Measuring Forest Area Loss Over Time Using FIA Plots and Satellite Imagery

Michael L. Hoppus and Andrew J. Lister[1]

Abstract.—How accurately can FIA plots, scattered at 1 per 6,000 acres, identify often rare forest land loss, estimated at less than 1 percent per year in the Northeast? Here we explore this question mathematically, empirically, and by comparing FIA plot estimates of forest change with satellite image based maps of forest loss. The mathematical probability of exactly estimating a 5-percent loss within a 600,000-acre forest, where 5 percent has actually been converted, is 18 percent. A GIS experiment in Connecticut, using 452 FIA plots and a satellite-derived forest cover map, where 5 percent of the total forest area was "lost" by 7.5-acre units, indicates that the sample estimates a 5-percent loss 35 percent of the time with a range of estimated loss of 3 to 8 percent. Satellite image classification can probably estimate the amount of forests lost to urbanization more accurately, especially over small areas, while providing a more useful map of forest loss.

Forest Inventory and Analysis (FIA), a program of the USDA Forest Service, is responsible for the nationwide forest inventory and monitoring of the United States. Congress mandates, through the Forest and Rangeland Renewable Resources Planning Act of 1974 and the McSweeney-McNary Forest Research Act of 1928, that FIA continuously determine the extent, condition, and volume of timber, as well as the growth and depletion on the Nation's forest land. FIA inventories must meet specified sampling errors: a 3-percent error per 1 million acres of timberland is the maximum allowable for area. Timberland is a category of forest land that is producing or capable of producing 20 cubic feet of industrial wood per acre per year (Hansen *et al.* 1992). Timberland area is usually 80 percent or more of the total forest land of the States in the Northeast.

Users of FIA data in the Northeast increasingly are interested in how much forest land is being converted to other land uses, such as residential housing developments. A low rate of forest land loss per year can still amount to an ecologically significant area. An annual 0.3 percent loss of forest land in the Northeast would equal about 436 square miles, or 2,180 square miles of forest land in 5 years (1.5 percent). The question is whether the current FIA inventory program can identify small rates of forest loss when it occurs somewhat randomly over large areas.

Another source of survey information that the FIA program is evaluating is Landsat 7 satellite imagery. Imagery from two dates can provide a forest loss map. The maps have no sampling error but do have classification or mapping errors. The question is whether the accuracy of such maps is sufficient to determine how much forest is being lost.

Objectives

One objective of this study was to see if it is reasonable to reject the null hypothesis that the density of FIA plots (1 plot per 6,000 acres) does not permit accurate estimates of forest land loss, if the area of loss is only 1 to 5 percent of the total forest area. This hypothesis was evaluated both in terms of mathematical probability and by an empirical GIS evaluation of how actual FIA plots located on a real forest-cover map identify forest loss that was artificially induced at random with a computer.

Another objective was to evaluate the ability of Landsat satellite imagery to detect and map forest loss. Several change-detection methods were evaluated and the resulting change maps compared with the corresponding estimates of forest change made by the FIA ground plot survey. The ultimate goal of the investigators was to evaluate the ability of the FIA survey design to estimate the rare occurrence of forest loss compared to total forest cover in the Northeast, and to determine

[1] Research Forester and Forester, respectively, U.S. Department of Agriculture, Forest Service, Northeastern Research Station, Newtown Square, PA 19073. Phone: 610–557–4039; fax: 610–557–4250; e-mail: mhoppus@fs.fed.us.

how well satellite-derived change-detection maps could provide additional forest loss information.

Methods

Determining the Binomial Probabilities of Forest Loss Given the General FIA Sampling Design

To determine the likelihood that the FIA survey design identifies rare patches of forest loss, a binomial probability function was applied to 100 FIA ground plots within a 600,000-acre forest in which 5 percent of the forest area has been cleared at random in circular patches of 5 acres. For simplicity, we assume that each FIA ground plot consists of a 1-acre circle. (An actual plot consists of four 0.04-acre circular subplots distributed evenly within a 1-acre circle.) The 600,000-acre forest consists of 100 hexagons covering 6,000 acres each. Each hexagon contains one FIA ground plot.

The probability that a plot will hit a cleared patch exactly r times, P(r), is given by the binomial probability function:

P(r) = $$P(r) = \left(\frac{n!}{r!\,(n-r)!}\right)p^{r}\left(1-p\right)^{n-r}$$

where:

- p = the probability of a plot hitting a forest loss patch on a single trial
- n = the number trials
- r = the total number of times that plots hit any forest loss patch

A hit occurs when a plot center falls within any portion of the 5-acre circular patches of cleared forest. The numbers represented by p and n were computed by throwing 6,000 5-acre patches of "forest loss" at random into the 600,000-acre forest that contains 100 plots (1 plot per 6,000 acres).

