

Vegetation patterns in the Salmon-Selway ecosystem

An improved land cover classification using Landsat TM imagery and wilderness botanical surveys



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INTRODUCTION

Aerial views of the earth's surface have provided useful and valuable geographic information to humans since we first looked down from high places. Such views were first recorded remotely as photographs from balloons more than 100 years ago (Colwell 1960). By the 1950's, natural resource professionals were relying on aerial photo interpretation to better inventory and manage land resources, at least in those parts of the world that were relatively accessible to airplanes and ground-reference crews. The advent of orbiting satellites in the 1960's offered scientists the prospect of standardized and repeatable recordings of the entire earth's surface. Such capability materialized in 1972 with the launch of the first Earth Resources Technology Satellite (ERTS-1), later renamed Landsat 1 (Short et al. 1976; Williams and Carter 1976). It did not take long for ecologists to recognize the potential of satellite remote sensing for mapping and monitoring land cover and land use (see review by Goward and Williams 1997).

Craighead (1976) and Craighead, Sumner and Scaggs (1982) first proposed, developed, and applied methods for combining botanical survey (ground truthing) and Landsat Thematic Mapper (TM) imagery to map wilderness vegetation and delineate critical habitat on an ecosystem scale. The first "ecospectral" vegetation map was produced for a 204 km² primary study area in the Scapegoat Wilderness of northwestern Montana, validated with additional ground truthing in two secondary study sites, and then extrapolated with good accuracy to more than 4500 km² of surrounding terrain. Although the map was developed with primary reference to grizzly bear habitat requirements, the authors explicitly recognized and advocated the much broader potential application of landscape scale vegetation maps to conservation (see also Craighead 1982; Craighead et al. 1986). These first methods were refined and tested in the Kobuk River region of Alaska, an arctic ecosystem with markedly different plant associations and geology (Craighead et al. 1988). The Kobuk River vegetation map was combined with new techniques for satellite remote-sensing of animal location (Craighead and Craighead 1987) to monitor and describe grizzly bear habitat use in the ecosystem (Craighead 1998). The close historical connection between the development of methods for satellite-aided vegetation mapping and grizzly bear habitat evaluation was no accident. The methods are particularly appropriate for species, like the grizzly, that have space-intensive life histories and prefer or require wilderness landscapes (Craighead et al. 1995).

In this report, we present a new, remote-sensing aided classification of vegetation patterns in the Salmon-Selway ecosystem of Idaho and Montana. Guided and enabled by the Scapegoat and Alaska mapping projects, our studies in the Salmon-Selway followed directly from the specific suggestion by Craighead (1982) that an inventory of habitat should precede any program, such as that recently proposed by the US Fish and Wildlife Service (U.S. Fish and Wildlife Service 2000), to reintroduce grizzly bears to the ecosystem. We intend, however, a much broader application of our results to the study and conservation of biodiversity in the region (Craighead 1982). We have taken full advantage of improved methods of mapping arising during a virtual explosion of remote-sensing applications in the last decade (including some provided by authors of the current report). However, the fundamental elements of ecosystem mapping have remained unchanged. We have also retained, from the first mapping studies, the core philosophy that remote sensing is an aid to, not a replacement for, on-the-ground field biology. Remotely sensed data have limited value to conservation until supported by appropriate investment in field-based

surveys designed to define, guide, and validate ecological classifications of landscapes at large spatial scales (Craighead 1980).

STUDY AREA

The broad region of interest was the Salmon-Selway ecosystem (Figure 1). This 100,000 km² complex of mountains, foothills, canyons, and river valleys is centered on the Idaho Batholith in central Idaho and western Montana. The ecosystem is approximately bounded by the Snake River plain to the south, Hells Canyon and the Palouse Prairie of the Idaho panhandle to the west, the Missoula and Clark Fork River valleys in the north, and the Bitterroot and Sapphire Mountains to the east. The study area was defined by the boundaries of adjacent Landsat TM scenes P41/R28 (dated July 20, 1991) and P41/R29 (dated July 31, 1995) which together cover the majority of the broader region of interest.

Two major rivers have their headwaters in the Salmon-Selway: the Selway River in the north and the Salmon River in the south. Tributaries of the Snake, Clearwater, Bitterroot, and Clark Fork Rivers drain the southern, western, eastern, and northern fringes of ecosystem, respectively. The northern portion of the Salmon-Selway is characterized by a Pacific Maritime climate and features an expanse of relatively mesic, montane forest and shrublands above which rise the island-like peaks and alpine plant communities of the Selway Crags and Bitterroot Mountains. In contrast, the more uniformly rugged, mountainous terrain of the southern Salmon-Selway is influenced by an arid Basin and Range weather pattern and features a more complex mosaic of grass, shrub, and forest plant community types. The transition between these broad ecological zones of the ecosystem is fairly abrupt and roughly coincides with the area of overlap between the northern (P41/R28) and southern (P41/R29) TM scenes.

METHODS

Botanical Data

Sources: We used botanical data from three sources: (i) Craighead Wildlife-Wildlands Institute (CWWI) (collected 1996–98), (ii) USDA Forest Service (FS) Region 1 (R1) (collected 1994–95), and (iii) FS Region 4 (R4) (compiled 1996).

Sampling Design: CWWI training plot locations were chosen via a hierarchical process and according to both ecological and spectral criteria. We first stratified the ecosystem into broad biogeographic regions which, considering topographic and climatic conditions, could reasonably be expected to capture most of the ecological diversity in the study area. These regions included the arid canyon country of the middle and main forks of the Salmon River, mountain massifs such as the Bighorn Crags and Sawtooth Mountains, the broad, upland basin of Chamberlain Creek, and the mesic forest lands of the upper Lochsa and Selway Rivers. Within each biogeographic region, we then sub-sampled four to six, 60 km² quadrangles corresponding in size and boundaries to 7.5 minute, USGS topographic maps.

In 1996–97, quadrangles were selected for high ecological diversity, high spectral diversity as revealed by the TM imagery, or both characteristics. We used our knowledge, and that of others

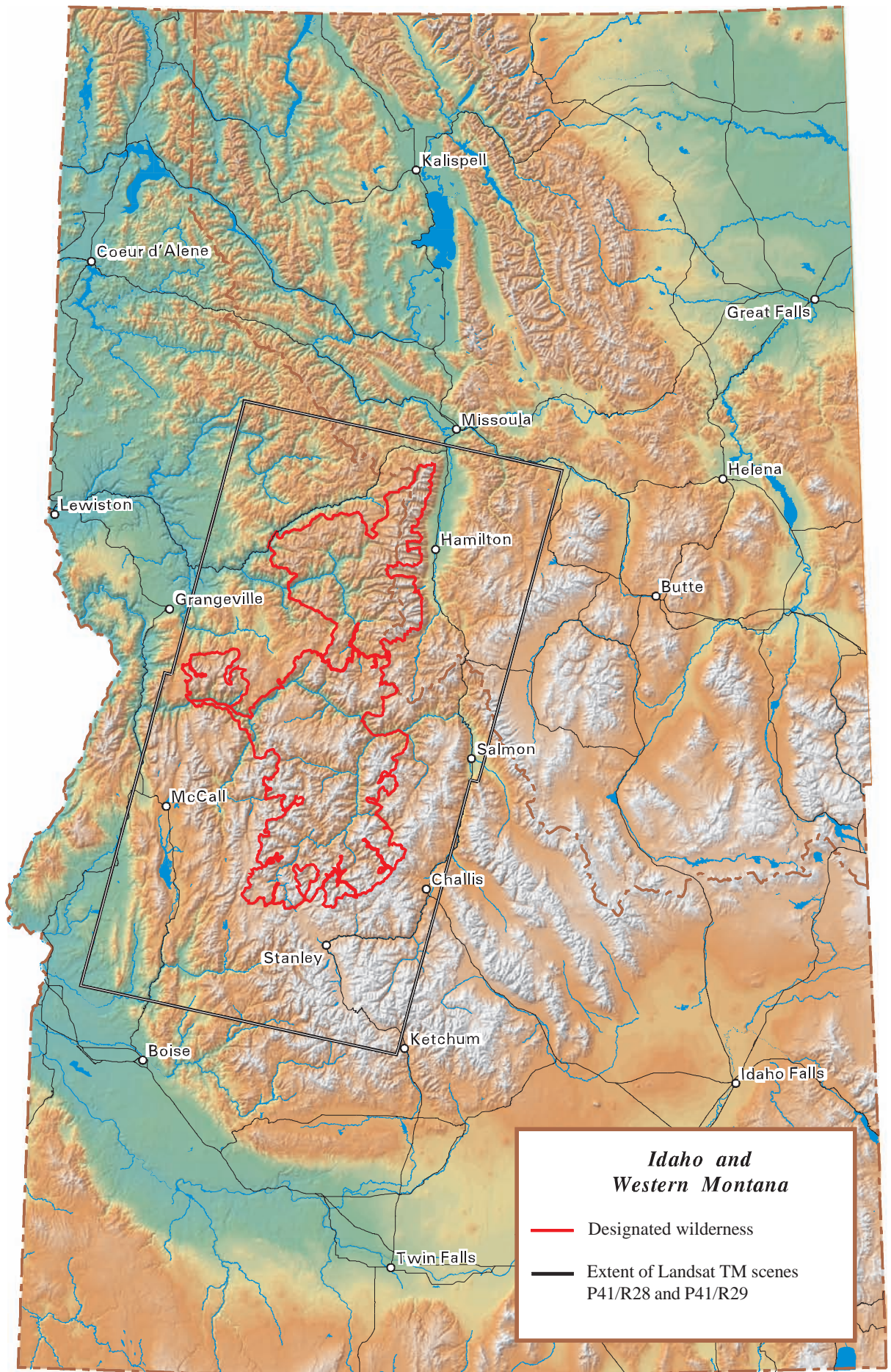


Figure 1. The study area (TM scenes P41/R28 and P41/R29) in the context of major physiographic features and urban centers in Idaho and western Montana.

familiar with a particular region, to identify quadrangles having high ecological diversity. A simple count of spectral classes in the unsupervised image was used to rank quadrangles by spectral diversity. Plot placement within selected quadrangles was largely determined by spectral information. First, we located plots so that most if not all spectral classes represented on the TM image of the quadrangle in question were sampled. Second, we generally selected areas that were spectrally homogeneous; plots were usually placed within polygons (map regions) in which 70–80% of the polygon's constituent pixels were of a single spectral class. However, in areas where spectral heterogeneity was widespread and appeared to reflect vegetational mosaics, we did not select for monotypic polygons. We used topographic maps, TM imagery, and Global Positioning Systems (GPS) (GeoExplorers, Trimble Navigation, Inc.) to navigate to polygons selected for plot location. One-tenth acre plots were laid out 100–120 m in from the polygon border at a point judged to be representative of vegetation in the polygon as a whole. The plot was then GPS-located. We did not place plots in polygons of the same spectral class that were separated by less than 500 m.

In 1998, quadrangles and plot locations were chosen without regard to spectral pattern as follows. We first identified quadrangles within biogeographic regions and sampling areas within quadrangles that captured major land form features (canyons, ridges, etc.) in rough proportion to their areal extent in the larger area (biogeographic region or quadrangle). Transects were located along access routes (trails) within sampling areas. Transect origins were determined by selecting a random number between 300 and 1000 and walking that number of meters from the start of the access route (or origin of the previous transect). Transect bearings (azimuths) were similarly determined by selecting a random number between 0 and 360 (degrees). Finally, locations of one-tenth acre plots along these transects were determined by selecting a random number between 100 and 500 and walking that number of meters from the transect origin (or previous plot). In contrast to 1996–97, replicate CWWI plots within the same polygon were permitted. All plots were GPS-located.

R1 sampling methods in 1994 were very similar to those we used in 1996–97. In 1995, R1 shifted from a spectrally-based sampling design to one in which under-sampled (fewer than 20 plots) cover types were targeted for additional ground truthing. Aerial photos, timber stand data, and local knowledge of FS staff were used to guide field crews to areas containing the under-sampled types. In both years, one-tenth acre, GPS-located plots were placed at representative locations 100 m in from the polygon boundary (Redmond et al. 1996).

The R4 training set was obtained in several ways (field plots, aerial photo interpretation, and timber stand maps) and assembled from two sources (data obtained for a 1996 classification of P41/R29 and pre-existing inventories made for various other reasons). Thus, there was no consistent sampling design corresponding to the spectrally-based or transect-based methods used by CWWI and/or R1. Training points from pre-existing inventories were less than ten years old, from subsequently undisturbed sites, and positioned near the center of homogeneous patches of vegetation that were at least 20 (upland) or 1 (riparian) acres in size. Training points were not GPS-located (Redmond et al. 1997).

Land Cover Classification Systems: Botanical plots were field-assigned membership in a hierarchical system of forest-canopy and non-forest vegetation associations based on Anderson et

al. (1975). This system was previously developed by the Wildlife Spatial Analysis Lab (University of Montana) in consultation with agency and academic ecologists. The classification first divides by life form (forest versus non-forest). Forest and non-forest are divided at additional levels by ecological, additional life form, and taxonomic criteria. Categories in the final level are defined by dominant or co-dominant plant species. Field assignments of plots were made to categories in this final level which, following Craighead et al. (1988), we refer to as plant community types.

The understory (all non-canopy strata) of forest plots was field-assigned separately according to the USDA Forest Habitat Type System. Most of the forest lands in P41/R28 fell under the Northern Idaho Forest Habitat Type System (Cooper et al. 1991) whereas those in P41/R29 fell under the Central Idaho Forest Habitat Type System (Steele et al. 1981). Although habitat types include information regarding *potential forest-canopy* associations, we emphasize that we used the habitat type classification system to describe only *existing understory* plant associations. Following terminology for forest-canopy and non-forest associations, we sometimes refer to habitat types as forest-understory plant community types.

Summary of Plot Data: Variables recorded on plot and methods of measurement were modeled on Ecodata format (Keane et al. 1990), in part because we anticipated combining our plot data with existing data of this type. Minimum data for CWWI plots in all years were (i) a GPS location, (ii) a forest-canopy and forest-understory plant community type label *or* a non-forest plant community type label, and (iii) visual estimates of plant species composition and coverages necessary to determine plant community type labels. In 1996, we estimated coverage for all plant species in each of three vegetative layers (lower, middle, and upper) to trace (0–1%). In 1997, we estimated coverage for only those species with at least 1% coverage except for habitat type indicator species and grizzly bear food plants which we recorded to trace. For most 1998 plots, we did not estimate the coverage of individual species unless coverage was required to determine plant community type or the plant was a bear food. However, roughly 100 plots were obtained according to 1997 coverage criteria in order to have a good spatial distribution of plots for ecological descriptions of mapped vegetation complexes.

R1 plot data had an Ecodata format. The primary differences with CWWI plot data were (i) species coverages were recorded to a 5–15% minimum coverage class and (ii) habitat types were not always recorded for forest plots (Redmond et al. 1996). R4 did not use Ecodata or a comparable plot data format. Plot data were limited to a forest-canopy or non-forest vegetation type label (Redmond et al. 1997). For convenience, we use the term “full plot” to refer to any CWWI or R1 plot on which coverage was estimated for each species present at $\geq 5\%$ coverage.

Data Management: CWWI plot data were entered into FoxPro databases using custom data entry screens and custom error- and logic-check routines. Error checks flagged entries that were outside the range of possible values for a given field. Logic checks flagged entries in two or more fields that were incompatible (one or more impossible entries given the value of the others). We checked flagged entries against the field data forms and corrected errors whenever possible. Plot data from FS Region 1 (but not Region 4) sources were subjected to a similar battery of error and logic tests. Region 1 plots with errors having an obvious correction (i.e., spelling or typographical errors) were corrected and retained. If an error existed but the correction was not

obvious, the plot was discarded. We differentially corrected latitude and longitude recorded for CWWI plots in GPS rover files with Pathfinder software using base station files from the appropriate base station (Idaho City, McCall or Missoula). Region 1 plots were differentially corrected by the agency.

We examined plots from all sources for statistical outliers in spectral values and removed 328 (P41/R28) and 496 (P41/R29) outlier plots from the data set. We moved 249 (P41/R28) and 104 (P41/R29) training plots located within 30–60 m (1–2 pixels) of a polygon boundary into an adjacent polygon because the spectral signature of the initial polygon did not match the general life form (forest versus non-forest) of the plot. Such mismatches are attributable in part to measurement error in GPS-derived locations. Finally, we removed from the data set 1317 Region 4 plots located within clear cuts but assigned by the agency to a (potential) forest-canopy plant community type. Plots that fell within polygons belonging to manually-labeled land cover classes (urban, agriculture, water, snow, cloud, cloud shadow) were also deleted.

Unsupervised Image

The Landsat TM images had a resolution of 30 m. For each 30 by 30 m unit (pixel), reflectance intensity was measured for seven bands (TM1–TM7) of the electromagnetic spectrum by Landsat TM satellites. We assigned pixels to one of approximately 130 spectral classes depending on values for TM channels 3, 4, and 5. We then aggregated (merged) pixels into map units of variable size using a rule-based merging method (Ford et al. 1997; Ma et al. 2001; Winne 2000). These map units (polygons) could be as small as one pixel if the pixel had sufficient spectral contrast with its neighbors. This method tends to form larger polygons (usually greater than 2 ha) in upland settings than in valley bottoms, at least as applied by Williams et al. (2000). The spectral class assigned to the polygon as a whole was the spectral class in the majority among member pixels. We will refer to the unmerged spectral map of pixels as the pixel image and the merged spectral map of polygons as the unsupervised image.

Spatial Classifiers

A classifier is a statistical procedure for using classified (training) observations to predict the group membership of unclassified observations. For vegetation mapping using remotely sensed data, classifiers are used to predict vegetation type for all polygons delineated in an unsupervised Landsat TM image. Classification is accomplished by comparing measurements made on a given unclassified polygon to those obtained for polygons containing training plots field-assigned to vegetation type. We used k-nearest neighbor classifiers (Steele and Patterson 2000) to provide initial estimates of an unclassified polygon's probability of membership in each vegetation type. These initial estimates were then modified using spatial information conveyed by the vegetation type memberships of training data that were geographically near a given unclassified polygon (Steele and Redmond 2000; Steele 2000). The unclassified polygon was predicted to be a member of the vegetation type with the largest modified probability of membership. Polygon attributes used in classification were TM bands 1–7, the modified normalized vegetation index (MNDVI), elevation, slope, slope/aspect, latitude, and longitude. MNDVI is a function of TM bands 3, 4, and 5 (Nemani et al. 1993). Slope/aspect is an index of insolation calculated from slope and aspect.

Vegetation Maps

Forest-Canopy/Non-Forest Vegetation Complexes: We initially attempted to classify the unsupervised TM image to plant community type or, when training data were fewer than about 20 for individual types, to small groupings of ecologically similar types. Initial map accuracies were unacceptably low. We then iteratively agglomerated plant community types and re-evaluated the accuracy with which the agglomerated types were classified until the overall map accuracy, and that of most agglomerations of plant community types, exceeded about 0.50. Because the land cover classification system we used (above) is hierarchical, we agglomerated plant community types simply by moving up a level in the classification. We again follow Craighead et al. (1988) in referring to groupings of two or more forest-canopy and non-forest plant community types as forest-canopy and non-forest vegetation complexes.

Forest-Understory Complexes: The procedure for grouping forest-understory plant community types (habitat types) was more complicated. Step one involved making an initial grouping of eight to nine complexes per scene. These groups were determined by an evaluation of the ecological similarity of habitat types (using Pfister et al. 1977; Steele et al. 1981; Cooper et al. 1991) and consideration of previous habitat type groupings (Crane and Fischer 1986; Smith and Fischer 1997; Keane et al. 1998). Each initial understory complex constituted a disjoint collection of habitat types, and each observed habitat type was assigned to a single complex. We then used the training plots to formulate classification rules for assigning polygons to understory vegetation complex. Attributes examined for their predictive ability in this procedure were the seven TM spectral bands, MNDVI, elevation, slope, and slope/aspect. We estimated the overall accuracy of the classification to forest-understory complex using leave-one-out cross-validation (McLachlan 1992; see next section). In addition to this overall accuracy rate, we used leave-one-out cross-validation to calculate the frequency at which training plots assigned to a specific habitat type were predicted to be a member of each initial understory vegetation complex. This calculation gave an assessment of the fidelity of each habitat type to each (provisional) understory complex. Subject to the constraint that the ecological integrity of the habitat type group was maintained, we then revised the grouping of habitat types to maximize the frequency with which plots of a known habitat type were predicted to belong to its parent understory complex. For example, if a habitat type H was assigned to understory complex i and the training observations from H were more often predicted to be members of understory complex j , then its assignment to understory group would be changed from i to j , provided that species commonly occurring in H also were common in j . The entire process of accuracy assessment and understory complex revision was repeated until no further improvements were apparent.

Final Classification: Using groupings of the training data determined by these procedures, we independently classified the two TM scenes in a hierarchical sequence of three steps. First, we classified polygons to life form (forest versus non-forest). Second, we classified non-forest polygons to one of eight (P41/R28) or seven (P41/R29) non-forest vegetation complexes (or plant community types) and forest polygons to one of seven (P41/R28) or eight (P41/R29) forest-canopy vegetation complexes (or plant community types). Finally, forest polygons were also classified into one of eight understory vegetation complexes (habitat type groups). Water, snow, cloud, cloud shadow, urban, and agricultural areas were manually labeled. Burned areas were mapped by a combination of statistical classification and manual labeling. Because manual

labeling could not distinguish between the two types of burn associations (Conifer Regeneration and Shrub-Herbaceous Dominated) distinguished in the field, these areas were subsequently classified to burn type using spatial classifiers. Following their independent classification, P41/R28 and P41/R29 were edge-matched in the region of scene overlap.

Classification Accuracy

We evaluated classification accuracies by leave-one-out cross-validation (McLachlan 1992). Cross-validation was applied by removing each training observation from the training set one at a time and constructing a new classification rule from the reduced training set. This new rule was then used to classify the left-out training observation. The process was repeated until all observations were held out and classified once. The estimated accuracy rate was the percentage of (left-out) observations correctly classified. A correct classification was one for which the vegetation label predicted for a polygon matched that which had been field-assigned to the training plot present within the polygon.

We calculated three estimates of map accuracy using this general procedure. Complex-specific user's accuracies were computed (via leave-one-out cross-validation) as the fraction of all ground-truthed polygons predicted to be vegetation complex *i* that were in fact field-assigned to complex *i*. Complex-specific producer's accuracies were computed (via leave-one-out cross-validation) as the fraction of all ground-truthed polygons field-assigned to complex *i* that were correctly predicted to belong to complex *i*. Overall map accuracy was computed (via leave-one-out cross-validation) as the number of correct predictions over all vegetation complexes divided by the number training observations. We also displayed and examined the spatial pattern of classification accuracy using the technique of Steele et al. (1998). Briefly, rates of mis-classification were estimated at each reference point (training plot) using bootstrap methods. Estimated mis-classification probabilities were then interpolated from reference points to a lattice of points (cell size 500 m) using exponential smoothing and a point evaluation routine in Arc Info. Radius and decay settings for this interpolation were 5,000 m and 30,000 m, respectively.

RESULTS

Nature and Spatial Distribution of Botanical Data

The information available from field plots varied somewhat within and, especially, between the three sources of data. CWWI and FS Region 1 data emphasized field plots with relatively comprehensive data content located in and around wilderness cores. Region 4 plots were frequently located peripherally in multiple-use areas, missing some key data for our application (e.g., habitat type or species composition lists), and/or based upon photo interpretation rather than field survey. Data content and plot totals for each source are summarized in Table 1. Locations of plots (training plots) used to predict forest-canopy, non-forest, and forest-understory complex membership are presented in Figures 2 and 3. A total of 3422 and 5929 training plots were used to classify TM scenes P41/R28 and P41/R29, respectively, to forest-canopy/non-forest complex. A total of 2188 and 3641 training plots were used to classify TM scenes P41/R28 and P41/R29, respectively, to forest-understory/non-forest complex.

Table 1. Source and number of (i) training plots used in the classification of the unsupervised image to forest-canopy, forest-understory, and non-forest vegetation complex, and (ii) “full” plots used to estimate plant species constancy, coverage, and related statistics.

Source of plot data	North scene (P41/R28)				South scene (P41/R29)			
	Number of training plots				Number of training plots			
	Forest	Non-forest	Under-story	Number of “full” plots	Forest	Non-forest	Under-story	Number of “full” plots
Craighead Wildlife-Wildlands Institute	748	164	725	219	1165	466	1126	960
USDA Forest Service Region 1	693	255	586	600	64	19	17	22
USDA Forest Service Region 4	1104	458	0	—	2202	2013	0	—
Total	2545	877	1311	—	3431	2498	1143	—

Summary Statistics for Full Botanical Plots

In addition to helping classify the unsupervised image, full plots are important as a primary quantitative reference on which to base an ecological description of each mapped vegetation complex (see “Vegetation Atlas”). In Appendix A to the CD version of this report, we present summary statistics for a variety of plant composition-related variables measured on full plots. These statistics were calculated for each vegetation complex and for all species recorded at $\geq 5\%$ absolute coverage on at least one full plot. The 5% threshold was chosen to standardize plot data from different sources. The variables summarized in Appendix A to the CD version of this report, their definitions, and terminology for certain summary statistics are as follows:

Absolute coverage: the percentage of the one-tenth acre plot area covered by the projection (onto the plot surface) of all individual canopies belonging to species *i*. The phrases “most common” and “most abundant” will sometimes be used to indicate species with the largest absolute coverage averaged over all plots assigned to a given complex. We defined **conditional coverage** as absolute coverage averaged over only those plots on which species *i* was present at $\geq 5\%$ absolute coverage. The product of conditional coverage and constancy (below) is equivalent to the absolute coverage of species *i* averaged over all plots within a complex.

Relative coverage: a ratio of absolute coverages. For example, if the absolute coverage of all tree species in the upper layer on a given plot was 50% and the absolute coverage of whitebark pine was 10%, then the relative coverage of whitebark (relative to upper layer tree species as a group) on that plot was 20%.

Occurrence: a dichotomous variable indicating presence/absence. We defined “presence” as $\geq 5\%$ absolute coverage. As such, occurrence corresponds to Pfister et al.’s

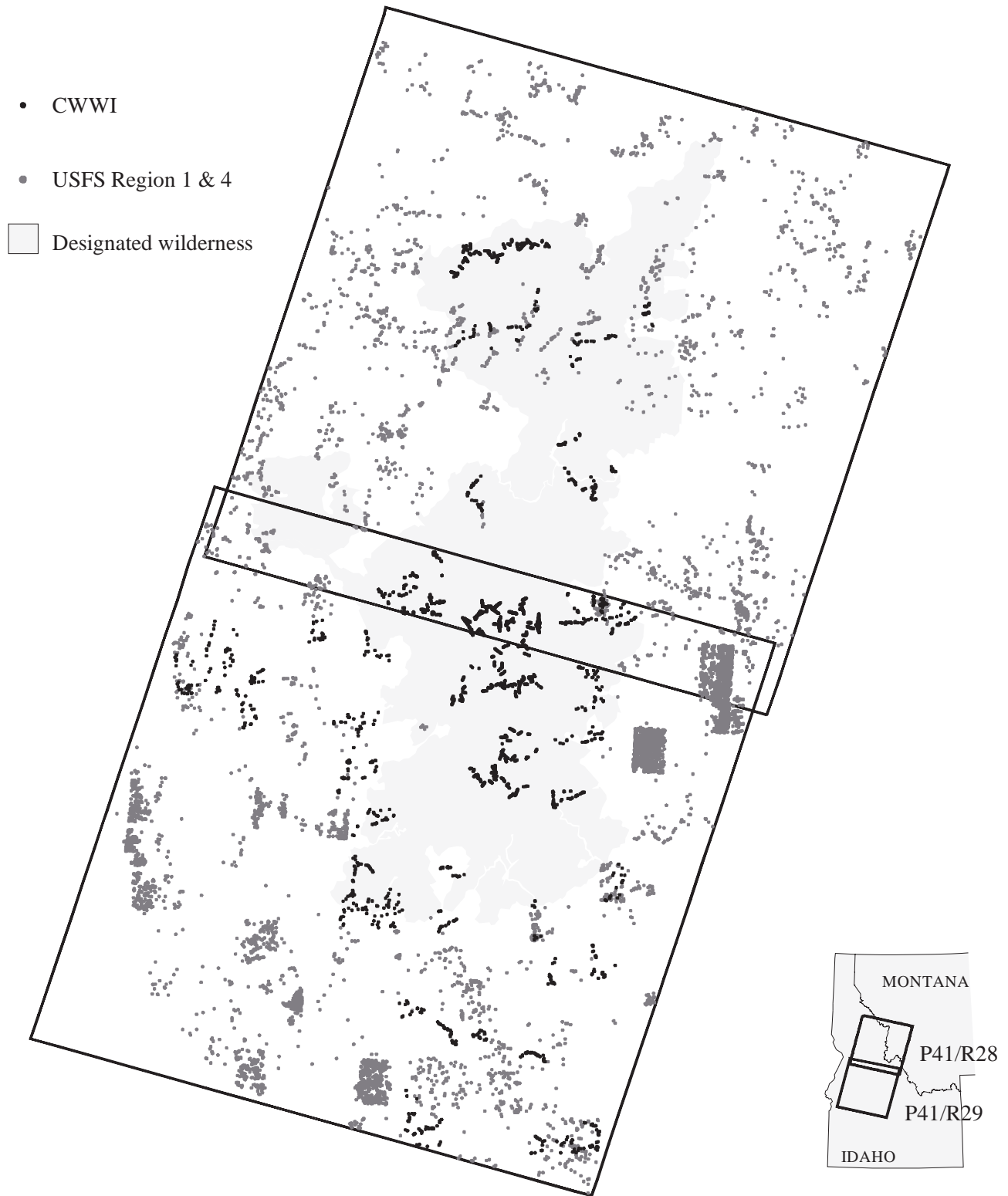


Figure 2. Spatial distribution of training plots for the forest-canopy/non-forest classification.

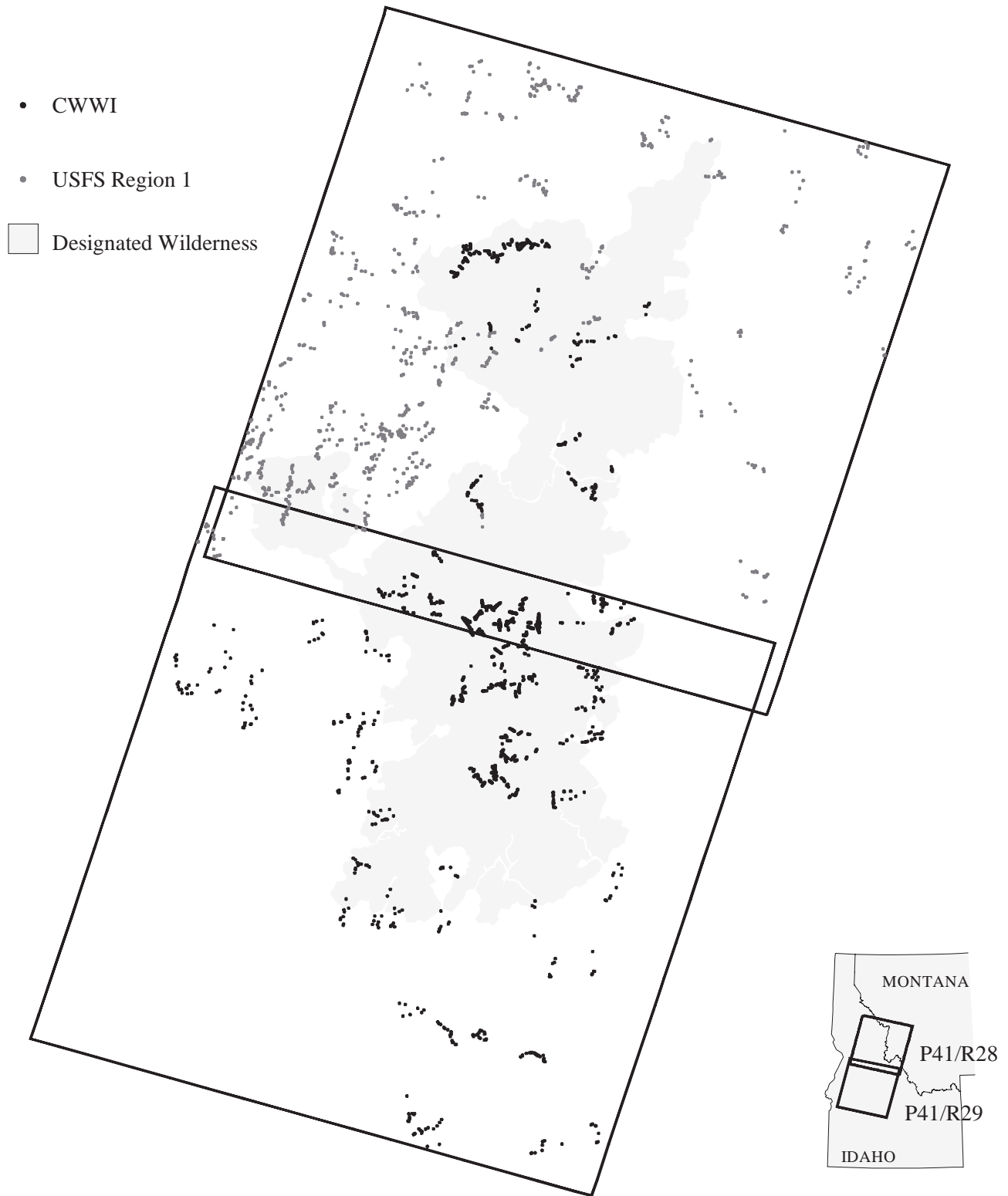


Figure 3. Spatial distribution of training plots used in the classification of forest polygons to forest-understory complex.

(1977) “well represented” versus “poorly represented” abundance classes. The statistic **constancy** is mean occurrence expressed as a percentage; i.e., the percentage of plots on which the species in question was recorded at $\geq 5\%$ absolute coverage. The phrases “frequency of occurrence” and “most frequent” will be used synonymously with or in reference to constancy, respectively.

Volume: the product of the absolute coverage of an individual plant and that plant’s height summed over all individuals of species *i* on plot. As such, volume was a measure of “dominance” in terms of biomass.

To give a sense of the vertical structure of each complex, we calculated constancy and coverages separately for an upper, middle, and lower vegetation layer. The upper layer included all trees pole size or greater. The middle layer was all shrub life forms as well as the seedlings and saplings of tree species. The lower layer included all forbs and graminoids as well as ferns and their allies. Although plots from the north and the south scenes are combined in Appendix A to the CD version of this report, there was often north-to-south variation in species composition within complexes. Strong latitudinal patterns are noted in the ecological description of the appropriate complexes (below).

