Using Cluster Analysis and a Classification and Regression Tree Model to Developed Cover Types in the Sky Islands of Southeastern Arizona

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Abstract—*The objective of this study was to develop a rule based cover type classification system for the forest and woodland vegetation in the Sky Islands of southeastern Arizona. In order to develop such a system we qualitatively and quantitatively compared a hierarchical (Ward's) and a non-hierarchical (k-means) clustering method. Ecologically, unique groups represented by only a few plots were appropriately distinguished using k-means, while Ward's combined these unique plots into the large mixed conifer groups. Similarly, plots dominated by more than one species were more appropriately grouped with other mixed-species plots using k-means. The two clustering methods were numerically compared using a classification and regression tree (CART) model. Groups based on the two clustering methods had similar recovery rates, but k-means groups required fewer nodes or decision rules. Based on these results we developed a detailed cover type classification system for the existing vegetation of the Sky Islands in southeastern Arizona. The final cover types were based on the original k-means clusters, with some minor modifications made using CART analysis to compensate for overlapping values. This allowed us to transform the CART output into a dichotomous identification key for 20 detailed cover types. Finally, these detailed cover types were linked to a flexible three-level hierarchical framework that allows users to aggregate or segregate forest lands as needed. The hierarchical organization of this framework is similar to the natural organization of ecosystems, which will aid our understanding of natural processes in these forest and woodlands.*

Introduction

Classification schemes are an important tool used to separate large areas into manageable units (Layser 1974). Classification systems provide a framework to organize information that differs between vegetation types, such as fire history, fire behavior, productivity, aesthetics, and wildlife habitat. Such information then can be used to evaluate and assess problems or opportunities to improve resource management (Layser 1974; Pfister 1975; McRae 1996). Classification systems also standardize the identification and definition of vegetation groups (Layser 1974), enhancing communication among managers and researchers (Volland 1975).

In North America, classification of forest and woodland vegetation typically is based on either potential (Moir and Ludwig 1983) or existing conditions (Eyre 1980). Potential or "climax" conditions define "habitat types" (Layser and Shubert 1979). In contrast, "cover types" classify forested lands based on the existing composition of dominant tree species (Eyre 1980).

In the Sky Islands of the Southwestern United States and Northern Mexico, both habitat types and cover types have been described (USDA 1997a,b; Shreve 1919; Wallmo 1955; Lowe 1961; Brady and Bonham 1976; Brown 1982; Niering and Lowe 1984). Earlier studies focused on describing plant communities along elevational/moisture gradients (Whittaker and Niering 1968), and provided valuable knowledge about the relationship among vegetation groups and their ordering in ecological space. However, there is still a need for deterministic models that can distinguish between vegetation groups, similar to the mechanism already in place for identifying habitat types (Muldavin et al. 1996).

Currently, numerous forest classification schemes describe cover types at different levels. Several authors (O'Hara et al. 1996; Pregitzer et al. 2001) have called for a hierarchical classification framework that would unite both existing and newly developed classification schemes at various spatial scales and levels of detail. Such a framework would standardize and relation classes facilitating crosswalking from a landscape to a stand level as necessary. Forests in the Western United States have been classified into broad cover types (Eyre 1980); these cover types do not fully illustrate the interactions between individual species or the modal distribution of species along environmental gradients. These broad cover types could be used in conjunction with more detailed classification systems to build a hierarchical classification framework.

In this study, we subdivided broad forest cover types to develop a detailed classification of mid-elevation forest cover types in the Sky Islands of southeastern Arizona. Our objectives were to: (1) group plots into vegetation groups based on similarity in species composition, (2) identify quantitative differences that distinguished each group, and (3) quantitatively describe each of the unique cover types resulting. These detailed cover types allow for finer scale ecological assessments than the broader types, and can be integrated with coarser types to facilitate assessments at multiple scales.

