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Accuracy Assessment of Percent Canopy Cover, Cover Type, and Size Class

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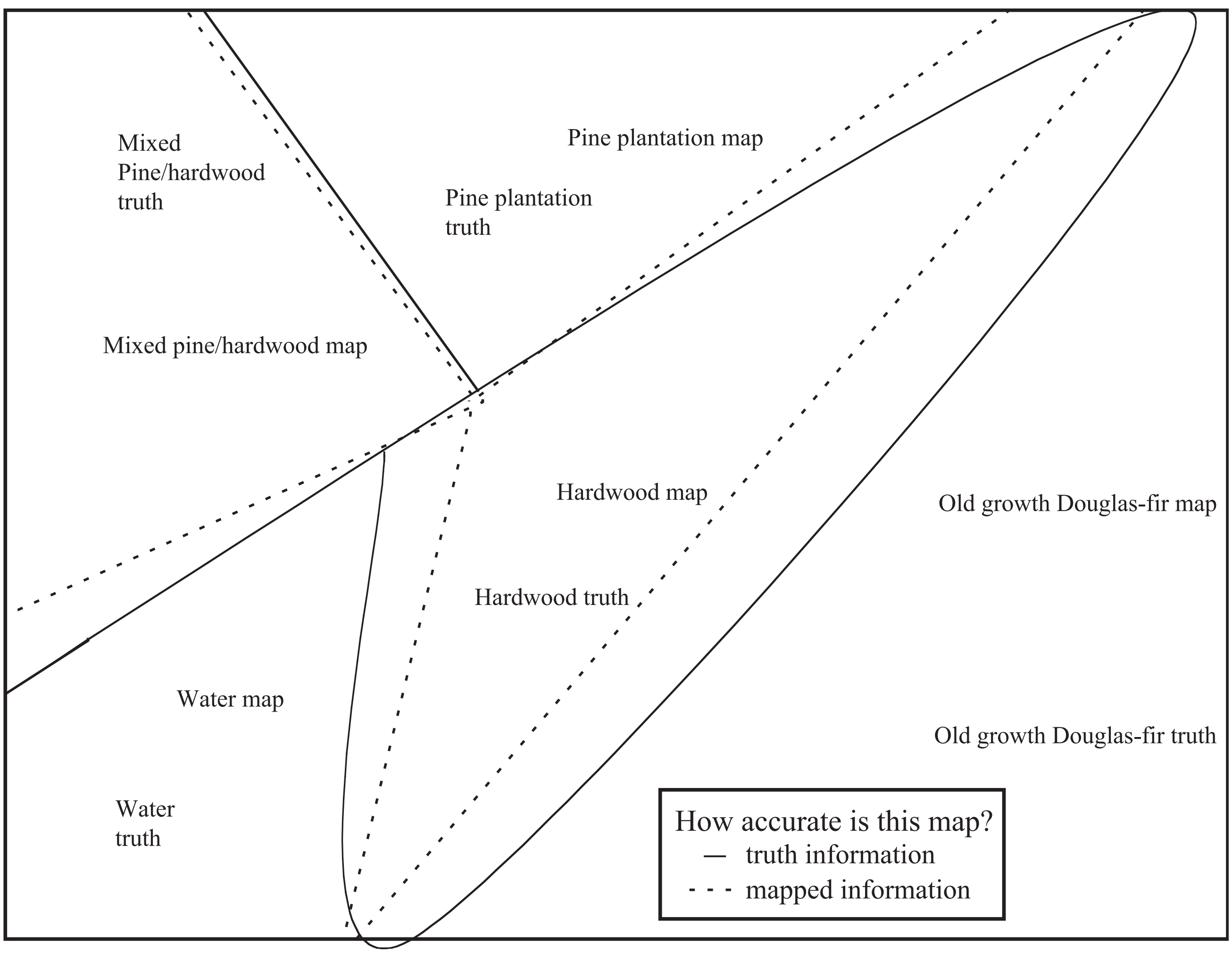

Abstract

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Truth for vegetation cover percent and type is obtained from very large-scale photography (VLSP), stand structure as measured by size classes, and vegetation types from a combination of VLSP and ground sampling. We recommend using the Kappa statistic with bootstrap confidence intervals for overall accuracy, and similarly bootstrap confidence intervals for percent correct for each category and user and producer accuracy. A procedure is given for mapped plots to be assessed as being partially or totally correct. We recommend the use of primary accuracy for management decisions and secondary accuracy for research decisions to distinguish between accuracy desired.

