Modeling Talus Habitat Using NAIP Imagery and Topographic Features in Portions of Idaho, Montana and Wyoming

A project to support wolverine habitat analyses

Julia Smith and Kimberly Heinemeyer

4/21/2017

Round River Conservation Studies
104 East Main St, Suite 302
Bozeman, MT 59715
www.roundriver.org

Modeling Talus Habitat Using NAIP Imagery and Topographic Features in Portions of Idaho, Montana and Wyoming

A project to support wolverine habitat analyses

Julia Smith and Kimberly Heinemeyer
Round River Conservation Studies

April 21, 2017

Report prepared for Idaho Department of Fish and Game

Citation: Smith, J. and K. Heinemeyer. 2017. Modeling talus habitat using NAIP imagery and topographic features in portions of Idaho, Montana and Wyoming. Report to Idaho Department of Fish and Game. Round River Conservation Studies, Bozeman, MT. 42pp. Available at www.roundriver.org/wolverine

ACKNOWLEDGEMENTS

We are grateful for the support of our multiple partners, collaborators, and field crews who have helped make this project possible. Funding for this effort was contributed by the Idaho Fish and Game Department and Round River Conservation Studies (RRCS). We would also like to thank the ESRI Conservation Program for the generous grant which provided the ArcGIS software used in this analysis. We are grateful to Diane Evans Mack, Idaho Fish and Game, Regional Wildlife Diversity Biologist for her time and assistance in developing the project as well as in planning field sites, organizing and mobilizing field crews, and compiling the data from multiple study sites. We would also like to thank U.S. Forest Service Wildlife Biologist Robin Garwood for organizing field crews in the Sawtooth, Boulder and Whitecloud Mountains. We thank Rebecca Watters for organizing and leading the field efforts in the western Yellowstone region.

This project would not have been possible without the efforts of our field technicians and volunteers: – Betsy Wagner, Curt Mack, Dian Evans-Mack , Ed Papenberg, Ian Smith, Nathan Borg, and Regan Berkley in McCall; Avery Lavoie, Celina Moreno, Chris Klinger, Katy Nelson, Robin Garwood, and Scott Friedman in Ketchum; and Alison Fauvre, Amanda Watters, Dylan Taylor, and Rebecca Watters in the western Yellowstone region. Thank you for your time, patience, and dedication, even in the face of unpredictable mountain weather and unusually curious bears.

Contents

ABSTRACT

The purpose of this project was to develop spatial data on the location of talus habitats to inform the analyses of habitat selection by wolverines. Most existing land cover classifications combine ridgetop, cliff, talus, and alpine habitats into a single "sparse" or "alpine" class with limited utility for wildlife habitat modeling if selection within these habitat types is expected. Our goal was to use high resolution imagery to map rocky alpine habitats such as talus and exposed rock with a specific intent of identifying large boulder talus areas. Our study region covered six study areas that spanned central Idaho, southwestern Montana, and western Wyoming, to coincide with our existing wolverine location information. We used four band (B-G-R-NIR) 1 m resolution National Agriculture Imagery Program (NAIP) imagery and 10 m resolution digital elevation models (DEMs) in model development. A maximum likelihood classifier with equal probabilities was chosen to produce spectral as well as combined spectral/topographic signatures. A uniform signature could not be identified for talus across all six study areas; therefore, classifiers were built for each study area individually. The talus land cover class was field validated in August - September 2016, with a total of 453 field sites visited. In addition, 10,000 remotely assessed validation points were collected. Despite concerted efforts, we were unable to reliability differentiate large boulder talus from other types of talus. Both the field and remote validation efforts found that ~80% of talus slopes contain large boulders; therefore the majority of talus appears to provide areas of large boulder structure. Ten land cover classes were included in the final model: talus, bare rock, sparse, coniferous, deciduous, burn, wetland, water, snow, and shadow. The model containing both spectral and topographic predictors had an overall 70.2% accuracy in identifying talus and 87% accuracy in identifying a combination of talus and bare rock land cover types. This model substantially improves our ability to identify important talus habitats at a landscape scale for use in habitat analyses for wide-ranging species such as wolverine that may select talus habitats for foraging, resting or other life requisites.

INTRODUCTION

Wolverines (*Gulo gulo*) are a mid-sized carnivore of northern latitudes that occurs at naturally low densities across a circumpolar range. Within the United States, wolverines are currently found in boreal subalpine and alpine habitats, primarily within the northern Rocky Mountains of Wyoming, Montana, and Idaho, and the northern Cascades of Washington (Aubry et al. 2007). The low density of wolverines combined with the remote characteristic of their habitats has contributed to limited scientific research but we know that wolverines use large home ranges, and that in the winter, they rely primarily upon carrion for food, which they seek through extensive movements across their home ranges. Females establish reproductive dens between mid-February and early March, with dens dug into snow and often accessing complex structures – typically either large boulder scree or downed woody structures – within which they may create a complex system of snow tunnels (Magoun and Copeland 1998).

Between 2010 and 2015, a research effort to document wolverine movements, habitat use and responses to winter recreation resulted in the GPS collaring of 24 wolverines (Heinemeyer and Squires 2015; prior progress reports available at www.roundriver.org/wolverine). Preliminary observations from this research effort ('wolverine –winter recreation study') identified large boulder talus slopes as potentially important habitat for female denning and for resting habitat. In the winter, the large crevices, tunnels and gaps between the boulders create subnivean spaces that may provide thermal protection for animals as well as potential subnivean foraging opportunities. A notable portion of the reproductive dens documented by the wolverine-winter recreation study are found in these large boulder talus fields. Anecdotal information from other studies also suggests the importance of these habitats for foraging (e.g., on marmots).

PURPOSE

Wolverine habitat and behavioral analyses being undertaken as part of the wolverine-winter recreation study would be enhanced by high-resolution spatial documentation of talus habitats and particularly large boulder talus. There are no existing spatial datasets across the study region that identify or predict the location and/or areal extent of talus fields. The purpose of this project was to develop such spatial information. Most available land cover classification efforts are large in scale, coarse in resolution, and largely focused on differentiating vegetation classes for forestry management purposes, therefore combining all ridgetop, cliff, talus, and alpine habitats into a single "sparse" or "alpine" class. This class in most land cover products is both overly general in description and too coarse in resolution to be of use to scientists studying specifically alpine-dependent species at finer scales. Currently available land cover products include LANDFIRE, with a spatial resolution of 30 m and an accuracy in the Northern Rockies of less than 50% (Rollins et al 2006); the National Land Cover Dataset (NLCD), which combines all talus, rock, sand, and clay classes into a single "barren" category, again at 30 m resolution (Wickham et al. 2013); and the Region 1 USFS VMap , with a minimum mapping unit of ~2,000m^2 which comes with a disclaimer that "the expected accuracy does not warrant their use for analyses [for]… assessments that typically require 1:24,000 data" (Brohman & Bryant, 2005).

Our goal in this effort was to use high resolution imagery to map rocky alpine habitats such as large boulder talus and exposed rock at a fine enough scale to be useful in habitat selection and other behavioral analyses. Thus, our objectives were: 1) to discern if areas of rock and talus could be successfully mapped at higher resolutions based on 4-band spectral data in combination with topographic landscape variables ; 2) to successfully map talus fields at a finer scale (> 15 m) and at a larger extent than currently available through public and private land cover products; and 3) discern large boulder talus habitats from smaller scree and bare rock, since these large boulders provide potentially important habitats to wolverines during denning and resting.

STUDY AREA

Our study region for this project was the collective home range boundaries of all GPS-collared wolverines in the study. The wolverine home ranges covered six study areas that spanned central Idaho, southwestern Montana, and western Wyoming (Figure 1), covering a total of 9,321 km^2 (3,599 mi^2).

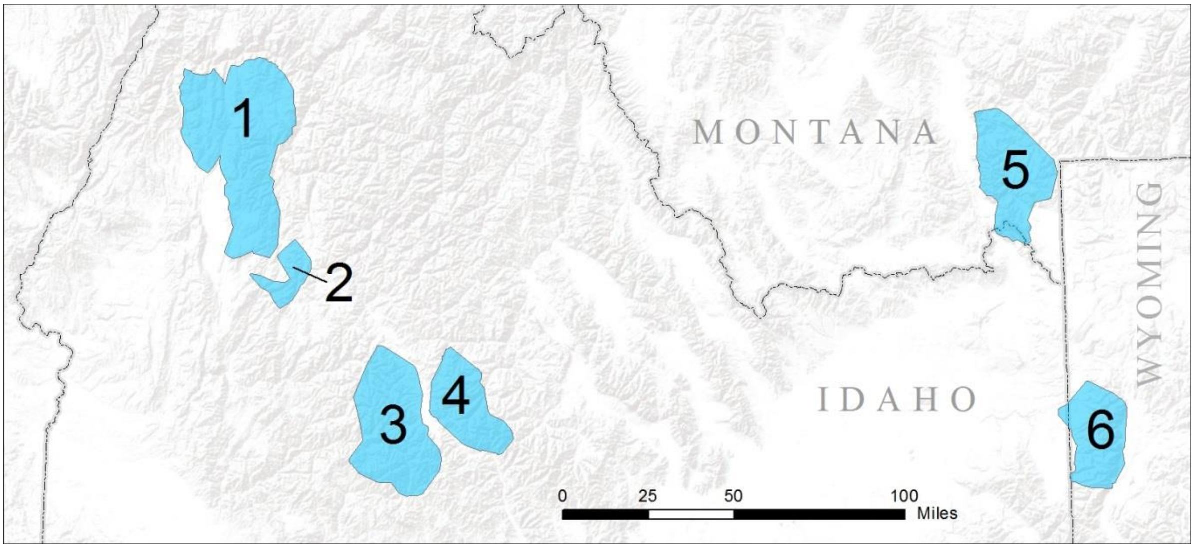


Figure 1. *Home range areas of wolverines in central Idaho, southwestern Montana, and western Wyoming, based on GPS collar data collected 2010 – 2015.*

METHODOLOGY

Four band (B-G-R-NIR) 1 m resolution National Agriculture Imagery Program (NAIP) imagery (2015) was downloaded in tiles from the USDA Server, and later from the Google Earth Engine platform to cover the study areas. Additionally, 10 m resolution digital elevation models (DEMs) were downloaded from the USGS National Elevation Dataset. The DEMs were used to generate: aspect, slope, flow accumulation, terrain ruggedness index (TRI; Riley et al. 1999), topographic position index (TPI; Weiss 2001), and vector ruggedness measure (VRM; Sappington et al. 2007) for the study areas. To assess the impact of neighborhood size when calculating certain topographic variables, TPI was calculated at three scales and

VRM at five. For the purposes of this study, a large boulder talus field was defined as a talus area having two or more large boulders, with large boulders defined as free-standing rocks with at least one dimension greater than 3m (Figure 2).

To test the importance of topographic variables in identifying talus and particularly large-boulder talus, 1,235 polygons were digitized around talus fields using high resolution (30 – 65 cm) Digital Globe imagery available on CalTopo (www.caltopo.com) and Google Earth (www.google.com/earth). The presence of large boulders and the location of the boulders within the talus field of the boulders (upper, lower, lateral edge, scattered) were recorded for each polygon. A total of 2,000 random points were generated within these polygons, in addition to 844 points in bare rock training polygons and 8,000 random points distributed across the study areas to analyze the significance of topographic variables.

Several image classification methods were tested, including multiple versions of a maximum likelihood classifier, object-based image classification using ENVI, and several classifiers available in the Google Earth Engine. A maximum likelihood classifier with equal probabilities (Figure 3) was chosen to produce spectral

Figure 2. *Large boulder talus; one of the field sites visited along Badger Creek in the Teton range, western Wyoming.*

as well as combined spectral/topographic signatures, with likelihood (Lk) of a pixel belonging to a certain class defined as follows:

$Lk = P(k/\mathbf{X}) = P(k)*P(X/k) / \Sigma P(i)*P(\mathbf{X}/i)$
where P(k) : prior probability of class k
P(X/k) : conditional probability to observe **X** from class k, or probability density function

In this case, P(k) is assumed to be equal to each other and P(i)*P(X/i) is also common to all classes.