Vegetation Complexes

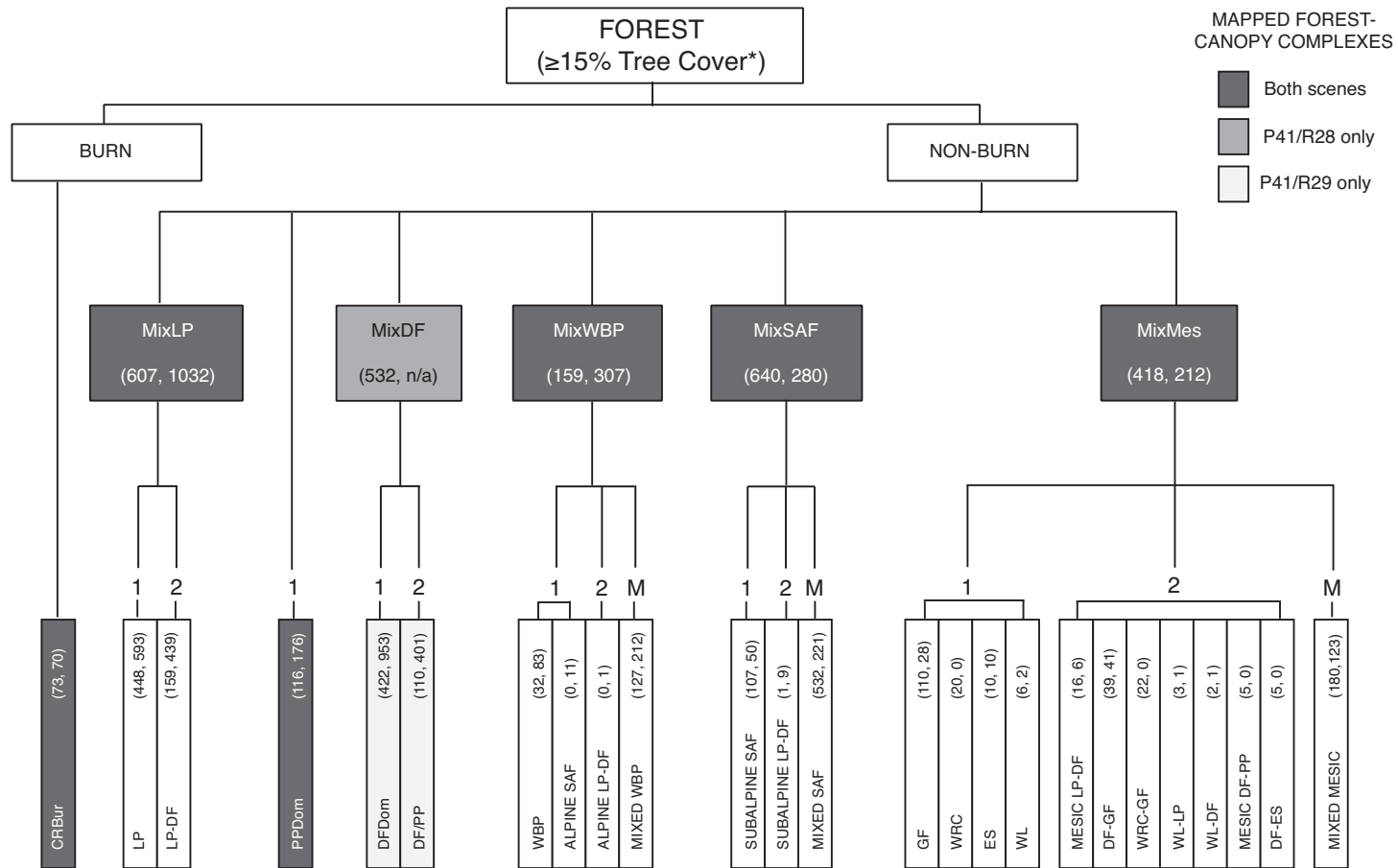
Forest-Canopy/Non-Forest Complexes: A hierarchical organization of all forest-canopy and non-forest plant community types recorded in this study is presented in Figures 4 and 5. These diagrams are not intended to define a comprehensive, all-purpose classification of plant associations for the ecosystem. Rather, they depict how the plant community types recorded in the field were agglomerated into vegetation complexes for purposes of mapping. In other words, they describe how we grouped the training data in classifying the unsupervised image. Although we were able to map some individual plant community types with acceptable accuracy, for convenience we generally refer to mapped vegetation associations (shaded boxes in Figures 4 and 5) as vegetation complexes. Three groupings of forest-canopy plant community types appear repeatedly in Figure 4. These are as follows:

Species *i* Dominant Forest: At least 66% relative coverage of tree species *i* in the middle and upper vegetative layers.

Species *i* / Species *j* Co-Dominant Forest: At least 80% relative coverage of tree species *i* plus species *j* in the middle and upper vegetative layers (with relative coverage of each species $< 66\%$).

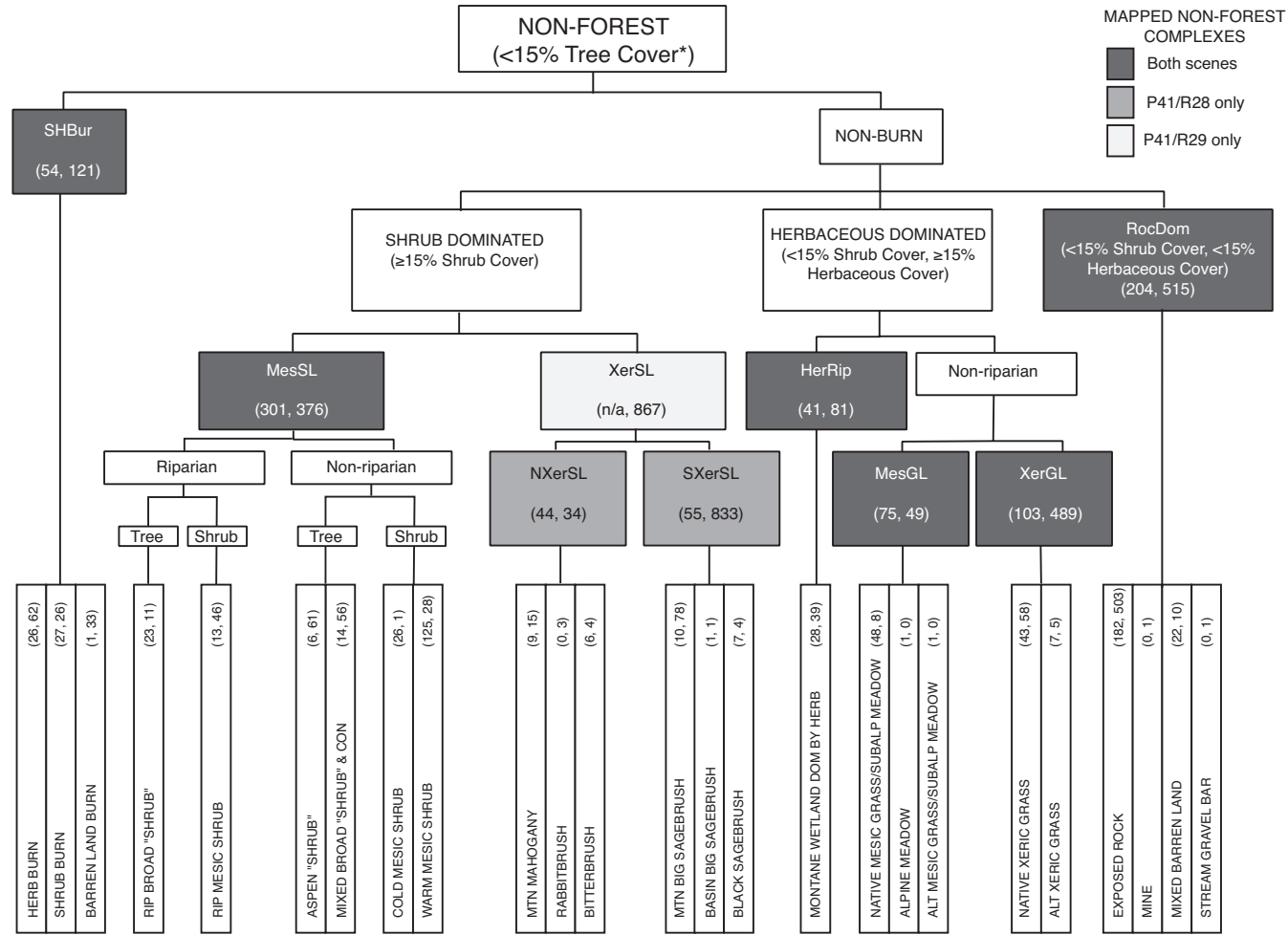
Mixed Forest: Any mixture of three or more tree species in the middle and upper layers that did not meet the criteria for dominant or co-dominant forests.

We also used the “mixed forest” label to indicate groupings of dominant, co-dominant, and mixed forest plant community types (tier two in Figure 4); i.e., for mixtures of forest types rather than of tree species within the same canopy. Context (one versus several plant community types) will determine which usage is intended. Finally, “open,” “partially closed,” and “closed” were



* "Cover" refers to absolute coverage. 1 = One Dominant Species; 2 = Two Co-Dominant Species; M = Mixed Species Canopy. LP = Lodgepole Pine; DF = Douglas-Fir; PP = Ponderosa Pine; WBP = Whitebark Pine; SAF = Subalpine Fir; GF = Grand Fir; WRC = Western Red Cedar; ES = Engelmann Spruce; WL = Western Larch.

Figure 4. Grouping scheme for the set of training data used to predict membership with respect to forest-canopy complex. The lowest tier of boxes indicate field-defined forest plant community types for which plot data were collected. Boxes in the upper tier represent groups of community types constructed for purposes of map classification. Shaded boxes indicate the plant community types and higher level groups that were actually mapped (complex abbreviations defined in Table 6). The numbers of training plots obtained for each type and group are in parentheses, with numbers for P41/R28 listed before P41/R29. Plot totals for mapped complexes sometimes exceed the sum for component plant community types because field-assignments of some R4 plots were made at the more general level.



* "Cover" refers to absolute coverage. HERB = Herbaceous; DOM = Dominated; RIP = Riparian; BROAD = Broadleaf; SHRUB = Shrublands; "SHRUB" = Shrubland-like forest types (see text); CON = Conifer; MTN = Mountain; GRASS = Grasslands; SUBALP = Subalpine; ALT = Altered.

Figure 5. Grouping scheme for the set of training data used to predict membership with respect to non-forest complex. The lowest tier of boxes indicates field-defined non-forest plant community types for which plot data were collected. Boxes in the upper tier represent groups of community types constructed for purposes of map classification. Shaded boxes indicate the plant community types and higher level groups that were actually mapped (complex abbreviations defined in Table 6). The numbers of training plots obtained for each type and group are in parentheses, with numbers for P41/R28 listed before P41/R29. Plot totals for mapped complexes sometimes exceed the sum for component plant community types because field-assignments of some R4 plots were made at the more general level.

used to describe forest canopies having 15–35%, 35–65%, and 65–100% absolute coverage of upper level trees, respectively.

In a small number of cases, plots field-assigned to the same plant community type were placed in different groupings of the training data. For example, plots that met the criteria for a Lodgepole Pine/Douglas-Fir Co-Dominant Forest plant community type but had 10% relative coverage of *Pinus albicaulis* and/or *Larix lyallii* were placed in the training set for Mixed Whitebark Pine Forest rather than Mixed Lodgepole Pine Forest. Our logic was that significant numbers of certain tree species were diagnostic of plant associations that were overall more typical of one branch versus another. In the example given above, the presence of 10% relative coverage *Pinus albicaulis* and/or *Larix lyallii* suggests a relatively cool/dry versus warm/dry regime and an overall species composition more typical of Mixed Whitebark Pine than Mixed Lodgepole Pine Forest.

In practice, these distinctions had no detectable impact on map detail (number of complexes mapped) or map accuracy relative to that obtained from a grouping of the training set that ignored such subtypes. However, the merit of this approach should not be decided by our application. The number of plots differently grouped by subtype was so small that sample size alone would preclude subtype-driven improvements in map detail or accuracy.

Forest-Understory Complexes: Using the statistical and ecological procedure described on p. 7, we grouped 123 (P41/R28) and 88 (P41/R29) observed habitat types into eight understory vegetation complexes (four per scene). Forty-eight and 35 habitat types in P41/R28 and P41/R29, respectively, accounted for roughly 80% of the understory training sets. These common types had greater statistical influence in map classification and are given correspondingly greater weight in the ecological characterizations of each understory complex (p. 72).

For purposes of presentation (Tables 2 and 3), we sorted habitat types within each understory complex by series and arranged series-groups according to the elevation of the zone in which the series species occurs as a climax dominant in the forest overstory (e.g., Figure 45 in Steele et al. 1981). Within each series, we ordered habitat types according to the soil moisture preference of the type's indicator species. Within each series/indicator combination, we ordered habitat types by the soil moisture preference of the type's phase species. Moister types were often also cooler, but this was not always true. For example, dry soils are found on cold, high elevation ridges and subsurface sources of water may saturate soils at warm, low-elevation sites. The rankings are ordinal; some adjacent habitat types may be more different in their moisture/temperature preferences than other pairs separated by several ranks. Finally, we assigned each habitat type to broad, absolute categories of soil moisture and temperature preference (Tables 2 and 3). These categories of preference are roughly comparable between series within complexes, between complexes, and so on. They are the basis of the descriptive clauses giving overall soil moisture and temperature ranges for each forest-understory complex (Table 4 and below). We used habitat type descriptions in Steele et al. (1981), Cooper et al. (1991), and Pfister et al. (1977) to assign relative moisture preferences and absolute moisture and temperature labels.

Table 2. Forest-understory complex membership (northern classification) for all habitat types represented in the training set. Sample sizes (N) are the number of plots field-assigned to each habitat type. Habitat types are sorted within each complex by increasing elevation of the climax zone for the series and by moisture preferences of indicator and phase species. See text for details of ordering and Steele et al. (1981), Cooper et al. (1991), and Pfister et al. (1977) for habitat type descriptions and species abbreviations.

North Understory Complex 10						North Understory Complex 20						North Understory Complex 30						North Understory Complex 40					
Series	Indic	Phase	Moist	Temp	N	Series	Indic	Phase	Moist	Temp	N	Series	Indic	Phase	Moist	Temp	N	Series	Indic	Phase	Moist	Temp	N
PINPON	AGRSPI	.	dry	hot	4	ABIGRA	CLIUNI	TAXBRE	moist	cool	2	PICENG	GALTRI	.	moist	cool	1	PINCON	FESIDA	.	dry	cool	3
PINPON	FESIDA	.	dry	hot	3	ABIGRA	ASACAU	MENFER	wet	cool	8	ABIGRA	LINBOR	XERTEN	moist	warm	35	PINCON	CARGEY	.	dry	cool	5
PINPON	FESIDA	FESIDA	dry	hot	2	ABIGRA	ASACAU	ASACAU	wet	cool	15	ABIGRA	LINBOR	LINBOR	moist	warm	15	PINCON	VACCAE	.	dry	cool	10
PINPON	SYMALB	.	dry	hot	3	ABIGRA	ASACAU	TAXBRE	wet	cool	11	ABIGRA	CLIUNI	PHYMAL	moist	cool	7	PINCON	VACSCO	.	dry	cold	60
PINPON	PHYMAL	.	dry	hot	3	THUPLI	CLIUNI	XERTEN	wet	cool	4	ABIGRA	CLIUNI	XERTEN	moist	cool	16	PINCON	XERTEN	.	moist	cool	5
PSEMEN	AGRSPI	.	dry	hot	6	THUPLI	CLIUNI	MENFER	wet	cool	11	ABIGRA	CLIUNI	MENFER	moist	cool	14	PICENG	HYPREV	.	moist	cool	4
PSEMEN	FESIDA	PINPON	dry	hot	2	THUPLI	CLIUNI	CLIUNI	wet	cool	32	ABIGRA	CLIUNI	CLIUNI	moist	cool	18	ABIGRA	XERTEN	.	moist	cool	31
PSEMEN	FESIDA	.	dry	hot	6	THUPLI	CLIUNI	TAXBRE	wet	cool	2	ABIGRA	SENTRI	.	wet	cool	8	ABIGRA	XERTEN	VACGLO	moist	cool	30
PSEMEN	SPIBET	PINPON	dry	hot	1	THUPLI	ASACAU	MENFER	wet	cool	7	TSUMER	CLIUNI	MENFER	moist	cool	6	ABIGRA	XERTEN	COPOCC	moist	cool	16
PSEMEN	SPIBET	.	dry	hot	1	THUPLI	ASACAU	ASACAU	wet	cool	21	ABILAS	LINBOR	VACSCO	moist	warm	2	TSUMER	XERTEN	VACSCO	moist	cool	5
PSEMEN	SPIBET	CALRUB	dry	hot	1	THUPLI	ASACAU	TAXBRE	wet	cool	4	ABILAS	LINBOR	XERTEN	moist	warm	3	TSUMER	XERTEN	VACGLO	moist	cool	2
PSEMEN	SYMALB	PINPON	dry	hot	2	THUPLI	GYMDRY	.	wet	cool	2	ABILAS	LINBOR	LINBOR	moist	warm	5	TSUMER	XERTEN	LUZHIT	moist	cool	8
PSEMEN	SYMALB	AGRSPI	dry	hot	8	THUPLI	ADIPED	.	wet	cool	5	ABILAS	MENFER	MENFER	moist	cool	7	TSUMER	LUZHIT	.	moist	cold	2
PSEMEN	SYMALB	.	dry	hot	3	THUPLI	ATHFIL	ADIPED	wet	cool	3	ABILAS	MENFER	.	moist	cool	15	TSUMER	MENFER	XERTEN	moist	cool	17
PSEMEN	SYMALB	SYMALB	dry	hot	3	THUPLI	ATHFIL	ATHFIL	wet	cool	9	ABILAS	CLIUNI	XERTEN	moist	cool	7	TSUMER	MENFER	LUZHIT	moist	cool	18
PSEMEN	SYMALB	CALRUB	dry	hot	4	THUPLI	OPLHOR	.	wet	cool	1	ABILAS	CLIUNI	MENFER	moist	cool	16	ABILAS	SPIBET	.	dry	warm	2
PSEMEN	BERREP	BERREP	dry	warm	1							ABILAS	CLIUNI	CLIUNI	moist	cool	5	ABILAS	CARGEY	CARGEY	dry	cold	1
PSEMEN	BERREP	CARGEY	dry	warm	1							ABILAS	CLIUNI	ARANUD	moist	cool	1	ABILAS	CALRUB	.	dry	warm	9
PSEMEN	CARGEY	PINPON	dry	warm	1							ABILAS	ALNSIN	.	moist	cool	2	ABILAS	VACCAE	.	dry	cool	4
PSEMEN	CARGEY	.	dry	warm	6							ABILAS	STRAMP	MENFER	wet	cool	11	ABILAS	VACSCO	PINALB	dry	cold	9
PSEMEN	CALRUB	PINPON	dry	warm	8							ABILAS	STRAMP	LIGCAN	wet	cool	12	ABILAS	VACSCO	CALRUB	dry	cool	4
PSEMEN	CALRUB	ARCUVA	dry	warm	6							ABILAS	CALCAN	LIGCAN	wet	cool	3	ABILAS	VACSCO	.	dry	cold	4
PSEMEN	CALRUB	CALRUB	dry	warm	27							ABILAS	CALCAN	CALCAN	wet	cool	10	ABILAS	VACSCO	VACSCO	dry	cold	33
PSEMEN	VACCAE	.	dry	warm	1							ABILAS	XERTEN	.	moist	cool	74	ABILAS	XERTEN	VACSCO	moist	cool	161
PSEMEN	PHYMAL	PINPON	dry	warm	1							ABILAS	XERTEN	VACGLO	moist	cool	37	ABILAS	XERTEN	VACGLO	moist	cool	37
PSEMEN	PHYMAL	CALRUB	dry	warm	17							ABILAS	XERTEN	LUZHIT	moist	cool	98	ABILAS	XERTEN	COPOCC	moist	cool	6
PSEMEN	PHYMAL	PHYMAL	dry	warm	43							ABILAS	XERTEN	COPOCC	moist	cool	6	ABILAS	VACGLO	VACSCO	moist	warm	8
PSEMEN	PHYMAL	SMISTE	dry	warm	4							ABILAS	VACGLO	VACSCO	moist	warm	10	ABILAS	VACGLO	VACGLO	moist	warm	4
PSEMEN	ACEGLA	ACEGLA	moist	warm	4							ABILAS	LUZHIT	VACSCO	moist	cold	44	ABILAS	LUZHIT	VACSCO	moist	cold	24
PSEMEN	VACGLO	ARCUVA	moist	warm	1							ABILAS	LUZHIT	LUZHIT	moist	cold	2	ABILAS	LUZHIT	LUZHIT	moist	cold	2
PSEMEN	VACGLO	XERTEN	moist	warm	7							ABILAS	MENFER	VACSCO	moist	cool	29	ABILAS	MENFER	VACSCO	moist	cool	15
PSEMEN	VACGLO	VACGLO	moist	warm	5							ABILAS	MENFER	XERTEN	moist	cool	15	ABILAS	MENFER	LUZHIT	moist	cool	19
PSEMEN	LINBOR	SYMALB	moist	warm	1							ABILAS	CALCAN	VACCAE	moist	cool	2	ABILAS	CALCAN	LEDGLA	wet	cool	15
PSEMEN	LINBOR	CALRUB	moist	warm	2							ABILAS	CALCAN	VACCAE	moist	cool	2	ABILAS	CALCAN	LEDGLA	wet	cool	15
PSEMEN	LINBOR	VACGLO	moist	warm	3							ABILAS	CALCAN	.	wet	cool	15	LARLYA	ABILAS	.	moist	cool	3
ABIGRA	SPIBET	.	dry	warm	3							ABILAS	CALCAN	.	wet	cool	15	PINALB	.	.	dry	cold	5
ABIGRA	PHYMAL	PHYMAL	dry	warm	22							ABILAS	CALCAN	.	wet	cool	15	PINALB	ABILAS	.	dry	cold	11
ABIGRA	PHYMAL	COPOCC	dry	warm	4																		
ABIGRA	VACGLO	.	moist	warm	10																		
ABILAS	COPOCC	.	moist	warm	2																		

Table 3. Forest-understory complex membership (southern classification) for all habitat types represented in the training set. Sample sizes (N) are the number of plots field-assigned to each habitat type. Habitat types are sorted within each complex by increasing elevation of the climax zone for the series and by moisture preferences of indicator and phase species. See text for details of ordering and Steele et al. (1981), Cooper et al. (1991), and Pfister et al. (1977) for habitat type descriptions and species abbreviations.

South Understory Complex 50						South Understory Complex 60						South Understory Complex 70						South Understory Complex 80						
Series	Indic	Phase	Moist	Temp	N	Series	Indic	Phase	Moist	Temp	N	Series	Indic	Phase	Moist	Temp	N	Series	Indic	Phase	Moist	Temp	N	
PINPON	AGRSPI	.	dry	hot	1	PSEMEN	CALRUB	CALRUB	dry	warm	62	PICENG	CARDIS	.	wet	cool	1	PINCON	FESIDA	.	dry	cool	6	
PINPON	FESIDA	.	dry	hot	2	PSEMEN	VACCAE	.	dry	warm	4	ABILAS	VACSCO	VACSCO	dry	cold	64	PINCON	CARGEY	.	dry	cool	10	
PINPON	PURTRI	AGRSPI	dry	hot	1	PSEMEN	VACGLO	.	moist	warm	16	ABILAS	XERTEN	VACSCO	moist	cool	72	PINCON	VACCAE	.	dry	cool	9	
PINPON	PHYMAL	.	dry	hot	1	PICENG	HYPREV	.	moist	cool	4	ABILAS	XERTEN	.	moist	cool	7	PINCON	VACSCO	.	dry	cold	60	
PSEMEN	AGRSPI	.	dry	hot	9	PICENG	GALTRI	.	moist	cool	5	ABILAS	XERTEN	LUZHIT	moist	cool	21	ABILAS	CARGEY	ARTTRI	dry	cold	4	
PSEMEN	FESIDA	PINPON	dry	hot	15	PICENG	EQUARV	.	moist	warm	3	ABILAS	LUZHIT	VACSCO	moist	cold	50	ABILAS	CARGEY	CARGEY	dry	cold	67	
PSEMEN	FESIDA	FESIDA	dry	hot	8	ABIGRA	VACCAE	.	dry	warm	1	ABILAS	LUZHIT	LUZHIT	moist	cold	5	ABILAS	RIBMON	.	dry	cool	1	
PSEMEN	CERLED	.	dry	hot	7	ABIGRA	XERTEN	VACGLO	moist	cool	2	ABILAS	MENFER	LUZHIT	moist	cool	3	ABILAS	VACSCO	PINALB	dry	cold	57	
PSEMEN	JUNCOM	.	dry	hot	1	ABIGRA	XERTEN	COPOCC	moist	cool	2	ABILAS	CALCAN	VACCAE	moist	cool	1	PINALB	.	.	dry	cold	8	
PSEMEN	SPIBET	PINPON	dry	hot	23	ABIGRA	VACGLO	.	moist	warm	11	ABILAS	CALCAN	LEDGLA	wet	cool	9	PINALB	ABILAS	.	dry	cold	14	
PSEMEN	SPIBET	.	dry	hot	1	ABIGRA	LINBOR	XERTEN	moist	warm	1	ABILAS	CALCAN	.	wet	cool	12							
PSEMEN	SPIBET	SPIBET	dry	hot	5	ABIGRA	LINBOR	VACGLO	moist	warm	2													
PSEMEN	SPIBET	CALRUB	dry	hot	19	ABIGRA	CLIUNI	.	moist	cool	8													
PSEMEN	SYMALB	PINPON	dry	hot	11	ABIGRA	CLIUNI	TAXBRE	moist	cool	3													
PSEMEN	SYMALB	SYMALB	dry	hot	21	ABIGRA	SENTRI	.	wet	cool	1													
PSEMEN	SYMORE	.	dry	hot	4	ABILAS	SPIBET	.	dry	warm	15													
PSEMEN	ARNCOR	ARNCOR	dry	hot	1	ABILAS	ARNCOR	.	dry	warm	2													
PSEMEN	BERREP	BERREP	dry	warm	2	ABILAS	CALRUB	.	dry	warm	67													
PSEMEN	BERREP	CARGEY	dry	warm	6	ABILAS	VACCAE	.	dry	cool	4													
PSEMEN	CARGEY	PINPON	dry	warm	6	ABILAS	VACSCO	CALRUB	dry	cool	27													
PSEMEN	CARGEY	SYMORE	dry	warm	5	ABILAS	ACEGLA	.	moist	cool	3													
PSEMEN	CARGEY	CARGEY	dry	warm	11	ABILAS	XERTEN	VACGLO	moist	cool	18													
PSEMEN	CALRUB	PINPON	dry	warm	30	ABILAS	VACGLO	VACSCO	moist	warm	17													
PSEMEN	CALRUB	FESIDA	dry	warm	2	ABILAS	VACGLO	.	moist	warm	4													
PSEMEN	PHYMAL	PINPON	dry	warm	23	ABILAS	VACGLO	VACGLO	moist	warm	32													
PSEMEN	PHYMAL	PSEMEN	dry	warm	31	ABILAS	LINBOR	LINBOR	moist	warm	2													
PSEMEN	PHYMAL	CALRUB	dry	warm	41	ABILAS	MENFER	MENFER	moist	cool	15													
PSEMEN	PHYMAL	PHYMAL	dry	warm	3	ABILAS	COPOCC	.	moist	warm	2													
PSEMEN	ACEGLA	ACEGLA	moist	warm	16	ABILAS	CLIUNI	MENFER	moist	cool	1													
ABIGRA	SPIBET	.	dry	warm	3	ABILAS	CLIUNI	CLIUNI	moist	cool	2													
ABIGRA	PHYMAL	PHYMAL	dry	warm	3	ABILAS	ALNSIN	.	moist	cool	1													
ABIGRA	PHYMAL	COPOCC	dry	warm	1	ABILAS	STRAMP	MENFER	wet	cool	1													
						ABILAS	STRAMP	LIGCAN	wet	cool	6													
						ABILAS	CALCAN	LIGCAN	wet	cool	1													
						ABILAS	CALCAN	CALCAN	wet	cool	4													

Table 4. Ecological characterization and numeric code for the eight forest understory vegetation complexes mapped north and south of the edge-match boundary.

Region	Understory complex code	Temperature class	Moisture class	Understory indicator species	Trees present ¹
North	10	hot to warm	dry	bunchgrass, ninebark, mountain snowberry, pinegrass, blue huckleberry	ponderosa pine, Douglas-fir
	20	cool	wet	queencup, wild ginger	western red cedar, grand fir
	30	warm to cool	moist to wet	queencup, twinflower, twisted stalk	grand fir, subalpine fir
	40	warm to cold	dry to moist	huckleberry, grouse whortleberry, beargrass, false huckleberry, bluejoint, smooth woodrush	grand fir, lodgepole pine, mountain hemlock, subalpine fir, whitebark pine
South	50	hot to warm	dry	bunchgrass, ninebark, mountain snowberry, pinegrass, elk sedge, white spirea	ponderosa pine, Douglas-fir
	60	warm	dry to moist	queencup, pinegrass, blue huckleberry, false huckleberry	Douglas-fir, grand fir, lodgepole pine, subalpine fir
	70	cool to cold	dry to moist	grouse whortleberry, beargrass, bluejoint, smooth woodrush	lodgepole pine, subalpine fir
	80	cold	dry	grouse whortleberry, elk sedge	lodgepole pine, subalpine fir, whitebark pine

¹ Characteristic species existing in the canopy or regenerating in the understory.

All eight understory complexes are ecologically quite broad. No two- or three-word label adequately captures the ecological linkages joining habitat types within a complex. Therefore, we created numeric labels for use when brevity is important and indexed the numeric labels to a four-part, descriptive clause appropriate to each understory complex (Table 4). The first part in each descriptive clause reflects temperature class (hot, warm, cool, cold), the second moisture class (dry, moist, wet), the third indicator species, and the fourth characteristic tree species. Characteristic tree species can be existing in the canopy or regenerating in the understory. Thus, this part of the description should not be confused with the labels used to describe forest-canopy complexes (Figure 4). Forest-canopy complex labels emphasize species existing in the canopy.

Vegetation Maps

Classifiers and sets of predictor variables used to label polygons in the unsupervised image to vegetation complex are listed in Table 5. Predicted spatial distributions for all mapped forest-canopy, forest-understory, and non-forest vegetation complexes are shown for the entire study area in Figures 6 and 7. In Figures 8 and 9, we have magnified one small portion of the southern scene to illustrate the level of resolution present throughout but not evident in the study-area-level presentations of the vegetation maps (Figures 6 and 7).

Predicted total acreage for each mapped vegetation complex north and south of the edge-match boundary is presented in Table 6. A cross-tabulation of predicted forest-canopy versus forest-understory labels for all forest polygons in the study area is presented in Table 7. This cross-tabulation represents our estimate of the frequency with which different canopy/understory

Table 5. Summary of statistical procedures used to classify polygons to vegetation complex.

Region	Classification	Classification rule	Predictor variables
North	Life form	Resampling distance weighted with mean group spatial classifier (k=5)	TM 1–7, elevation, slope, MNDVI
	Forest-canopy	Dudani distance weighted with nearest member group spatial classifier (k=17)	TM 1, 3, 4, 6, 7, elevation, aspect, slope
	Non-forest	Dudani distance weighted with mean group spatial classifier (k=18)	TM 1–3, 5–7, elevation, aspect, slope, MNDVI
	Forest-understory	Dudani distance weighted with mean group spatial classifier (k=40)	TM 1, 4–7, elevation, aspect, slope
South	Life form	Dudani distance weighted with mean group spatial classifier (k=9)	TM 1–7, elevation, aspect, slope, MNDVI
	Forest-canopy	Macleod distance weighted with mean group spatial classifier (k=16)	TM 4, 5, 6, elevation, aspect, slope
	Non-forest	Resampling distance weighted with nearest member group spatial classifier (k=6)	TM 1–7, elevation, slope
	Forest-understory	Dudani distance weighted with mean group spatial classifier (k=19)	TM 2–6, elevation, slope

combinations occur in the Salmon-Selway ecosystem. It also provides a means for evaluating how often ecologically-unlikely pairs of predictions were made. A similar cross-tabulation of all training set field assignments to forest-canopy versus understory is given in Table 8. This cross-tabulation summarizes observed canopy/understory combinations for a relatively small sample of area in the ecosystem.

When reviewing Figures 6–9 and Table 6, the reader should keep in mind that some apparent north-to-south patterns are the result of our having to map or define different vegetation complexes in the north versus the south. Specifically, we mapped Sage and Non-Sage Xeric Shrublands in the north but an agglomeration of these complexes (Xeric Shrublands) in the south. Similarly, we mapped Douglas-Fir Dominant and Douglas-Fir/Ponderosa Pine Co-Dominant Forests in the south but an agglomeration of these complexes (Mixed Douglas-Fir Forest) in the north. Finally, although north versus south understory complexes were generally ecologically related, we used different colors to represent each of the eight complexes. We did, however, use more similar colors for related complexes.

Table 6. Estimated area (hectares and percent of region) of each mapped non-forest, forest-canopy, and forest-understory vegetation complex in the Salmon-Selway ecosystem.¹

Vegetation complex	North of edge-match boundary		South of edge-match boundary	
	Hectares	(%)	Hectares	(%)
<u>Non-Forest</u>				
XerGL Xeric Grasslands	148,871	(4.8)	305,415	(9.2)
MesGL Mesic Grasslands/Subalpine Meadows	110,961	(3.6)	53,725	(1.6)
MesSL Mesic Shrublands	260,388	(8.4)	188,596	(5.7)
XerSL Xeric Shrublands	—	—	353,656	(10.7)
NXerSL Non-Sage Xeric Shrublands	9,606	(0.3)	—	—
SXerSL Sage Xeric Shrublands	32,457	(1.0)	—	—
SHBur Shrub-Herbaceous Dominated Burn	5,858	(0.2)	74,059	(2.2)
HerRip Herbaceous Riparian	6,871	(0.2)	25,539	(0.8)
RocDom Rock Dominated	96,753	(3.1)	238,901	(7.2)
Subtotal	671,764	(21.6)	1,239,892	(37.5)
<u>Forest-Canopy</u>				
MixLP Mixed Lodgepole Pine Forest	484,626	(15.6)	477,534	(14.4)
PPDom Ponderosa Pine Dominant Forest	90,905	(2.9)	166,975	(5.0)
MixDF Mixed Douglas-Fir Forest	486,958	(15.7)	—	—
DFDom Douglas-Fir Dominant Forest	—	—	547,197	(16.5)
DF/PP Douglas-Fir/Ponderosa Pine Co-Dominant Forest	—	—	95,306	(2.9)
MixWBP Mixed Whitebark Pine Forest	57,433	(1.8)	248,447	(7.5)
MixSAF Mixed Subalpine Fir Forest	499,243	(16.1)	227,642	(6.9)
MixMes Mixed Mesic Forest	736,028	(23.7)	212,688	(6.4)
CRBur Conifer Regeneration Dominated Burn	17,868	(0.6)	22,716	(0.7)
Subtotal	2,373,062	(76.4)	1,998,505	(60.4)
<u>Forest-Understory²</u>				
10 North Understory Complex 10	597,779	(19.2)	—	—
20 North Understory Complex 20	277,238	(8.9)	—	—
30 North Understory Complex 30	735,358	(23.7)	—	—
40 North Understory Complex 40	762,686	(24.5)	—	—
50 South Understory Complex 50	—	—	640,565	(19.4)
60 South Understory Complex 60	—	—	679,988	(20.5)
70 South Understory Complex 70	—	—	157,100	(4.7)
80 South Understory Complex 80	—	—	520,852	(15.7)
Subtotal	2,373,062	(76.4)	1,998,505	(60.4)
Other ³	63,030	(2.0)	70,957	(2.1)
Total	3,107,856	(100.0)	3,309,354	(100.0)

¹ A missing value (—) indicates that the vegetation complex was not mapped in this region.

² See Table 4 for an ecological characterization of understory complexes.

³ urban, agriculture, water, snow, cloud, and cloud shadow

Table 7. For each mapped forest-understory complex, the percentage of member polygons classified to each of the seven (north) or eight (south) possible forest-canopy complexes. Percentages sum to 100 across each row.

Forest-understory complex ¹	Forest-canopy complex ¹										No. of polygons
	PPDom	DF/PP	DFDom	MixDF	MixMes	MixLP	MixSAF	MixWBP	CRBur		
North 10	15.7	—	—	53.0	7.2	17.3	6.0	0.2	0.7	158,495	
20	1.0	—	—	3.6	94.6	0.3	0.5	0.0	0.1	66,066	
30	2.3	—	—	10.3	56.6	9.7	20.9	0.1	0.2	173,016	
40	0.8	—	—	12.5	3.0	37.3	37.1	8.2	1.2	186,124	
Total										583,701	
South 50	22.0	12.2	42.5	—	14.1	5.5	1.7	0.8	1.3	148,618	
60	3.2	2.2	32.5	—	14.7	31.4	12.9	2.2	0.9	139,731	
70	0.2	0.7	6.3	—	1.0	52.8	23.5	14.0	1.4	30,345	
80	0.8	1.3	14.2	—	0.9	23.3	16.5	41.7	1.3	113,367	
Total										432,061	

¹ For explanation of forest-understory numeric codes and forest-canopy abbreviations, see Tables 4 and 6, respectively.

