EVALUATION OF USDA LARGE AREA CROP ESTIMATION TECHNIQUES

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ABSTRACT

The USDA's EDITOR system registers and digitizes the ground truth and raw Landsat data, clusters, classifies, and develops area estimates by regressing the ground truth hectarage onto the number of pixels classified per segment (a sampling unit of one square mile). A research program was conducted to evaluate the performance of EDITOR and make selected improvements to components of EDITOR. It was found that the use of multitemporal data over unitemporal significantly improved crop hectarage estimates. Performance measures on an independent test set and a jackknifed test set decreased, indicating that the current procedure of using a single data set for training the classifier, developing the regressions and evaluating the results leads to overoptimistic performance estimates. An alternative clustering algorithm, CLASSY, when substituted for the current EDITOR clustering method, produced improved estimates. Use of a simpler classifier, namely Mean Square Error classifer, did not produce significantly better hectarage estimates but showed more extendibility of the regression lines to an independent test set. The calibration approach to regression pointed out a fundamental problem in the current regression model and suggested an alternative estimation approach which has several theoretical advantages.

I. OBJECTIVES

This paper describes the results of the National Aeronautics and Space Administration (NASA) Domestic Crops and Land Cover Classification and Clustering study on crop area estimation[1]. One objective was to evaluate the current crop area estimation approach of the Economics and Statistics Service (ESS) of the United States Department of Agriculture (USDA) in terms of the factors that are likely to influence the bias and variance of the estimator. A second objective was to investigate procedures that would improve crop area estimation, with major emphasis on alternative clustering and classification algorithms. In addition, the calibration regression model was investigated as an alternative approach to the current regression estimator.

II. BACKGROUND

The software system used by ESS in their crop area estimation is called EDITOR. This system is used for registration and digitization of ground truth and raw Landsat data, clustering, classifying, and developing area estimates. The current EDITOR crop area estimator is a regression estimator. Ground truth is collected during the yearly June Emumerative Survey for small geographic areas called segments. The corresponding pixels are clustered and classified using the Gaussian maximum likelihood classifier. For each crop, the ground truth hectarage (Y) is regressed onto the number of pixels classified (X) per segment, treating the latter as a fixed variable without error: $Y = \alpha + \beta X + \varepsilon$. These regressions then can be used for crop area estimation provided that the area of interest has been classified. Thus if a segment-sized area has been classified to obtain X_0, then the estimated hectarage is given by $\hat{Y} = a + bX_0$, where a and b are least squares estimates of α and β.

In the current ESS estimation procedure, all segments for which ground truth is available are used to train the classifier. Those same segments are then classified and used to obtain the regression estimator. Ideally, the data set upon which the regressions are developed should be independent from the data set used for training a classifier. One way to accomplish this would be to divide the

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available data into training and estimation portions. Alternatively, if the amount of available data is small, quasi-independent segments for regression could be generated using a jackknifing technique. Both methods were employed in this study to better evaluate the performance of the estimator.

The candidate alternative clustering and classification algortithms are referred to as the CLASSY clustering algorithm and the Mean Square Error Classification algorithm. Consideration of these alternative algorithms was principally motivated by two factors. First, it was believed that a more theoretically based clustering algorithm would be appropriate. The current EDITOR clustering algorithm is a modified k-means method using Swain-Fu distance as a cluster merge criterion[2]. The CLASSY clustering algorithm[3,4,5,6] developed at the Johnson Space Center had performed well in previous tests. In particular, CLASSY is fundamentally a density estimation algorithm which approximates the overall data distribution as a mixture of multivariate normal distributions. A second factor was the belief that the data set upon which the regressions are developed should be independent from the data set used for training a classifier. This resulted in the choice of the Mean Square Error Classification algorithm[7,8] which is a nonparametric, least squares classifier that can be weighted through the input of a loss matrix. The properties enjoyed by this classifier were exploited in this study: that is, it produces few, thus stable parameter estimates implying extendibility to areas on which it was not trained, and it can be easily modified for use in jackknifing techniques. A quadratic discriminant function was used with this classifier.

