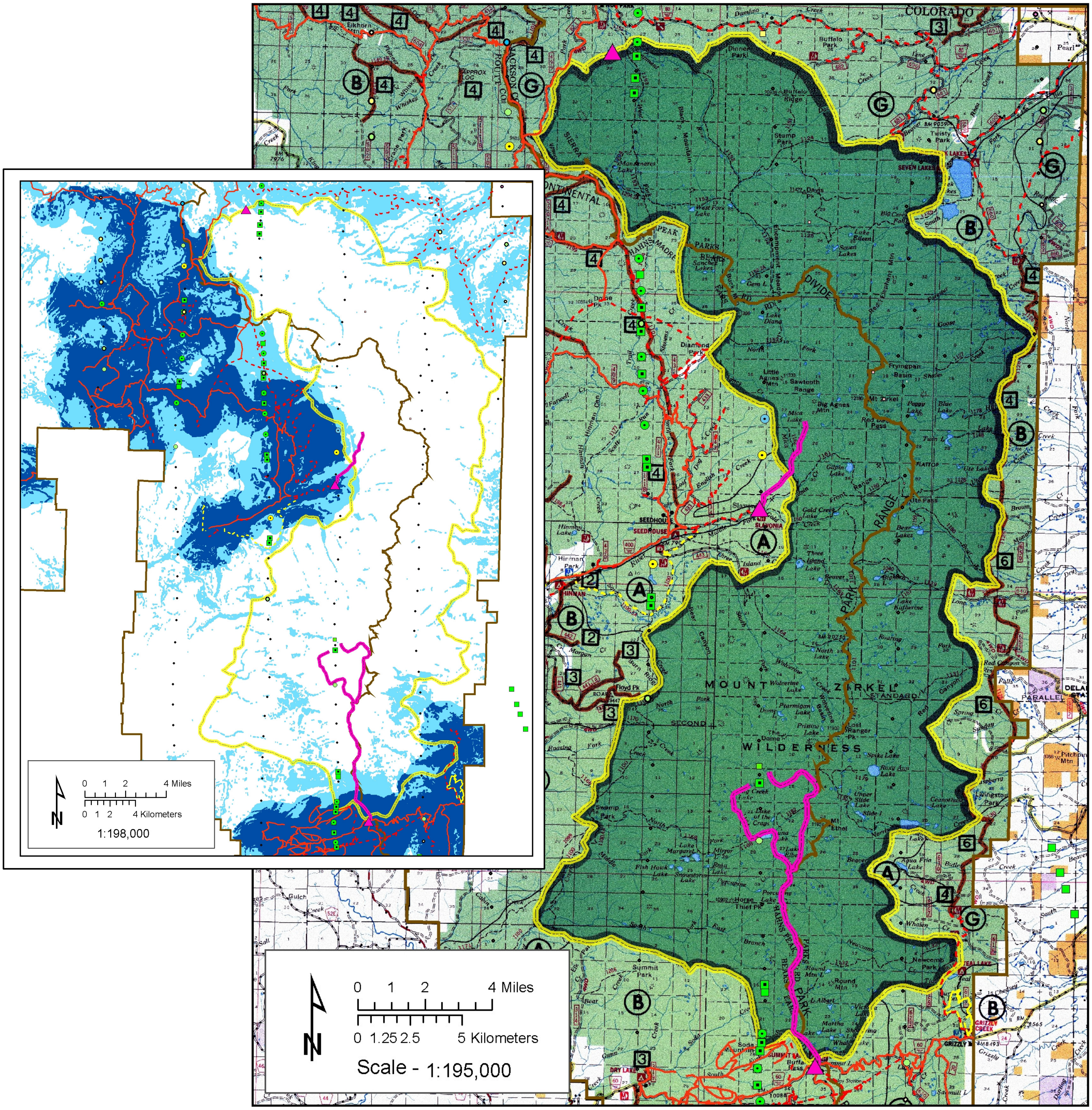


Figure 12e: Sarvis Creek Wilderness

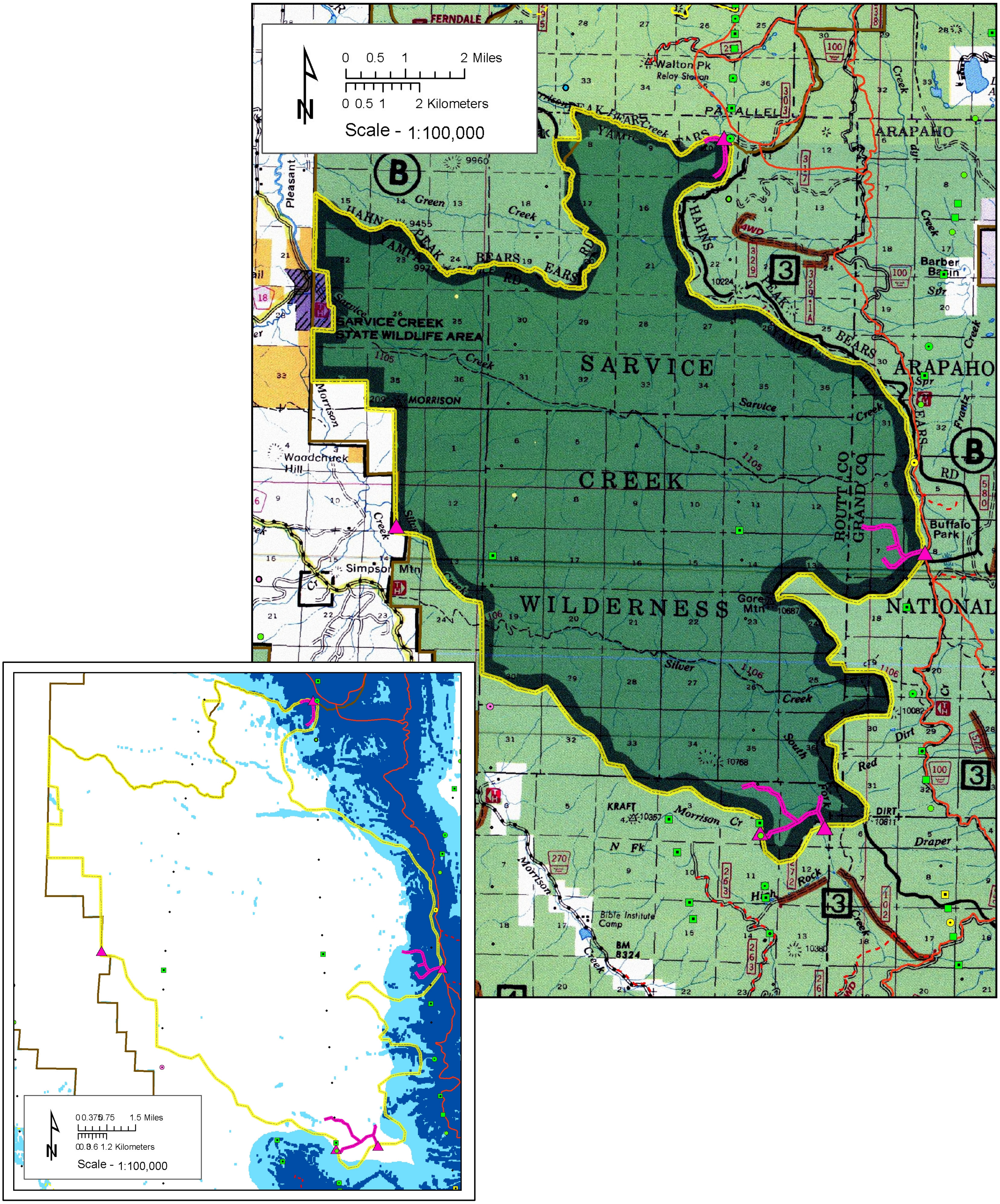


