Alternative Method to Validate the Seasonal Land Cover Regions of the Conterminous United States

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Abstract.— An accuracy assessment method involving double sampling and the multivariate composite estimator has been used to validate the prototype seasonal land cover characteristics database of the conterminous United States. The database consists of 159 land cover classes, classified using time series of 1990 1-km satellite data and augmented with ancillary data including terrain, climate, and ecological definitions. Reference data from more than 2,200 1 km² plots were independently collected; data included descriptions of dominant land cover types. Validity of the database is presented in terms of conditional probabilities and variability estimates. This case study demonstrates the usefulness of the method in describing the reference composition of the mapped categories, handling different classification schemes between the database and reference, and comparing various regrouping complexities. The validation results support using the database as a vegetation baseline in large scale environmental simulation models.

INTRODUCTION

Data acquired by the National Oceanic and Atmospheric Administration's advanced very high resolution radiometer (AVHRR) represent one of the most important data sources for global change research (Townshend 1994). The daily coverage of a large area and 1-km spatial resolution (at nadir) of AVHRR allow users to effectively and efficiently map and study vast areas, at scales from continental to global. An example is a recent prototype land cover characteristics database for the conterminous United States (Brown and others 1993, Loveland and others 1993, 1995).

The conterminous U.S. (CONUS) land cover characteristics database, produced by the U.S. Geological Survey's EROS Data Center, in cooperation with the University of Nebraska-Lincoln, defines 159 seasonally distinct classes.

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Vegetation seasonal properties, or phenology, are defined by a time series of the normalized difference vegetation index (NDVI), a transformation of the first two AVHRR spectral bands. Each class in the CONUS database exhibits a unique combination of seasonal characteristics and landscape pattern, such as vegetation, climate, and elevation. However, the concept and use of polythetic regionalization (Loveland and others 1995) imply that the classes consist of a mixture of land cover types within each class.

The CONUS land cover characteristics database has been widely used in large-scale environmental simulation modeling (Steyaert and others 1994). The concept and methods of the prototype database are also being used to produce similar land cover characteristics databases for the major continents of the world (Loveland and others 1995). Because of the current utility and the future applications, validation of the CONUS database is an important issue. Loveland and others (1995) discussed the importance of validation and various validation plans, including a study reported by Merchant and others (1994). Preliminary results from that study indicated that the database closely represented land cover regions of the conterminous United States. The objective of this research is to test an alternative method for validating the CONUS database, as presented below.

ACCURACY ASSESSMENT ALTERNATIVES FOR CONUS

Accepted conventional methods for accuracy assessment, as reviewed in Congalton (1991), require that reference data and the remote sensing product in question share a common classification scheme, i.e., have the same number of corresponding classes. Positional accuracy for the map product is assessed with a square error matrix that shows percent sample points correctly classified, where the sample points are geographically coincident. The construction of error matrices also allows calculation of the kappa statistic (Congalton 1991).

The error matrix and kappa statistic approach is routinely used to validate land cover classifications with moderate to fine ground resolutions. This method has not been effective for coarse resolution products, such as those that are based on AVHRR data, for several reasons. First, the 1 km^2 pixel on the ground often contains a mosaic of different cover types; finding corresponding reference classes at this resolution and scale is difficult. Second, requirements of the error matrix restrict the use of reference data acquired under a classification scheme different from the one used for the satellite map. Third, image geometry is complex and identification of ground samples is difficult or speculative. Additionally, the original design philosophy (Loveland and others 1991) of the CONUS database was a flexible database of land characteristics, classes were meant to be translated or combined in different ways to meet the needs of a wide range of applications (Steyaert and others 1994). A single reference data set would be insufficient and difficult for comparing at all levels of complexities.

The consideration in this study for validation of the CONUS database was that the reference data and validation method would be designed to describe reference land cover compositions of the mapped land cover classes, thereby allowing evaluation of the database at different levels and providing measures of map data quality to users. The method needs to be flexible and practical to permit use of a common reference for different classification schemes and to incorporate multiphase, multistage designs for improved efficiency.

The alternative method used in this study to validate the CONUS land cover characterization database is that of the multivariate composite estimator (Czaplewski 1992). The formulation for this approach is given in detail in Czaplewski (1992, 1994, 1995); a brief overview follows.