The data set used in this investigation consisted of thirty-three segments in northern Missouri, each having an area of approximately 1 square mile (259 hectares). Landsat acquisitions from May 14 and August 3, 1979 were available. The major crops in this study were corn, soybeans, and pasture, which represented about 12, 25, and 30 percent of the crops present, respectively. Three additional crops were also studied: winter wheat (3 percent), dense woodland (8 percent) and other hay (7 percent). About 15 percent of the segment data consisted of other crops, mainly wasteland. Unless explicitly stated, all analyses were conducted using multitemporal data.

III. ANALYSIS

The analyses were conducted in three levels. The first level consisted of training and developing regression equations using all 33 segments. This corresponds to the current USDA estimation procedure. In the second level, the data set was partitioned into a training set of 25 segments and a test set of 8 segments to assess the performance and validity of the current ESS estimation procedure. Jackknifing techniques were used in the third level as a means of obtaining test sets which were larger than those obtainable by using a single training-and-test partitioning of the data.

To compare alternative clustering and classification algorithms, the analyses in levels 1 and 2 were run in parallel. That is, the current EDITOR clustering and classification was first used in an analysis and the process was repeated with the only change being the use of the CLASSY clustering algorithm to generate cluster statistics which were then inserted into the EDITOR system. Then a corresponding analysis was performed using the Mean Square Error classifier. In addition, unitemporal analyses were conducted in level 1 using the current EDITOR clustering and classification.

Multivariate paired t-tests (hereafter referred to as Hotelling's T^2 tests) were used to compare the regression estimates obtained when using the current EDITOR clustering and classification algorithms with the regression estimates obtained when the alternative components, namely CLASSY and the Mean Square Error Classifier were inserted into the ESS estimation procedure. Multivariate statistical analysis techniques have been applied, because the major objective is to evaluate the performance of the alternative components in estimating the crop hectarages of all six crops simultaneously. The criterion adopted in this study is a vector consisting of the absolute differences between the ground truth and the regression estimate for each of the six crop types of interest. To compare the EDITOR procedure with CLASSY (for instance), a test is made of the equality of the two mean vectors of these absolute differences (vector of means of the absolute value of the differences). If the hypothesis of equal mean vectors is rejected, the procedure yielding a smaller mean vector of absolute differences between the ground truth and the regression estimates is preferred.

Hotelling's T^2 test was also used in comparing regression estimates obtained from multitemporal data with unitemporal data.

A. LEVEL 1: TRAINING AND ESTIMATING WITH ALL 33 SEGMENTS

The current USDA practice of training on a sample and developing the regressions on the training set was performed using all 33 segments. The following comparisons were made:

1. Comparison of unitemporal versus multitemporal - The entire estimation process was carried out for unitemporal data and for multitemporal data within the current EDITOR system. Summary statistics are presented in Table 1. Hotelling's T^2 test was used to determine if multitemporal data produced significantly better estimates than unitemporal. (August, the better of the unitemporal dates was used.) The computed T^2 was 44.8324. Because $T^2_{0.05}$ (6,32) = 17.4 and the mean vector of absolute differences between ground truth and estimated hectarage for all six crops was uniformly larger for unitemporal than for multitemporal data, it was concluded that the use of multitemporal data over unitemporal significantly improved crop hectarage estimates.

2. Comparison of the current EDITOR clustering algorithm versus the CLASSY clustering algorithm - The entire estimation process was repeated but with the CLASSY cluster statistics inserted into the EDITOR system. Summary statistics are presented in Table 2. The Hotelling's T^2 test was used to determine if the use of the CLASSY clustering algorithm produced significantly better estimates on the training set than the current EDITOR clustering algorithm. The computed T^2 was 44.1959 and $T^2_{0.05}$(6,32) was 17.4, indicating a significant difference. Because the mean vector of absolute differences between ground truth and estimated hectarage for all six crops was uniformly smaller for CLASSY than the current clustering algorithm, it was concluded that the use of CLASSY did improve crop hectarage estimates.