The talus land cover class was ground-truthed in the field in August - September of 2016. Field validation was distributed across each study area based on the availability of field crews in specific areas (Figure 4). Constraints due to the timing and logistical challenges for field validation required us to develop classification training sites and individual, site-specific models within a 1 kilometer buffer of trails accessible to field crews, rather than an consistent, wall-to-wall classification for the entire study area. Talus areas from the individual models were extracted and 50-75 random points were distributed per trail within these sampling areas. Crews were directed to stratify their sampling within each trail if they could not feasibly reach all points. Data collected by field crews included: primary cover, secondary/alternate cover(s), length (m) of talus fields both laterally and perpendicular to slope, presence/absence of large boulders, relative location of boulders, presence of vegetation in talus fields, signs of pika and marmot, as well as 4-6 photos of the site. Opportunistic sampling data were also collected along designated routes and in areas outside of the pre-determined validation areas. Attributes collected from opportunistic sites were similar to those collected at designated sites.

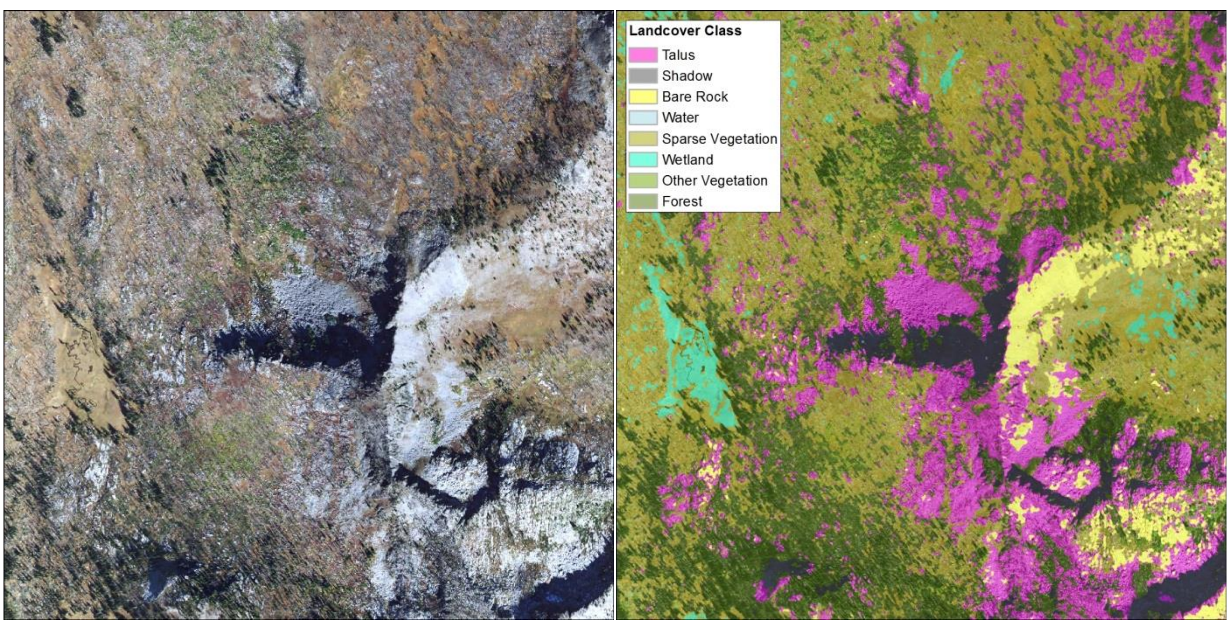


Figure 3. *Preliminary maximum likelihood classification results of 1 m NAIP imagery. Classes of interest are talus and bare rock.*

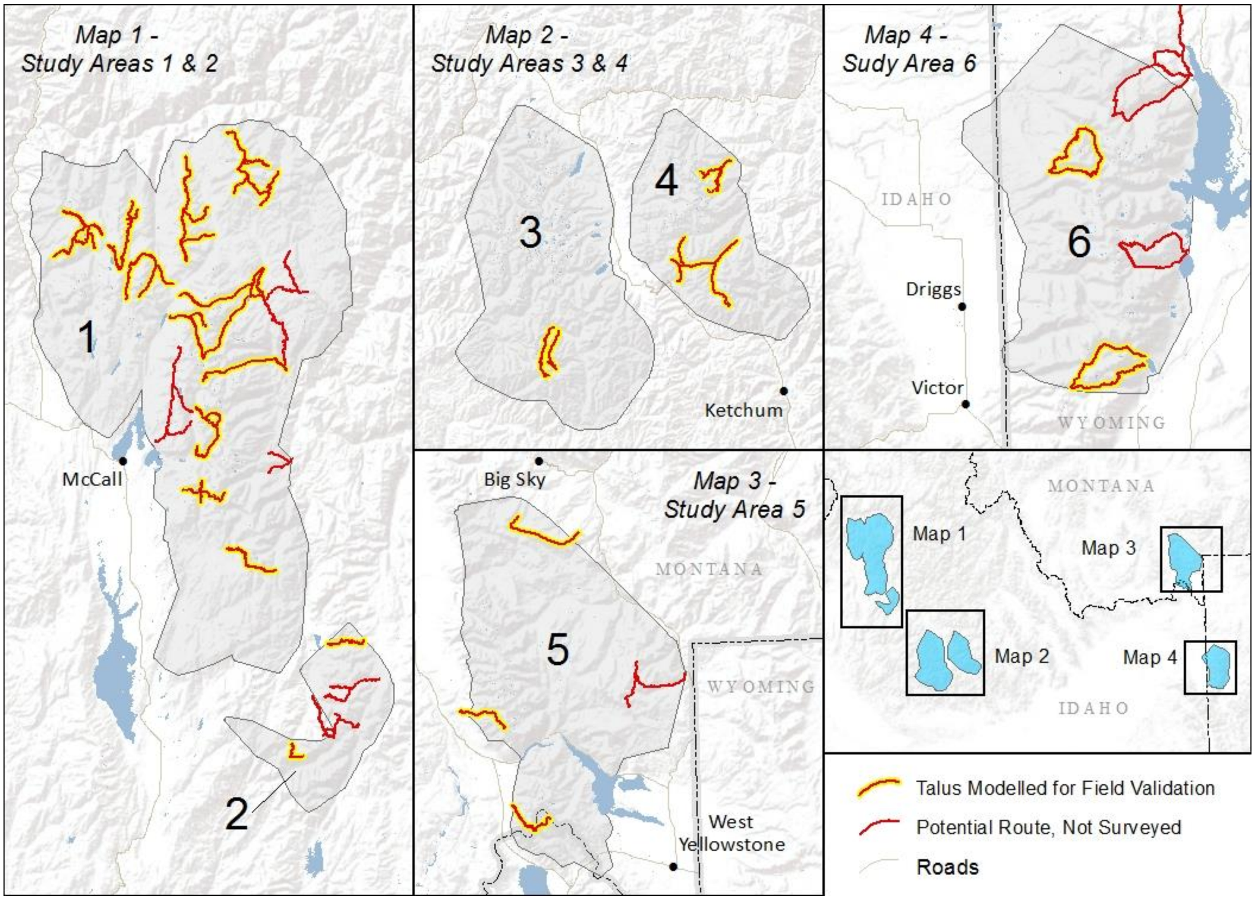


Figure 4. *Access trails for field validation of mapped talus. Routes highlighted in yellow were surveyed August – September 2016*

Due to variations in spectral signatures and image date collection, a uniform signature could not be identified for talus across all six study areas; therefore, classifiers were built for each study area individually. These were constructed upon the collective training sites initially developed for field validation with additional training sites added to produce signatures that were accurate across each study area. Two different maximum likelihood classifications were created in each of the six study areas to assess the change in model accuracy when including topographic variables. Both classifications used the same training data and the four spectral bands of the NAIP, but the topographic model included topographic variables in its signatures. Images were classified on a pixel-by-pixel basis then passed twice through focal majority filters to smooth the data and remove anomalous pixels. Similar regions were identified and grouped based on whether or not the pixels shared at least one of four boundaries with its own class. A minimum mapping unit (MMU) of 200m^2 was used to produce the final classification map, with regions containing less than 200 m^2 of homogenously-classified data removed and replaced with a coarser-scale majority filter to produce the final classification image.

Remote accuracy assessment of the models was carried out on the final models using 10,000 validation points. Some of these were generated randomly across the study areas, while others were constrained to areas previously modelled as talus to ensure a large enough sample size in our target land cover class.

These points were assessed individually using high resolution Digital Globe imagery to record the primary (<5 m window) and secondary/alternate cover types (15 m window). Additionally, at points where talus was present, the size of the talus field was recorded as well as the presence/absence of large boulders. The final classifications were validated with the remotely-classified ground truth points based on whether the model classification matched either the primary or secondary ground truth cover type. Accuracy was assessed for each model at four different levels: Level IV (7 classes) which analyzed the performance of all classes separately; Level III (6 classes) which grouped rock and talus into one class; LeveI II (3 classes) which analyzed rock and talus separately but groups all remaining classes into a single "other" class; and Level I (2 classes) which grouped the talus and rock classes together and assesses accuracy compared to the combined "other" class.

RESULTS

Of the different classifiers we experimented with, the maximum likelihood classifiers produced the best results, particularly in differentiating talus from rock. Initial results of the object-based image classifiers in ENVI on the same test areas proved less accurate, particularly in classifying talus. The classifiers available in Google Earth Engine (GEE) were also tested, but initial efforts were derailed due to a user memory limit error. This issue with GEE could potentially be addressed with object-growing algorithms and would likely perform more efficiently than client-side analysis programs, but was not investigated further for the current effort.

While some classifications performed better than others, none of the tested spectral classifications were able to differentiate talus from large boulder talus. The initial maximum likelihood classification scheme used for field validation produced spectral signatures for ten classes, including talus, bare rock, forest (coniferous), sparse vegetation, other vegetation (shrub/deciduous), wetland, water, burn, snow, and shadow (see Figure 3). These cover types encompassed the diversity of signatures across the landscape to assist in distinguishing the unique signatures of talus and rock from other land covers.

The initial classifications used to produce the field validation points were created with site-specific training data based only on 4-band spectral signatures. Analysis of topographic variables showed that two topographic variables were consistently significant in differentiating talus in general, as well as talus from rock and large boulder talus from other talus – the topographic position index (TPI) at a scale of 20 m and the vector ruggedness measure (VRM) at a scale of 15 m. A visual example of the difference in classification results when using topographic variables is illustrated in Figure 5.

The random points distributed in the digitized talus fields revealed that 82% of the polygons were identified as large boulder talus, and 85% of large boulder talus fields had large boulders scattered throughout, rather than restricted to the upper (2%), lower (6%), or other (7%) regions of the talus slope. Additionally, both the field and remote validation efforts estimate that ~80% of talus slopes fall into the "large boulder" category. Neither the spectral model nor the spectral-topographic model could successfully differentiate large boulder talus from talus without large boulders.

