Project Report: Land Cover Change Detection Error Assessment.

Chris Witt, GIS/RS Technician, GIS Training and Research Center, Idaho State University, Campus Box 8130, Pocatello, ID 83209-8130

Keith T. Weber, GIS Director, GIS Training and Research Center, Idaho State University, Campus Box 8130, Pocatello, ID 83209-8130

*INTRODUCTION***:** The utility of remotely sensed imagery for detecting and monitoring changes in land cover has become widely recognized (Price et al., 1992, Ram and Kolarkar 1993). This is, in part, because the rate and scale at which change is occurring requires repeated broad-scale coverage that satellite imagery can provide (Lunetta et al., 1991). Because of limitations in computing power and spatial resolution, the bulk of change detection and monitoring has been done using AVHRR (Advanced Very High Resolution Radiometer). These sensors are capable of roughly 1km absolute spatial resolution and may not be useful for smaller scale natural resource applications. For these smaller scale applications, Landsat Thematic Mapper (approximately 30m resolution) is frequently employed. However, until recently, computer software has been unable to handle large (regional scale) amounts of data at this resolution. With the advent of more powerful computing systems and the availability of higher spatial resolution imagery, it is now possible to investigate regional trends in land cover change at a relatively high spatial resolution using remotely sensed imagery.

A common method to quantify land cover change over time using satellite imagery is to acquire Landsat or SPOT imagery from the same date (day and month) from two or more different years. This process is known as anniversary date synchronization (Lillesand and Kiefer 2000). Although this method is commonly used it fails to recognize potential differences in temperature and precipitation between years. These variables are closely tied to and can have profound effects on the phenology of a region (Rauzi and Dubrenz 1970, French and Sauer 1974). By using imagery that is similar phenologically, a significant source of potential error can be removed. Comparing imagery that has been phenologically synchronized should provide more accurate and useful information on temporal change than would be available by comparing anniversary date synchronized imagery (Weber 2001).

In addition to the limitations of “anniversary date” image selection and the past problems with spatial resolution, the choice of bandwidth ratios can also have important consequences on the analysis of data. For measuring vegetation cover the Normalized Difference Vegetative Index (NDVI) is commonly used. This index incorporates a 4:3 band ratio. This ratio is typically used with Thematic Mapper data and incorporates wavelengths in the red and near infrared range (0.63-0.90um) (Verbyla 1995). This ratio is known to be useful in identifying vegetation type, however, when addressing vegetation cover change, the presence or absence of bare soil may be more indicative of cover change than a shift in vegetation type. The mid-infrared band (5) (1.55-1.75um) is more proficient at detecting exposed soils. Principle Component Analysis (PCA) indicated a 5:3:4 ratio would preserve more unique data and should detect gains and losses in vegetative cover more accurately than NDVI , so was chosen for our analysis.

The intent of this study was to incorporate the previously unavailable and unused image selection and analysis techniques mentioned above in a regional scale study. We intended to gain insight into the accuracy and utility of such an application by measuring vegetation changes that occurred over a ten year span on an area over 175,000 km^2 in size. Because of a limited field season and subsequent small sample size, this research was exploratory in nature and not designed to be scrutinized through rigorous statistical analysis. We intended to gain information on the effectiveness of our sampling techniques and trends in how change detection predictions relate to real world situations. This information allows us to develop and refine image analysis interpretation and field ground truthing techniques. It can also have important land management applications in the fields of urban growth, rangeland health, habitat fragmentation, and invasive species monitoring and management.

METHODS:

Area of Concern: The area of concern (AOC) for this study covers roughly 200,000 km^2 of the upper Snake River Plain and Greater Yellowstone Ecosystem. It incorporates parts of five states, two national Parks (Yellowstone and Grand Teton), five Bureau of Land Management districts, and twelve national forests (Fig. 1). It is an area characterized by sagebrush steppe braided by riparian areas at lower elevations. Higher elevations see large tracts of coniferous forests mixed with meadows and intermittent wetlands. This region was chosen because of the variety of issues facing resource managers in the area and because of the unique hydrological significance of the area. Range management, fire ecology, invasive weeds, rare and sensitive species, timber harvest practices, and urban sprawl all impact this region and present challenges to land managers. Information gathered in this research can support them in decision-making processes.