Figure 12f: Flat Top Wilderness

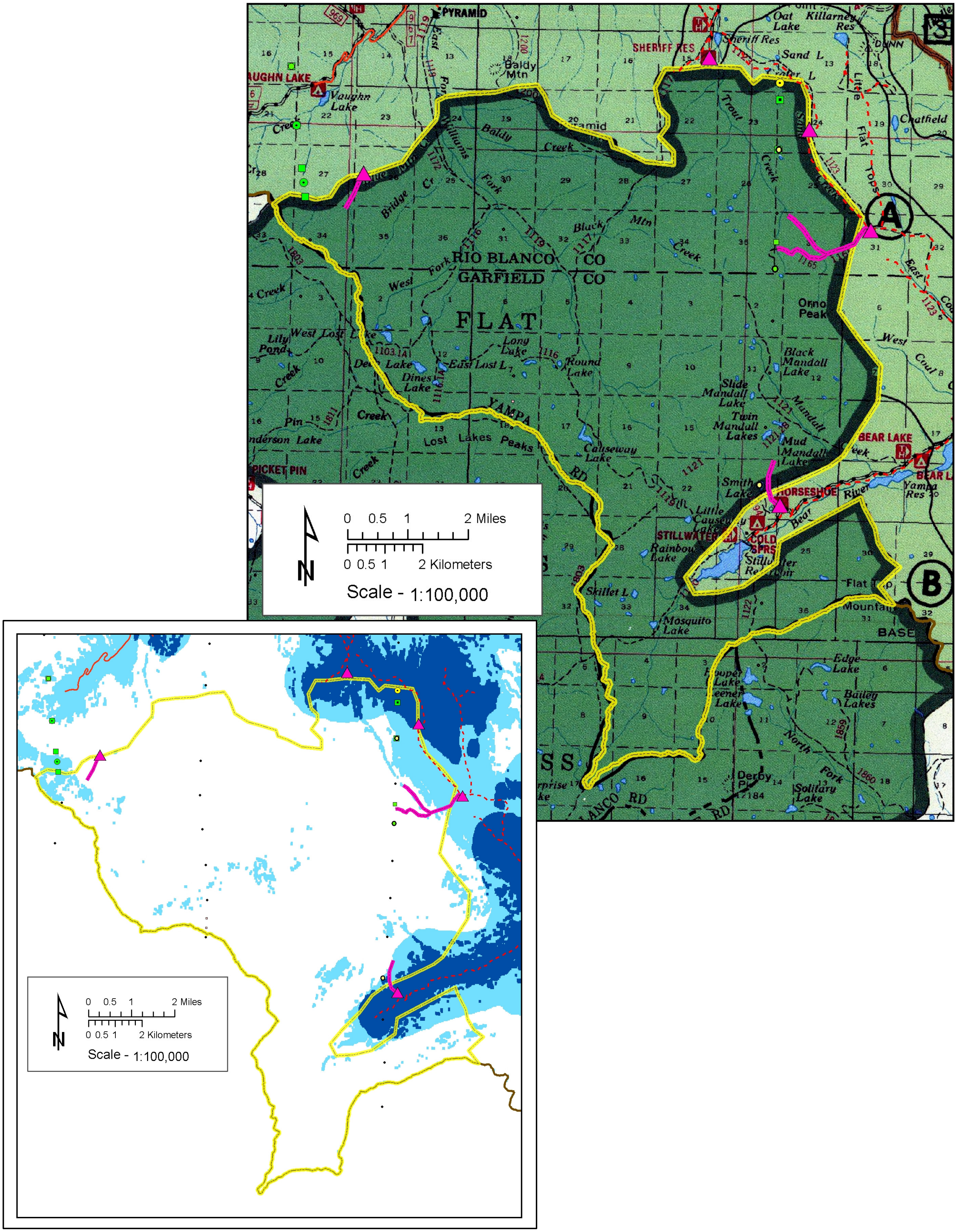
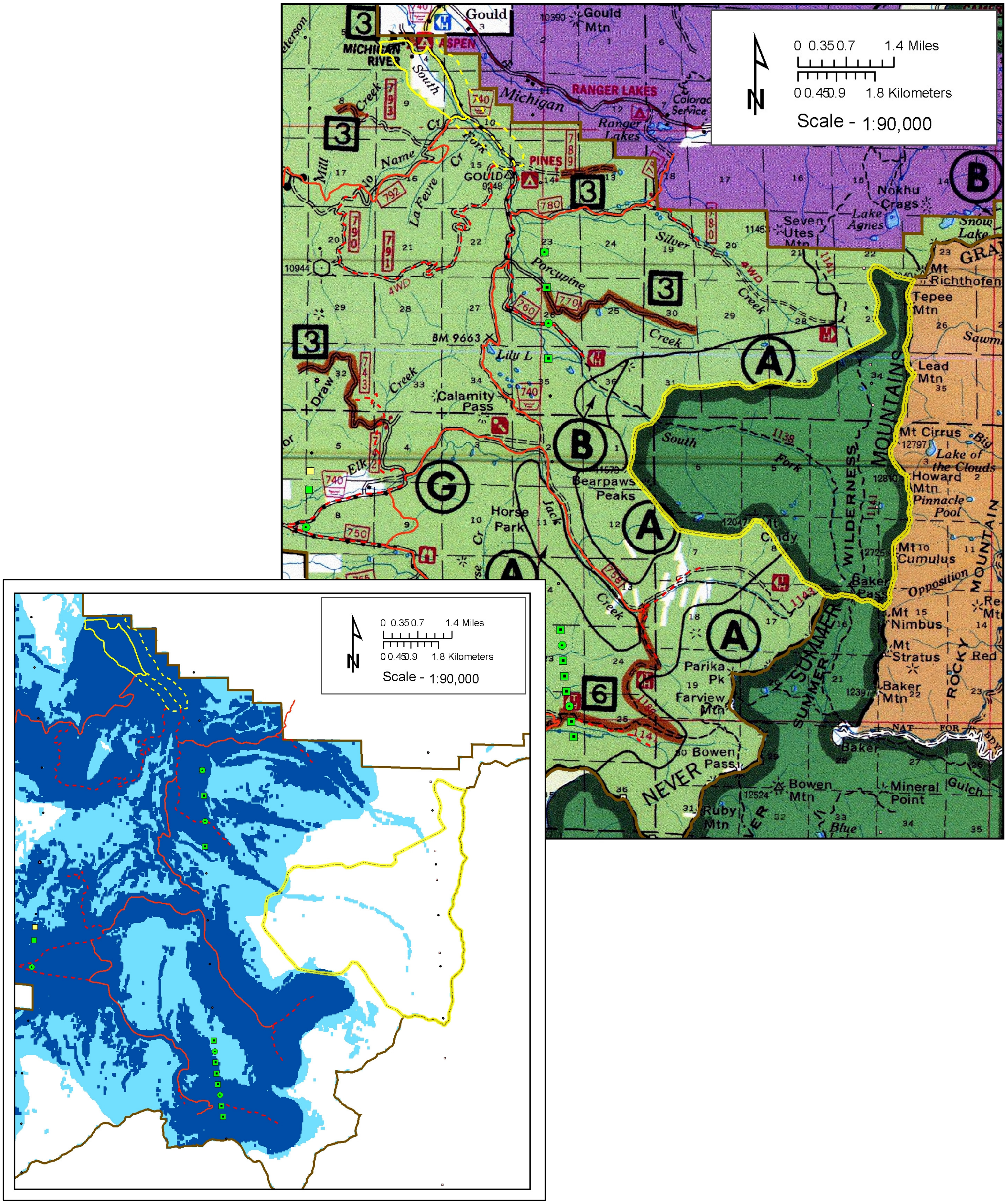