Keywords: valid accuracy assessment, truth, mapped management information, bootstrap errors, partially correct information

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Accuracy Assessment of Percent Canopy Cover, Cover Type, and Size Class

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Introduction

Management of National Forests and Bureau of Land Management lands requires reliable maps of percent cover, stand structure as measured by size class, and vegetation types. Such maps require frequent updating, and generating such maps is expensive. Remote sensing sources such as the Landsat Thematic Mapper (TM) are convenient for this purpose because its frequent, large area coverage at moderate resolution, digital format, and readily available software make it the easiest way to generate such maps. Considerable work has gone into making such maps. Although TM contains useful information for maps, there are serious limitations on just how much. For example, such TM information is likely not to be useful for size class, a variable that is difficult to measure even on the ground. Similarly, vegetation types are even difficult to define and may vary from one user to another—regardless of what medium is used—so that they are quite subjective. Because it is expensive to do a true accuracy assessment, many studies report invalid results. This paper came about because accuracy assessments that were done for the Idaho Panhandle National Forests in Idaho, part (R1 - Idaho, Montana) of the USDA Forest Service Region 1, reported wildly different results on two different mapping methods of the same area.

The purpose of this study is to clearly establish what needs to be done for percent cover, vegetation types, and size class regarding what truth is, how to measure it, and how to determine the accuracy of the maps for these variables in a statistically valid yet practical manner.

Review of Literature

It is desirable for the Forest Service to integrate its multiple land management objectives using an ecosystem management paradigm in order to practice adaptive management and to coordinate with other resource agencies regionally. To do this, a vegetation map is needed with spatial details. Such information can then be combined with georeferenced field inventory data, and other mapped data, to provide the necessary information for management decisions. It follows that digital maps desired need to yield the following attributes: vegetation life form and land cover types, forest cover as measured by crown cover (Jennings and others 1999), and tree size classes.

Although one would expect that better maps could be produced with better spatial resolution, this is not necessarily true with digital image processing. Woodcock and Strahler (1987) note that the effect of increased spatial resolution on classification accuracy is a tradeoff between an increase in boundary pixels increasing classification accuracy, and increased spatial variance of land cover types resulting in lower classification accuracy by decreasing the spectral variability of classes. The increased spatial variance is often referred to as “scene noise,” an unfortunate label because such variance reflects the actual world in which most classes are not pure or spatially homogeneous. Because it is not clear yet that such increased spatial resolution is helpful, and because the vast amount of data generated by improved sensors will need to be examined over a period of several years, TM data are still used heavily at this time.

Stehman and Czaplewski (1998) indicate that the three basic components of an accuracy assessment are: (1) the sampling design to select the reference sample which includes the sample plot;(2) the design, how to measure truth on the sampling units selected, and (3) the analysis procedure to apply once the data have been collected. They also list the following accuracy parameters already identified by others earlier (Rosenfield and Fitzpatrick-Lins 1986): overall proportion of area classified correctly; user’s accuracy for land cover class i (in other words, the conditional probability that a randomly located point classified into category i by the map is correct); the producer’s accuracy for land cover class j, (in other words, the conditional probability that a randomly selected point classified as category j is classified correctly as category j); the probability of a commission error, the conditional probability that a randomly selected point classified as category i by the map is classified as category k by the truth data; and the probability of an omission error, the conditional probability that a randomly selected point classified as category j by the truth data is classified as category k by the map.

Stehman (1999) elaborates on the above criteria in Stehman and Czaplewski (1998): The design should include (1) probability sampling protocols, (2) simple to implement and analyze, (3) result in low variability for estimates requiring the highest accuracy levels, (4) allow for reliable variance estimation, (5) result in a well-distributed sample, and (6) be cost effective.

