University of Wyoming

Final Report

Central Wyoming Remote Sensing Project

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5/14/2010

Final Report

Central Wyoming/Lander Area Shrub Steppe Remote Sensing Project

Wyoming Game and Fish Department
Contract #06SC0406955: Addendums 1 & 2

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31 December 2009 (version14 May 2010)

Executive Summary

This report describes land cover mapping, snow cover scenario mapping and change detection work completed using satellite data and existing maps for a large area of central Wyoming between June 2005 and December 2009. This work articulates with other similar projects that have been completed in Wyoming or that are planned for the future, and provides more detailed geospatial data for land managers across the broad area than has been available previously.

Specifically, land cover was mapped by Wyoming Geographic Information Science Center (WyGISC) personnel using Landsat5 Thematic Mapper (TM), National Aerial Photography Program (NAPP), and Shuttle Radar Topography Mission (SRTM) imagery for a 6,490,062 acre area of Central Wyoming. Landcover information is provided at 2 acre minimum mapping units (MMUs) as 0.222 acre pixels (i.e. 30m on a side raster file pixels).

Snow cover maps were created from Landsat TM satellite data that depict fractional snow cover for an "average" and "heavy" snow year, as determined in consultation with Wyoming Game and Fish and Bureau of Land Management field personnel and by comparison of SNOTEL snow water equivalent data to long-term average snow water equivalent for stations in the study area. These maps, though necessarily "snapshots" of snow cover on the targeted dates, provide information on winter habitat availability.

Land cover change visualization maps were also produced using Landsat Thematic Mapper (TM) satellite data collected at 5 year intervals from the mid-1980s until the present (2009). These products highlight changes in vegetation cover using remote sensing change detection algorithms and enhancements chosen to emphasize changes in the amount of green vegetation and in the amount of bare, exposed soil. This series of change images can provide land managers with information about habitat gain and loss during the last ~30 years in central Wyoming.

All of these products are described in detail in this report and provided as digital GIS data in ArcGIS (v. 9.3.1) map documents. Users should ensure that these products are appropriate for specific management or other applications, as is the case for all geospatial data.

Acknowledgements

A project of this scope would not be possible without the contributions of many people. We wish to thank the following participants in the Southwest, Central, and Bighorn Basin projects and planning committees, in no particular order. We sincerely hope that we have not left anyone out, but if we have, please accept our apologies and gratitude.

- Wyoming Game and Fish Department: Bill Gerhart, Gary Butler, Carrie Dobey, Dan Stroud, Bert Jellison, Nick Scribner, Kirk Nordyke, Troy Gerhardt, Keith Schoup, Jerry Altermatt, Dennis Oberlie, Nyssa Whitford.
- BLM: Tom Rinkes, Gretchen Meyer, Vicki Herren, Connie Breckenridge, Tim Kramer, Andy Warren, Dennis Saville, Steve Laster, Mark Williams, Larry Neasloney, Nick Schultz, Oakley Ingersoll, Tim Stephens, Martin Griffith, Dave Roberts, Jeff Carroll.
- Chicago Botanical Gardens: Kelli Bartholomew, Jodi Daline, Robert Howells, Benjamin Rechahn.
- USFS: Mark Engler, Ken Ostrom, Kent Houston, Melinda McGann
- BIA: Charlie Dillahunty, Nash Degarmo, Eric Rhodenbaugh, Antonio Pingree.
- Wind River Tribal Fish and Game: Ben Warren.
- NRCS: Karen Clause, Chris Krassin, Jennifer Hayward, Randy Wiggins.
- USFWS: Pat Hnilicka, Dave Skates.
- TNC: Holly Copeland.
- Wyoming State Climatologist: Jan Curtis (Former)
- UW faculty, staff and students: George Jones, Gary Beauvais, Bonnie Heidel, Ron Hartman, Melissa Thompson, Tess Anderson, Curtis McCann.
- WyGISC staff: Ken Driese, Heather Allen Enloe, Shawn Lanning, Phil Polzer, Kathy Olson, Kassandra Ricks, Fawn Sprague, Khristian Owens, Ramesh Sivanpillai, Jeff Hamerlinck, and Jim Oakleaf.

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Chapter 1

Introduction and Objectives

1.1 Background

Mapping and monitoring land cover and animal habitat are critical components of environmental management. The project described in this report is a step towards creating a spatially consistent land cover database for Wyoming and has been designed to articulate with similar projects that have been completed or are planned or underway elsewhere in the state. In this report we describe the methods used to create land cover maps, change detection visualizations and snow cover scenario maps, and we provide guidance on interpretation of these products while offering discussions of how they should best be used. Appendices include relevant technical data and tabular results.

This project was funded in the June 2005 and draft products were completed in November 2009 and distributed for review.

1.2 Objectives

The general objective of this work was to produce three thematic products for the study area in central Wyoming (Fig. 1.1). These products include: existing land cover, snow cover for high and average snow scenarios, and change analysis on 5 year intervals since 1985.

Specifically, we:

1. Used our satellite image archive and our unique relationship with the USGS EROS Data Center to help the WGFD identify and acquire the best imagery for this project.
2. Modeled natural vegetation (see Chapter 3) using Classification and Regression Tree (CART) analysis of remotely sensed imagery and topographic variables guided by training data collected during four field seasons (see Chapter 2) and existing ancillary data.
3. Mapped land use types in the Lander mapping region using GIS analysis or aerial photograph interpretation (see Chapter 4).
4. Mapped snow cover in the study areas using the Normalized Difference Snow Index, a commonly used snow enhancement algorithm (see Chapter 5).
5. Highlighted changes in land cover at 5 year intervals using commonly used change detection algorithms including image subtraction and change stack visualizations (see Chapter 6).

1.3 Description of WyGISC

WyGISC is unique in mission, scope, size and numbers of trained personnel in Wyoming with a staff of 19 full and part-time persons. Computer arrays in a central server complex provide operational software, computational power, and data for WyGISC, UW, and, through data serving arrays, the state and nation. As the primary source of digital spatial data for Wyoming, it serves 150 Gb of spatial data via web servers, 350 Gb via Oracle servers, and over 2 Tb as imagery, including satellite data and orthophotos. It performs applied research on behalf of many federal (e.g. USDA-ARS and NRCS, USGS, BLM and USFS), state (e.g. Dept of Environmental Quality, Game & Fish, Water Conservation Commission, Geological Survey and State Engineer), and private clients using GIS, GPS, remote sensing and data serving tools. WyGISC administers GIS and remote sensing software licenses (Erdas Imagine, ENVI, ArcGIS, See5) and provides technical support, project collaboration and spatial data for university personnel. In addition it presents professional training courses in its dedicated fixed and mobile labs for personnel throughout the state and region. WyGISC actively participates with other state agencies in the development of geospatial capacity throughout the public and private sectors. The Remote Sensing Unit at WyGISC was established in 2001 under the leadership of Dr. Kenneth L. Driese.

1.4 Project Management

The Principal Investigator on this project was Eli Rodemaker (M.S.). Eli has 15 years of experience both in the private sector and academia using remote sensing and other geospatial tools to map, monitor and study vegetation in the intermountain west and the northwestern U.S. Eli was responsible for the hands-on project management and much of the analysis performed for this project.

Arne Buechling, WyGISC Staff Vegetation Ecologist, developed the land cover vegetation modeling for the montane regions, see chapter 3 for explanation, assisted in compilation of all field training data for land cover, see chapter 2 for explanation. Arne also developed a riparian floodplain model for use in the modeling of land cover, see chapter 3 for explananation. Additional analysis was performed by Travis Yeik, Research Technician, especially for the snow cover and change detection tasks.

1.5 Description of Study Area

The study area for this project included 6,490,062 acres in central Wyoming ranging in landforms from the Wind River valley, across desert basins, rims and plateaus, to medium stature isolated mountains such as Crooks and Green Mountains and included the eastern flank of the Continental Divide of the Wind River Mountains (Fig. 1.1). Moisture ranges from an average of 36 inches per year in the mountains to 8 inches per year (USDA, 1999).

The mapping region is contained within portions of Fremont, Natrona, Hot Springs, Sweetwater, and Carbon Counties. The lower elevation lands of the region experience a semi-desert climate regime and land cover is dominated by shrubs, grasses, and barren lands with occasional stands of limber pine, juniper, and other woody species (See Chapter 3 for a detailed description of land cover).

Land cover mapping using Classification and Regression Trees (CART), GIS analysis, and image interpretation with remotely sensed data is described in Chapters 2, 3, and 4 of this report. Snow cover mapping and change detection for this mapping region are described in Chapters 5 and 6, respectively. This area was buffered by 3 km to facilitate future edge matching with adjacent areas. All three product types were buffered.

Figure 1.1. The extent of the study area superimposed on a map of Wyoming county lines with mapping region label in red. Land use and land cover, snow mapping, and change detection were performed for the entire study area, including a 3 km buffer (not shown).

1.6 Report Overview

The chapters in this report correspond to the major tasks that were completed to produce the digital land cover, snow, and change products for southwestern Wyoming. Chapter 2 describes field data collection techniques used during the two field seasons that occurred in the project period. Chapter 3 describes land cover mapping in the Lander mapping region, unique in that this region was mapped by WyGISC from imagery rather than from existing map products. Chapter 4 describes the production of non-natural cover types with GIS and image interpretation analyses and the intergration of the products into a region-wide product at 2 acre MMU. Chapter 5 describes snow cover mapping which was done for all mapping regions. Change detection methods and products are described in Chapter 6 followed by a concluding chapter (Chapter 7). Appendices provide technically relevant information that is too lengthy to include in the report narrative or that does not fit logically into a single chapter.

1.7 Literature Cited

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Chapter 2

Land Cover Mapping: Field Data Collection

2.1. Background

Any remote sensing based land cover classification rests on the back of field data and the creation of the Lander mapping region was no exception. Extensive field data were collected for this area during from 2005 to 2009 supporting both CART modeling of natural cover types and to guide photointerpretation and GIS mapping of anthropogenic types. The field data themselves are a valuable data set and we devote this chapter to describing how they were collected and used.

2.2. Sampling Scheme

Land cover samples were collected for features at the appropriate mapping scale and image resolution to meet the requirements of the technologies used to create the Lander map, which included remote sensing and CART modeling. The principal remote sensing instrument was the Landsat 5 Thematic Mapper (TM5). As a basis of mapping, satellite resolution inherently controls the spatial scale of mapping and sampling. TM5 has a spatial resolution of 30 meters, meaning that each image pixel represents a square area on the ground 30 m on a side (900 m^2 total area). To ensure confident association of individual image pixels, whose position includes some spatial uncertainty, to on-the-ground cover samples, it is necessary to sample large homogenous areas much larger than a single pixel. For this project minimum sampled areas were 1 ha. Since the satellite samples areas of homogeneous terrain as well as transitional or mixed areas, field reference sites were limited to the interior of terrain units, away from edges, where only samples of the 'pure' or homogeneous terrain are sampled.

Field crews were instructed to sample with no *a priori* assumptions about land cover patches other than scale limitations. Crews were instructed to travel to an area and fully sample all perceived types in the area as access allowed. In this way the sampling protocol can be described as stratification by access (roads, ownership) and was quasi-random within strata. There is no requirement for unbiased sampling to build a classification model like the one we used for this project but instead importance is placed on representing all target cover types with field data. Our sampling scheme attempted to 'advantageously' sample the breadth of recognizable environmental gradients in the mapping region. Field crews were provided with a type list (classification) as reference but were encouraged to recognize potential new types. Crews were therefore not limited to predefined strata, only to sampling at an appropriate spatial scale.

2.3. Sampling Protocols

The primary goal of the field protocol was to provide samples of homogeneous terrain units at the appropriate scale. The sampling protocol selects the 'pure' pixels in the center of a terrain unit and eliminates 'edge' pixels which are not.

Reference data were collected by multiple field crews. Some crews used a GPS and laptop with remotely sensed imagery and GIS layers as reference. These crews delimited a GIS polygon over the imagery as a spatial sample of a field reference site. Other crews used a GPS unit and described the spatial relationship of the field reference site to a GPS coordinate. All crews collected site photos and completed a 'two page' field form (or digital GPS Data Dictionary) containing spatial, terrain, and floristic data fields for each sample site. Field collection data included notes on perceivable anthropogenic impact, soil color, relationship to neighboring sites, and the sampling confidence or fitness of the unit type. See Appendix A for an example field form, the data collection instructions and foliar cover chart examples. Appendix B includes the cover type list.

The sampling protocol, partly due to the demands of the modeling technique, relied on a large sample size in trade for some level of detail and precision in measurement. The primary tool for estimation of vegetation cover was ocular estimation. Cover for the project, including field sampling and classification purposes is a measure of all plant tissues (living and dead) above the ground. In order to provide consistency among field crews and within a crew from day to day, crews used "comparison charts for visual estimation of foliage cover" adapted from Terry and Chilingar (Anderson 1986). Often termed the "Petri Dish" charts, they provide a calibration to various foliar covers in different spatial patterns. See Appendix 1 for an example. Importantly, all crews were also trained together in multiple seminar and field trip meetings early in the project and as calibration regrouped during the field season on multiple occasions. At the trainings, crews used line-intercept and quadrat sampling methods as well as ocular estimation at test areas to become experienced with sampling cover. At the calibration meetings, crews again compared ocular estimates to line-intercept or quadrat sampling as well as reviewed sampling protocols and planned target areas or types. Through the field season crews were encouraged to employ line-intercept or similar sampling as needed to retain estimation confidence.

Crews also received training from botanical experts on vegetation species identification. As needed, crews were instructed to collect specimens of unknown species with significant abundance. These unknown species were either identified by local experts or, in the case of some sagebrush, using the 'black light' florescence technique. Sagebrush species identification and nomenclature followed Alma Winward's 2004 (Winward 2004) treatment with cross reference to Alan Beetle's 1982 treatment (Beetle and Johnson 1982) and other previous publications or treatments from neighboring states such as Montana and Idaho (Beetle 1960, Frisina and Wambolt 2004, Tart 1996, Hironaka et.al. 1983, Rosentreter, 2003). 'Black lighting' of sage species followed the process and florescence categorization of Rosentreter (2003) and Rinkes (2006).

Figures 2.1 and 2.2 (below) show example GIS data generated during field sampling. Examples of samples where polygon spatial information was digitized in the field with a laptop computer are shown in Figure 2.1. Figure 2.2 shows an example where point based data were collected with differentially corrected GPS waypoints.

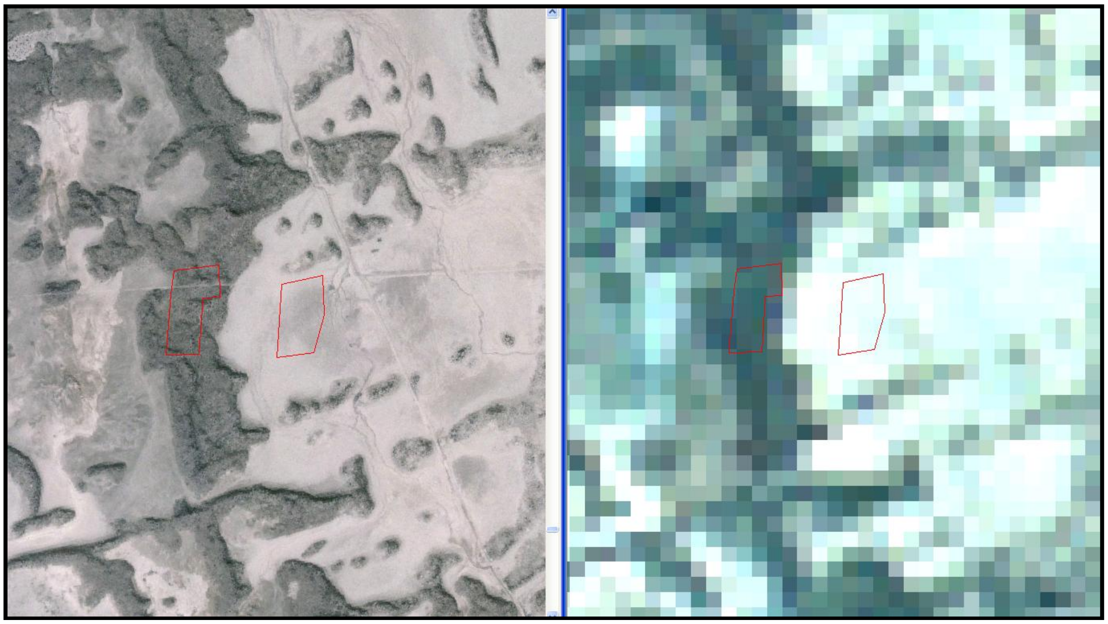

Figure 2.1. One-meter color infrared imagery on the left and Landsat Thematic Mapper (TM5) imagery on the right with GIS overlay of two polygons digitized in the field for spatial samples of terrain units.

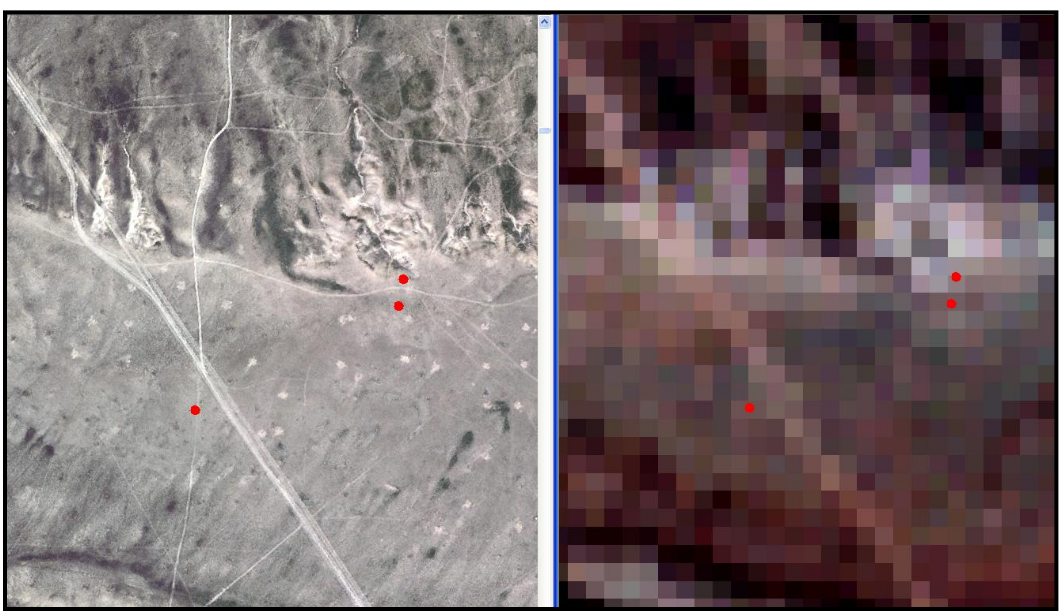

Figure 2.2. Differentially corrected GPS waypoints used to reference sampled terrain units.

Ultimately, field reference data were used to sample specific Landsat Thematic Mapper pixels (30 x 30 m or 900 m^2). To do this, the GPS-collected field data were translated from points to a spatial extent using information about each sample point. For instance, some of the sites inaccessible to the field crews were moved in the lab based on field notes. Further, as mapping strata were refined, the spatial position of the GPS and polygon data were reviewed and sometimes adjusted based on field notes and remotely sensed imagery, *e.g.* into a more representative pixel or pixels. In general the spatial extent of the samples generated from GPS only were kept small due to subjectivity of interpreting field notes and the relative inexperience of the field crew. An example of the derived spatial samples is shown in Figure 2.3.

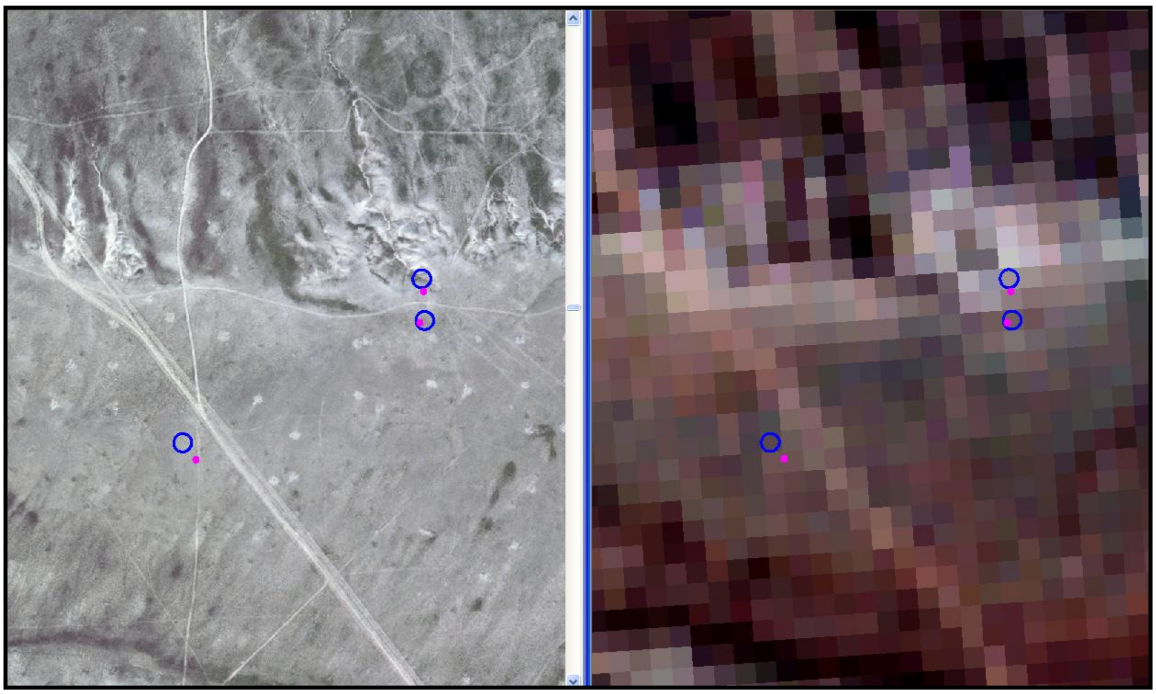

Figure 2.3. 1m Color Infrared Aerial imagery on the left with Landsat Thematic Mapper on the right. On both images GIS overlays of the GPS waypoints and a polygon overlay of the derived spatial sample are shown.

2.4 Field Data Ordination

Mapping strata were refined by a process of ordination, where each field reference site was investigated for fitness to the classification. This process resulted in both a verified and potentially revised classification, and a verification and potential modification of the samples themselves. In this process samples were sometimes relabeled or spatially adjusted to provide better representation of cover types. The ordination was an iterative process and was revisited during modeling as required to improve the model result. While heavily reliant on the field data statistics published references were used to investigate known plant associations. Electronic databases, such as the USDA Forest Service Fire Effects

Information System (http://www.fs.fed.us/database/feis/plants/) and the USDA NRCS PLANTS Database (http://plants.usda.gov/) were referenced as well.