Study Area and Methods

The Sky Island mountains of southeastern Arizona, which are separated by a low elevation desert matrix, are a northern extension of the Sierra Madre Occidental of Northwestern Mexico. Geographically, the Sky Islands are located at the intersection of four major biomes (the Sonoran and Chihuahuan Deserts plus the Sierra Madre and Rocky Mountains [McLaughlin 1995]). Southeastern Arizona has a bimodal moisture pattern receiving winter precipitations that falls as snow (rains) at high (low) elevations in additions to the summer monsoonal rains (Sellers and Sanderson-Rae 1985). Total precipitation varies between approximately 45 cm at 1,500-meter elevation to 70 cm at 2,500 meters (Shreve 1919). The vertical relief and unique geographic position of these mountains combine to create a diverse mosaic of vegetation assemblages stratified along elevation/moisture gradients (Whittaker and Niering 1968; Lowe 1961; Niering and Lowe 1984). Plant communities at higher elevations (above 2,000 meters) are closely related to the Cordilleran/Rocky Mountain floristic province, and lower elevation communities (below 1,500 meters) are more closely related to the Madrean floristic province (McLaughlin 1995).

Our study sites were located in the Santa Rita, Santa Catalina, Huachuca, Chiricahua, and Pinaleño Mountains in the Coronado National Forest. We established four to eight line transects in each range, depending on their relative sizes. Transects were stratified by general cover types, although vegetation at low and high-elevation extremes (oak savannas and spruce-fir forest) were not included in this analysis. Transect origins and orientations were randomly selected with the constraint that they fell within 1.6 km of an accessible road or trail. Each transect consisted of 12 central points, with four vegetation plots established in and around each point. One plot was centered on the point itself, and three satellite plots were systematically distributed at least 80 meters apart. We used 954 plots from 27 partial and complete transects in the analysis.

Within each plot, we recorded genus, species, and diameter at breast height (DBH) for all standing trees >10 cm DBH within a 0.1 ha circular area. A total of 52 tree species were identified in the field and narrowed to 23 variables for the analysis. Species in the genera *Acer*, *Fraxinus*, and *Juniperus* were recorded at the genus level; hybrid and less common species of *Quercus* were also recorded. Unidentified tree species were recorded as a separate category. To standardize for the different physiognomy of oaks and conifers (Barton 1999), variables were represented according to the percent of the total basal area (%BA) they contributed. In addition to its simple interpretation, this attribute incorporates the strong relationship between BA, canopy cover (Mitchell and Popovich 1997), and overstory dominance (Neldner and Howitt 1991).

We initially separated the 954-plot dataset, represented by 23 variables, into 20 groups using the k-means clustering method (Romesburg 1984). This non-hierarchical method minimizes the variance within each group by independently organizing plots according to the desired number of groups (del Moral 1975; Belbin and McDonald 1993). This process avoids the sequential merging of entire groups typical of hierarchical clustering thereby improving homogeneity within clusters. We arbitrarily chose 20 clusters based on our desire to (1) include groups of both pure and mixed species composition, and (2) strike a balance between creating a classification scheme that was sufficiently detailed yet did not include an unmanageable number of cover types. Each group was named after the dominant species, with mixed species groups named after co-dominant species or species groups such as "Madrean oaks."

After the grouping of plots by cluster analysis a classification and regression tree (CART) model was used to identify critical distinctions between each of the 20 clusters. CART analysis has the advantage of being non-parametric, robust to outliers, and provides results that are easy to interpret in the form of dichotomous keys (Verbyla 1987). The CART models discriminate by sequentially selecting specific values, within the range of dependent variables that best partition the plots into purest group membership. The dependent variables we used were the 23 species plus 2 additional variables that aggregated conifer and woodlands species, respectively. Using %BA, the CART model initially separates all plots into their original groups. However, CART then selects the optimal solution (or number of splits) for the overfitted model by "pruning" the classification tree using a cross-validation technique.