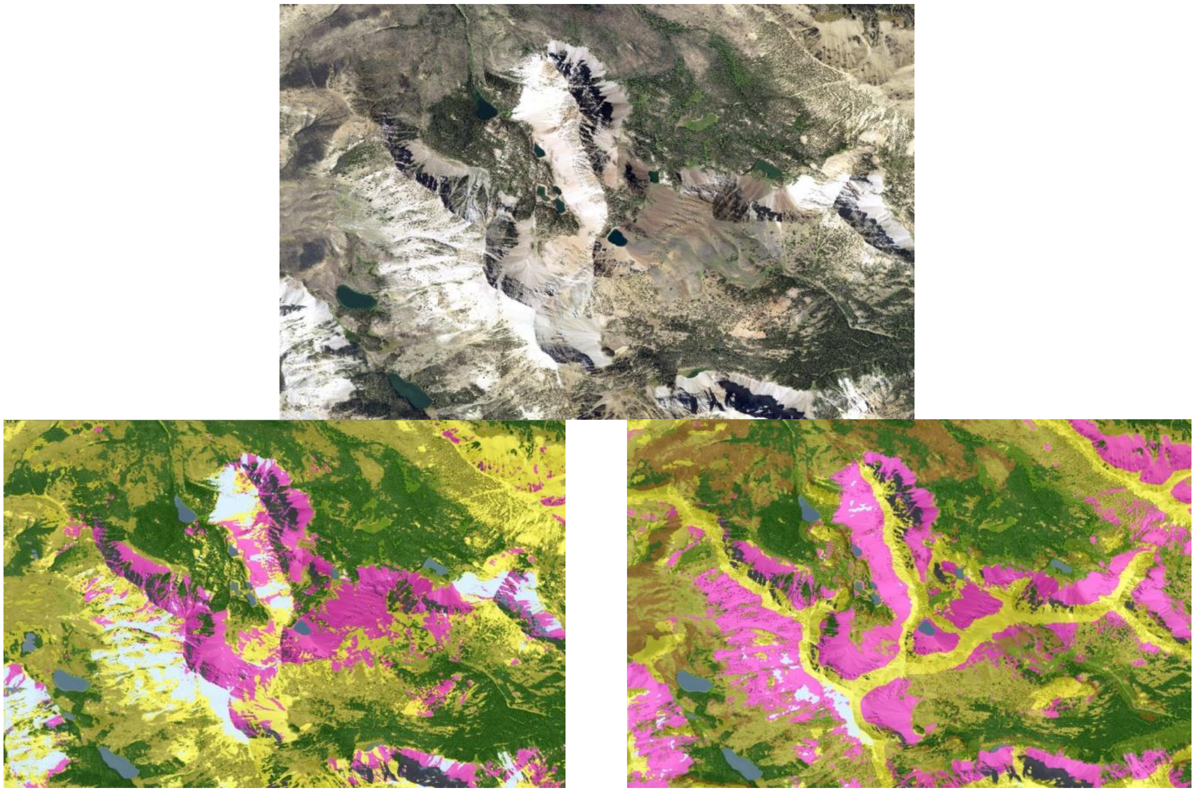


Figure 5. *Comparison of two different maximum likelihood classifications. Top image is the raw NAIP image, bottom left is spectral-only classification, and bottom right is classification with both spectral and topographic variables (TPI and VRM). Talus is in pink, bare rock in yellow, see Figure 3 for full legend.*

The ten classes initially identified in test models (talus, bare rock, sparse, coniferous, deciduous, burn, wetland, water, snow, shadow) were carried forward into the final model development. Not all classes were present in all study areas. Remote validation points classified as snow or shadow were removed from the accuracy assessment, as those classes are highly temporal and cannot be accurately validated with supplemental imagery or in the field. In the final stages of modelling, the wetland and sparse classes were combined due to low accuracy for wetland (14%) and high confusion between these two classes, likely due to the similar spectral signatures and the relatively small presence of the wetland class on the overall landscape. If the training data for these two classes had been combined before the initial classification, results may be slightly different than those produced here.

Field validation efforts were conducted by crews of at least two field technicians between the dates of August 1 – September 27, 2016 using 19 different access trails. More resources were available for study areas 1 and 2 (see Figure 3), resulting in more validation efforts carried out in those areas. A total of 453 field validation points were visited where data was collected: 424 designated field sites and 29 opportunistic sites. Of the 424 designated sites visited, 295 (70%) were found to be talus, and 414 (98%) were either talus or bare rock (Table 1).

Data from the field sites were used to assess model accuracy at four levels (see Methods). All of the designated field sites were located in areas modeled as talus by the initial, site-specific spectral models, but

Table 1. Summary of talus field sites visited by field crews August –September 2016 across the 6 study areas

Number of field sites visited (designated)	**453 (424)**
Ground truthed as talus (designated)	72% (70%)
Ground truthed as talus or rock	98%
Average talus slope area	16.16 km^2
Average length parallel to slope	128 m
Average length perpendicular to slope	106 m
Talus classified as large boulder	78.9%
Vegetation present in talus slopes	25.7%
Boulder Location	
Upper	9.7%
Scattered	85.8%
Lower	4.5%
Pika presence in talus fields	69.5%

Table 2. Summary of accuracy for two different classification models across all study areas. Model 1 is the spectral-only classification; Model 2 has topographic variables added.

Class, Model	*Producer's Accuracy (%)*	*User's Accuracy (%)*	*Overall Accuracy (%)*
Talus, Model 1	72.2	52.68	62.4
Talus, Model 2	78.7	61.7	70.2
Talus/Rock, Model 1	91.9	82.9	87.4
Talus/Rock, Model 2	92.8	80.9	86.85
Large Boulder Talus captured in Talus class, Model 1	71.6		
Large Boulder Talus captured in Talus class, Model 2	78.7		
Large Boulder Talus captured in Talus/Rock class, Model 1	96.36		
Large Boulder Talus captured in Talus/Rock class, Model 2	96.66		
Model 1, Level II			73.3
Model 2, Level II			77.5
Model 1, Level I			89.19
Model 2, Level I			87.65

not all of them were classified as talus by the final model. Of the field sites classified as talus by the final model, 85% were field verified as either talus or rock. The field data, both opportunistic and at designated field sites, validated a Level II accuracy for talus of 78% and a Level I accuracy for talus/rock of 95%. Over all included classes, we found a Level II accuracy of 66.5% and Level I accuracy of 89.6%. Neither the size of the talus field nor the presence of vegetation affected the accuracy of classification results.

Remote validation efforts were conducted in addition to field validation as another form of accuracy assessment. Table 2 describes the differences in Level II (Talus/Rock) and Level I (Talus) accuracy between the spectral (Model 1) and spectral-topographic (Model 2) models based on the 10,000 remotely-assessed validation points.

Because large boulder talus was not mapped separately by the models, we could not produce a user's accuracy metric for that class. However, by examining the validation points classified as large boulder talus in the field or on higher-resolution imagery, we can ascertain how much of the large boulder talus areas were captured by the talus class of each model (producer's accuracy). Model 2 captured 7% more large boulder talus in its talus class (78.7% compared to 71.6%), and Level I assessment showed more than 96% of large boulder talus was accurately captured in the combined talus/rock class in both models. The producer's accuracy for talus is noticeably higher than user's accuracy in all cases. Grouping the rock and talus classes together produces a class accuracy that is 85% or above, which is relatively high for a land cover classification at this fine of resolution. The remotely-assessed accuracy findings are similar to those attained by field validation efforts.

Because the purpose of this project was to identify talus specifically, Model 2, which uses both spectral and topographic information, was chosen as the final model. While slightly less accurate in overall Level I validation, Model 2 performed significantly better in the talus class in general, in addition to capturing the most large boulder talus within that class. While it was not possible to model the large boulder talus as a separate class from other talus, both the field and remote validation efforts found that ~80% of talus slopes fall into the "large boulder" category because large boulders are present in some portion of the talus field, suggesting the majority of talus fields offer large boulder structure.

Images of the final classification maps for each study area can be found in Appendix A. A summary of the relative breakdown of the modeled land cover classes within each study area, as well as a break down by study area, can be found in Table 3.

Full confusion matrices for Level I, II, III, and IV validations can be found in Appendix B. The final model produced can be used either to examine the talus class individually, or by grouping the talus/rock classes together for a higher accuracy. Individual model accuracies varied by study area – Table 4 shows a summary of the users, producers, and overall model accuracies for the six study areas independently. Comprehensive confusion matrices for the six separate study areas can be found in Appendix C.

Table 3. Summary of relative coverage of modelled land cover classes in the six different study areas generated by Model 2 from site-specific training data.

	Area 1	*Area 2*	*Area 3*	*Area 4*	*Area 5*	*Area 6*	*Overall*
Talus (%)	2.2	1.2	12.2	16.9	12.9	11.2	8.8
Bare Rock (%)	7.7	6.8	9.6	19.8	6.3	10.2	9.5
Sparse (%)	15.6	24.9	17.2	20.7	16.1	20.8	17.6
Coniferous (%)	34.7	27.8	30.0	19.4	33.9	41.8	32.4
Burn (%)	21.0	32.2	25.0	9.1	14.1	0.0	17.3
Deciduous (%)	11.1	4.5	2.1	12.6	9.6	9.9	8.8
Water (%)	2.8	0.0	0.9	0.3	1.6	1.4	1.6
Snow (%)	0.0	0.0	0.0	0.4	0.8	0.4	0.2
Shadow (%)	4.9	2.6	3.0	0.8	4.7	4.4	3.8
Total	100.0	100.0	100.0	100.0	100.0	100.1	100.0
Total Area (km^2)	3,214	377	1,988	1,087	1,517	1,138	9,321

Table 4. Summary of accuracy for talus, rock, and talus/rock classes for each study area

	Producer's Accuracy (%)	*User's Accuracy (%)*	*Overall Accuracy (%, (Level III/IV)*	*Overall Accuracy (%, Level I/II)*
Talus				
Study Area 1	56.1	69.5	54.8	77.2
Study Area 2	0.0*	0.0*	64.8	92.0
Study Area 3	85.5	64.3	61.7	82.3
Study Area 4	89.3	60.2	63.8	70.7
Study Area 5	79.1	49.1	54.3	79.2
Study Area 6	79.8	66.6	70.9	81.6
Rock				
Study Area 1	64.2	47.1	54.8	77.2
Study Area 2	66.7	28.6	64.8	92.0
Study Area 3	54.7	47.8	61.7	82.3
Study Area 4	61.0	74.2	63.8	70.7
Study Area 5	52.5	35.0	54.3	79.2
Study Area 6	70.0	59.5	70.9	81.6
Talus/Rock				
Study Area 1	84.6	78.9	64.0	86.4
Study Area 2	77.8	30.4	65.3	92.4
Study Area 3	93.2	75.9	68.1	88.7
Study Area 4	89.3	60.2	64.0	77.3
Study Area 5	88.2	59.3	59.0	84.0
Study Area 6	98.9	85.7	81.6	92.3

**None of the remote validation points were ground-truthed as talus, so it was impossible to calculate model accuracy.*

Discussion

We were able to map rock and talus habitats based on 4-band spectral data and topographic variables, and we were able to map these habitats at a finer scale and higher accuracy than currently available products. Our objective to discern large boulder talus from smaller scree and bare rock was not realized. A number of factors challenged our ability to successfully model large boulder talus distinct from other kinds of talus and rock habitats including the inability of 4-band spectral signatures to account for subtle differences in spectral signatures between the different rocky habitats, inconsistent image acquisition dates across the study area (ranging from mid-June to late September, with some of the later dates obscuring mountains with snow), and inconsistent image quality (some areas more washed out than others). Additionally, we learned through our validation data that it appears that a large majority (>80%) of talus fields contain large boulders in a portion of the area, and that ~85% of those boulders are scattered throughout the field which makes using topographic variables ineffective in predicting the location of these large boulder areas. Further, this suggests that a model identifying talus may be sufficient to characterize the location of large-boulder talus for wolverine or other wildlife habitat modeling purposes at landscape scales. Our final model captures 78% of large boulder talus in its talus class, and up to 97% when grouped as talus/rock, but we cannot provide a metric of user's accuracy. Taking into account that the producer's accuracy for talus as a whole is noticeably higher than the user's accuracy for talus in all models, we can assume that the model is over-predicting the occurrence of talus to some extent. When the producer and user accuracies are averaged together, the accuracy of the talus class is 67%, jumping to 87% when talus and rock are taken together. Considering the existing land cover alternatives, this model represents the best available predictor for talus and rock land cover classes in the context of habitat modeling.