3. Comparison of the current EDITOR clustering and classification with the Mean Square Error classifier - The entire estimation process was performed using the Mean Square Error classifier as a component. The summary statistics are presented in Table 3. Hotelling's T^2 test was used to determine if the use of the Mean Square Error classifier produced significantly better estimates on the training set than the current EDITOR clustering and classification algorithms. The computed T^2 was 21.777 and $T^2_{0.05}$ (6,32) was 17.4, indicating that the two procedures do not perform equally. However, since the results were inconsistent across crop types (the Mean Square Error classifier provided better results for some crops and worse for others), it cannot be concluded that one classifer performed uniformly better than the other.

B. LEVEL 2: TRAINING ON 25 SEGMENTS AND TESTING ON 8 SEGMENTS

The data were divided into two sets: a training set of 25 and a test set of 8 segments. The classifier developed on the training set was used to classify both the training and test sets. Regressions for the six crops of interest were developed on the training set and also on the test set. This was carried out with the current EDITOR clustering and classification algorithms and again with CLASSY as a component of the EDITOR system, and finally with the Mean Square Error classifier. The summary statistics are presented in Table 4, Table 5 and Table 6. The following tests were made.

1. For each of the three classification choices, an F-test was performed to determine if the regression line developed on the training set for a given crop was equal to the regression line developed on the test set. (A preliminary test for homogeneity of variance must be carried out first.) This test indicates if the regression line developed on the training set is extendible to the test set. For the current EDITOR clustering and classification procedure homogeneity of variances was rejected for the major crops of corn, permanent pasture, and soybeans. Of the three remaining crops, the equality of the training set regression line and the test set regression line was rejected for the crop other hay. With the use of CLASSY, corn and permanent pasture did not pass the homogeneity of variance test. The test for equality of regression lines indicated that there were differences for dense woodland and other hay. Corn and permanent pasture again failed the homogeneity of variance test when the Mean Square

Table 1.- Current Procedure - Train and Estimate on 33 Segments

(a) EDITOR multitemporal performance measures

Crop	r^2	Proportion correct	Proportion omission error	Proportion commission error	MSE
Corn	0.80	0.73	0.27	0.37	68.2
Winter wheat	.38	.29	.71	.56	24.6
Permanent pasture	.79	.79	.21	.46	320.9
Soybeans	.85	.79	.21	.33	128.8
Dense woodland	.62	.47	.53	.54	83.9
Other hay	.20	.22	.78	.60	92.4
Overall percent correct = 57.77					

(b) EDITOR August performance measures

Crop	r^2	Proportion correct	Proportion omission error	Proportion commission error	MSE
Corn	0.42	0.52	0.48	0.55	197.8
Winter wheat	.27	.34	.66	.68	28.8
Permanent pasture	.74	.72	.27	.52	391.5
Soybeans	.75	.74	.26	.37	214.0
Dense woodland	.44	.31	.68	.58	125.8
Other hay	.03	.08	.92	.79	111.4
Overall percent correct = 51.66					

(c) EDITOR May performance measures

Crop	r^2	Proportion correct	Proportion omission error	Proportion commission error	MSE
Corn	0.07	0.26	0.74	0.76	313.4
Winter wheat	.01	.02	.98	.88	39.0
Permanent pasture	.58	.68	.32	.51	648.9
Soybeans	.61	.67	.33	.52	326.4
Dense woodland	.44	.33	.67	.65	125.2
Other hay	.05	.16	.84	.64	109.1
Overall percent correct = 45.15					

TABLE 2.- CLASSY Procedure - Train and Estimate on 33 Segments

Crop	r^2	Percent correct	Omission error	Commission error	MSE
Corn	0.93	72.31	27.69	29.47	23.33
Winter wheat	.44	38.05	61.95	58.35	22.07
Permanent pasture	.84	75.45	24.55	45.50	239.79
Soybeans	.89	81.57	18.43	34.01	85.95
Dense woodland	.72	49.74	50.26	51.50	62.53
Other hay	.48	26.14	73.86	63.05	59.45
Overall percent correct = 58.10.					