Results and Discussion

Dichotomous Identification Key

Using the classification tree of the k-means clusters we were able to develop an identification key for 20 detailed cover types (table 1). This key is based on a series of sequential criteria taken from the discriminant values identified in the CART analysis. Using this key a cover type is identified when all criteria are met. Therefore, the sequence itself provides important information for understanding differences between groups. Also, the parameters clearly define and facilitate the identification of these cover types. This process is simple to implement and could allow researchers in other areas to apply the clustering method and CART analysis to an existing

Table 1—Dichotomous key to identify 20 cover types in the Sky Islands of Southeastern Arizona. The 20 groups were originally separated using the k-means clustering method then modified using classification and regression tree (CART) analysis. Each criteria or node was based on percent basal area by species. The four letter codes represent the first two letters of the genus and species scientific names.

1. POTR ≥ 43%	Pure Aspen
2. QUSP ≥ 63%	Oak Scrub
3. CUAR ≥ 31%	Pure Arizona Cypress
4. QUAR ≥ 63%	Pure Arizona White Oak
5. PIDI ≥ 42%	Pure Pinyon
6. JUSP ≥ 49%	Pure Juniper
7. QUEM ≥ 23%	7a
7a. PIEN ≥ 25%	Apache Pine/Oak
7b. PIEN < 25%	Emory/Arizona White Oak
8. PILE ≥ 26%	Chihuahua Pine/Oak
9. PIPO ≥ 55%	Pure Ponderosa Pine
10. PSME ≥ 53%	10a
10a. PIPO ≥ 25%	Douglas-fir/Ponderosa Pine
10a. PIPO < 25%	Pure Douglas-fir
11. ABCO ≥ 26%	11a
11a. $UPLN ≥ 56%	11b
11a. $UPLN < 56%	11c
11b. ABCO ≥ 36%	Pure White fir
11b. ABCO < 36%	Douglas-fir/Ponderosa Pine
11c. QUGA ≥ 44%	Gambels Oak
11c. QUGA < 44%	White Fir/Maple
12. PIST ≥ 24%	White Pine/Mixed Conifer
13. QUGA ≥ 25%	Gambels Oak
14. PIEN ≥ 22 %	Apache Pine/Silverleaf Oak
15. QUHY ≥ 45%	15a
15a. PIPO ≥ 22%	Silverleaf Oak/Ponderosa Pine
15a. PIPO < 22%	Pure Silverleaf Oak
16. JUSP ≥ 21%	Juniper/Oak
17. QUAR ≥ 31%	Arizona White/Silverleaf Oak
18. QUHY ≥ 23%	Silverleaf oak/Ponderosa Pine
19. PSME ≥ 29%	Douglas-fir/Ponderosa Pine
20. $UPLN ≥ 86%	White Pine/Mixed Conifer
21. #WDLN ≥ 30%	Silverleaf Oak/Ponderosa Pine
22. #WDLN < 30%	Douglas-fir/Ponderosa Pine

Woodland (WDLN) species include: POTR, ABCO, QUGA, PIST, PSME, RONE, PIPO, PILE, PIEN, *Acer* spp, and *Fraxinus* spp.

$ Upland (UPLN) species include: QUHY, QUAR, PIDI, QUEM, ARAR, JUMA, PLWR, CUAR, *Juniperus* spp., and hybrid oak species.

data set and develop their own classification key to classify existing or future plots.

Cover Type Description

The 20 cover types developed can be aggregated into seven broader forest cover types (tables 2 and 3). For example, the broader deciduous forest type was separated into the Pure Aspen and Gambel oak cover types (table 2). Both detailed cover types (CT) are limited in spatial extent within the Sky Islands, but provide important contributions to diversity in Sky Island forests. Both quaking aspen (*Populus tremuloides*) and Gambel oak (*Quercus gambelii*) are seral species in mixed conifer forest, which tend to dominate certain sites following severe disturbances such as wildfire. The Aspen CT was limited to mesic sites at high elevations, and dominated by quaking aspen forming mostly pure stands. In contrast, the Gambel oak CT had greater species diversity and a strong component of conifers, especially ponderosa pine (*Pinus ponderosa*) and Douglas-fir (*Pseudotsuga menziesii*).