Given the large extent of our study region, it was difficult to generate representative training data for each model class. We had to create separate models in each of our six study areas due to regional variations, and even within some of those study areas several iterations of training data were needed to adequately capture the spectral variations. We originally envisioned expanding the model to the state of Idaho, but this was not feasible given time and resource limitations. Given the variability of the image acquisition dates and quality, it would be challenging to develop a spectral-based model at this resolution across such a large area. Models using NAIP and DEM data as were used here could be developed for additional areas of Idaho, as needed.

Another option for image classification would be Worldview 3 imagery from Digital Globe, which is both a higher spatial (31 cm) and spectral (8 bands) resolution than NAIP. The additional spectral signatures and band combinations contained in that larger dataset could build upon the current model and refine it further, possibly refining a signature for large boulder talus. However, the size and accessibility of this imagery currently makes it impractical to work with over large study areas. LIDAR technology could also be used to enhance the model where topographic variables are concerned, but again, it is better suited to smaller study areas. It is also expensive to acquire and there is limited existing coverage within our study area. The greatest challenge with expanding this model will be finding consistent model inputs and acquiring enough storage space and processing power to operate over a larger area.

Given the importance of large boulder habitats to a diversity of wildlife species including potentially wolverines as well as species such as pikas and marmots, there is growing recognition of the need to map these habitats with reasonable accuracy and resolution. Large landscape or regional efforts to identify this relatively fine-scale habitat will continue to be challenging but advances in data and processing power may make such endeavors feasible in the near future. Currently, researches are investigating the possibility of combining high-resolution LIDAR elevation data and aerial imagery to model talus at much finer scales across much smaller areas (A. Johnston, personal communication, 7 December 2015) than would be applicable for predicting habitat availability for a wide-ranging species such as wolverine. As both data availability and image processing capabilities improve over time, the results of both that research and this model may be more feasibly applicable to larger areas.

LITERATURE CITED

Aubry, K. Distribution and Broadscale Habitat Relations of the Wolverine in the Contiguous United States. Journal of Wildlife Management 71(7): 2147-2158)

Brohman, R.; Bryant, L. eds. 2005. Existing Vegetation Classification and Mapping Technical Guide. Gen. Tech. Rep. WO–67. Washington, DC: U.S. Department of Agriculture Forest Service, Ecosystem Management Coordination Staff. 305 p.

Heinemeyer, K and J. Squires. 2015. Wolverine – winter recreation research project: Investigating the interactions between wolverines and winter recreation, 2015 progress report. Available at www.roundriver.org/wolverine.

Magoun, A.J. and J.P Copeland.1998. Characteristics of wolverine reproductive den sites. Journal of Wildlife Management 62: 1313-1320.

Riley, S. J., S. D. DeGloria and R. Elliot (1999). A terrain ruggedness index that quantifies topographic heterogeneity, Intermountain Journal of Sciences, vol. 5, No. 1-4,1999

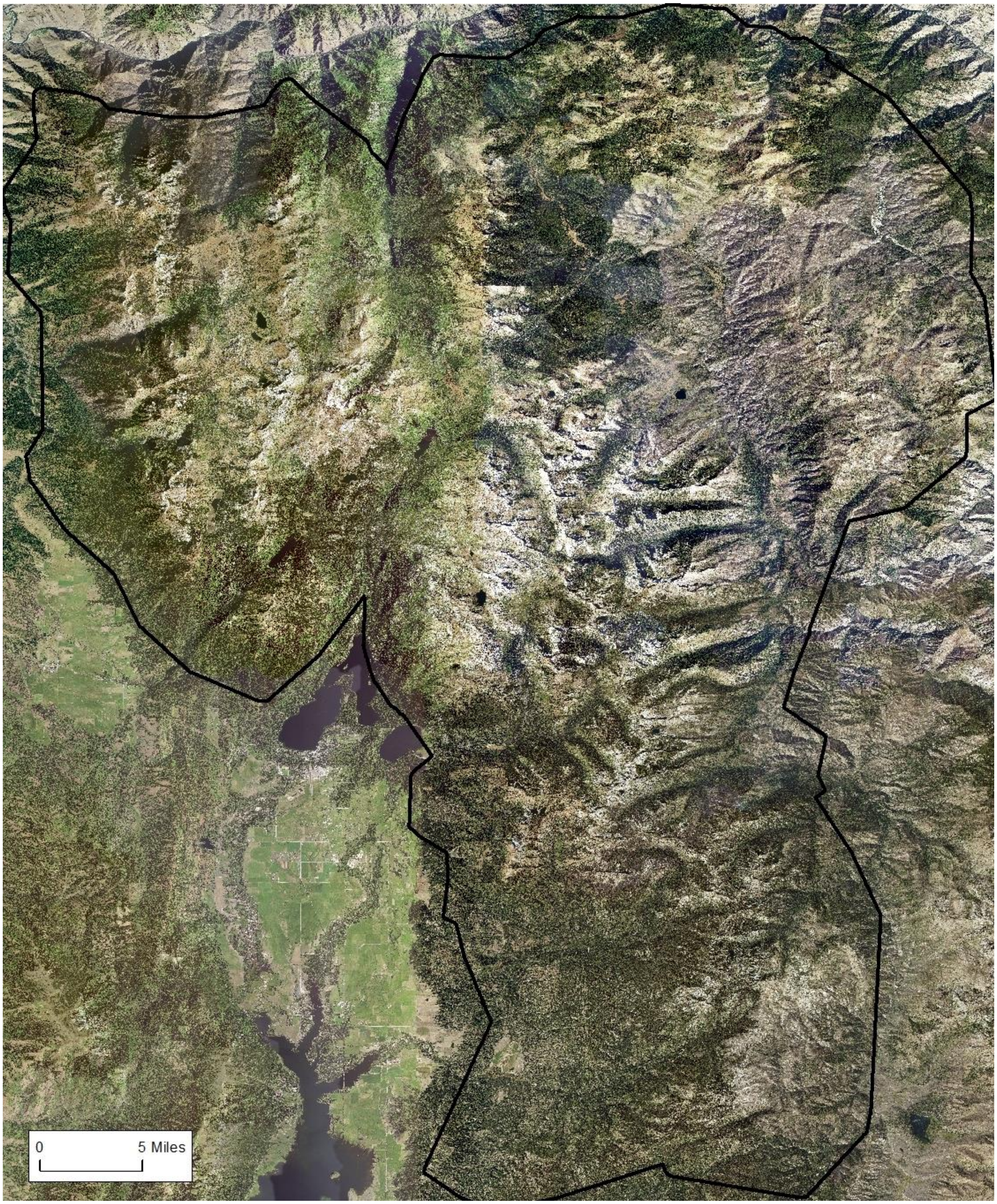
Rollins, M.G.; Frame, C.K., tech. eds. 2006. The LANDFIRE Prototype Project: nationally consistent and locally relevant geospatial data for wildland fire management. Gen. Tech.Rep. RMRS-GTR-175. Fort Collins: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 416 p.

Sappington, J. M., K. M. Longshore, and D. B. Thompson. 2007. Quantifying landscape ruggedness for animal habitat analysis: A case study using bighorn sheep in the Mojave Desert. Journal of Wildlife Management 71:1419-1426.

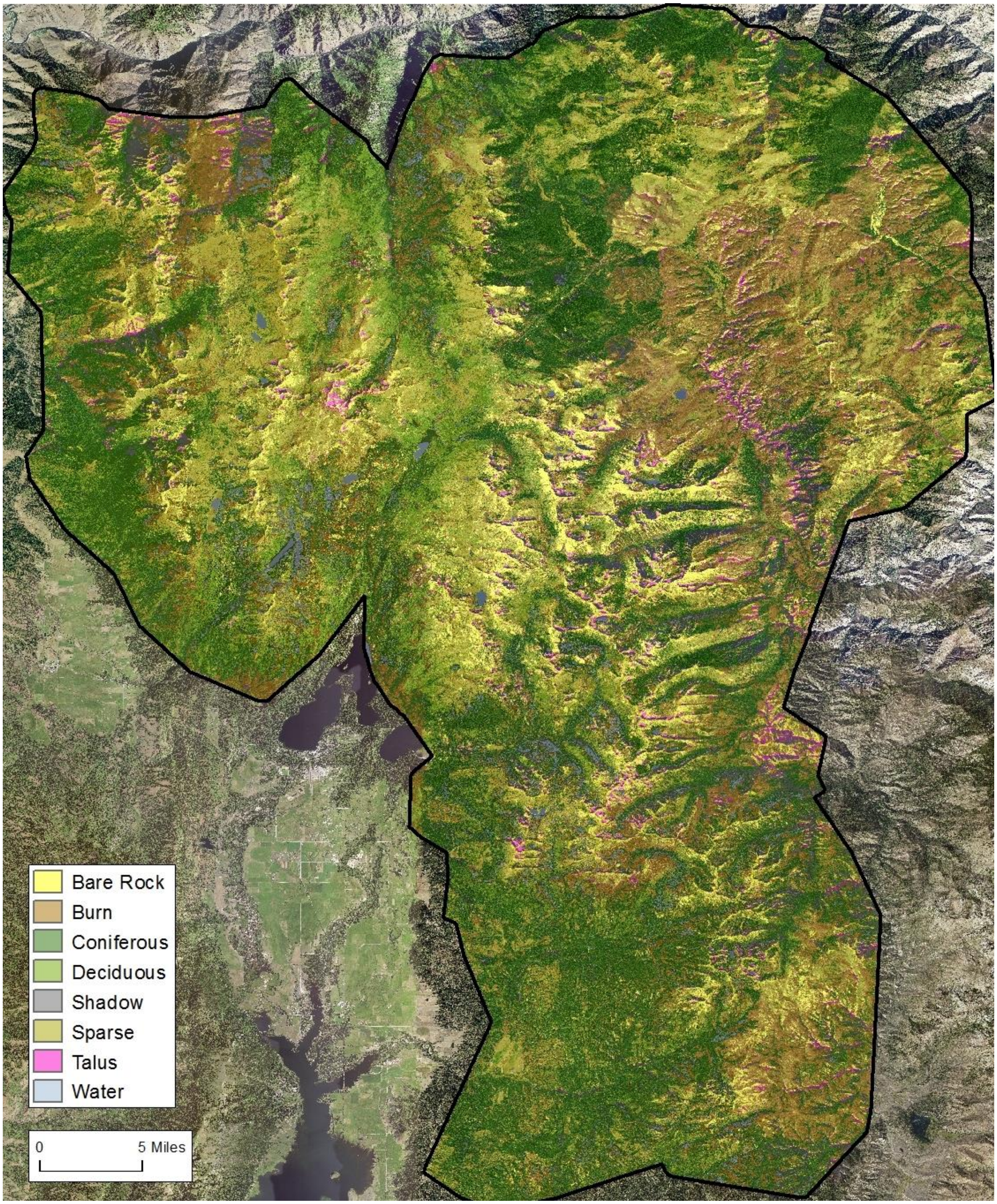
Weiss, A. 2001. Topographic Position and Landforms Analysis. Poster presentation, ESRI User Conference, San Diego, CA.

Wickham, J. S.V. Stehman, L. Gass, J. Dewitz, J.A. Fry & T.G. Wade. 2013. Accuracy Assessment of NLCD 2006 land cover and impervious surface. Remote Sensing of the environment 130: 294-304.