During ordination the spatial position of the field polygon was verified and often shifted to representative neighbor pixels. The ordination also helped highlight under-sampled types. Additional reference samples were created by photo-interpretation techniques and inference from the existing field samples. In the lab, additional reference samples were created for the types: Aspen, Aspen-Conifer and Limber Pine (3 closure classes), Juniper, Juniper-Sage and Mixed Xeric Mountain Shrubs.

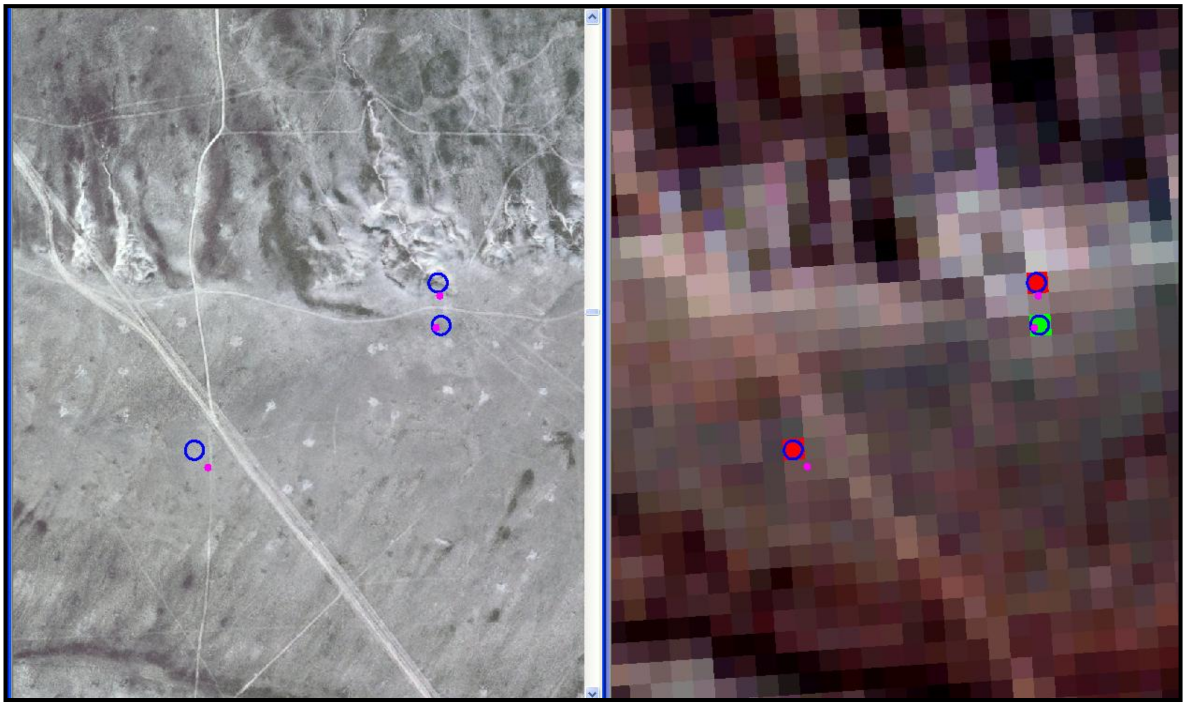

Figure 2.4. 1m Color Infrared Aerial imagery on the left with Landsat Thematic Mapper on the right. On the left GIS overlays of the GPS waypoints is shown with spatially corrected sample. On the right are also the two GIS point and polygon overlays with the final sample set as colored pixels used in the modeling process. The final sample set of pixels are color coded by the ordination results, showing two types model.

2.5 Results

Field data were mainly collected in 2005 and 2006 with additional samples added in 2007, 2008, and 2009. Personnel collecting field data included Wyoming Game and Fish Department staff and their intern, two field crews from the BLM's Chicago Botanical Gardens Internship program, US Fish and Wildlife Service staff and their intern, and WyGISC. The total number of field sites visited on the ground was 2,662 (Figure 2.5). Additional samples were digitized in the lab using photointerpretation techniques. These additional samples were only added to the dependent variable (raster) dataset used in CART modeling. In total the field and lab-generated sites translated to 17243 pixels or samples used as the statistical population.

Field data was stratified into two model domains; one for high elevation areas in the Wind River Mountains and southern Absaroka Range and another for the remainder of the study area. The montane model was able to use 294 field collected sites, but we were able to leverage efforts by the US Forest Service (USFS) Region 2, Shoshone National Forest, and Wyoming Game and Fish Department to boost the total number of training sites to 964 for a total of 3,474 pixels or samples The additional data was derived by interpreting a soils field data set collected by Kent Houston at the Shoshone Forest, the USFS Region2 dataset R2Veg, and the WGFD southern Wind River Mule Deer Herd Habitat Management Plan developed by Jack Welch. In all 32 types were modeled for the montane model. The remainder of the mapping area produced a CART model of 82 types (84 types were present in the field dataset lotic and lentic water samples were excluded from the CART model). The lower elevation model used 2,368 field collected sites for a total of 13,769 pixels or samples.

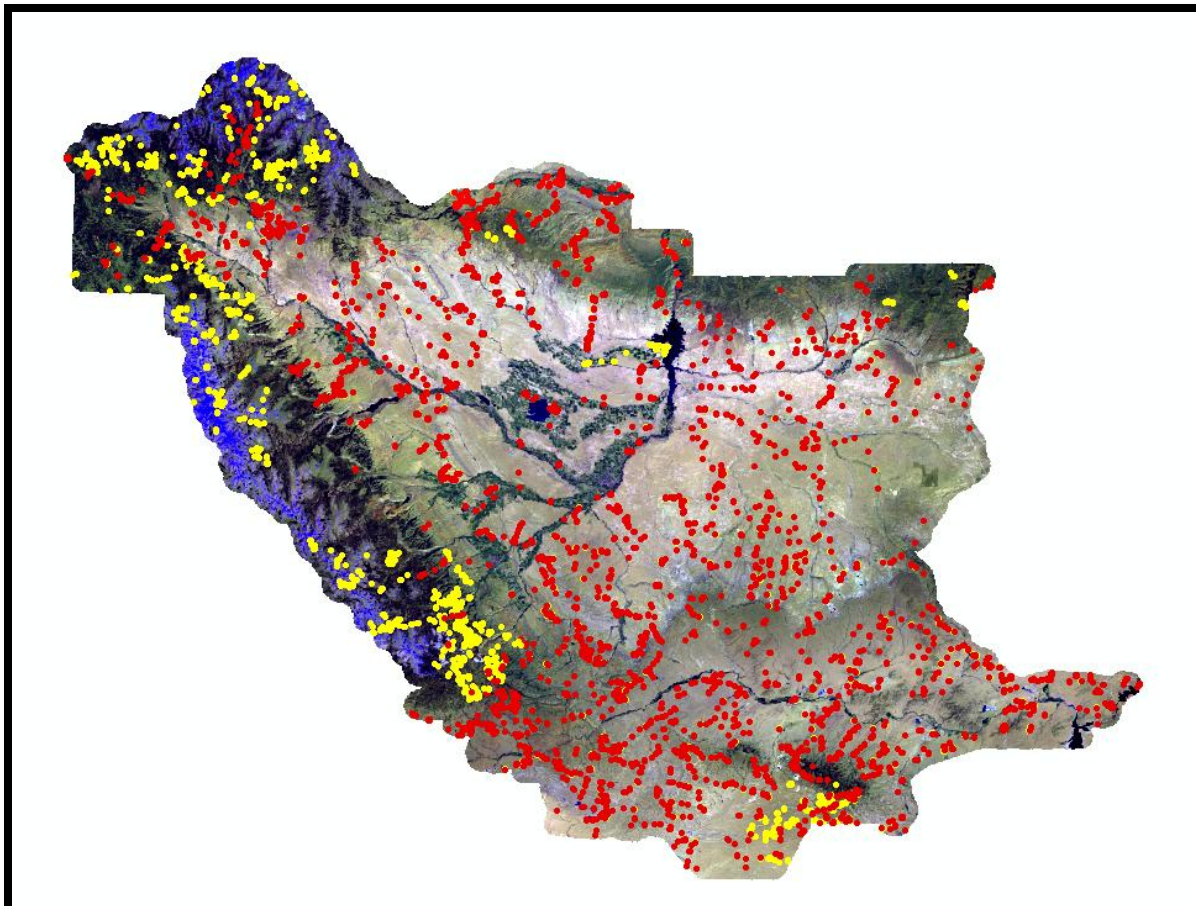

Figure 2.5. Landsat Thematic Mapper image with locations of reference samples as GIS overlays. Red samples were collected during the field survey and yellow sites were added in the laboratory.

2.6 Conclusions

Application of a terrain and image spectral modeling approach, in this case with CART, is limited by the completeness of the reference population across the range of terrain and vegetation gradients. This completeness is measured by how the breadth of a range is sampled and the precision of samples within the range. Measures of fitness for this type of modeling will be related to both sample population completeness and the fitness of the ordination of the sample population. Areas or modeling elements that do not fit well can be shown to be either deficiencies in modeling and ordination or, interestingly, related to the continuous nature of gradients across the terrain being forced into a discrete classification. For instance, areas of low fitness may represent ecotones, mixed, or transitional areas with mixed plant communities or, as is common in Wyoming vegetation, the area may represent areas of unknown or mixed genetic composition. The archetypal example of mixed genetics are continuous stands of big sagebrush hybrids (*e.g.* Goshute/Bonneville 'B' big sagebrush or Tall Black sagebrush) or stands with mixed community composition such as a black sage co-dominant with big sage stands.

A primary goal of this mapping effort is to identify the type mapping potential (classification) for the mapping area, increase understanding of vegetation communities on the landscape, and develop technologies to discriminate appropriate types. The field data collected for this project are the basis of this work. In the case of the Lander mapping effort our classifification is shown in Appendix B. Mixed community composition not present in our classification such as black sage co-dominant with Wyoming big sage was typed as the more rare type black sage.

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Chapter 3
Land Cover Mapping: Natural Cover Type Modeling

3.1 Background

The Wyoming Game and Fish Department in partnership with the USDI-Bureau of Land Management –Wyoming recognize the need for statewide Land Use and Land Cover (LULC) maps. The WGFD and BLM have both conducted more recent mapping efforts for select regions of Wyoming and are working to 'fill in' a state map with ongoing region-level mapping projects. These maps are useful for many endeavors such as vertebrate animal habitat analysis and stratification for inventory and monitoring, and 2vegetation health assessments to name a few.

The primary impetus for the product described in this chapter was habitat assessment, inventory, and monitoring for portions of a sagebrush-steppe and semi-arid desert ecosystem in central Wyoming (the Lander mapping region described in Chapter 1). This area is undergoing widespread oil and gas extraction and infrastructure development. The area also hosts important habitat for large populations of sagebrush obligate species such as greater sage grouse, pronghorn antelope, Rocky Mountain elk, mule deer, and many other animals. The primary goal of this mapping effort was to create an LULC map suitable for Greater Sage-grouse (*Centrocercus urophasianus*) habitat inventory. To that end a map was needed with 2 acre Minimum Mapping Units and detailed strata attributes including floristic composition and canopy closure. The mapping effort was also intended to assist in Range Management Planning efforts of the BLM for the Lander Field Office Area. Further with support from the USFWS the mapping product included the Wind River Indian Reservation.

To create this product, WyGISC used an algorithm known as Classification and Regression Tree (CART) analysis (Quinlan 1986, 1993) supported by extensive field data collection (See Chapter 2) to classify Landsat Thematic Mapper (TM) imagery. This technique allowed the analyst to model cover types based on spectral characteristics in combination with ancillary data that helped solve spectral confusion. Consequently, CART could better distinguish the cover types desired by habitat managers in Wyoming than methods based on spectral data alone.

3.2 Stakeholder Involvement

Because this project included multiple stakeholders with differing data needs, their participation in planning and implementation of the mapping was critical. Stakeholder personnel, in this case from federal and state land management agencies, working at regional, local, and site levels, formed a working committee to identify common needs and help guide the project. The working committee for this project reviewed user needs, project scope and timelines, and developed an initial classification scheme as part of a Southwest Wyoming mapping project (Rodemaker and Driese, 2006); efforts in Central Wyoming set to follow the strategies implemented in that project and improve on those results where possible. Results of these initial meetings allowed WyGISC to develop a more formal project plan tailored to multi-agency collaborative implementation.

3.3 Classification Scheme

The development of a classification scheme is an important and often under-examined facet of a mapping project. Factors affecting 'appropriateness' of a classification include: user needs, the availability of resources and technology, and the setting to be mapped. General land cover mapping goals developed for this project included 2 acre MMUs with attributes suitable for habitat management in general and sage grouse habitat evaluation in particular. An initial classification was developed from the recommendations of the collaborative committee (see 3.2 above) and on coordination with other ongoing statewide activities. Early in this project, experts from habitat and fire mapping programs met with the project manager (Rodemaker) and developed a target classification. This classification was provided to other experts within the mapping region for further review. Once this classification scheme was approved and finalized, the project manager developed a field sampling protocol (Chapter 2).

The Wyoming Game and Fish Department's Wildlife Observation System version 22 Jan, 1997 (WOS97) was used as the basis of cover type classification. Some cover types were categorized into more detailed classes by aerial cover (Table 3.1). Cover for the project, including field sampling and classification purposes is a measure of all plant tissues above the ground. For types mapped with closure or cover categories, three breaks were implemented to derive low, medium, and high classes. Definition of cover breaks were developed by the working committee based on needs of Greater Sage-grouse habitat management and fire fuels management programs. Shrub and herbaceous types mapped to cover classes were broken using important habitat characteristics noted in Greater Sage-grouse habitat analysis and utilization documents (Connelly *et. al*. 2000, Hagen *et. al*. 2007, and Connelly *et. al*. 2003). Forested types mapped to closure classes mainly followed definitions desired by fire fuels mapping and management experts (Schmidt *et. al*. 2002).

The resulting classification provided a framework for ordination of cover types statewide based on the expert knowledge of the committee, user needs, and literature. The classification is hierarchically organized from coarser to finer definitions of cover types. At the coarsest level of the classification the hierarchy follows land use or physiognomic definitions. Subsequent levels are defined along floristic or land use characteristics. Most cover types at these finer levels equate to plant community, association, or alliance level classes. Other cover types correspond to specific definitions of land use (*e.g*. urban) or land type (*e.g*. barren or sand dune). Finally, at the most detailed level of classification some cover types are separated by canopy cover/closure, or herbaceous cover class definitions. To be considered a vegetated cover type, vegetative cover had to be greater than 5% sagebrush cover or greater than 7.5% total vegetation cover. Cover type units of appropriate size with less vegetation than these definitions were classed as a non-vegetated land use or land cover type.

Unless a mapping region has been thoroughly studied and previously mapped using similar techniques; a classification should be flexible to allow incorporation of unanticipated cover types. The initial phases of field investigation are largely aimed at validating and potentially modifying the target classification. This resulted in some classes being dropped, renamed, or added to the classification, resulting in the list of mapped types shown in Table 3.1 below.

Table 3.1. Land cover types occurring in the final LULC map for the Lander mapping region and mapped for this project. The Cell Value is the code that occurs in the map file provided as a deliverable. The Cover Type Code is the code used to designate cover types in the WOS 1997 classification. The Cover Type Description describes the dominant species or physiognomic type for each mapped type and in some case the amount of canopy closure.

Cell Value	Cover Type Code	Cover Type Description
3	01.10.1	Lodgepole Pine 20-32% closure
4	01.10.2	Lodgepole Pine 33-67% closure
5	01.10.3	Lodgepole Pine >67% closure
11	01.20.1	Douglas Fir 20-32% closure
12	01.20.2	Douglas Fir 33-67% closure
13	01.20.3	Douglas Fir >67% closure
15	01.25.1	Spruce 20-32% closure
16	01.25.2	Spruce 33-67% closure
20	01.30.2	Spruce-Subalpine Fir 33-67% closure
21	01.30.3	Spruce-Subalpine Fir >67% closure
39	01.60.1	Limber Pine 20-32% closure
40	01.60.2	Limber Pine 33-67% closure
41	01.60.3	Limber Pine >67% closure
43	01.61.1	Limber Pine-Douglas Fir 20-32% closure
44	01.61.2	Limber Pine-Douglas Fir 33-67% closure
45	01.61.3	Limber Pine-Douglas Fir >67% closure
47	01.70.1	Whitebark Pine 20-32% closure
48	01.70.2	Whitebark Pine 33-67% closure
51	01.80.1	Mixed Conifer-Juniper 20-32% closure
52	01.80.2	Mixed Conifer-Juniper 33-67% closure
55	01.90.1	Mixed Conifer-Dominant 20-32% closure
56	01.90.2	Mixed Conifer-Dominant 33-67% closure
57	01.90.3	Mixed Conifer-Dominant >67% closure
59	01.94.1	Conifer-Aspen 20-32% closure
60	01.94.2	Conifer-Aspen 33-67% closure
69	02.10.1	Aspen 20-32% closure
70	02.10.2	Aspen 33-67% closure
71	02.10.3	Aspen >67% closure
73	02.20.1	Aspen-Conifer Mix 20-32% closure
74	02.20.2	Aspen-Conifer Mix 33-67% closure

Cell Value	Cover Type Code	Cover Type Description
75	02.20.3	Aspen-Conifer Mix >67% closure
77	02.30.1	Cottonwood-Riparian 20-32% closure
78	02.30.2	Cottonwood-Riparian 33-67% closure
79	02.30.3	Cottonwood-Riparian >67% closure
88	03.20	Juniper
91	03.21	Juniper-Sage
94	03.35	Juniper-Limber Pine
101	04.20	Greasewood
102	04.21	Greasewood-Sagebrush
103	04.22	Greasewood-Saltbush
104	04.41	Saltbush
105	04.45	Saltbush-Sagebrush
107	04.60	Birdfoot Sage
108	04.70	Mixed Desert Shrubs
109	04.90	Other Desert Shrubs
110	04.80	Mixed Desert Shrubs 2
116	05.11.2	Basin Big Sagebrush 16-25% closure
117	05.11.3	Basin Big Sagebrush >25% closure
119	05.12.1	Wyoming Big Sagebrush 5-15% closure
120	05.12.2	Wyoming Big Sagebrush 16-25% closure
121	05.12.3	Wyoming Big Sagebrush >25% closure
123	05.13.1	Mountain Big Sagebrush 5-15% closure
124	05.13.2	Mountain Big Sagebrush 16-25% closure
125	05.13.3	Mountain Big Sagebrush >25% closure
126	05.14	Black Sagebrush
127	05.15	Mountain Silver Sagebrush
128	05.16	Wyoming Three-tip Sagebrush
129	05.17	Alkali/Early Sagebrush
131	05.19	Plains Silver Sagebrush
132	05.20	Rabbitbrush
134	05.29	Other Big Sagebrush
141	05.41	Bitterbrush-Sagebrush
143	05.94	Mixed Xeric Mountain Shrub
144	05.33	Fringed Sage
145	05.95	Willow-Upland
148	06.10	Willow
149	06.12	Willow-Other Shrubs
151	06.90	Mixed Riparian Shrubs
157	07.20.1	Basin Grassland 7.5-20% cover
158	07.20.2	Basin Grassland 21-40% cover
159	07.20.3	Basin Grassland >40% cover
161	07.30.1	Foothills Grassland 7.5-20% cover
162	07.30.2	Foothills Grassland 21-40% cover
163	07.30.3	Foothills Grassland >40% cover

Cell Value	Cover Type Code	Cover Type Description
166	07.40.2	Alpine Grassland 21-40% cover
169	07.60	Riparian/Wet Meadow
185	09.00	Marsh-Swamp Wetlands
189	10.10	Water-Lentic (Standing)
190	10.14	Playa
191	10.20	Water-Lotic (Running)
196	11.20	Irrigated Agricultural Fields
200	11.90	Rural Development
201	11.91	Ranch-Farm Facilities
204	12.40	Rock or Talus Slope
205	12.60	Sand Dunes
207	12.90	Bare Ground
206	12.80	Snow
213	99.10	Roads and Railroads
214	99.20	Mining Areas
216	99.50	Burned Areas
218	99.80	Oil and Gas Developments
220	99.90	Urban/Industrial Land

3.4 Cover Type Modeling

3.4.1 Map Class Development

As the list of mapped classes shows (Table 3.1), types include both natural and anthropogenic land units. Methods used to distinguish these fundamentally different groups were distinct in this project. Natural areas were modeled based on an implementation of the Classification And Regression Tree (CART) technique (Quinlan, 1986 and 1993). Anthropogenic areas were mapped with GIS, remote sensing, or a combination of techniques (Chapter 4).

Modeling of the natural cover types employed gradient analysis and potential natural vegetation modeling (Roberts and Cooper 1987, Franklin 1995, Guisan and Zimmermann 2000), and relied heavily on the spectral response of the land surface captured by remotely sensed imagery. Production of a natural cover type map was accomplished by generating a statistical model using CART and then applying this model spatially to generate a map.

The CART technique we used (See5) recursively partitions input variables hierarchically into a classification 'tree.' Breaks in the tree or hierarchy are determined by binary partition of an independent (response) variable to the field sample or dependent variables. Splits at each node of the hierarchy are optimized to provide maximum reduction of population variance or minimize deviance. The classification tree is then recursively developed by top down spitting of the data into a hierarchy. Overview of the classification technique can be found in the text Classification and Regression Trees by Breiman *et.al*. 1984. Examples of use of the CART in remote sensing based classification of land cover are common (*e.g*., Friedl and Brodley 1997, Lawrence and Wright 2001 and many others).

The CART model was applied using GIS tools developed at the USGS Eros Data Center Land Characterization Project (see National Land Cover Dataset 2001, http://www.mrlc.gov/mrlc2k_nlcd.asp). WyGISC, as a collaborator in USGS programs such as AmericaView, was provided with these GIS tools at no cost. The USGS CART tools are implemented as a module in the ERDAS Imagine Software (ERDAS, Atlanta, GA).

3.4.2 Model Variable Development

Mapping of natural land cover types was accomplished by creating a spatially explicit model of ecological units. This model mapped potential ecological units, using topographic gradients of site potential, and then refined the site potential classification by using remotely sensed spectral data that relate to actual land cover at a site. In other words, the model uses environmental relationships to identify potential sites for land cover types and then populates these with actual cover using the remotely sensed imagery.

The independent variables used in this project included remotely sensed imagery and derived variables from the imagery including topographic data. Other sources of data were investigated, such as geology, soils, land types, climatic and precipitation zones. Most of these were used qualitatively or as investigative information but were not directly a part of map production. Further, many GIS layers showing anthropogenic features or boundaries were employed either directly or indirectly during the project.

Topographic variables were derived from the United States Shuttle Radar Topographic Mapping Mission (SRTM) (SRTM website: http://srtm.usgs.gov/). SRTM elevation data for Wyoming are at 30m pixel resolution and have an approximate horizontal accuracy of +/- 20m and vertical accuracy of +/-16m (RMSE). These data provided an advantage over the USGS National Elevation Dataset (NED) also available for the mapping areas, in that the NED data are derived from at least three disparate data sources and are historically older. The resulting inconsistencies in derived topographic variables from NED were disadvantageous for modeling when compared to the SRTM (Fig. 3.1).