The broad mixed conifer forest type was subdivided into six cover types (table 2). Of these six, the White fir/maple cover type (CT) occurred in the most mesic sites, such as shady ravines. This cover type was dominated by white fir (*Abies concolor*), but also had a large component of deciduous species (table 2). In contrast, within the Pure white fir CT, white fir accounted for more than 36% of the BA and lacked a pronounced deciduous component. The White pine/mixed conifer CT was an unusual type that occurred at higher elevations (2,540 m), and was dominated by a combination of Douglas-fir, southwestern white pine, (*P. strobiformis*), and ponderosa pine.

Douglas-fir had a wide elevational distribution, forming a Pure Douglas-fir CT at around 2,550 m, with Douglas-fir accounting for at least 50% of the BA, and ponderosa pine contributing <25% (table 1). In slightly less mesic sites, Douglas-fir intermixed with ponderosa pine to create the Douglas-fir/ponderosa pine CT. This mixed species type was a transition between the Pure Douglas-fir and Pure ponderosa pine CT. The latter type was dominated by ponderosa pine, which contributed at least 55% of stand BA (table 1).

The transitional or pine/oak forest typically occurred between 2,300 and 1,975 m. This broad cover type was partitioned into three more detailed cover types. The Silverleaf oak/ponderosa pine CT occurred at higher elevations and was dominated by silverleaf oak (*Quercus hpoleucoides*) and ponderosa pine, which co-occurred with a wide variety of other species (table 2). The Apache pine/oak and Chihuahua pine/oak CTs occurred at similar elevations and were comparable to each other in terms of species composition, differing mainly in relative proportions of Apache (*P. engelmannii*) and Chihuahua (*P. leiophylla*) pine, respectively (table 2). The Apache pine/oak CT also had a stronger component of silverleaf oak, and was more limited in geographic distribution (personal observation).

The overlap in the ecological distribution of silverleaf and Arizona white oak (*Q. arizonica*) created four detailed cover types within the broadleaf evergreen woodlands type (table 3). The Pure silverleaf oak CT was dominated by silverleaf oak, which accounted for at least 45% of the BA. The Arizona white oak/silverleaf oak CT had a strong component of both dominant oak species, whereas the Arizona white oak CT lacked a strong silverleaf oak component (table 3). The Emory/Arizona white oak had strong components of both Arizona white oak and Emory oak (*Q. emoryi*). This cover types usually was found at lower elevations where it blendes into pure Emory oak woodland and eventually into desert grasslands. These latter cover types were not included in this analysis.

In addition to broadleaf evergreen woodlands, our analysis also identified three cover types within the broader conifer woodlands type (table 3). The Juniper/oak CT was dominated by various species of juniper (*Juniperus* spp.) and Arizona white oak, in addition to a considerable component of silverleaf oak and border pinyon (*P. discolor*). Pinyon and juniper often co-occurred, but in the Sky Islands each of

Table 2—Mean and standard deviation (in parentheses) of basal area (m²/ha) by species for 11 detailed cover types found at higher elevations in the Sky Islands of southeastern Arizona. Bolded numbers indicate dominant species used in distinguishing cover types. These 11 cover types aggregate to three broader forest types, as shown.