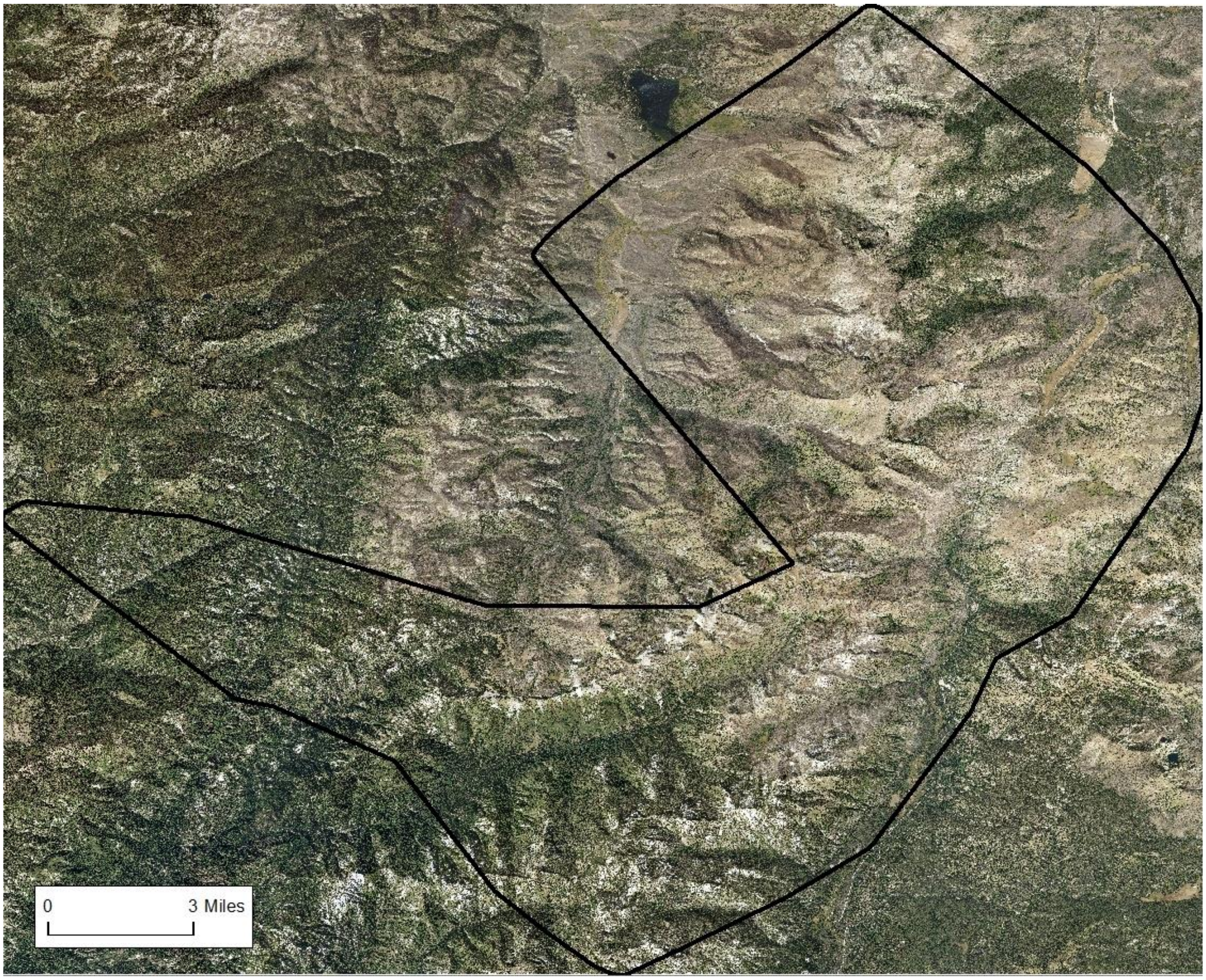
APPENDIX A – CLASSIFIED MAPS



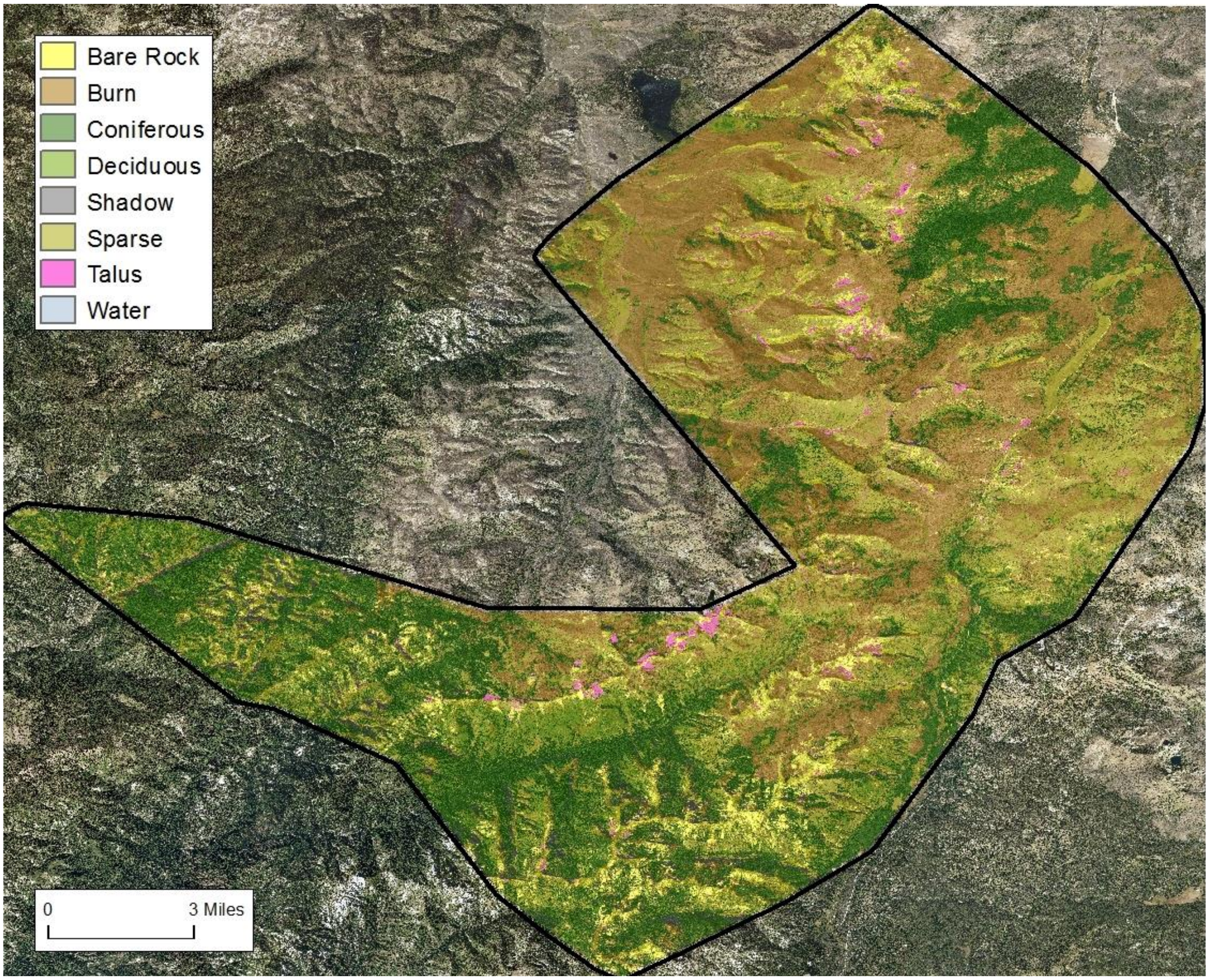
Appendix A- 1. NAIP imagery, study area 1.



Appendix A- 2. Classified image using Model 2, study area 1

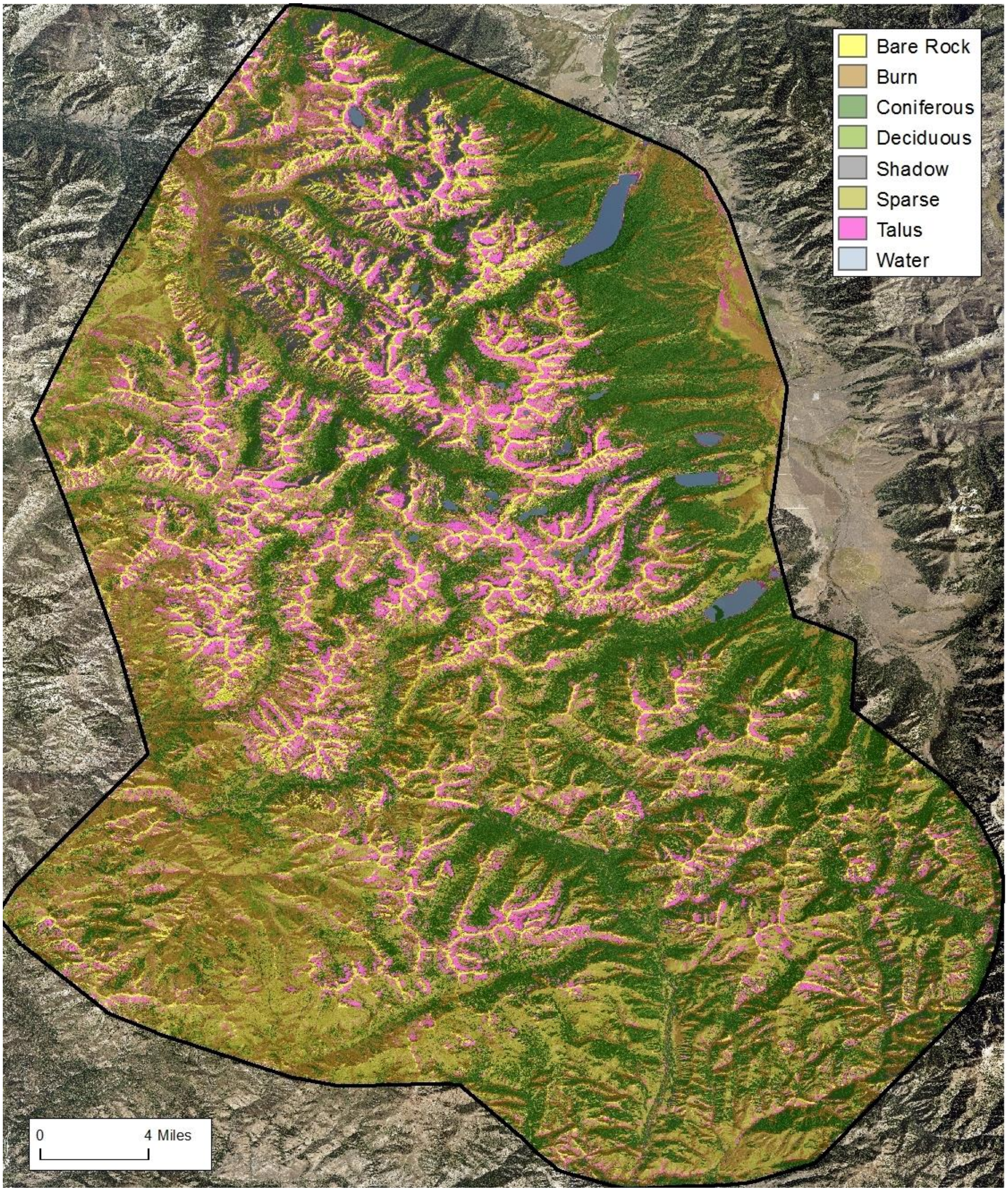


Appendix A- 3. NAIP image, study area 2.