The formula presented here is not precisely correct because it applies to sampling with replacement. It unrealistically allows two forest loss patches to be located on the same piece of ground. However, this formula still accurately approximates the probability that the total number of times a plot hits a forest loss patch equals r, since n, the number of trials, is small compared to the total number of trials possible (Huntsburger and Billingsley 1977). The formula that deals with sampling without replacement is difficult to use with large differences between p and (1-p)—hypergeometric probability is generally applied to much smaller problems.

GIS Experiment Using FIA Plot Locations in Connecticut and a Forest Cover Map of the State

A more empirical approach to determining how well the FIA plots estimate forest loss was used to experiment with various levels of loss in a more realistic setting. Using GIS software, we combined the actual FIA plot locations with a forest/nonforest map produced from the U.S. Geological Survey Multi-Resolution Landscape Characterization (MRLC) vegetation cover map for Connecticut derived from a classified 1993 Landsat TM satellite image. Connecticut had about 1,825,700 acres of forest land (59 percent) out of a total land area of 3,117,800 acres (Brooks *et al.* 1993). Plots located in forested areas, according to the MRLC map, totaled 300 out of 452. Five levels of forest loss were applied to the forest area of the map: 1, 2, 3, 4, and 5 percent. Each level of loss was applied at random in multiples of 7.5-acre units. For example, a 1 percent loss in forest land in Connecticut (18,257 acres) required 2,434 unit areas of loss at 7.5 acres each. Random selection of forest loss was repeated 250 times, and the number of forested plots changing to nonforest counted for each percentage level of loss. A histogram of the 250 counts of the number of plots hitting an area of forest loss was plotted for each of the loss levels. In this experiment, a hit occurred when the center of a previously forested plot fell on any portion of an area of forest loss. If the plots can capture low rates of loss, the expected value (mean), or highest frequency in the histogram (mode), should be equal to the percent loss applied to the forested map area.

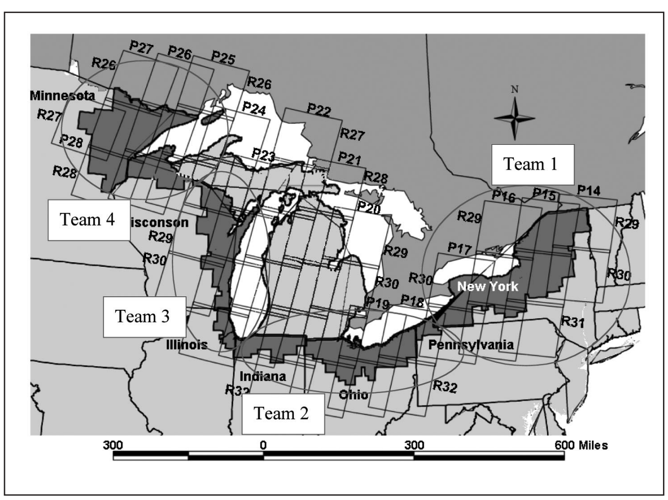
A Comparison Between Change (Loss) Detection Maps Produced from Landsat TM Satellite Imagery and Estimates of Forest Change Provided by the FIA Survey Reports

Change detection maps derived from two Landsat satellite images, taken 5 to 6 years apart, were evaluated for their ability to estimate forest land area that had changed to other land cover types. If accurate, these maps also could show where this change is taking place and the size class distribution of the change. First, a change map of a large portion (64 percent) of

New York State was evaluated. This map, commissioned by the National Oceanic & Atmospheric Administration (NOAA) was produced by Earth Satellite Corp. (Earthsat). The NOAA Coastal Change Analysis Program (C-CAP) is a national effort to develop and distribute regional land cover and change analysis data for the coastal zone (including the Great Lakes) by using remote sensing technology. C-CAP classifies land cover types into 22 standardized classes that include forested areas, urban areas, and wetlands (fig. 1). For New York, the changes between two dates of satellite imagery, 1995 and 2000, are based on how these 22 classes of land cover are converted from to another over the 5-year interval. There are five classes of forest land: Deciduous, Evergreen, Mixed, Palustrine Forested Wetland, and Estuarine Forested Wetland. In the C-CAP classification scheme, these forest classes can change to: High Intensity Developed, Low Intensity Developed, Cultivated, Grassland, Shrub Land, Shrub Wetland, Emergent Wetland, Shore Land, Bare Land, Water, Tundra, and Palustrine Aquatic Bed, as well as snow, clouds, and image background.