Table 8. For each mapped forest-understory complex, the percentage of field-assigned training plots that were (simultaneously) field-assigned to each of the seven (north) or eight (south) possible forest-canopy complexes. Percentages sum to 100 across each row.

Forest-understory complex ¹	Forest-canopy complex ¹										No. of training plots
	PPDom	DF/PP	DFDom	MixDF	MixMes	MixLP	MixSAF	MixWBP	CRBur		
North 10	13.9	—	—	51.8	6.5	24.9	0.8	0.0	2.0	245	
20	0.0	—	—	5.4	88.3	0.0	6.3	0.0	0.0	111	
30	0.5	—	—	5.2	48.4	12.0	32.8	0.0	1.0	192	
40	0.0	—	—	1.7	5.9	29.4	39.8	14.5	8.7	763	
Total										1311	
South 50	6.7	17.3	63.3	—	1.3	9.9	0.6	0.0	1.0	313	
60	0.3	1.7	25.8	—	11.5	29.5	26.6	0.9	3.7	349	
70	0.0	0.0	0.0	—	0.8	26.9	39.2	26.1	6.9	245	
80	0.0	0.0	2.1	—	0.0	30.5	24.2	27.5	15.7	236	
Total										1143	

¹ For explanation of forest-understory numeric codes and forest-canopy abbreviations, see Tables 4 and 6, respectively.

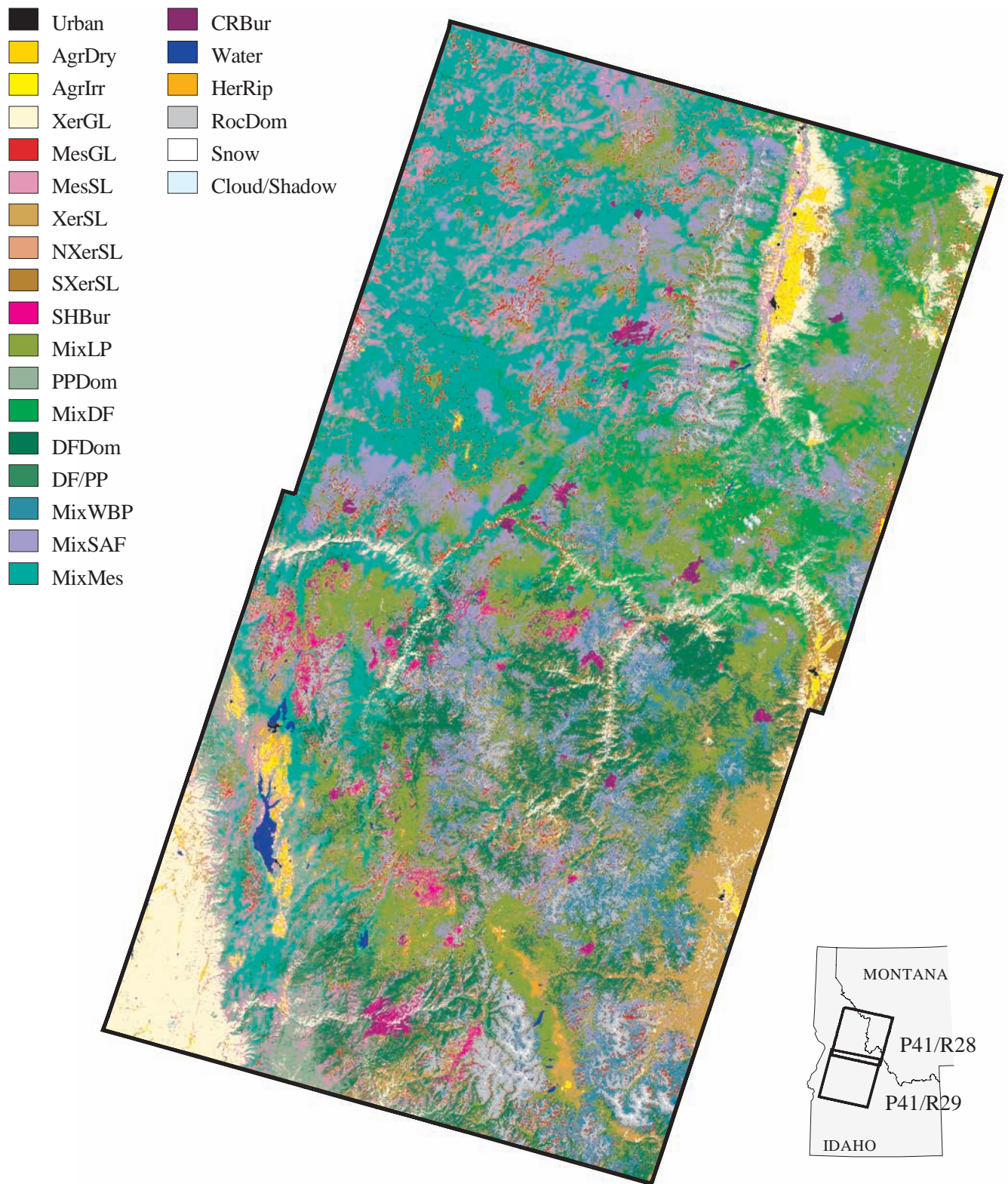


Figure 6. Spatial distribution of nine forest-canopy and nine non-forest vegetation complexes in the Salmon-Selway ecosystem.

Northern forest-understory complexes

10

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Southern forest-understory complexes

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60

70

80

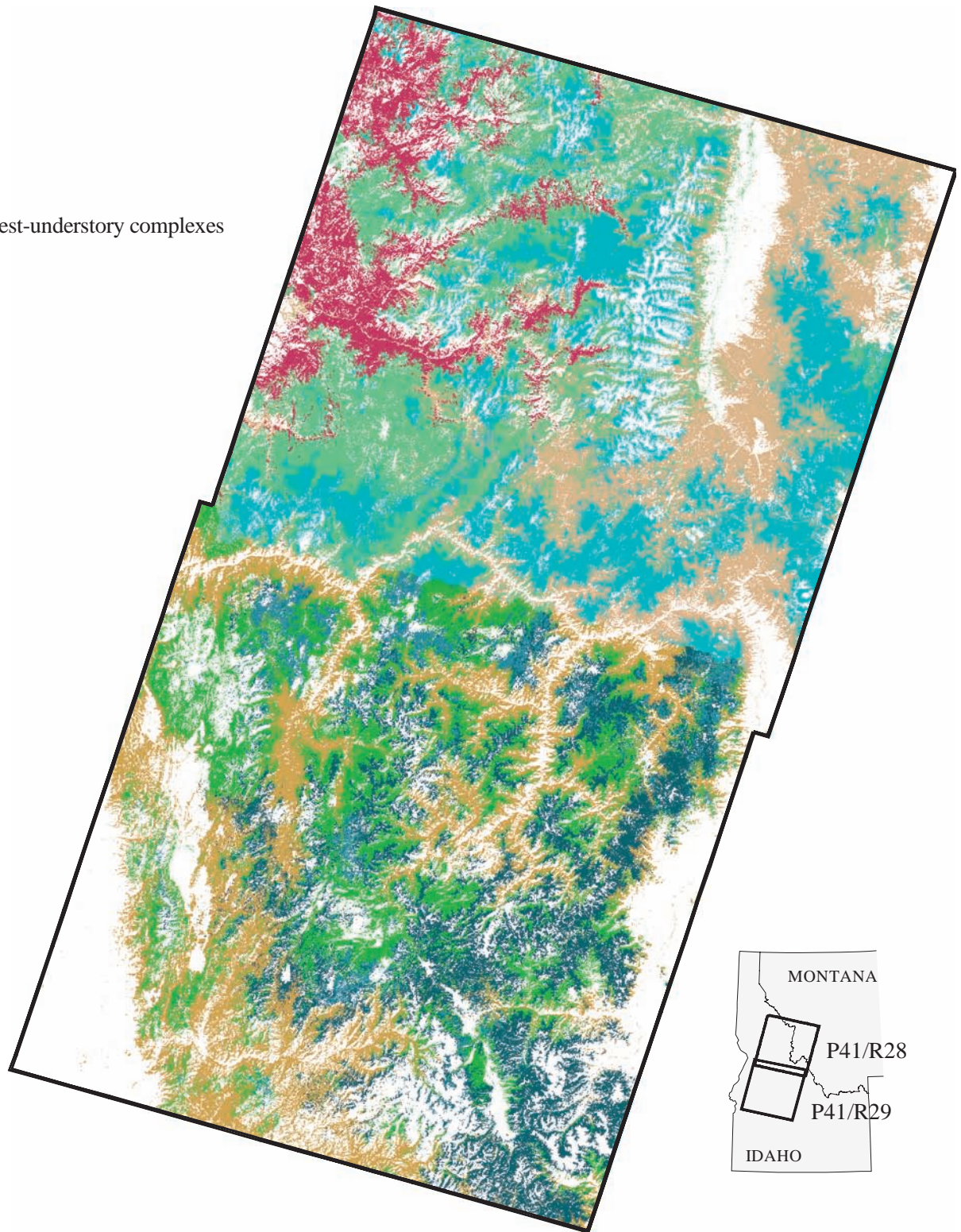


Figure 7. Spatial distribution of eight forest-understory vegetation complexes in the Salmon-Selway ecosystem. All non-forest polygons (see Figure 6) are coded white.

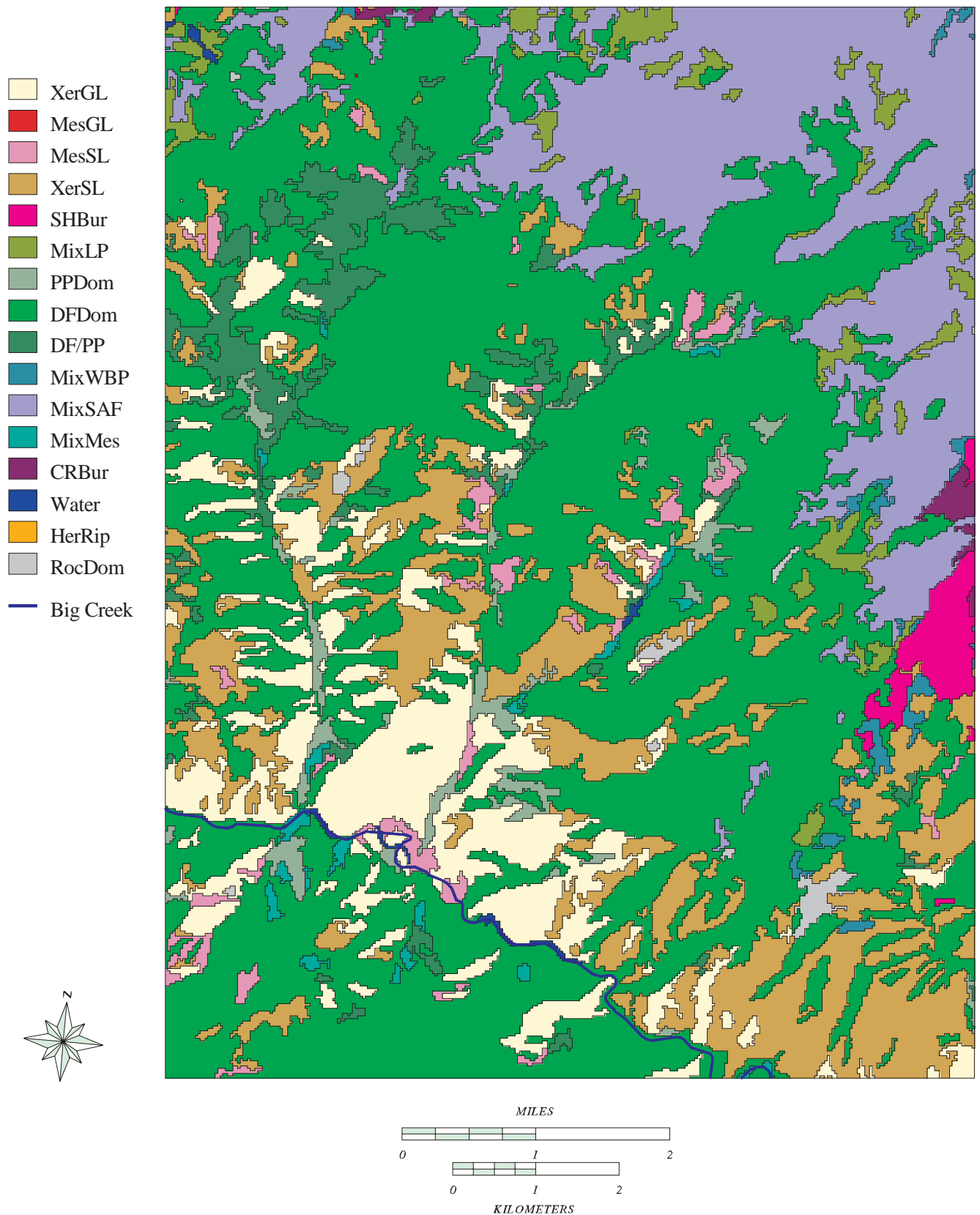


Figure 8. A portion of the forest-canopy/non-forest vegetation map illustrating the structure and color-based labeling of individual polygons. The area depicted is Big Creek (running diagonally at lower left) at its confluence with Cave and Cabin Creeks (flowing north to south). This area was severely burned in the summer of 2000.

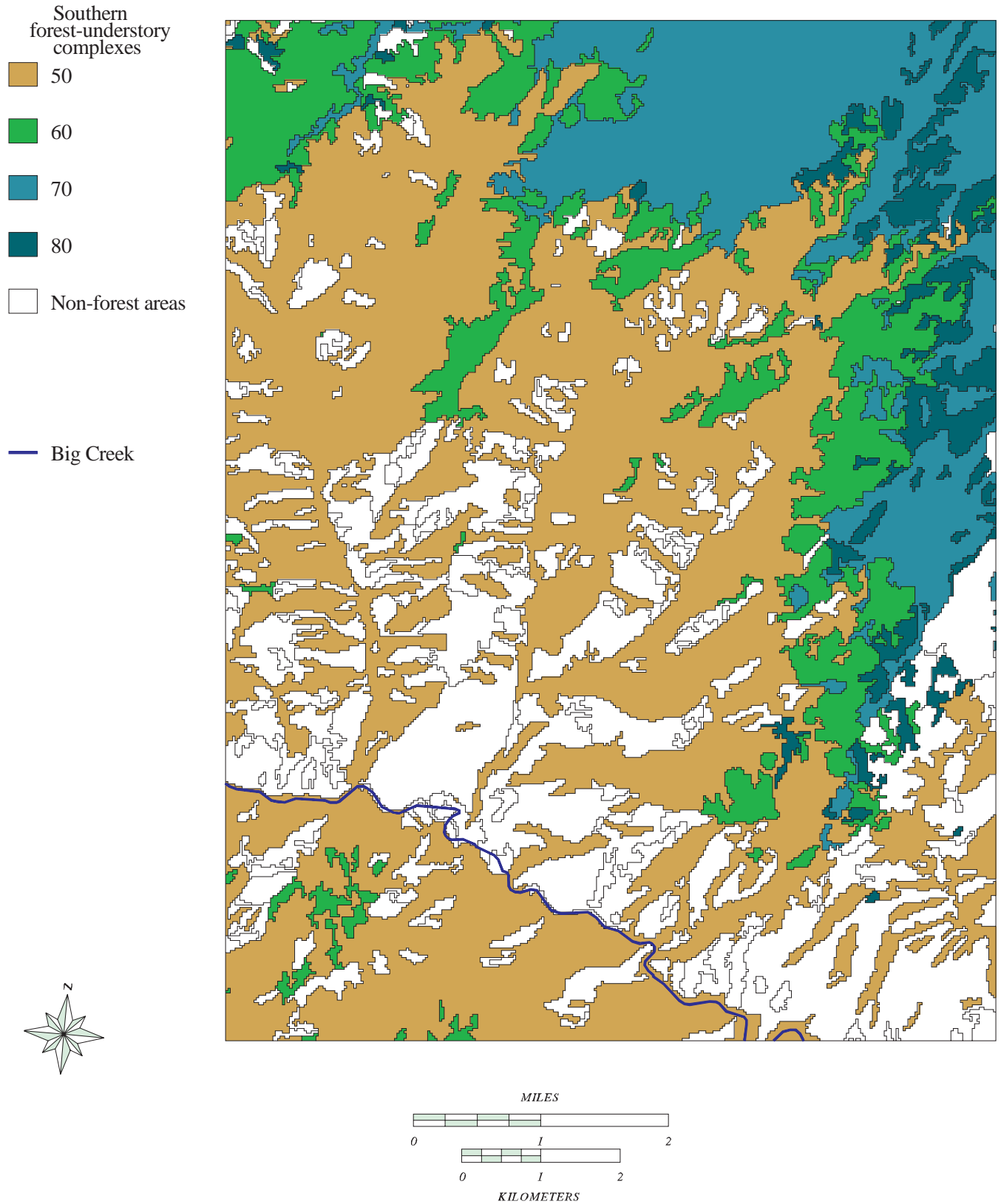


Figure 9. A portion of the forest-understory/non-forest vegetation map illustrating the structure and color-based labeling of individual polygons. All non-forest polygons are coded white. The area depicted is Big Creek (running diagonally at lower left) at its confluence with Cave and Cabin Creeks (flowing north to south). This area was severely burned in the summer of 2000.

Accuracy Assessment

In this section, we present several evaluations of map accuracy. These include estimates of (i) complex-specific user's accuracy, (ii) complex-specific producer's accuracy, (iii) overall accuracy, (iv) accuracy of the life form classification and for selected groups of vegetation complexes, and (v) spatial variation in accuracy.

User's Accuracy: User's accuracies were computed (via leave-one-out cross-validation; McLachlan 1992) as the fraction of all ground-truthed polygons predicted to be vegetation complex i that were in fact field-assigned to complex i . These fractions of correct prediction are presented, for each mapped complex and scene, on the diagonals of Tables 9–12. Off diagonal entries give the fraction of polygons that were predicted to be complex i but were field-assigned to another complex. Fractions sum to 1.0 down each column. User's accuracies most closely estimate the probability that a field observer, upon navigating to a polygon randomly chosen from our maps, would find that the predicted vegetation complex label correctly describes the plant association present at that site. All references in this report to complex-specific "map accuracy" are based upon the diagonal entries (user's accuracies) of Tables 9–12 unless noted otherwise.

Producer's Accuracy: Producer's accuracies were computed (via leave-one-out cross-validation) as the fraction of all ground-truthed polygons field-assigned to complex i that were correctly predicted to belong to complex i . These fractions of correct prediction are presented, for each mapped complex and scene, on the diagonals of Tables 13–16. Off diagonal entries are estimates of the fractions of polygons mis-classified to each other complex. Fractions sum to 1.0 across each row. In this report, we employ producer's accuracies to estimate the extent to which a given vegetation complex was mis-classified as each other complex. That is, we use only the off diagonal entries (producer's errors) from Tables 13–16 unless noted otherwise.

Overall, Life Form, and Complex Group Map Accuracy: Overall map accuracy was estimated (via leave-one-out cross-validation) as the number of training observations correctly classified over all vegetation complexes divided by the total number of training observations. Overall map accuracy ranged from 0.68 to 0.79 depending on scene and map (Table 17). We have listed four other sets of accuracies in Table 17. The set for "life form" gives the fraction of polygons correctly predicted to have a forest versus non-forest structure (ignoring whether the complex-specific label was correct or not). Life form was predicted with accuracies in excess of 0.90 in both north and south. The sets titled "forest-canopy," "forest-understory," and "non-forest" report a weighted average of user's accuracies for all complexes belonging to the group (Tables 9–12).

Spatial Accuracy: Spatial variation in overall map accuracies are depicted in Figures 10 and 11. Iso-lines are estimated local probabilities of correct prediction equal to 0.50, 0.60, 0.70, 0.80, and 0.90. Lighter tones indicate relative peaks in local accuracy and darker tones relative troughs.

Table 9. Complex-specific user’s accuracy (and error) matrix for the forest-canopy/non-forest vegetation map north of the edge-match boundary. Accuracies were computed using leave-one-out cross-validation. See Table 6 for explanation of abbreviations used to identify vegetation complexes.

Actual complex membership	Predicted complex membership															N
	XerGL	MesGL	MesSL	NXerSL	SXerSL	SHBur	MixLP	PPDom	MixDF	MixWBP	MixSAF	MixMes	CRBur	HerRip	RocDom	
XerGL	0.62	0.05	0.03	0.16	0.12	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.02	103
MesGL	0.03	0.40	0.09	0.00	0.02	0.03	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.01	75
MesSL	0.05	0.36	0.71	0.00	0.00	0.00	0.02	0.05	0.04	0.00	0.01	0.02	0.00	0.09	0.00	301
NXerSL	0.09	0.00	0.00	0.67	0.02	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	44
SXerSL	0.12	0.03	0.01	0.02	0.71	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.02	0.00	0.00	55
SHBur	0.01	0.01	0.00	0.00	0.02	0.79	0.01	0.00	0.00	0.00	0.00	0.00	0.16	0.05	0.00	54
MixLP	0.00	0.01	0.03	0.00	0.00	0.03	0.61	0.01	0.07	0.02	0.16	0.08	0.02	0.05	0.01	607
PPDom	0.03	0.00	0.03	0.07	0.00	0.00	0.00	0.66	0.06	0.00	0.00	0.02	0.00	0.00	0.00	116
MixDF	0.01	0.01	0.02	0.02	0.00	0.00	0.08	0.19	0.72	0.01	0.02	0.16	0.02	0.00	0.00	532
MixWBP	0.00	0.00	0.00	0.00	0.00	0.03	0.02	0.00	0.00	0.73	0.08	0.00	0.00	0.00	0.04	159
MixSAF	0.00	0.01	0.01	0.00	0.00	0.00	0.18	0.01	0.02	0.17	0.69	0.06	0.00	0.00	0.00	640
MixMes	0.00	0.01	0.03	0.00	0.00	0.00	0.02	0.02	0.06	0.00	0.03	0.65	0.00	0.00	0.00	418
CRBur	0.00	0.00	0.00	0.00	0.07	0.13	0.02	0.00	0.00	0.00	0.00	0.00	0.77	0.00	0.00	73
HerRip	0.01	0.03	0.03	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.82	0.00	41
RocDom	0.04	0.07	0.01	0.05	0.02	0.00	0.00	0.01	0.00	0.05	0.00	0.00	0.03	0.00	0.93	204
Total																3422

Table 10. Complex-specific user’s accuracy (and error) matrix for the forest-canopy/non-forest vegetation map south of the edge-match boundary. Accuracies were computed using leave-one-out cross-validation. See Table 6 for explanation of abbreviations used to identify vegetation complexes.

Actual complex membership	Predicted complex membership															N
	XerGL	MesGL	MesSL	XerSL	SHBur	MixLP	PPDom	DFDom	DF/PP	MixWBP	MixSAF	MixMes	CRBur	HerRip	RocDom	
XerGL	0.86	0.00	0.01	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	489
MesGL	0.00	0.71	0.02	0.00	0.02	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.05	0.00	49
MesSL	0.00	0.12	0.82	0.00	0.00	0.01	0.07	0.04	0.03	0.00	0.00	0.02	0.00	0.27	0.00	376
XerSL	0.11	0.02	0.02	0.86	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.02	867
SHBur	0.00	0.02	0.00	0.00	0.83	0.01	0.00	0.00	0.00	0.01	0.02	0.00	0.13	0.00	0.01	121
MixLP	0.00	0.00	0.00	0.00	0.00	0.75	0.01	0.10	0.02	0.06	0.13	0.05	0.06	0.00	0.00	1032
PPDom	0.00	0.00	0.04	0.00	0.00	0.00	0.52	0.01	0.11	0.00	0.00	0.03	0.00	0.00	0.00	176
DFDom	0.00	0.00	0.03	0.01	0.00	0.11	0.08	0.71	0.11	0.05	0.06	0.09	0.02	0.00	0.00	953
DF/PP	0.00	0.00	0.01	0.00	0.00	0.02	0.26	0.07	0.67	0.00	0.00	0.10	0.00	0.00	0.00	401
MixWBP	0.00	0.05	0.00	0.00	0.01	0.01	0.00	0.02	0.00	0.72	0.15	0.00	0.00	0.00	0.04	307
MixSAF	0.00	0.02	0.01	0.00	0.01	0.06	0.01	0.03	0.00	0.12	0.60	0.02	0.00	0.00	0.00	280
MixMes	0.00	0.00	0.01	0.00	0.00	0.01	0.05	0.01	0.06	0.00	0.02	0.70	0.00	0.00	0.00	212
CRBur	0.00	0.00	0.00	0.00	0.11	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.79	0.00	0.00	70
HerRip	0.00	0.02	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.68	0.00	81
RocDom	0.02	0.02	0.00	0.03	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.91	515
Total																5929

Table 11. Complex-specific user’s accuracy (and error) matrix for the forest-understory/non-forest vegetation map north of the edge-match boundary. Accuracies were computed using leave-one-out cross-validation. See Tables 4 and 6 for explanation of numeric codes and abbreviations used to identify vegetation complexes.

Actual complex membership	Predicted complex membership												N
	XerGL	MesGL	MesSL	NXerSL	SXerSL	SHBur	HerRip	RocDom	10	20	30	40	
XerGL	0.63	0.05	0.04	0.17	0.12	0.00	0.00	0.02	0.01	0.00	0.00	0.00	103
MesGL	0.03	0.41	0.10	0.00	0.02	0.03	0.00	0.01	0.00	0.00	0.01	0.01	75
MesSL	0.05	0.36	0.74	0.00	0.00	0.00	0.09	0.00	0.09	0.08	0.04	0.02	301
NXerSL	0.09	0.00	0.00	0.72	0.02	0.00	0.00	0.00	0.02	0.00	0.00	0.00	44
SXerSL	0.12	0.03	0.01	0.03	0.71	0.00	0.00	0.00	0.01	0.00	0.00	0.01	55
SHBur	0.01	0.01	0.00	0.00	0.02	0.79	0.05	0.00	0.00	0.00	0.00	0.02	54
HerRip	0.01	0.03	0.03	0.00	0.00	0.00	0.82	0.00	0.00	0.01	0.01	0.01	41
RocDom	0.04	0.07	0.01	0.05	0.02	0.00	0.00	0.94	0.01	0.00	0.00	0.01	204
10	0.02	0.00	0.04	0.03	0.00	0.03	0.00	0.00	0.66	0.10	0.12	0.05	245
20	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.02	0.68	0.09	0.00	111
30	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.06	0.11	0.46	0.06	192
40	0.00	0.04	0.01	0.00	0.07	0.15	0.05	0.04	0.12	0.03	0.28	0.82	763
Total													2188

Table 12. Complex-specific user’s accuracy (and error) matrix for the forest-understory/non-forest vegetation map south of the edge-match boundary. Accuracies were computed using leave-one-out cross-validation. See Tables 4 and 6 for explanation of numeric codes and abbreviations used to identify vegetation complexes.

Actual complex membership	Predicted complex membership											N
	XerGL	MesGL	MesSL	XerSL	SHBur	HerRip	RocDom	50	60	70	80	
XerGL	0.85	0.00	0.00	0.09	0.00	0.00	0.01	0.01	0.00	0.00	0.00	489
MesGL	0.00	0.74	0.02	0.00	0.02	0.04	0.00	0.00	0.00	0.00	0.02	49
MesSL	0.01	0.13	0.91	0.00	0.00	0.28	0.00	0.14	0.04	0.01	0.04	376
XerSL	0.12	0.05	0.01	0.86	0.00	0.00	0.03	0.01	0.00	0.00	0.00	867
SHBur	0.00	0.00	0.00	0.00	0.82	0.00	0.02	0.01	0.02	0.03	0.04	121
HerRip	0.00	0.03	0.04	0.00	0.00	0.67	0.00	0.00	0.00	0.00	0.00	81
RocDom	0.02	0.00	0.00	0.03	0.00	0.00	0.94	0.00	0.00	0.00	0.01	515
50	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.70	0.15	0.00	0.03	313
60	0.00	0.00	0.00	0.00	0.02	0.01	0.00	0.10	0.56	0.07	0.11	349
70	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.01	0.10	0.73	0.14	245
80	0.00	0.05	0.00	0.00	0.04	0.00	0.01	0.02	0.13	0.15	0.60	236
Total												3641

Table 13. Complex-specific producer’s accuracy (and error) matrix for the forest-canopy/non-forest vegetation map north of the edge-match boundary. Accuracies were computed using leave-one-out cross-validation. See Table 6 for explanation of abbreviations used to identify vegetation complexes.

Actual complex membership	Predicted complex membership															N
	XerGL	MesGL	MesSL	NXerSL	SXerSL	SHBur	MixLP	PPDom	MixDF	MixWBP	MixSAF	MixMes	CRBur	HerRip	RocDom	
XerGL	0.70	0.04	0.10	0.07	0.05	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.03	103
MesGL	0.04	0.40	0.37	0.00	0.01	0.01	0.07	0.01	0.01	0.01	0.04	0.00	0.00	0.00	0.01	75
MesSL	0.02	0.09	0.70	0.00	0.00	0.00	0.05	0.02	0.06	0.00	0.03	0.04	0.00	0.01	0.00	301
NXerSL	0.23	0.00	0.00	0.66	0.02	0.00	0.02	0.02	0.05	0.00	0.00	0.00	0.00	0.00	0.00	44
SXerSL	0.25	0.04	0.05	0.02	0.53	0.00	0.05	0.00	0.00	0.04	0.00	0.00	0.02	0.00	0.00	55
SHBur	0.02	0.02	0.00	0.00	0.02	0.57	0.17	0.00	0.00	0.00	0.00	0.00	0.19	0.02	0.00	54
MixLP	0.00	0.00	0.01	0.00	0.00	0.00	0.67	0.00	0.06	0.00	0.17	0.07	0.00	0.00	0.00	607
PPDom	0.03	0.00	0.07	0.03	0.00	0.00	0.01	0.53	0.27	0.00	0.00	0.07	0.00	0.00	0.00	116
MixDF	0.00	0.00	0.01	0.00	0.00	0.00	0.11	0.03	0.66	0.00	0.03	0.16	0.00	0.00	0.00	532
MixWBP	0.00	0.00	0.00	0.00	0.00	0.01	0.09	0.00	0.01	0.53	0.31	0.00	0.00	0.00	0.05	159
MixSAF	0.00	0.00	0.01	0.00	0.00	0.00	0.19	0.00	0.02	0.03	0.70	0.05	0.00	0.00	0.00	640
MixMes	0.00	0.00	0.02	0.00	0.00	0.00	0.04	0.00	0.07	0.00	0.05	0.82	0.00	0.00	0.00	418
CRBur	0.00	0.00	0.00	0.00	0.04	0.07	0.19	0.00	0.01	0.00	0.01	0.00	0.67	0.00	0.00	73
HerRip	0.02	0.05	0.22	0.00	0.00	0.00	0.10	0.02	0.00	0.00	0.10	0.05	0.00	0.44	0.00	41
RocDom	0.02	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.03	0.00	0.00	0.01	0.00	0.87	204
Total																3422

Table 14. Complex-specific producer’s accuracy (and error) matrix for the forest-canopy/non-forest vegetation map south of the edge-match boundary. Accuracies were computed using leave-one-out cross-validation. See Table 6 for explanation of abbreviations used to identify vegetation complexes.

Actual complex membership	Predicted complex membership															N
	XerGL	MesGL	MesSL	XerSL	SHBur	MixLP	PPDom	DFDom	DF/PP	MixWBP	MixSAF	MixMes	CRBur	HerRip	RocDom	
XerGL	0.82	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	489
MesGL	0.00	0.61	0.12	0.02	0.04	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.10	0.00	49
MesSL	0.01	0.01	0.70	0.01	0.00	0.03	0.04	0.10	0.02	0.00	0.00	0.01	0.00	0.07	0.00	376
XerSL	0.06	0.00	0.01	0.91	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	867
SHBur	0.00	0.01	0.00	0.02	0.70	0.08	0.00	0.01	0.01	0.03	0.04	0.00	0.05	0.00	0.04	121
MixLP	0.00	0.00	0.00	0.00	0.00	0.84	0.00	0.10	0.01	0.02	0.03	0.01	0.00	0.00	0.00	1032
PPDom	0.01	0.00	0.07	0.01	0.00	0.03	0.57	0.07	0.22	0.00	0.00	0.03	0.00	0.00	0.00	176
DFDom	0.00	0.00	0.01	0.01	0.00	0.14	0.02	0.73	0.04	0.02	0.01	0.02	0.00	0.00	0.00	953
DF/PP	0.00	0.00	0.00	0.01	0.00	0.05	0.12	0.17	0.59	0.00	0.00	0.05	0.00	0.00	0.00	401
MixWBP	0.00	0.01	0.00	0.01	0.00	0.03	0.00	0.05	0.00	0.74	0.10	0.00	0.00	0.00	0.06	307
MixSAF	0.00	0.00	0.01	0.01	0.00	0.26	0.00	0.12	0.00	0.14	0.44	0.02	0.00	0.00	0.00	280
MixMes	0.00	0.00	0.01	0.00	0.00	0.08	0.05	0.04	0.09	0.00	0.02	0.72	0.00	0.00	0.00	212
CRBur	0.00	0.00	0.00	0.00	0.16	0.23	0.00	0.04	0.00	0.03	0.01	0.00	0.53	0.00	0.00	70
HerRip	0.00	0.01	0.15	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.83	0.00	81
RocDom	0.02	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.91	515
Total																5929

Table 15. Complex-specific producer’s accuracy (and error) matrix for the forest-understory/non-forest vegetation map north of the edge-match boundary. Accuracies were computed using leave-one-out cross-validation. See Tables 4 and 6 for explanation of numeric codes and abbreviations used to identify vegetation complexes.

Actual complex membership	Predicted complex membership												N
	XerGL	MesGL	MesSL	NXerSL	SXerSL	SHBur	HerRip	RocDom	10	20	30	40	
XerGL	0.70	0.04	0.10	0.07	0.05	0.00	0.00	0.03	0.02	0.00	0.00	0.00	103
MesGL	0.04	0.40	0.37	0.00	0.01	0.01	0.00	0.01	0.01	0.00	0.03	0.11	75
MesSL	0.02	0.09	0.70	0.00	0.00	0.00	0.01	0.00	0.07	0.03	0.03	0.06	301
NXerSL	0.23	0.00	0.00	0.66	0.02	0.00	0.00	0.00	0.09	0.00	0.00	0.00	44
SXerSL	0.25	0.04	0.05	0.02	0.53	0.00	0.00	0.00	0.04	0.00	0.00	0.07	55
SHBur	0.02	0.02	0.00	0.00	0.02	0.57	0.02	0.00	0.00	0.00	0.00	0.35	54
HerRip	0.02	0.05	0.22	0.00	0.00	0.00	0.44	0.00	0.00	0.02	0.07	0.17	41
RocDom	0.02	0.02	0.01	0.01	0.00	0.00	0.00	0.87	0.01	0.00	0.00	0.04	204
10	0.01	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.63	0.04	0.12	0.15	245
20	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.04	0.70	0.21	0.01	111
30	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.07	0.06	0.62	0.22	192
40	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.01	0.04	0.00	0.09	0.83	763
Total													2188

Table 16. Complex-specific producer’s accuracy (and error) matrix for the forest-understory/non-forest vegetation map south of the edge-match boundary. Accuracies were computed using leave-one-out cross-validation. See Tables 4 and 6 for explanation of numeric codes and abbreviations used to identify vegetation complexes.