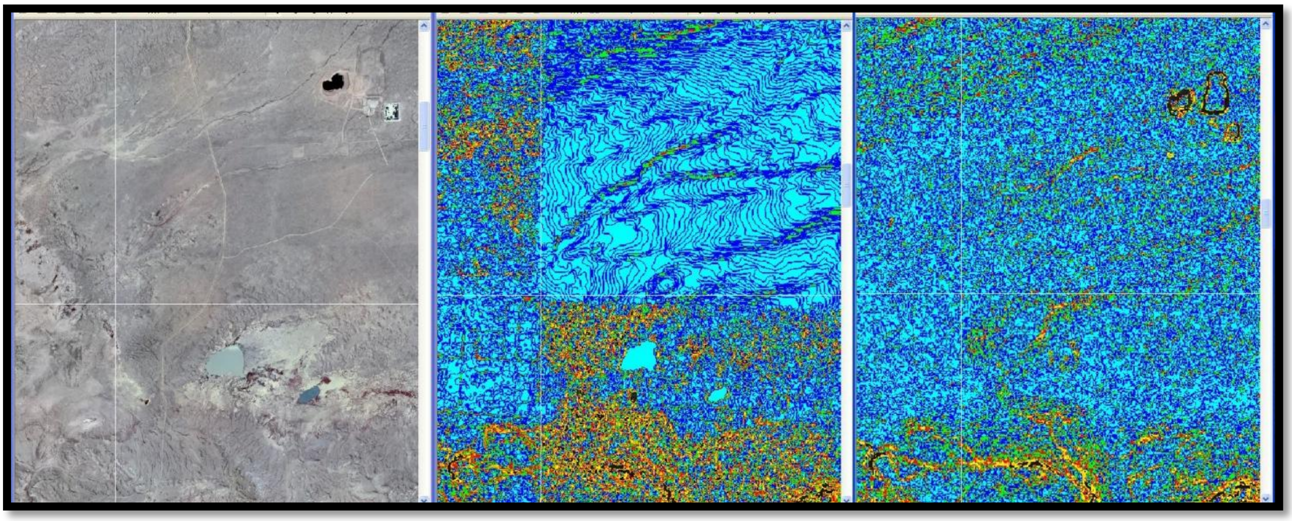


Figure 3.1. Elevation source data shown as derived slope for NED (center) and SRTM data (far right), with representative area on 1m aerial CIR photograph at left.

Topographic variables used in modeling included; elevation in meters, percent slope, and aspect as nine categories. Aspect was categorized as eight cardinal directions and flat, with North representing greater than 375.5 and less than or equal to 22.5 degrees and the rest of the categories represented by 45 degree increments. The aspect categories were sorted from cold to hot in relation to average direct solar radiation to the order: North, Northeast, Northwest, East, Flat, Southeast, South, West, and Southwest.

Remote sensing derived variables also included spectral data from Landsat 5 Thematic Mapper image (TM) and 1m Color Infrared (CIR) aerial imagery composites acquired in the fall of 2001. Full coverage of the study area required Landsat imagery from 3 satellite overpasses or paths. Using the Landsat positioning World Reference System2 the image overpasses were from Paths 35, 36, and 37 (Fig. 3.2) acquired on the dates: 6 July 2007 for Path 35, 29 June 2008 for Path 36, and 9 July 2003 for Path 37. Imagery from the three images dates was normalized to the central image, Path 36, by linear regression. Regression data points were chosen from adjacent portions of the imagery for Psuedo-Invariant Features on each image (Schott et.al. 1988). Once normalized the images were mosaicked to one with the use of a spatial 'cut-line' that followed terrain features visible on the imagery, see figure 3.2 showing the cut-line boundary employed to the Path 36 image. The Landsat at satellite radiance (as represented by the satellite pixel digital numbers or DNs) for all six reflective TM bands, the derived Normalized Difference Vegetation Index (NDVI) and Normalized Difference Wetness Index were final model variables.

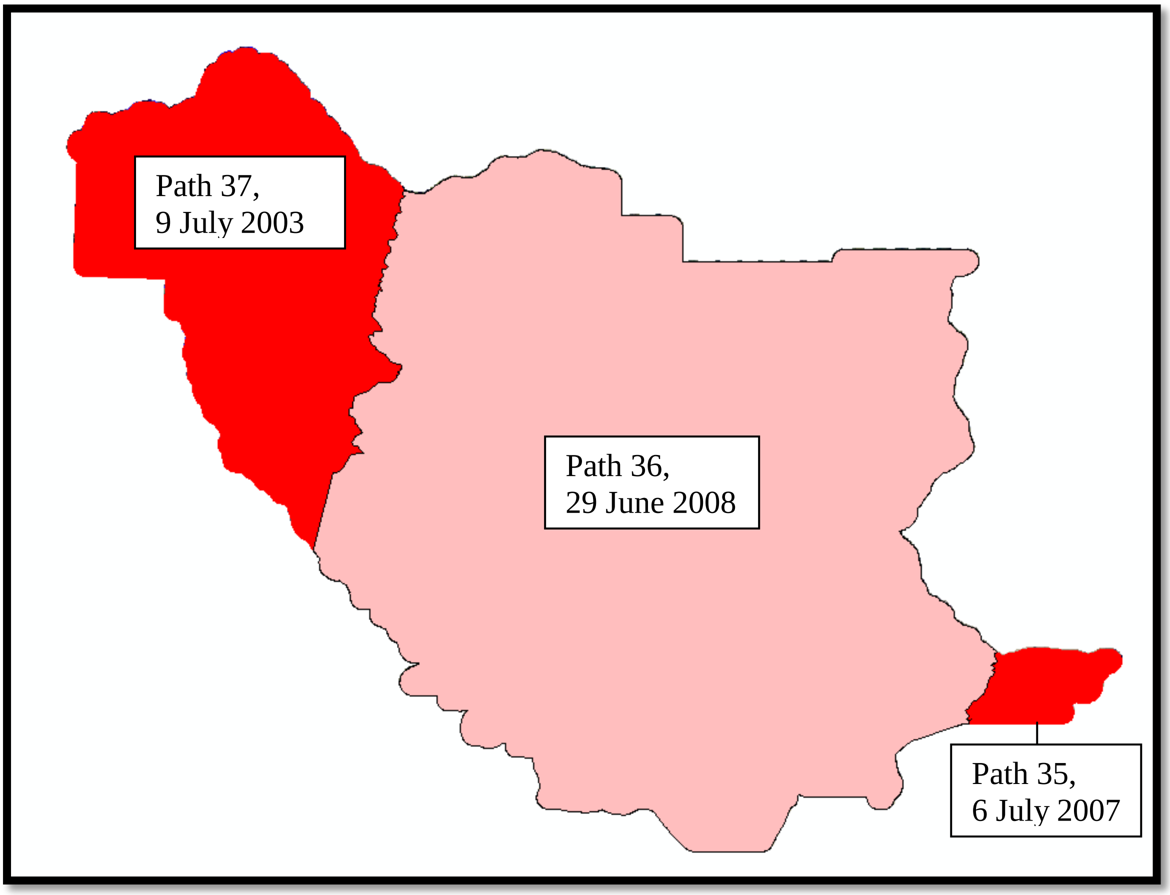
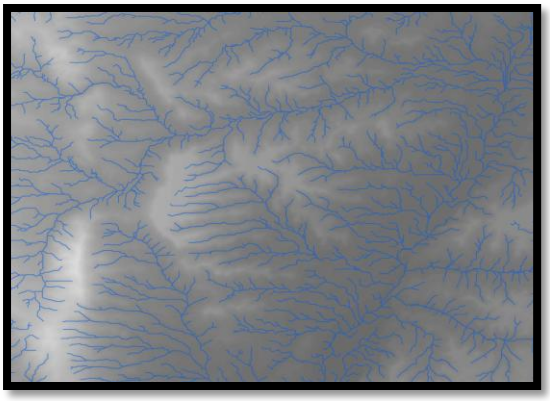


Figure 3.2. Boundaries of Landsat5 Thematic Mapper used in mapping land cover.

Spatial metrics were developed from the 1 m CIR aerial imagery (Roller *et.al.*, 2004). Three variables sensitive to the spatial pattern of vegetation content and image or feature brightness were created at a 1 m spatial resolution. These values were then scaled to the Landsat 30 m pixel resolution. These metrics included; vegetation variability, brightness variability, and relative brightness. The two variability metrics are one way to incorporate land cover texture, a property that can be diagnostic of some land cover types.

For this project we employed a new WyGISC potential riparian zone model to help delineate the habitats of sagebrush species. The explanatory model delineating the riparian or flood zone was also developed from the SRTM elevation data and various hydrologic analysis tools available in ArcGIS 9.3. A stream network was first calculated from elevation values (Figure 13). Regions of pixels representing the spatial extent of riparian areas were subsequently delineated based on slope and elevation gradients adjacent to the computed stream network locations (Figure 14). A cost distance tool in GIS was used to delimit the riparian zones based on specified maximum slope thresholds. A total of 9 riparian classes, representing various stream orders, and one upland class were generated in an automated fashion. Additional information was added for waterbodies, such as reservoirs and lakes, using the National Hydrography Dataset (NHD: http://nhd.usgs.gov/).



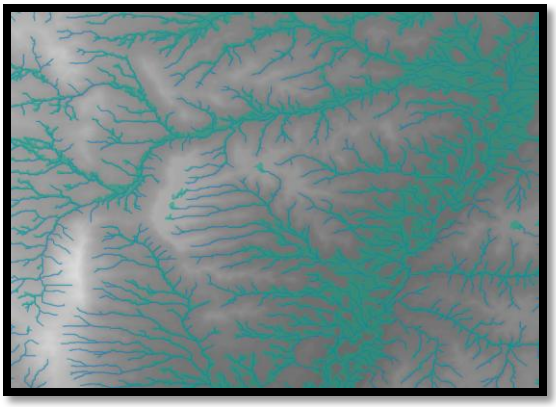


Figure 3.3. Stream locations computed from DEM.

Figure 3.4. Floodplain extent estimated from slope and elevation thresholds.

An area of the riparian layer and a corresponding area of a Landsat image are shown in the figure below over. The colors in the riparian area layer are related to stream order or position within the watershed.

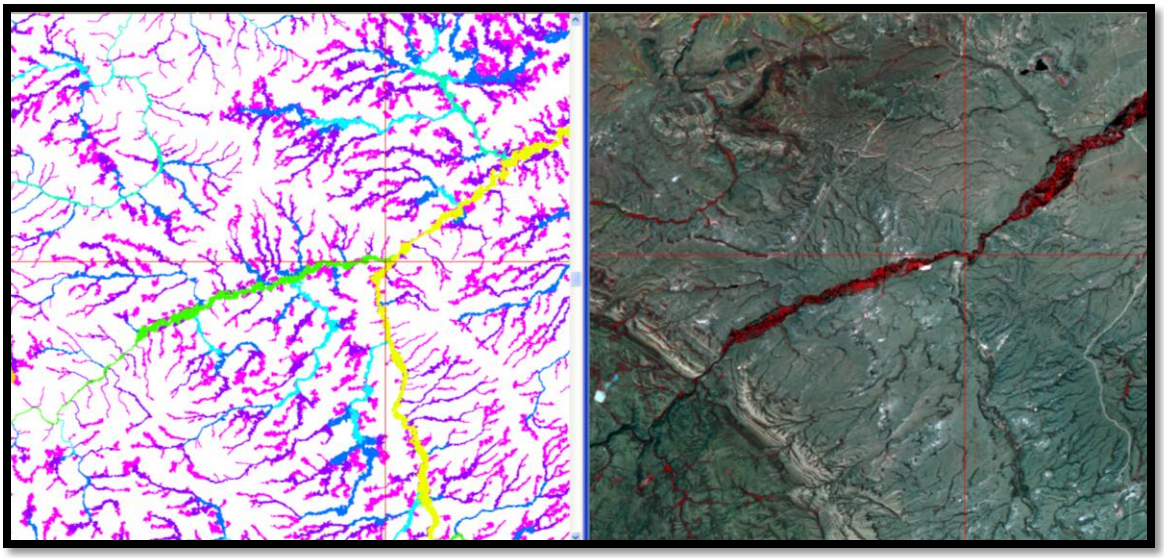


Figure 3.5. Color coded riparian delineations on the left shown with a corresponding area of Landsat Thematic Mapper imagery (Path36, 29 Jun2008 shown as bands 4, 3, 2 as Red, Green, Blue channels).

Figure 3.5a. Corresponding color coding of riparian delineation.

The riparian area layer will help delimit certain sagebrush species, such as Basin big sagebrush, that are contained to soil types of riparian zones. The riparian area layer is also added to the habitat database for potential modeling efforts such as seasonal ranges.

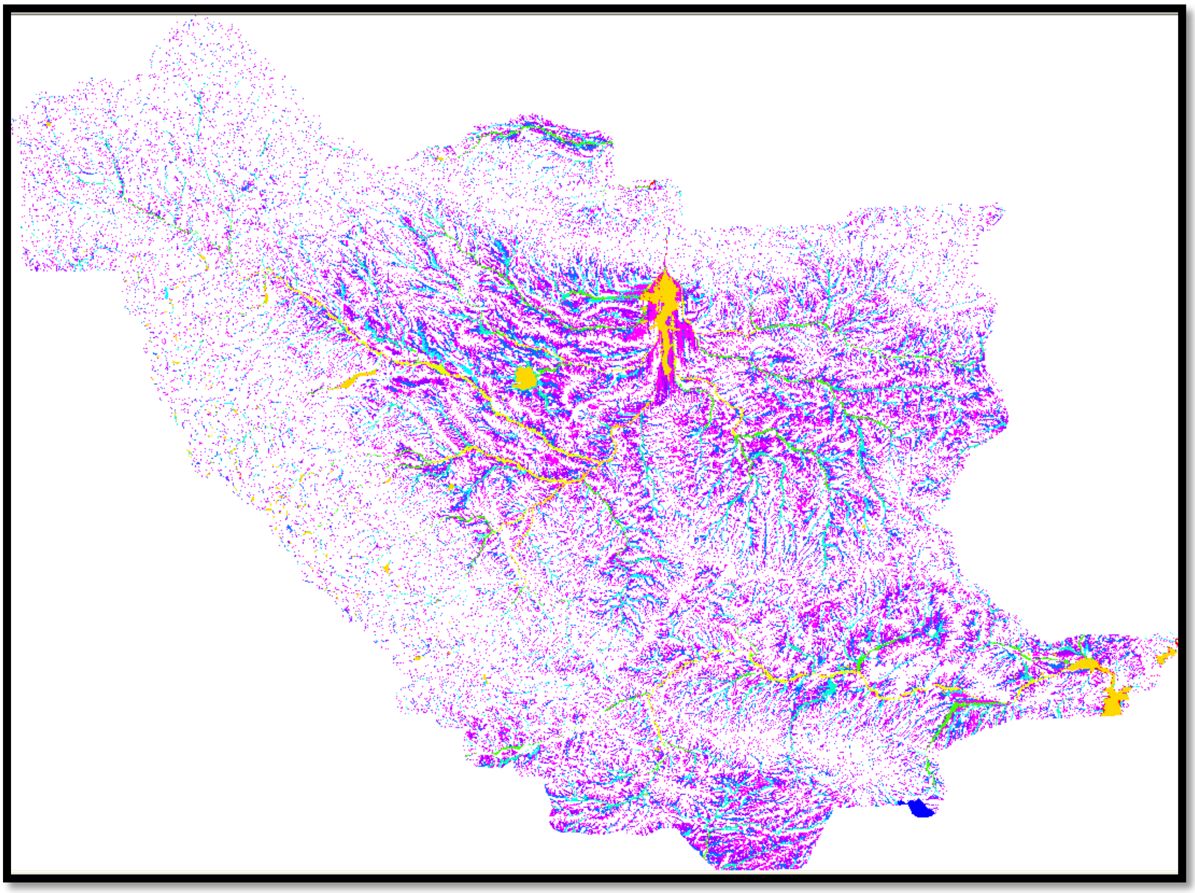


Figure 3.6. Riparian zones across the mapping domain.

3.4.3 Model Generation and Refinement

Generation of the classification model was accomplished using the CART technique. This required user-guided selection of mapping or independent variables and then fitting the dependent 'ordinated' field samples (See Chapter 2) to a classification tree or model. Tools developed at the USGS EROS Data Center allowed for a spatial representation of the CART model results. Once the model was mapped we investigated the results and verified the choices of dependent variables and the independent variable set. Extensive effort was then applied to the independent or field reference variables. Numerous sites were added, many were removed, and some were modified spatially or were changed in classification. Most changes to the independent dataset were accomplished in small increments and then the new spatial map was extensively reviewed. This resulted in multiple iterations of a more and more refined model.

3.5 Results

3.5.1 Overview of Mapped Area

The Lander mapping region encompasses a wide range of habitats from the highest point (13,804 feet above sea level) in Wyoming at Gannet Peak down through desert shrublands and the valley of the Wind River as it enters the Wind River Canyon. The upper elevation montane regions of the study area are comprised of foothill grass and shrublands, coniferous forests, alpine grasslands, rocky escarpments and glaciers. The lower elevations of the the Lander mapping area can be described as a 'Basin and Rim' landscape (see Knight 1994). Elsewhere in the study area the landscape is a mosaic of rims, areas of orogenic relief with usually low slope or 'flat tops' and steep rim faces, and associated basins. These rims are characterized by erosion, especially eolian, with geologic substrate controlling the soil characteristics. Rim material is deposited through wind and water erosion in the adjacent basins resulting in an overall gradient of soil properties (salinity, texture, etc) across the basins away from the rims. Precipitation in the study area ranges dramatically from an annual 6 to 8 inch zone up to a 40 to 44 inch zone.. Most precipitation occurs in the form of winter snow with infrequent precipitation during the summer. The overall environment can be characterized by moisture availability and salinity gradients controlling plant species distribution.

3.5.2 Results for Mapped Classes

Ninety eight classes were mapped at the pixel level for the three km buffered study area boundary (Fig. 3.7). Of these ninety eight classes, eighty seven were mapped using the CART technique, described in section 3.4.1 and 3.4.2 above, while 10 were mapped using other tools as described in Chapter 4.

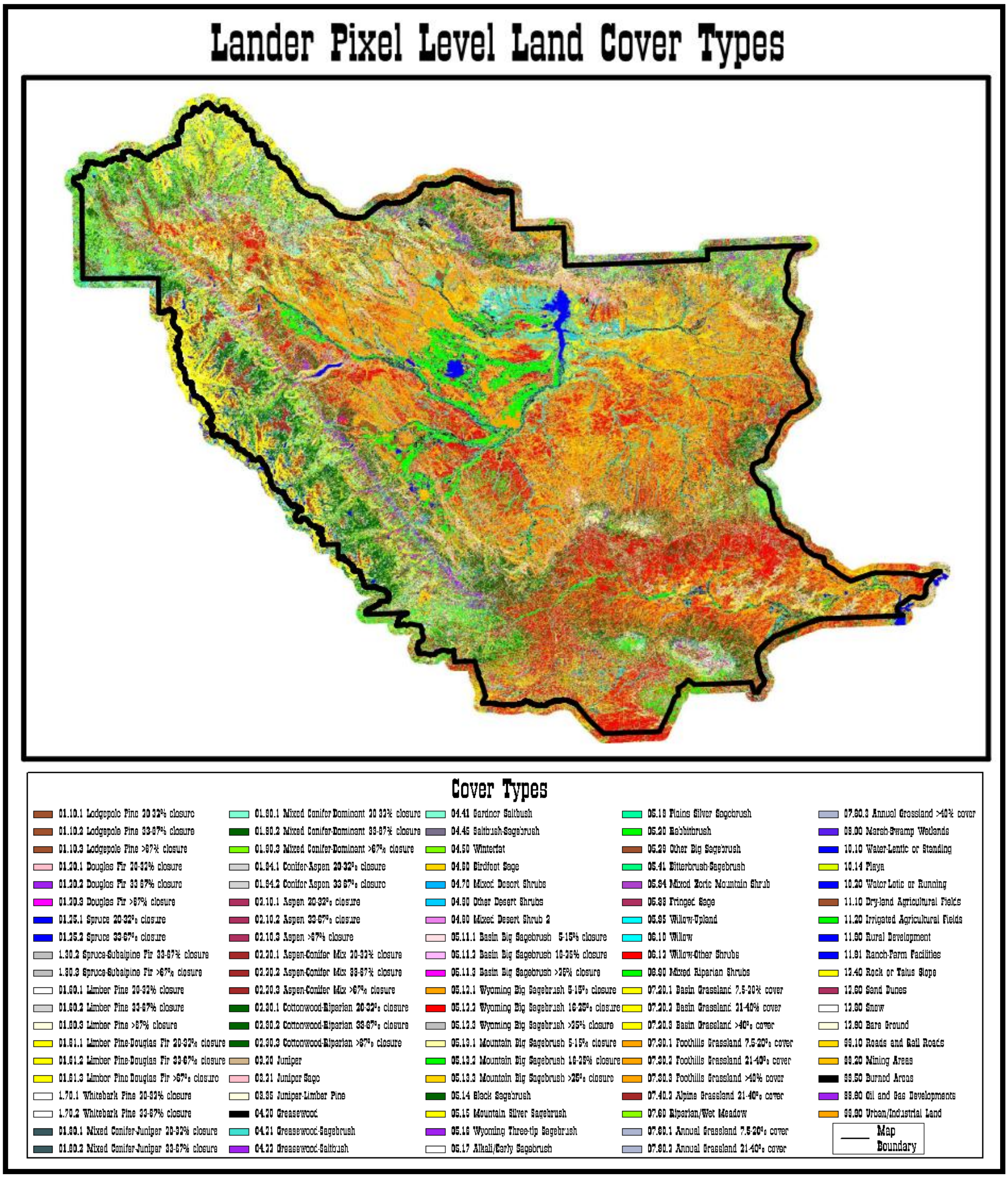


Figure 3.7. Land cover map at the 30 meter pixel level for the 'Lander' mapping area (RFO).

The mapping area was stratified into two major zones to be used as distinct CART model domains. Each CART model domain area was mapped separately. All cover type classifications were assimilated into one map at the individual pixel level. Figure 3.8 shows the boundaries of the two mapping areas found in the final pixel level map, one for the highest elevation mountain ranges and one for the remainder as one combined map. At the boundary of the two mapping zones shown in Figure 3.8 the mapping domain for CART modeling was initially wider to provide for an overlap zone to be edge matched. The western high 'montane' zone produced thirty three mapped types while the eastern ‘basin’ zone produced eighty two mapped types. The basin model was overlain on the montane model as shown in Figure 3.8 and then the non-modeled classes, e.g. roads, mines, urban, and agriculture, were overlain over the product. Aggregation of the pixel level map was then accomplished using the ‘Ecological Similarity Aggregator’ described in Chapter 4 (following), resulting in terrain or cover type patches of 2 acres and larger in size, the project MMU.

Figure 3.8. Mapping zone extents of CART based modeling.

3.6 Accuracy Assessment

Thematic map accuracy was assessed qualitatively by the analyst (Rodemaker) during the iterative process of CART modeling and addition of non-modeled classes. An absence of independent field samples prohibited traditional accuracy assessment using a ‘confusion matrix.’ However, two measures of accuracy from the CART modeling process are available to provide evaluation of the modeled portion of the map product.