The image processing technique employed by Earthsat starts by classifying the two scenes using a combination of unsupervised and supervised methods. Unsupervised classification was used to create a signature file for 233 classes. The signature file was then run through a maximum likelihood supervised classification process. For a general description of

Figure 1.—*Landsat images used for NOAA's Great Lakes Coastal Change Map (outlined square image footprints) and the area extent of the Change Map (dark gray). Note that two-thirds of New York was mapped. (Reproduced with permission from NOAA and Earthsat, Corp.)*



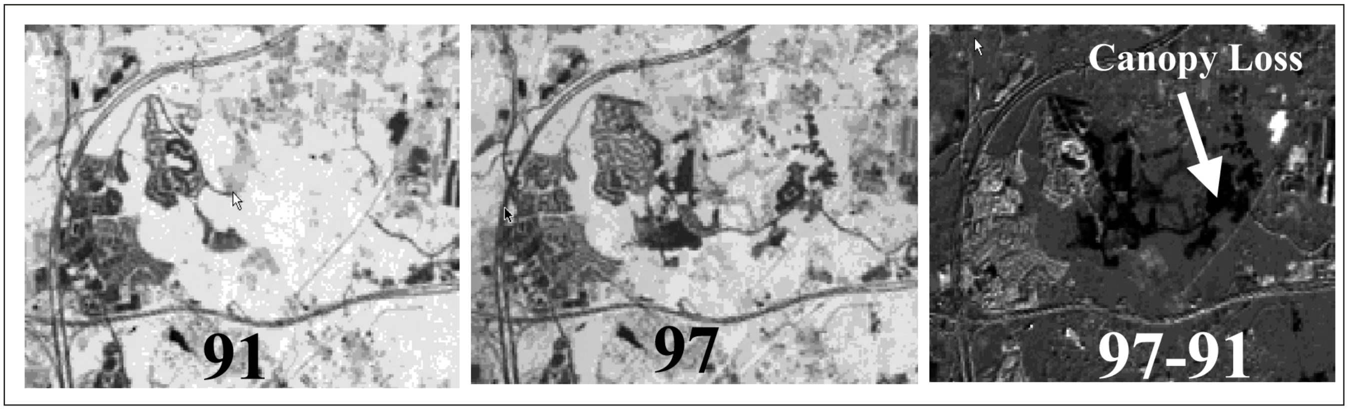
these classification methods, see Jensen (1996). The resulting clusters were labeled using the Earthsat-developed addition to ERDAS Imagine 8.5 image processing software, called Geotools, which uses field and aerial photo-derived estimates. A change map was then constructed by using an Earthsat change detection technique called Cross Correlation Analysis (CCA). This analysis technique uses the labeled cluster file of the early-date image combined with the late-date multispectral image and statistically analyzes it against the labeled cluster file of the late-date image with the early-date multispectral image. Each pixel is ultimately placed into a change category (including "no change") based on the CCA process. More details on the method are located in the map metadata found in the C-CAP citation. The advantage is that it performs well regardless of seasonal differences because it uses former class boundaries summarized with new class signatures to determine the relationship between pixel brightness values and a feature class. In fact, direct pixel value comparison between the different scenes is not required (NOAA 2002).

The percentage area of forest land lost to urbanization and other land cover based on the NOAA change map was compared to the FIA estimates of percentage forest land change from 1980 to 1993 in the three New York FIA survey units that are wholly contained within the NOAA mapped area.

A change detection map based on the difference between pixel brightness values between two dates of Landsat imagery was also evaluated. For two counties in New Jersey, Monmouth and Ocean, change maps were produced using 1991 and 1997 Landsat images. Three different change layers were used to construct the map: a red band subtraction layer; a Normalized Difference Vegetation Index (NDVI) subtraction layer; and a layer consisting of the fourth principal component of a principal component analysis of the "brightness" and "greenness" layers of the *Tasseled Cap* transformation of both images. Again, for a detailed discussion of these bands, the NDVI, and band transformations, see Jensen (1996). In each of these layers, the pixel brightness values are highly correlated with a gain or loss of green biomass.

