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Mapping forest alliances and associations using fuzzy systems and nearest neighbor classifiers

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Abstract

The study and management of biological communities depends on systems of classification and mapping for the organization and communication of resource information. Recent advances in remote sensing technology may enable the mapping of forest plant associations using image classification techniques. But few areas outside Europe have alliances and associations described in detail sufficient to support remote sensing-based modeling. Northwestern Montana has one of the few completed plant association classifications in the United States compliant with the recently established National Vegetation Classification system. This project examined the feasibility of mapping forest plant associations using Landsat Enhanced Thematic Mapper Plus data and advanced remote sensing technology and image classification techniques.

Suitable reference data were selected from an extensive regional database of plot records. Fifteen percent of the plot samples were reserved for validation of map products, the remainder of plots designated as training data for map modeling. Key differentiae for image classification were identified from a suite of spectral and biophysical variables. Fuzzy rules were formulated for partitioning physiognomic classes in the upper levels of our image classification hierarchy. Nearest neighbor classifiers were developed for classification of lower levels (alliances and associations), where spectral and biophysical contrasts are less distinct.

Maps were produced to reflect nine forest alliances and 24 associations across the study area. Error matrices were constructed for each map based on stratified random selections of map validation samples. Accuracy for the alliance map was estimated at 60%. Association classifiers provide between 54 and 86% accuracy within their respective alliances. Alternative techniques are proposed for aggregating classes and enhancing decision tree classifiers to model alliances and associations for interior forest types.
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Keywords: Vegetation mapping; Map design; Image classification; Fuzzy logic; Nearest neighbor; Plant association; Accuracy assessment

1. Introduction

Land cover maps are basic to the study and management of natural resources. As natural resources have become more scarce they have become more valuable, as evidenced by increased controversy over their management (Cohen et al., 2001; Congalton & Green, 1999), elevating the need for more current and accurate spatial data (Bobbe et al., 2001; Jennings et al., 2003).

While satellite imagery has been used for coarse-scale vegetation mapping for over three decades, satellite data have rarely been applied successfully for mapping at the floristic level. Cover types have been mapped successfully by various regional and mid-scale efforts (e.g., Brown de Colstoun et al., 2003; Collins et al., 2004; Vogelmann et al., 1998), but since dominance types can possess broad ecological and geographic ranges, they are less useful for some community-level studies. Recent advances in remote sensing technology and interpretation techniques, however, have made satellite imagery useful for vegetation type mapping at finer scales (e.g., Brown de Colstoun et al., 2003; Daniel & Fox, 1999).

Plant associations express characteristic patterns in their composition beyond that which would be expected by chance (Drake, 1990). Different plant taxa that occupy the same plant

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community are not identical in habitat niche; rather, the particular community is an expression of where their ecological amplitudes overlap. Certain plant assemblages can reappear over the landscape wherever there are similar environments (Daubenmire, 1968; Leavell, 2000). The ability to recognize patterns within natural systems makes possible the multivariate statistical (classification) and spatial (mapping) depiction of plant communities.

While a *potential* vegetation type provides an *interpretive* classification of a plant community, the *existing* vegetation type provides a *descriptive* classification of current vegetation (Arno et al., 1985). Much of the resources directed toward the classification, inventory, and mapping of plant communities in the western United States have been focused on potential vegetation (e.g., Cooper et al., 1991; Daubenmire & Daubenmire, 1968; Muldavin et al., 1996; Pfister et al., 1977). Until recently existing vegetation has received far less attention. The National Vegetation Classification system (NVC) has brought about needed consistency in classification standards for existing vegetation across federal lands in the United States (TNC & ESRI, 1994). Included in the NVC are both physiognomic and floristic hierarchies as originally identified by the Federal Geographic Data Committee in 1997 (FGDC, 1997). Physiognomic classification levels include *division*, *order*, *class*, *subclass*, *group*, *subgroup*, and *formation*. Floristic levels, at the bottom of the hierarchy, include plant *associations* nested under *alliances* according to floristic similarity. The Ecological Society of America (ESA) has established protocols for the classification of existing vegetation in the United States (Jennings et al., 2003). Critical to mapping applications is the ability to uncouple physiognomic and floristic hierarchies. In this way, alliances and associations can be mapped without requiring subclassification based on the degree of canopy cover imposed at the level of *class* (see below).