The first of these is a model confidence map. Rather than a spatial depiction of map error *sensu* traditional map accuracy assessment, it instead provides a pixel by pixel estimate of the fit of the independent variables to the model class mapped at the pixel versus all other potential classes. It expresses this by providing a range of modeled ‘fitness’ from 0 (always wrong) to 100 (always correct). In other words, it shows how well a particular pixel fit the model used for its cover type (Fig. 3.9).

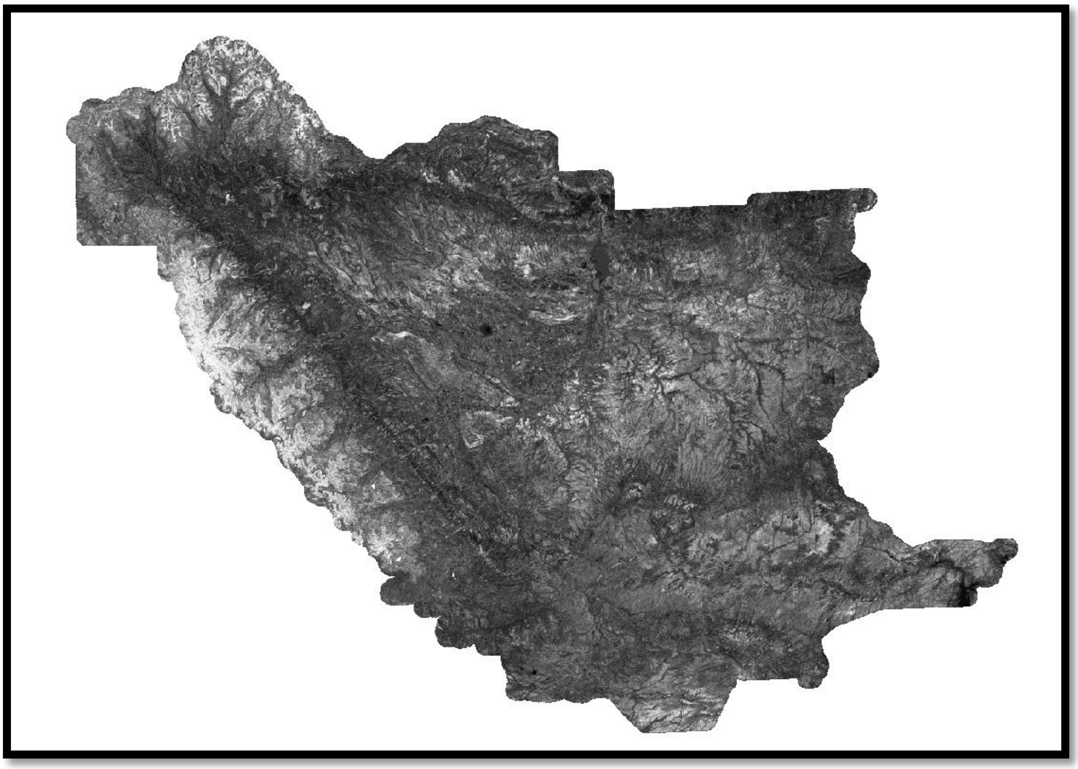


Figure 3.9. Map showing goodness of fit of individual pixels to the CART model. See report text for explanation.

The second measure of accuracy used by CART employed a technique called the F-fold test. This technique is a variant of a 'Monte-Carlo' approach where unique sets of the training data are used to build separate models. Ten models were generated in the F-fold by splitting the training dataset (dependents) into ten subsets and using them to create independent models. Variability between the 10 independent models provides a metric of overall model performance. F-fold results suggest 86.7% overall mapping accuracy.

The CART software can perform an independent accuracy assessment by class but was limited to only twenty classes, precluding use for this model. Finally, the high cost and ambitious nature of this mapping effort encouraged the full use of field reference data for modeling. Collection of an independent field reference set for accuracy essentially entails a high investment in 'another field season' of work and is to be performed if desired by the WGFD as stated in the project RFP.

Our understanding of the land cover in the model domain and the model results suggests that individual class accuracies vary considerably around the overall map accuracy of 86.7% suggested by the CART assessment described above. Some lower accuracy classes may result from a paucity of field reference data. Others may not fit the model well as designed, potentially in the independent or dependent variables. Areas of lower accuracy illuminate possibilities for future research, such as floristic inventory, applied ecology, or model variable development.

Use of the map for stratified inventory can be improved with understanding of potential map error. Statistical summary of the CART-generated fitness map values to 2 acre mapped classes may provide a measure of the variability within each class or strata (Table 3.3). The statistics suggest the *average fit* of individual cover types to the CART generated model.

Strata sampling for inventory could be weighted by variability with more samples collected for variable types. By using a stratified inventory of reference data and perhaps double sampling, the map can potentially be revisited and improved. Finally, it should be remembered that this mapping effort is designed for a regional level habitat assessment. Project (or site) level use of the map will normally result in some need for refinement.

Table 3.3. Statistical summary of CART fitness map by modeled strata with other classes omitted.

	CART Model Confidence Layer Statistics (100 Perfect Fit to 0 Does Not Fit)							
Cover Type:	Majority	Mean	Median	Minimum	Maximum	Std. Dev.	Majority Cnt Pixels	Majority%
01.10.1 Lodgepole Pine 20-32% closure	31	46	43	11	100	15	521	4%
01.10.2 Lodgepole Pine 33-67% closure	41	45	42	10	100	15	8118	4%
01.10.3 Lodgepole Pine >67% closure	32	49	44	11	100	20	3185	4%
01.20.2 Douglas Fir 33-67% closure	31	39	36	12	100	13	2424	5%
01.20.3 Douglas Fir >67% closure	33	43	41	12	100	15	3870	5%
01.25.1 Spruce 20-32% closure	24	28	25	11	55	7	186	14%
01.25.2 Spruce 33-67% closure	13	28	26	11	64	10	60	8%
1.30.2 Spruce-Subalpine Fir 33-67% closure	41	44	42	11	100	13	4697	3%
1.30.3 Spruce-Subalpine Fir >67% closure	50	56	53	19	100	17	2802	4%
01.60.1 Limber Pine 20-32% closure	32	41	37	10	100	17	4501	4%
01.60.2 Limber Pine 33-67% closure	31	40	39	11	100	15	1243	4%
01.60.3 Limber Pine >67% closure	37	48	45	12	100	17	572	3%
01.61.1 Limber Pine-Douglas Fir 20-32%	39	47	44	11	100	15	11054	3%

closure								
01.61.2 Limber Pine-Douglas Fir 33-67% closure	31	41	39	11	100	13	12240	4%
01.61.3 Limber Pine-Douglas Fir >67% closure	35	35	34	11	85	9	954	7%
1.70.1 Whitebark Pine 20-32% closure	45	49	47	11	100	16	17007	5%
1.70.2 Whitebark Pine 33-67% closure	43	51	50	13	100	16	5634	3%
01.80.1 Mixed Conifer-Juniper 20-32% closure	33	36	33	11	100	13	988	4%
01.80.2 Mixed Conifer-Juniper 33-67% closure	22	46	43	11	100	20	682	5%
01.90.1 Mixed Conifer-Dominant 20-32% closure	35	49	46	11	100	16	14670	3%
01.90.2 Mixed Conifer-Dominant 33-67% closure	51	56	54	11	100	18	30760	2%
01.90.3 Mixed Conifer-Dominant >67% closure	42	54	52	12	100	17	16956	3%
01.94.1 Conifer-Aspen 20-32% closure	23	27	25	12	60	7	271	10%
01.94.2 Conifer-Aspen 33-67% closure	37	41	39	11	100	13	6460	4%
02.10.1 Aspen 20-32% closure	30	34	33	11	93	11	392	5%
02.10.2 Aspen 33-67% closure	33	44	41	10	100	17	2333	4%
02.10.3 Aspen >67% closure	23	39	35	10	100	18	1727	4%
02.20.1 Aspen-Conifer Mix 20-32% closure	23	36	34	11	78	11	136	6%
02.20.2 Aspen-Conifer Mix 33-67% closure	33	44	41	11	100	14	4121	4%
02.20.3 Aspen-Conifer Mix >67% closure	29	26	27	16	56	7	35	13%
02.30.1 Cottonwood-Riparian 20-32% closure	31	47	43	11	100	17	1758	3%
02.30.2 Cottonwood-Riparian 33-67% closure	43	49	47	11	100	17	3666	4%
02.30.3 Cottonwood-Riparian >67% closure	38	37	37	12	84	8	1091	10%

03.20 Juniper	33	43	41	10	100	16	13141	4%
03.21 Juniper-Sage	32	40	38	10	100	14	16490	3%
03.35 Juniper-Limber Pine	33	44	41	10	100	17	14600	4%
04.20 Greasewood	32	44	41	10	100	16	37592	4%
04.21 Greasewood-Sagebrush	32	44	42	11	100	16	49594	4%
04.22 Greasewood-Saltbush	76	45	41	12	100	17	1206	6%
04.41 Gardner Saltbush	43	50	46	10	100	18	8720	3%
04.45 Saltbush-Sagebrush	42	45	42	11	100	16	10081	4%
04.50 Winterfat	24	33	33	11	80	9	1144	11%
04.60 Birdfoot Sage	42	52	50	11	100	19	27503	3%
04.70 Mixed Desert Shrubs	33	39	36	10	100	14	7105	4%
04.90 Other Desert Shrubs	38	45	43	11	100	15	3525	4%
04.80 Mixed Desert Shrub 2	31	39	37	11	100	13	6600	5%
05.11.1 Basin Big Sagebrush 5-15% closure	23	31	30	11	91	11	1902	6%
05.11.2 Basin Big Sagebrush 16-25% closure	25	36	33	11	100	13	7628	5%
05.11.3 Basin Big Sagebrush >25% closure	23	36	34	11	100	13	4315	4%
05.12.1 Wyoming Big Sagebrush 5-15% closure	51	53	51	10	100	17	169546	3%
05.12.2 Wyoming Big Sagebrush 16-25% closure	51	53	51	11	100	18	141477	3%
05.12.3 Wyoming Big Sagebrush >25% closure	33	44	42	11	100	15	31133	4%
05.13.1 Mountain Big Sagebrush 5-15% closure	33	43	40	11	100	16	31981	4%
05.13.2 Mountain Big Sagebrush 16-25% closure	32	44	41	11	100	16	29779	3%
05.13.3 Mountain Big Sagebrush >25% closure	33	43	40	11	100	16	10099	3%
05.14 Black Sagebrush	42	47	44	11	100	16	68517	3%
05.15 Mountain Silver	25	32	30	11	89	10	2804	8%

Sagebrush								
05.16 Wyoming Three-tip Sagebrush	33	45	42	12	100	17	24151	4%
05.17 Alkali/Early Sagebrush	32	38	35	12	95	12	3649	5%
05.19 Plains Silver Sagebrush	29	43	41	11	100	16	8812	4%
05.20 Rabbitbrush	24	38	34	11	100	16	2545	5%
05.29 Other Big Sagebrush	34	42	41	12	93	14	3995	5%
05.41 Bitterbrush-Sagebrush	32	42	39	11	100	15	18856	4%
05.94 Mixed Xeric Mountain Shrub	24	35	32	11	100	14	1908	9%
05.33 Fringed Sage	33	42	38	11	100	17	4529	4%
05.95 Willow-Upland	100	54	50	15	100	20	7237	6%
06.10 Willow	51	55	52	12	100	19	12000	3%
06.12 Willow-Other Shrubs	32	40	39	11	100	13	2444	4%
06.90 Mixed Riparian Shrubs	34	45	43	12	100	16	6106	4%
07.20.1 Basin Grassland 7.5-20% cover	31	41	38	11	100	15	12012	4%
07.20.2 Basin Grassland 21-40% cover	34	46	42	12	100	17	12665	4%
07.20.3 Basin Grassland >40% cover	23	34	31	11	100	14	3268	7%
07.30.1 Foothills Grassland 7.5-20% cover	33	48	44	12	100	17	8065	4%
07.30.2 Foothills Grassland 21-40% cover	32	40	36	12	100	15	8366	4%
07.30.3 Foothills Grassland >40% cover	34	49	45	12	100	20	4918	3%
07.40.2 Alpine Grassland 21-40% cover	100	63	62	16	100	20	28741	5%
07.60 Riparian/Wet Meadow	34	48	43	12	100	21	23119	5%
07.80.1 Annual Grassland 7.5-20% cover	27	27	27	13	57	8	55	7%
07.80.2 Annual Grassland 21-40% cover	25	26	25	13	75	6	335	12%
07.80.3 Annual Grassland >40% cover	23	31	28	13	75	10	59	7%

09.00 Marsh-Swamp Wetlands	41	44	41	13	100	15	5913	8%
10.14 Playa	31	36	33	13	94	14	121	5%
12.40 Rock or Talus Slope	100	70	75	12	100	26	396290	21%
12.60 Sand Dunes	40	42	41	15	100	13	399	4%
12.80 Snow	100	92	100	15	100	15	35627	68%
12.90 Bare Ground	33	46	42	13	100	17	19388	3%
99.50 Burned Areas	34	44	40	13	100	18	354	5%

3.7 Review and Distribution

Project principals (local field biologists) from the US Fish and Wildlife Service and the Wyoming Game and Fish were provided with initial products in November, 2009. Comments from this review were incorporated into new iterations of the CART modeling process and refinement of the additional class mapping process. A finalized product will then be distributed to one representative from each agency and added to the WyGISC internet mapping and data clearinghouse applications.

Both pixel level and 2 acre MMU products are supplied. Assessment of the usefulness of either product will be determined by project collaborators and end users on a case specific basis.

3.8 Conclusions

The results of CART modeling and mapping of land cover in the Lander mapping region is a moderate resolution land cover map incorporating our best knowledge of the spectral properties of the target cover classes, their relationship to terrain variables derived from digital elevation data, and incorporation of extensive field knowledge. Additional spatial data for un-modeled types incorporates the best spatial data available augmented by image analysis. This map is a substantial improvement over previously available cover maps at this scale and should be a good tool for land managers in the area if used in a manner appropriate to its resolution, as is true for all geospatial data.

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Chapter 4
Land Cover Mapping: Land Use Types and Aggregation of Final Map

4.1 Background

This chapter describes development of the non-natural or land use for the Lander cover type map, combining these classes with the CART based natural types model, and aggregating the product to a 2 acre minimum mapping unit.

While most of the landscape of Wyoming has been modified to a certain extent by human interactions some features are so modified as to no longer fit a natural cover type definition. Anthropogenic features on the landscape often are clearly defined such as urban areas or roads and railroads. However, others such as agricultural uses range from the obvious to ephemeral.

4.2 Methods of Producing Land Use Classes

Classes not mapped using the techniques described in the previous sections included; water, agriculture and pasture lands, oil and gas development, urban areas, mining areas, roads and railroads, and other disturbance. A brief note about class specific production techniques follows:

Agricultural, Pastoral, and Rural Development Classes were mapped by image interpretation, reference to GIS layers of land ownership and roads, and an existing agricultural mapping effort (relevant to 1984). Some field reference data were also available. All these areas were digitized on the screen using manual photointerpretation.

Oil and Gas Development was mapped using the Wyoming Oil and Gas Commission (WOGC) GIS database, field reference data, and remote sensing analysis. WOGC data included a set of reference points for permitted drilling activities in Wyoming, including; tests, active, capped, and permitted with no activity. Project collaborator Holly Copeland of The Nature Conservancy – Wyoming supplied a version of the WOGC point database with extensive interview-based attribution of well or drilling status. This database was sorted by potential impact to an 'impacted subset'. These points were then buffered to a 150 meter or approximately 20 acre radius to capture most potential well pad area. Landsat NDVI was then used in each buffered area to stratify impacted areas by a vegetation abundance threshold.

Urban Areas were digitized on the screen using photointerpretation after field visitation.

Mining Areas, mainly in the form of strip mines and small quarries, were digitized based on field visitation and photointerpretation.

Roads and Railroads were produced by buffering existing GIS data. The railroads were buffered 75m from the 1:100,000 scale TIGER dlg files. Roads were buffered from the TIGER data to 30m and from a GIS layer of Wyoming major roads at 60m on a side.

4.3 Discrimination of Water Bodies

Water is an exception to this chapter in that it is not necessarily an anthropogenic feature, but it was also not modeled with the CART process for the Lander LULC map. Water, both running and standing, was mapped using Landsat imagery by spectral signature clusters and the thresholding of the Normalized Difference Wetness Index. Additionally, a slope 'mask' or stratification was applied to the imagery to remove high slope angle terrain not illuminated by direct sun light (shadowed). This produced a layer of distinguishable water at the Landsat 30m spatial scale. Many streams and river stretches in the study area were too small to be distinguished as water and should have mapped as another type, frequently a riparian vegetation types.

Running water was distinguished from standing water by the use of a GIS overlay technique. The National Hydography Dataset (NHD) was used to extract a running water GIS as line features. The NHD line features were then buffered 320m and those water pixels intersecting the buffer were flagged as lotic or running water.

4.4 Discrimination of Playas

While playas were including in the CART modeling process review of the NHD data showed some omitted playas. This is partly due to the similarity of playas to simple bare ground and the confusion of the model between the two types. Those playas identified on the NHD dataset as playa were added to the LULC map. Additionally where NHD identified playas photointerpretation was used to add other playas evident on the NAPP and NAIP aerial photographs.

4.5 Overlay of Elements to One Land Use and Land Cover Map

The order of overlays and the conversion of GIS polygons to the final raster pixels influenced the appearance of the map. The natural vegetation CART model formed the base layer. In order on top of the base layer were the oil and gas layer, the water and playa data, the urban and agricultural developments, and finally roads and railroads.

4.6 Aggregation to a 2 Acre MMU

For this project, WyGISC developed a 'smart' or expert decision rule program that aggregated pixel level (30 m) classification to the desired 2 acre MMU. The aggregation used decision rules based on the ecological similarity of mapped classes to one another. The routines were coded in ESRI software using the VBA programming language. WyGISC has termed this methodology the 'Ecological Similarity Aggregator' or ESA (see Homer et al. 2007 for a similar procedure).

In the ESA process the pixel-level data in the maps were clumped into mapping units by physiognomic class. Those clumps (regions) less than 2 acres in size were aggregated by finding the most ecologically similar neighbor. Once an MMU-level map was generated, the pixel-level data were revisited for all terrain regions and the majority cover type of pixels in an aggregate was assigned to all pixels in a map unit (region). Decision rules were based on an ecological similarity matrix for physiognomic classes (Table 4.3).

Table 4.1. The Ecological Similarity Matrix used in the ESA aggregation routine (see text for details). Similarity Values (1 least to 13 most) are present in each column and the rows are not used.

	Conifer Forest	Deciduous forest	Woodland	Desert Shrubs	Sagebrush - Grassland	Mountain Shrubs	Riparian Shrubs	Grass-like Types	Marsh-Swanp Wetlands	Aquatic Types	Cropland - Agriculture	Other Non-vegetated	Human or Disturbed Areas
Conifer Forest	13	12	12	1	3	6	7	1	4	3	2	2	5
Deciduous Forest	12	13	11	6	4	9	9	2	7	6	6	1	4
Woodland	11	11	13	5	8	11	6	5	3	2	3	4	3
Desert Shrubs	1	5	5	13	10	7	2	7	2	1	1	8	7
Sagebrush-Grassland	4	7	8	12	13	10	4	12	6	8	8	6	8
Mountain Shrubs	10	10	10	7	11	13	11	9	10	9	5	3	2
Riparian Shrub	9	9	9	9	9	12	13	11	12	11	7	5	1
Grass-like Types	8	8	7	11	12	8	8	13	9	10	11	7	9
Marsh-Swamp Wetlands	7	6	6	8	2	5	12	10	13	12	9	9	6
Aquatic Cover Types	6	4	4	3	1	4	10	6	11	13	4	10	10
Cropland-Agricultural Land	2	3	3	2	6	3	5	8	8	7	13	11	11
Other Non-Vegetated Types	5	1	2	10	7	1	1	4	1	5	10	13	12
Human or Disturbed Areas	3	2	1	4	5	2	3	3	5	4	12	12	13

Ecological similarity values were determined using the expert knowledge of project researchers based on experience in the field and discussions with agency field personnel.

4.7 Results

The interpretation of anthropogenic features poses the question of map temporal relevance, when does a historic anthropogenic use, such as livestock management mean that a feature is no longer 'natural'. This mapping effort, being constrained by practical considerations of cost and time of performance, in the light of available management information was able to create a reasonable regional assessment of land use practices. Some features are more accurate than others. For instance, the mapping of pivot irrigation features is relatively straight forward using remotely sensed data. However, the definition of lands used as pasturage or lands reclaimed from mining operations may be much more difficult to discern from natural features.

In general mapped features were created through a process where either the type was identified by a distribution model or was found through GIS analysis processes if not. The process involved modeling the entire map domain with the CART generation distribution model and then the other types, water, playa, anthropogenic, were added as an overlay replacing a mapped CART produced type. The most common type of error therefore of types mentioned in this chapter is to be omitted from the map.

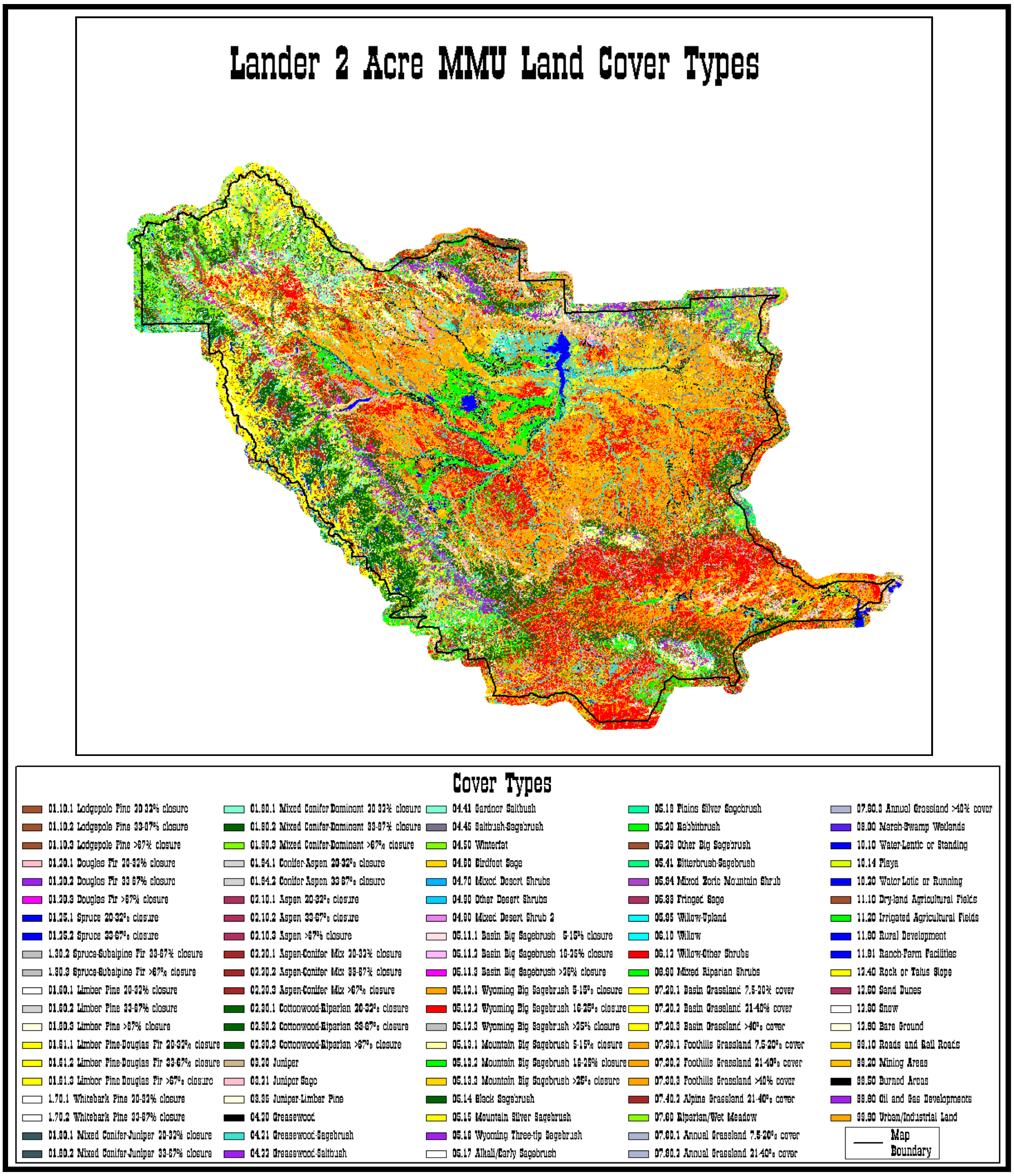

Figure 4.2. Central Wyoming land use and land cover after aggregation to a 2 acre MMU.