Assume that, as a special case of multiphase sampling, a set of satellite-classified (map) pixels and reference points is obtained. The proportions of each category in the sampled map and reference data are expressed with their respective state vectors and estimated covariance matrices. The multivariate composite estimator is a linear transformation matrix of the independent map and reference state vectors, with a covariance matrix calculated as the linear function of map and reference covariance matrices.

From the multivariate composite estimator, two very useful vectors are derived. The first is a vector of joint probabilities (i.e., a vectorized contengency table) showing unbiased estimates of proportions of the map and reference categories occurring together (Czaplewski 1992). The second is a nonlinear transformation vector of estimated conditional probabilities, showing estimated true ground proportions given each map category. The approximate variance estimator for the conditional probabilities is given in Czaplewski (1994).

The important features of the above work are that it provides a means of statistically describing reference composition of coarse resolution map categories, and the descriptions can be done at various levels of detail with the same reference data set. The approach accommodates the situation where different classification schemes are used by the remote sensing product and the reference data (Czaplewski 1992), and it allows for more complex sampling designs (Czaplewski 1994) beyond the simple random sample of point plots required by the conventional method (Congalton 1991).

The U.S. Forest Service has produced a software program based on this approach (Williams and Beach 1995). The program produces the joint probability vector, the conditional probability vector, and the confidence intervals calculated using the estimated variance and the beta-binomial distribution (Czaplewski 1995).

SAMPLING PROTOCOL AND REFERENCE PLOTS

Congalton (1991) states that the sample size for reference data used to assess accuracies of remote sensing products is often dictated by practical considerations. In the case of the CONUS database, the study area (conterminous United States) is very large, the number of classes (159) is high, and the AVHRR spatial resolution makes reference data expensive. Because of these constraints, the sampling design described below was a process evolving between the original design (Burgan and others 1993) and practical compromises at later stages.

A two-stage, stratified sampling design (Burgan and others 1993) was used to select 698 primary sampling units (PSU) and 3,500 secondary sampling units (SSU). The PSU's were USGS 7.5 minute quadrangle maps and the SSU's were 1-km^2 field plots corresponding to 1-km^2 pixels in CONUS database. A decision was made not to sample classes with fewer than 5,000 pixels, as well as urban areas and water. Field work was coordinated by the U.S. Forest Service (Burgan and others 1993) and carried out by personnel from several Federal and State agencies. Because of various difficulties, the actual number of SSUs measured as reference materials was 2,284. This accounted for a 0.03 percent sample intensity for 7.6 million pixels, from 129 classes, in the database. According to the procedure for reference data, each 1-km^2 SSU selected in a PSU was transferred to aerial photographs, interpreted, and then field-checked using a field form designed for the project. More than 100 reference variables were collected or calculated, including plot coordinates, land cover composition, and primary and secondary vegetation cover types or species.

Among these variables, the most pertinent to this validation were those of 17 dominant cover types (listed as the reference classification at the top of the figures 1-4). Within each of the 1 km^2 plots, percent values of land cover by the 17 cover types were tallied and summed to 100 percent. For example, the reference data for plot number 3 was 20-percent conifer with crown closure less than 30 percent, 20-percent conifer with crown closure greater than 60 percent, 50-percent mixed forest with crown closure less than 30 percent, and 10-percent shrub. The CONUS map classification for plot 3 was western U.S. conifer forests of evergreen needleleaf species. The 17 variables and the 2,284 reference points were used for comparisons to the CONUS database classes.

RESULTS AND DISCUSSION

The reference data set was used to assess several categorical simplifications (groupings) of the CONUS database to validate the map for applications. Conditional probability vectors, standard errors, and confidence intervals at the 80 percent confidence level were obtained for the following simplications: 6 land cover classes (figure 1), 12 land cover classes (figure 2), a modified Anderson level II classification (Anderson and others 1976) (figure 3), and a Biosphere-Atmosphere Transfer Scheme (BATS) (Dickinson and others 1986) translation (figure 4). Actual data for the four simplifications as well as the full 129 CONUS classes are also available from the authors.