Phenological date synchronization: To perform a phenological synchronization of satellite imagery, daily weather data for the area to be analyzed are required. Suitable data sets can be obtained from National Weather Service offices or via the Internet by accessing sites such as Agrimet (http://mac1/pn/usbr.gov/agrimet/ webarcread.html). To use these data in Pheno-Calc software (available from the author at http://giscenter.isu.edu/software) the raw data set containing date, daily precipitation, and daily minimum and maximum temperature is saved as a Microsoft Excel spreadsheet. Once this procedure has been accomplished, the data are ready to be used in Pheno-Calc software.

With these tools, the user can identify the date in each year where both phenological surrogates, growing degree-day (GDD) and accumulated precipitation (AP), were most similar. Once specific dates have been chosen and a temporal window (the range of dates satisfying the user's criteria) has been identified, acquisition of satellite imagery proceeds normally.

Because of the potential bias introduced with the use of anniversary date synchronized satellite imagery, Pheno-Calc software was used to identify a temporal window where phenology was effectively the same between 1987 and 1997. To describe the phenology of our study area historical weather data was acquired for Aberdeen and Rexburg, Idaho (42.95°N 112.83°W and 43.83°N 111.79°W respectively) and Afton, Wyoming (42.75°N 110.96°W). These sites were chosen because the data was readily available in digital format and because the location of the sites best approximated the centroid of the Landsat scenes used in this study.

The temporal window based on GDD was 24 June - 8 July while the temporal window based on precipitation was 29 April - 27 July. Once the temporal window was defined we began to search for available Landsat thematic mapper data for our study area (http://edc.usgs.gov/webglis/). Ideally, all scenes for a given year would have been acquired on the same day, however this is not possible as a study area of this size (requiring 9 scenes over 3 paths) cannot be acquired on one day by Landsat thematic mapper. In addition, cloud contamination was a major impediment to the acquisition of satellite imagery.

The imagery selected for this research was recorded on dates that were within the previously identified temporal window but did not yield the perfect phenological matches. Most of the acquired imagery contained little to no cloud cover. However, some portions of the imagery were obscured by cloud cover requiring ancillary data sets (e.g., digitized cloud perimeters) to remove the cloud-contaminated areas from the imagery.

Testing relative accuracy of band-width ratio 5:3:4 : The 5:3:4 band ratio was determined by a Principle Components Analysis using IDRISI software. To test the relative accuracy of the 5:3:4 band ratio against NDVI (4:3), we compared imagery with a known area of change: the 1988 Yellowstone National Park fire. Using heads-up digitizing we removed cloud contamination from the fire scar imagery before change analysis was performed. We then used LUCCAS (Land Use and Cover Change Analysis System) software to predict areas of vegetation gain and loss (Fig 2). We employed ARCView and an error matrix to determine which ratio recognized the most change in the known areas of change. The 5:3:4 ratio was found to be better at recognizing vegetation cover change so it was used for analysis (Fig. 3).

LUCCAS Analysis and ground-truthing: After phenological synchronization and band ratio were established, nine satellite scenes from 1987 and 1998 were used for analysis. After all areas of cloud contamination were removed, the images were analyzed by LUCCAS. We used image differencing techniques to analyze the imagery. The resulting data contained pixels with one of four classifications by LUCCAS: vegetation gain, vegetation loss, no change in vegetation cover, and no data. These data were converted to a vector coverage using ArcInfo and a 1.25 ha. Minimum mapping unit was applied.

IDRISI software was employed to perform an unsupervised classification of vegetation types in the 1987 imagery. IDRISI separated vegetation types into nine different categories. This coverage was imported into ARCView where 150 sets of randomly located points were generated. The sets of points were generated under the following parameters: 1. Each set of points fell into the same 1987 vegetation type. 2. One of the points in a pair fell in a no change polygon with the other in a vegetation gain or loss polygon in the 1997-1998 imagery. 3. Points must be < 70m from a source of possible edge effect (roads) and no greater than 500m from a road. 4. Points must be on public land.