Rosenfield and Fitzpatrick-Lins (1986) note that remote sensing researchers desire a single coefficient to represent the accuracy of thematic map and also for an accuracy value for each category on the map. An obvious first estimator of overall accuracy is the ratio of the sum of all correct over the total number of cell counts in the contingency table. Similarly, estimators of the error of commission are the proportions of diagonal values to row sums, and the proportions of diagonal values to column sums are estimators of errors of omission. A widely accepted coefficient of agreement now used is the Kappa statistic:

$$\hat{K} = (p_0 - p_c)/(1 - p_c) = 1 - (\text{observed agreement/expected agreement}) \qquad (1)$$

Where $p_o = \sum_{i,j}^{k} p_{ij} w_{ij}$ = proportion of units that agree and

$p_c = \sum_{i,j}^{k} w_{ij} p_{i.} p_{.j}$ = proportion of units or expected chance agreement and

$p_{i.} = \sum_{j=1}^{k} p_{ij}, p_{.j} = \sum_{i=1}^{k} p_{ij}$ where w_{ij} is the assigned weight of importance of agreement for (i, j) with $w_{ij} = 1$ for all i, j for the simple unweighted Kappa statistic, and $0 \le w_{ij} \le 1$ for the weighted Kappa. Weights can be assigned if the accuracy of some classes is more important than for others, with the disadvantage inherent that such weights would be subjective. Here $\hat{K} = 0$ indicates that obtained agreement equals chance agreement, $\hat{K} > 0$ indicated greater than chance agreement, $\hat{K} < 0$ less than chance agreement, and $\hat{K} = 1$ is perfect agreement. Rosenfield and Fitzpatrick-Lins (1986) discuss several other measures of agreement but recommend the Kappa statistic because it has the statistical basis of being an interclass correlation coefficient. For small sample sizes, Kraemer (1980) recommends use of jackknifing to obtain confidence intervals for Kappa.

Alegria (2000) discusses the accuracy assessment of stand structure and cover in National Forest Service (NFS) and the Bureau of Land Management (BLM) for their Interagency Vegetation Mapping project (IVMP) used in Oregon and Washington. This was done for broadleaf, conifer, and total vegetation cover. He notes that for stand structure the IVMP uses quadratic mean diameter (QMD), which is the diameter at breast height (d.b.h.) of the tree of average basal area. QMD was calculated as being truth using only the dominant and codominant trees derived from ground plots collected in the five subplots used to sample the 1-ha plot. Cover is obtained from aerial photos where a grid of 20 dots within a circle on a clear plastic template is centered on pinpricked aerial photos representing the center of the ground plot. The size of the template was adjusted to the scale of the photos so that it occupies the approximate area of the plot. Each dot on the photo was interpreted for the type of vegetation. The mapped data were collected by averaging 13 25 by 25 m pixels circumscribed by the 1-ha plots laid out in a 1, 3, 5, 3, 1 set of pixels across the circular plots (the 25 by 25 m pixels are resamples from 30 by 30 m pixels). Predicted mapped cover and QMD values were calculated using regression models so that the predicted values for both are continuous. These continuous values were then grouped into classes. Floating boundaries, rather than rigid class boundaries, were used for a given class width. Then the mapped value was compared to the range of the class around that reference point. A mapped value falling within the range would be considered correct, otherwise incorrect. This process was done for each class width of interest and plotted using the percent success rate on the y-axis and class width on the x-axis in 2 percent increments starting with 2 percent. Clearly, as the class widths become larger, the proportion of map values falling in the class becomes greater. Such graphs give the potential users an idea if the maps have sufficient accuracy for their uses. An 80 percent confidence interval (CI) for the population proportion using 1,000 iterations was obtained by a rescaling bootstrap method as described in Sitter (1992). Schreuder and Williams (2000) recommend using classical CI based on the assumption of normality if they can be computed. Otherwise the t-distribution based bootstrap should be used.

Gopal and Woodcock (1994) address the issue of low accuracy with thematic mapper-based maps. They point out that the traditional method of assessing accuracy—as for example computed above—suffers from the following limitations:

1. Each area in the map has to be assigned unambiguously to a single map category.
2. Information on the size of the errors is limited to observing the pattern of mismatches between categories in the map.

3. The user requires more complete and interpretable information than is currently provided with the map.

To address these issues they recommend classifying TM map evaluations for each class into absolutely wrong, understandable but wrong, reasonable or acceptable, good, and absolutely right. This fuzzy set approach with proper analysis of the data leads to a clearer understanding of the errors in the maps and what could be done about them.

Zhu and others (2000) used a two-stage cluster sampling design, selecting primary sampling units (psu's) from 333 grid cells across the area, and then selected a stratified random sample from the 333 grid cells as geographic strata of equal area. In their test region they stratified only by rare classes. They recommend using a two-stage cluster sample for assessment of Environmental Protection Agency Federal regions using a single design stratified by all land cover types, not just the rare classes.