Figure 12e: Never Summer Wilderness



APPENDIX 1: FIELD PROTOCOL

1. GEAR: Be sure you have the following before getting into the plane.
    a. 2 GPS units: Ensure that they have adequate battery life and/or extra batteries are available. Make sure they have the transect routes loaded into them.
    b. 2 PVC sighting scopes.
    c. 50+ datasheets and associated ortho-photographs
    d. clipboard and writing utensils
    e. binoculars
    f. digital camera
    g. laptop: To download tracklogs and waypoints at the end of a flight (or whenever GPS memory is full).
    h. personal items: e.g., motion sickness pills, sunglasses, warm clothes, raingear, water, snacks.
2. CONFER WITH PILOT: If flying with a pilot that has not assisted us with these surveys previously, go over this protocol with him/her and make sure he/she understands it before you get up in the air. Make sure that the pilot is aware of the following:
    a. He/she must fly the plane due-north (or south) along transects from the designated starting points to the designated ending points. It is important that we remain as true as possible to transects, so the pilot should use the plane's GPS unit to ensure that the plane remains within about 100 m of the transect's course. Crosswinds and other factors will cause the plane to drift, so frequent checks should be made.
    b. The plane height should be maintained at about 1000 m from the ground surface while transects are being conducted (i.e., adjust for topography).
    c. The plane should remain as level as possible to maintain a consistent viewing angle through the sighting scope (i.e., course corrections should be gradual, not abrupt).

3. TECHNICAN DUTIES:
    a. SET GPS UNITS: Make sure the clocks of the GPS units are synchronized and reporting time in 24hr format. Make the trip computer and memory are cleared of extra data. Make sure the units are set to record data in *UTM NAD 83*. Make sure batteries are fully charged and spare batteries are at hand. At the pre-determined starting point, set the GPS tracking feature (i.e., tracklog) to automatically record a position *every 10 seconds*.
    b. Fill in all header information on the data sheets and organize them for easy reference during the flight.

c. At 20-second intervals, view the ground through the sighting scope by placing the side with the angular cut against the plains window and looking through the straight end. This should result in a viewing angle that is approximately 45º from horizontal.

d. Record snow compaction data seen within the field of view of the sighting scope. If any part of a snow compaction event is visible, it is considered "in" and should be recorded on the data sheet (see attached). Time of observations is taken directly from a source that is synchronized to the GPS unit that is recording the tracklog. Time is recorded to the nearest second in the following format: HHMM:SS (e.g., 1308:55 represents 8 minutes and 55 seconds after 1 PM). All other information will be recorded using codes listed on the bottom of the data sheet. Binoculars may be used to determine the use-type and use-intensity of an observation.

e. Between points, scan the area around the plain and, if possible, note use areas on ortho-photos and/or take documentation photographs of compaction events. Record use type and intensity for each event sketched or photographed, using the same codes noted on the datasheet (see attached).

    i. Save each tracklog upon completion of the transect and label the file with its transect ID number.

    ii. Guide the pilot to the next transect starting point.