Sample points were ground-truthed from June-August 2000. Each point was reached using hand-held GPS navigation. Once at a point, a Trimble Pro-XR GPS was used to record the location. These points were then differentially corrected using Pathfinder Office software and base stations from Idaho State University's GIS Training and Research Center. At each location, a 40m base line was run north from the sample point. At 10m increments (0,10, and 20m along the base line), three 25m transects were run east off the base transect. Ground cover was recorded along each of these transects at 1cm resolution. Cover was classified as bare, rock, litter, herbaceous, graminiod, woody, or deadfall. If species of plant could be determined, it was noted. An ocular ranking of species was then performed by walking within and around the line transects and locating every possible species of plant in the area. We ranked each species by its relative abundance from 1-4 where a rank of 1 indicated the species was rare in the area and a rank of 4 meant that the species was the dominant species in the community.

Forage quality and biomass was determined using AUM (Animal Unit Months). We tossed a $0.25m^2$loop arbitrarily at each 10m increment along the baseline. We then clipped and weighed the forage found within the perimeter of the hoop. These weights were entered into AUM Analyzer (developed by the Montana State University Extension Service) to calculate AUM values. Lastly, an ocular estimate of community type was made using Idaho GAP code assignments. This was done to verify GAP vegetation classifications in our AOC. Cover data gathered from the field was compiled and we determined percent cover for classification types at all points.

RESULTS: A total of 24 sets (n = 48) of points were sampled in 2000. A difference threshold of 5% change between points in a pair was used for creating error matrices (Weber 2001). LUCCAS estimated a change where as little as 1% change in cover occurred, but due to small sample size and a large amounts of variability (environmental heterogeneity) we decided to be conservative when assigning an arbitrary threshold. No statistical differences were found in the *total* vegetative cover of points designated as "no change" versus those designated as "change" (*t*-test; $t = -0.738$, df = 22, p = 0.468). However, the error matrices suggest that LUCCAS is accurately detecting changes in grass and woody cover. We expected differences in the percentage of bare ground between pairs of points to be most indicative of LUCCAS accuracy but this was not the case. Percent bare ground had a lower producer's accuracy (54.17%) than percent grass (79.17%) or percent woody species (83.33%) (Table 1).

DISCUSSION: The 2000 field season failed to yield as many sample points as we had hoped. Our small sample size hindered our ability to analyze the data in a rigorous fashion. However, there are some interesting trends revealed by the error matrices. An error matrix illustrates the amount of agreement between observed and expected values. In our case, the most telling metric was "producer's accuracy". This compares what was predicted by image analysis and what ground truthing confirmed to actually be present. In essence, producer's accuracy tells us how often LUCCAS was correct in predicting vegetation change. All matrices were calculated using a 5% threshold.

The percent grass and woody species most closely agreed with LUCCAS change prediction. LUCCAS may be more sensitive to the spectral responses of these cover types than to bare ground, herbaceous species, or litter cover. This may be because the dominant cover in nearly every point was either woody (coniferous trees *Chrysothamnus*, and *Artemisia* species) or grass (*Poa*, *Stipa*, *Agropyron*, and *Bromus* species). The hope was that the spectral response of bare ground would be weighed more than changes in biomass but this does not seem to be the case. It appears that LUCCAS is weighing losses and gains in grass and woody species rather than losses and gains in soils. Intuitively, one would equate the loss of biomass with a gain in exposed soil. However, there may be replacement of one type of vegetation with another type or with litter and deadfall. Whether or not LUCCAS can discern the difference between these scenarios will require multiple subsets of vegetative cover measurement at each point to account for environmental heterogeneity and a larger overall sample size to increase statistical power. We intend to perform these analyses during the 2002 field season. We will also be obtaining 2000 imagery to compare with our 1997 imagery. In this way we can begin to explore rate of change. We will also be able to compare imagery from two ground-truthed years. This will allow us to minimize potential error introduced by the unsupervised classification performed by IDRISI and we will be able to assess LUCCAS accuracy with a greater degree of confidence.