Table 3.- MSE Classifier Procedure - Train and Estimate on 33 Segments

Crop	r^2	Percent correct	Omission error	Commission error	MSE
Corn	0.85	65.61	34.39	24.12	51.90
Winter wheat	.38	20.13	79.87	40.13	24.63
Permanent pasture	.76	85.34	14.66	50.01	361.16
Soybeans	.85	83.48	16.52	35.73	128.02
Dense woodland	.57	33.98	66.02	47.65	95.15
Other hay	.00	1.87	98.13	47.06	115.38
Overall percent correct = 57.04					

Table 4.- Current EDITOR Clustering and Classification Procedure

(a) Train on 25 segments

Crop	r^2	Percent correct	Omission error	Commission error	MSE
Corn	0.91	74.24	25.76	31.13	28.805
Winter wheat	.50	35.46	64.54	66.05	21.628
Permanent pasture	.88	66.56	33.44	44.56	176.736
Soybeans	.86	83.69	16.31	31.09	119.426
Dense woodland	.66	54.55	45.45	50.12	72.595
Other hay	.37	32.52	67.48	71.89	79.541
Overall percent correct = 57.70					

(b) Test on an independent set (8 segments)

Crop	r^2	Percent correct	Omission error	Commission error	MSE
Corn	0.61	54.98	45.02	42.89	202.865
Winter wheat	.00	32.97	67.03	71.15	37.275
Permanent pasture	.39	51.76	48.24	47.87	1268.635
Soybeans	.40	71.74	28.26	63.17	395.029
Dense woodland	.88	27.04	72.96	55.80	36.662
Other hay	.24	39.81	60.19	88.64	52.365
Overall percent correct = 42.00					

Table 5.- CLASSY Procedure

(a) Train on 25 Segments

Crop	r^2	Percent correct	Omission error	Commission error	MSE
Corn	0.92	77.12	22.88	30.48	24.06
Winter wheat	.58	35.73	64.27	67.34	18.22
Permanent pasture	.84	73.12	26.88	44.66	230.88
Soybeans	.87	84.15	15.85	31.43	112.10
Dense woodland	.77	50.19	49.81	42.44	49.45
Other hay	.58	32.29	67.71	62.13	53.90
Overall percent correct = 59.62					

(b) Test on an independent set (8 segments)

Crop	r^2	Percent correct	Omission error	Commission error	MSE
Corn	0.40	55.97	44.03	48.04	313.48
Winter wheat	.34	41.76	58.24	53.09	24.48
Permanent pasture	.44	64.20	35.80	48.84	1162.13
Soybeans	.71	70.43	29.57	59.70	186.40
Dense woodland	.83	19.15	80.85	55.56	52.15
Other hay	.21	26.21	73.79	87.32	54.47
Overall percent correct = 45.38					

Table 6.- MSE Classifier Procedure

(a) Train on 25 segments

Crop	r^2	Percent correct	Omission error	Commission error	MSE
Corn	0.92	71.36	28.64	24.22	26.37
Winter wheat	.49	16.90	83.10	44.74	22.09
Permanent pasture	.79	87.13	12.87	46.13	316.55
Soybeans	.87	86.02	13.98	32.43	109.97
Dense woodland	.56	32.91	67.09	49.55	93.93
Other hay	.07	2.79	97.21	59.32	111.99
Overall percent correct = 44.69					