4. RECORDING ACTIVITY. Snow compaction events, either at transect points or referencing photographs or polygons delineated on ortho-photo sheets, will be assigned the following codes. When documenting areas via photograph or ortho-photos, focus only on compacted areas that are larger than about *15 acres*, which is roughly equivalent to the Buttress of Medicine Bow Peak (for skiers) or the meadow by Green Rock Picnic area (for snowmobilers). Any motorized activity encroaching on a wilderness area should be mapped, regardless of size or activity level.

a. Activity Type:

    i. Ski track (ST): linear feature used by commuting skiers

    ii. Ski slope (SS): polygonal feature used by recreating skiers

    iii. Snowmobile track (MT): linear features used by commuting snowmobilers

    iv. Snowmobile play area (PA): polygonal feature used by recreating snowmobilers

b. Activity Level for polygonal features (snowmobile play areas and ski slopes):

    i. Low: < 25% of surface area covered in tracks

    ii. Medium: 25 - 50% of surface area covered in tracks

    iii. High: > 50% of surface area covered in tracks

c. Activity Level for linear features (snowmobile or ski tracks):

    i. Low: Single use track, likely traveled by only a few users

ii. Medium: Multiple use track traveled by roughly 10 -20 users

iii. High: Multiple use track that has likely been traveled by more than 20 users

d. Habitat Type

i. Dense Conifer (ConD): stands of predominantly conifer with canopy closure roughly greater than 40%

ii. Sparse Conifer (ConS): stands of predominantly conifer with canopy closure roughly less than 40%

iii. Aspen (Asp): stands of predominantly aspen

iv. Shrubland (Shrub): areas covered predominantly with shrub overstory, such as willow or sagebrush

v. Open (Open): areas below timberline and having no discernable woody overstory, including meadows and clearcuts with regeneration below the snow surface

vi. Alpine (Alp): areas above timberline and having no discernable woody overstory

vii. Developed (Dev): areas dominated by human development, such as roads or parking lots

5. Dealing with delays

a. Defer to the pilot's discretion in instances where transects enters areas that are unsafe to fly or cross restricted airspace. Record via GPS the point at which transects are discontinued and the point at which they are resumed.

b. If the plane must refuel, weather creates unsafe flying conditions (e.g., heavy winds, lightning, etc.), or weather hinders your ability to conduct the survey (e.g., heavy fog or rain) temporarily suspend transects until conditions are favorable, then resume transect at the point of suspension.

6. IDENTIFICATION NUMBERS:

a. Transects: Code = T f # x. (e.g., Tm5a is the identification for the first visit to the fifth transect of the Medicine Bow unit.)

i. T designates a transect

ii. f designates the forest unit (R - Route, S - Sierra Madre, M - Medicine Bow)

iii. # designates the transect number (1 - 20)

iv. x denotes the date of visit (a - first visit, b - second visit, c - third visit)

b. Ortho-photo sheets: Code = f # x - y. (e.g., s7b-24 is the identification for the sheet from the 2^{nd} visit to the 7^{th} transect of the Sierra Madre unit that is at the 24^{th} row of photo sheets from the southern boundary of the study.)

i. f designates the forest unit (R - Route, S - Sierra Madre, M - Medicine Bow)

ii. # designates the transect number with which the ortho-photo sheet is associated

iii. x denotes the date of visit (a - first visit, b - second visit, c - third visit)

iv. y denotes the north-south component of the sheet's orientation along the transect, where all transects at the same latitude have the same y-value. The southernmost ortho-photo sheet of the entire project will have y=1.

c. Detail Polygons: Code = D f x - z. (e.g., Drc-32 represents the 32nd detailed impact area mapped on the 3rd flight over the Route National Forest. This will have a use type and use level associated with it on the map, such as Medium-use Play Area.)

i. D designates this as a Detailed Map identifier

ii. f designates the forest unit in which the map occurs (R - Route, S - Sierra Madre, M - Medicine Bow)

iii. x denotes the date of visit and should correspond to x in the Transect and ortho-photo sheet identifiers (a - first visit, b - second visit, c - third visit)

iv. z is the number of the mapped figure, which should start sequentially at the beginning of the day's survey.

Sheet Number ____

MedBow-Route Snow Compaction Inventory -- Aerial Survey Datasheet

Please Return To: Douglas A. Keinath, University of Wyoming, 307-766-3013, dkeinath@uwyo.edu

Date (dd-MMM-yy)**:**	**Transect ID:**	**Scope Tech**:	**GPS Tech:**
GPS Information: *All data recorded in UTM Zone13, NAD1983*		**Trackfile(s):**	
Transect Start UTM-E:	UTM-N:	**Transect End** UTM-E:	UTM-N:
Notes (weather, etc.):		**Pilot**: ____________________ **Plane Type**:	

GPS Time (hhmm:ss)	Use Type[1]	Use Level[2]	Cover Type[3]	_____ (____)	Photo Number	______ ______	Notes

[1] Use Type: Ski Track = ST, Ski Slope = SS; snowmobile Track = MT, snowmobile Play Area = PA
[2] Use Level: Low use = 1 (single-use track or <25% of area covered in tracks), Medium use = 2 (multiple-use track or 25-50% of area covered), High use = 3 (>20 users of track or >50% of area covered).
[3] Cover Types: Dense Conifer - ConD; Sparse Conifer - ConS; Aspen - Asp; Shrubland (sage, willow, mahagany, etc.) - Shrub; Meadow or Clearcut - Open; Alpine (above timberline) - Alp; Developed (road, parking lot, etc.) - Dev.