ACKNOWLEGEMENTS

This study was part of the Integrated Environmental Analysis research alliance project funded jointly by Idaho State University and the U.S. Department of Energy, Assistant Secretary for Environmental Management, under DOE Idaho Operations Office Contract DE-AC07-99ID13727. I would also like to acknowledge the assistance and support of Dr Richard Inouye and Robert Breckenridge.

LITERATURE CITED

French N. and R. H. Sauer. 1974. Phenological Studies and Modeling in Grasslands. pages 227-236 in Lieth, H. (ed.) Phenology and Seasonality Modeling. Springer-Verlag, New York, NY, 444pp.

Lillesand, T. M. and R. W. Kiefer. 2000. Remote sensing and image interpretation. 4th ed. John Wiley and Sons, New York, NY, 724pp.

Lunetta, R.S., R.G. Congalton, L.K. Fenstermaker, J.R. Jensen, K.C. McGwire, and L. R. Tinney. Remote sensing and geographic information system data intergration: error sources and research issues. Photogrammetric Engineering and Remote Sensing, 57 (6), 677-687, 1991.

Price, K.P.,D.A. Pike, and L. Mendes. Shrub dieback in a semiarid ecosystem: The integration of remote sensing and geographic information systems for detecting vegetation change. Photogrammetric Engineering and Remote Sensing, 58 (4), 455-463, 1992.

Ram, B. and A.S. Kolarker. Remote sensing application in monitoring land-use changes in arid Rajasthan. Int. J. of remote Sensing, 13 (150, 2783-2799, 1992.

Rauzi, F., and A. K. Dubrenz. 1970. Seasonal variation of chlorophyl in western wheatgrass and blue gramma. J. Range. Manage. 23:372-373.

Verbyla, D.L., 1995. Satellite remote sensing of natural resources. CRC Lewis Publishers, New York, New York. 198pp.

Weber, K.T., 2001. A method to incorporate phenology into land cover change analysis. J. Range. Manage, (in press, March 2001)

Table 1a-f: Error matrices of the six cover variables measured during the 2000 field season.

a: WOOD		Observed			
		Change	**No Change**	**row totals**	**Producer Accuracy**
	Change	**20**	4	24	83.33
Expected	**No Change**	0	**24**	24	100
	Totals	20	28	48	
					Overall Agreement/Accuracy
	accuracy	100	85.71		**91.67**

b: GRASS		Observed			
		Change	**No Change**	**row totals**	**Producer Accuracy**
	Change	**19**	5	24	79.17
Expected	**No Change**	0	**24**	24	100
	totals	19	29	48	
					Overall Agreement/Accuracy
	accuracy	100	82.76		**89.58**

c: BARE		Observed			
		Change	**No Change**	**row totals**	**Producer Accuracy**
	Change	**13**	11	24	54.17
Expected	**No Change**	0	**24**	24	100
	column totals	13	35	48	
					Overall Agreement/Accuracy
	User Accuracy	100	68.57		**77.08**

d: LITTER		Observed			
		Change	**No Change**	**row totals**	**Producer Accuracy**
	Change	**12**	12	24	50.00
Expected	**No Change**	0	**24**	24	100
	totals	12	36	48	
					Overall Agreement/Accuracy
	accuracy	100	66.67		**75.00**

e: HERB		Observed			
		Change	**No Change**	**row totals**	**Producer Accuracy**
	Change	**11**	13	24	45.83
Expected	**No Change**	0	**24**	24	100
	totals	11	37	48	
					Overall Agreement/Accuracy
	accuracy	100	64.86		**72.92**

f: DEAD		Observed			
		Change	**No Change**	**row totals**	**Producer Accuracy**
	Change	**5**	19	24	20.83
Expected	**No Change**	0	**24**	24	100
	column totals	5	43	48	
					Overall Agreement/Accuracy
	User Accuracy	100	55.81		**60.42**

Figure 1: General map of our area of concern.