Actual complex membership	Predicted complex membership											N
	XerGL	MesGL	MesSL	XerSL	SHBur	HerRip	RocDom	50	60	70	80	
XerGL	0.82	0.00	0.00	0.17	0.00	0.00	0.01	0.00	0.00	0.00	0.00	489
MesGL	0.02	0.59	0.14	0.02	0.04	0.08	0.00	0.00	0.00	0.02	0.08	49
MesSL	0.01	0.01	0.69	0.01	0.00	0.08	0.00	0.12	0.05	0.01	0.02	376
XerSL	0.06	0.00	0.00	0.91	0.00	0.00	0.01	0.00	0.00	0.00	0.00	867
SHBur	0.00	0.00	0.00	0.03	0.66	0.00	0.08	0.02	0.07	0.06	0.07	121
HerRip	0.00	0.01	0.14	0.00	0.00	0.84	0.00	0.00	0.00	0.01	0.00	81
RocDom	0.02	0.00	0.00	0.05	0.00	0.00	0.92	0.00	0.00	0.00	0.01	515
50	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.71	0.24	0.00	0.02	313
60	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.09	0.79	0.04	0.06	349
70	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.01	0.20	0.64	0.11	245
80	0.00	0.01	0.00	0.00	0.02	0.00	0.02	0.03	0.26	0.14	0.52	236
Total												3641

Table 17. Accuracy of classification to life form and various vegetation complex groups¹ (e.g., forest-canopy, forest-understory, etc.) north and south of the edge-match boundary.

Classification	Classification accuracy	
	North of edge-match	South of edge-match
Life form	0.95	0.96
Forest-canopy	0.67	0.70
Forest-understory	0.73	0.64
Non-forest	0.73	0.85
Forest-canopy/non-forest	0.68	0.77
Forest-understory/non-forest	0.72	0.79

¹ calculated as the weighted average of user's accuracies for all vegetation complexes in the group

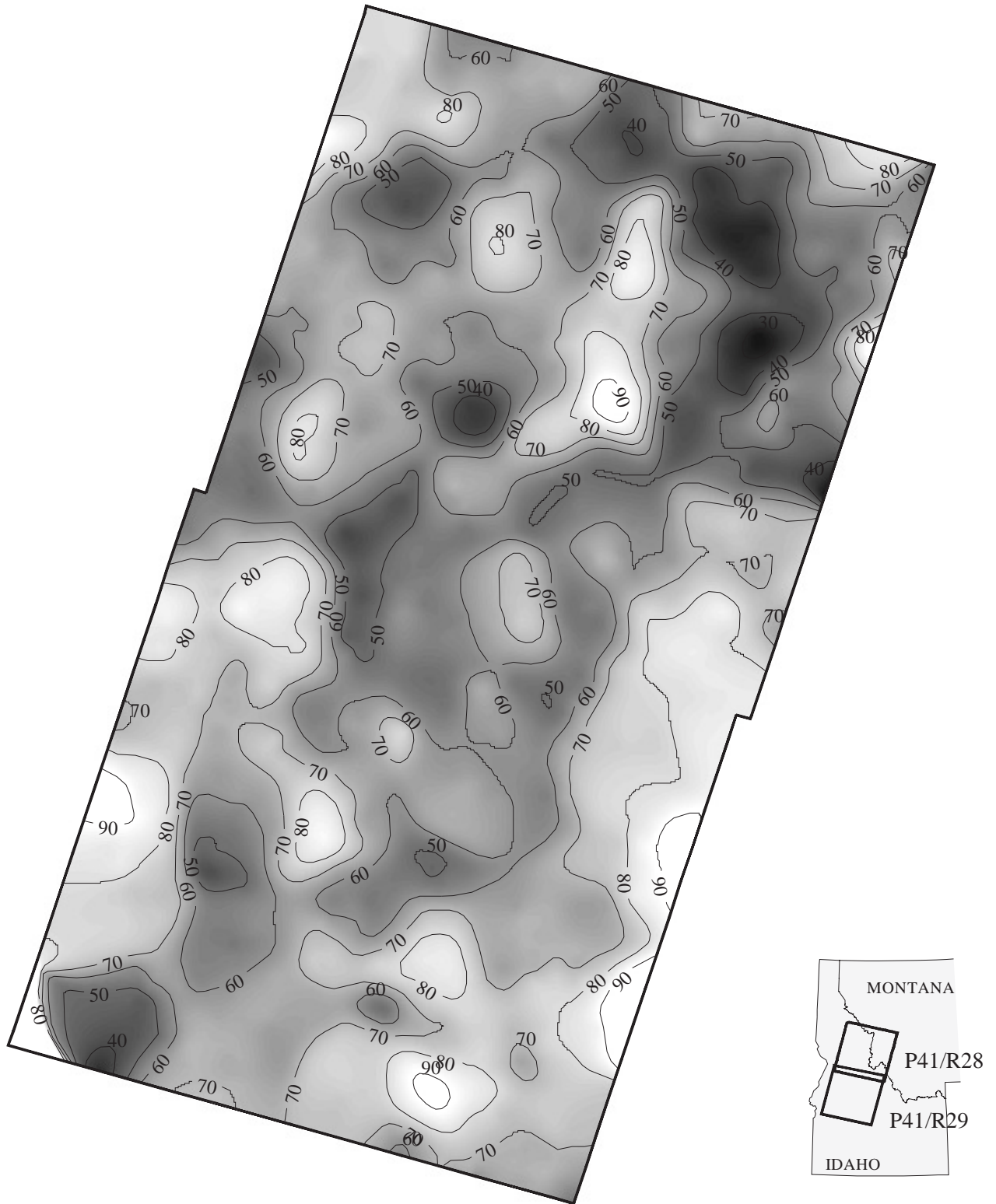


Figure 10. Contour map of overall accuracy in the classification of polygons to forest-canopy/non-forest vegetation complex.

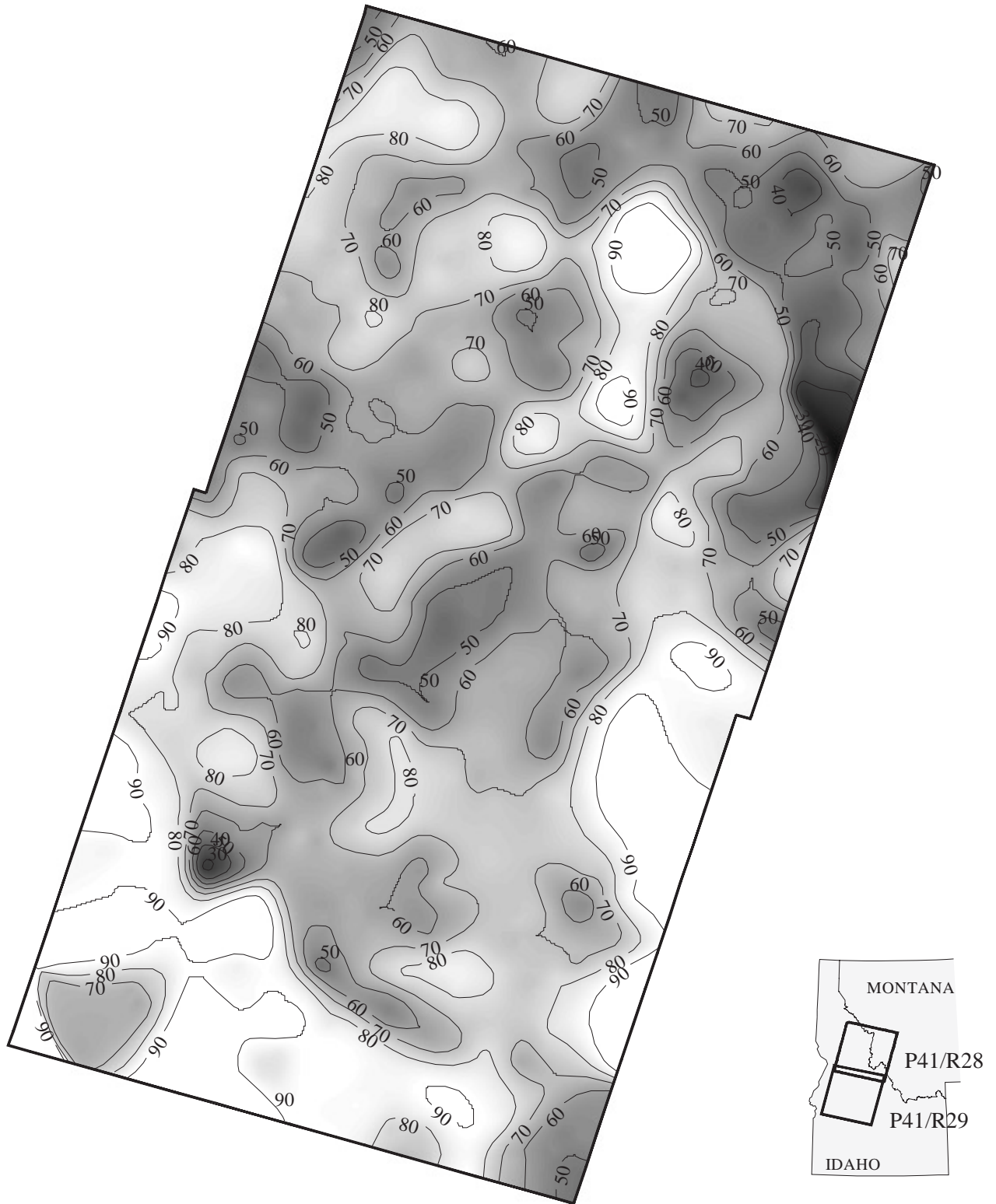


Figure 11. Contour map of overall accuracy in the classification of polygons to forest-understory/non-forest vegetation complex.



-Clara K. Smith

Vegetation Atlas: Ecological Descriptions of Mapped Complexes

The following sections provide descriptive information for each mapped vegetation complex. The format differs somewhat for forest-canopy and non-forest versus forest-understory complexes. Subsections for the former set of complexes are as follows. “Field definition” identifies necessary and sufficient criteria for assignment of training plots to the complex. “Ecological notes” are based on the summaries of full plots presented in Appendix A to the CD version of this report, general observations recorded on plot, and previous descriptions of the same or similar types. “Full plot totals” is straightforwardly the number of full plots available for the ecological description. This total is always much less than the number of training plots because species lists to 5% area coverage were not obtained for most training plots. “User’s accuracy” and notes on “Mis-classification” were based on Tables 9–12 and Tables 13–16, respectively. Finally, “Predicted elevation” gives summary statistics on elevation for all polygons classified to the vegetation complex in question. Polygon elevation was computed as the average elevation of all member pixels. Elevation range is presented with values in the upper and lower five percentiles trimmed (“trimmed range”).

Subsections in the forest-understory complex descriptions are those for non-forest and forest complexes except that “Field definition” has been omitted and “Existing forest overstories” has been added. Field definitions for component habitat types can be found in Pfister et al. (1977), Steele et al. (1981), and Cooper et al. (1991). Readers wanting more detailed information on the species composition of individual habitat types should consult constancy tables in these same references. Content for the “Existing forest overstories” section was derived from a cross-tabulation (for all understory training plots) of field assignment to forest-understory versus field assignment to forest-canopy complex. (These cross-tabulations are collated for all complexes in Table 8.) This type of cross-tabulation should not be confused with the distribution of these same understory training plots across habitat types (Tables 2 and 3). The tree species identifying habitat types reflects the (potential) climax dominant whereas field assignments of training plots to forest-canopy complex were based on all tree species existing in upper and middle layers—some or all of which might have been seral associates.

The text, photograph(s), and distribution map for each complex are presented on facing pages. Overall, the atlas is organized as follows:

- non-forest vegetation complexes (nine total)
- forest-canopy vegetation complexes (nine total)
- north forest-understory vegetation complexes (four total)
- south forest-understory vegetation complexes (four total)

Within each of these groups, member complexes are ordered (approximately) in terms of increasing elevation at which the complex was typically found.

Xeric Grasslands

Field definition:

At least 15% absolute coverage by herbs, less than 15% absolute coverage of trees, less than 15% absolute coverage of shrubs, and greater volume of dry versus mesic site herbaceous species.



Bighorn Crags quadrangle

—J. Hogg

Ecological notes:

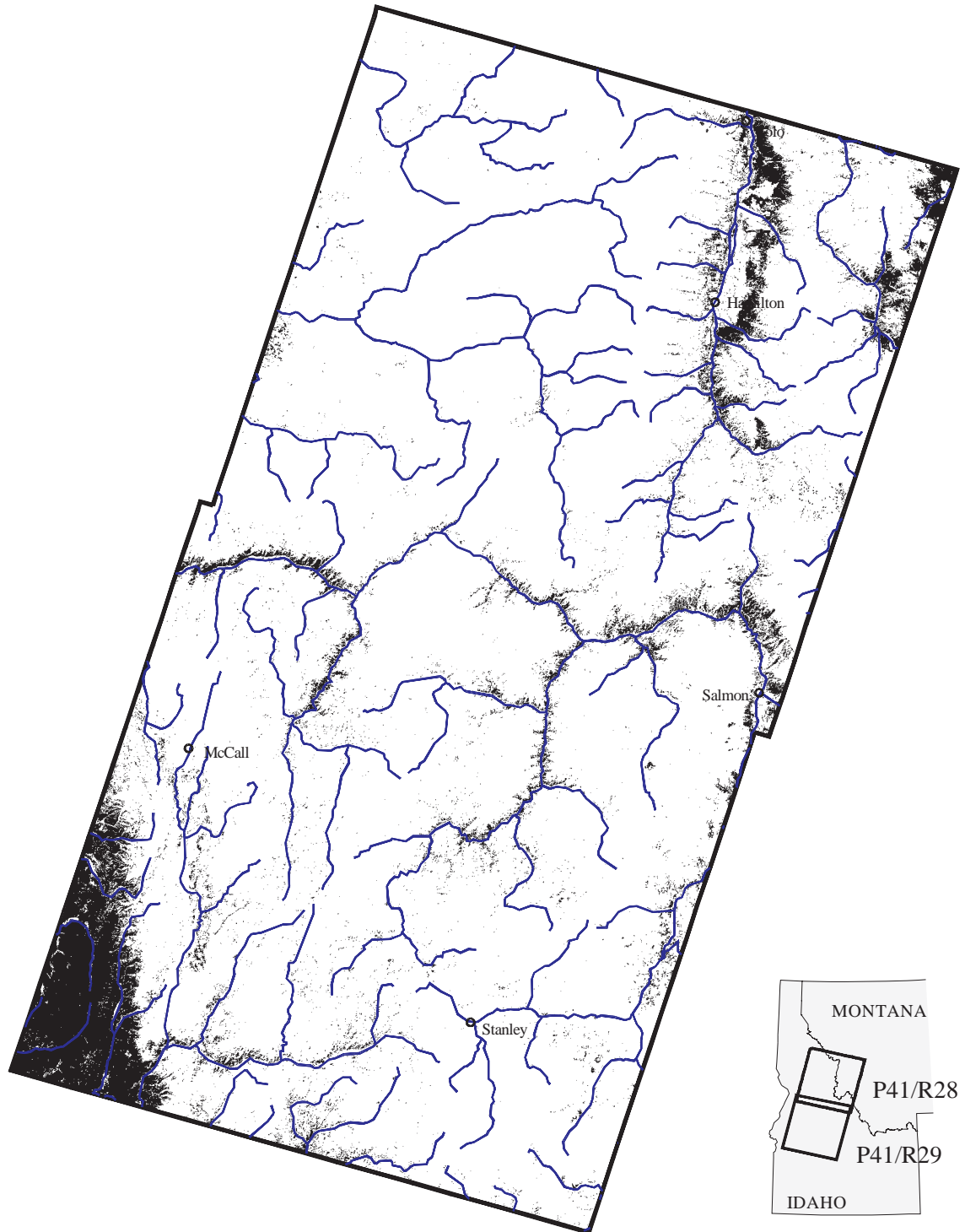
Xeric Grasslands were found at low to mid-elevation sites in arid valley bottoms, foothills, and rolling uplands. There was usually substantial exposed soil and rock and little or no accumulation of litter. Considering all life forms, the most frequent and common species were *Agropyron spicatum*, *Festuca idahoensis*, *Balsamorhiza sagittata*, and, in the “altered xeric grasslands” plant community type, the exotic, *Bromus tectorum*. Another exotic, *Centaurea maculosa*, was frequent and abundant in the north reflecting, in part, heavy infestations in the Selway River corridor. When trees were present, they were species common to the interface between forest and non-forest, usually *Pinus ponderosa* and *Pseudotsuga menziesii*. Among shrubs, only *Purshia tridentata* was recorded in more than a few percent of plots (7%), but a variety of shrubs had conditional coverages on the order of 10% (e.g., *Cercocarpus ledifolius*, *Artemisia* spp., *Physocarpus malvaceus*, *Amelanchier alnifolia*, and *Ceanothus velutinus*).

Full plot totals: 46 (P41/R28); 45 (P41/R29)

User’s accuracy: 62% (P41/R28); 86% (P41/R29)

Mis-classification: In P41/R28, the Xeric Grasslands complex was most frequently mis-classified as either Sage or Non-Sage Xeric Shrublands (12%) and as Mesic Shrublands (10%). In P41/R29, it was most commonly mis-classified as Xeric Shrublands (16%), which is an agglomeration of the Sage and Non-Sage Xeric Shrublands complexes. The Xeric Shrublands types occupied similarly dry sites at low elevation and were often intermixed with or adjacent to Xeric Grasslands.

Distribution of Xeric Grasslands:



Estimated Area: 454,286 total ha (7.1% of study area)

Predicted Elevation: mean 1590 m; median 1558 m; trimmed range 1013 - 2297 m

Mesic Grasslands/Subalpine Meadows

Field definition:

At least 15% absolute coverage by herbs, less than 15% absolute coverage of trees, less than 15% absolute coverage of shrubs, and greater volume of mesic versus dry site herbaceous species.



Cold Meadows quadrangle

—M. Pokorny

Ecological notes:

These were relatively moist, mid- to high-elevation grasslands

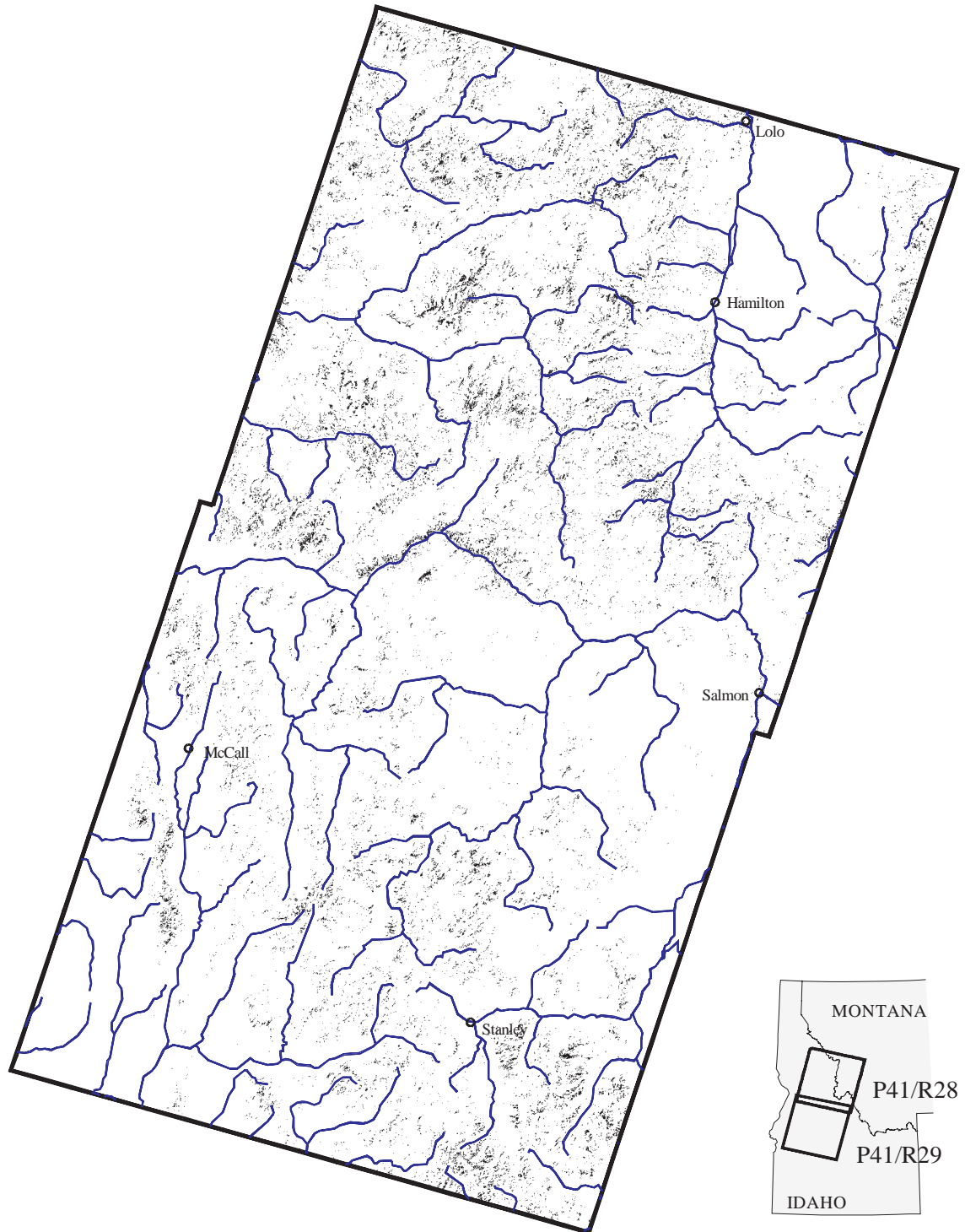
typically found in patches within montane forests or more extensively near upper timberline. Higher elevation grasslands in this complex were subject to late snow melts, brief growing seasons, and seasonally saturated soils. The most frequent and common plants were *Carex geyeri* and *Xerophyllum tenax*. Trees such as *Abies lasiocarpa*, *Pinus contorta*, *Pinus albicaulis*, and *Pseudotsuga menziesii* were frequently present but mainly as scattered seedlings or saplings. Among shrubs, only *Vaccinium scoparium* was present in more than a few percent of plots in both scenes (8% and 7% in the north and south, respectively). However, in the north, several “mesic” (see footnote 1, p. 40) shrubs had constancy and conditional coverage on the order of 5% and 10%, respectively (e.g., *Amelanchier alnifolia*, *Symphoricarpos mollis*, and *Vaccinium globulare*).

Full plot totals: 40 (P41/R28); 28 (P41/R29)

User’s accuracy: 40% (P41/R28); 71% (P41/R29)

Mis-classification: The Mesic Grasslands/Subalpine Meadows complex was predominately mis-classified in P41/R28 as Mesic Shrublands (37%), a complex that occupied comparably moist sites and shared many herbaceous and shrub species. In P41/R29, it was mis-classified with low and roughly equal frequency among two similarly moist, high-productivity, non-forest associations (Mesic Shrublands [12%] and Herbaceous Riparian [10%]) and one high elevation forest complex (Mixed Whitebark Pine [10%]).

Distribution of Mesic Grasslands/Subalpine Meadows:



Estimated Area: 164,686 total ha (2.6% of study area)

Predicted Elevation: mean 1899 m; median 1932 m; trimmed range 1083 - 2657 m

Non-Sage Xeric Shrublands

Field definition: Less than 15% absolute coverage of trees, at least 15% absolute coverage of shrubs, and greater volume of non-sage xeric shrubs than sage xeric shrubs or mesic shrubs.¹

Ecological notes: This complex was found in arid valley bottoms, river canyons (e.g., Salmon River Breaks), and foothills up to lower timberline and in small patches on west and south aspects within the forest zone. Soil and rock were frequently exposed and litter accumulation limited. There was typically a sparse and relatively species-poor herbaceous layer of bunchgrasses (most frequently *Agropyron spicatum* and *Festuca idahoensis*) and forbs (most frequently *Balsamorhiza sagittata*). The exotics *Bromus tectorum* and *Centaurea maculosa* had high conditional coverages on many sites. Among shrubs, *Purshia tridentata* and *Cercocarpus ledifolius* were most frequent and abundant. *Chrysothamnus nauseosus* and *Artemisia tridentata vaseyana* were also well represented. *Pinus ponderosa* and *Pseudotsuga menziesii* were occasionally recorded at low frequency and absolute coverage in the upper layer of this complex.



Atlanta East quadrangle

—M. Jones

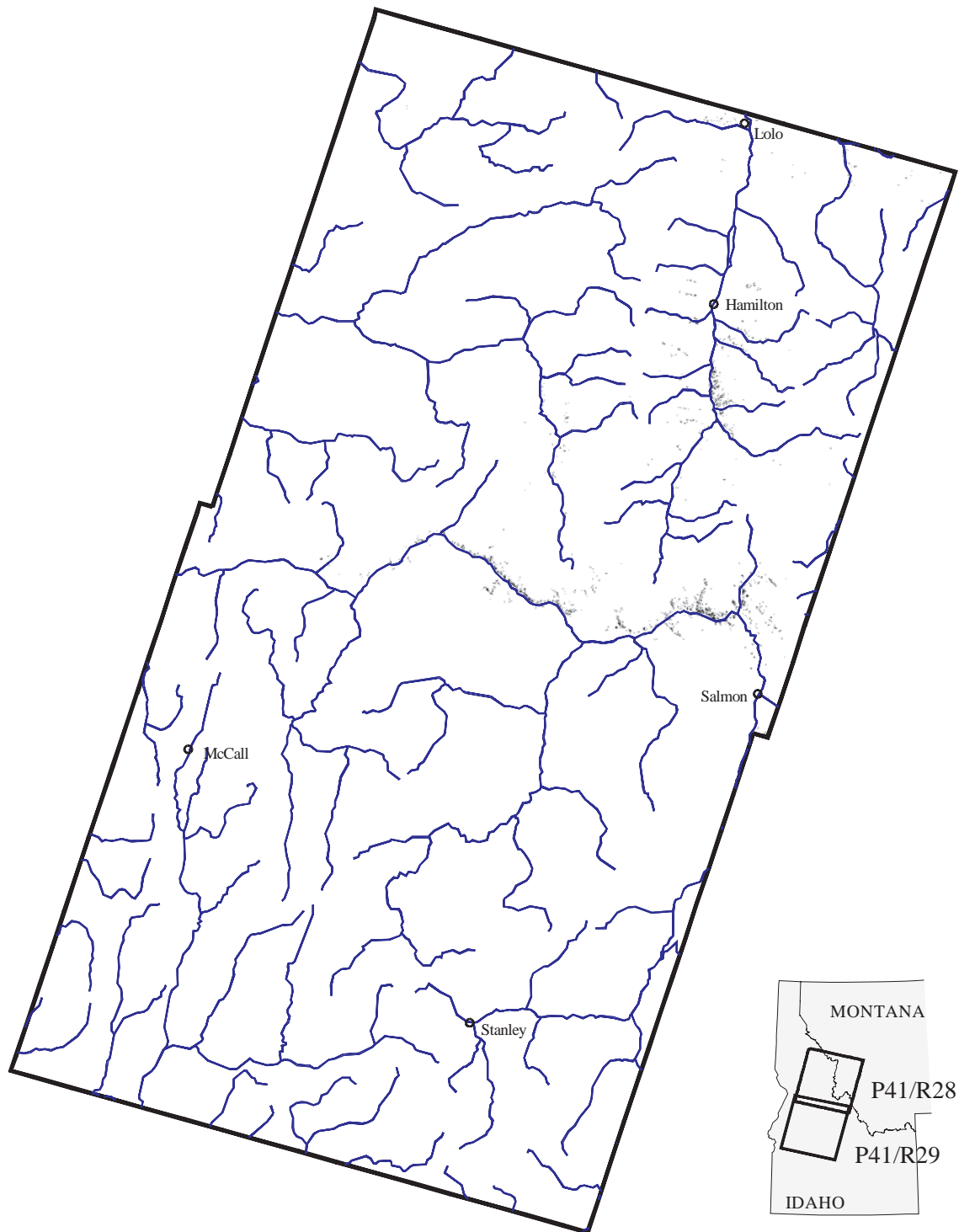
Full plot totals: 7 (P41/R28); 15 (P41/R29)

User's accuracy: 67% (P41/R28); — (P41/R29)

Mis-classification: In P41/R28, Non-Sage Xeric Shrublands were most frequently misclassified as Xeric Grasslands (23%), but were rarely (2%) confused with the Sage Xeric Shrublands. Nonetheless, we were unable to distinguish Non-Sage and Sage Xeric Shrublands with acceptable accuracy in the south. Hence, training data for these two complexes were lumped in P41/R29 where we mapped an agglomeration of Non-Sage and Sage Xeric Shrublands labeled Xeric Shrublands (below).

¹ Non-sage xeric shrubs were all *Chrysothamnus* spp., *Cercocarpus ledifolius*, *Purshia tridentata*, and all *Atriplex* spp. Sage xeric shrubs were all species in the genus *Artemisia*. “Mesic” shrubs are best described by exclusion; the group includes all shrubs not belonging to the five “xeric” shrub genera (*Artemisia*, *Atriplex*, *Cercocarpus*, *Chrysothamnus*, and *Purshia*). Warm-site mesic shrubs included *Physocarpus malvaceus*, *Ceanothus* spp., and *Prunus* spp. Cold-site mesic shrubs included all *Vaccinium* spp., *Ledum glandulosum*, and *Menziesia ferruginea*.

Distribution of Non-Sage Xeric Shrublands:



Estimated Area: 9,606 total ha (0.3% of study area north of edge-match)

Predicted Elevation: mean 1404 m; median 1397 m; trimmed range 1000 - 1814 m

Sage Xeric Shrublands

Field definition:

Less than 15% absolute coverage of trees, at least 15% absolute coverage of shrubs, and a greater volume of sage species (*Artemisia*) than non-sage xeric or mesic shrubs.

Ecological notes:

This complex occupied many of the same physiographic sites as did Non-Sage Xeric Shrublands (valley bottoms and foothills to lower



Clayton quadrangle

—C. Riegel

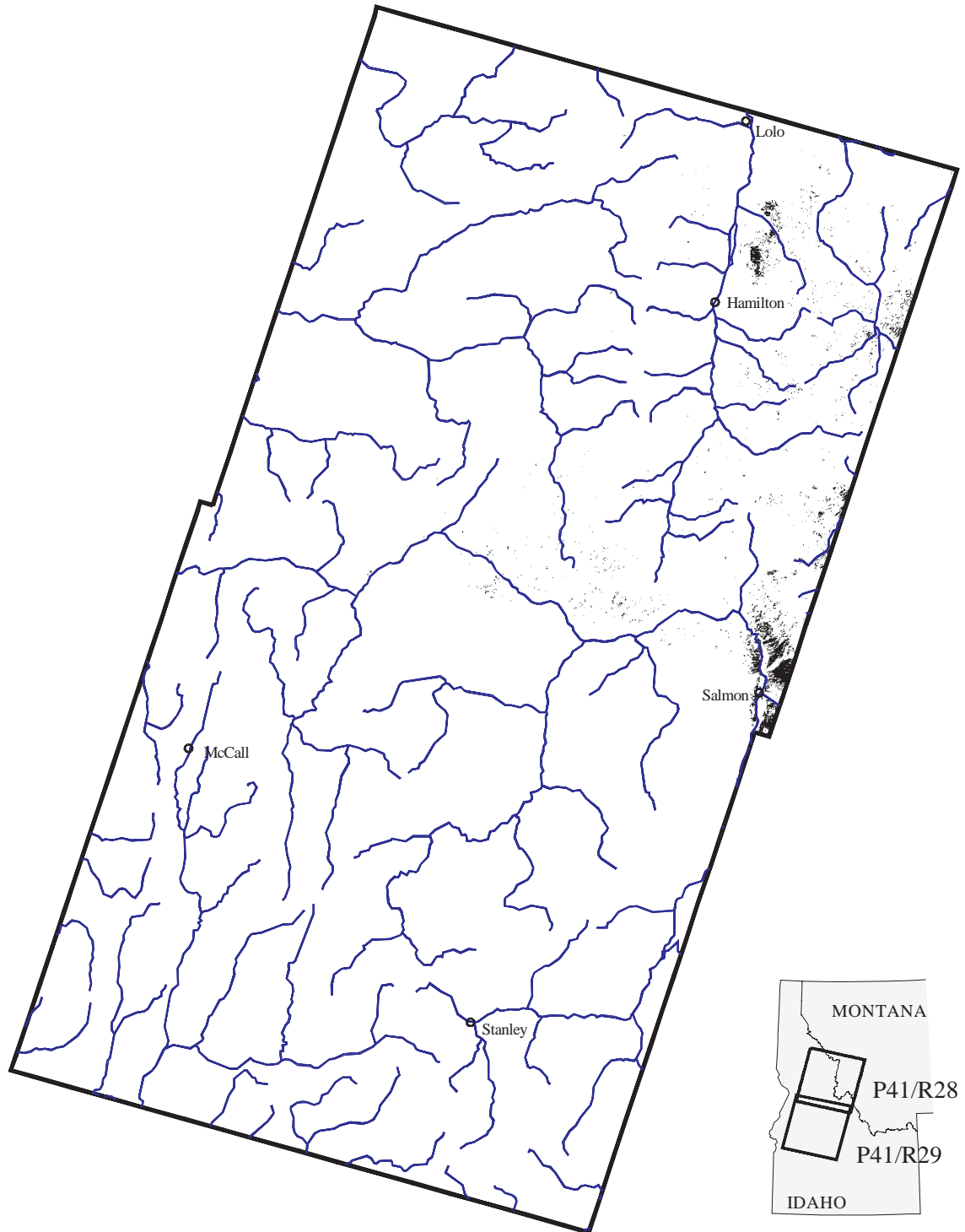
timberline, west and south aspects within the forest zone). In addition, Sage Xeric Shrublands were encountered on dry ridge lines at upper timberline. Sage Xeric Shrublands also resembled non-sage shrublands in having low overall species richness, a sparse herbaceous layer, and little litter accumulation. Trees (most frequently *Pseudotsuga menziesii* and *Pinus contorta*) were occasionally present in the middle and upper layers at low conditional coverage. The *vaseyana* subspecies of *Artemisia tridentata* was by far the most frequent and abundant shrub. In fact, this subspecies was almost ubiquitous (constancy 99%). Only one other shrub, *Purshia tridentata*, was present with appreciable frequency and absolute coverage. The herbaceous component was most frequently and commonly *Agropyron spicatum* and *Festuca idahoensis* and, to a lesser extent, *Carex geyeri*, *Balsamorhiza sagittata*, and *Bromus tectorum*.

Full plot totals: 3 (P41/R28); 80 (P41/R29)

User's accuracy: 71% (P41/R28); — (P41/R29)

Mis-classification: Sage Xeric Shrublands were most often mis-classified in P41/R28 as Xeric Grasslands (25%), a complex which occupied similar or adjacent sites, had broadly overlapping species composition, and often graded into shrublands. The complex was rarely (2%) confused with the Non-Sage Xeric Shrublands. Nonetheless, we were unable to distinguish Sage and Non-Sage Xeric Shrublands with acceptable accuracy in the south. Hence, training data for these two complexes were lumped in P41/R29 where we mapped an agglomeration of Sage and Non-Sage Xeric Shrublands labeled Xeric Shrublands (below).

Distribution of Sage Xeric Shrublands:



Estimated Area: 32,457 total ha (1.0% of study area north of edge-match)

Predicted Elevation: mean 1827 m; median 1885 m; trimmed range 1223 - 2347 m

Xeric Shrublands

Field definition: Less than 15% absolute coverage of trees, at least 15% absolute coverage of shrubs, and a greater volume of xeric (sage *or* non-sage) than mesic shrubs.

Ecological notes:

This is an agglomeration of Sage and Non-Sage Xeric Shrublands that was classified in P41/R29 only. Please refer to the preceding two sections for ecological notes on these two component complexes and for full plot totals.