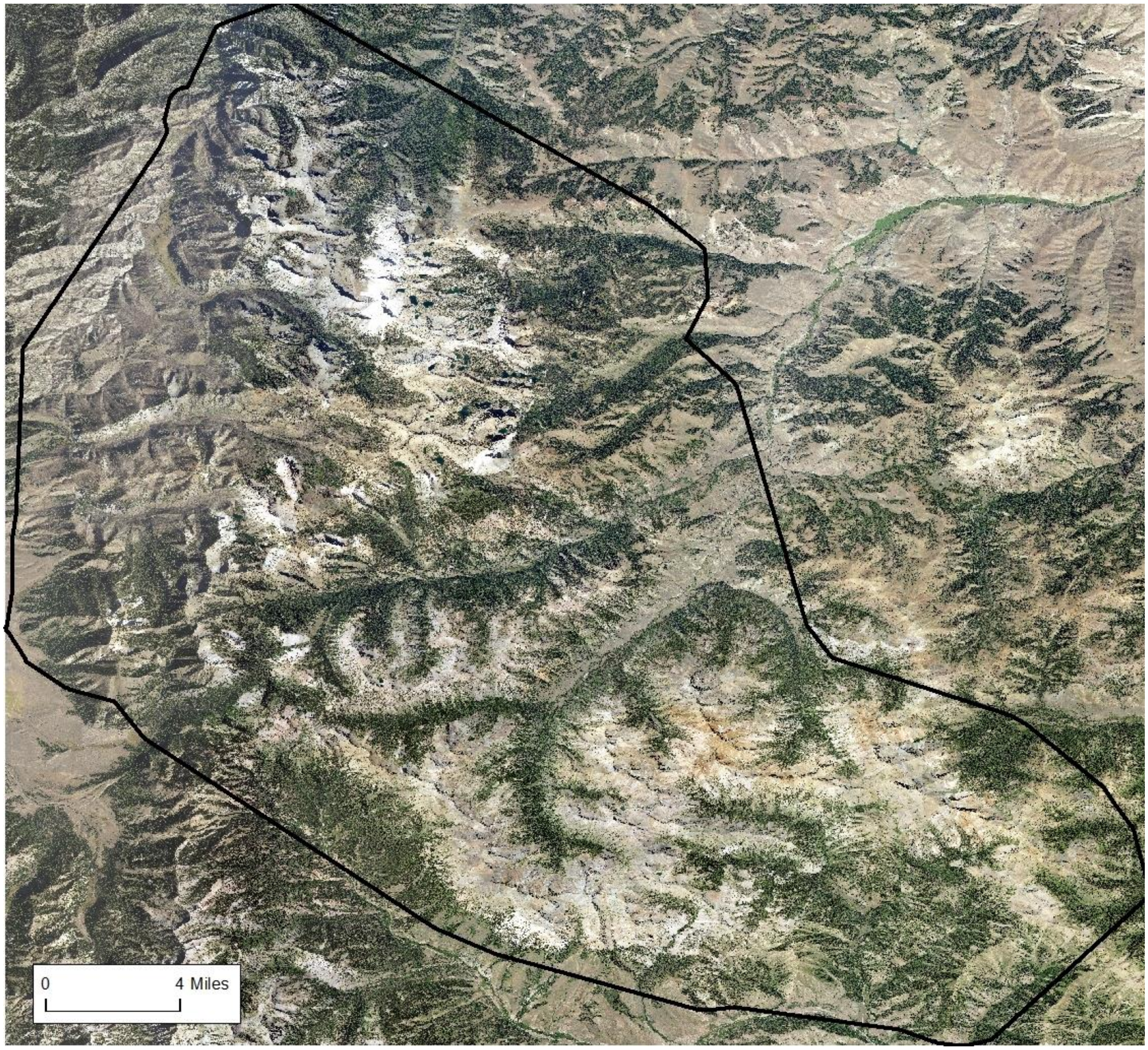


Appendix A- 4. Classified image using Model 2, study area 2.

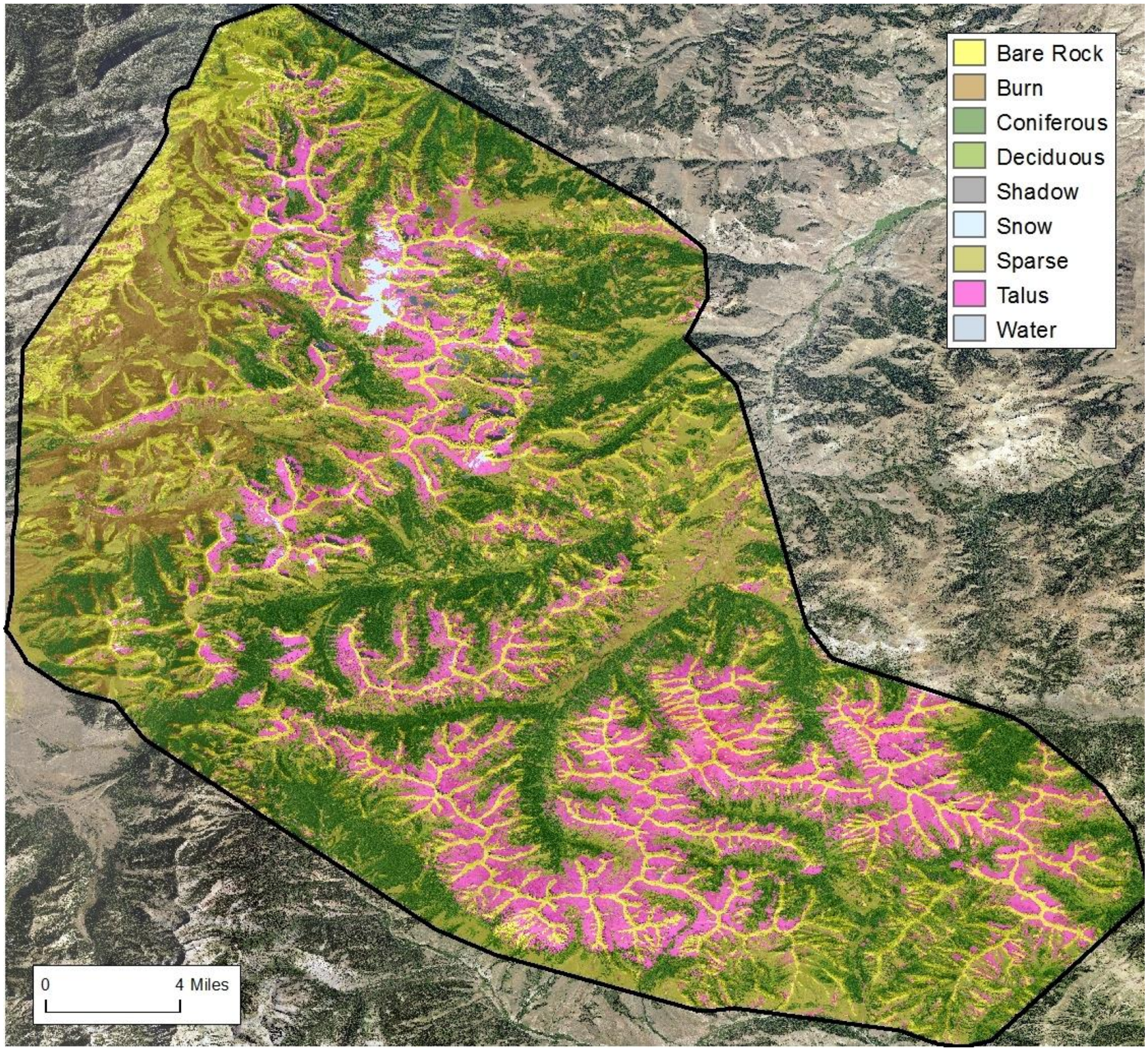
Appendix A- 5. NAIP image, study area 3.



Appendix A- 6. Classified image using Model 2, study area 3.

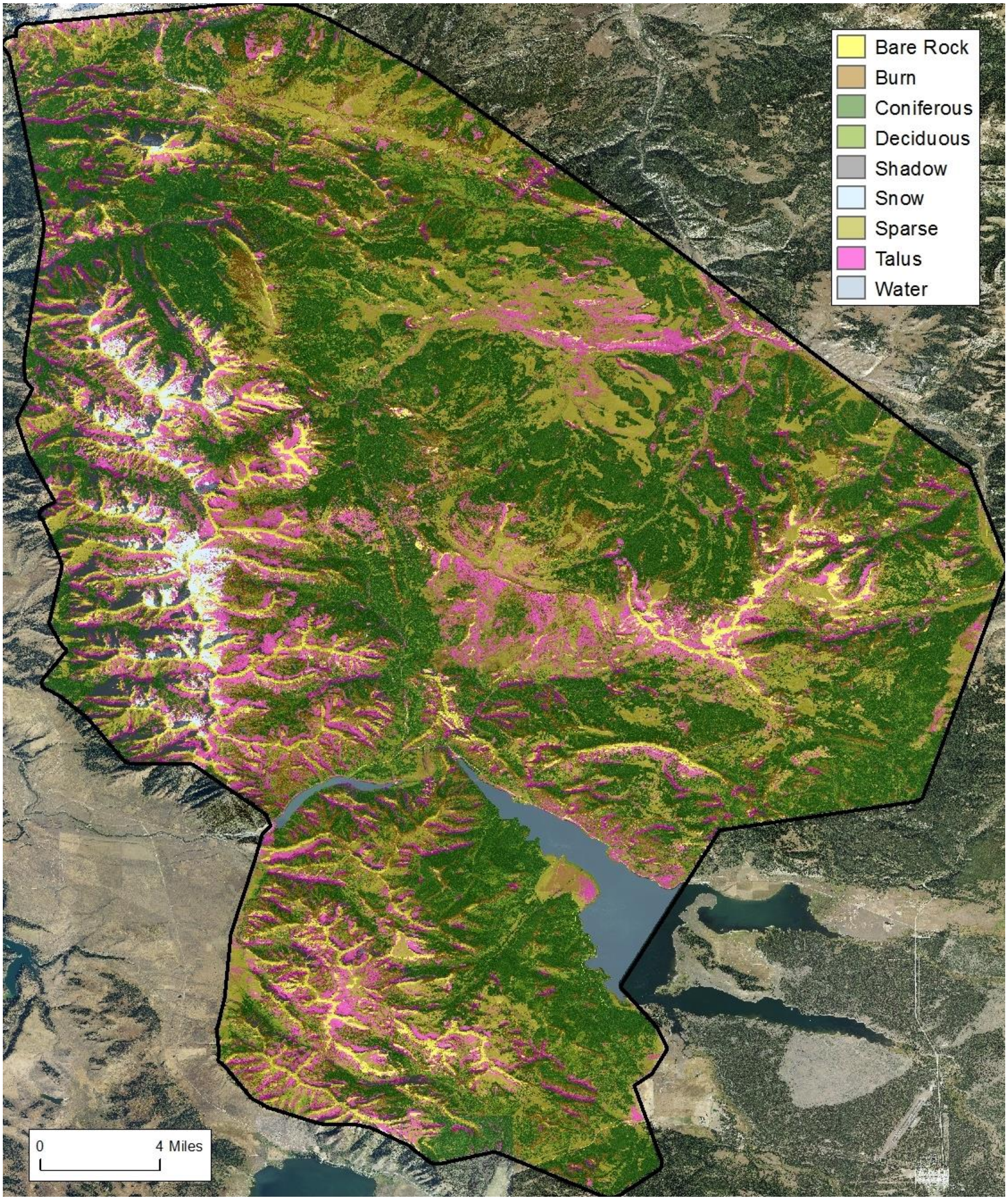


Appendix A- 7. NAIP image, study area 4.