(b) Test on an independent set (8 segments)

Crop	r^2	Percent correct	Omission error	Commission error	MSE
Corn	0.40	54.73	45.27	45.85	313.74
Winter wheat	.05	32.79	67.03	36.17	35.38
Permanent pasture	.39	76.46	23.53	47.64	1269.16
Soybeans	.67	74.78	25.22	59.10	213.21
Dense woodland	.88	18.59	81.41	53.85	37.38
Other hay	.01	2.91	97.09	70.00	68.24
Overall percent correct = 49.24					

Error classifier was used, and all other crops which passed the homogeneity of variance test also passed the equality of regression lines test.

2. Hotelling's T^2 tests were used to determine if use of CLASSY or the Mean Square Error classifier produced significantly better estimates on an independent set than the use of the current EDITOR clustering and classification algorithm. For each of the three procedures, the regression lines developed on the training sets were used to obtain ground truth estimates for the test set. These estimates along with the actual ground truth were then used in Hotelling's T^2 tests in a manner similar to that described earlier. The two computed T^2 were 11.035 and 25.1924, and $T^2_{0.05}(6,7)$ = 409.52. With a test sample of 8 segments, there was not enough statistical evidence to show any difference between procedures on an independent test set. A larger independent test set would be more appropriate because the critical value $T^2(p,N-1)$ decreases rapidly as the sample size N increases.

C. LEVEL 3: JACKKNIFING TECHNIQUES WITH THE CURRENT EDITOR CLUSTERING AND CLASSIFICATION ALGORITHM

When it is impossible to have a large training sample as well as a large sample with which to develop the regression lines, a jackknifing procedure can be employed. The jackknifing, which is now described, simulates the method of training a classifier on a sample and then developing a regression on an independent sample.

The 33 segments were grouped into 11 sets containing 3 segments each. One set of 3 segments became the test set, while the remaining 10 sets were pooled and used to train a classifier. The test set containing three segments was then classified. This procedure was repeated 10 more times, with each set of 3 segments being the test set exactly once, and the remaining 30 segments being used to train a classifier. The 11 test sets were then combined, resulting in a sample of 33 segments, each having ground truth (Y) and a classification variable (X).

Regression equations for the six crops of interest were developed on this combined set of 33 segments. The regression MSE'S, r^2's, and classification performance measures are given in Table 7 for this combined set. (See table 1 for classification results obtained when all 33 segments were used for training.) With only one exception, the omission and commission error rates are higher in the jackknifed set than the set when all 33 segments were used in the training. Also, the r^2's are lower in the jackknifed set. For the major crops of corn, permanent pasture, and soybeans, the decrease in r^2 is 0.15, 0.23, and 0.14, respectively. The results of this jackknifing study indicate that performance measures for the current procedure are overly optimistic, and that more realistic performance measures are obtained from a separate test set.

Due to the overlap of the training sets, no statistical tests were performed.

Table 7.- Current EDITOR Clustering and Classification Procedure - Results for a Jackknifed Test Set of 33 Segments

Crop	r^2	Percent correct	Omission error	Commission error	MSE
Corn	0.75	67.50	32.50	37.51	83.106
Winter wheat	.13	23.19	76.81	74.76	34.538
Permanent pasture	.56	62.75	37.25	51.20	680.577
Soybeans	.71	78.45	21.55	37.26	243.650
Dense woodland	.59	48.24	51.76	59.62	92.173
Other hay	.02	15.48	84.52	80.74	113.273
Overall percent correct = 51.62					