In the figures, for each class category, conditional probabilities of the 17 reference dominant cover types are shown with 80 percent confidence intervals. For example, in figure 1, if the CONUS class is deciduous forests, the actual

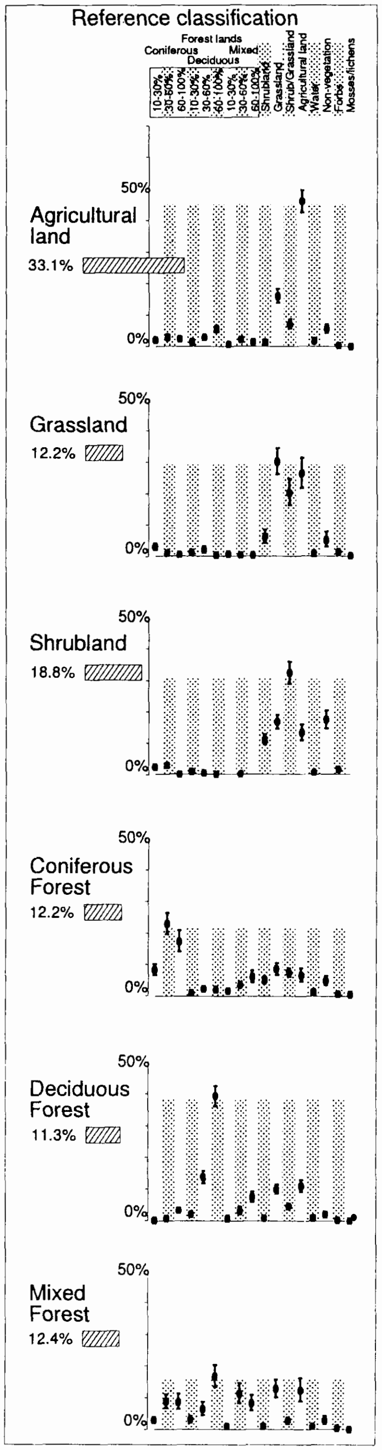

Figure 1. -- Probability of reference classification given collapsed CONUS classfication system with 6 categories. Horizontal bars show prevalance of CONUS mapped categories.