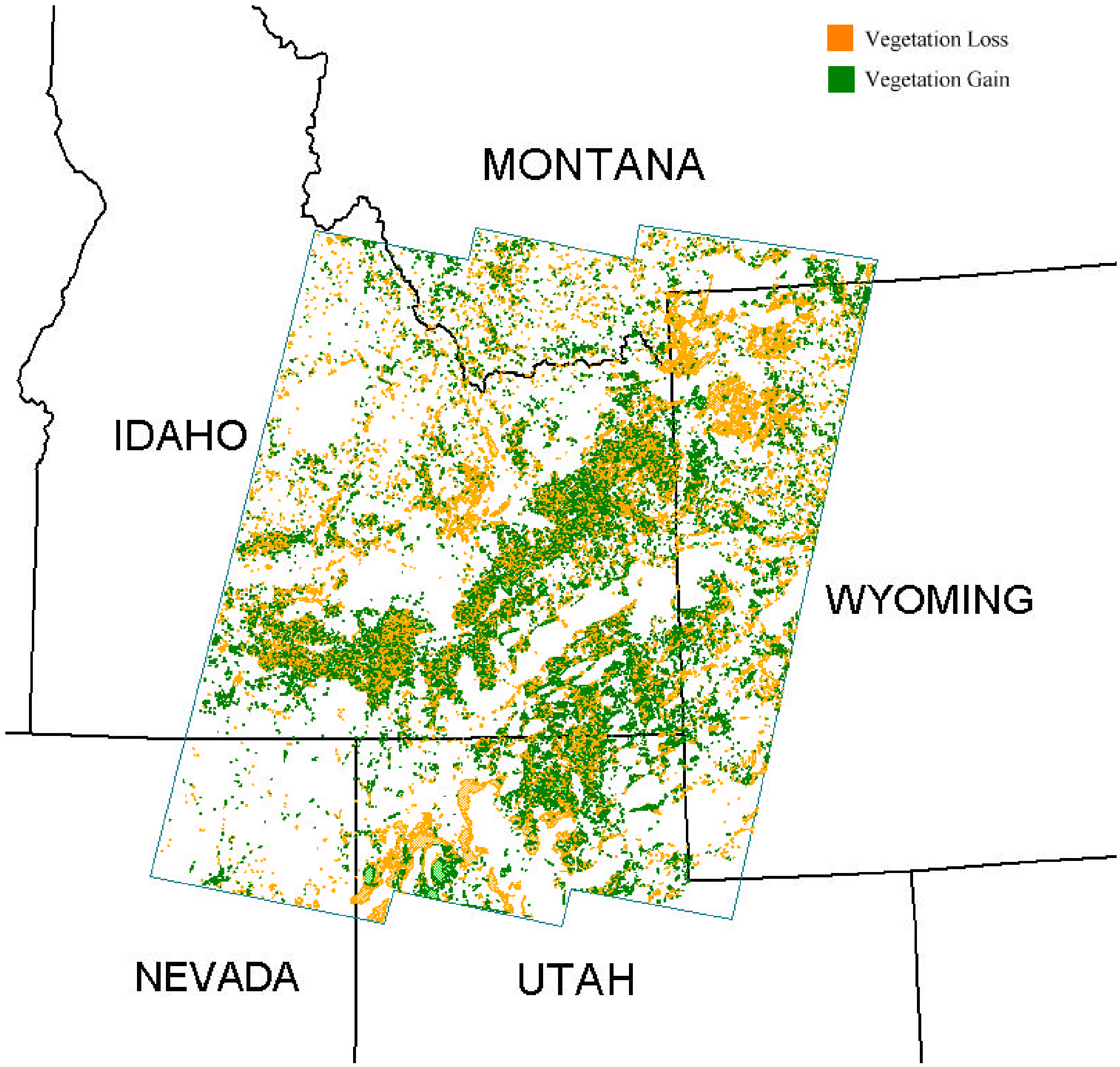

Figure 2: ArcView image of the predicted areas of vegetation loss and gain within the Area of concern (AOC).