User's accuracy:

— (P41/R28); 86% (P41/R29)

Mis-classification: As with the Sage and Non-Sage Xeric Shrublands components in P41/R28 (above), Xeric Shrublands were most frequently mis-classified as Xeric Grasslands (6%).



Atlanta East quadrangle

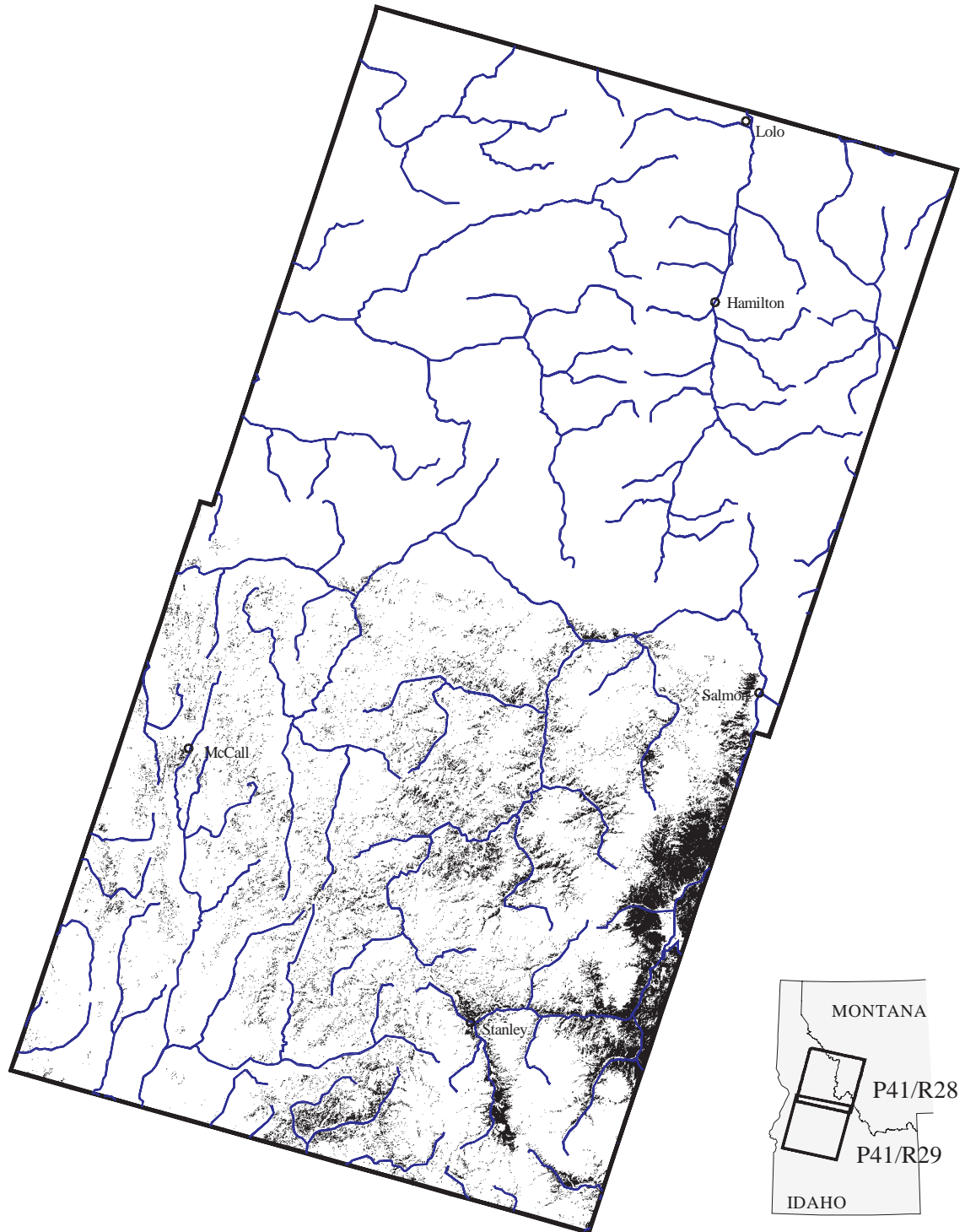
—M. Jones



Clayton quadrangle

—C. Riegel

Distribution of Xeric Shrublands:



Estimated Area: 353,656 total ha (10.7% of study area south of edge-match)

Predicted Elevation: mean 2013 m; median 2081 m; trimmed range 1331 - 2418 m

Mesic Shrublands

Field definition: Less than 15% absolute coverage of trees, at least 15% absolute coverage of shrubs, and a greater volume of “mesic” than xeric shrubs.

Ecological notes: These were typically moist sites subject to repeated disturbance (e.g., avalanching) or otherwise slow to return to a conifer-dominated forest structure. In addition to those species universally regarded as having a shrub life form, we included within the mesic shrub group a few species of small-statured, broadleaf



Fitsum Summit quadrangle

–M. Jones

trees (primarily *Populus tremuloides*) commonly found in dense groves or colonies. The motivation for this grouping was both spectral and ecological. Spectrally, stands of aspen or mixed broadleaf forest were rarely mis-classified as Mesic Forest but were routinely confused with Mesic Shrublands. Ecologically, these broadleaf trees and true mesic shrubs occupied similarly moist sites and occurred in plant associations having broadly overlapping species composition and similar vegetative structure (number of strata, stem densities, leaf type, etc.).

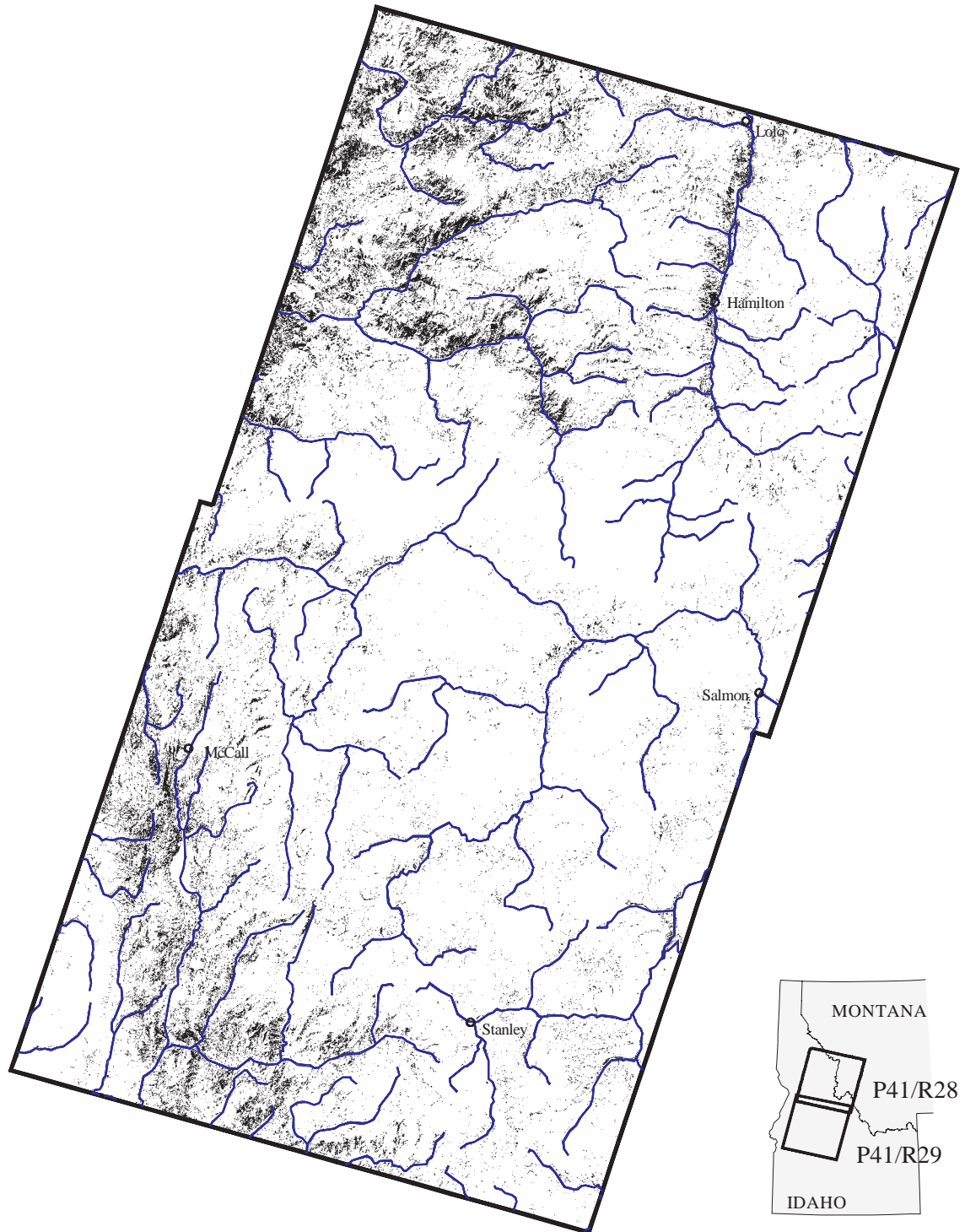
When measured by summing occurrence ($\geq 5\%$ absolute coverage) over all full plots and life forms, Mesic Shrublands had 2–5 times the vascular species diversity of the other mapped non-forest complexes. The most frequent and abundant shrubs were *Acer glabrum*, *Symphoricarpos albus*, *Amelanchier alnifolia*, *Alnus sinuata*, *Ceanothus velutinus*, *Physocarpus malvaceus*, *Rubus parviflorus*, *Vaccinium globulare*, *Spiraea betulifolia*, and, as a group, several *Salix* species. Although the overall diversity of shrub species was similar in the north versus the south, shrub species held in common tended to have greater constancy in the north and larger conditional coverages in the south. Tree species such as *Pinus ponderosa*, *Pinus contorta*, *Abies grandis*, *Abies lasiocarpa*, and especially *Pseudotsuga menziesii* were often present as seedlings or saplings. The complex had greater tree species diversity in the north due to the presence of maritime-influenced conifers like *Thuja plicata*, *Tsuga mertensiana*, and *Pinus monticola*. *Carex geyeri*, *Agropyron spicatum*, *Calamagrostis rubescens*, and, in the north, bracken fern (*Pteridium aquilinum*) and beargrass (*Xerophyllum tenax*) were all relatively frequent and common in the herbaceous layer.

Full plot totals: 124 (P41/R28); 77 (P41/R29)

User’s accuracy: 71% (P41/R28); 82% (P41/R29)

Mis-classification: Mesic Shrublands were most frequently confused with Mesic Grasslands/Subalpine Meadows (9%) and Mixed Douglas-Fir Forest (6%) in P41/R28, and, in P41/R29, with Douglas-Fir Dominant Forest (10%) and another moist-site non-forest association, Herbaceous Riparian (7%). The cause of the mis-classification with Douglas-fir forests is not obvious. However, the other two complexes held many species in common with Mesic Shrublands and were often adjacent or formed mosaic patterns in wet valley bottoms and subalpine meadows.

Distribution of Mesic Shrublands:



Estimated Area: 448,984 total ha (7.0% of study area)

Predicted Elevation: mean 1626 m; median 1603 m; trimmed range 972 - 2336 m

Herbaceous Riparian

Field definition: Less than 15% absolute coverage of shrubs, less than 15% absolute coverage of trees, at least 15% absolute coverage of herbs, and location adjacent to surface water or on otherwise hydric soils.

Ecological notes:

These were lush, warm to cool, wet-site associations characterized by saturated soils and a high diversity of both



Chamberlain Basin, Idaho

-L. Thompson

forb and graminoid species. Most forbs were present on plot at less than 5% absolute coverage. However, some graminoids were individually abundant, particularly *Carex* spp. such as *Carex aquatilis* and *Carex microptera*. Shrubs were primarily represented at low frequency and abundance by a variety of *Salix* spp. Tree species were most frequently seedlings or saplings of either *Pinus contorta* or *Picea engelmannii*.

Full plot totals:

11 (P41/R28); 34 (P41/R29)

User's accuracy:

82% (P41/R28); 68% (P41/R29)

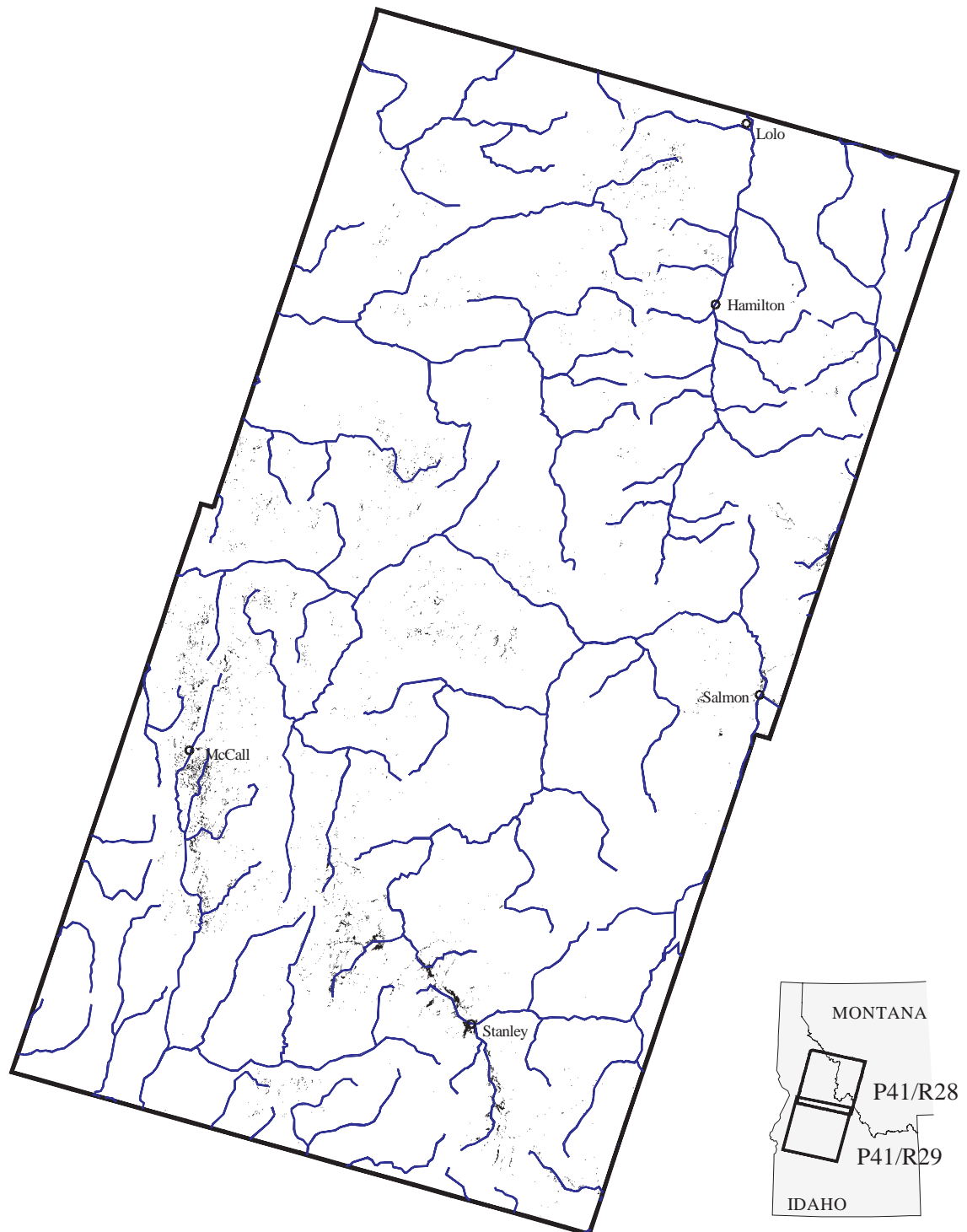
Mis-classification: This complex was most frequently confused with Mesic Shrublands in both the north (22%) and the south (15%). Mesic shrublands were often adjacent to or intermixed with Herbaceous Riparian associations (see comments for Mesic Shrublands).



Puddin Mountain quadrangle

-J. Coop

Distribution of Herbaceous Riparian:



Estimated Area: 32,410 total ha (0.5% of study area)

Predicted Elevation: mean 1868 m; median 1944 m; trimmed range 1330 - 2312 m

Rock Dominated

Field definition:

Less than 15% absolute coverage of trees, less than 15% absolute coverage of shrubs, and less than 15% absolute coverage of herbs.

Ecological notes:

This complex occupied sites at all elevations but was most commonly represented by (i) scree fields and cliff formations



Mount McGuire quadrangle

—J. Hogg

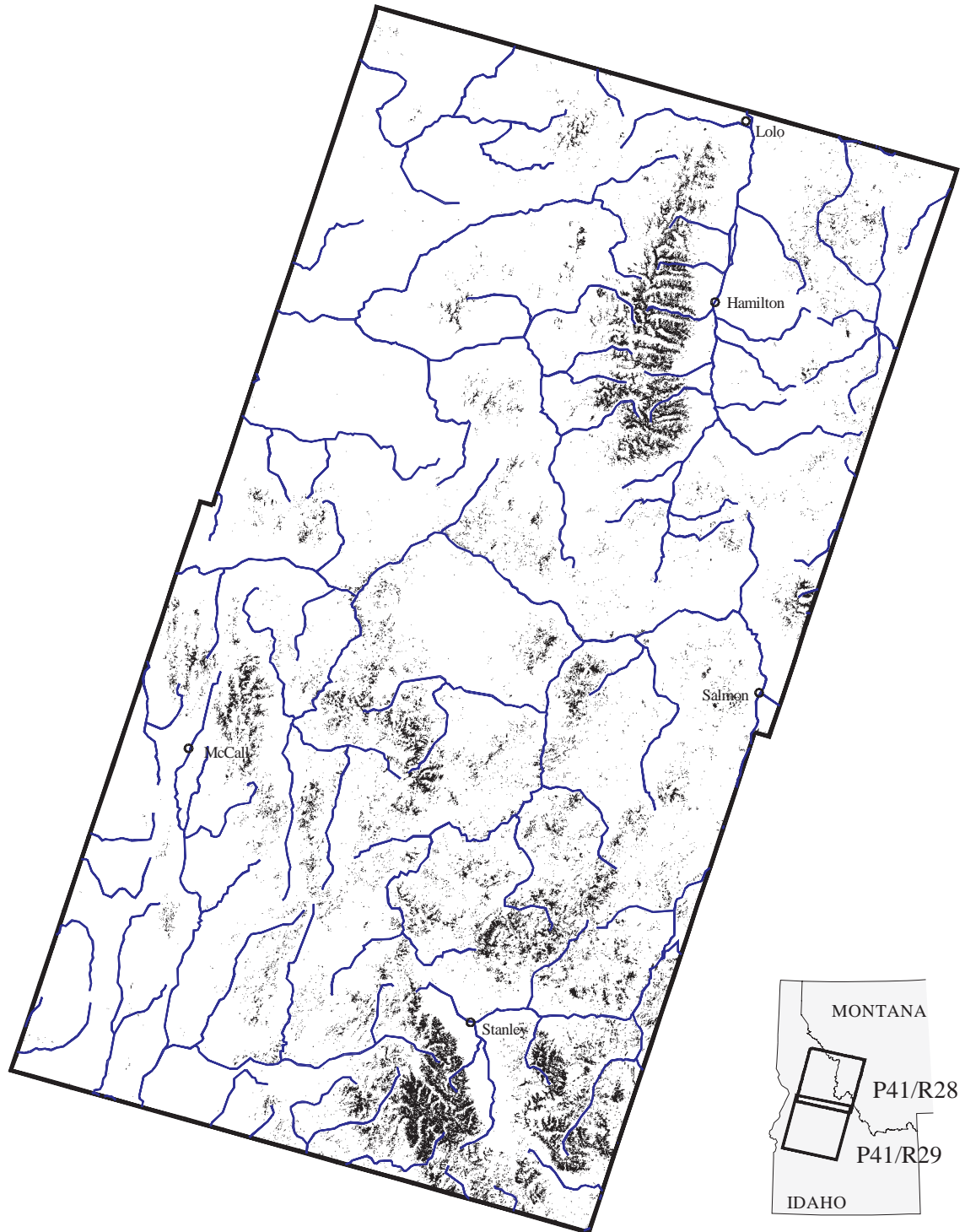
near or above upper timberline and (ii) scree fields and cliff formations in arid canyons within the Salmon River breaks. Other, less extensive representatives of the complex included stream gravel bars, cliffs and rock outcrops within forests, and rock waste from mines. Because the Rock Dominated complex was found in quantity at both low and upper elevations, it encompassed a correspondingly disparate array of plant associations. For example, on upper-elevation (alpine), dry, cold sites, *Abies lasiocarpa* and *Larix lyallii* (in the north) and *Pinus albicaulis* (in the south), *Vaccinium scoparium* or *Phyllodoce empetriiformis*, and *Xerophyllum tenax* were the most frequent tree, shrub, and herbaceous species, respectively. On low-elevation (canyon), dry, warm sites, these roles were filled by *Pseudotsuga menziesii*, *Artemisia tridentata vaseyana*, and *Agropyron spicatum*.

Full plot totals: 22 (P41/R28); 59 (P41/R29)

User's accuracy: 93% (P41/R28); 91% (P41/R29)

Mis-classification: Although rare, mis-classification of Rock Dominated sites usually involved low-elevation, dry-site complexes with high proportions of exposed rock and soil (e.g., Xeric Shrublands and Xeric Grasslands).

Distribution of Rock Dominated:



Estimated Area: 335,654 total ha (5.2% of study area)

Predicted Elevation: mean 2169 m; median 2215 m; trimmed range 1501 - 2671 m

Shrub-Herbaceous Dominated Burn

Field definition: “Recently” burned areas with less than 15% absolute coverage of trees.

Ecological notes: As with the Conifer Regeneration Dominated Burn (next section), this complex was found on a variety of physiographic sites, reflecting substantial variability in the location of stand replacing fire (Agee 1993). Standing dead trees were frequently present in the upper layer and burnt, felled trees often littered the ground. In general, recent burns tend to be dominated by species with highly dispersive propagules, fire resistant propagules, and/or fire resistant root systems (Agee 1993). In our plots, *Carex geyeri*, *Xerophyllum tenax*, and *Calamagrostis rubescens* were the most frequent and abundant in the herbaceous layer, and *Vaccinium scoparium* was the most frequent and abundant shrub. Regenerating conifers were relatively uncommon. For example, although *Pinus contorta* occurred with high frequency (48%) in the middle layer, it had very low conditional coverage there (less than 1%).



Blue Bunch Mountain quadrangle

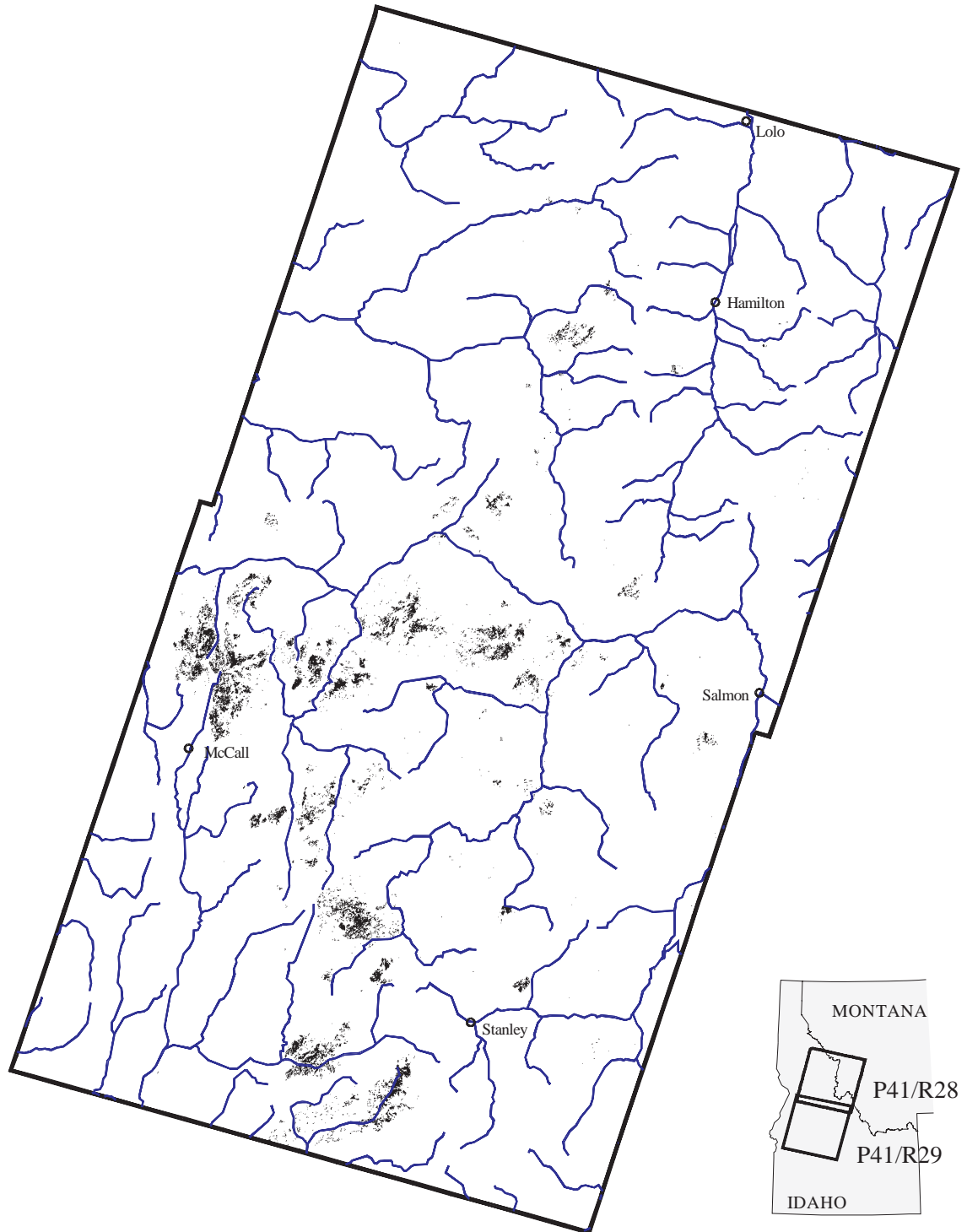
–M. Pokorny

Full plot totals: 2 (P41/R28); 92 (P41/R29)

User’s accuracy: 79% (P41/R28); 83% (P41/R29)

Mis-classification: This complex was most frequently mis-classified in both scenes as Mixed Lodgepole Pine Forest and Conifer Regeneration Dominated Burn. Although *Pinus contorta* was not common overall in the training set for this complex, this pattern of mis-classification may reflect more extensive regeneration by lodgepole pine in a proportion of training plots. Note that burns were mapped by a combination of manual labeling (most areas) and statistical classification (pp. 7-8).

Distribution of Shrub-Herbaceous Dominated Burn:



Estimated Area: 79,917 total ha (1.2% of study area)

Predicted Elevation: mean 2049 m; median 2087 m; trimmed range 1476 - 2452 m

Conifer Regeneration Dominated Burn

Field definition: “Recently” burned areas with at least 15% absolute coverage of live conifer tree species (regenerating in the middle layer or remnant in the upper layer).

Ecological notes: Although standing dead trees were often present, and live trees (*Abies lasiocarpa*, *Picea engelmannii*, *Pseudotsuga menziesii*, and especially *Pinus contorta*) were occasionally persistent in the upper layer, this complex was structurally most similar to some of the non-forest complexes

(e.g., Mesic Shrublands or Shrub-Herbaceous Dominated Burn). Nonetheless, we have treated it as a forest type in a stand initiation phase (Figure 4). *Pinus contorta* was the most frequent and common conifer regenerating in the middle layer. *Vaccinium scoparium* was the dominant shrub while *Xerophyllum tenax*, *Calamagrostis rubescens*, and *Carex* spp. were most frequent and abundant in the herbaceous layer.

Full plot totals:

0 (P41/R28); 7 (P41/R29)

User’s accuracy: 77% (P41/R28); 79% (P41/R29)

Mis-classification: The complex was most often mis-classified as Mixed Lodgepole Pine Forest and Shrub-Herbaceous Dominated Burn in both the north and south. Note that burns were mapped by a combination of manual labeling and statistical classification (pp. 7-8).



Blue Bunch Mountain quadrangle

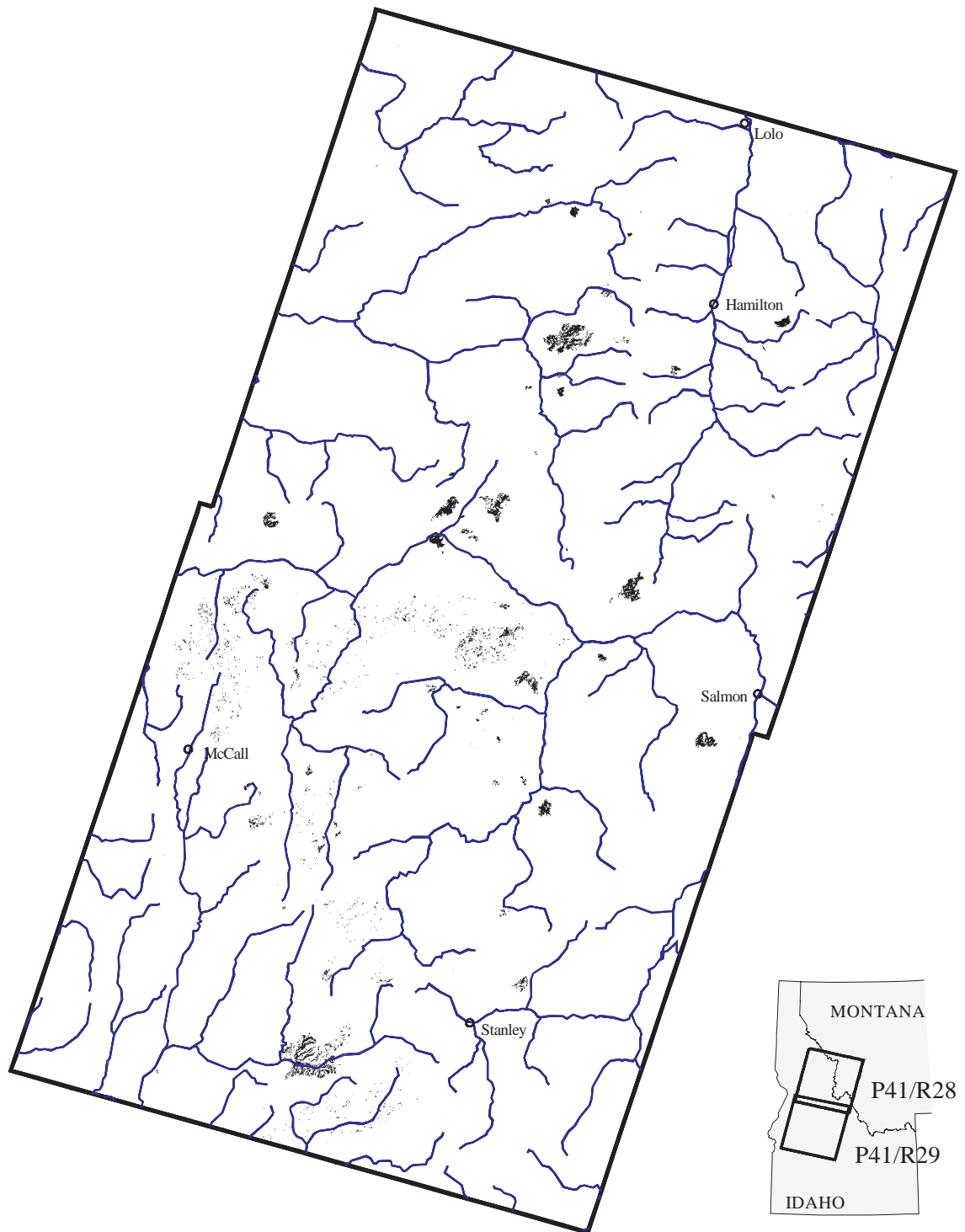
–M. Pokorny



Wildfire, Middle Fork of the Salmon River

–J. W. Craighead

Distribution of Conifer Regeneration Dominated Burn:



Estimated Area: 40,584 total ha (0.6% of study area)

Predicted Elevation: mean 2017 m; median 2059 m; trimmed range 1498 - 2370 m

Ponderosa Pine Dominant Forest

Field definition: At least 15% absolute coverage of trees and at least 66% relative coverage of *Pinus ponderosa* with respect to all other tree species.

Ecological notes: These were low-elevation forests occupying dry, hot sites. They were typically found at the transition between non-forest and forest at lower timberline and on south to west aspects with well-drained, mineral soils higher in the forest zone. Vegetative structure in the upper layer included open to



Dog Creek quadrangle

–J. Hogg

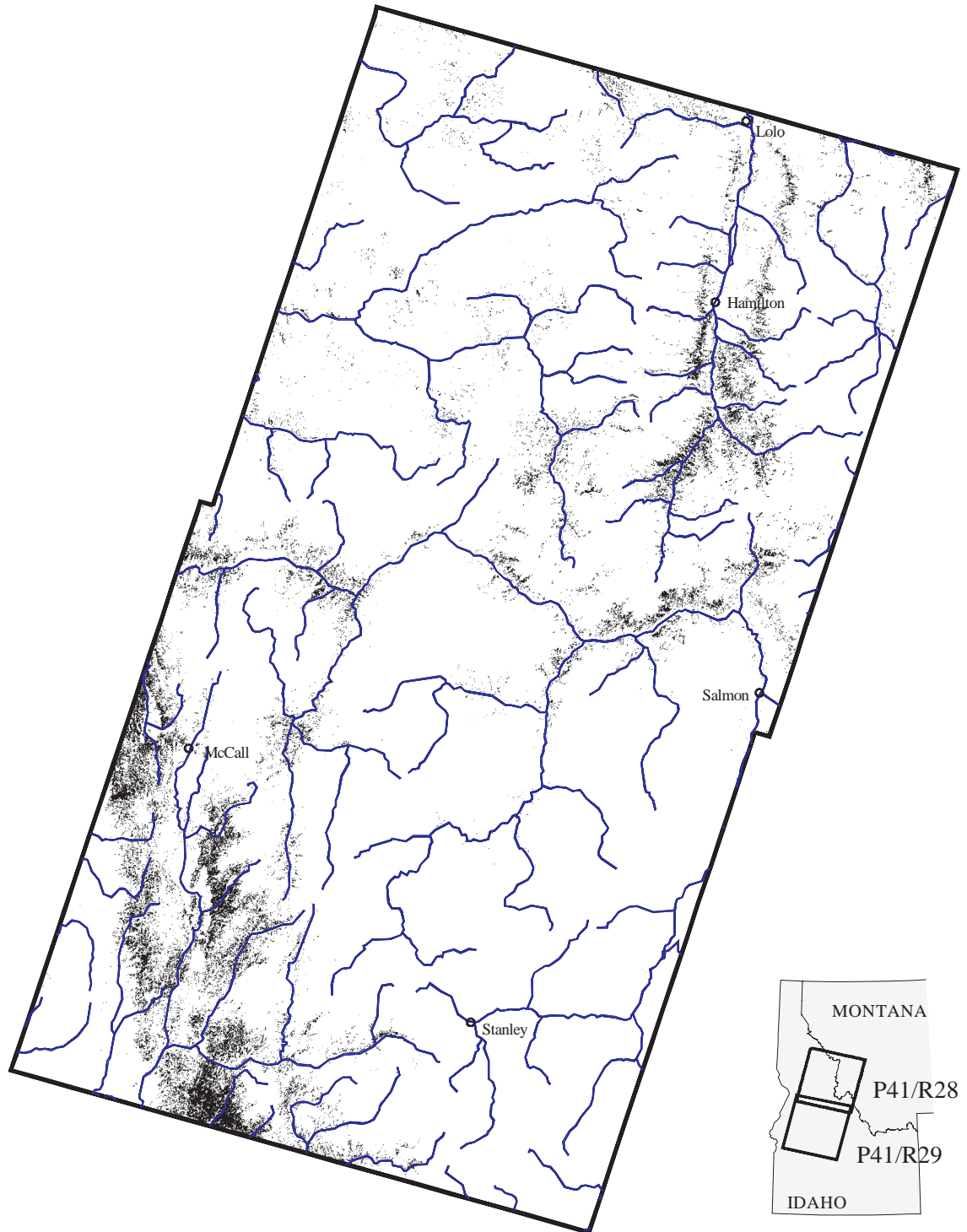
partially closed canopies and low to moderate densities of stems. *Pinus ponderosa* dominant stands in this area may represent climax associations (on drier sites) or a seral stage in the *Pseudotsuga menziesii* series (Steele et al. 1981; Cooper et al. 1991; Steele and Geier-Hayes 1995). Stands represented in our plots were often in the closed stem exclusion structural class of O'Hara et al. (1996). *Pseudotsuga menziesii* had high constancy in both the upper and middle layers but low conditional coverages. Trees other than *Pinus ponderosa* were represented predominantly by seedlings and saplings at very low frequencies and abundance. Understory associations included bunchgrasses (most frequently *Agropyron spicatum*) and seasonal forbs (most frequently *Balsamorhiza sagittata*), rhizomatous mats of *Calamagrostis rubescens* and *Carex geyeri* on moister sites, and, occasionally, virtually continuous layers of the shrub *Physocarpus malvaceus*. *Symphoricarpos albus* and *Amelanchier alnifolia* were other relatively frequent and common shrubs. The exotics *Centaurea maculosa* and *Bromus tectorum* and the fern *Pteridium aquilinum* were recorded at appreciable frequency and abundance in the north.