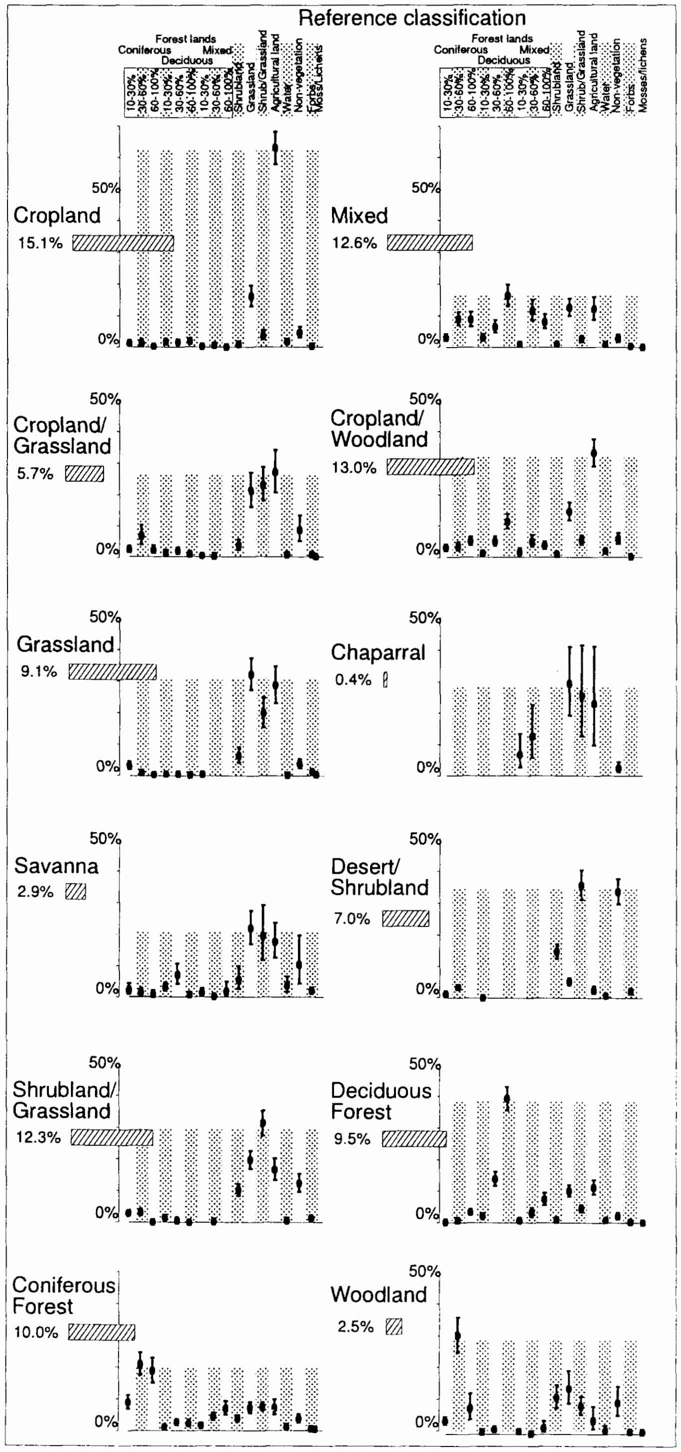

Figure 2. -- Probability of reference classification given collapsed CONUS classfication system with 12 categories. Vertical lines display 80% confidence interval for the sampling error from the 698 sample quadrangles. Horizontal bars show prevalance of CONUS mapped categories.