Broad	Deciduous Forest		Mixed Conifer Forest						Transitional Forest		
Detailed Cover Types	**Pure Aspen**	**Gambel Oak**	**White Fir/Maple**	**Pure White Fir**	**White Pine/ Mixed Conifer**	**Pure Douglas-fir**	**Douglas-fir/ Ponderosa Pine**	**Pure Ponderosa Pine**	**Silverleaf Oak/ Ponderosa Pine**	**Apache Pine/ Madrean Oak**	**Chihuahua Pine/ Madrean Oak**
POTR	**21.4** (12.3)		2.3 (5.6)	.4 (1.1)	.0 (.5)	.6 (2.6)	1.0 (4.1)				
QUGA		**11.8** (4.9)	3.2 (4.4)	2.0 (3.4)	1.0 (2.2)	1.1 (2.5)	1.6 (2.7)	.4 (1.4)	.3 (1.1)	.1 (.3)	
ACSP	.6 (.7)	.6 (2.3)	**5.2** (5.5)	.8 (1.6)			.1 (.6)				
ABCO	1.7 (1.2)	1.7 (2.7)	**9.4** (5.3)	**21.6** (10.1)	.8 (1.6)	2.8 (4.1)	3.1 (4.5)	.1 (.3)	.2 (.8)	.0 (.1)	
PIST		1.3 (2.0)	.1 (.2)	2.4 (3.0)	**10.2** (4.3)	2.1 (3.2)	1.7 (2.4)	1.1 (.4)	.6 (.9)	.3 (.7)	.1 (.3)
PSME	.7 (.9)	3.8 (5.5)	1.5 (2.4)	6.0 (5.7)	**6.4** (5.0)	**26.2** (13.9)	**13.0** (6.3)	2.6 (1.8)	3.5 (3.8)	.7 (1.7)	.6 (1.0)
PIPO		5.0 (6.1)	1.0 (2.9)	2.2 (3.8)	**7.0** (4.4)	1.7 (2.5)	**7.5** (6.1)	**21.3** (11)	**6.5** (6.2)	.5 (1.5)	2.0 (7.0)
PIEN				.3 (1.6)	.2 (1.0)	.0 (.3)	.2 (.7)		.4 (1.1)	**10.9** (6)	1.5 (2.8)
PILE				.0 (.2)		.0 (.2)	.3 (1.0)	.3 (1.2)	.6 (1.4)	.7 (1.2)	**10.2** (5.4)
QUHY		.7 (1.3)	.3 (.8)	.2 (.9)	1.0 (3.6)	.3 (1.0)	2.0 (2.6)	2.1 (2.8)	**8.8** (4.8)	6.0 (4.6)	3.3 (2.9)
QUAR		.3 (.6)		.1 (.3)	.1 (.2)	.2 (.5)	1.0 (2.1)	.3 (.9)	2.8 (2.6)	2.9 (2.4)	3.4 (2.9)
Other	.4 (.4)	1.2 (2.1)	4.6 (3.9)	.4 (.7)	.5 (1.5)	.7 (1.5)	1.5 (3)	.4 (.9)	2.4 (2.8)	3.1 (4.5)	1.4 (1.3)
# Samples	4	27	8	40	37	80	80	161	88	50	26
Elevation	2837	2348	2368	2531	2540	2550	2366	2313	2169	2029	2015
	(90)	(194)	(295)	(275)	(279)	(275)	(258)	(178)	(135)	(140)	(131)

these species also dominated distinct sites. Juniper typically dominated sites at around 2,115 m., whereas border pinyon was less common and tended to dominate at slightly lower elevations (table 3).

Cover Type Framework

The broad and detailed cover types described in this paper are related to each other and to other classification systems. For example, the seven broad types can be related to an even broader classification such as the Anderson system (Anderson et al. 1976), which is used to classify remotely sensed images into land cover classes. Similarly, the 20 more detailed cover types can be further subdivided into structurally distinct classes (Iniguez 2000) to assess successional status. These classification schemes all are based on existing or current conditions, but each describes vegetation communities with different levels of detail. Consequently, these schemes can be used jointly to aggregate or segregate forest lands as needed for specific analyses, while maintaining a standardized conceptual framework across scales.

The detailed cover types described in this paper have a wide range of management implications. For example, although Mexican spotted owls (*Strix occidentalis lucida*) are typically found in the broad mixed conifer forest type, more specifically they favor Pure white fir and Pure Douglas-fir over Pure ponderosa pine cover types (e.g., Ganey and Dick 1995). Similarly, insect and disease outbreaks are typically species-specific requiring detailed cover type information to evaluate susceptibility and speculate damages (e.g., Dahms and Geils 1997).