Full plot totals: 30 (P41/R28); 14 (P41/R29)

User's accuracy: 66% (P41/R28); 52% (P41/R29)

Mis-classification: In P41/R28, the complex was most frequently mis-classified as Mixed Douglas-Fir Forest (27%) which was found on similar low-elevation, dry sites and can have significant amounts of ponderosa pine in the canopy (e.g., as in the Douglas-Fir/Ponderosa Pine Co-Dominant plant community type) and similar plant associations in the understory. In P41/R29, it was most frequently confused with Douglas-Fir Dominant Forest (7%) and Douglas-Fir/Ponderosa Pine Co-Dominant Forest (22%)—the two complexes agglomerated in P41/R28 to form Mixed Douglas-Fir Forest.

Distribution of Ponderosa Pine Dominant Forest:



Estimated Area: 257,880 total ha (4.0% of study area)

Predicted Elevation: mean 1538 m; median 1559 m; trimmed range 1031 - 1969 m

Douglas-Fir/Ponderosa Pine Co-Dominant Forest

Field definition:

At least 15% absolute coverage of trees, less than 66% relative coverage (with respect to all tree species) of each *Pseudotsuga menziesii* and *Pinus ponderosa*, but at least 80% relative coverage of *Pseudotsuga menziesii* and *Pinus ponderosa* combined.



Gardiner Peak quadrangle

—J. Hogg

Ecological notes:

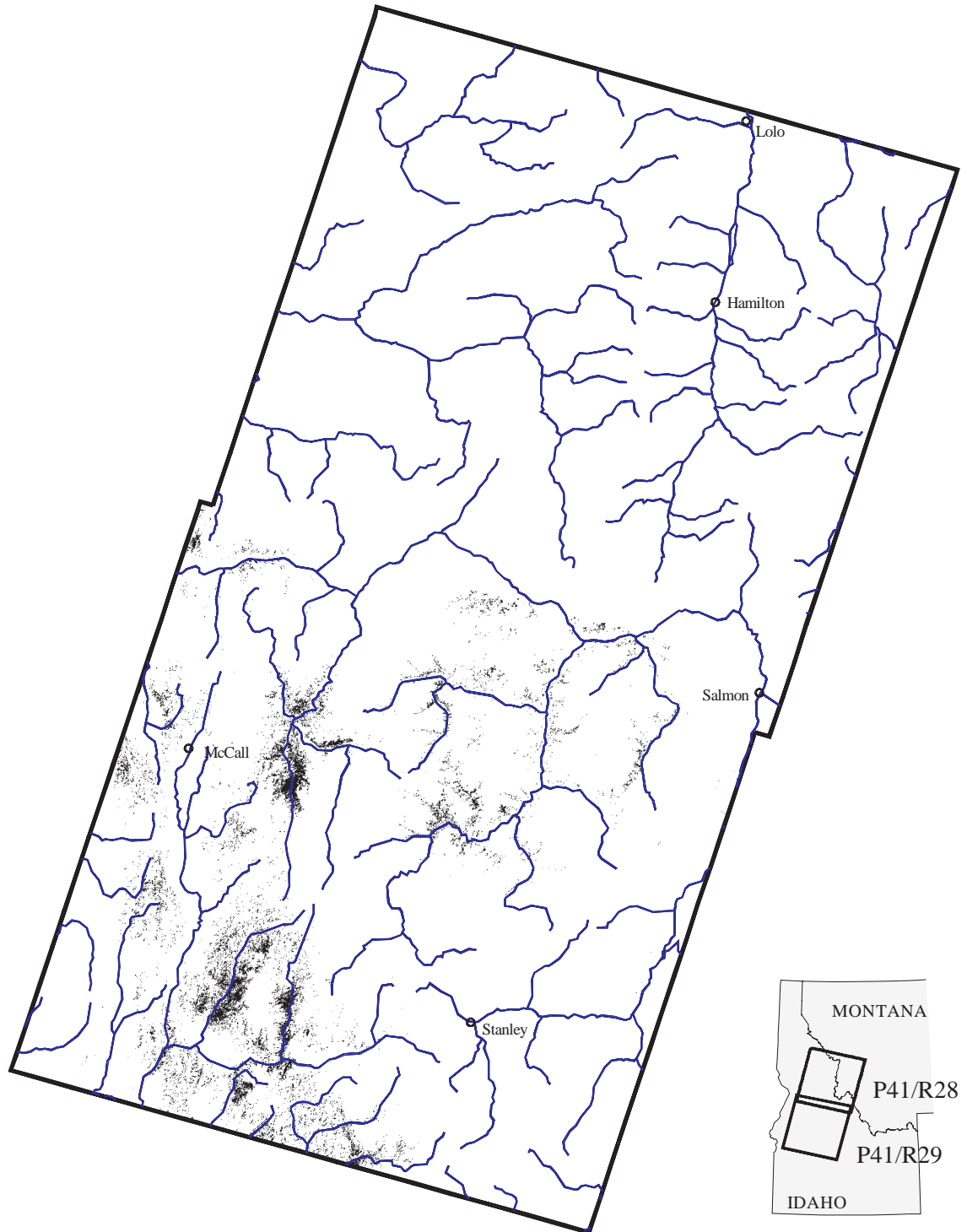
This was a low-elevation, warm-site forest complex with a usually open to partially closed canopy structure. It was often transitional between Douglas-Fir Dominant Forest and Ponderosa Pine Dominant Forest. *Pinus contorta* was frequent in the upper and middle vegetation layers but had a low conditional coverage in both layers. A variety of other tree species were present at much lower constancy and conditional coverage typically as seedlings and saplings. The understory consisted of warm-site shrubs, graminoids, and forbs. The most frequent and abundant shrubs were *Arctostaphylos uva-ursi*, *Physocarpus malvaceus*, *Symphoricarpos albus*, and *Spiraea betulifolia*. *Vaccinium globulare* was relatively less frequent but had high coverage in the north when present. Bunchgrasses or rhizomatous graminoids dominated in the lower layer. The grass *Calamagrostis rubescens* was by far the most frequent and abundant herb.

Full plot totals: 17 (P41/R28); 18 (P41/R29)

User's accuracy: — (P41/R28); 67% (P41/R29)

Mis-classification: This complex was most frequently mis-classified as Ponderosa Pine Dominant Forest (12%) or Douglas-Fir Dominant Forest (17%). These three forest types are points along a continuum of canopy mixtures involving Douglas-fir and ponderosa pine. We were unable to map this complex with acceptable accuracy in P41/R28. There, training data for Douglas-Fir Dominant Forest and Douglas-Fir/Ponderosa Pine Co-Dominant Forest were lumped and used to map an agglomeration of these types labeled Mixed Douglas-Fir Forest.

Distribution of Douglas-Fir/Ponderosa Pine Co-Dominant Forest:



Estimated Area: 95,306 total ha (2.9% of study area south of edge-match)

Predicted Elevation: mean 1703 m; median 1719 m; trimmed range 1281 - 2076 m

Douglas-Fir Dominant Forest

Field definition: At least 15% absolute coverage of trees and at least 66% relative coverage of *Pseudotsuga menziesii* with respect to all tree species.

Ecological notes: The Douglas-Fir Dominant Forest complex was often transitional in the study area between *Pinus ponderosa* stands at lower timberline and subalpine forests. In our full plots, the relative coverage of *Pseudotsuga menziesii* usually greatly exceeded the 66% field-definition threshold, reflecting the absence or very low conditional coverage of other tree species. Canopies were typically partially closed to closed. Stands in this complex were recorded in a relatively large number of forest structural classes (O'Hara et al. 1996),

including closed stem exclusion, understory re-initiation, old forest single-stratum, and old forest multi-strata. In contrast to the monotypic species composition of the upper layer, understory plant associations were variable, reflecting the elevation and edaphic range of this forest type. *Carex geyeri* and, especially, *Calamagrostis rubescens* were the most abundant graminoids whereas *Arnica* spp. and *Xerophyllum tenax* were the most frequent and common forbs. Shrub species with the greatest constancy and conditional coverage were *Physocarpus malvaceus*, *Symphoricarpos albus*, *Acer glabrum*, *Spiraea betulifolia*, and *Vaccinium globulare*. *Vaccinium scoparium* had relatively low frequency of occurrence but very high conditional coverage relative to other shrubs.

Full plot totals: 79 (P41/R28); 131 (P41/R29)

User's accuracy: — (P41/R28); 71% (P41/R29)

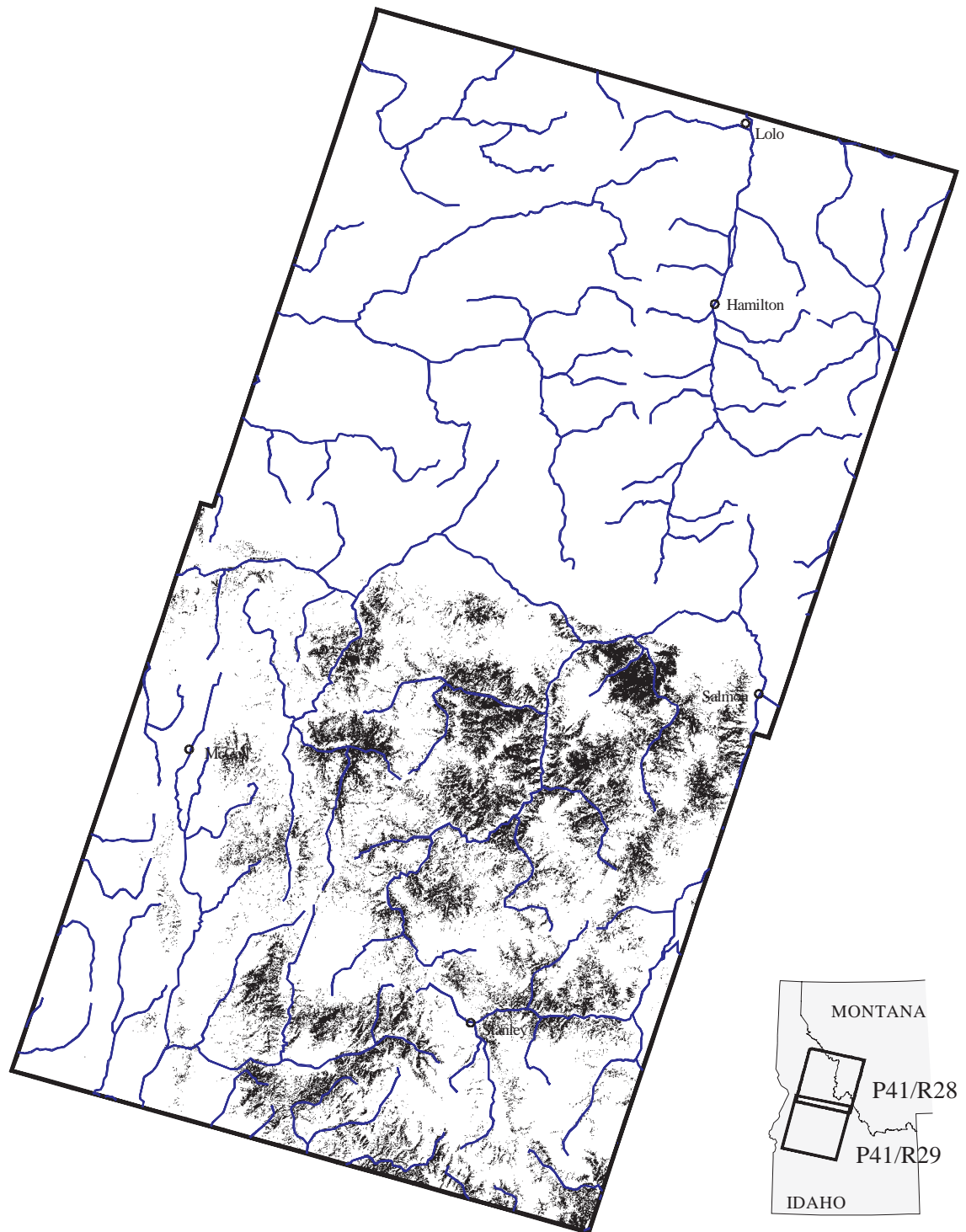
Mis-classification: In P41/R29, this complex was most frequently confused with Mixed Lodgepole Pine Forest (14%). Lodgepole pine was the most abundant other upper layer tree species in the southern training set for the Douglas-Fir Dominant Forest type. We were unable to map this complex with acceptable accuracy in P41/R28. There, training data for Douglas-Fir Dominant Forests and Douglas-Fir/Ponderosa Pine Co-Dominant Forests were lumped and used to map an agglomeration of these types labeled Mixed Douglas-Fir Forest.



Medicine Lake quadrangle, Granite County, Montana

—L. Goodhart

Distribution of Douglas-Fir Dominant Forest:



Estimated Area: 547,197 total ha (16.5% of study area south of edge-match)

Predicted Elevation: mean 2055 m; median 2109 m; trimmed range 1435 - 2474 m

Mixed Douglas-Fir Forest

Field definition: At least 15% absolute coverage of upper layer trees *and* (i) at least 66% relative coverage *Pseudotsuga menziesii* or (ii) at least 80% relative coverage of *Pseudotsuga menziesii* and *Pinus ponderosa* combined.



Medicine Lake quadrangle, Granite County, Montana
—L. Goodhart

Ecological notes: This is an agglomeration of the Douglas-Fir Dominant and Douglas-Fir/Ponderosa Pine Co-Dominant Forest complexes that was applied to P41/R28 only. Please refer to the preceding two sections for ecological notes on these component complexes and for full plot totals.

User's accuracy: 72% (P41/R28); — (P41/R29)

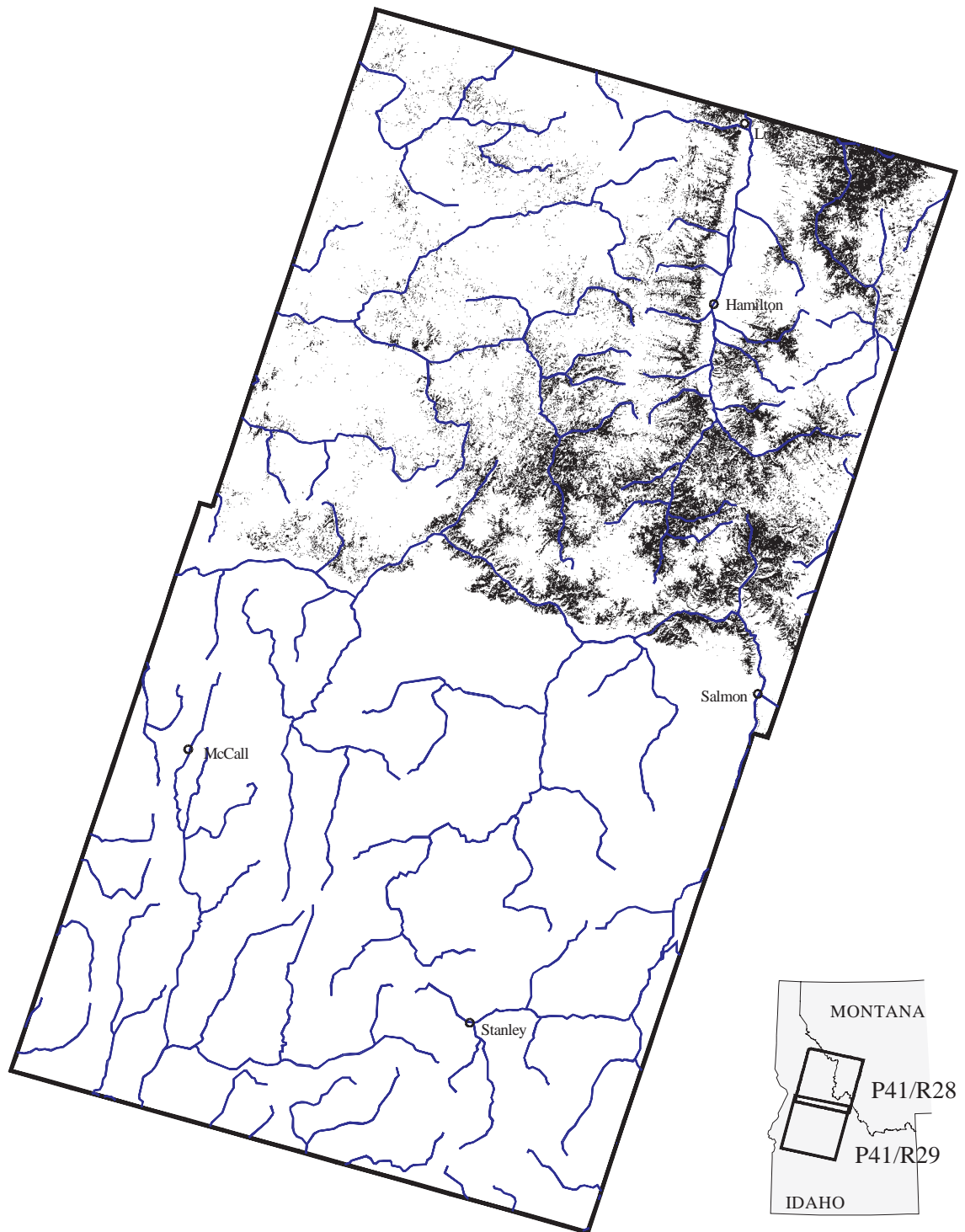
Mis-classification: The complex was most frequently mis-classified as Mixed Mesic Forest (16%) and Mixed Lodgepole Pine Forest (11%).



Gardiner Peak quadrangle

—J. Hogg

Distribution of Mixed Douglas-Fir Forest:



Estimated Area: 486,958 total ha (15.7% of study area north of edge-match)

Predicted Elevation: mean 1698 m; median 1741 m; trimmed range 994 - 2296 m

Mixed Mesic Forest

Field definition: At least 15% absolute coverage of trees *and* (i) at least 66% relative coverage of a “mesic”² species with respect to all tree species *or* (ii) at least 80% combined relative coverage for two species, at least one of which is “mesic” *or* (iii) mixed canopies having at least 10% relative coverage of a “mesic” species with respect to all tree species.



White Sand Lake quadrangle

–J. Hogg

Ecological notes: Mixed Mesic Forest is an umbrella complex for a variety of moist forest plant community types typically found in valley bottoms or at middle elevations on mountain slopes with north trending aspects. Forest canopies were typically closed and the understory multi-layered. Litter layers were deep and bare rock and soil usually absent. Of all the mapped complexes, Mixed Mesic Forest had the greatest site-specific and overall tree species diversity. Eight tree species were present in the upper layer at greater than 13% frequency of occurrence. This group included *Abies lasiocarpa*, *Larix occidentalis*, *Picea engelmannii*, *Abies grandis*, *Pseudotsuga menziesii*, and *Thuja plicata*. *Abies grandis* was most frequent and abundant in both the upper and middle layers. Among shrubs, *Vaccinium globulare* was most frequent and common. Other characteristic shrub species included *Menziesia ferruginea*, *Linnaea borealis*, *Acer glabrum*, *Rubus parviflorus*, and, in the south primarily, *Vaccinium scoparium*. *Calamagrostis rubescens*, *Xerophyllum tenax*, *Arnica* spp., *Clintonia uniflora*, and *Coptis occidentalis* were relatively frequent and abundant in the herbaceous layer.

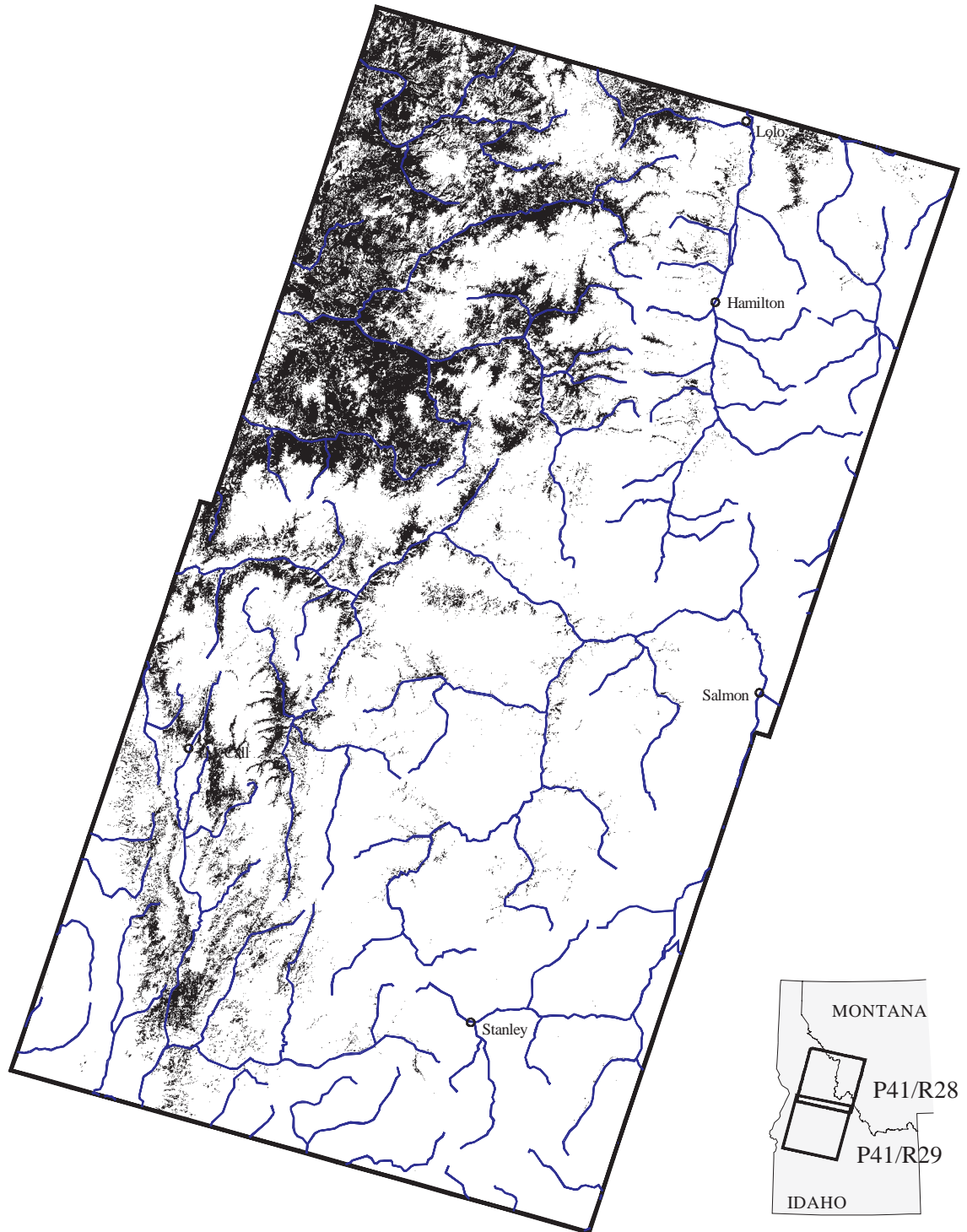
Full plot totals: 201 (P41/R28); 51 (P41/R29)

User’s accuracy: 65% (P41/R28); 70% (P41/R29)

Mis-classification: The complex was mis-classified with low frequency (2–9%) to each of four or five other forest complexes, depending on scene. This lack of pattern in mis-classification presumably reflects the large number and varied character of plant community types grouped under the Mixed Mesic Forest umbrella.

² Mesic species are *Abies grandis*, *Picea engelmannii*, *Thuja plicata*, *Tsuga heterophylla*, and *Larix occidentalis*.

Distribution of Mixed Mesic Forest:



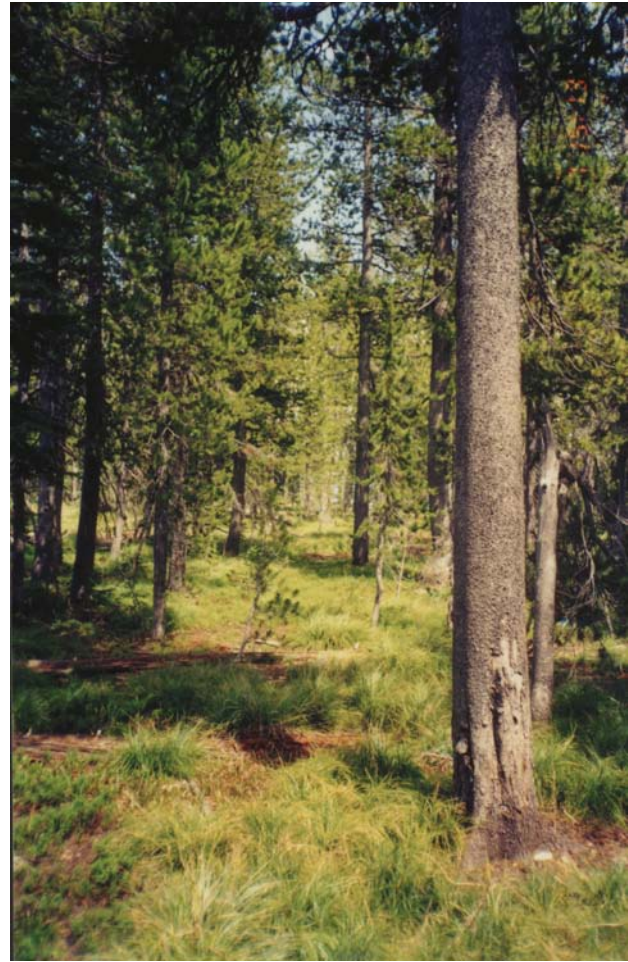
Estimated Area: 948,716 total ha (14.8% of study area)

Predicted Elevation: mean 1579 m; median 1626 m; trimmed range 991 - 2012 m

Mixed Lodgepole Pine Forest

Field definition: At least 15% absolute coverage of trees *and* (i) at least 66% relative coverage of lodgepole pine (with respect to all tree species) *or* (ii) at least 80% relative coverage of lodgepole pine and Douglas-fir combined.

Ecological notes: This is a dry-site complex found in the mid to upper regions of the forested zone. In our study area, these were often seral stands regenerating to other forest types. *Pseudotsuga menziesii* was the only tree species, other than *Pinus contorta*, that was well represented in the upper layer (3% mean absolute coverage) but seedlings and saplings of *Abies lasiocarpa*, *Pinus albicaulis*, *Picea engelmannii*, and, especially, *Pseudotsuga menziesii*, were frequently present and potentially regenerating in the middle layer. Mixed Lodgepole Pine Forest stands typically had high densities of trees but sparse, open canopies, substantial light and wind penetration, and relatively arid understories. The shrub component tended to be more developed structurally in the north where there was also greater representation of mesic species such as *Vaccinium globulare*, *Linnaea borealis*, *Menziesia ferruginea*, and *Alnus sinuata*. However, *Vaccinium scoparium* had the greatest frequency of occurrence and conditional coverage in both scenes. *Carex geyeri*, *Calamagrostis rubescens*, and *Xerophyllum tenax* were the most frequent and common members of the herbaceous layer.



Salmon-Selway ecosystem

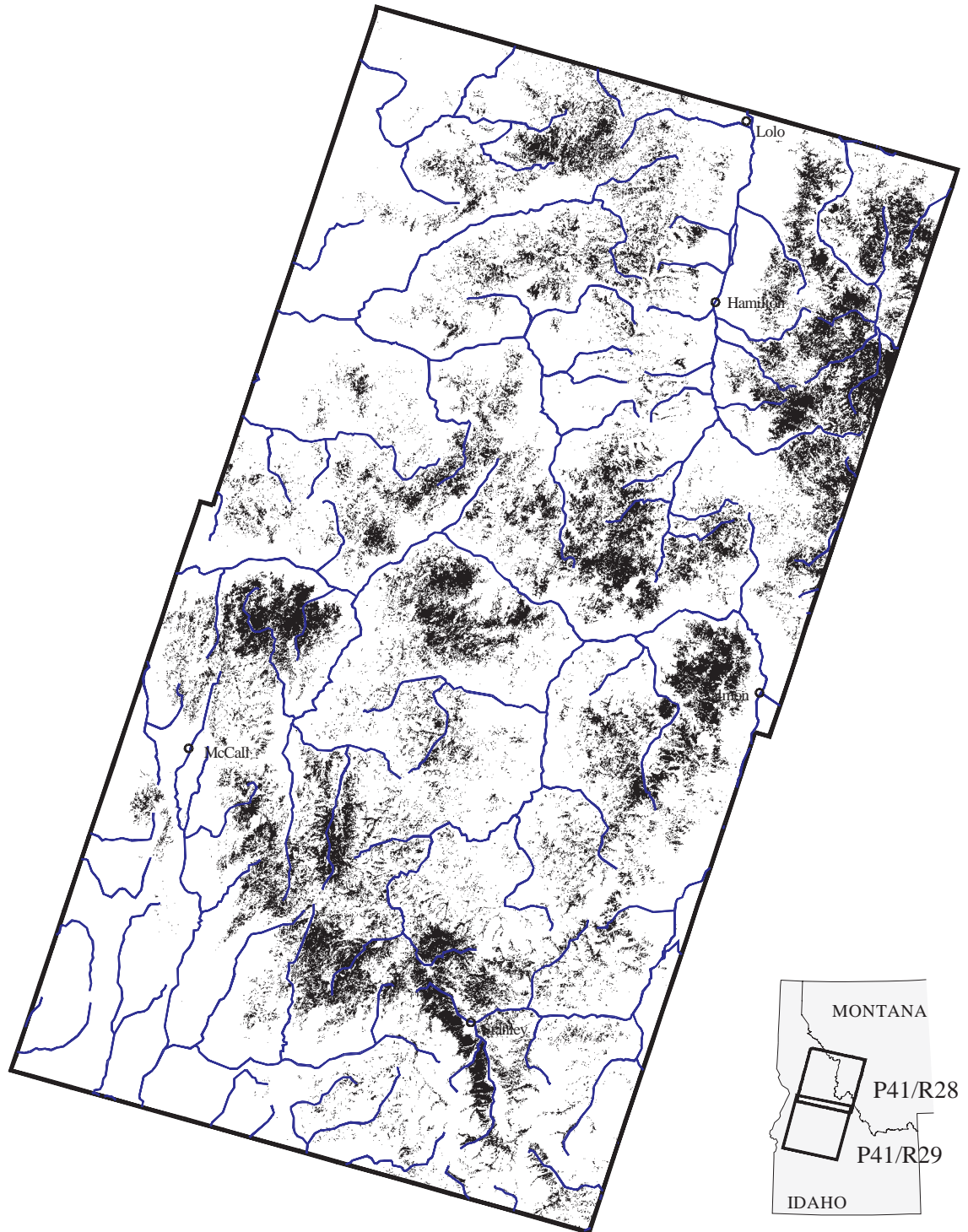
-CWWI

Full plot totals: 120 (P41/R28); 143 (P41/R29)

User's accuracy: 61% (P41/R28); 75% (P41/R29)

Mis-classification: In the north, the complex was most frequently mis-classified as Mixed Subalpine Fir Forest (17%). In P41/R29, it was most often confused with Douglas-Fir Dominant Forest (10%) and only infrequently with Mixed Subalpine Fir Forest (3%). The between-scene difference in mis-classification may reflect more arid conditions in the south and greater representation there of dry-adapted understory associates of lodgepole pine.

Distribution of Mixed Lodgepole Pine Forest:



Estimated Area: 962,160 total ha (15.0% of study area)

Predicted Elevation: mean 2010 m; median 2016 m; trimmed range 1531 - 2456 m

Mixed Subalpine Fir Forest

Field definition:

Any mix of conifer species having at least 15% absolute coverage of trees *and* (i) at least 66% relative coverage of subalpine fir with respect to all tree species *or* (ii) at least 10% relative coverage of subalpine fir with respect to all tree species in a mixed forest plant community type.



Hoodoo Meadows quadrangle

–J. Hogg

Ecological notes:

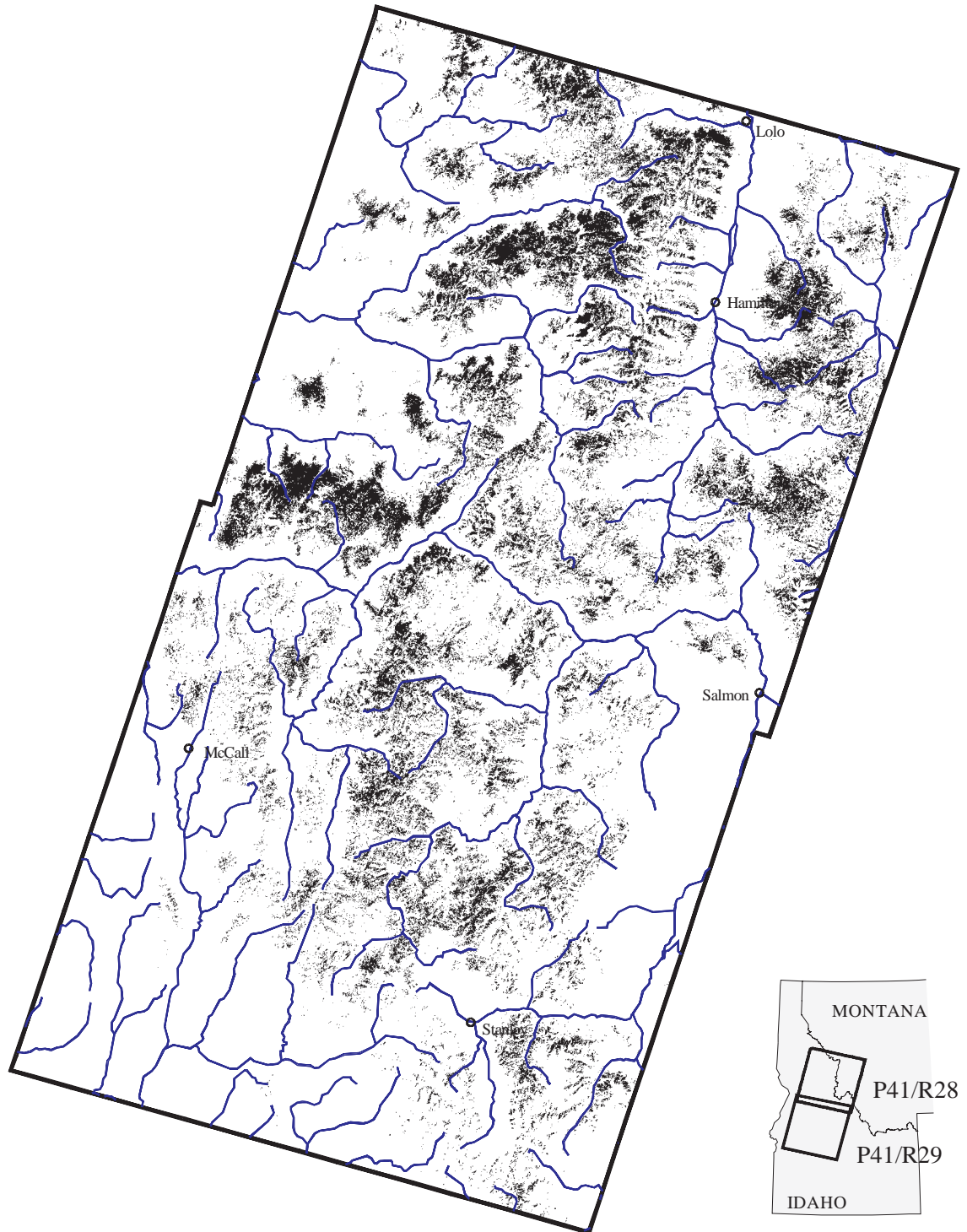
This is a broadly distributed forest type found on moist to wet and cool to cold sites in the subalpine zone. These forests were usually multi-layered with well-developed shrub and herbaceous understories. Composition of the upper layer ranged from pure stands of *Abies lasiocarpa* to highly mixed canopies in which *A. lasiocarpa* was present at the field definition threshold of 10% relative coverage. Other frequently occurring tree species in the upper and middle forest layers of the complex were *Pinus contorta*, *Picea engelmannii*, *Pseudotsuga menziesii*, and *Pinus albicaulis*. Shrub and herbaceous layers were relatively species-rich. Two types of huckleberry, *Vaccinium scoparium* and *Vaccinium globulare*, were the most frequent and abundant shrubs. *Menziesia ferruginea* was also well represented. The most abundant herbs were *Xerophyllum tenax*, *Calamagrostis rubescens*, *Luzula hitchcockii*, and *Carex geyeri*. Many shrub and forb species were recorded in this forest type with constancies on the order of 5–10% and absolute coverages of 1–5%.