Table 4.2. Areas, in acres, of classes mapped in the Lander study area. From left to right the columns correspond to; the mapped class, the pixel level acreage per class mapped for the study area expanded by a 3km buffer, the acreage per class mapped for the study area only (no buffer), the 2 acre MMU level acreage per class mapped for the buffered study area, and the 2 acre MMU level acreage per class mapped for the unbuffered study area.

Lander Classes	3km Buffer Pixel Level, Acreage	No Buffer Pixel Level, Acreage	3km Buffer 2acre MMU, Acreage	No Buffer 2acre MMU, Acreage
01.10.1 Lodgepole Pine 20-32% closure	2614.2	2156.1	2305.6	1926.4
01.10.2 Lodgepole Pine 33-67% closure	42431.9	38729.9	35180.7	31954.0
01.10.3 Lodgepole Pine >67% closure	18572.3	16473.2	19165.5	16893.5
01.20.2 Douglas Fir 33-67% closure	11139.0	10669.3	8037.3	7923.7
01.20.3 Douglas Fir >67% closure	15831.8	15397.9	20292.1	19815.7
01.25.1 Spruce 20-32% closure	254.4	211.1	141.7	121.9
01.25.2 Spruce 33-67% closure	130.5	116.3	105.9	91.0
1.30.2 Spruce-Subalpine Fir 33-67% closure	29681.6	23906.5	18000.3	13715.9
1.30.3 Spruce-Subalpine Fir >67% closure	14752.1	12212.3	11203.3	9064.8
01.60.1 Limber Pine 20-32% closure	26243.4	23191.5	22808.7	20305.2
01.60.2 Limber Pine 33-67% closure	7266.7	6583.3	6395.2	5780.0
01.60.3 Limber Pine >67% closure	4546.6	3806.9	4653.1	3861.2
01.61.1 Limber Pine-Douglas Fir 20-32% closure	70073.7	65390.9	76154.4	71473.9
01.61.2 Limber Pine-Douglas Fir 33-67% closure	70836.2	65775.2	53368.3	50268.4
01.61.3 Limber Pine-Douglas Fir >67% closure	2935.2	2586.4	792.8	751.2
1.70.1 Whitebark Pine 20-32% closure	77242.8	57714.6	73086.0	53085.0
1.70.2 Whitebark Pine 33-67% closure	38653.4	31277.3	27473.9	21935.6
01.80.1 Mixed Conifer-Juniper 20-32% closure	4955.2	4309.3	3363.5	2887.6
01.80.2 Mixed Conifer-Juniper 33-67% closure	3205.6	2632.9	2756.6	2255.5
01.90.1 Mixed Conifer-Dominant 20-32% closure	104104.4	91090.8	96158.9	85867.0
01.90.2 Mixed Conifer-Dominant 33-67% closure	280767.4	253033.8	341401.2	306696.4
01.90.3 Mixed Conifer-Dominant >67% closure	115518.3	99226.4	138392.0	117724.5
01.94.1 Conifer-Aspen 20-32% closure	588.7	530.2	114.1	102.7
01.94.2 Conifer-Aspen 33-67% closure	37263.7	34541.3	28928.3	27616.0
02.10.1 Aspen 20-32% closure	1547.0	1299.2	878.2	755.7
02.10.2 Aspen 33-67% closure	11508.7	10376.7	8134.7	7448.6
02.10.3 Aspen >67% closure	10208.1	8508.6	8552.2	7318.3
02.20.1 Aspen-Conifer Mix 20-32% closure	435.0	338.5	126.8	97.4
02.20.2 Aspen-Conifer Mix 33-67% closure	22772.7	21200.4	17981.7	16730.3
02.20.3 Aspen-Conifer Mix >67% closure	55.6	44.3	10.9	10.9
02.30.1 Cottonwood-Riparian 20-32% closure	8333.5	7946.4	6942.5	6699.0

Lander Classes	3km Buffer Pixel Level, Acreage	No Buffer Pixel Level, Acreage	3km Buffer 2acre MMU, Acreage	No Buffer 2acre MMU, Acreage
02.30.2 Cottonwood-Riparian 33-67% closure	13871.6	13082.8	10637.3	10021.5
02.30.3 Cottonwood-Riparian >67% closure	1553.4	1521.4	992.8	977.0
03.20 Juniper	70138.6	61075.8	61248.0	51996.6
03.21 Juniper-Sage	98601.2	89452.2	95571.1	87211.3
03.35 Juniper-Limber Pine	84128.5	75918.4	81513.4	73549.0
04.20 Greasewood	158445.7	149867.0	155144.9	147115.6
04.21 Greasewood-Sagebrush	252859.0	239503.4	237465.1	225938.7
04.22 Greasewood-Saltbush	3892.8	3875.7	2154.6	2154.6
04.41 Gardner Saltbush	56640.2	54919.1	56447.6	54843.5
04.45 Saltbush-Sagebrush	52152.5	50714.0	41790.5	40993.4
04.50 Winterfat	2023.1	1971.5	1373.9	1362.6
04.60 Birdfoot Sage	199456.7	185949.3	194100.5	180437.5
04.70 Mixed Desert Shrubs	37630.4	31970.7	27312.2	22753.3
04.90 Other Desert Shrubs	20515.6	20443.1	16395.8	16366.6
04.80 Mixed Desert Shrub 2	31217.2	30202.2	21205.3	20714.9
05.11.1 Basin Big Sagebrush 5-15% closure	5935.9	5190.7	2124.8	1725.1
05.11.2 Basin Big Sagebrush 16-25% closure	28666.1	25754.1	25629.8	22511.2
05.11.3 Basin Big Sagebrush >25% closure	18598.8	16962.7	11851.8	10953.8
05.12.1 Wyoming Big Sagebrush 5-15% closure	1201350.7	1142686.7	1366458.2	1302068.7
05.12.2 Wyoming Big Sagebrush 16-25% closure	975963.5	899711.6	1066610.4	981487.8
05.12.3 Wyoming Big Sagebrush >25% closure	181506.8	165353.2	162749.2	147335.8
05.13.1 Mountain Big Sagebrush 5-15% closure	182966.4	157469.1	165991.7	140128.4
05.13.2 Mountain Big Sagebrush 16-25% closure	191261.7	161912.3	179828.2	148422.6
05.13.3 Mountain Big Sagebrush >25% closure	65673.4	56144.0	68852.9	58889.2
05.14 Black Sagebrush	411032.7	379124.9	416967.3	386042.3
05.15 Mountain Silver Sagebrush	6990.5	4357.6	7189.3	4198.8
05.16 Wyoming Three-tip Sagebrush	119401.5	104656.6	130323.1	113981.1
05.17 Alkali/Early Sagebrush	15105.0	13396.3	10332.2	9382.1
05.19 Plains Silver Sagebrush	37752.9	36823.3	25171.0	24823.4
05.20 Rabbitbrush	10764.8	10226.6	5211.4	4964.1
05.29 Other Big Sagebrush	15562.5	15517.5	9531.6	9516.0
05.41 Bitterbrush-Sagebrush	102150.0	89898.1	104907.2	91845.8
05.94 Mixed Xeric Mountain Shrub	4399.8	3065.0	3217.6	2117.9
05.33 Fringed Sage	19797.7	17729.0	17666.8	16107.8
05.95 Willow-Upland	26596.8	17560.0	23552.6	15105.9
06.10 Willow	59950.1	50857.3	64821.2	55451.9
06.12 Willow-Other Shrubs	9588.1	8990.3	10944.9	10381.1
06.90 Mixed Riparian Shrubs	23108.1	22368.6	24548.3	23658.0
07.20.1 Basin Grassland 7.5-20% cover	59413.4	57802.2	43446.0	42514.8
07.20.2 Basin Grassland 21-40% cover	60569.7	57504.2	47212.7	45007.6

Lander Classes	3km Buffer Pixel Level, Acreage	No Buffer Pixel Level, Acreage	3km Buffer 2acre MMU, Acreage	No Buffer 2acre MMU, Acreage
07.20.3 Basin Grassland >40% cover	8557.1	7448.2	4560.6	3928.6
07.30.1 Foothills Grassland 7.5-20% cover	37833.2	34893.8	35427.1	33091.5
07.30.2 Foothills Grassland 21-40% cover	39002.6	36365.9	26279.0	24549.0
07.30.3 Foothills Grassland >40% cover	37783.2	28962.6	36608.7	27512.1
07.40.2 Alpine Grassland 21-40% cover	116097.6	93150.1	116987.7	93946.5
07.60 Riparian/Wet Meadow	74515.5	62323.0	60478.0	50745.4
07.80.1 Annual Grassland 7.5-20% cover	147.9	125.9	4.7	4.7
07.80.2 Annual Grassland 21-40% cover	556.0	502.4	46.5	36.9
07.80.3 Annual Grassland >40% cover	176.1	171.5	90.3	90.3
09.00 Marsh-Swamp Wetlands	5734.2	5512.3	5055.7	4891.1
10.10 Water-Lentic or Standing	61535.7	50174.1	62285.2	50537.5
10.14 Playa	641.6	612.0	375.6	365.2
10.20 Water-Lotic or Running	5175.1	5042.1	5343.9	5204.2
11.20 Irrigated Agricultural Fields	112781.1	99828.2	114316.9	101305.1
11.90 Rural Development	2296.0	2296.0	2285.1	2285.1
11.91 Ranch-Farm Facilities	3325.0	3325.0	3253.0	3253.0
12.40 Rock or Talus Slope	418661.2	322672.0	390696.3	295768.8
12.60 Sand Dunes	1852.8	1823.0	991.2	983.6
12.80 Snow	11603.0	8955.4	10278.2	8051.8
12.90 Bare Ground	119953.5	115597.5	91605.0	88734.3
99.10 Roads and Rail Roads	408799.2	375588.9	422881.6	388665.9
99.20 Mining Areas	1652.8	1652.8	1656.6	1656.6
99.50 Burned Areas	1484.7	774.4	828.6	390.5
99.80 Oil and Gas Developments	5538.5	4851.5	3902.1	3455.6
99.90 Urban/Industrial Land	8235.9	8235.9	8002.6	8002.6

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Chapter 5
Snow Cover Mapping

5.1 Background

Wyoming's long, cold winters can stress animals, especially when access to winter habitat is impeded by natural barriers, weather events or human development. Additionally, spatial and temporal variation in snow cover affects access to forage and shelter for many species and these effects are difficult to predict. This project addresses this by mapping two "snapshots" of snow cover in central Wyoming, "average snow" and "high snow," with an emphasis on characterizing the relative amount of vegetation emerging above the snow. We did not attempt to map absolute snow depth for these two scenarios but rather snow cover relative to vegetation height with the implicit assumption that vegetation emerging from the snow is available for animals to use.

Mapping of this kind is partly subjective for several reasons. First, it is difficult to define exactly what is meant by "average" and "high" snowfall in a spatially explicit way. Individual snow events are spatially variable and they interact with pre- and post-storm conditions to affect the pattern of snow depth on a landscape. Secondly, the snow cover maps created for this project represent the distribution of a spectral index related to snow "purity" in satellite image pixels and does not attempt to distinguish other measures of habitat quality. Third, the practical difficulties of defining "average" and "high" snow events that are spatially uniform over the study area and that are represented by cloud-free imagery are substantial. We did this in consultation with WGFD personnel and with painstaking image searches, but still were forced to use mosaics of images that are from different dates and storms. This was unavoidable. Despite these problems, the product presented here provides a starting point for evaluating the effect of winter conditions on habitat in central Wyoming.

5.2 Identification of Target Storm Events

The definition of 'average and high snow' cover requires the identification of a specific time relative to long term trends to determine 'average' or 'high' snow years. Also, the definition of high and average snow more specifically was related to its effect on the availability of habitat for animal species. This winter habitat availability is known to be dynamic spatially and temporally within one winter season. Use of remotely sensed imagery to map winter habitat provides a 'snapshot' of a situation at one time where the spatial phenomena of an event, such as snow distribution, can be well described.

This project mapped snow cover at all locations in the study area for two snow cover situations. Obviously, mapping at the time of a storm or immediately after, when snow is likely to cover all vegetation is not informative. Similarly, mapping a 'no snow' situation does not contribute to our understanding of winter habitat. Between these extremes, mapping snow with satellite based remote sensing systems is constrained by image availability, which in turn depends on; 1) the historical record and longevity of the satellite platform, and 2) the ‘revisit time’ of the satellite to a specific location. In contrast, in-situ measurement via instrumentation such as the ‘Sno-Tel’ climatological station network provides detailed data at a fine temporal ‘grain’, but is not appropriate for determining site-specific snow cover across a broad spatial domain.

In this project, we chose to use Landsat Thematic Mapper (TM) satellite imagery. Landsat TM provides the advantages of a long history of collection (1982 to present), moderate spatial resolution (30 x 30 m pixels), appropriate spectral properties for robust snow cover mapping, and low cost. Other satellite imagers, such as the NOAA Pathfinder systems, revisit a location on the earth multiple times a day, but are limited by coarse spatial resolution (1 x 1 km pixels) and less robust spectral properties for snow mapping.

Appropriate dates for mapping ‘average’ and ‘high’ snow cover scenarios would ideally be chosen using expert knowledge and published records. However, rarely is an expert available to make this assessment. Further, high and average are necessarily defined in terms of long term trends. In this project the Wyoming State Climatologist and land management personnel from the mapping area were interviewed for their opinions of representative winters. Their answers were anecdotal and could not incorporate spatial variability. To improve on this, quantitative and historical climate information was collected from *in-situ* weather stations, including the SNOTEL network (http://www.wcc.nrcs.usda.gov/snow/index.html). While these stations supply detailed data, such as Snow Water Equivalent and Snow Depth at a precise time intervals, they are spatially limited.

For this project, we identified all stations available for each of the three satellite image paths (WRS paths 37, 36, and 35) required to cover the study area. Snow Water Equivalent (SWE) data were selected that corresponded to the timing of satellite overpasses and SWE at the time of overpass and averaged within regions (Fig. 5.1). From this representation we chose those images that were near the 30 year normal SWE (average snow cover situation) or were significantly higher than the 30 year normal SWE (high snow cover situation). Each potential high and average choice was then investigated for atmospheric clarity (low cloud cover). Finally, the choice of images was limited to the late January through early March time period to control for the strength of solar radiation through the winter and to choose a ‘late winter’ timing where snow depth has accumulated.

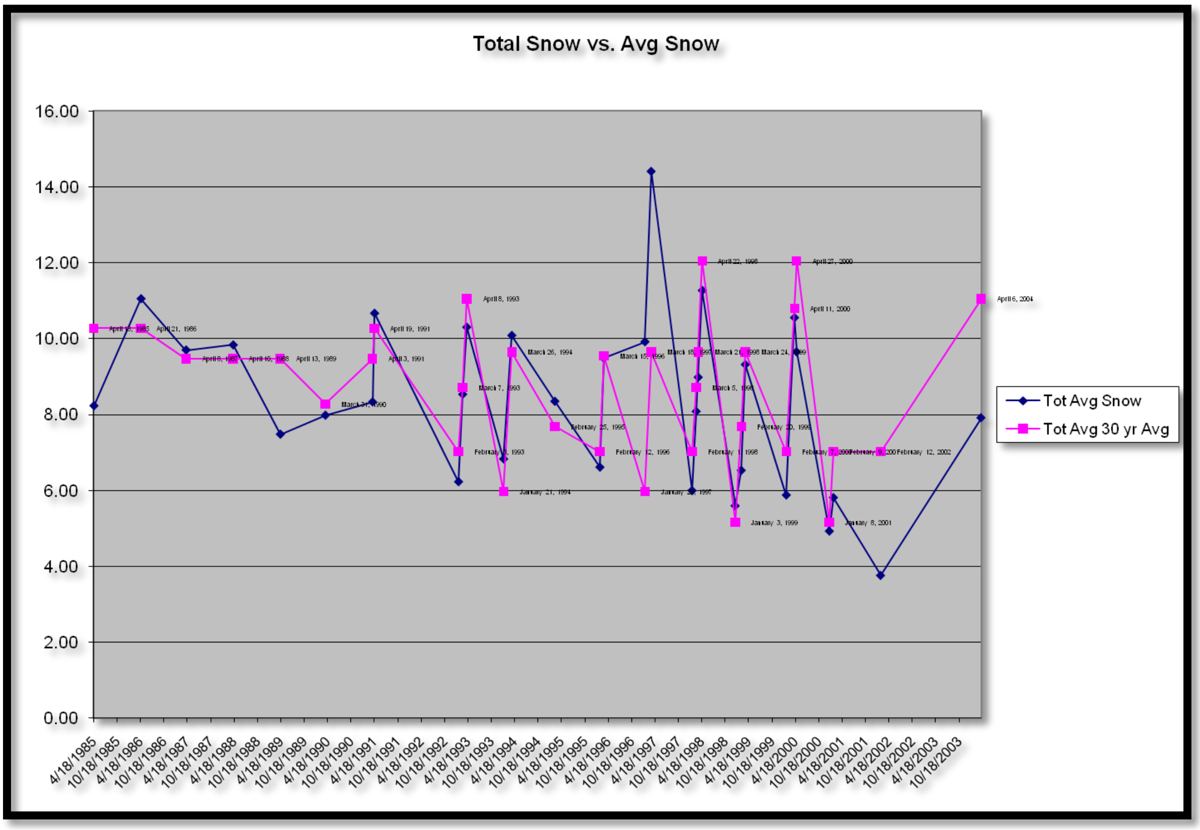


Figure 5.1. Comparison of snow water equivalent (SWE) and 30 year average SWE at SNOWTEL stations in the area of the Landsat5 scene path 35 and row 30. These comparisons were used to make an objective determination of average and high snow cover scenarios which were then used for snow cover mapping. See text for details.

Using the plots of SWE from the snotel station data for each scene we arrived at the following relatively cloud free dates.

Table 5.1. Landsat5 imagery dates chosen for each path representing an average or high snow cover condition.

Area/Snow Condition	Date
Average Snow Path 35, Rows 30 and 31	2 February 1986
Average Snow Path 36, Rows 30 and 31	14 March 1998
Average Snow Path 37, Row 30	1 February 1998
High Snow Path 35, Rows 30 and 31	16 February 1997
High Snow Path 36, Rows 30 and 31	7 February 1997
High Snow Path 37, Row 30	29 January 19997

5.3 Data Processing and Mapping Methods

5.3.1 NDSI Calculation

Data processing of the snow event images (Sections 5.2, 5.3 above) focused on calculation of a spectral index called the Normalized Difference Snow Index (NDSI) (Hall *et al*.1995, 1998) which is an indicator of fractional snow cover in an image pixel. The NDSI is based on the spectral reflectance of snow and ice, which is very high (bright) in the visible wavelengths but low (dark) in mid-infrared (MIR). Because vegetation, in contrast, has low reflectance in the visible and moderately high reflectance in the MIR, the NDSI is sensitive to the amount of vegetation mixed with snow in a pixel and thus functions as an index of snow purity or fractional snow cover. This in turn indicates the amount of vegetation emerging from the snow or the relative area in a pixel that isn't snow covered..

For Landsat TM data, the equation used in the NDSI calculation is given by:

Eq. 5.1. NDSI = (TM2 – TM5)/(TM2 + TM5)

where: TM2 = TM Band 2 (Green reflectance)
TM5 = TM Band 5 (MIR reflectance)

Calculation of this index results in pixel values that range from -1.0 to 1.0 with high positive values representing relatively pure snow (high snow cover fraction) and low negative values representing mostly vegetation or bare ground and little snow (low snow cover fraction). We calculated this index for each of the winter snow scenario images discussed in the preceding sections.

5.3.2 NDSI Classification

The final step in snow mapping was to assign individual image pixels to snow classes specified in the WGFD contract. These snow classes include subjective categories described as: 1) mostly vegetation, 2) partial snow/vegetation and 3) mostly snow. Temporal and spatial variability in the storm events and dates that were used for snow cover mapping added complexity to this process that would not have existed had we been able to use a single uniform snow event on a single date for the entire study area. In other words, because we were dealing with different storm events in different images, applying uniform classification bins based on raw NDSI values across all images would result in a spatial pattern affected by image boundaries as well as by snow conditions on the ground.

To create meaningful snow cover classes over the entire study area, we applied a thresholding procedure to each image path. Threholding entails visually examining a portion of the NDSI values from the maximum or minimum value through a range that fits a descriptive category. Using this approach we expanded the partial snow/vegetation category to three categories or proportions of snow and exposed vegetation. For instance for the path 35 NDSI range describing an average snow event we thresholded no snow as values -1.0 to 0.11562, mostly vegetation with some snow to 0.11562 to 0.287974, evenly mixed snow and vegetation to 0.287974 to 0.64742, mostly snow with low vegetation exposure to 0.64742 to 0.79246, and full snow cover to 0.79246 to 1. Table 5.1 below shows the threshold value breaks for each path and scenario.

Table 5.2**.** NDSI threshold values for each class in each of the 4 images used for snow cover mapping in the study area. Colors represent a gradient of five snow cover classes with gold depicting no significant snow cover, yellow depicting low fractional snow cover (mostly vegetation), cyan depicting partial snow mixed with vegetation, purple depicting high fractional snow cover (low vegetation cover) and blue depicting full snow cover. These colors match the colors used to code the classes in the ArcMap document provided as a deliverable.