Methods

Maps to be Evaluated for Accuracy

For management purposes, detailed polygon maps are required. The large areas to be mapped require satellite data, specifically TM data at this time. There are a number of methods in the classification of satellite data to generate maps. Most of these maps are produced using pixel classifications. Increasingly, maps are being generated through some form of image segmentation and merging process, such as Region 1, 3, 5, and 6 of the USDA Forest Service and the Satellite Imagery Landcover Classification (SILC) process of Montana State University. In creating polygons by whatever method, a number of inclusions will occur, such as a small agricultural field of 0.1 ha in a large forest area. Clear definitions are crucial, as illustrated well in Kleinn (2001), for example.

Establishing Truth

Before anything else, a clear definition of truth is needed and how it can and will be assessed. Truth should be defined exactly for each variable of interest and measured correctly rather than defining truth as the best readily available information, as is done frequently in remote sensing. Practicality may need to be accommodated. For example, ideally we may want 30 vegetation types, but it may not be practical even on the ground to identify all of them easily, and we may need to settle for 10 that can be clearly defined and measured and are still useful for management purposes. Similarly, inclusions need to be carefully defined in classes such as vegetation types. Inclusions are those classes of a few pixels that are included in a polygon to which they clearly do not belong.

Establishing Accuracy Assessment (AA) Plots

Plots can be located by a number of probabilistic methods. For practical purposes, use a grid such as used by Forest Inventory and Analysis (FIA), but this has the shortcoming that some relatively rare classes may not have a sufficient sample size. The sample size for such classes can be increased by sample allocation using stratified sampling. Sampling for accuracy also requires that the plot size used is large enough that if an inclusion is encountered, we know it is an inclusion. Both very large-scale photos (VLSP) and ground plots are required at the locations to assess accuracy in a practical yet reliable manner.

Proposed Approach

In the following we use an example for the Idaho Panhandle National Forests in Idaho, part of Region 1 (R1 - Idaho, Montana) of the USDA Forest Service. There is no literature available on what is acceptable accuracy for management purposes, and this is needed. This has been addressed in a paper by Schreuder and Schreuder (2002).

We have 500 very large-scale photos covering a grid of 1-ha plots of a 400,000-acre area of the Idaho Panhandle National Forests (IPNF). The same 1-ha plots were subsampled on the ground by use of the Region 1 plot, a slightly modified forest health-monitoring plot (fig. 1). The field crews used