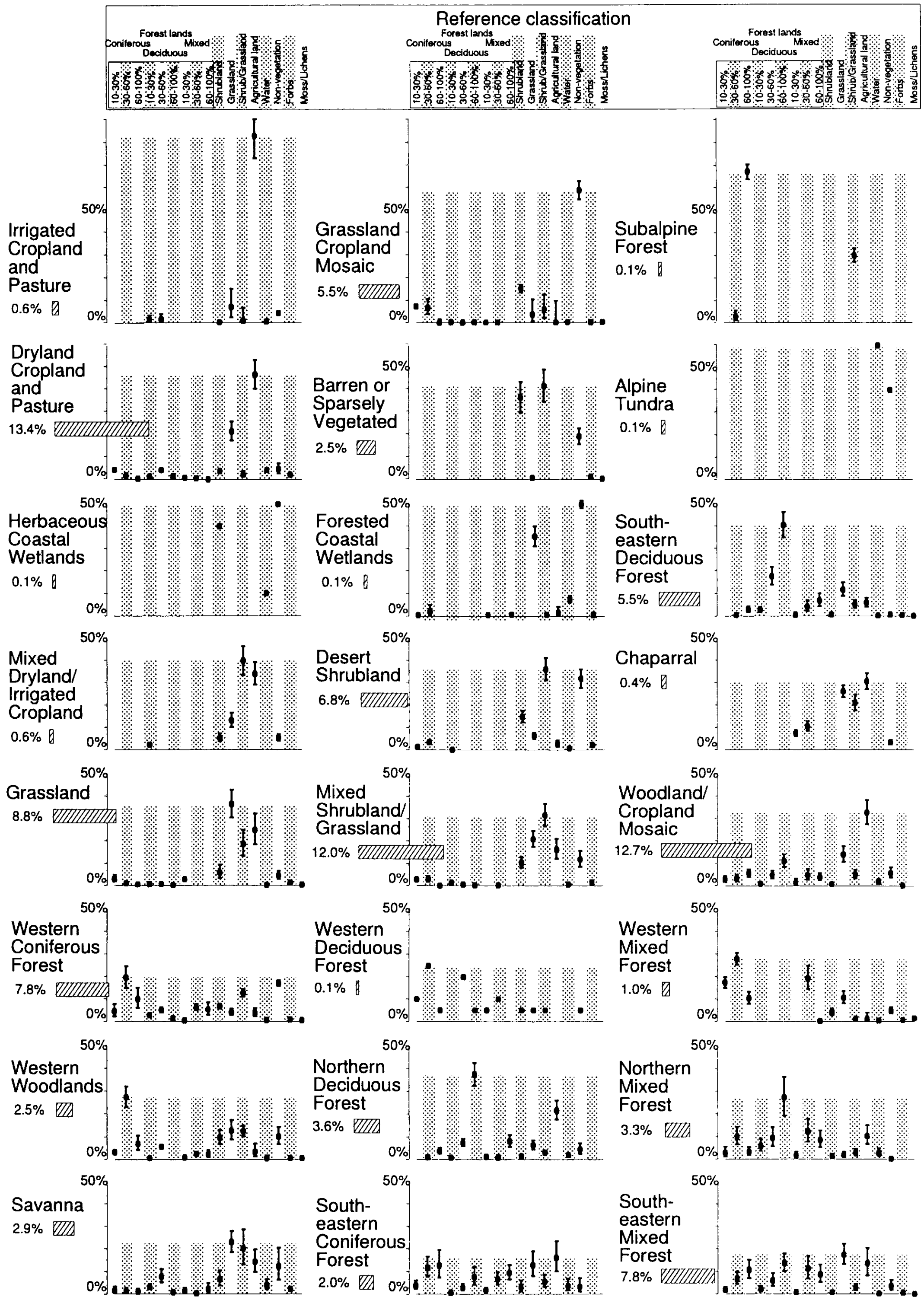

Figure 3. -- Probability of reference classification given collapsed CONUS classfication system that approximates a modified Anderson Level II system. Vertical lines display 80% confidence interval for the sampling error from the 698 sample quadrangles. Horizontal bars show prevalance of mapped Anderson categories.