Full plot totals: 91 (P41/R28); 123 (P41/R29)

User's accuracy: 69% (P41/R28); 60% (P41/R29)

Mis-classification: In both P41/R28 and P41/R29, Mixed Subalpine Fir Forest was most frequently mis-classified as Mixed Lodgepole Pine Forest (19% and 26%, respectively) probably because there was a substantial *Pinus contorta* component in many forest types forming the complex. The upper layer absolute coverage of *Pinus contorta* in the training set for Mixed Subalpine Fir Forest was fully one-half that of *Abies lasiocarpa*.

Distribution of Mixed Subalpine Fir Forest:



Estimated Area: 726,885 total ha (11.3% of study area)

Predicted Elevation: mean 2095 m; median 2113 m; trimmed range 1607 - 2546 m

Mixed Whitebark Pine Forest

Field definition: At least 15% absolute coverage of trees and any combination of conifer species having at least 10% relative coverage of whitebark pine with respect to all tree species.

Ecological notes: This complex was found on dry, cold sites on mountain slopes and ridge lines at upper timberline. *Pinus albicaulis*-dominated stands in this area tend to be most frequent on more exposed (wind and sun) and nutrient-poor sites at higher elevation whereas mixed *P. albicaulis* forests are typically found at somewhat lower elevations and on a greater range of exposures and soils (Arno and Hammerly 1984). In our plots, the Mixed Whitebark Pine plant community type was usually a mixture of *Pinus albicaulis*, *Abies lasiocarpa*, and *Pinus contorta*. Canopy structure in both “pure” and mixed stands was typically open and there was often substantial exposed soil and rock. The complex as a whole had a somewhat more mesic character in the north due to the upper layer presence of *Larix lyallii* or, occasionally, *Tsuga mertensiana* and relative absence of some drier-site shrubs found in the south (e.g., *Spiraea betulifolia* and *Ceanothus velutinus*). Nonetheless, *Vaccinium scoparium* was the most frequent and abundant shrub, and *Xerophyllum tenax*, *Luzula hitchcockii*, and *Carex geyeri* the most frequent and abundant herbs in both scenes.



Mount McGuire quadrangle

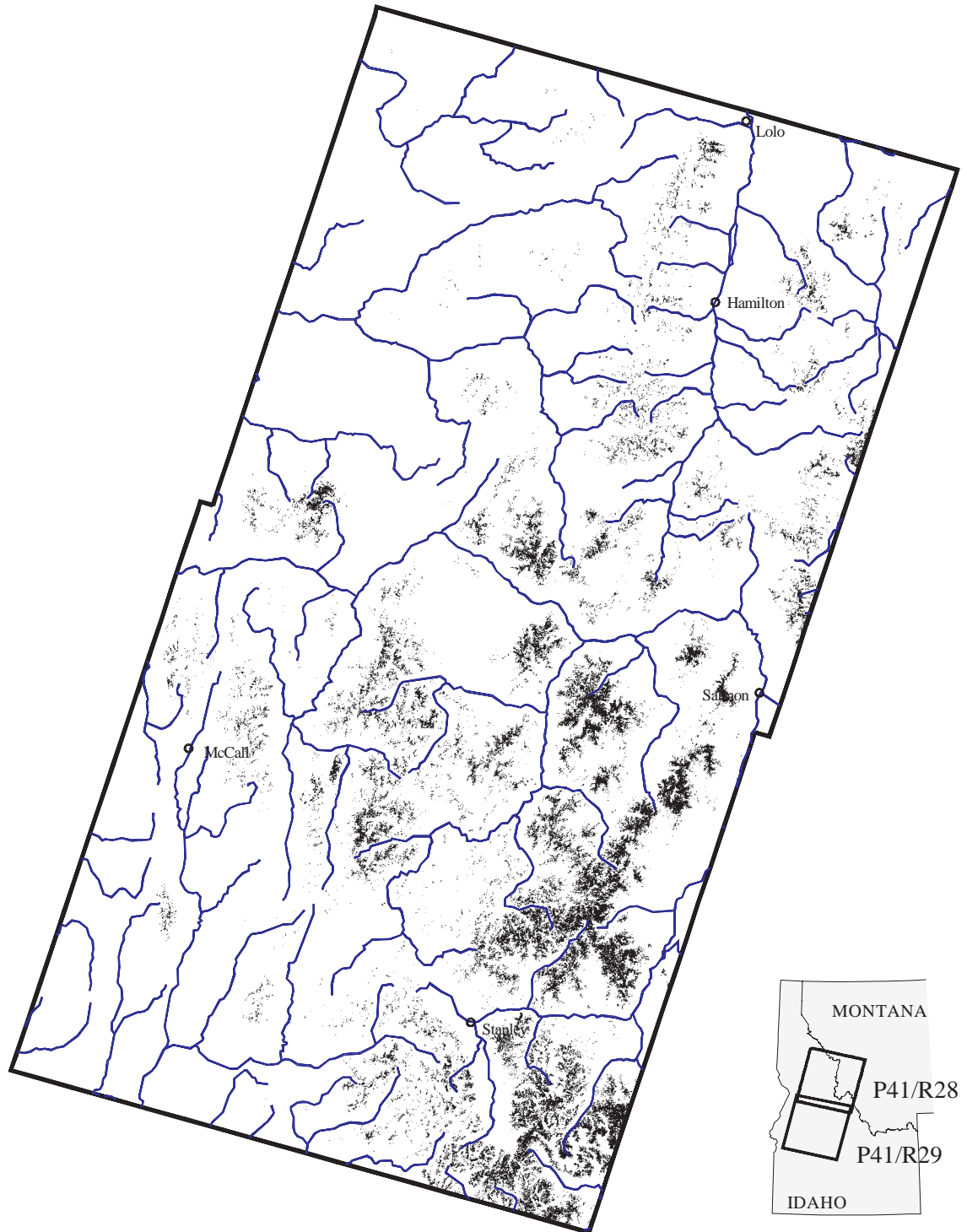
–M. Mahr

Full plot totals: 27 (P41/R28); 65 (P41/R29)

User’s accuracy: 73% (P41/R28); 72% (P41/R29)

Mis-classification: Mixed Whitebark Pine Forest was most frequently mis-classified in both scenes as Mixed Subalpine Fir Forest, although the predominance of this type of error was much more marked in the north than south (31% versus 10%). Stands in the Mixed Subalpine Fir and Mixed Whitebark Pine Forest complexes were often mixtures of the same conifer species in different relative abundances.

Distribution of Mixed Whitebark Pine Forest:



Estimated Area: 305,880 total ha (4.8% of study area)

Predicted Elevation: mean 2376 m; median 2381 m; trimmed range 2057 - 2679 m

North Understory Complex 10

Ecological notes: These were dry to moist, hot- to warm-site associations at low to mid elevations of the forest zone. All recorded, northern habitat types in the *Pinus ponderosa* and *Pseudotsuga menziesii* series were placed in this complex. However, the training set was dominated by shrub-defined types in the *Pseudotsuga menziesii* series (especially PSEMEN/PHYMAL) and some of the drier shrub types in the *Abies grandis* series (especially ABIGRA/PHYMAL) (Table 2).



PSEMEN/CALRUB-PINPON

Bighorn Crags quadrangle
-M. Kolster

Thus, the training data were weighted toward the relatively moist, warm extreme for the complex. Soils associated with habitat types in this complex are typically well-drained, acidic, sandy loams or silts containing some gravel (Cooper et al. 1991). Vegetative structure varied from park-like stands with open canopies and bunchgrass understories (at lower elevation and/or on south-to-west aspects) to closed canopy forests with well-developed shrub understories and/or herbaceous mats dominated by *Calamagrostis rubescens* and *Carex geyeri* (at higher elevation and/or on less severe exposures).

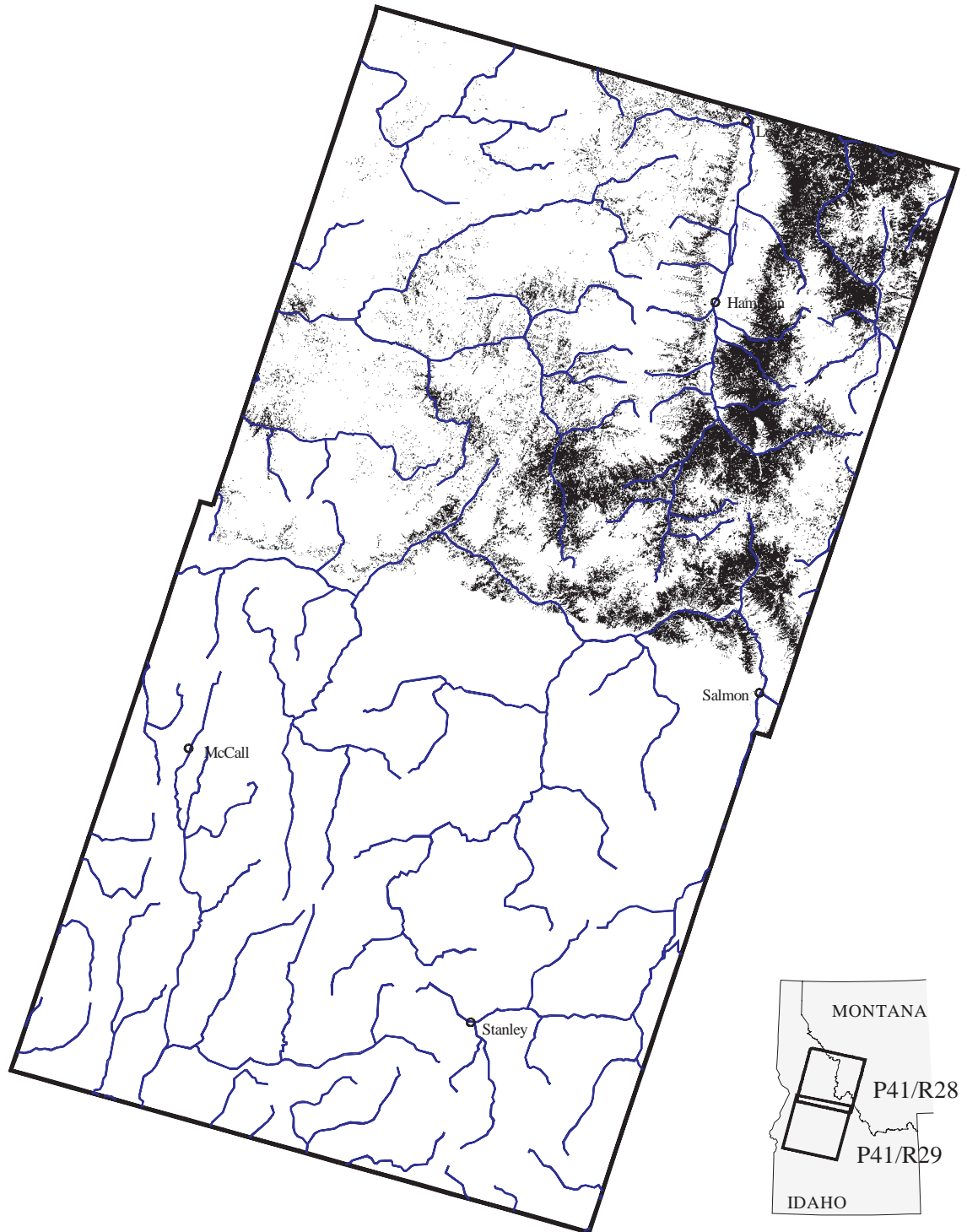
Existing forest overstories (n=245 training plots):

- 2.0% Conifer Regeneration Dominated Burn
- 13.9% Ponderosa Pine Dominant Forest
- 51.8% Mixed Douglas-Fir Forest
- 6.5% Mixed Mesic Forest
- 24.9% Mixed Lodgepole Pine Forest
- 0.8% Mixed Subalpine Fir Forest
- 0.0% Mixed Whitebark Pine Forest

User's accuracy: 66%

Mis-classification: Complex 10 was most often mis-classified as Complex 30 (12%) and Complex 40 (15%). Complexes 10 and 30 overlapped in elevational range and sometimes intergraded in species composition. For example, on more northerly aspects, the PSEMEN/PHYMAL habitat type of Complex 10 often graded into the relatively moist ABIGRA/CLIUNI association of Complex 30. Mis-classification as Complex 40 may be due to a high percentage of rock and exposed soil in both the dry, hot, low-elevation forests of Complex 10 and the dry, cold, upper-elevation extremes of Complex 40.

Distribution of North Understory Complex 10:



Estimated Area: 597,779 total ha (19.2% of study area north of edge-match)

Predicted Elevation: mean 1625 m; median 1630 m; trimmed range 970 - 2211 m

North Understory Complex 20

Ecological notes: Plant associations in this complex were those of wet, cool sites in valley bottoms and on north trending slopes at low to mid elevation. Although habitat types in the *Thuja plicata* series predominated, the *Abies grandis* series was also well represented in the training set (Table 2). *Thuja plicata* habitat types were largely restricted to portions of P41/R28 (north and west) with a strong maritime influence. The *Abies grandis* series replaces *Thuja plicata* types to the south and east as continental influences increase (Cooper et al. 1991). Soils for habitat types in the complex are



THUPLI/CLIUNI-CLIUNI

Mink Peak quadrangle
—C. Riegel

generally silty loams, silty clay loams, and loamy sands having fine textures and high moisture retention (Cooper et al. 1991). Forest canopies were typically closed or nearly so and understories varied from species-rich carpets of forbs (e.g., *Clintonia uniflora* and *Asarum caudatum*) to dense fern swards (e.g., *Athyrium filix-femina*) or well-developed middle layers of shade-tolerant shrubs (e.g., *Menziesia ferruginea*). This complex had no ecological equivalent in the south.

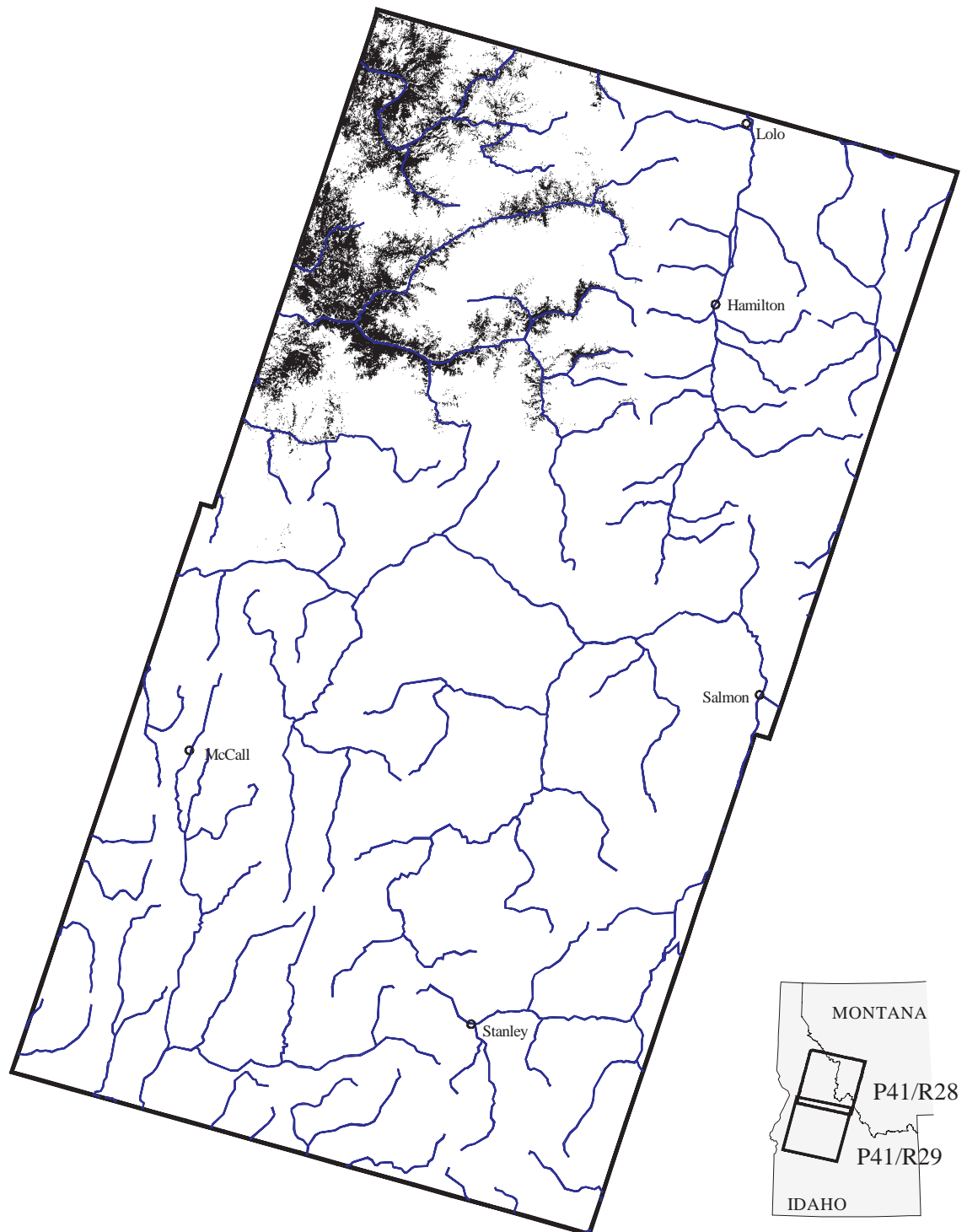
Existing forest overstories (n=111 training plots):

- 0.0% Conifer Regeneration Dominated Burn
- 0.0% Ponderosa Pine Dominant Forest
- 5.4% Mixed Douglas-Fir Forest
- 88.3% Mixed Mesic Forest
- 0.0% Mixed Lodgepole Pine Forest
- 6.3% Mixed Subalpine Fir Forest
- 0.0% Mixed Whitebark Pine Forest

User's accuracy: 68%

Mis-classification: Complex 20 was most frequently mis-classified as Complex 30 (21%). Both complexes are agglomerations of moist habitat types having overlapping elevational ranges and which may intergrade. For example, the ABIGRA/ASACAU habitat type of Complex 20 graded into the ABIGRA/CLIUNI types of Complex 30 as site conditions became drier and cooler.

Distribution of North Understory Complex 20:



Estimated Area: 277,238 total ha (8.9% of study area north of edge-match)

Predicted Elevation: mean 1283 m; median 1301 m; trimmed range 825 - 1659 m

North Understory Complex 30

Ecological notes: These were moist to wet, warm to cool sites in the lower subalpine zone. The training set for Complex 30 was dominated by relatively moist associations from the *Abies grandis* series (ABIGRA/LINBOR and ABIGRA/CLIUNI) and their ecologically similar counterparts in the *Abies lasiocarpa* series (ABILAS/LINBOR and ABILAS/CLIUNI) (Table 2). The occurrence of these habitat types was as strongly influenced by site-specific topographic and edaphic features (e.g., low angled slopes, frost pockets, and cool air drainages) as by aspect and elevation. Soils for habitat types in the complex range from saturated to moist but well-drained and are predominately loams, silt loams, and clays (Cooper et al. 1991). Forest canopies were typically closed to partially closed and shrub (*Menziesia ferruginea*) or sub-shrub (*Linnaea borealis*) understories well-developed. Common indicator forbs were *Streptopus amplexifolius* and *Calamagrostis canadensis* on saturated soils and *Clintonia uniflora* on better-drained sites.



ABIGRA/CLIUNI

Brundage Mountain quadrangle
—M. Jones

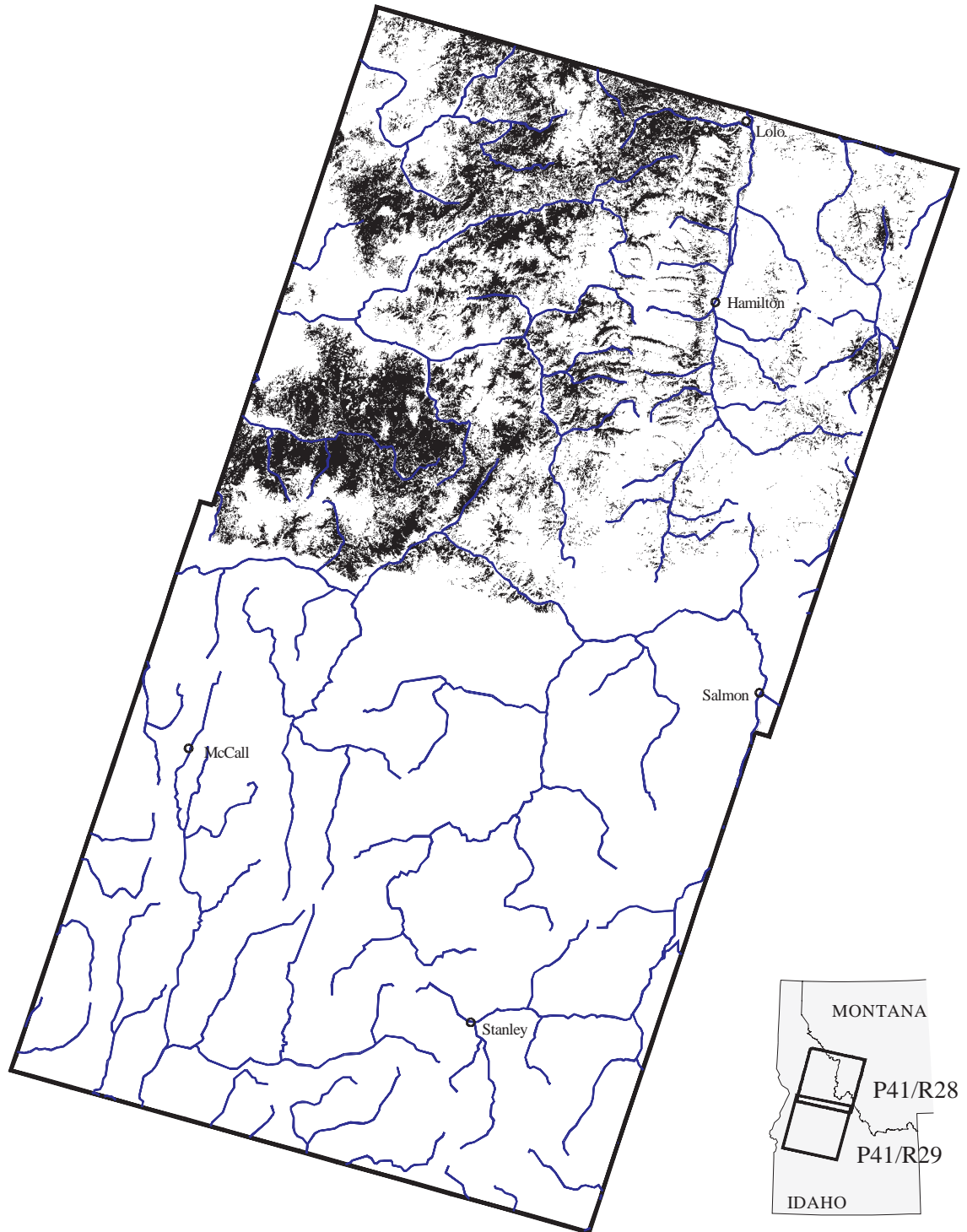
Existing forest overstories (n=192 training plots):

- 1.0% Conifer Regeneration Dominated Burn
- 0.5% Ponderosa Pine Dominant Forest
- 5.2% Mixed Douglas-Fir Forest
- 48.4% Mixed Mesic Forest
- 12.0% Mixed Lodgepole Pine Forest
- 32.8% Mixed Subalpine Fir Forest
- 0.0% Mixed Whitebark Pine Forest

User's accuracy: 46%

Mis-classification: Complex 30 was most frequently (22%) confused with Complex 40. Complex 30 and especially Complex 40 are dominated by habitat types in the *Abies lasiocarpa* series. Member habitat types consequently overlapped over a broad elevation range and sometimes formed intergrading mosaics in response to local topographic and edaphic variation. For example, the ABIGRA/CLIUNI-XERTEN type of Complex 30 is ecologically intermediate between the relatively warmer phases of ABIGRA/CLIUNI also in Complex 30 and the drier, colder ABIGRA/XERTEN types of Complex 40.

Distribution of North Understory Complex 30:



Estimated Area: 735,358 total ha (23.7% of study area north of edge-match)

Predicted Elevation: mean 1632 m; median 1660 m; trimmed range 1041 - 2142 m

North Understory Complex 40

Ecological notes: This group of habitat types was indicative of dry to moist, warm to cold sites at upper elevations in the forest zone. Overall, the training set was dominated by mid- to upper-subalpine habitat types from the *Abies lasiocarpa* series (Table 2). In the maritime northwest, where *Tsuga mertensiana* may replace *Abies lasiocarpa* as the climax overstory dominant (Cooper et al. 1991), similar habitat types from the *T. mertensiana* series predominated. Many stands in this complex, particularly those in the *Abies lasiocarpa* series, have been disturbed by fire and consequently have *Pinus contorta*, *Pseudotsuga menziesii*, and *Larix occidentalis* present as seral dominants in the upper layer (Cooper et al. 1991). The prevalence of *Xerophyllum tenax*-defined and *Vaccinium scoparium*-defined understory associations in all three major series represented in the complex (*Abies grandis*, *Abies lasiocarpa*, and *Tsuga mertensiana*) indicates cooler climatic conditions than for Complex 30 and relatively shallow, well-drained soils. The training set included a few habitat types characteristic of the transition from forest to alpine tundra (e.g., ABILAS/LUZHIT and PINALB) as well as some for which *Pinus contorta* is regarded non-seral and self-perpetuating (Table 2). Understory associations varied from well-developed shrub layers (e.g., *Vaccinium globulare*, *Vaccinium scoparium*, and *Menziesia ferruginea*) to patches of woodrush (mainly *Luzula hitchcockii*) and swards of beargrass (*Xerophyllum tenax*).



ABILAS/UACSCO-CALRUB
Greyhound Mountain quadrangle

—M. Kolster

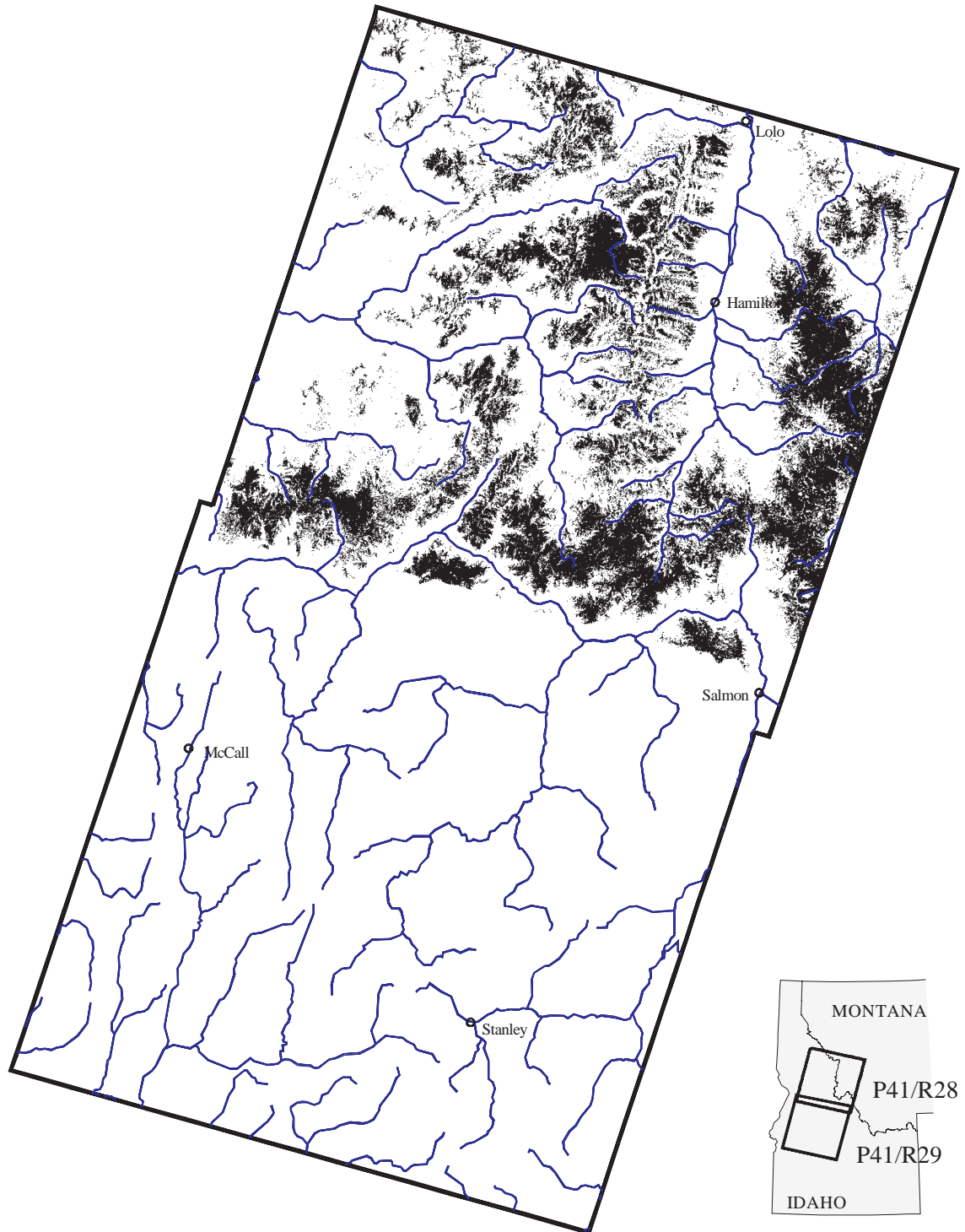
Existing forest overstories (n=763 training plots):

- 8.7% Conifer Regeneration Dominated Burn
- 0.0% Ponderosa Pine Dominant Forest
- 1.7% Mixed Douglas-Fir Forest
- 5.9% Mixed Mesic Forest
- 29.4% Mixed Lodgepole Pine Forest
- 39.8% Mixed Subalpine Fir Forest
- 14.5% Mixed Whitebark Pine Forest

User's accuracy: 82%

Mis-classification: Complex 40 was most frequently mis-classified as Complex 30 (9%). Presumably, this reflects similarity in species composition, broad overlap in elevation range, and a mosaic distribution pattern of complexes in the overlap zone (see the comments on mis-classification for Complex 30).

Distribution of North Understory Complex 40:



Estimated Area: 762,686 total ha (24.5% of study area north of edge-match)

Predicted Elevation: mean 1886 m; median 1866 m; trimmed range 1544 - 2315 m

South Understory Complex 50

Ecological notes: Although the correspondence in component habitat types is not exact, Complex 50 is in most respects the southern, ecological equivalent of North Understory Complex 10. Both associations were characteristic of dry, hot to warm sites at or near lower timberline. Most of the ecological notes presented for North Understory Complex 10 therefore apply with equal force here and will not be repeated. The primary



PSEMEN/SPIBET-CALRUB

Yellow Jacket quadrangle
—M. Pokorny

difference is that PSEMEN/VACGLO habitat types, which represented the moist, cool extreme for Complex 10, were grouped in the south into Complex 60 (below).

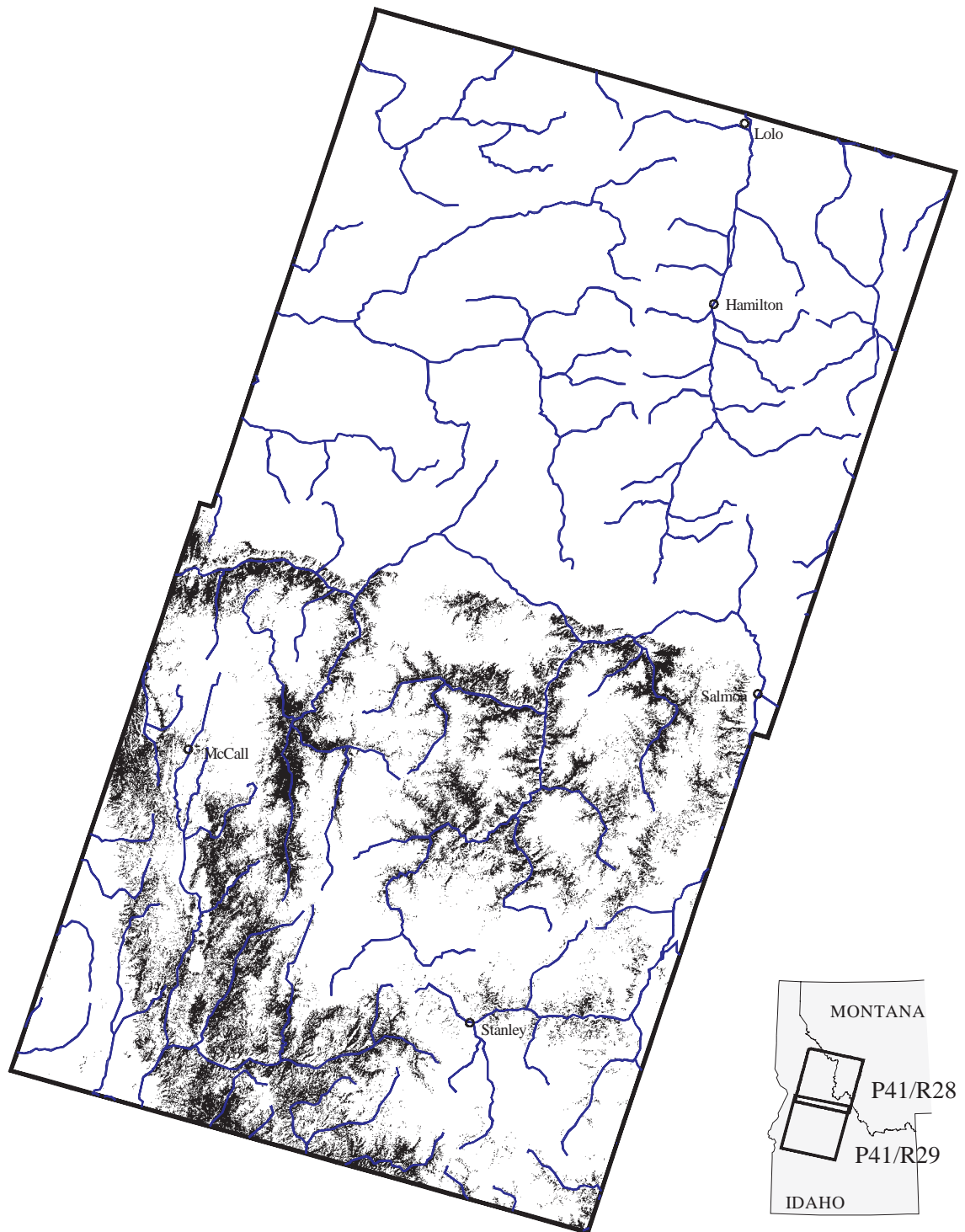
Existing forest overstories (n=313 training plots):

- 1.0% Conifer Regeneration Dominated Burn
- 6.7% Ponderosa Pine Dominant Forest
- 17.3% Douglas-Fir/Ponderosa Pine Co-Dominant Forest
- 63.3% Douglas-Fir Dominant Forest
- 1.3% Mixed Mesic Forest
- 9.9% Mixed Lodgepole Pine Forest
- 0.6% Mixed Subalpine Fir Forest
- 0.0% Mixed Whitebark Pine Forest

User's accuracy: 70%

Mis-classification: Complex 50 was most frequently mis-classified (24%) as Complex 60. The latter complex generally occupied moister sites at higher elevation but the two complexes were contiguous in places and sometimes formed local mosaics in response to variation in topographic and edaphic conditions. For example, the PSEMEN/PHYMAL habitat types of Complex 50 can grade into the ABIGRA/CLIUNI types of Complex 60 with increasing soil moisture on cooler aspects. Note that North Understory Complex 30 (the northern ecological equivalent of Complex 60) was similarly a primary source of mis-classification for North Understory Complex 10 (the northern ecological equivalent of Complex 50).