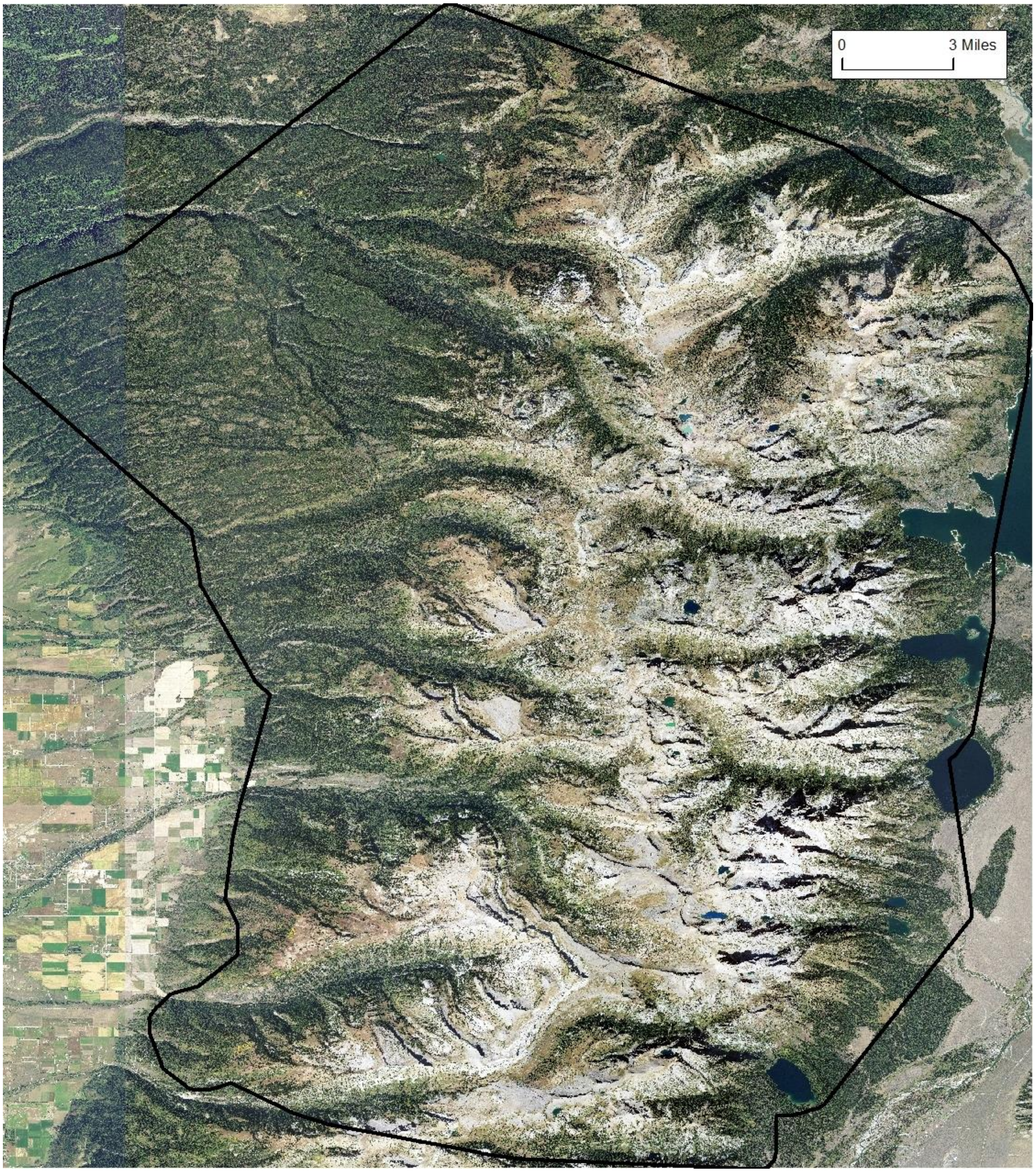


Appendix A- 8. Classified image using Model 2, study area 4.

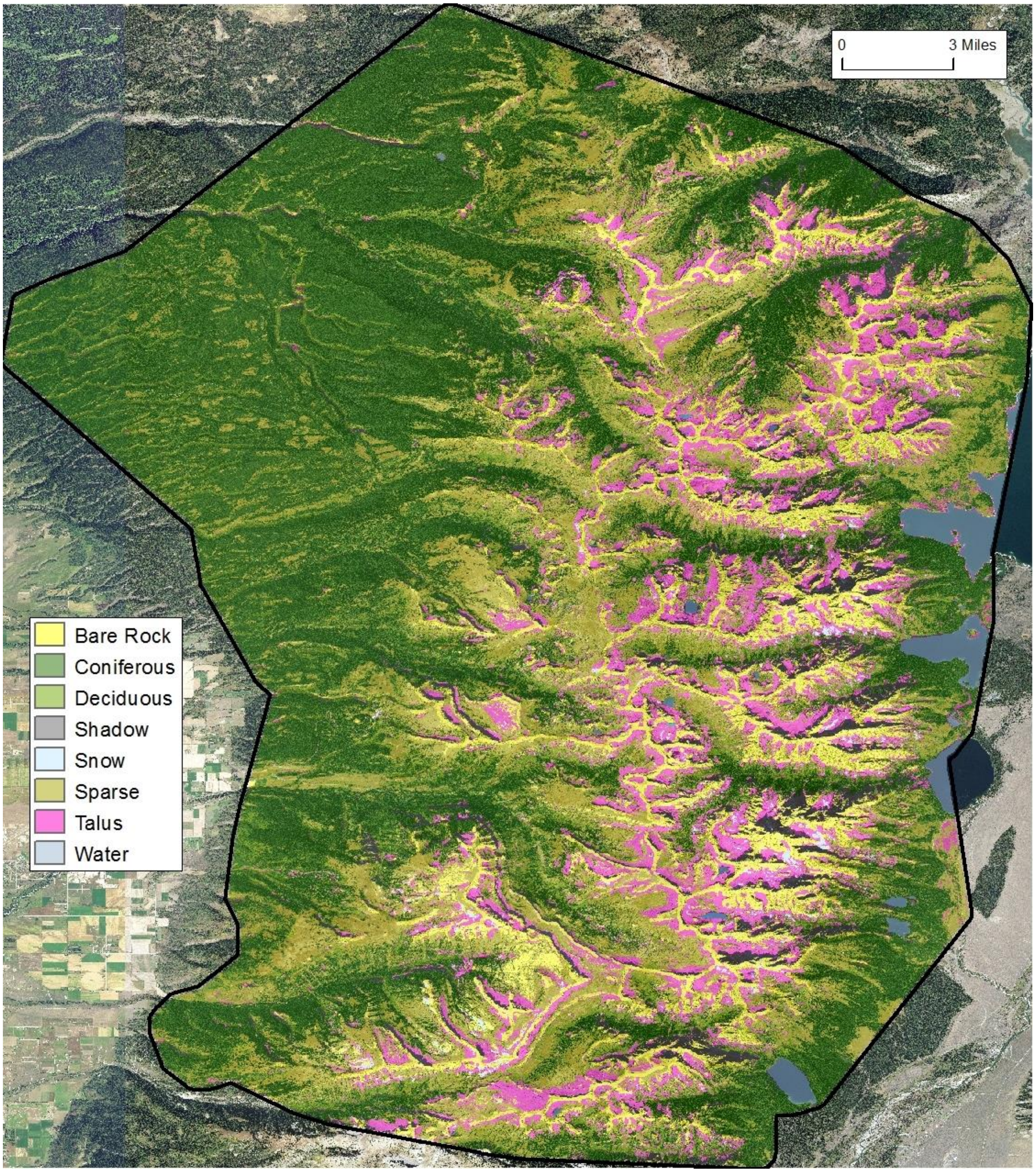
Appendix A- 9. NAIP image, study area 5.



Appendix A- 10. Classified image using Model 2, study area 5.



Appendix A- 11. NAIP image, study area 6.



Appendix A- 12. Classified image using Model 2, study area 6.

APPENDIX B – FINAL MODEL CONFUSION MATRICES

LEVEL IV ACCURACY ASSESSMENT — Ground Truth

Classification	Talus	Rock	Sparse	Coniferous	Burn	Deciduous	Water	*Classification Overall*	User Accuracy
Talus	1584	512	338	57	5	57	14	2567	61.71%
Rock	355	1184	332	110	25	38	1	2045	57.90%
Sparse	19	34	684	96	26	410	3	1272	53.77%
Coniferous	6	10	33	1623	9	68	4	1753	92.58%
Burn	42	168	209	326	370	127	2	1244	29.74%
Deciduous	5	2	47	200	6	238	4	502	47.41%
Water	0	0	3	36	2	7	38	86	44.19%
Truth Overall	2011	1910	1646	2448	443	945	66	9469	
Producer Accuracy (Precision)	78.77%	61.99%	41.56%	66.30%	83.52%	25.19%	57.58%		60.42%
Cohen's Kappa	0.5150178								

LEVEL III ACCURACY ASSESSMENT — Ground Truth

Classification	Talus/Rock	Sparse	Coniferous	Burn	Deciduous	Water	*Classification Overall*	User Accuracy
Talus/Rock	3733	598	154	30	82	15	4612	80.94%
Sparse	53	684	96	26	410	3	1272	53.77%
Coniferous	16	33	1623	9	68	4	1753	92.58%
Burn	210	209	326	370	127	2	1244	29.74%
Deciduous	7	47	200	6	238	4	502	47.41%
Water	0	3	36	2	7	38	86	44.19%
Truth Overall	4019	1574	2435	443	932	66	9469	
Producer Accuracy (Precision)	92.88%	43.46%	66.65%	83.52%	25.54%	57.58%		70.61%
Cohen's Kappa	0.5871564							

Classification	**LEVEL II ACCURACY ASSESSMENT**	Ground Truth				
		Talus	Rock	Other	*Classification Overall*	User Accuracy
	Talus	1584	512	471	2567	61.71%
	Rock	355	1184	506	2045	57.90%
	Other	72	214	4571	4857	94.11%
	Truth Overall	2011	1910	5548	9469	
	Producer Accuracy (Precision)	78.77%	61.99%	82.39%		77.51%
	Cohen's Kappa	0.6240439				

Classification	**LEVEL I** ACCURACY ASSESSMENT	Ground Truth			
		Talus/Rock	Other	*Classification Overall*	User Accuracy
	Talus/Rock	3733	879	4612	80.94%
	Other	286	4571	4857	94.11%
	Truth Overall	4019	5450	9469	
	Producer Accuracy (Precision)	92.88%	83.87%		87.70%
	Cohen's Kappa	0.7529679			

APPENDIX C – STUDY-AREA-SPECIFIC CONFUSION MATRICES

STUDY AREA 1 CONFUSION MATRIXES

Level IV Accuracy Assessment		Ground Truth: Study Area 1								
		Talus	Bare Rock	Sparse	Coniferous	Burn	Deciduous	Water	*Classification Overall*	User Accuracy
Classification	Talus	266	59	29	8	4	13	4	383	69.45%
	Bare Rock	179	335	115	43	20	19	0	711	47.12%
	Sparse	4	6	196	34	16	162	2	420	46.67%
	Coniferous	3	5	10	426	7	27	2	480	88.75%
	Burn	21	117	90	108	212	63	1	612	34.64%
	Deciduous	1	0	13	55	4	121	0	194	62.37%
	Water	0	0	3	35	2	7	8	55	14.55%
	Truth Overall	474	522	456	709	265	412	17	2855	
	Producer Accuracy (Precision)	56.12%	64.18%	42.98%	60.08%	80.00%	29.37%	47.06%		54.78%

	Level III Accuracy Assessment	Ground Truth: Study Area 1							
		Talus/Rock	Sparse	Coniferous	Burn	Deciduous	Water	*Classification Overall*	User Accuracy
Classification	Talus/Rock	863	131	46	24	26	4	1094	78.88%
	Sparse	10	196	34	16	162	2	420	46.67%
	Coniferous	8	10	426	7	27	2	480	88.75%
	Burn	138	90	108	212	63	1	612	34.64%
	Deciduous	1	13	55	4	121	0	194	62.37%
	Water	0	3	35	2	7	8	55	14.55%
	Truth Overall	1020	443	704	265	406	17	2855	
	Producer Accuracy (Precision)	84.61%	44.24%	60.51%	80.00%	29.80%	47.06%		63.96%

	Level II Accuracy Assessment	**Ground Truth: Study Area 1**				
		Talus	Rock	Other	*Classification Overall*	User Accuracy
Classification	Talus	266	59	58	383	69.45%
	Rock	179	335	197	711	47.12%
	Other	29	128	1604	1761	91.08%
	Truth Overall	474	522	1859	2855	
	Producer Accuracy (Precision)	56.12%	64.18%	86.28%		77.23%