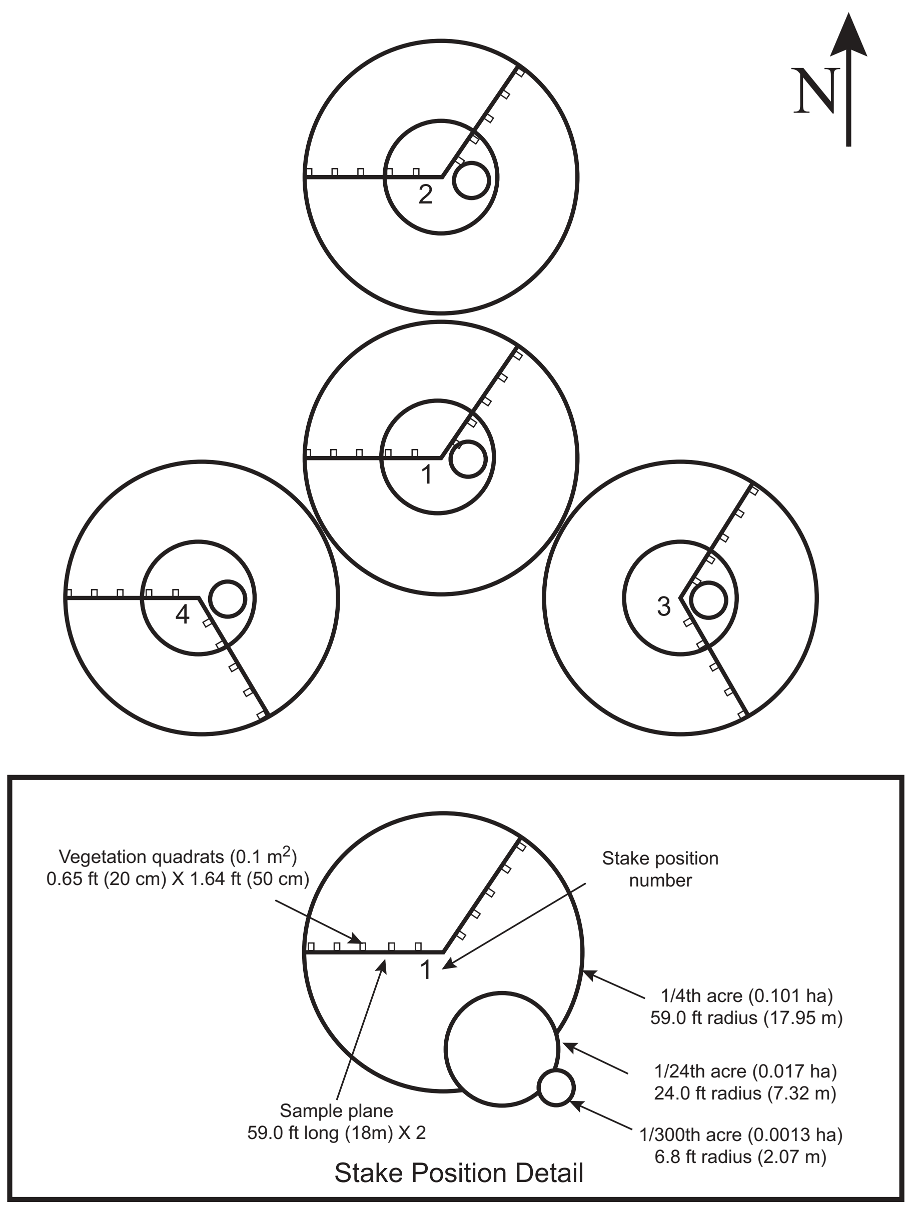

Figure 1—Plot design used by Region 1 of the USDA Forest Service (the 1-ha circular plot around the four subplots is not shown).

Global Positioning Systems (GPS) to locate themselves with the coordinates that were calculated for the plots within the grid**.** The analysis needs to be aware of potential errors from using GPS that can introduce additional errors into the accuracy assessment. Coordinates from a field grade, sometimes referred to as resource grade GPS, are not precise locations so there is no guarantee that you are in the polygon you are measuring when near a polygon boundary. It is possible to be 10 m more or less from the precise location using a GPS. This depends on the GPS instrument being used, users knowledge, and other factors. This combined with errors generated from the mapping technology, how the polygons were created, and processing of the data can result in positional errors of several pixels in some cases. Unfortunately we have to live with such errors at this time, but such errors will become negligible in the future with improved GPS units.

Proceed with the following steps:

1. For percent cover:
    - Locate the same 1-ha AA plots on both the VLSP and on the polygon maps to be assessed for accuracy. This can be done by using the coordinates that were generated when the VLSP were acquired to locate the position on the polygon maps.
    - Determine if the plots contain inclusions; if so, be sure that the same definitions are used when assigning a label to the AA plot. Measure the percent of cover for each 1-ha plot on the VLSP by imposing a suitable percent cover photo interpretation aid over the plot on the photo. Various photo interpretation aids are designed and available for this task. Placing the photo aid over the plot center and comparing the percent of cover between the photo aid and the plot while viewing the photos in stereo will accomplish this. This can be done with a standard stereoscope. This percentage for each hectare would then be compared to the percent mapped coverage for the plot. Overall percent correct coverage would be truth for the 1-ha plot. Such percent correct coverage can and often will include more than one legitimate class. If the additional class is simply an inclusion, ignore it.
2. Vegetation types and tree size classes:
    - Do the same as above in step 1 for vegetation types and tree size classes.
    - When obtaining the vegetation types in low-density areas (typically defined as from 0 to 25 percent cover) use data from the VLSP plots; use both VLSP and ground plots in medium density areas with primary emphasis on the VLSP plots; in high-density areas use ground and VLSP plots with emphasis on the ground sampling data. The combinations of VLSP and ground data are used when the canopy is too thick or dense to view the big picture. In other words, ground data may not capture the overstory, while the VLSP may not capture the understory, and both may be required to make an accuracy analysis. Determine size classes in the same method as vegetation types. If the vegetation types and/or tree size classes for a plot have to be determined by an algorithm, the plot information needs to be complete enough to accurately identify the proper class. If data are inadequate to do so, additional data will need to be collected adjacent to the sample condition in the same class to obtain the necessary sufficient data. This may require additional measurements in the field or photo interpretations.