Distribution of South Understory Complex 50:



Estimated Area: 640,565 total ha (19.4% of study area south of edge-match)

Predicted Elevation: mean 1924 m; median 1982 m; trimmed range 1334 - 2343 m

South Understory Complex 60

Ecological notes: These were dry to moist, warm to cool sites in areas with moderate relief at low to mid elevation in the forest zone. The training set for the complex was dominated by habitat types from the relatively moist, cool extreme for the *Pseudotsuga menziesii* series and types typical of the low to middle subalpine zone from the *Abies lasiocarpa* series (Table 3). The set included most habitat types assigned in the north to Complex 30 as well as a few types representing the relatively moist, cool extreme for North Understory Complex 10, on the one hand, and the relatively dry, warm extreme for North Understory Complex 40 on the other. As such, Complex 60 is ecologically most similar to North Understory Complex 30 with somewhat expanded moisture/temperature extremes. Canopy structure was typically closed to partially closed. Understories often had a well-developed shrub component (especially *Vaccinium globulare*, *Vaccinium scoparium*, *Vaccinium caespitosum*, *Menziesia ferruginea*). *Calamagrostis rubescens* was frequent and abundant, sometimes forming a continuous cover, in the herbaceous layer. All southern *Vaccinium globulare* habitat types were grouped into Complex 60. Soils for habitat types in the complex are typically gravelly loams to sandy loams from granitic parent materials (Steele et al. 1981).



ABILAS/XERTEN-VACGLO
Mink Peak quadrangle

—C. Riegel

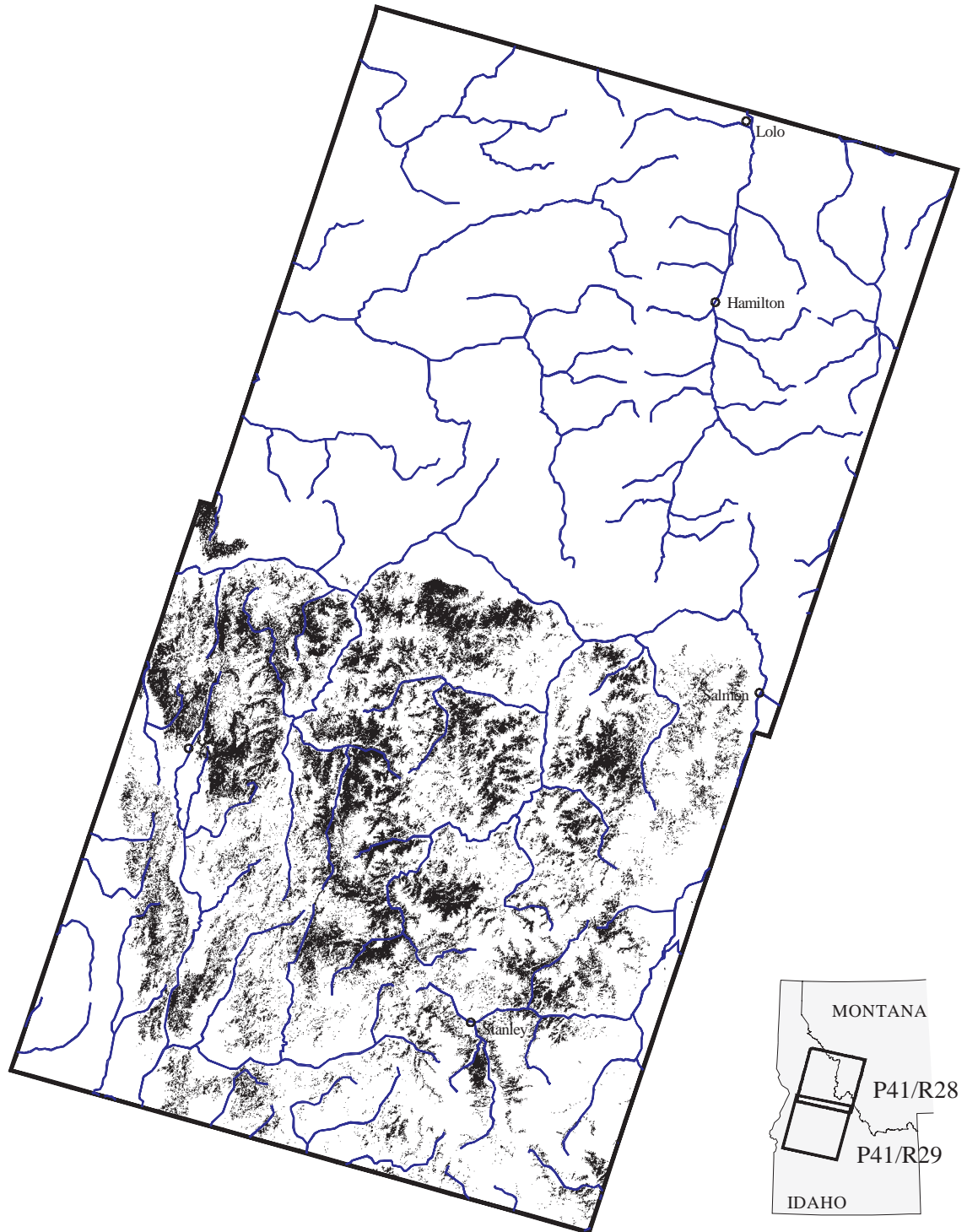
Existing forest overstories (n=349 training plots):

- 3.7% Conifer Regeneration Dominated Burn
- 0.3% Ponderosa Pine Dominant Forest
- 1.7% Douglas-Fir/Ponderosa Pine Co-Dominant Forest
- 25.8% Douglas-Fir Dominant Forest
- 11.5% Mixed Mesic Forest
- 29.5% Mixed Lodgepole Pine Forest
- 26.6% Mixed Subalpine Fir Forest
- 0.9% Mixed Whitebark Pine Forest

User's accuracy: 56%

Mis-classification: Complex 60 was mis-classified to each of the three other southern understory complexes with similar, low frequency (4–9%). Complex 60 overlapped in elevation range at either its upper or lower extreme with each of the other three complexes and contained habitat types that grade into types belonging to each of the other complexes. For example, PSEMEN/CALRUB-CALRUB at the dry, warm extreme for Complex 60 may grade into types such as PSEMEN/PHYMAL-CALRUB at the moist, cool extreme for Complex 50.

Distribution of South Understory Complex 60:



Estimated Area: 679,988 total ha (20.5% of study area south of edge-match)

Predicted Elevation: mean 2051 m; median 2117 m; trimmed range 1538 - 2400 m

South Understory Complex 70

Ecological notes: These were dry to moist, cool to cold, often leeward sites in the upper subalpine zone. Late snow melt and/or nearby surface water (streams and pools) were common site characteristics. Networks of surface water often created islands and stringers of wet-site plant associations (e.g., ABILAS/CALCAN) surrounded by dry-site associations (e.g., ABILAS/XERTEN). This mosaic pattern, a relatively open tree canopy, and understories dominated by



ABILAS/LUZHIT-VACSCO

Mount McGuire quadrangle
—L. Baldwin

herbs (*Calamagrostis canadensis*, *Luzula hitchcockii*, and *Xerophyllum tenax*) or low shrub (*Vaccinium scoparium*) characterized the vegetative structure of the complex. The training set was comprised almost entirely of habitat types from the *Abies lasiocarpa* series (Table 3). Ecologically, Complex 70 is most similar to the moist and upper-elevation extremes of North Understory Complex 40.

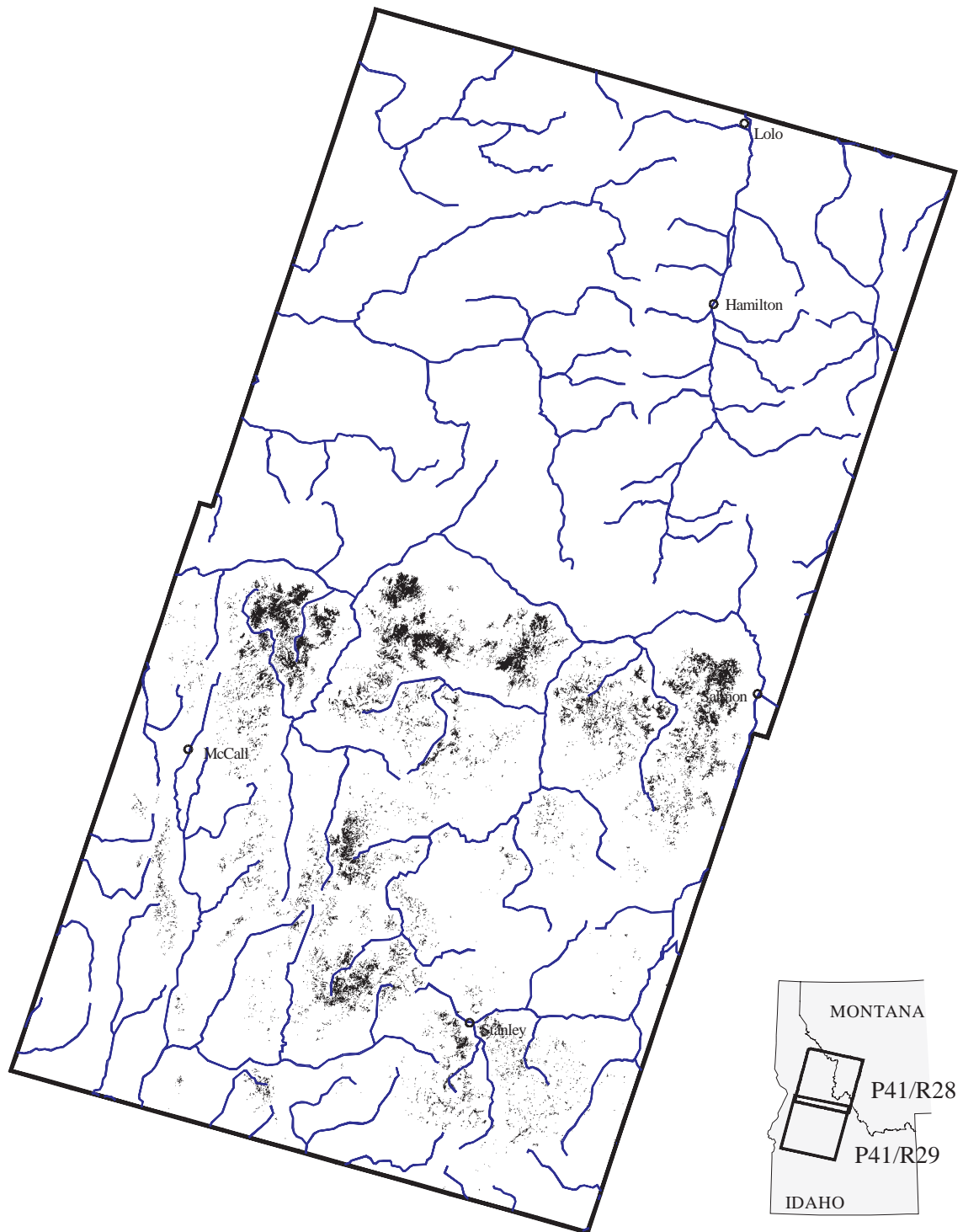
Existing forest overstories (n=245 training plots):

- 6.9% Conifer Regeneration Dominated Burn
- 0.0% Ponderosa Pine Dominant Forest
- 0.0% Douglas-Fir/Ponderosa Pine Co-Dominant Forest
- 0.0% Douglas-Fir Dominant Forest
- 0.8% Mixed Mesic Forest
- 26.9% Mixed Lodgepole Pine Forest
- 39.2% Mixed Subalpine Fir Forest
- 26.1% Mixed Whitebark Pine Forest

User's accuracy: 73%

Mis-classification: Complex 70 was most frequently mis-classified as Complex 60 (20%) or Complex 80 (11%). Habitat types in these three complexes were sometimes adjacent and intergraded along moisture or elevation gradients. Considering all southern understory complexes, Complexes 60 and 70 overlapped most in terms of species composition in both the upper and lower vegetation layers.

Distribution of South Understory Complex 70:



Estimated Area: 151,100 total ha (4.7% of study area south of edge-match)

Predicted Elevation: mean 2282 m; median 2274 m; trimmed range 1971 - 2646 m

South Understory Complex 80

Ecological notes: These were dry, cool to cold, often windward sites in the upper subalpine zone. Soils for habitat types in the complex are often granitic, coarse-textured loams to sandy loams with much gravel (Steele et al. 1981). The combination of aspects with high exposure to sun and drying winds and well-drained soils produced relatively arid conditions despite high precipitation (Arno and Hammerly 1984). Litter and soil layers were consequently shallow and there was substantial exposed soil and rock. The training set for Complex 80 was composed of habitat types from the *Pinus contorta*, *Abies lasiocarpa*, and *Pinus albicaulis* series (Table 3). Forest canopies were open and understories typically sparse associations of low shrub (*Vaccinium scoparium*) and sedge (*Carex geyeri*). The ridge-top ribbon forest formation described by Arno and Hammerly (1984) is an example of a forest type with understories common to this complex. Complex 80 was most similar ecologically to the dry, cold extremes for North Understory Complex 40.



PINALB/

Galena quadrangle
—R. Vinkey

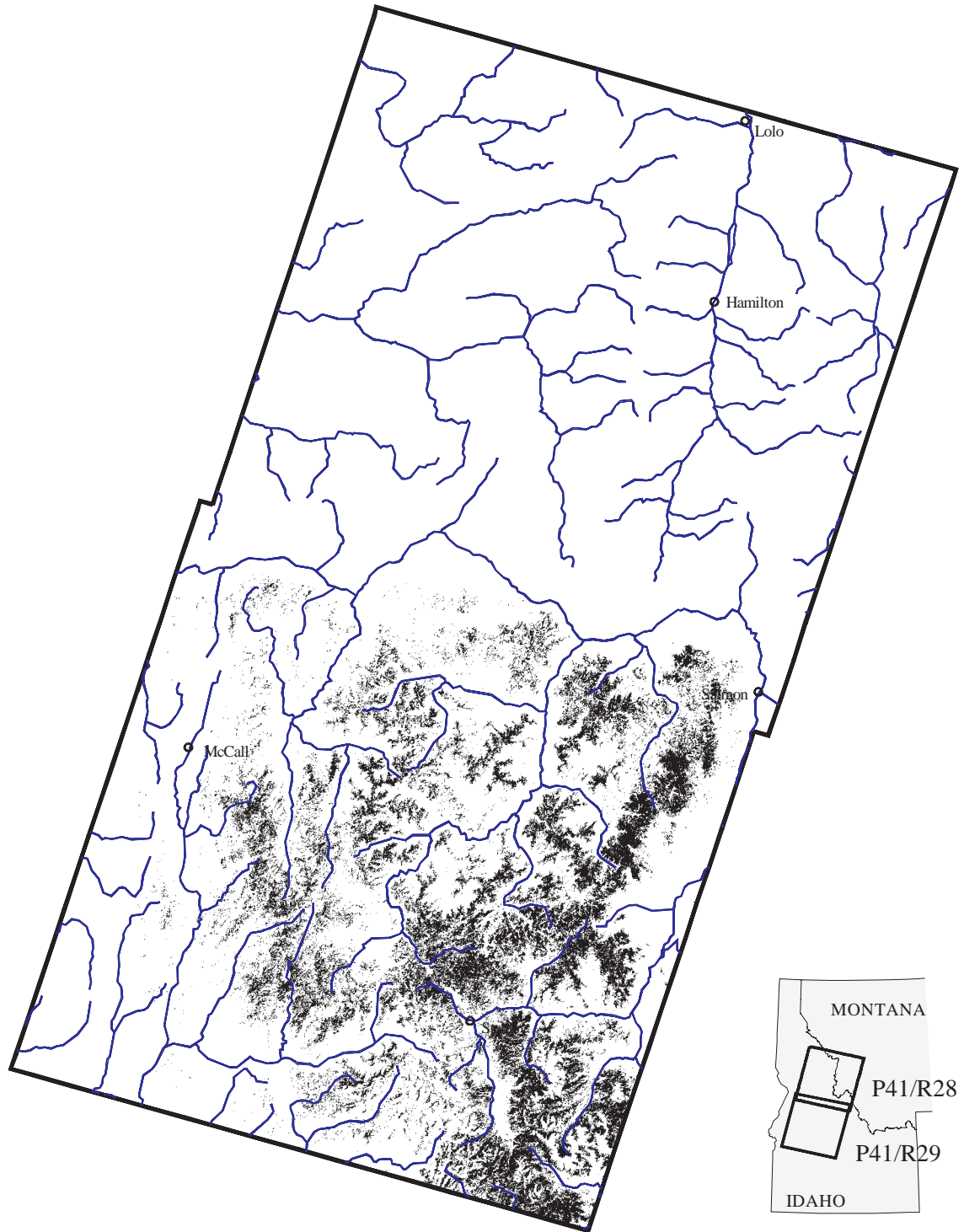
Existing forest overstories (n=236 training plots):

- 15.7% Conifer Regeneration Dominated Burn
- 0.0% Ponderosa Pine Dominant Forest
- 0.0% Douglas-Fir/Ponderosa Pine Co-Dominant Forest
- 2.1% Douglas-Fir Dominant Forest
- 0.0% Mixed Mesic Forest
- 30.5% Mixed Lodgepole Pine Forest
- 24.2% Mixed Subalpine Fir Forest
- 27.5% Mixed Whitebark Pine Forest

User's accuracy: 60%

Mis-classification: This complex was most often mis-classified as Complex 60 (26%) and Complex 70 (14%) presumably for reasons of adjacency and intergradation (see comments for Complexes 60 and 70). It isn't obvious why Complex 80 was more frequently mis-classified as Complex 60 than as the elevationally similar Complex 70. One possibility is that Complex 60 was a more diverse assemblage of habitat types and hence more apt to include types having spectral and other characteristics similar to those in Complex 80.

Distribution of South Understory Complex 80:



Estimated Area: 520,852 total ha (15.7% of study area south of edge-match)

Predicted Elevation: mean 2219 m; median 2249 m; trimmed range 1702 - 2621 m

DISCUSSION

Purpose of Map

Technical Objectives: The technical objectives of this study were five-fold. First, to collect and collate a large training set composed of accurately located botanical plots. Second, to use spectral information from Landsat TM images to delineate discrete map units (polygons) representing patterns of existing vegetation on the ground. Third, to assign polygons to vegetation type using classification rules derived from the training set. Fourth, to provide a thorough statistical evaluation of map accuracy and complete documentation of our field, image processing and image classification methodologies. Fifth, and finally, to employ the best methods available for the production of Landsat-based maps at the ecosystem-level scale.

Notable features of this classification of the Salmon-Selway ecosystem include (i) improved techniques for image segmentation (Winne 2000), (ii) novel spatial classifiers (Steele and Redmond 2000; Steele and Patterson 2000; Steele 2000), (iii) new methods of error analysis (Steele et al. 1998), (iv) a much larger and better distributed set of training data than previously available, and (v) new methods for mapping forest understory. We have not attempted to evaluate the individual contribution to map quality for any of these features. However, their joint effect was certainly large. For example, Winne (2000) found that the smaller, more spectrally uniform polygons produced by their methods could be labeled to cover type with higher accuracy than larger, more heterogeneous polygons. Although their analysis was limited to rangeland settings, we see no reason that their results should not apply to mountainous ones as well. Similarly, spatial classifiers alone are known to improve the estimated accuracy of map classification in mountainous landscapes by 10–20% over conventional k-nearest neighbor classifiers (Steele and Redmond 2000; Steele 2000). Finally, previous to this study, there were very few training data available within wilderness boundaries. Considering the number of training plots added and the spatial extent of these previously unsampled areas, the improvement in local and overall map accuracy due to these new data was very likely substantial.

Application: Our practical objective in producing a new map of the Salmon-Selway ecosystem was to provide a multipurpose descriptive tool for application in future ecosystem-level studies in conservation and ecological science. One example of such an application of the map is Hogg et al. (2000) where we used the map to predict the distribution and abundance of grizzly bear food-plant groups. In fact, a primary motivation for developing methods for mapping forest understories was the recognition that habitat use by many species of conservation interest, including the grizzly bear, is more keyed to the structure and composition of forest understory than to that of the forest canopy. The map is therefore particularly appropriate for studies of habitat suitability for such species. However, many other applications are possible. Potential users should contact the Montana Conservation Science Institute regarding availability of the data. In the following sections, we discuss some issues of map interpretation that may help such groups or individuals decide whether this GIS is appropriate for their application.

Interpretation of Map

Distribution of Training Data: The optimal spatial distribution of training data for use with spatial classification rules has not been formally investigated. Training observations should be “well-distributed” across the landscape of interest, but whether this best done with a grid-based sample, probability sample, or other methodology is not yet clear. Nonetheless, some general points can be made regarding the distribution of the Salmon-Selway training set. First, the performance of spatial classifiers has been shown to be quite robust to variation in total and local densities of training observations (Steele and Redmond 2000; Steele 2000). This suggests that the marked concentration of R4 training plots in a few southern quads (Figure 2) did not unduly influence estimates of overall or complex-specific map accuracy. Second, although a primary contribution of this study was extensive ground truthing in three large and previously unsampled subregions of designated wilderness, inspection of Figures 2 and 3 reveals that many fairly large areas still lack training data. Regions without training data are problematic with respect to the assessment of map accuracy for at least two reasons. One is that spatial classifiers work best when the distances separating training observations are similar to those separating training observations and unclassified polygons. When the former distances tend to be less than the latter (as will be the case when large data gaps are present), estimates of map accuracy may be optimistic. The second is that large gaps introduce uncertainty in the interpretation of spatial error maps. When the vegetation and physiography of unsampled regions is similar to that of sampled regions, then overall and complex-specific map accuracies may be high despite the local absence of training data. However, the accuracy of classification within such regions cannot be assessed. Methods for displaying spatial patterns of accuracy do provide estimates for unsampled regions, but these are interpolated from training data in adjacent sampled regions (Steele et al. 1998). Interpolation error increases with the distance between sampled and unsampled points. Spatial estimates of map accuracy within large unsampled regions should therefore be viewed with caution.

In summary, we have made some progress in improving the spatial distribution of training observations for the Salmon-Selway ecosystem. Because our training set included ca. 10,000 observations reasonably well-distributed across two TM scenes, we believe that estimates of map accuracy are within a few percent for all vegetation complexes and at most locations. We note that ecosystem-scale, Landsat TM-based vegetation maps have generally not used training data located according to statistical principles. Exceptions include a very few studies using USDA Forest Inventory and Analysis training data (He et al. 1998). We recommend that, in the design of field sampling protocols, investigators place more emphasis on identifying the appropriate spatial distribution of training data given the methods chosen for image classification and error estimation.

Quality and Date of TM Data: Spectral data are of the highest quality and maximum utility when haze, cloud, and snow cover are absent, local spatial variation in insolation is minimized, and plant-leaf areas maximized (Redmond et al. 1998). In the Northern Rockies these conditions are generally best met in the latter half of July. This period typically precedes the late summer onset of wildfires but is well after spring burning in agricultural areas. Moreover, snow melt is

typically complete in alpine areas, the summer solstice is just past, and plant growth is at its peak. Imagery for this study was obtained during this optimal seasonal window and from days and years when cloud cover and snow cover, respectively, were insignificant (<1% of the study area).

Ideally, training data should be obtained in the same year as the TM imagery. When dates of collection for spectral versus botanical data differ, ecological disturbance or succession in the intervening period can cause mismatches between the spectral data associated with a training plot and its vegetative composition as recorded in the field. In our case, the difference between dates of TM imagery versus training data collection varied from +1 to -3 years in the south and -3 to -7 years in the north. Fire was the most frequent and widespread cause of ecological disturbance in these time frames. We corrected for the effects of fire in the interval between collection of plot and spectral data by deleting these plots. We made no attempt to evaluate the effects of succession in periods separating plot and image acquisition. The cumulative effect of successional change was almost certainly small and probably largely limited to non-forest vegetation complexes in the north. We also did not attempt to delineate burns that occurred after the dates of image collection. Most of these areas would have been mis-classified to one of the (non-burn) forest-canopy vegetation complexes.

Map Detail: The resolution of the unsupervised map was constrained by the 30 m² (0.4 ha) resolution of the TM scanner and the extent to which “features” on the ground presented unique spectral patterns. Given the first constraint, one can assume that ground features appreciably smaller than 30 m in one or both dimensions were not delineated as a map polygons in the unsupervised classification. Examples include small wetlands, thin stringers of riparian vegetation along intermittent streams, or small rock outcrops in forests. Features larger than 0.4 ha may or may not have been delineated depending on the level of spectral contrast between the set of pixels representing the feature and those surrounding it. The rule-based method we used to merge pixels is highly repeatable. However, outcomes are also highly site-specific. Thus, other than to say that a one hectare pond in the middle of a coniferous forest was more likely to be delineated than a one hectare patch of willows surrounded by broadleaf forest, few generalizations about map detail for features above the 0.4 ha threshold are possible.

Whether a feature delineated as a distinct polygon during image segmentation was subsequently labeled to a land cover type distinct from that of surrounding polygons depended on the performance of the classifier (see below). Boundaries between contiguous polygons labeled to the same cover type do not appear in the final vegetation maps (although such polygons were maintained as distinct spatial units in the GIS). Because adjacent polygons in the unsupervised image often received the same cover type label (despite being somewhat distinct spectrally) the vegetation maps have a much less detailed structure than the unsupervised image. In extreme cases, continuous areas of one vegetation type in excess of 100,000 ha appear on the final vegetation map.

Homogeneity of Mapped Complexes: For a given training set and polygon structure, there is a tradeoff between thematic detail and map accuracy. Greater thematic detail (number of

vegetation types mapped) will come at the expense of reduced success in correctly predicting the membership of polygons with respect to vegetation group. Our philosophy in map construction was to first attempt to classify the study area at the level of plant community type (the lowest tier of plant associations depicted in Figures 4 and 5), but to combine ecologically related plant community types until the group was mapped with acceptable accuracy. This led to some unevenness in terms of the vegetative homogeneity of the mapped complexes. For example, we were able to map some plant community types (e.g., Ponderosa Pine Dominant Forest) in both scenes. Such complexes should present a relatively homogeneous associations of plant species across member polygons. In contrast, other complexes were agglomerations of two or more plant community types (e.g., Mixed Mesic Forest was an agglomeration of 14 types). Member polygons for these complexes present a more heterogeneous range of plant associations. We see little justification for attempting a more detailed map of the Salmon-Selway ecosystem at this time. The effort would be better applied in support of additional field work to obtain an improved training set for use with spectral data from the next generation of satellite scanners.

Evaluating Map Accuracy: All of the information presented on map accuracy (user's, producer's, overall, complex-specific, and spatial) will be relevant to most applications. However, the most pertinent considerations may vary. Three examples follow.

Overall versus complex-specific accuracy: Vegetation complexes for which there are many training plots are more heavily weighted in the calculation of overall map accuracies. Thus, accurate classification of a few common vegetation types can produce a high overall map accuracy despite frequent mis-classification of many other, relatively rare complexes. Thus, applications that focus on one or more rare and less sampled complexes should look carefully at the appropriate complex-specific user's accuracies (the diagonals of Tables 9–12) rather than the various presentations based on overall map accuracy (Table 17; Figures 10 and 11).

Mis-classification: The primary purpose for including comments on "Mis-classification" with the description of each mapped complex was to show by repeated example that there were different levels of error in predicting membership to vegetation complex. Specifically, these comments illustrate that mis-classifications often involved an ecologically very similar plant association. For example, we classified Mesic Grasslands/Subalpine Meadows with low user's accuracy in the north (40%). But inspection of producer's error reveals that almost all mis-classifications of this complex were to the Mesic Shrublands complex. For some applications, the ecological distinction we have drawn between these two complexes, or other frequently confused pairs, may be unimportant. In such cases, more pertinent estimates of accuracy are sums of two or more column entries from Tables 9–12 rather than the diagonal entries only. In the above example, an estimate of user's accuracy for a post-classification agglomeration of Mesic Grasslands/Subalpine Meadows and Mesic Shrublands is 0.76 (the sum of 0.40 and 0.36 from column 2, Table 9, which applies to polygons labeled Mesic Grasslands/Subalpine Meadows), or 0.80 (the sum of 0.09 and 0.71 from column 3, Table 9, which applies to polygons labeled Mesic Shrublands).

Spatial variation in accuracy: Overall and complex-specific map accuracies were not constant over the study area. Rather, there was considerable spatial variation in accuracy. Figures 10 and 11 show this for overall accuracy, but such maps constructed for individual complexes would show similar variation. Spatial variation in overall map accuracy might have been caused by spatial variation in the density of training data, spatial variation in the distribution of vegetation types with more- versus less-distinct spectral signatures, spatial variation in vegetative structure and composition within complexes, or some combination of these effects. In any case, the presence of substantial spatial variation in map accuracies implies that applications that are constrained in geographic scope and location should carefully evaluate the spatial pattern of accuracy as well as estimates of overall and complex-specific map accuracy. This recommendation does not apply if the region of interest has no nearby training data; as noted above spatial maps of accuracy may be unreliable in such regions.

Mapping Forest Understory

Historical Context: Most applications of passive remote-sensing technologies to vegetation mapping have focused on predicting overstory canopy conditions. Stenback and Congalton (1990) were perhaps the first to evaluate the potential of Landsat TM imagery to measure understory characteristics in coniferous forests. Though limited to the detection of a vegetated understory (e.g., presence/absence), their study included detailed accuracy assessments for six different band combinations, thereby showing which TM bands were most sensitive to understory structure. To our knowledge, forest understory classes defined by species composition have been mapped only by manual methods, such as aerial photo interpretation. In Yellowstone National Park, for example, Despain (1986; 1990) interpreted potential climax vegetation (habitat types) on a sample of true-color aerial photos then extrapolated the results to the full extent of the park using GIS. A formal assessment of accuracy for this map was not presented. However, the author indicated a user's accuracy in excess of 80%.

Our approach combines features from each of these earlier efforts. Like Stenback and Congalton, we used TM data to classify the forest understory but, like Despain, we defined understory types according to species composition rather than crude structural criteria. Similarly, like Despain, we mapped understories at a spatial scale relevant to ecosystem conservation but, like Stenback and Congalton, we used explicit, automated, and highly repeatable rules of classification.

Relation of Understory Complexes: We mapped four forest-understory complexes in each scene. Each of the eight complexes had different sets of component habitat types (Tables 2 and 3). For this reason, we gave each complex unique numeric and color codes. However, with the exception of North Understory Complex 20, which was limited to the northwestern portion of P41/R28, all of the understory complexes had fairly close ecological counterparts across the edge-match boundary. These relationships were noted in the descriptions of the understory complexes. Briefly, North Understory Complex 10 and South Understory Complex 50 are broadly similar, South Understory 60 is comparable to North Understory 30 expanded somewhat

at both its dry/warm and moist/cool extremes, and North Understory 40 is the northern equivalent of South Understory Complexes 70 and 80 combined. From a coarser ecological perspective, then, it could be argued that the entire forested portion of the study area was mapped to five general rather than eight distinct understories. As with forest-canopy and non-forest complexes, the limit to the number of understory complexes that might be resolved in this ecosystem with these methods will not be discovered until a much larger training set is accumulated. Certainly that number is larger than five. However, because a given understory complex may occur under a variety of forest canopies, the addition of even five understory groups substantially increases the number of unique forest types and overall level of map detail. In theory, given eight forest-canopy complexes, five forest-understory complexes could amplify the number of unique forest types to 40. In practice, because some combinations of canopy and understory are rare or do not occur and because of scene differences in map detail, the number of unique forest types generated with canopy and understory information was less but still substantial (on the order of 20; see Tables 7 and 8).

Such a combination map (forest-canopy/forest-understory/non-forest) does raise additional issues regarding accuracy. Since both forest canopy and forest understory are predicted with error, the accuracy of the combined canopy/understory complex assignment should be less than that of either component assignment. Leave-one-out cross-validation estimates of accuracy could be calculated for the joint classification of forest polygons to canopy and understory complex. However, we did not make this calculation.

Predictors of Understory: Classification of the forest understory was determined primarily by spectral (TM bands 1–7) as opposed to physiographic (slope, aspect, and elevation) variables. Although physiographic variables were included in the final model for both scenes, their addition never increased estimated forest-understory map accuracy by more than a few percent and in some cases (e.g., addition of aspect in the south) actually reduced it. Given that forest canopy composition is not a good predictor of forest understory (habitat type) and given shielding of the understory by canopy vegetation, one might expect that physiographic rather than spectral data would drive prediction of forest understory.

Several factors likely contributed to the greater utility of spectral data. First, whereas individual habitat types are often associated with particular physiographic characteristics, agglomerations of many habitat types will inevitably display an increased physiographic amplitude. Agglomerations should therefore show reduced correlations with physiographic measurements. Second, forest canopies in the study area were generally not completely closed. Thus, for a majority of the forested area, some reflectance in TM bands 1–7 must have come from understory vegetation and/or the non-vegetated forest floor. Even when substantially limited by canopy shielding, spectral data may have been more predictive of understory simply because it was a more direct measurement of understory plant associations than was physiographic data. Finally, there exists a technical limitation peculiar to the physiographic data. Polygons could be assigned only a single value for each physiographic variable (elevation, slope, aspect). These values were derived from the 7.5 minute digital elevation model (DEM). For elevation and slope, values of component pixels were averaged to get the polygon value. For aspect, the modal

pixel value was used. Since elevation, slope, and aspect varied within polygons (more so the larger the polygon), average or modal values may have often failed to reflect the physiography associated with the 30 m² training plot. Such error in measurement will reduce the predictive power of physiographic variables. It is true that polygons also received a single value for each TM spectral variable. However, pixels were initially aggregated into polygons on the basis of spectral similarity (rather than similarity in aspect, etc.). Thus, TM values assigned to polygons may have been more often representative of training-site-specific values.

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