GPS Time (24hr)	Use Type[1]	Use Level[2]	Cover Type[3]	Detail (#)	Photo Number	______ ______	Notes

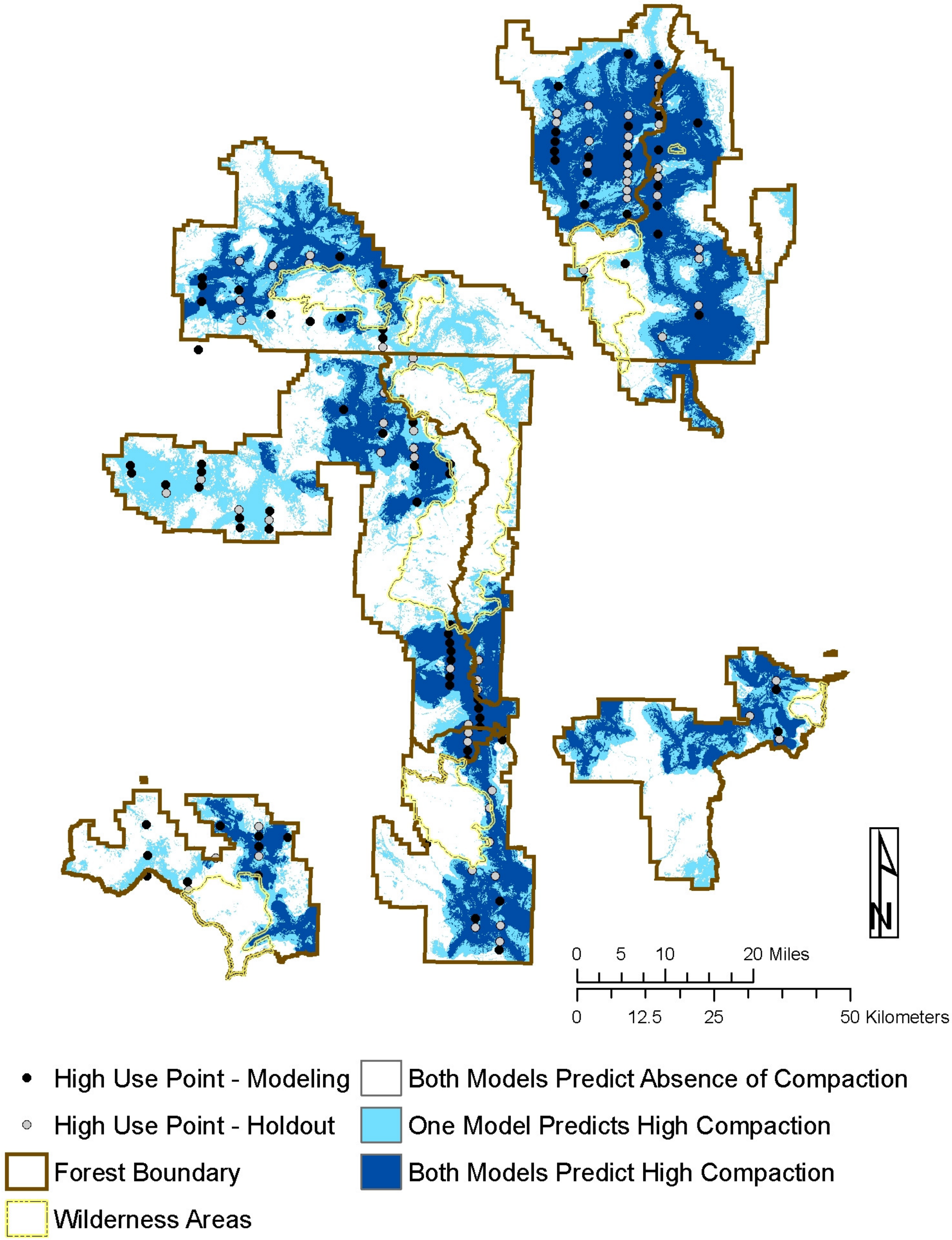
[1] Use Type: Ski Track = ST, Ski Slope = SS; snowmobile Track = MT, snowmobile Play Area = PA

[2] Use Level: Low use = 1 (single-use track or <25% of area covered in tracks), Medium use = 2 (multiple-use track or 25-50% of area covered), High use = 3 (>20 users of track or >50% of area covered).

[3] Cover Types: Dense Conifer - ConD; Sparse Conifer - ConS; Aspen - Asp; Shrubland (sage, willow, mahagany, etc.) - Shrub; Meadow or Clearcut - Open; Alpine (above timberline) - Alp; Developed (road, parking lot, etc.) - Dev.

APPENDIX 2: SNOW COMPACTION MODEL SUMMARIES

Combined Recreational Snow Compaction Model for the Medicine Bow – Routt National Forest



Combined Recreational Snow Compaction Model for the Medicine Bow – Routt National Forest