Conclusion

In this paper, we present a detailed classification scheme for mid-elevation forests in the Sky Islands of southeastern Arizona, as well as a dichotomous key allowing for identification of the cover types recognized. This key allows users to classify new plots and to quantitatively differentiate between cover types. We recognize that some areas will be transitional between the distinct cover types recognized; therefore, our quantitative breakpoints should be viewed as approximations. The key should allow users to determine approximately where they are within the classification scheme, but will not clearly define all stands. Despite this "fuzziness" at some boundaries, we believe that the classification scheme presented will improve our understanding of the ecological relationships among forest types in the Sky Islands.

We also provide a general quantitative description of the 20 cover types recognized based on the distribution of basal area among species within each cover type, in hopes that this information will be useful to researchers and managers in the Sky Islands region. The cover types identified and described here fit within a larger hierarchical framework, and thus facilitate our ability to classify forested lands at varying levels of detail.

Table 3—Mean and standard deviation (in parentheses) of basal area (m^2/ha) by species for detailed cover types found at lower elevations in the Sky Islands of southeastern Arizona. Bolded numbers indicate dominant species used in distinguishing cover types. These nine cover types aggregate to four broader forest types, as shown.

Broad	**Broadleaf Evergreen Woodlands**				**Conifer Woodland**			**Conifer Riparian**	**Other**
Detailed Cover Types	**Pure Silverleaf Oak**	**AZ White/ Silverleaf Oak**	**Pure AZ White Oak**	**Emory/AZ White Oak**	**Juniper/ Oak**	**Pure Juniper**	**Pure Pinyon**	**AZ Cypress**	**Shrub Oak**
PSME	1.0 (1.7)	.9 (1.7)	.2 (.6)	.1 (.2)	1.7 (4.3)	.3 (.7)	.2 (.7)	.3 (.6)	
PIPO	.5 (1.0)	.6 (1.6)	.0 (.2)	.1 (.2)	.7 (1.9)	.1 (.3)		.2 (.6)	
PIEN	.9 (1.4)	.4 (.9)	.2 (.5)	1.2 (1.6)	.2 (.7)	.2 (.8)			
PILE	.4 (1.2)	.6 (1.1)	.1 (.3)	.2 (.5)	.8 (1.8)	.1 (.4)	.0 (.1)	.3 (.8)	
QUHY	**12.8** (5.1)	**3.5** (3.1)	1.2 (1.6)	2.8 (3.4)	2.0 (2.9)	1.1 (2.8)	0.4 (.8)	0.1 (.2)	0.1 (.2)
QUAR	3.1(2.4)	**8.5** (3.7)	**12.2** (6.6)	**5.6** (3.7)	**5.0** (3.0)	2.9 (3.3)	1.8 (2.0)	1.5 (1.6)	
JUSP	.6 (1.5)	1.4 (1.4)	.7 (1.1)	.3 (.5)	**6.9** (4.2)	**10.2** (7.1)	1.3 (2.2)		
PIDI	.2 (.9)	.8 (1.5)	.3 (.5)	.2 (.4)	1.8 (2.2)	1.4 (2.9)	**7.6** (3.8)	.9 (1.2)	
CYAR	.0 (.1)	.0 (.2)			.1 (.5)		.2 (.5)	**10.2** (7.5)	
QUEM	.1 (.6)	.2 (.5)	.2 (.5)	**5.8** (2.1)	.2 (.7)	.2 (.7)	.1 (1.2)	.1 (.2)	
QUSP	.3 (.6)	.2 (.5)	.1 (.3)	.1 (.1)	.2 (.5)	.3 (.9)	.3 (1.2)	.4 (.4)	**1.5** (1.9)
Other	1.2 (1.6)	.8 (1.3)	.6 (1.0)	1.8 (3.1)	.7 (2.0)	.4 (1.1)	.4 (.4)		
# Samples	76	68	47	67	27	44	13	9	2
Elevation	2039	2050	2124	2062	2166	2115	1989	1928	2430
	(162)	(180)	(149)	(206)	(303)	(129)	(55)	(55)	(242)

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