- In areas of low-density cover, the measurement of the 1-ha VLSP plot vegetation types and size classes can be accomplished by a well-trained photo interpreter familiar with the area in question assisted by photo aids. In medium density areas, measured ground plots are an aid for the VLSP photo interpretation. However, in high-density areas, 1-ha ground plots have to be measured completely or sub-sampled to establish truth for the variable of interest.

Region 1 uses the following definitions of truth for the above variables:

- Percent canopy cover is the area of the ground covered by a vertical projection of canopy (Jennings and others 1999). With this definition it cannot exceed 100 percent.
- Structure or size class ideally distinguishes five classes, but two are used (9 inches + and less than 9 inches) classes plus a "plantation" class (only if the latter is actually used in practice). Technology at this time cannot do a very good job of accurately doing all five.
- For cover type, only 10 classes are defined rather than the 20 ideally desired to achieve reasonable accuracy. The definitions used are: consider it a single species if 60 percent or more of the "dominant" canopy is in that species. If it is 60 percent or more in two species but neither one of them is 60 percent or more, then give it a two-species label. If it is more complex, label it mixed conifer. For truth purposes it is clear that what is "dominant" may be different as seen from the photos or from the ground, so this definition needs to be sharpened further to yield complete consistency in classification.

These are the definitions used for operational purposes. For the maps generated, we are interested in assessing their accuracy. This is called primary accuracy because we use these maps for management purposes to define sampling strategies within the delineated map areas and to manage these areas for various objectives. It is clear from the above that we would like more detailed maps but do not use them because we are not sure how accurate such maps would be. We do generate these maps but assess their accuracy only for the future, such as for research purposes. It may be that the managers decide to change their definitions because of new information or find that they can live with a different definition if that results in better accuracy of their maps. We call this secondary accuracy.

We call the truth variables y, where interest is in percent canopy cover = y_1, y_2 = vegetation type, and y_3 = size class. Whether we are talking about primary or secondary accuracy, the procedures will be the same except that we should have more of the problems discussed below for secondary accuracy because it is likely that more classes will be mapped for such accuracy. The mapped variables corresponding to y_1, y_2, and y_3 are called x_1, x_2, x_3. We then have the following:

For the n = 500 plots, 1 ha in size:

a. n plots with y_1 from VLSP coverage
b. n plots with y_2 from VLSP and ground coverage, n_1 from VLSP only, and n_2 from ground sampling combined with the VLSP information
c. n plots with y_3 from VLSP and ground sampling, some of them from VLSP only and some from ground sampling combined with the VLSP information.

For all three variables, it is likely that some plots will contain more than one class.

At this point it is not important whether truth comes from VLSP only as in the case of percent canopy cover or from VLSP plus ground sampling as in the case of the other two variables, except that for percent canopy cover, the truth is mapped error free for the whole plot. With the other two variables plot information may have sampling error associated with the plot truth. We assume that for the n plots of 1 ha we have truth and the mapped information to be assessed for accuracy. We ignore location error for the mapped information because we do not know what it is, but it is unlikely to be serious and generally will lead to an underestimate of the actual accuracy. Unless we have detailed information about errors in plot locations, we cannot correct for them. We address the situation here that the truth and the mapped plot both can contain more than one category and consider that in the following. Traditionally plots are made to fall into one category only, which biases the results.

For a certain number of plots, n_s all the information falls within one category only for the variable of interest, for n_{c1} the mapped information falls into more than one category, and for n_{c2} the truth information falls into more than one category. The following treats the case of both x and y labeling only the same two "truth" classes occurring on a truth plot, the extension to more than two is straightforward.

For a given plot, assume that the part x labels x_{ij} is part of or covers the part y_{ij} called that by the truth plot. If the truth plot and mapped plot could be overlaid completely, this assumption is not needed. But the truth plot may only provide estimated areas of the hectare in the classes of interest for y_2 and y_3; we need to make this assumption because we will not know what part of the plot belongs to the category estimated. That is the situation we currently have to live with. Generally violation of this assumption will result in higher estimates of accuracy than actually obtained.

Percent canopy cover will have to be put into classes, like the other two variables, in order to determine whether it was mapped correctly or not. This can be done objectively, for example, the 10 classes 0 to 10 percent, 10+ to 20 percent, ...90+ to 100 percent.