Area/Snow Condition	1	2	3	4	5
Average Snow Path 35	<-0.11562	<0.287974	<0.64742	<0.79246	>0.79246
Average Snow Path 36	<-0.03507	<0.429983	<0.677608	<0.762163	>0.762163
Average Snow Path 37	<-0.05255	<0.237568	<0.442355	<0.556125	>0.556125
High Snow Path 35	<-0.20948	<0.195298	<0.420815	<0.576941	>0.576941
High Snow Path 36	<-0.00491	<0.251321	<0.456303	<0.592958	>0.592958
High Snow Path 37	<-0.19568	<-0.05494	<0.273442	<0.450665	>0.450665

The 5 NDSI classes in each image are numbered from least snow cover (Class 1) to most snow cover (Class 5). We provide the classified fractional snow cover images, the original unclassified NDSI images and the original untransformed Landsat data so that data users have access to all of the information available and retain flexibility for comparing the data to actual field conditions. All of these products are included with the ArcMap document provided as a deliverable.

5.4 Results

The procedure described in the preceding sections resulted in raster maps depicting the spatial distribution of snow cover for an “average” and a “high” snow event. These maps are provided as classified images in Erdas Imagine (.img) format, which in turn are organized in an ArcMap map document (.mxd) along with the original Landsat multispectral images and the raw NDSI snow index images.

The east-west extent of the study area requires 3 Landsat paths for full coverage. This resulted in one image from path 37, two images 36/30 and 36/31 for path 36, and two images 35/30 and 35/31 for path 35 although a smaller area.

5.4.1 Average Snow Year Results

For the average snow year scenario the procedure described above resulted in a map depicting the distribution of each of the five target classes across central Wyoming (Fig. 5.2). In this visualization, no snow cover (mostly vegetation or soil -- gold in Fig. 5.2) occupies extensive areas in the low elevation parts of the study area. Moderate snow cover (with emergent vegetation – yellow, cyan, and purple) is found in many locations in the study area with the cyan class largely associated with forest cover. Heavier snow (no emergent vegetation -- blue) is found at both low and high elevations. The distribution of snow appears to be both related to residual snow associated with elevation and storm specific events.

The spatial and temporal variability in snow cover expressed in this map is probably storm-specific in ways that are difficult to predict. Consequently, we recommend that this map be used as a general guide for analyzing patterns of available habitat and not as a predictor of "typical" snow cover in specific places. While the general patterns are instructive, the details are probably not consistent from one storm to another or from one year to the next, and specific sites should be investigated carefully on the ground.

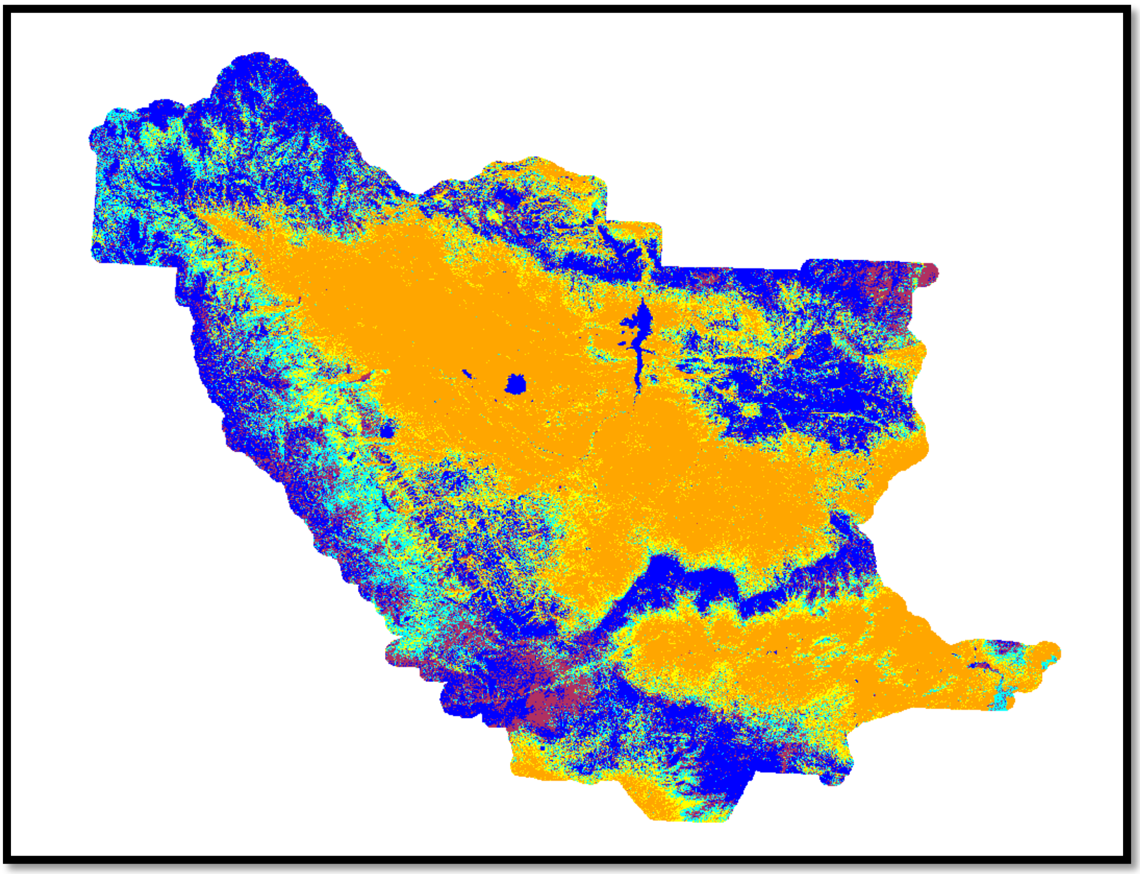


Figure 5.2. Results of classification of NDSI for the average snow year (see text for explanation). Five classes show a gradient of relative snow to exposed vegetation

cover. Path 37 is to the left (west), path 36 is in the center and path 35 is to the far right (east).

5.4.2 High Snow Year Results

For the high snow year scenario the thresholding procedure resulted in a map (Fig. 5.3) depicting the distribution of each of the five target classes across the study area just as for the average snow year. In this visualization, the no snow cover class (gold) is limited to specific low elevation areas. The moderate fractional snow cover classes are much more extensive than in the average snow classification scenario, with the cyan class still encompassing many forested areas. The full snow cover class, blue, is found at both high and low elevations. The same *caveats* about spatial and temporal variability that were raised in the discussion of the average snow result above should be applied here. General patterns might be seen from one year to another but specific sites probably vary significantly in snow coverage depending on intensity and path of particular storms, wind speed and direction, previous snow condition and other factors.

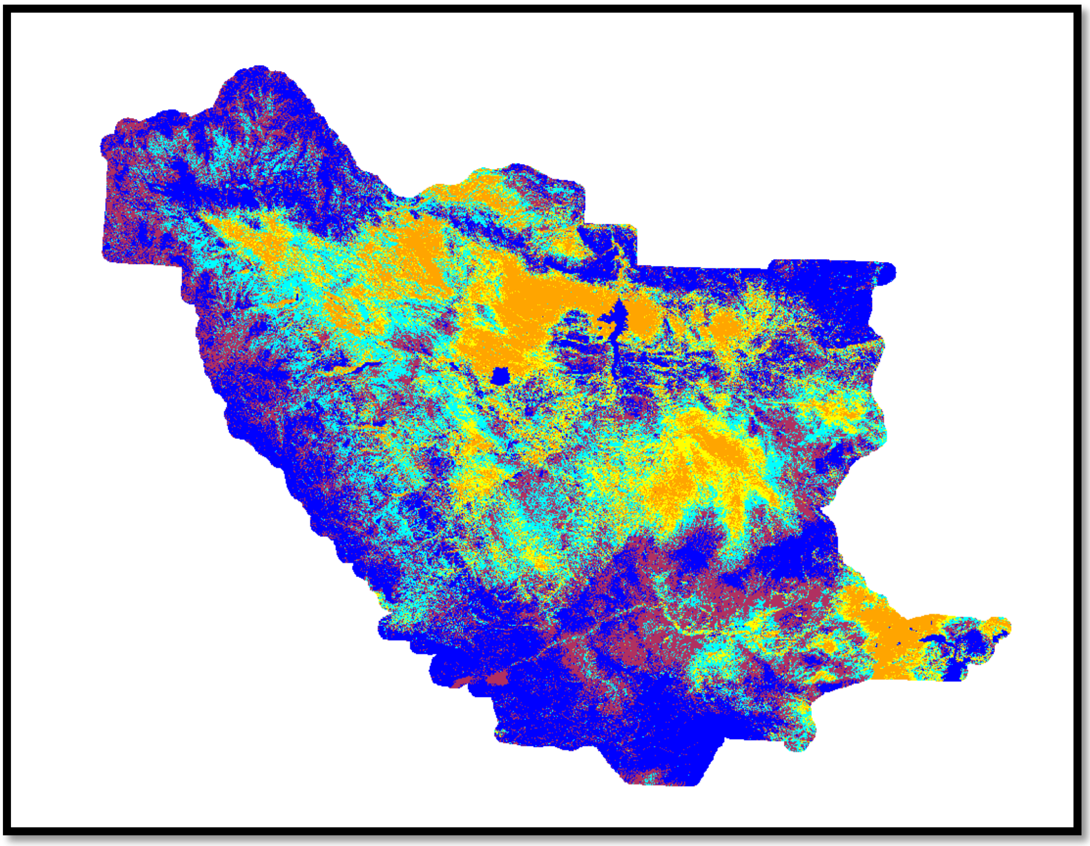


Figure 5.3. Results of classification of NDSI for the high snow year (see text for explanation).

5.5 Conclusions and Recommendations

The snow cover mapping portion of this project resulted in maps depicting the three target snow cover classes as they are distributed across the study area under average and high snow year scenarios. The maps were delivered as dynamic ArcGIS map documents (.mxd) that give map users flexibility to re-interpret the classes for various applications or based on field experience. In this way we have tried to provide products that have maximum usefulness.

Although these products provide particular views of snow cover in the region, the temporal and spatial variability present from storm to storm and year to year is problematic. One solution to this for future projects of this type might be to calculate NDSI for all available cloud free images through several winter seasons and then to integrate these results into a map showing the relative probabilities of snow cover fraction for each pixel. In this way, variability could be averaged across time and space to provide a more generally applicable interpretation. This approach was beyond the scope of the current contract, and would require more images and more image processing.

5.6 Literature Cited

Hall, D.K., Foster, J.L., Verbyla, D.L., and Klein, A.G. 1998. Assessment of snow-cover mapping accuracy in a variety of vegetation-cover densities in central Alaska. *Remote Sensing of Environment* 66: 129-137.

Hall, D.K., Riggs, G.A., and Salomonson, V.V. 1995. Development of methods for mapping global snow cover using moderate resolution imaging spectroradiometer data. *Remote Sensing of Environment* 54:127-140.

Chapter 6
Change Detection

6.1 Background

Land cover in Wyoming is a product of environmental conditions, chance and history. Changes wrought by disturbance and ongoing anthropogenic activities all leave marks on current land cover that can be better understood if one can characterize land cover condition at regular intervals through time. Remote sensing provides one tool for doing this. The Landsat satellites have been archiving global imagery (including Wyoming) every 16 days for approximately 35 years (since 1972) and aerial photography has been collected even longer, though less regularly. We can use these images to objectively look back in time to create spatially explicit depictions of land cover change.

As part of the work described in this report, WyGISC was asked to characterize land cover change across the central Wyoming study area on approximately 5 year intervals since the launch of the first Landsat Thematic Mapper (TM) instrument in 1982. Previous change detection work in SE Wyoming (Driese and Nibbelink 2004) that used 10 year intervals suggested that many changes occurring in such long intervals are difficult to detect because of rapid regrowth of annual grasses and forbs, and that shorter intervals may be more fruitful.

For the work described here, we used two image enhancements, the Normalized Difference Vegetation Index (NDVI) and overall image brightness as captured by the first principal component (PC1) of all reflected (non-thermal) TM bands, to highlight land cover features that may be indicators of change. NDVI is a well-tested measure of the amount of green vegetation in an image pixel and provides a relative assessment of vegetation condition at a site. Conversely, overall brightness as captured by PC1 is indicative of the amount of bare soil at a site. These two indices were calculated for each date and used with two often-used change detection algorithms to produce the change products described in the remainder of this chapter.

The products that we provide are visualizations highlighting places where change in terms of the two enhancements (NDVI; PC1) are detected. We do not attempt to interpret the cause or nature of these changes or their importance, and leave those decisions to field office personnel familiar with their areas of interest. In this way the products are a guide for more detailed investigations in response to specific management applications.

6.2 Satellite Data Acquisition

Identification of satellite imagery on approximately 5 year intervals since the early 1980s was the first requirement for this portion of the project. Several factors are important for choosing imagery for change analysis. First, imagery should have similar spectral and spatial characteristics across the time interval being studied. Second, imagery should be collected at approximately the same time of year at each time interval to minimize phenological differences in vegetation. Third, imagery should be chosen to minimize interference by clouds. Fourth, imagery for each interval should ideally be chosen from a single year to minimize differences in weather, etc. In most situations these criteria cannot all be satisfied simultaneously and compromises must be made.

For this study, the first criterion is satisfied by using Landsat TM and ETM+ imagery as the basis for all analyses. This imagery has identical spectral and spatial resolution. The other three criteria, however, must be balanced with constraints imposed by the interaction of clouds with the 16-day return interval of Landsat. Because the satellite collects images of a particular place once every 16 days, a single cloudy acquisition can mean gaps in useable image acquisitions of a month (32 days), which in Wyoming is a significant portion of the growing season. Additionally, because the study area spans three Landsat paths, images in the western part of the area (path 37) could not be obtained on the identical day as images in the central (path 36) and eastern (path35) parts, another circumstance that required compromise.

The study area encompassed a wide range of terrain feature elevations ranging from the crest of the Wind River Mountains to desert basins. For the western portion of the study area we collected a set of images optimal to the high elevation areas (August/September) and another set for the low elevation areas (June/July). We performed an extensive survey of all Landsat imagery for the study area for the target time intervals to best balance the criteria described above and to identify images for each of the approximate 5-year target intervals. Specifically, we gave more weight to phenological similarity and cloud status for each interval than to maintaining single year acquisition when compromise was required. This resulted in the identification of images for 6 temporal “snapshots” of the central Wyoming study area with the goal of targeting 1985, 1990, 1995, 2000, 2005 and 2009 but with specific image dates bracketing these targets as necessary (Table 6.1).

Table 6.1. Images chosen for change detection across the study area.

Target Date	Actual Dates Path 35	Actual Dates Path 36	Actual Dates Path 37 Basin	Actual Dates Path 37 Montane
2009	6/24/2008	6/29/2008	6/23/2009	9/11/2009
2005	7/13/2004	7/2/2003	6/9/2003	8/31/2005
2000	7/2/2000	6/7/2000	7/6/1999	9/8/1999
1995	7/71996	5/22/1994	6/30/1994	8/17/1994
1990	7/4/1989	6/15/1991	7/2/1989	9/26/1991
1985	7/6/1984	6/4/1987	6/21/1985	None

For all of these images, clouds were minimized, although some clouds were unavoidable for some dates.

6.3 Methods

Image processing for the change detection analyses was performed on each image path (35, 36, 37). Processing included calculating vegetation and soil enhancements, and application of change detection algorithms to create spatially explicit visualizations of changes in the study area. All of these processes were accomplished using the Erdas Imagine v. 9.3 (ERDAS, Atlanta, GA) image processing software and final products are provided using ArcGIS v. 9.2 (ESRI, Redlands, CA) map documents (.mxd) to facilitate viewing and manipulation by users.

One of the challenges in change detection remote sensing is in the interpretation of change images to separate changes relevant for particular management goals from other changes that might be caused by things like natural variability in vegetation, changes in year-to-year climate (*e.g*. dry vs. wet years), or changes caused by differences in phenology from one time of year to another. For this reason, after discussions with the WGFD, we have agreed to provide a collection of images that highlight changes without attempting to interpret them. These image data should provide users with information necessary to identify places that have changed in particular time intervals for any reason. The job of the user is to apply this information to the problem at hand using knowledge from the field and/or field visits to areas of interest.

6.3.1 Image Enhancements

Image enhancements use spectral information to emphasize (or suppress) features so that they stand out either visually or quantitatively from other features. For change detection analysis of SW Wyoming we were particularly interested in changes in land cover and the two enhancements we used, NDVI and PC1 brightness (see Section 6.1) highlight land cover with respect to the amount of green vegetation and the amount of bare soil in a pixel, respectively. These enhancements were chosen to provide products that are relatively easy to interpret.

6.3.2 The Normalized Difference Vegetation Index (NDVI)

The NDVI is a vegetation index that accentuates the unique spectral qualities of plants in the red (RED) and near-infrared (NIR) wavelengths, which are captured by bands 3 and 4, respectively, of the Landsat TM and ETM+ instruments. Unlike soil and water, green leaves have very low RED reflectance and very high NIR reflectance with a characteristic large difference between reflectance in these two spectrally adjacent wavelength regions. This difference is caused by the high absorbance of RED light by chlorophyll for use in photosynthesis. NIR light is not used for photosynthesis and consequently is less absorbed. NDVI accentuates the difference between NIR and RED reflectance and by doing so is sensitive to the amount of green biomass in a pixel (Eq. 6.1):

Eq. 6.1: $NDVI = (NIR - RED)/(NIR + RED)$

We calculated NDVI for each image pixel in each of the five image mosaics (Section 6.3.1) using standard Erdas Imagine tools. The result was a series of images depicting the NDVI values of each pixel, which have a possible range from -1.0 to +1.0. High positive NDVI corresponds to a high proportion of green biomass in a pixel. Neutral (low positive) NDVI values are related to bare soil, and highly negative values generally correspond to water. When displayed as images, the NDVI results show dense vegetation as bright areas, sparse vegetation as gray and wet places without vegetation as very dark.

6.3.3 Overall Image Brightness (PC1)

Although there is variability, in general, soils (and bare rock) are highly reflective across the spectrum compared to vegetation. For this reason, overall image brightness in many satellite bands can be an indicator of exposed soil. Consequently, changes in overall image brightness across time may indicate removal of vegetation from a surface, either due to natural processes (*e.g.*, drought) or more acute disturbance (*e.g.*, fire, human activity). To capture these types of changes, which are relevant to land managers, we used a multivariate statistical technique called principal components analysis (PCA) to isolate the variance across image bands that might be related to overall image brightness. This component of variance is captured by the first principal component (PC1). In some cases PC1 captures land cover change better than NDVI, thus providing a complementary view to a direct measure of the amount of green vegetation.

Principal components were computed from the six reflected TM/ETM+ bands in the original image mosaics (Section 6.3.1) using standard Erdas Imagine tools. Only PC1 was used for change detection. When displayed as an image, PC1 is bright where the original image is bright across all bands and dark where the original bands were dark. In general, bright places correspond to bare soil and gray and dark places correspond to vegetated surfaces and water.

6.3.4 Change Detection Analysis

Change detection uses historical and recent imagery to highlight changes that have occurred during the intervals between image dates. There are many techniques for comparing multi-temporal imagery to highlight changes, though some are more commonly used than others. For this project, we selected image subtraction and change stack visualizations to show changes on five-year intervals as required. We chose these two techniques to provide complementary views, so that users of the products would have alternative ways to visualize the data. By applying both of these change detection techniques to both of the image enhancements (see previous sections) we provide a suite of visualizations that give users tools for locating and interpreting changes.

To simplify the remainder of the discussion we used the following designations for each of the 5-year intervals used for change detection:

Date 01: 2009
Date 02: 2005

Date 03: 2000
Date 04: 1995
Date 05: 1990
Date 06: 1985

6.3.4.1 Image Subtraction

Image subtraction means subtracting imagery of one date from imagery of a second date.

Image Subtraction: DateA – DateB = Change Image

This technique creates an output image that quantitatively depicts changes in the input variable (in this case NDVI or PC1) between the two dates used in the subtraction.

For this project we subtracted older images from newer images in every possible combination of the 6 image dates to produce a series of change images (Table 6.2) which are the products.

Table 6.2. Subtractions that were performed for each of the NDVI and PC1 image dates and the length of time each subtraction captures in years. See explanation in section 6.3.5 above for calendar dates.

Dates Subtracted	Approximate Interval Length (years)	Dates Subtracted	Approximate Interval Length (years)
Date01 – Date02	5	Date02 – Date05	15
Date01 – Date03	10	Date02 – Date06	20
Date01 – Date04	15	Date03 – Date04	5
Date01 – Date05	20	Date03 – Date05	10
Date01 – Date06	25	Date03 – Date06	15
Date02 – Date03	5	Date04 – Date05	5
Date02 – Date04	10	Date04 – Date06	10
		Date05 – Date06	5

Each of these subtractions results in a new single layer (grayscale) image in which the magnitude of change is associated with the pixel values. Guidance for interpretation of these results is provided in Section 6.4 below, but in general unchanged areas in the resulting images appear as a neutral gray color and changed areas appear either brighter or darker than neutral gray depending on the direction and magnitude of change. Darker places experienced a reduction of the input variable (PC1 brightness or NDVI) over time and brighter places experienced an increase.

To facilitate the interpretation of the image subtractions a 'highlight' file was created for each difference layer. In this portrayal green represents increased vegetation cover and red represents a decrease in cover, such as a burn. The highlight thresholds were chosen as a percent increase or decrease from no difference between the two image enhancement dates. The percentages were chosen by the image analyst and checked by visual interpretation of the before and after multispectral imagery. As such they are subjective interpretations and are at best a starting point for the users.

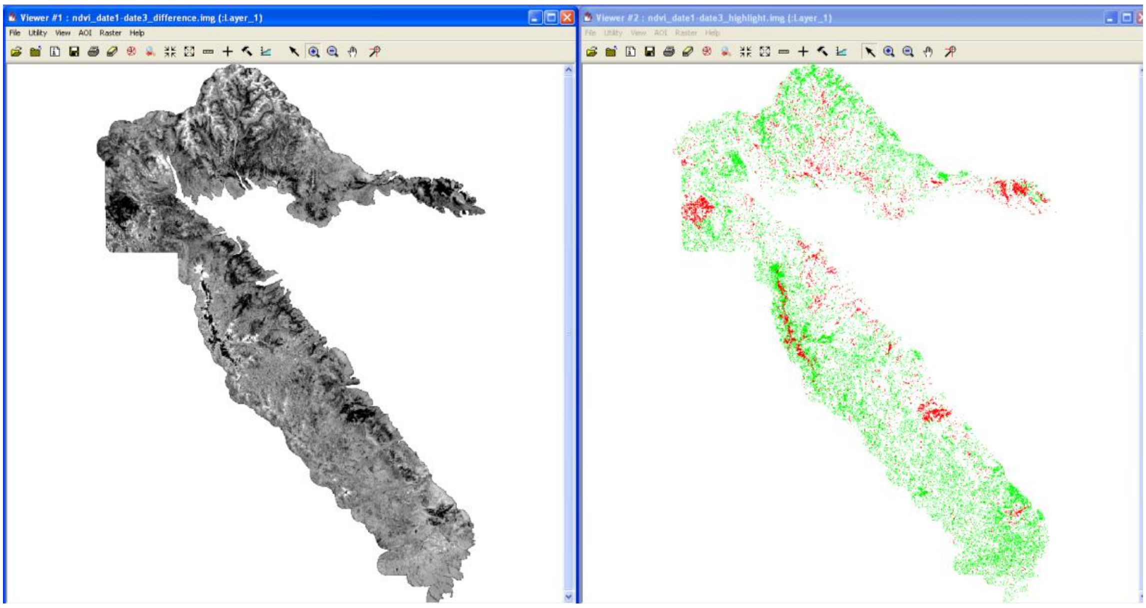


Figure 6.1. NDVI based results of image differences for the montane region between image date1 and image date3. On the left is the image difference file and on the right is the highlight file where green represents increased vegetation cover and red represents decreased cover.