	Level I Accuracy Assessment	**Ground Truth: Study Area 1**			
		Talus/Rock	Other	*Classification Overall*	User Accuracy (Recall)
Classification	Talus/Rock	863	231	1094	78.88%
	Other	157	1604	1761	91.08%
	Truth Overall	1020	1835	2855	
	Producer Accuracy (Precision)	84.61%	87.41%		86.41%

STUDY AREA 2 CONFUSION MATRICES

Level IV Accuracy Assessment — **Ground Truth: Study Area 2**

Classification		Talus	Bare Rock	Sparse	Coniferous	Burn	Deciduous	*Classification Overall*	User Accuracy
	Talus	0	1	1	0	0	0	2	0.00%
	Bare Rock	0	6	7	3	2	3	21	28.57%
	Sparse	0	2	28	4	7	22	63	44.44%
	Coniferous	0	0	1	49	1	5	56	87.50%
	Burn	0	0	9	7	62	4	82	75.61%
	Deciduous	0	0	0	4	0	8	12	66.67%
	Truth Overall	0	9	46	67	72	42	236	
	Producer Accuracy (Precision)	0.00%	66.67%	60.87%	73.13%	86.11%	19.05%		64.83%

Level III Accuracy Assessment — **Ground Truth: Study Area 2**

Classification		Talus/Rock	Sparse	Coniferous	Burn	Deciduous	*Classification Overall*	User Accuracy (Recall)
	Talus/Rock	7	8	3	2	3	23	30.43%
	Sparse	2	28	4	7	22	63	44.44%
	Coniferous	0	1	49	1	5	56	87.50%
	Burn	0	9	7	62	4	82	75.61%
	Deciduous	0	0	4	0	8	12	66.67%
	Truth Overall	9	46	67	72	42	236	
	Producer Accuracy (Precision)	77.78%	60.87%	73.13%	86.11%	19.05%		65.25%

	Level II Accuracy Assessment	Ground Truth: Study Area 2				
		Talus	Rock	Other	*Classification Overall*	User Accuracy
Classification	Talus	0	1	1	2	0.00%
	Rock	0	6	15	21	28.57%
	Other	0	2	211	213	99.06%
	Truth Overall	0	9	227	236	
	Producer Accuracy (Precision)	0.00%	66.67%	92.95%		91.95%

	Level I Accuracy Assessment	Ground Truth: Study Area 2			
		Talus/Rock	Other	*Classification Overall*	User Accuracy
Classification	Talus/Rock	7	16	23	30.43%
	Other	2	211	213	99.06%
	Truth Overall	9	227	236	
	Producer Accuracy (Precision)	77.78%	92.95%		92.37%

Study Area 3 Confusion Matrices

	Level IV Accuracy Assessment	Ground Truth: Study Area 3								
		Talus	Bare Rock	Sparse	Coniferous	Burn	Deciduous	Water	*Classification Overall*	User Accuracy
Classification	Talus	254	50	77	5	0	4	5	395	64.30%
	Bare Rock	33	87	54	5	0	2	1	182	47.80%
	Sparse	4	3	157	15	1	50	0	230	68.26%
	Coniferous	1	1	11	346	0	21	0	380	91.05%
	Burn	5	18	60	93	59	48	0	283	20.85%
	Deciduous	0	0	1	10	1	19	0	31	61.29%
	Water	0	0	0	0	0	0	11	11	100.00%
	Truth Overall	297	159	360	474	61	144	17	1512	
	Producer Accuracy (Precision)	85.52%	54.72%	43.61%	73.00%	96.72%	13.19%	64.71%		61.71%

	Level III Accuracy Assessment	Ground Truth: Study Area 3							
		Talus/Rock	Sparse	Coniferous	Burn	Deciduous	Water	*Classification Overall*	User Accuracy
Classification	Talus/Rock	438	119	8	0	6	6	577	75.91%
	Sparse	7	157	15	1	50	0	230	68.26%
	Coniferous	2	11	346	0	21	0	380	91.05%
	Burn	23	60	93	59	48	0	283	20.85%
	Deciduous	0	1	10	1	19	0	31	61.29%
	Water	0	0	0	0	0	11	11	100.00%
	Truth Overall	470	348	472	61	144	17	1512	
	Producer Accuracy (Precision)	93.19%	45.11%	73.31%	96.72%	13.19%	64.71%		68.12%

	Level II Accuracy Assessment	Ground Truth: Study Area 3				
		Talus	Rock	Other	*Classification Overall*	User Accuracy
Classification	Talus	254	50	91	395	64.30%
	Rock	33	87	62	182	47.80%
	Other	10	22	903	935	96.58%
	Truth Overall	297	159	1056	1512	
	Producer Accuracy (Precision)	85.52%	54.72%	85.51%		82.28%

	Level I Accuracy Assessment	Ground Truth: Study Area 3			
		Talus/Rock	Other	*Classification Overall*	User Accuracy
Classification	Talus/Rock	438	139	577	75.91%
	Other	32	903	935	96.58%
	Truth Overall	470	1042	1512	
	Producer Accuracy (Precision)	93.19%	86.66%		88.69%

Study Area 4 Confusion Matrices

Level IV Accuracy Assessment		Ground Truth: Study Area 4								
		Talus	Rock	Sparse	Coniferous	Burn	Deciduous	Water	*Classification Overall*	User Accuracy
Classification	Talus	715	322	140	6	0	4	1	1188	60.19%
	Rock	74	567	80	33	3	7	0	764	74.21%
	Sparse	7	15	100	16	1	24	1	164	60.98%
	Coniferous	0	1	3	141	1	5	1	152	92.76%
	Burn	4	23	26	12	32	3	1	101	31.68%
	Deciduous	1	2	14	56	1	17	4	95	17.89%
	Water	0	0	0	1	0	0	2	3	66.67%
	Truth Overall	801	930	363	265	38	60	10	2467	
	Producer Accuracy (Precision)	89.26%	60.97%	27.55%	53.21%	84.21%	28.33%	20.00%		63.80%

Level III Accuracy Assessment		Ground Truth: Study Area 4							
		Talus/Rock	Sparse	Coniferous	Burn	Deciduous	Water	*Classification Overall*	User Accuracy
Classification	Talus/Rock	1704	195	38	3	11	1	1952	87.30%
	Sparse	22	100	16	1	24	1	164	60.98%
	Coniferous	1	3	141	1	5	1	152	92.76%
	Burn	27	26	12	32	3	1	101	31.68%
	Deciduous	3	14	56	1	17	4	95	17.89%
	Water	0	0	1	0	0	2	3	66.67%
	Truth Overall	1757	338	264	38	60	10	2467	
	Producer Accuracy (Precision)	96.98%	29.59%	53.41%	84.21%	28.33%	20.00%		80.91%

Level II Accuracy Assessment	Ground Truth: Study Area 4				
Classification	Talus	Rock	Other	*Classification Overall*	User Accuracy
Talus	715	322	151	1188	60.19%
Rock	74	567	123	764	74.21%
Other	12	41	462	515	89.71%
Truth Overall	801	930	736	2467	
Producer Accuracy (Precision)	89.26%	60.97%	62.77%		70.69%

Level I Accuracy Assessment	Ground Truth: Study Area 4			
Classification	Talus/Rock	Other	*Classification Overall*	User Accuracy
Talus/Rock	1704	248	1952	87.30%
Other	53	462	515	89.71%
Truth Overall	1757	710	2467	
Producer Accuracy (Precision)	96.98%	65.07%		87.80%

Study Area 5 Confusion Matrices

	Level IV Accuracy Assessment				**Ground Truth: Study Area 5**					
		Talus	Bare Rock	Sparse	Coniferous	Burn	Deciduous	Water	*Classification Overall*	User Accuracy
Classification	Talus	140	23	58	35	1	27	1	285	49.12%
	Bare Rock	20	42	35	22	0	1	0	120	35.00%
	Sparse	3	3	78	15	0	78	0	177	44.07%
	Coniferous	1	2	4	374	0	2	1	384	97.40%
	Burn	12	10	24	106	5	9	0	166	3.01%
	Deciduous	1	0	8	59	0	22	0	90	24.44%
	Water	0	0	0	0	0	0	6	6	100.00%
	Truth Overall	177	80	207	611	6	139	8	1228	
	Producer Accuracy (Precision)	79.10%	52.50%	37.68%	61.21%	83.33%	15.83%	75.00%		54.32%

	Level III Accuracy Assessment			**Ground Truth: Study Area 5**					
		Talus/Rock	Sparse	Coniferous	Burn	Deciduous	Water	*Classification Overall*	User Accuracy
Classification	Talus/Rock	240	83	53	1	27	1	405	59.26%
	Sparse	6	78	15	0	78	0	177	44.07%
	Coniferous	3	4	374	0	2	1	384	97.40%
	Burn	22	24	106	5	9	0	166	3.01%
	Deciduous	1	8	59	0	22	0	90	24.44%
	Water	0	0	0	0	0	6	6	100.00%
	Truth Overall	297	159	360	474	61	144	1228	
	Producer Accuracy (Precision)	80.81%	49.06%	103.89%	1.05%	36.07%	4.17%		59.04%

	Level II Accuracy Assessment	**Ground Truth: Study Area 5**				
		Talus	Rock	Other	*Classification Overall*	User Accuracy
Classification	Talus	140	23	122	285	49.12%
	Rock	20	42	58	120	35.00%
	Other	17	15	791	823	96.11%
	Truth Overall	177	80	971	1228	
	Producer Accuracy (Precision)	79.10%	52.50%	81.46%		79.23%

	Level I Accuracy Assessment	**Ground Truth: Study Area 5**			
		Talus/Rock	Other	*Classification Overall*	User Accuracy
Classification	Talus/Rock	240	165	405	59.26%
	Other	32	791	823	96.11%
	Truth Overall	272	956	1228	
	Producer Accuracy (Precision)	88.24%	82.74%		83.96%

STUDY AREA 6 CONFUSION MATRICES

	Level IV Accuracy Assessment				Ground Truth: Study Area 6				
		Talus	Bare Rock	Sparse	Coniferous	Deciduous	Water	*Classification Overall*	User Accuracy
Classification	Talus	209	57	33	3	9	3	314	66.56%
	Bare Rock	49	147	41	4	6	0	247	59.51%
	Sparse	1	5	125	12	74	0	217	57.60%
	Coniferous	1	1	4	287	8	0	301	95.35%
	Deciduous	2	0	11	16	51	0	80	63.75%
	Water	0	0	0	0	0	11	11	100.00%
	Truth Overall	262	210	214	322	148	14	1170	
	Producer Accuracy (Precision)	79.77%	70.00%	58.41%	89.13%	34.46%	78.57%		70.94%

	Level III Accuracy Assessment			Ground Truth: Study Area 6				
		Talus/Rock	Sparse	Coniferous	Deciduous	Water	*Classification Overall*	User Accuracy
Classification	Talus/Rock	481	62	6	9	3	561	85.74%
	Sparse	6	125	12	74	0	217	57.60%
	Coniferous	2	4	287	8	0	301	95.35%
	Deciduous	2	11	16	51	0	80	63.75%
	Water	0	0	0	0	11	11	100.00%
	Truth Overall	491	202	321	142	14	1170	
	Producer Accuracy (Precision)	97.96%	61.88%	89.41%	35.92%	78.57%		81.62%

	Level II Accuracy Assessment	**Ground Truth: Study Area 6**				
		Talus	Rock	Other	*Classification Overall*	User Accuracy
Classification	Talus	209	57	48	314	66.56%
	Rock	49	147	51	247	59.51%
	Other	4	6	599	609	98.36%
	Truth Overall	262	210	698	1170	
	Producer Accuracy (Precision)	79.77%	70.00%	85.82%		81.62%

	Level I Accuracy Assessment	**Ground Truth: Study Area 6**			
		Talus/Rock	Other	*Classification Overall*	User Accuracy
Classification	Talus/Rock	481	80	561	85.74%
	Other	10	599	609	98.36%
	Truth Overall	491	679	1170	
	Producer Accuracy (Precision)	97.96%	88.22%		92.31%