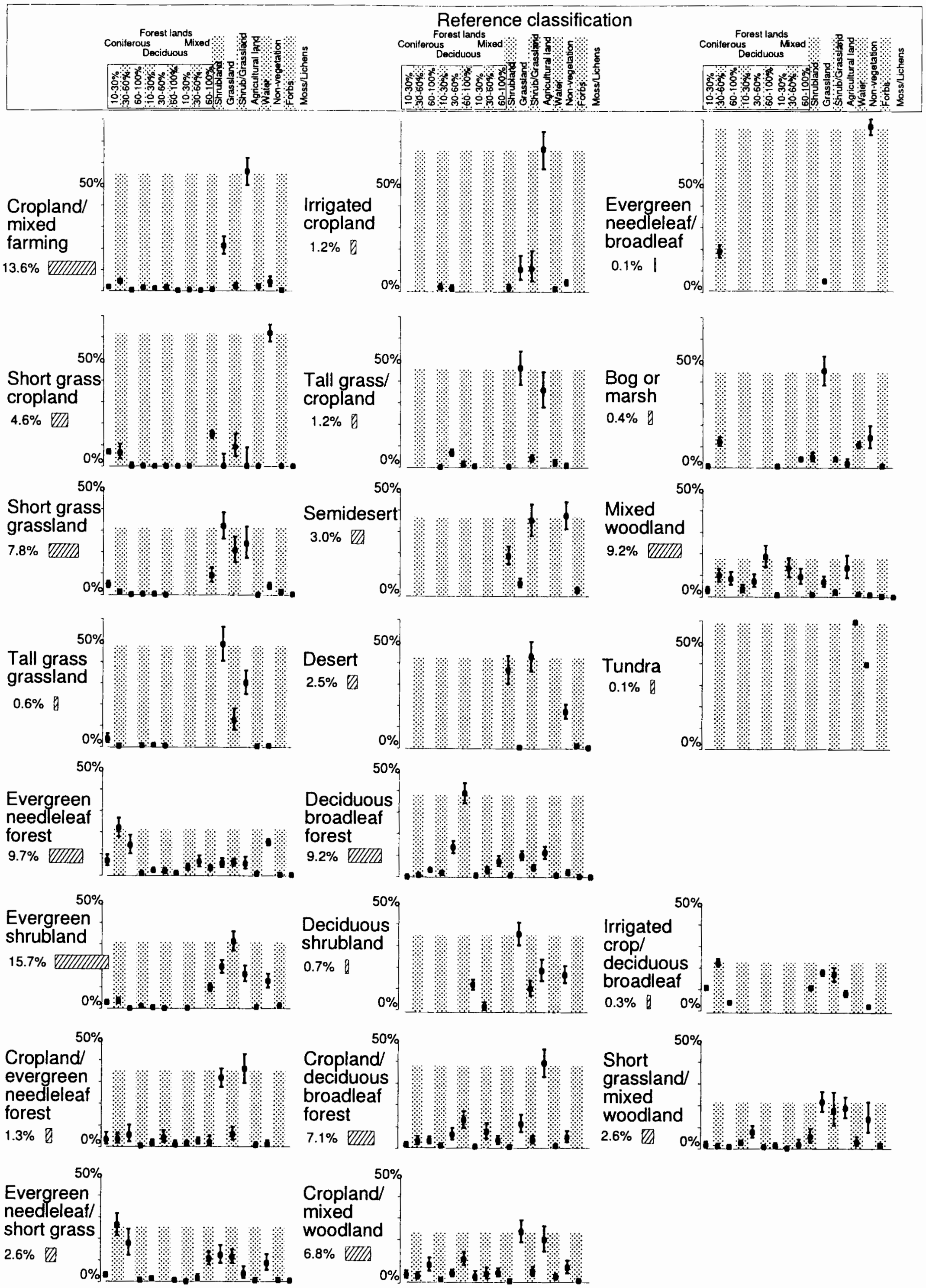

Figure 4. -- Probability of reference classification given collapsed CONUS classfication system that approximates the Biosphere-Atmosphere Transfer Scheme (BATS). Vertical lines display 80% confidence interval for the sampling error from the 698 sample quadrangles. Horizontal bars show prevalance of mapped BATS categories.

cover types, according to reference field plots, are approximately 40-percent deciduous forests with crown closure greater than 60 percent, 14-percent deciduous forests with crown closure between 30 and 60 percent, 11-percent agricultural lands, 10-percent grassland, and the remaining 25-percent other cover types. In other words, the collapsed CONUS class, despite its oversimplified label as deciduous forest, is a region of pixels with distinct seasonal properties but not necessarily the conventional, mutually exclusive land cover properties (Loveland and others 1995). This seasonal region is expressed as a function of the 17-element probability vector; values of the 17 elements indicate the composition of the region. In the example above, the "deciduous" seasonal region is composed of a majority of deciduous forests (55 percent), plus agricultural and grass land cover.

The grassland class is similarly expressed in figure 1 as a seasonal region consisting of not only "pure" grass land cover (30 percent), but also a mixture of grass and shrub, crop, and forests, as well as nonvegetated land. Interpreting the results requires an understanding of the interspersion of crop and forest land cover in some areas that may resemble grassland in terms of their spectral and temporal characteristics. Misclassification of nonvegetated land caused by factors such as AVHRR data quality (low sun angle, viewing geometry, atmospheric effects) may also partially contribute to the results.

The standard error and the confidence interval are measures of sampling error for individual estimated probabilities. These variability terms can be used in large-scale environmental simulation models for calculating error propagation. It should be noted that when sample size is small for an element of the probability vector, the variance estimators may not be reliable. In this case, the variance measures should be noted but not used.

Examination of figures 1 through 4 shows the flexibility of the alternative validation method in using common reference set at different levels of CONUS simplification. Note that when CONUS classes are recoded or translated, the constituent classes are changed. For example, grassland category in the 6 class scenario (figure 1) includes savanna class, but grassland is separate from savanna in the 12 class scenario (figure 2), and it is split into short and tall grass subcategories in a BATS translation (figure 4). Compositions of deciduous forests and other categories are similarly changed. However, as shown in figures 1 through 4, their validity in terms of probabilities of ground reference and standard errors generally holds throughout the simplifications of classification detail. Deciduous classes maintain similar constituencies except the northern deciduous forest class within the Anderson translation, where the seasonal region contains a larger share of agricultural lands.

SUMMARY

Land cover classifications and databases using coarse resolution AVHRR data represent important inputs into environmental simulation models for global change research. Validation of AVHRR based products is critical but is often not effectively fulfilled because of the mismatch between conventional methods for accuracy assessment and characteristics of AVHRR data.

An alternative, and complementary, approach involves using conditional probability and variability terms to describe the nature and validity of the CONUS land cover characterization database. It is important to realize that all land cover classifications contain errors. As stated before, CONUS classes are different from conventional, monothetic spectral classifications in that the CONUS classes are generally dominated by one land cover type, but at the same time are comprised of other types of land cover that share similar seasonal and spectral characteristics. Conditional probabilities and error terms from this study show that the CONUS classes accurately described such landscape patterns and are generally consistent across various levels of classifications and translations.

Additional research on the validation of large area land cover mapping should look at the correlations of spatial components. Evaluating spatial errors found between the probabilities of dominant reference cover types and the various CONUS land cover mappings should provide an understanding into any regionalization of land cover seasonal characteristics.

The validation method used in this study is flexible enough to handle different classification schemes for map and reference categories and complex sampling designs, and the same reference data set can be used to evaluate map categories translated at various levels of complexity. Therefore this approach of validation and accuracy improvement for area estimates of different land cover categories is useful in land cover mapping projects of the global scale.

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