Summary and Interpretation

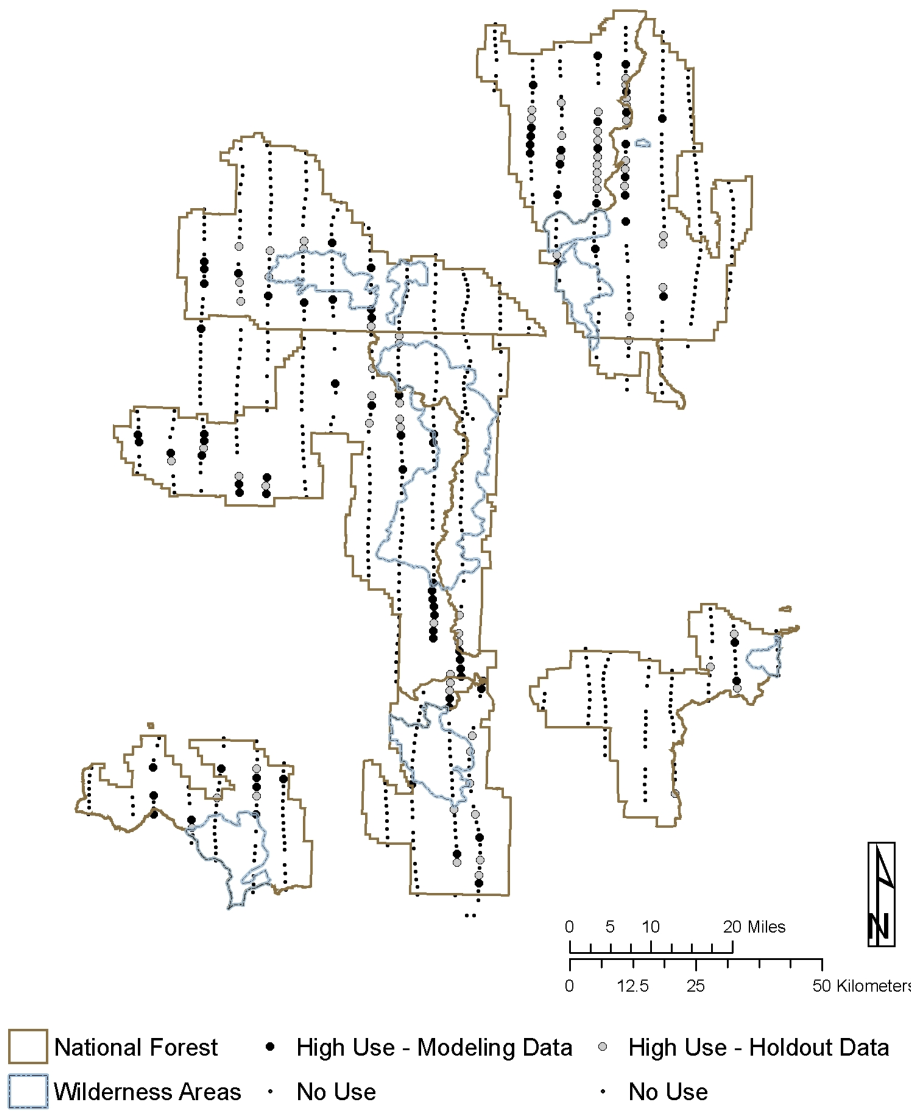
This predictive distribution model for high snow compaction due to winter recreation activity was created by overlaying two models derived from separate statistical approaches: (1) classification and regression trees using the Random Forests algorithm, and (2) the DOMAIN environmental similarity method. The areas where these models converge should be considered the area of most likely occurrence or absence. Those areas predicted to be compacted by only one model might be considered possible, but less likely, areas of potential compaction if they are geographically proximate to areas of positive model convergence. Details of the inputs and outputs of each model are presented in the following pages.

Both models validated well (Classification Success based on withheld validation data: Random Forest = 74.9% and DOMAIN = 69.3%), although DOMAIN predicted a larger area of the forest under compaction. Contiguous areas of model convergence should be considered good estimates of potential high snow compaction *at the scale of the whole forest*, but areas farther from the core of contiguous compacted zones should be deemed more uncertain. The most important predictors in both models were those relating to accessibility, most notably how close an area was to a posted snowmobile route, a parking lot, or a road. Considering the whole forest, areas closer to these features were much more likely to be compacted than more remote areas. At this scale, other factors, including tree cover, slope, elevation, and precipitation were less influential in predicting compaction.

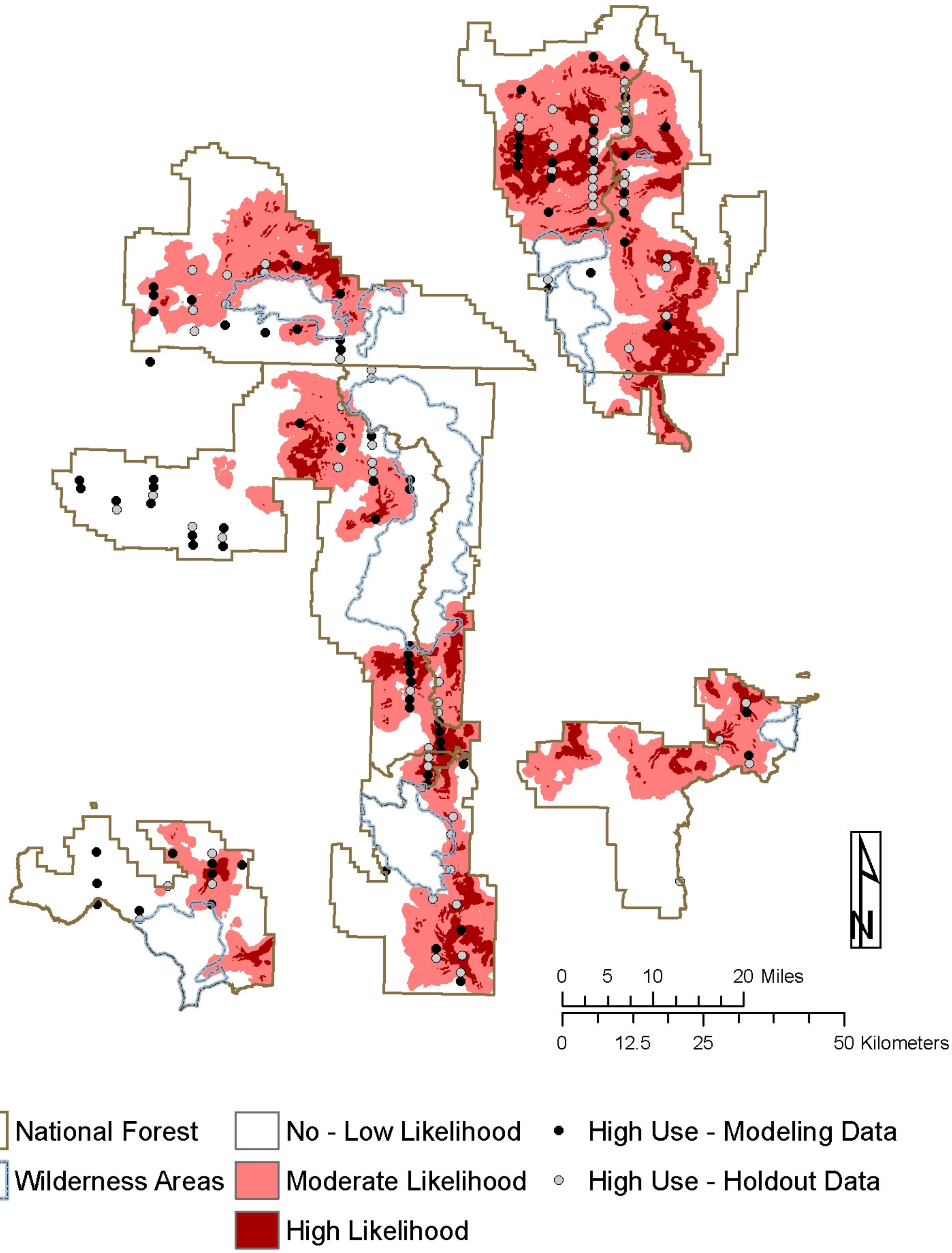
There are factors acting at finer scales that can greatly impact whether a particular area is compacted. For example, a dense stand of trees on a fairly steep, north-facing slope could retain deep, soft snow and be difficult for snowmobiles and skiers to traverse. Such micro-site conditions cannot readily be determined from available information at the scale of the entire Medicine Bow – Routt National Forest. ***Thus, the output of this model should be interpreted as area likely to be compacted given appropriate micro-site conditions.***