A plant community classification of existing vegetation was recently completed on the Kootenai NF according to NVC standards (Leavell, 2000). This treatment in conjunction with later supplemental classification work (Triepke, 2003) has resulted in the ordination and classification of nine forest alliances and 24 associations (Table 1). Unlike the original

Table 1
Summary of floristic map units of the Kootenai NF included in this study

Alliance association	Common name	Alias
Tsuga heterophylla/Thuja plicata	Western hemlock–western redcedar	TSUHET_THUPLI
Tsuga heterophylla–Thuja plicata/Tiarella trifoliata	Western hemlock–western redcedar/threeleaf foamflower	TSUHET_THUPLI/TIATRI
Thuja plicata–Thuja plicata/Paxistima myrsinites	Western hemlock–western redcedar/Oregon boxleaf	TSUHET_THUPLI/PAXMYR
Thuja plicata/Mnium spinulosum–Gymnocarpium dryopteris	Western redcedar/largetooth calcareous moss–Pacific oakfern	THUPLI/GYMDRY
Abies grandis	Grand fir	ABIGRA
Abies grandis/Acer glabrum–Linnaea borealis	Grand fir/Rocky Mountain maple–twinflower	ABIGRA_PSEMEN/ACEGLA
Larix occidentalis–Betula papyrifera	Western larch–paper birch	LAROCC_BETPAP
Larix occidentalis–Betula papyrifera/Acer glabrum	Western larch–paper birch/Rocky Mountain maple	LAROCC_BETPAP/ACEGLA
Picea glauca–Galium triflorum	White spruce–bedstraw	PICGLA_GALTRI
Picea glauca/Mitella nuda	White spruce/naked miterwort	PICGLA/MITNUD
Pinus contorta	Lodgepole pine	PINCON
Pinus contorta–Larix occidentalis/Vaccinium myrtillus	Lodgepole pine–western larch/dwarf bilberry	PINCON_LAROCC/VACMYR
Pinus contorta–Larix occidentalis	Lodgepole pine–western larch	PINCON_LAROCC
Pinus contorta–Larix occidentalis/Alnus viridis	Lodgepole pine–western larch/green alder	PINCON_LAROCC/ALNVIR
Abies lasiocarpa	Subalpine fir	ABILAS
Abies lasiocarpa/Alnus viridis	Subalpine fir/green alder	ABILAS/ALNVIR
Abies lasiocarpa–Larix occidentalis/Vaccinium globulare (*V. membranaceum*)	Subalpine fir–western larch/globe huckleberry	ABILAS_LAROCC/VACGLO
Abies lasiocarpa–Pinus contorta/Vaccinium myrtillus	Subalpine fir–lodgepole pine/dwarf bilberry	ABILAS_PINCON/VACMYR
Abies lasiocarpa–Picea engelmannii/Menziesia ferruginea	Subalpine fir–Engelmann spruce/fool's huckleberry	ABILAS_PICENG/MENFER
Abies lasiocarpa–Pinus albicaulis/Vaccinium globulare (*V. membranaceum*)	Subalpine fir–whitebark pine/globe huckleberry	ABILAS_PINALB/VACGLO
Pinus contorta/Xerophyllum tenax	Lodgepole pine/beargrass	PINCON/XERTEN
Abies lasiocarpa–Pinus albicaulis/Vaccinium scoparium	Subalpine fir–whitebark pine/grouse whortleberry	ABILAS_PINALB/VACSCO
Abies lasiocarpa/Luzula hitchcockii	Subalpine fir/Hitchcock's woodrush	ABILAS/LUZHIT
Picea/Ledum glandulosum	Spruce/Labrador tea	PICEA/LEDGLA
Larix lyallii/Poa cusickii	Alpine larch/Cusick's bluegrass	LARLYA/POACUS
Larix occidentalis–Pseudotsuga menziesii	Western larch–Douglas-fir	LAROCC_PSEMEN
Larix occidentalis–Pseudotsuga menziesii/Vaccinium myrtillus	Western larch–Douglas-fir/dwarf bilberry	LAROCC_PSEMEN/VACMYR
Larix occidentalis–Pseudotsuga menziesii/Vaccinium globulare (*V. membranaceum*)	Western larch–Douglas-fir/globe huckleberry	LAROCC_PSEMEN/VACGLO
Larix occidentalis–Pseudotsuga menziesii/Shepherdia canadensis	Western larch–Douglas-fir/buffaloberry	LAROCC_PSEMEN/SHECAN
Larix occidentalis–Pseudotsuga menziesii/Mahonia repens	Western larch–Douglas-fir/Oregon grape	LAROCC_PSEMEN/MAHREP
Pseudotsuga menziesii–Pinus ponderosa	Douglas-fir–ponderosa pine	PSEMEN_PINPON
Pseudotsuga menziesii–Pinus ponderosa/Mahonia repens	Douglas-fir–ponderosa pine/Oregon grape	PSEMEN_PINPON/MAHREP
Pseudotsuga menziesii–Pinus ponderosa/Physocarpos malvaceus	Douglas-fir–ponderosa pine/ninebark	PSEMEN_PINPON/PHYMAL

Map units include nine forest alliances and 24 associations.