6.3.4.2 Change Stack Visualization

Change compositing or change stack analysis, provides a result that is not quantitative but which can be visually effective in drawing the viewer's attention to areas of change. In this method each date range for each variable is combined into a single image such that each date is a "layer" or "band" in that image. This results in one 6-layer change "stack" for each of the two image enhancements (PC1 and NDVI) used. By displaying 3 dates (layers) simultaneously on the computer as an RGB color image, changes over time stand out as colored areas and small or no change areas show up as "black and white" or in some cases as a subtle but uniform color cast. In this way the human eye is drawn to color which can then be interpreted based on color theory (see section 6.4.2 below for interpretation guidance).

We created the change stack images for each enhancement by adding the individual dates as layers as follows:

Change Compositing:	Date01 = Layer 1
	Date02 = Layer 2
	Date03 = Layer 3
	Date04 = Layer 4

Date05 = Layer 5
Date06 = Layer6

For each image the layers can be viewed individually (gray scale) to see the visual representation of the input variables or as 3 layer RGB composite images (false color) by assigning one layer to red, one to green and one to blue (in ArcGIS or Erdas). Three layers are required to create a color visualization.

6.4 Results and Interpretation

6.4.1 Image Subtraction

The image subtraction portion of the change analysis resulted in 10 individual change images (Table 6.2 above) for each of the two enhancements. Each of these is a visualization of change that occurred between two of the five possible image dates. The individual change images are provided in an ArcMap (v. 9.2) document (.mxd) that allows a user to easily turn images on and off and to toggle between dates. As decided at the outset of the project, no attempt was made to interpret the change images. Instead, they are presented to allow users to easily see change and to identify areas where significant change has occurred which might then be characterized based on expert opinion or field visits.

The magnitude and direction (increase or decrease) of change is represented in the subtraction images with monochrome tones ranging from pure black, through shades of gray, to pure white. Interpretation of these tones requires one to think logically about the range of possible outcomes of subtracting NDVI or PC1 brightness in an older image from that in a newer image. We provide a general guide to interpreting these images (Table 6.3) and some specific examples for each of the two enhancements.

Table 6.3. General guide for interpretation of change subtraction results. “Date A” refers to the more recent of 2 dates used in image subtraction and “Date B” to the older image date. Values are for the input variables, in this case either NDVI or PC1 brightness. Recall that high NDVI means more green vegetation and high PC1 means more bare soil, in general.

Date A Value	Date B Value	Change Image Value	Appearance
high	high	0	middle gray
high	medium	medium positive	light gray
high	low	large positive	bright gray or white
medium	high	medium negative	dark gray
medium	medium	0	middle gray
medium	low	medium positive	light gray
low	high	large negative	dark gray or black
low	medium	medium negative	dark gray
low	low	0	middle gray

Interpretation Example for NDVI Subtraction

NDVI subtractions are visualizations of change in NDVI between two dates and can be viewed as proxy for changes in the amount of green vegetation over a time interval. Increases in NDVI over time mean that the amount of vegetation increased and decreases in NDVI signify loss of green vegetation. As an example, if you are examining the result of the Date01 (2009) – Date04 (1995) subtraction of the NDVI images (Fig. 6.2) you could interpret the results as follows:

Dark areas (large negative subtraction result) = places where NDVI (green vegetation) was low (sparse or absent vegetation) in Date01 but high (relatively high green vegetation amount) in Date02 meaning that there was more vegetation in that area in 1995 than at present.

Gray areas (subtraction result near zero) = relatively unchanged vegetation amounts during the time interval.

Bright areas (large positive subtraction result) = places where NDVI (green vegetation) was high in Date01 but low in Date02, meaning that vegetation grew into the area from 1995 to the present.

Similar logic can be used to interpret intermediate tones.

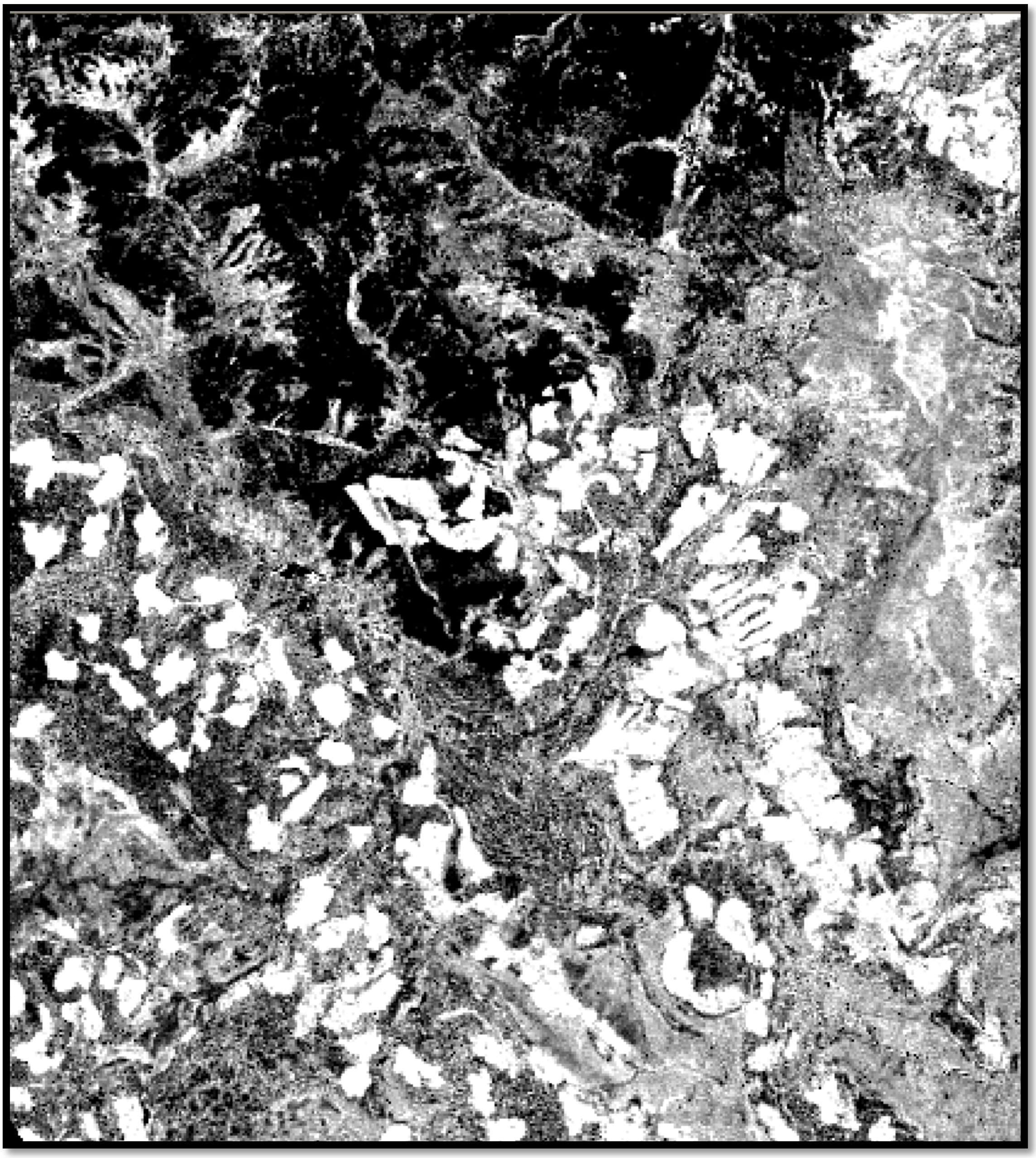


Figure 6.2. This image shows NDVI change in the Wind River Mountains between 2009 and 1995 based on image subtraction. The dark spots are dark because they had higher NDVI (vegetation cover) in 1995 than in 2009, indicating a forest fire at the top of the image. The white areas in the bottom of the image are regenerating clearcuts. The gray matrix represents relatively unchanged forest, at least in terms of the amount of green vegetation.

<u>Interpretation Example for Brightness Subtraction</u>

The philosophy of interpreting the PC1 brightness images is the same as for NDVI but because PC1 brightness depicts the “opposite” of NDVI the interpretation is reversed in terms of what happened to vegetation cover on the ground. For example, if you are examining the result of the Date01 – Date04 PC1 brightness subtractions (Fig. 6.3) you would interpret the result as follows:

Dark areas (large negative subtraction result) = places where Brightness was low in Date01 and high in Date04, meaning that the area lost brightness with time, perhaps because vegetation increased (bright bare soil decreased).

Gray areas (subtraction result near zero) = little or no change in brightness over time.

Bright areas = places where brightness was high in Date01 and low in Date04 meaning that perhaps the amount of vegetation decreased (bare soil increased) from the past to the present.

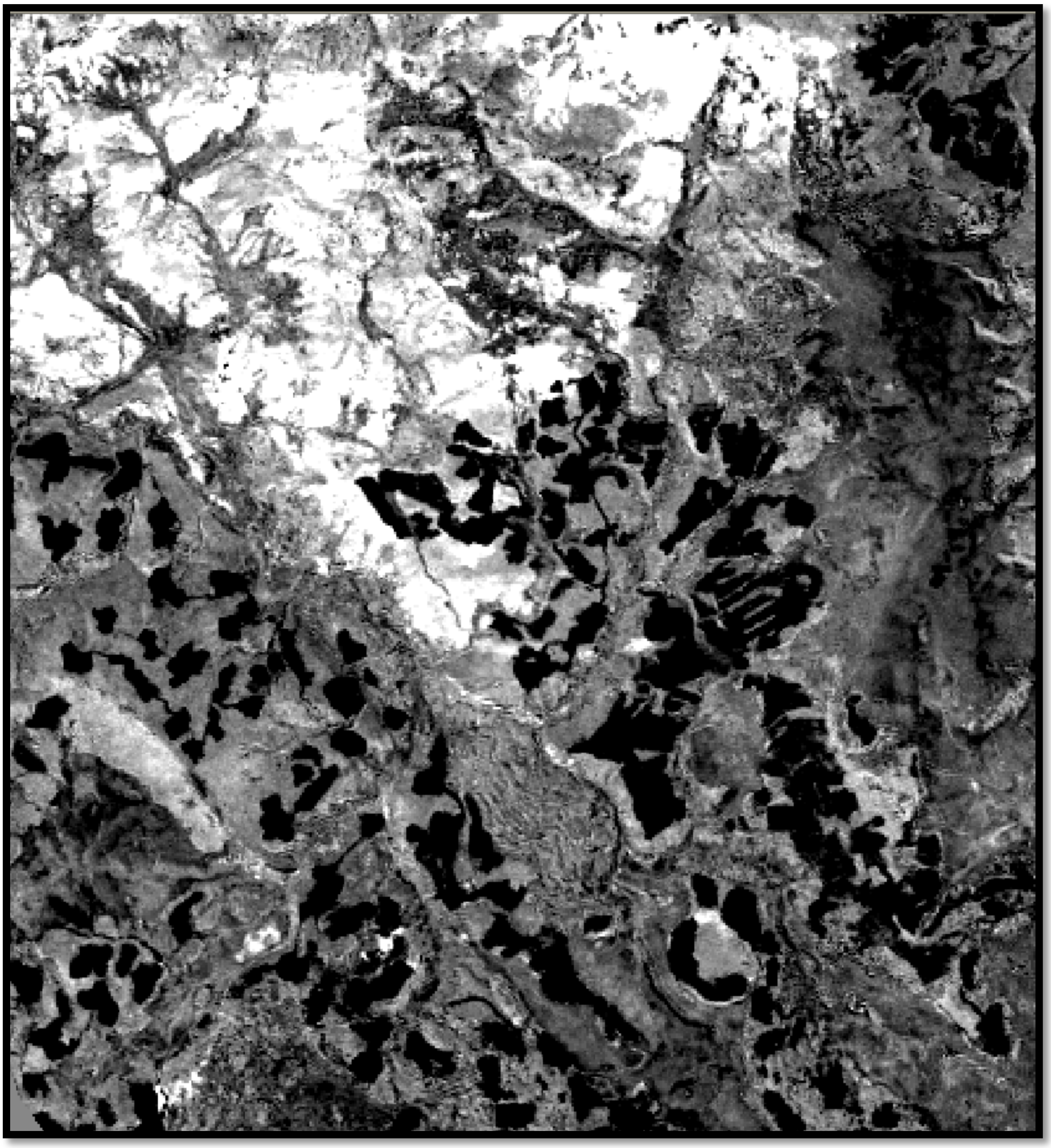


Figure 6.2. This image shows PC1 brightness change between 2009 and 1995 based on image subtraction for the same area used to illustrate NDVI change (Fig. 6.1) above. The bright spots are bright because they had lower PC1 brightness (bare soil) in 1995 than in 2009, indicating tree canopy loss. The dark areas in the bottom of the image are regenerating clearcuts. The gray matrix represents relatively unchanged shrublands, at least in terms of the amount of green vegetation.

6.4.2 Change Stacks

As described earlier in this chapter, change stacks were created for each of the two image enhancements. Each change stack file (Brightness and NDVI) include “layers” representing these enhancements for each of the six dates addressed in the change analysis (data01 to date06; See section 6.3.5 above). Change stack files are provided in a single ArcGIS (v. 9.3.1) map document (.mxd) that allows users to create change visualizations using combinations of 3 dates for each change stack.

Interpretation of color composite change stack images requires a basic knowledge of color theory, particularly with regard to how color images are produced on the computer screen using the three primary colors: red, green and blue. When you view a color image on your screen you are actually seeing, in each screen pixel, combinations of the three primary colors whose individual intensities are controlled by layers in an image. For remotely sensed data, 3 individual image layers control the intensity of each of the 3 colors, respectively.

In the case of a change stack, each layer in the image depicts some variable (in this case NDVI or Brightness) on a single date. By coloring one date red, one date green and one date blue and then displaying the three simultaneously, we can create a color image that depicts change. Interpretation of these images is based on the following color theory concepts:

1. Equal amounts of the 3 primary colors yields black, white or gray depending on their intensity. So if all three dates have more or less equal values for a pixel (no change across those dates) that pixel looks monochromatic (grayscale) with little or no color.
2. If one date has a significantly larger value in a pixel than the other two dates, that pixel will appear colored and the color will be the color that is assigned to the date with the high value. For example, if you display NDVI images for date01=red, date03=green and date05=blue and a pixel looks blue, then you can conclude that NDVI was highest on date05, the "blue date."
3. If two of the dates have equal values in a pixel and the third has a lower value, that pixel will appear as the color of a combination of the 2 primary colors assigned to the two dates with high and equal values. (red + blue = magenta; red + green = yellow; green + blue = cyan).

In short, monochrome pixels are relatively unchanged places and colored pixels are areas of change, with the color of each changed pixel determined by the dates with the highest pixel values.

Example for NDVI Change Stack

As an example, if you open the NDVI Change stack and assign date01 to red, date03 to green and date05 to blue and examine the resulting image you can make the following conclusions:

Red places mean that NDVI was highest (more veg) in date01
Green places mean that NDVI was highest (more veg) in date03
Blue places mean that NDVI was highest (more veg)in date05
Magenta places mean that NDVI was high in both date01 and date05 but lower in date03.

Yellow places mean that NDVI was high in both date01 and date03 but lower in date05.
Cyan places mean that NDVI was high in both date03 and date05 but low in date01.
Monochrome places (black, gray, white) mean that NDVI was the same in all three dates.

A little experimentation is ArcGIS (or Erdas) will help clarify the interpretation process.

6.5 Conclusions

Change detection analysis used 6 dates to capture changes in vegetation cover across the entire Central Wyoming study area. The analysis is based on two image enhancements, one (NDVI) that highlights the amount of green vegetation in a pixel, and the other (image brightness as represented by the 1st principal component (PC1) of all reflective satellite bands) that highlights the amount of bare soil. These two enhancements complement each other and comprise two ways of looking at the same kinds of changes. Visualizations of change include image subtractions for every combination of dates and change stack files that include all dates. Users of the products are encouraged to explore the data in the context of the information provided here to improve interpretation skills. No attempt has been made to interpret the meaning of the changes that are highlighted in these products, and such interpretation is the responsibility of personnel familiar with these areas.

6.6 Literature Cited

Driese, Kenneth L. and Nathan Nibbelink. 2004. Database development for analysis of cumulative impacts in Southeast Wyoming. Final Report to the Wyoming Game and Fish Department. Wyoming Geographic Information Science Center. December, 2004.

Chapter 7
Conclusions and Deliverables

7.1 Conclusions

The mapping and analyses described in this report are a step towards providing land managers in Wyoming with detailed, spatially explicit depictions of the land surface. Some of the data products, such as the change analysis and snow mapping, provide new and unique information not previously available to land managers. The data are also a step forward in map resolution over what has previously been available over this large area – primarily the Gap Analysis land cover data of the early 1990s. Moderate resolution maps, like those produced here, are appropriate for some management questions and not others, and it is the responsibility of data users to assess whether these products match particular questions and applications.

7.2 Deliverables

Deliverables from this project include digital data provided to the WGFD, USFWS, USFS, and the BLM on DVD media in ESRI ArcGIS version 9.3.1 map documents (.mxd) containing a variety of geospatial data, both raster and vector. Raster (cell-based) data created from satellite imagery is saved as Erdas Imagine version 9.3 image files (.img) which are themselves compatible with the ArcGIS software and other Geographic Information System (GIS) products.

7.2.1 Metadata

All digital data created and delivered for this project have been described using FGDC compliant metadata that are associated with each dataset in the GIS. These metadata describe the spatial characteristics of the data, their attributes, and important information about data creation and, along with this report and 'readme' documents, serve as the primary sources of information about the data characteristics. Data users are encouraged to explore the metadata if they are uncertain about whether these data are appropriate for specific applications.

7.2.2 Land Cover Data

Land cover mapping data for the central Wyoming project area is provided on one DVD that includes data organized in ArcMap (v.9.3.1) map documents. The DVD contains land cover mapping for the Lander mapping area presented in an ArcMap document. This database includes the Lander digital products and supporting materials including the following:

1. An image file (Erdas Imagine .img) of the pixel-level land use and land cover map.
2. An image file(Erdas Imagine .img) of the 2 acre MMU level land use and land cover map.

3. An image file (Erdas Imagine .img) of the pixel level land cover model fitness map.
4. Vector layers depicting the project study boundary and buffered (3 km) study boundary.
5. Data used for CART modeling, including:

   a. The Landsat satellite image mosaic.
   b. Shuttle Radar Topographic Mission digital elevation model (DEM) data.
   c. Derived topographic slope (percent).
   d. Derived topographic aspect (categorized).
   e. Landsat derived Normalized Difference Vegetation Index data.
   f. Landsat derived Normalized Difference Wetness Index data.
   g. NAPP aerial photograph derived spectral-spatial metrics
   h. Derived riparian zones (categorized).
   i. Field reference data converted to the model dependent variables and associated Excel spreadsheet of coding.
   j. A vector layers and a raster layer of field reference data.
   k. Associated documentation in Microsoft Word documents and Excel spreadsheets.

7.2.3 Snow Cover Scenario Data

The fractional snow cover data for average and high snow year scenarios (see chapter 5) are provided on a DVD containing an ArcMap (v. 9.3.1) map document containing the following data:

1. Original Landsat TM satellite imagery (10 scenes) used for calculating snow fractional cover for average and high snow years.
2. Image files containing the raw (unclassified) Normalized Difference Snow Index (NDSI) values for each of the 6 original Landsat TM image paths.
3. Images depicting NDSI values thresholded into 5 fractional snow cover classes. These are the fractional snow cover map images.
4. Vector data for orientation including: study area boundary (buffered and unbuffered), county boundaries, public land survey system (PLSS) boundaries, main roads.

7.2.4 Change Visualizations

Change visualization data represent change on approximately 5 year time intervals for two image enhancements chosen to capture vegetation change and changes in the amount of exposed soil present. Additionally, the change data are presented using 2 visualization techniques – image subtractions and change stacks (see chapter 6 for details). Consequently, the data are organized on 3 DVDs with contents as follows:

DVD 1: NDVI Subtractions

1. NDVI subtractions for each possible combination of dates. In total there are 10 grayscale images provided.
2. Raster layer of changes highlighted to 3 categories, loss, gain, and no change.
3. Vector data showing the buffered (3 km) study area boundary for the entire region.

DVD 2: PC1 Brightness subtractions

1. PC1 brightness subtractions for each possible combination of dates. In total there are 10 grayscale images provided.
2. Raster layer of changes highlighted to 3 categories, loss, gain, and no change.
3. Vector data showing the buffered (3 km) study area boundary for the entire region.

DVD 3: Change stack visualizations

1. A multi-layer (6 layers) image with each layer representing the NDVI for one of the change detection dates. Layer 1 is the most recent date and Layer 6 is the oldest date.
2. A multi-layer (6 layers) image with each layer representing the PC1 brightness for one of the change detection dates. As for NDVI above, Layer 1 is most recent and Layer 6 is the oldest date.
3. Vector data representing the buffered (3 km) study area boundary for the entire region.

7.3 Caveats

Geospatial data are created at specific resolution or scale, using a variety of techniques. All maps have errors and these errors can range from minor to serious, depending on what the map is being used for. The data created for this project are no exception. Map users should use this report, metadata and their knowledge of particular applications to decide if these data are appropriate in different situations.

7.4 Data Maintenance

At this writing, there is no formal mechanism in place for maintaining and updating these data, but such mechanisms could be put into place in the near future as WyGISC and the WGFD develop tools for web-based data dissemination and update. In the meantime, data users familiar with particular places in the study area are encouraged to provide WyGISC personnel with constructive feedback that can 1) be incorporated into these products in the future and 2) help us to improve our methodology for other ongoing and planned mapping projects. When providing feedback, please be cognizant of the scale and resolution of these products and realize that they may not be appropriate for sub-MMU (< 2 acre) patterns of land cover or other themes.

Use of the land cover product is primarily intended for land cover (habitat) inventory. Most surveys will find the use of stratified-random sampling at the appropriate scale effective. In the future, WyGISC intends to investigate the use of the 'CART model Error Map' to weight sample intensity per strata. See Chapter 3 and the Land Cover database for more information on the CART process and 'Error Map' data. Feedback on the relative effectiveness of the land cover stratification to WyGISC and local data users should be addressed by strata to improve inventory. Information specific to strata can be incorporated by local users to further improve sampling and stratification, such as the fitness of strata, additional attribution or description of the strata, and the condition of the habitat within strata.