IV. CALIBRATION MODEL

In view of the fact that the ground truth hectarages are controlled and the classification results depend upon spectral observations which can be regarded as chance occurrences and therefore relatively imprecise, the calibration regression model was investigated. In the calibration model, the number of pixels classified (X) is regressed onto the ground truth hectarage (Y): $X = \gamma + \delta Y + \epsilon'$. The ground truth hectarage Y of a segment-sized area is then estimated by observing the classification results X_o of that area and using the equation $\hat{Y}_1 = (X_o - c)/d$, where c and d are least squares estimates of γ and δ. Another estimator under this model, $\hat{Y}_2 = a + bX_o$, where a and b are defined earlier, was also considered. (Note that $\hat{Y}_2$ and $\hat{Y}$ from page 1, though having the same form $a + bX_o$, are two entirely different estimators because they are constructed under two different models.) Under the calibration model, $\hat{Y}_1$ is a maximum likelihood estimator and gives a readily interpreted analysis of variance. It may be noted here that the mean, variance, and MSE of $\hat{Y}_1 = (X - c)/d$ are infinite, since there is a nonzero probability that d may be zero. The mean, variance, and MSE of $\hat{Y}_2 = a + bX$ are finite for $N \geq 4$. However, it can be shown, with the help of Tchebycheff's inequality, that the probability of d lying in an interval that contains very small values, including zero, can be made very small by increasing n and choosing values of Y that are not very close to each other. The expressions of bias, variance, and MSE of $\hat{Y}_1$ and $\hat{Y}_2$ were given when the distribution is truncated for the value of d very close to zero[1]. From the expressions, it is evident that both estimators are biased, but $\hat{Y}_1$ is asymptotically unbiased whereas Y_2 is not. Berkson[9] has shown that when $|\sigma/\delta|$ is small, the asymptotic MSE of $\hat{Y}_1$ is smaller than that of $\hat{Y}_2$ except when Y_o, the quantity we wish to estimate, lies very close to $\bar{Y}$. Moreover, $\hat{Y}_1$ is consistent whereas $\hat{Y}_2$ is not. When applying the calibration model to the data on the 33 segments, it was found that the magnitude of bias $(\hat{Y}_1)$, was smaller than that of bias $(\hat{Y}_2)$, and that MSE $(\hat{Y}_1)$ would be smaller than MSE $(\hat{Y}_2)$ whenever Y_o is not very close to the sample mean $\bar{Y}$.

V. CONCLUSIONS

Results from the Hotelling's T^2 test showed that the use of multitemporal data over unitemporal significantly improved crop hectarage estimates. Performance measures on an independent test set and a jackknifed test set were poorer than those obtained using the current procedure. Performance measures decreased by an average of 15% indicating that the current ESS procedure of using a single data set for training the classifier, developing the regression and evaluating the results leads to overoptimistic performance measures. The CLASSY clustering algorithm, when substituted for the current ESS clustering method, produced significantly improved hectarage estimates when testing and training were done on all 33 segments. The independent test set of eight segments was not large enough to allow the detection of any significant difference between CLASSY and the current ESS procedure; however, the performance measures indicate an improvement when using CLASSY clustering.

It is worthwhile to note that CLASSY requires no decisions from an analyst concerning the number of clusters, separability thresholds, or other arbitrary parameters as does the current clustering method.

The MSE classifier did not produce significantly better hectarage estimates than the ESS procedure when evaluated on either the training set or the independent test set. However, this classifier showed less sensitivity to the training/test degradation discussed earlier. Also the overall percent correct on the independent test set decreased least when using the MSE classifier. This greater extendibility might be expected due to the fewer parameters required to be estimated in using this classifier. In addition the classifier requires no analyst interaction, and is efficient with respect to CPU usage.

The calibration approach to regression points out a fundamental problem in the current regression model and suggests an alternative which has several theoretical advantages.

VI. RECOMMENDATIONS

Several recommendations seemed appropriate at the conclusion of this study. First, the use of CLASSY clustering in place of the current EDITOR clustering algorithm was recommended. CLASSY seems to offer a tangible improvement to the current EDITOR system in terms of increased performance and decreased analyst interaction. It was recommended that some form of jackknifing also be implemented to obtain more reliable performance measures.

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