We then have the following example for a given plot k:

a. If truth calls it y_{ij} and $y_{ij'}$ with area weights $w^y_{ij}, w^y_{ij'}$ such that $w^y_{ij} + w^y_{ij'} + w^y_{iother} = 1$ and x calls it the same with area weights $w^x_{ij}, w^x_{ij'}$ such that $w^x_{ij} + w^x_{ij'} + w^x_{iother} = 1$ then if $w^x_{ij} \le w^y_{ij'}, w^x_{ij'} \le w^y_{ij'}$, correct classification for the plot gets a value of $(w^x_{ij} + w^x_{ij'})/n$ for p_0. $w^y_{ijother}, w^x_{ijother}$ indicate that either y or x defines a condition on the plot not recognized by the other. Plots that are completely classified correctly get a weight of 1/n.

b. If truth calls it y_{ij} and $y_{ij'}$ with weights $w^y_{ij}, w^y_{ij'}$ such that $w^y_{ij} + w^y_{ij'} + w^y_{iother} = 1$ and x calls it the same with weights $w^x_{ij}, w^x_{ij'}$ such that $w_{ij}^{x} + w_{ij'}^{x} + w_{iother}^{x} = 1$ then if $w_{ij}^{x} > w_{ij}^{y}, w_{ij'}^{x} < w_{ij'}^{y}$, correct classification for the plot gets a value of $(w_{ij}^{y} + w_{ij'}^{x})/n$ for p_0.

c. In fact the weight given to all partially correctly classified plots should be $(w_{ij}^{z1} + w_{ij'}^{z2})/n$ for p_0 where z1 and z2 are the smaller of w_{ij}^{y}, w_{ij}^{x}, and $w_{ij'}^{y}, w_{ij'}^{x}$, respectively.

We searched the literature including the key references by Agresti (1990), Fleiss (1981), and Congalton and Green (1999) but did not see a discussion anywhere of the use of fractional values of truth as described above. Nonetheless, we propose computing the Kappa statistic in equation (1), allowing for fractional values as can be computed above, so that a plot that is classified correctly completely gets counted as 1/n for p_0 whereas a plot that is 0.80 correct gets counted as 0.80/n.

By repeatedly taking n plots with replacement from the n sample plots, say, B times and applying the above to each sample, we generate a series of B estimates for each cell of our contingency table, producer and user accuracy, and a Kappa statistic for each. This bootstrap approach then allows us to construct confidence limits around all the cells in the table as well as for the Kappa statistic by treating the B samples as independent estimates of the same quantities.

Note that the contingency tables are the basic product from the AA. It is important that users study the contingency tables in order to attempt to explain the causes of misclassifications. Some are obvious while others need investigating. These misclassifications may result from problems with the technology used, user errors, errors in the final preparation of map products, or in calculations in the AA. Studying the results is essential in that it may explain or uncover errors that can be corrected.

It is also desirable for a manager to know how serious a misapplication of a treatment to an area may be expected to be if the area is thought to belong in one category when in fact it belongs to another one. There would be different consequences in applying a treatment to a category close to the desired one than to a different one.

Recommendations

1. Define realistic cover percent classes and well-defined vegetation types and size classes.

2. Explore the use of ambiguous classes as suggested by Skidmore and Turner (1992). The use of such classes should make it easier to classify the other data correctly, and knowing about such ambiguous classes could help management too.

3. Compute the contingency table and Kappa statistic for each of the three mapped categories of variables, producer and user accuracy, and use bootstrap standard errors and confidence intervals for them.

4. Do 1, 2, and 3 for both primary and secondary accuracy. It is likely that existing affordable remote sensing technology is insufficient to provide acceptable accuracy for primary accuracy for some maps.

What Remains to be Done

1. How serious are the sampling errors in assessing truth for sampled variables vegetation type and size classes? If measurement errors are found to be serious, we are right back at what is often done in the past—use a standard that is not really truth. Additional data need to be collected then to make the sampling errors acceptably small.

2. How serious are the effects of the errors in location of the plots used in evaluating accuracy? If there were serious errors, accuracy assessment would be seriously affected. Theoretically one could obtain 0 percent accuracy when actual accuracy was 100 percent. Generally, such errors should result in underestimates of actual accuracy with the method proposed.

3. Minimize or, if possible, eliminate measurement errors in truth by observers.

4. Ensure an adequate sample size in each of the categories of interest for the variables of interest. This can generally best be done by stratified sampling.

5. Provide guidelines on the implications of achieving a stated accuracy level in terms of making incorrect management decisions.

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