Further, land cover map users can recognize this map as a 'living document' and the map can be modified with human interpretation at the local level. A unit of mapped land cover can easily, in GIS, be attributed with a new cover type definition as changes or misclassifications are identified. Finally, an approach sometimes referred to as 'double sampling for stratification and inventory', a variant of multiphase sampling, can be employed. In this approach, the land cover data, intensively sampled for mapping, are used as strata for an inventory and samples are selected via appropriate techniques (*e.g*. randomized within strata). As samples are visited and the primary inventory data are collected, the samplers can in turn collect data to improve and describe the map used to develop strata. In other words, double sampling can provide new data (samples) for 're-mapping' the entire study domain, 'localized' improvement of the description applied to the terrain units where samples are collected, and an overall body of statistics describing the strata.

7.5 Data Availability

At the time of this writing data described in this report will be distributed to users through the WGFD State Office and the BLM State Office, both in Cheyenne, WY. Upon partner approval, data will be made available over web-based mapping services, such as WyGISC's Wyoming Geolibrary
http://partners.wygisc.uwyo.edu/wygeolibrary/explorer.jsf .

Appendix A: Field Protocols

1. **Example of field form used for field data collection.**

Date: ______________ Observer: ______________________

Agency: ___________ Observer contact (phone/e-mail): ________________________

Site Location Information (See detailed instructions on separate page)
This information must be sufficient to allow the site to be precisely depicted in a digital GIS database and to be associated with the land cover information on this form!!

Unique Site ID (initials_mmddyyhhmm): ______________________________
(hhmm in military time, 1m = 3.048ft; 1 ha = 2.471acres; 1ha = 10,000m^2; 1km^2 = 100ha)
Cover type area (circle one): $\leq$ 1 ha : > 1 ha and $\leq$ 1 km^2 : > 1 km^2 or list:___________
Training polygon boundary extent (e.g.200m E/W x 300m N/S): ____________
Terrain Position: Slope (circle one): Flat Slight Moderate Steep Cliff
Aspect: _________ (N, NW, S, SE, SSE, NNW, etc. or degrees)
Curvature (circle one): Flat Concave Convex Variable
Projection (e.g. UTM, Zone#, NAD83): ____

Coordinates Easting:____________________
Northing:_____________________
Units (e.g. Meters, Feet, Lat/Lon: DMS, DD, DM): ______________________

Coordinates taken within the site at least 60m?:(Yes / No), if No document at bottom.

GPS model: ____________________ Type of coordinate: __________________

Name of site sample polygon file:___________________ Type[e.g. shapefile]:

Site photo #s: _________ ID, filename or location of photo(s):____________
Orientation of photo(s): ____
Please provide a description of the site location [e.g., location of site relative to Coordinates above, description of areas neighboring site]:

Binding Area Do Not Write

Binding Area Do Not Write

Land Cover Description (See detailed instructions) **Site ID:** ____________________

Dominant Land Cover Type (from list): ______________________

Secondary Land Cover Type(s) if any (from list): ______________________

Fitness of Dominant Land Cover Type call (1 low to 5 high):_______

Sampling **Confidence** (1 low to 5 high):_______

Whitetail **Prairie Dogs** present (**Yes / No**) # of mounds/area:_______

Significant Cover Table:
Significant cover composition (use table below): Provide % cover (as can be identified) for either individual species, species groups (e.g. Bunchgrasses, willows, etc.), or the totals for each lifeform. For example, you may have a significant contribution of Pseudoroegnaria spicata that can be identified, but can only estimate the remaining grasses as either annuals or perennials. The goal is to describe all the cover and non-vegetated 'background' of the site in terms of percentages of the entire signal sensed by the imagery (i.e. *all percentages in the table summate to 100%*).

H is height of the plant species or type in inches, **%L** is live foliar cover**, %D** is dead cover and stems
BV is the 'brightness' value of non-living components (1 is darkest to 10 brightest)

TREES	%L	%D	H	SHRUBS	%L	%D	H	GRASS	%	H	FORBS	%	H	OTHER	%	BV
														ROCK		
														SOIL		
														LITTER		
														OTHER/ WATER		
TOTAL			X	TOTAL			X	TOTAL		X	TOTAL		X	TOTAL		X

Dominant **soil color** (e.g. *2.5YR 5/4* or tan, etc.): **DRY**__________**WET**_________

Were detailed plot data collected at the site? (**Yes / No**) If so, how do we access them?

Are the shrubs **hedged** by browsing? (**Yes / No**)

Comments and Condition (descriptive information about the site such as, disturbances, soil degradation, vegetation patchiness and inclusions – use extra sheet if necessary):

2. Data collection instructions used by field crews

Detailed Instructions for Collection of Remote Sensing Training Data

"Training Data" are ground-based examples of land cover types that may appear in the final land cover map of SW Wyoming. These data allow the remote sensing analyst to characterize the spectral and terrain characteristics of land cover types and develop statistics that describe them. We need to collect a multitude of field samples describing the range of land cover types **and** the range of associated terrain features across the landscape. For this reason, **high quality** (spatially precise and consistently described) training data are VERY IMPORTANT to the success of this mapping project. Review the two page 'Field Data Form;' the instructions below and notes on the form provide data estimation guidelines.

Site Location Information (Page 1 of Field Form):

1. Training sites should ideally **be relatively homogenous examples** of a particular cover type from the list of types to be mapped (included as **Attachment A** with these instructions).
2. When you describe the sites, try to **imagine a "birds eye view"**. Cover always looks denser when viewed from the side than from a satellite perspective.
3. Training sites MUST be **at least 100 x 100 meters** in size (1 ha or larger) and larger is better. The resolution of Landsat satellite data is too coarse to precisely associate smaller sites with places (pixels) on the imagery.
4. You **must provide information to allow us to precisely locate the sites on a map** – this means either GPS coordinates *with map projection information* and/or digital spatial files (e.g., shapefiles) *with map projection information* and clear links to the site descriptions from the data form and/or sites carefully drawn on maps that can be transcribed into a GIS. Vague location descriptions (e.g., township/range) are not useable. Coordinates are points while training data ultimately are polygons; describe the spatial relationship of the coordinate to the polygon or field site (e.g. point (coordinate) is located in NE corner of polygon, or edge of site is 500 meters southwest from point, etc.).
5. If a **digital polygon** for the field site is created, do not draw the polygon to the edge of the site. In remotely sensed imagery site edges are most frequently mixtures of the neighboring sites. **Draw the polygon at least 15 meters (preferably 45 meters) within the site from the edge**.
6. When describing the site location (**'Terrain Position'**) draw an imaginary polygon around the site boundary. Then describe the characteristics of this polygon; such as the **'Slope'** angle relative to horizontal, what **'Aspect'** it faces, and the shape of the terrain within the polygon (**'Curvature'**).
7. **Site photos are valuable**. If you take photos of the site, please provide them to us clearly marked with the site ID. If photos are digital, please be sure that there is a way to associate the photo with the data form. At least two photos representative of the site are ideal; one close-up and one at a distance showing the site in perspective to neighboring sites. Provide description of the photo **orientation**, e.g. *photo is looking to the west from the coordinate*.
8. Any **additional descriptive information** about the site that you can provide may be useful. Use another sheet of paper if necessary.

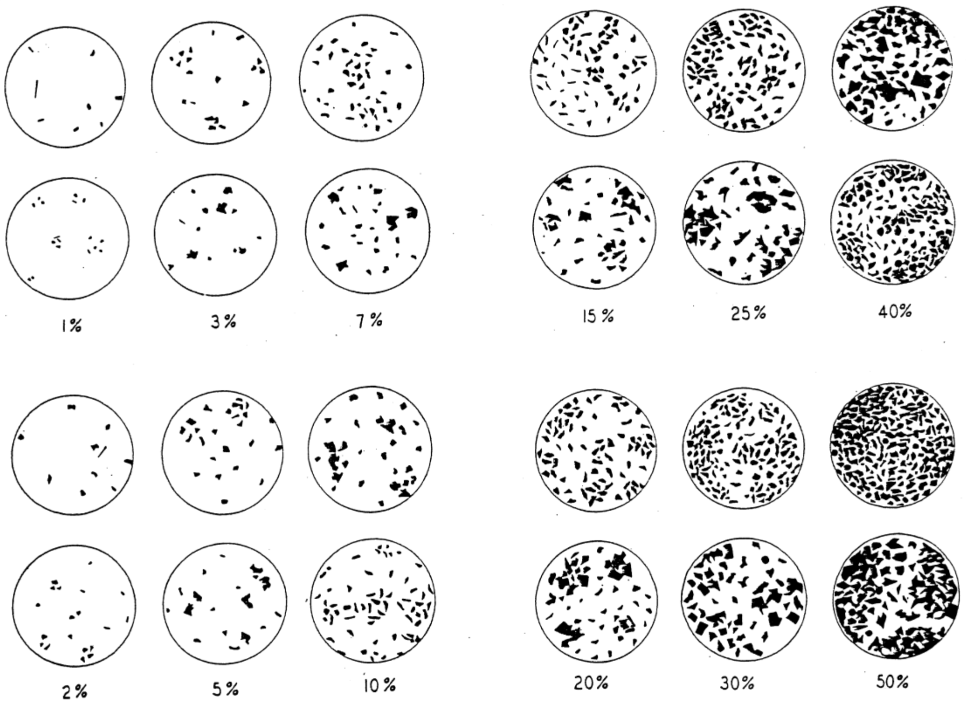
Land Cover Description (Page 2 of Field Form):

9. If site plant composition is not homogenous, please **provide as much detail as possible** about the nature of mixtures, patchiness of heterogeneities, etc. Note space is provided at bottom of page or use another sheet.
10. Some large tracks of terrain may not clearly fit into a land cover category, but are mixtures of types (e.g. ecotones). The field form allows for three methods of dealing with categorical confusion. First, the '**Significant Cover Table**' allows the specific plant composition to be detailed. Second, when naming the Land Cover Type category of mixed sites the field analyst has the option to list '**Secondary Land Cover Types**' as well as the '**Dominant Land Cover Type.**' Third, the analyst should provide a '**Confidence**' level for their Land Cover Type description of the site. This confidence describes how well the site fits into the classification scheme (see list from Attachment A). Further examples include disturbance such as burned areas or timber harvest, while the current cover type may be 'Recently Disturbed Areas' (see Attachment A category # 99.60) for our training purposes there is a difference between burned forest and burned rangelands.
11. In the '**Significant Cover Table**' the biotic and abiotic components of the site should summate to 100% of a 'birds eye view' or the remotely sensed perspective. Determine the relative proportions of significant species or lifeforms and non-vegetated features that contribute to the 'signal' sensed by the satellite imagery. Very precise estimates of these proportions are not required, in favor of greater number of field sites collected. Record cover percentages as 5 or 10% increments, e.g. true cover of 8% can be recorded as 10%. Also, use judgement regarding species labels to minimize cost and time, refer to the Land Use/Land Cover Type List (pgs3-9), especially concerning forbs and grasses. If a species call is relatively easy, has high confidence, or determines the '**Dominant Land Cover Type**,' then list it, if not subtotals for a lifeform column are usually sufficient (e.g. the site contains 15% forb cover).
12. In the '**Significant Cover Table**' '**BV'** refers to 'brightness value' of non-vegetated components (consider the difference between dark basalts and salt playas). '**H'** refers to the 'average' above ground stature of a species or lifeform; some species may have more than one age-class of differing heights. These age-classes should be listed separately, for example a stand of conifers may contain a species with significant overstory and understory occurrences as to warrant description. '**ROCK'** refers to very large boulders, rock outcrops and escarpments. '**SOIL/BG/LR'** refers to the combination of soil, '**B**ack **G**round' elements such as twigs, chaff and leaf litter on the ground, and '**L**arge **R**ocks' on the ground not noted as '**ROCK'**. '**WATER'** refers to standing water not soil water content. If significant, Coarse Woody Debris such as logs on the ground can also be listed in the '**OTHER'** section of the table.
13. **Land Cover Type** labeling does not have to be done in the field. The '**Significant Cover Table'** and '**Comments'** concerning disturbances and vegetation patterns, etc. will be used to verify, correct, or modify the Land Cover Type calls. A Land Cover categorization is traditionally a moving target that must be adjusted to data constraints, applicable methods, and user needs such as accuracy.

Thank you! We appreciate your willingness to collect training data for us!

3. Foliar cover chart example

COMPARISON CHARTS FOR VISUAL ESTIMATION OF FOLIAGE COVER 1/



1/ Developed by Richard D. Terry and George V. Chilingar. Published by the Society of Economic Paleontologist and Minerologist in its Journal of Sedimentary Petrology 25 (3): 229-234, September 1955.

Anderson, E. William 1986 A Guide for Estimating Cover RANGELANDS 8(5):236-238. October

Appendix B: Classified Cover Types

Central Wyoming Mapping Project
Land Use/Land Cover Types

Notes:

- Forested types are considered to have a minimum of 20% tree cover. To be designated a conifer type the stand would have >75% of tree cover as conifer species or to be designated a deciduous type the stand would have >75% of tree cover designated as deciduous species.
- Co-dominance is generally two species with each having >20% crown cover and is generally used for tree and shrub community cover type classes.
- Minimum crown cover of 20% determines the lifeform group for the Cover Type. For example 10% tree cover within a stand with >20% shrub cover would be called a shrub type.
- Sagebrush are an exception where >5% sagebrush cover and <20% juniper, tree, or other shrub species cover would be a sagebrush cover type.
- Barren lands, bare soil, rock types are generally considered to have <7.5% total vegetation cover.
- Mixed types may refer to 3 or more species within a vegetation stratum type such as mixed mountain shrub consisting of choke cherry/serviceberry/snowberry or a foothills shrub steppe dominated by a mixture of sagebrush/bitterbrush/rabbit brush or it may refer to mixed stratum dominance types such as juniper/mountain mahogany/sagebrush complex.
- Whenever approximate percentage ranges or terms such as sparse/low/open to medium/moderate or heavy/dense/closed are referred to it is assumed and/or understood there will be overlap in the categories or percentages
- Recently Disturbed Areas shall be defined as having occurred in 2001 or more recently.
- Within a year and across years the apparent abundance of many species will fluctuate, especially forbs and annual grasses. Cover type categories describe the common condition of a site and are reflected in the resulting classification as condition at the time of the remotely sensed imagery. Field data collected should reflect the current conditions of the site. Notes concerning phenologic stage of a field site can help normalize for these temporal factors.
- As a guideline the height threshold between mature shrub and tree forms is 12 feet.
- Some of these cover types may not occur in the project area**.**
- Specific notes about cover types are included below.

Cover Types	Cover Type Discussion/Description

Forest and Woodland Types

01.10 Lodgepole Pine	
01.10.1 20-32% closure	
01.10.2 33-67% closure	
01.10.3 >67% closure	
01.20 Douglas Fir	
01.20.1 20-32% closure	
01.20.2 33-67% closure	
01.20.3 >67% closure	
01.25 Spruce	
01.25.1 20-32% closure	
01.25.2 33-67% closure	
01.30 Spruce- Subalpine Fir	
01.30.2 33-67% closure	
01.30.3 >67% closure	.
01.60 Limber Pine	
01.60.1 20-32% closure	
01.60.2 33-67% closure	
01.60.3 >67% closure	
01.61 Limber Pine-Douglas Fir	
01.61.1 20-32% closure	
01.61.2 33-67% closure	
01.61.3 >67% closure	
01.70 Whitebark Pine	
01.70.1 20-32% closure	
01.70.2 33-67% closure	
01.80 Mixed Conifer-Juniper	
01.80.1 20-32% closure	
01.80.2 33-67% closure	
01.90 Mixed Conifer-Dominant	Type includes conifer co-dominants such as
01.90.1 20-32% closure	Whitebark-Subalpine fir or mixtures
01.90.2 33-67% closure	of more than two tree species with
01.90.3 >67% closure	>20% canopy cover as conifer.
01.94 Conifer-Aspen	Conifer stands with aspen canopy cover as >20%
01.94.1 20-32% closure to	<50
01.94.2 33-67% closure	
02.10 Aspen	
02.10.1 20-32% closure	
02.10.2 33-67% closure	
02.10.3 >67% closure	
02.20 Aspen-Conifer Mix	Aspen stands with conifer canopy cover as
02.20.1 20-32% closure	>20% to <50%.
02.20.2 33-67% closure	
02.20.3 >67% closure	
02.30 Cottonwood-Riparian	
02.30.1 20-32% closure	
02.30.2 33-67% closure	

02.30.3 >67% closure

03.20 Juniper 03.21 Juniper-Sage	Juniper cover >20%. Woodland, Shrub, Grassland cover types may also contain Juniper up to this minimum.

Shrub Types

04.00-0.500 Desert Shrub to Shrub-Steppe

Desert Shrubs

04.20 Greasewood	*Sarcobatus vermiculatus*.
04.21 Greasewood-Sagebrush	
04.22 Greasewood- Saltbush	
04.41 Saltbush	*Atriplex gardneri*.
04.60 Birdfoot Sage	*Artemisia pedatifida*.
04.70 Mixed Desert Shrubs	Found on flats and solidified sand dunes. May include; Wyoming big sage, bud sage, or early sage along with rabbitbrush, woody aster, horsebrush, four wing saltbush, broom snakeweed, etc.
04.80 Mixed Desert Shrubs2	Found on slopes and draws. May include; Wyoming big sage, greasewood, shadascale, skunkbush sumac, etc.
04.90 Other Desert Shrubs	May include; Yucca, Sand Sage (*A. filifolia*),

Sagebrush-Grassland

Sagebrush cover >5% crown closure.

05.11 Basin Big Sagebrush	*Artemisia tridentata* **ssp**. *tridentata*.
05.11.1 5-15% closure	
05.11.2 16-25% closure	
05.11.3 >25% closure	
05.12 Wyoming Big Sagebrush	*Artemisia tridentata* **ssp**. *wyomingensis*.
05.12.1 5-15% closure	
05.12.2 16-25% closure	
05.12.3 >25% closure	
05.13 Mountain Big Sagebrush	*Artemisia tridentata* var. *pauciflora*
05.13.1 5-15% closure 05.13.2 16-25% closure 05.13.3 >25% closure	Cover Type includes; Subalpine Big Sagebrush, *Artemisia tridentata* var. *vaseyana*, Spiked Big Sagebrush (*A. spiciformis*).
05.14 Black Sagebrush	*Artemisia nova dominant or co-dominant*.
05.15 Mountain Silver Sagebrush	*Artemisia cana* **ssp.** *viscidula*.
05.16 Wyoming Three-tip Sagebrush	*Artemisia tripartita* **ssp**. *rupicola*. (some Tall Three-Tip may be included)
05.17 Alkali\Early Sagebrush	*Artemisia arbuscula* ***ssp***. *longiloba*, Synonymy: *Artemisia longiloba*, *A. tridentata* **ssp.** *arbuscula* var. *longiloba*, *A. spiciformis* var. *longiloba*.
05.19 Plains Silver Sagebrush	*Artemisia cana* **ssp.** *cana*.
05.20 Rabbitbrush	Includes; *Chrysothamnus nauseosus* **ssp.**

	Nauseosus (Gray Rubber), *C. nauseosus* **ssp**. *graveolens* (Green Rubber), *C. viscidiflorus* (Douglas/Green Rabbitbrush) and less common species/subspecies.
05.29 Other Big Sagebrush	May include hybrids such as; Bonneville Big Sagebrush (*A. tridentata*, hybrid 'B'), Gosiute Big Sagebrush (*A. wyomingensis* hybrid w/ *A. vaseyana*), Tall Black Sagebrush (*A. nova* hybrid w/ *A. wyomingensis*).

Mountain Shrubs

05.41 Bitterbrush-Sagebrush	Sagebrush cover >20 but <50% (*Purshia tridentata*).
05.94 Mixed xeric mountain shrubs	May include mtn mahogany, sumac, serviceberry, woods rose, big sage, bitterbrush, etc.
05.95 Willow-Upland	
06.10 Willow	*Salix* species.
06.12 Willow-Other Shrubs	Willow as a co-dominant.
06.90 Mixed Riparian Shrubs	May include willow, water birch, alder, plum, buffaloberry, chokecherry, hawthorn, red osier dogwood, Russian olive, tamarisk.

Graminoid and Forb Types

07.00-08.00 Grass-like Types	May include up to about 5% sage or 20% shrub or tree cover and unless recently disturbed should have >7.5% vegetation cover. This includes both 07.00 and 08.00 categories.
07.20 Basin Grassland	Primarily native perennial grasslands restricted to lowest elevations.
07.20.1 7.5-20% cover	
07.20.2 21-40% cover	
07.20.3 >40% cover	
07.30 Foothills Grassland	Primarily native perennial grasslands occurring in foothills and low to middle montane regions.
07.30.1 7.5-20% cover	
07.30.2 21-40% cover	
07.30.3 >40% cover	
07.40 Alpine Grassland	Primarily native perennial grasslands occurring in middle montane to above tree line.
07.40.2 21-40% cover	
07.60 Riparian/Wet Meadow	May include grass/sedge/rush species.
07.80 Annual Grassland	Commonly Bromus species.
07.80.1 7.5-20% cover	
07.80.2 21-40% cover	
07.80.3 >40% cover	
09.00 Marsh-Swamp Wetlands	Larger areas dominated by cattail, bulrush,

		and/or wetland sedges.
10.10	Water-Lentic or Standing	Ponds, lakes, reservoirs, and larger stock ponds.
10.14	Playa	
10.20	Water – Lotic or Running	Rivers, larger streams and waterways.

Agricultural Types

11.10	Dry-land Agricultural Fields	Wheat, etc.
11.20	Irrigated Agricultural Fields	Alfalfa, grass hay, corn, beets, etc.
11.90	Rural Development	Large disturbed areas associated with agriculture
11.91	Ranch-Farm Facilities	Farm lots

Non-Vegetated Types

12.40	Rock or Talus Slope	Rock outcrops, canyons cliffs, and talus fields.
12.60	Sand Dunes	Bare sand with total vegetation cover <7.5% or sage cover < 5%.
12.80	Snow	Glaciers and snowfields.
12.90	Bare Ground	Barren areas with bare soils and generally <7.5% vegetation cover or sage cover <5%.
99.10	Roads and RR	Includes major roads such as highways, county, gravel surfaced and others and RR.
99.20	Mining Areas	Includes mines and infrastructure.
99.40	Range treatment	Range sites showing significant effects from mechanical, chemical, or biological alteration.
99.50	Burned areas	Burns of any vegetation type. Pre-burn cover type should noted if possible.
99.80	Oil and Gas Developments	Includes well pad areas.
99.90	Urban/Industrial Land	Human built-up areas. Includes impervious/semi-impervious surfaces, and human use areas such as athletic complexes and golf courses, etc. Some energy development areas will be included in this category when contiguous with residential and commercial land use areas.

Prepared for

Wyoming Game and Fish Commission

By

UNIVERSITY OF WYOMING