Input Points

Points of known compaction and suspected non-compaction (i.e., points where no compaction was observed) were drawn from survey flight data described in the main report. We used only those points that were within forest boundaries and had a high level of compaction (low and moderate compaction events were not used for modeling efforts). This resulted in 152 high compaction points and 675 points where compaction was suspected to be absent. 75% of these points were used to build the model, while the remaining 25% were withheld from model development and used to validate the resulting models.



Predicted Distribution of High Snow Compaction



DOMAIN Model of Recreational Snow Compaction

Modeling Notes

The similarity grid was created using the DOMAIN algorithm and the data layers, training points, and program options specified below.

Filter criteria for occurrence data
Landownership: Only FS Land
Use Level: Only High Use

Numbers of points after filtering

	Model	Validation	Total
Known Positive	82	70	152
Known Negative	571	104	675
Total	653	174	827

Predictor layers

1. Precipitation of the Coldest Quarter (Daymet P8)
2. Mean Annual Frost Days (Daymet tfa)
3. Elevation (30 meter DEM)
4. Slope (degrees based on 30m DEM)
5. Percent Tree Cover (from R2 Veg)
6. Distance to winter snowmobile trails (from FS)
7. Distance to snowmobile access points (from FS)
8. Distance to road (from FS)
9. Distance to stream

DOMAIN settings
Use Points: Yes
Use Transects: No
Complete Categorical Dissimilarity: No
Average closest [10] points: Yes
Compute Distance: No
Compute Similarity: Yes

Binary model grid (1/0 = predicted positive/negative)
Predicted positive above a similarity threshold of 9900 (0.9900), with the highest 25% of predicted positive points occurring above similarity threshold 9945 (0.9945). The threshold value used to create the binary model grid was determined by applying receiver operating characteristic (ROC) analysis to the confusion matrix generated from the validation data set. This method plots model sensitivity (true positive rate) against the commission error rate (false positive rate) and selects an optimal threshold by explicitly accounting for the prevalence of positive points.

Classification Rates

Model Points

	Predicted Positive	Predicted Negative	
Known Positive	57 (72.2%)	22 (27.8%)	Total Correct 72.3%
Known Negative	127 (27.7%)	331 (72.3%)	Total Incorrect 27.7%