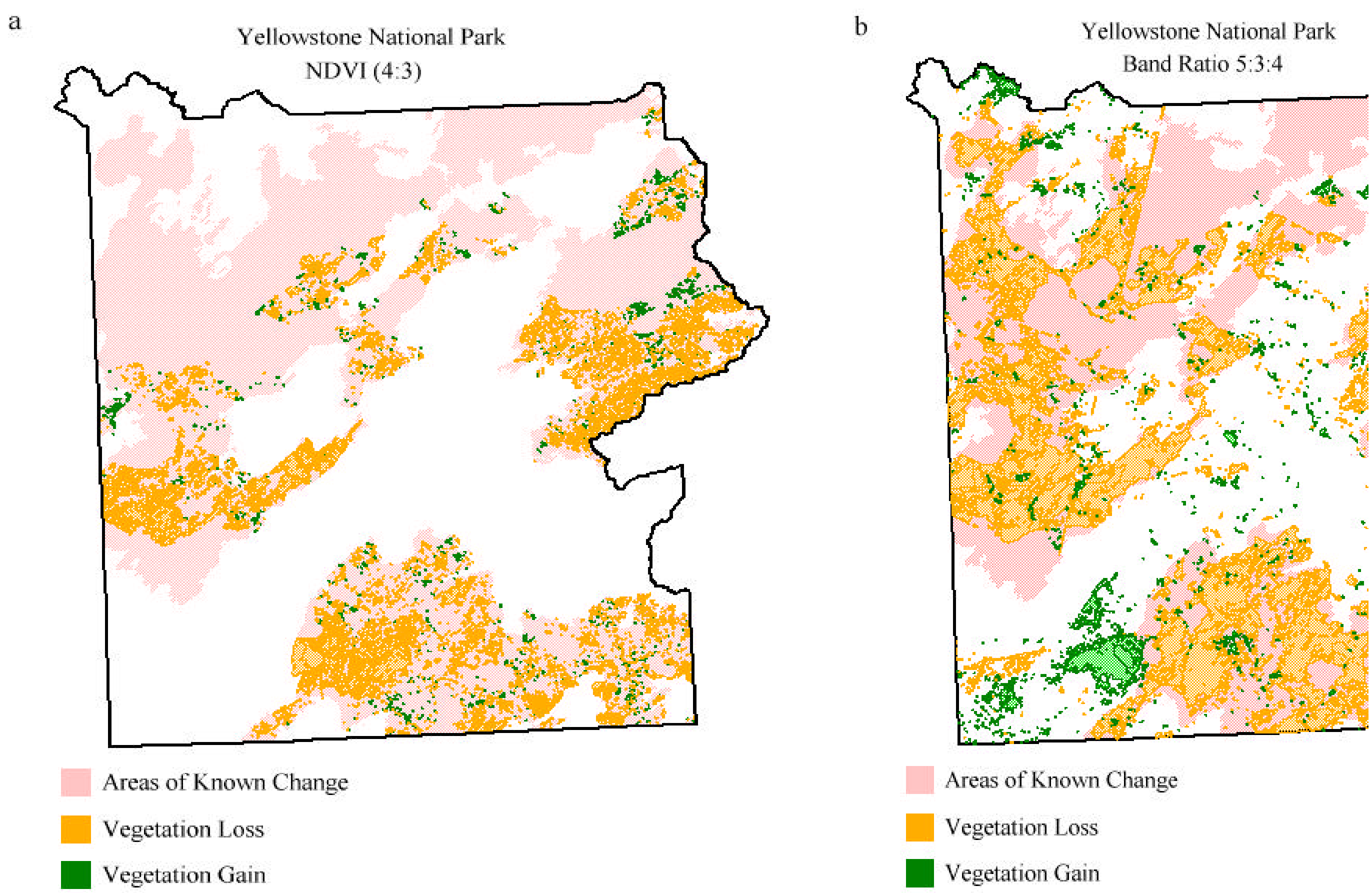

Figure 3: ArcView images of LUCCAS change predictions in a known area of change. a: Image using NDVI imagery using 5:3:4 ratio. Cloud contamination was removed from both images.