ROC AUC: 0.7524
Accuracy: 0.7225
Precision: 0.3098
Recall: 0.7215

Validation Points

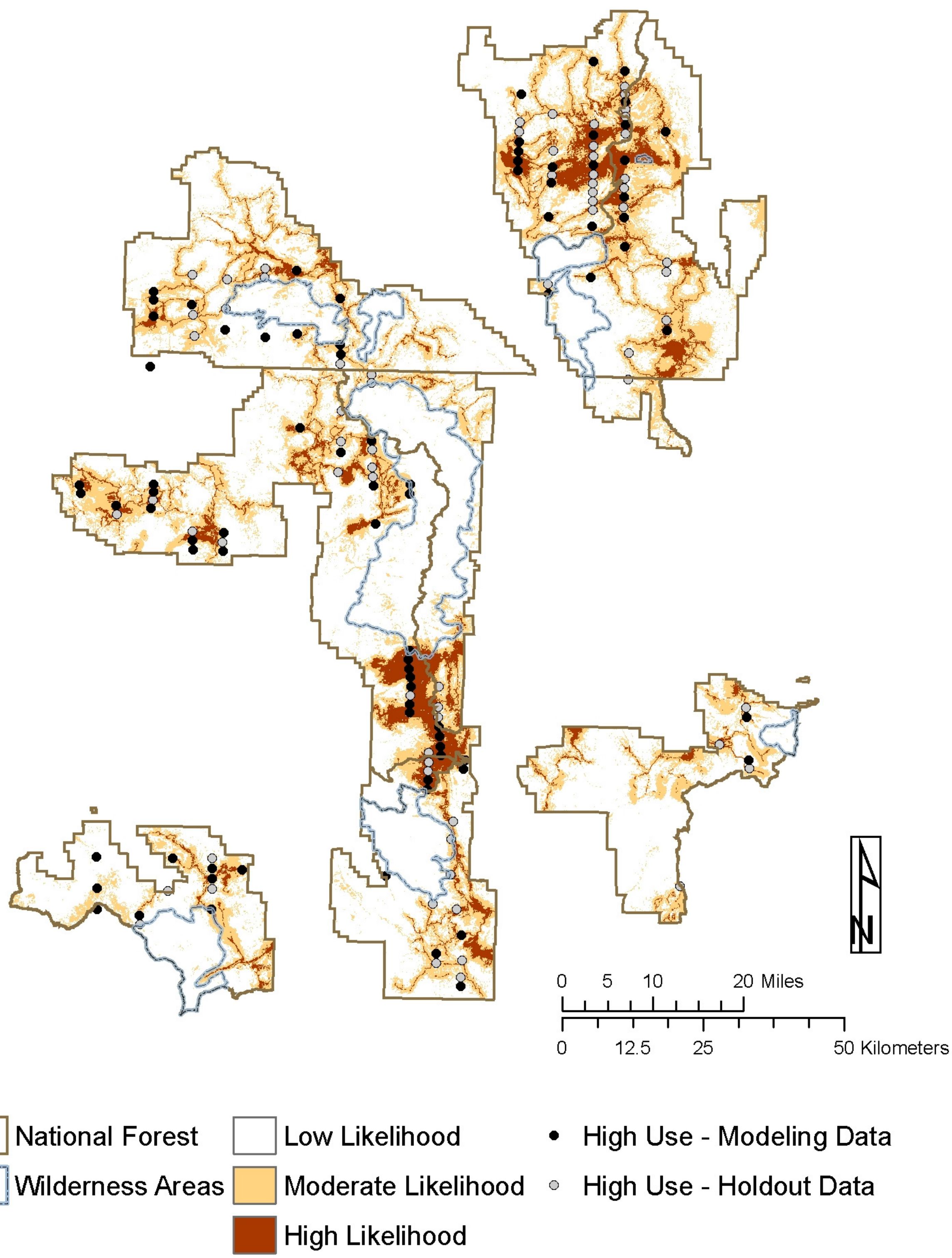
	Predicted Positive	Predicted Negative	
Known Positive	55 (78.6%)	40 (36.7%)	Total Correct 69.3%
Known Negative	15 (21.4%)	69 (63.3%)	Total Incorrect 30.7%

ROC AUC: 0.7278
Accuracy: 0.6927
Precision: 0.5789
Recall: 0.7857

Approximate Area of Predicted Distribution

Binary Positive: 41.1% of Forest (962,260 acres)
High Likelihood; i.e., Highest 25% of Positives: 10.3% of Forest (240,565 acres)

Predicted Distribution of High Snow Compaction in the Medicine Bow – Routt National Forest



Random Forest Model of Recreational Snow Compaction

Model Notes

The probability grid was created using the RANDOM FOREST algorithm and the data layers, training points, and program options specified below.

Filter criteria for occurrence data
Landownership: Only FS Land
Use Level: Only High Use

Numbers of points after filtering

	Model	Validation	Total
Known Positive	82	70	152
Known Negative	571	104	675
Total	653	174	827

Predictor layers
1. Precipitation of the Coldest Quarter (P8, from Daymet)
2. Mean Annual Frost Days (TFA, from Daymet)
3. Elevation (DEM30)
4. Slope (SLOPE, degrees based on 30m DEM)
5. Percent Tree Cover (PCTTRE, from R2 Veg)
6. Distance to winter snowmobile trails (RTFS, from Forest Service)
7. Distance to snowmobile access points (ACSPT, from Forest Service)
8. Distance to road (ROADFS, from Forest Service)
9. Distance to stream (STRM)

RANDOM FOREST Settings
Number of trees: 1000
Node size: 3

Binary model grid (1/0 = predicted positive/negative)
Predicted positive above a threshold of 0.1799, with the highest 25% of predicted positive points occurring above similarity threshold 0.4040. The threshold value used to create the binary model grid was determined by applying receiver operating characteristic (ROC) analysis to the confusion matrix generated from the validation data set. This method plots model sensitivity (true positive rate) against the commission error rate (false positive rate) and selects an optimal threshold by explicitly accounting for the prevalence of positive points.

Classification Rates
Model Points
OOB estimate of error rate: 13.41%

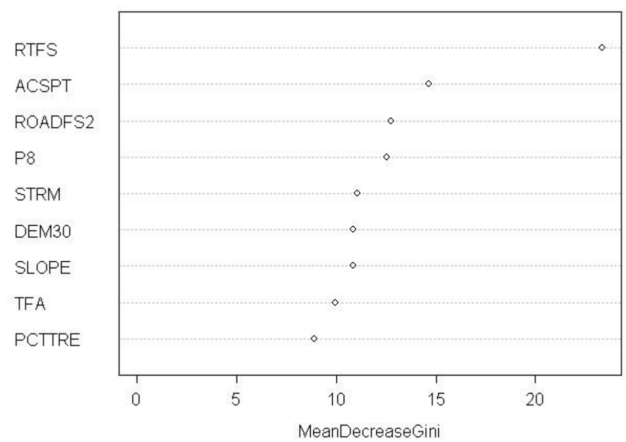
Validation Points

	Predicted Positive	Predicted Negative	
Known Positive	50 (71.4%)	20 (28.6%)	Total Correct 74.9%
Known Negative	25 (22.9%)	84 (77.1%)	Total Incorrect 25.1%

ROC AUC: 0.7963
Accuracy: 0.7486; Precision: 0.6667; Recall: 0.7143

Approximate Area of Predicted Distribution
Binary Positive: 34.1% of Forest (797,953 acres)
High Likelihood; i.e., Highest 25% of Positives: 8.5% of Forest (199,488 acres)

Variable Importance Plot



Error Rate Plot