When the red spectral layer of the 1991 image is subtracted from the 1997 image, a high (bright) pixel value indicates a loss of forest canopy if the pixel area was forested in 1991. Green biomass is dark in the red band due to photosynthetic

Figure 2.—*Urban development has removed forest cover between 1991 and 1997, as shown in these portions of NDVI scenes from the two dates. When the brightness values of the 1991 scene are subtracted from those of the 1997 scene, a forest canopy loss map is produced.*



light absorption. Similarly, when the 1991 NDVI is subtracted from the 1997 NDVI, a low (dark) pixel value indicates a loss of forest canopy. Green biomass has a high NDVI pixel value. A *Tasseled Cap* transformation produced a "brightness" band that is negatively correlated with forest canopies and a "greenness" band that is positively correlated with forest canopies for each of the images. Principal component analysis was applied to the four input layers to condense them into one biomass loss layer (Gessler *et al.* 1998). For each of the change images, a change map was constructed by selecting a pixel brightness threshold where forest canopy loss was on one side or the other. Threshold selection was based on aerial photo interpretation of areas where the forest canopy was completely removed (fig. 2).

Each of the change maps was very sensitive to even slight changes in the brightness value selected for the threshold. Furthermore, even though the maps were similar, the total number of pixels classified as "forest canopy loss" varied as much as 20 percent. So, a final forest canopy loss map was constructed by combining the three input maps. A pixel classified as "forested" in the USGS-MRLC map in 1991 and classified as "forest canopy loss" on all three change maps for New Jersey was required for a pixel to be labeled "forest canopy loss" in the final map.

Results

Binomial Probabilities

In our mathematical evaluation of how well FIA plots can estimate small amounts of forest loss equal to 5 percent of the total area, we found that the probability of a plot hitting an area of change exactly 5 times is 18 percent. In other words, 100 plots, distributed randomly at one 1-acre plot per 6,000 acres, will correctly estimate 5 percent loss of forest cover about one-fifth of the time. Only 1 percent of the time will no change of forest cover be detected at all; however, 50 percent of the time the estimate of forest loss will differ from that estimated by more that 1 percentage point, or by 9 square miles or more (fig. 3).

Figure 3.—*The probability that exactly a given number of plots will fall on change, if 5 percent of the area has changed and there are 100 plots. Note there is a relatively high probability (18 percent) the plots will estimate the exact area of change.*

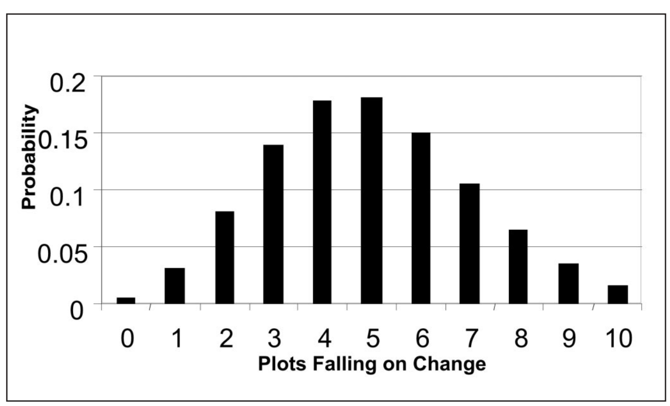
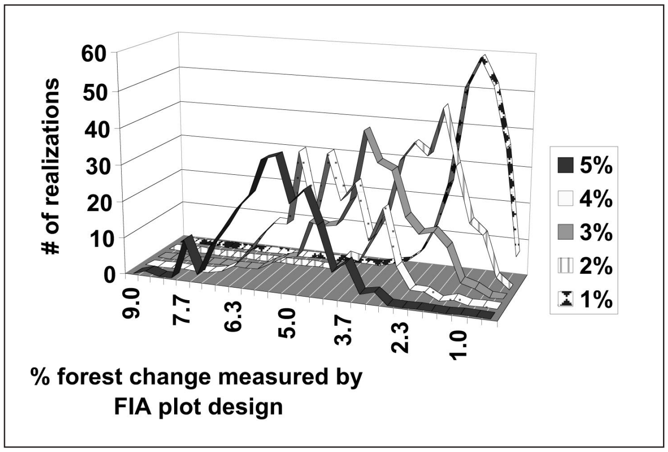


Figure 4.—*Histograms of 250 realizations each for a 1% through 5% GIS removal of the mapped forest cover of Connecticut (removed, at random, in unit areas of 7.5 acres). For each actual amount of forest removed, the frequency of realizations for each forest change percentage estimated by 300 forested plots is shown.*



GIS Experiment Using FIA Plot Locations in Connecticut and a Forest Cover Map of the State

In our GIS experiment, we found that the expected values of estimates of forest change are equal to the modes of the frequency distribution of 250 realizations for each actual percentage forest cover removed. Remember that a "realization" is the estimate of forest cover loss provided by 300 forested plots in Connecticut after a selected per-centage forest area is removed in multiples of 7.5-acre units. The range of estimates for each of the actual percentage removals was nearly identical to what the 99 percent confidence interval would be for a sample size of 300 and a fraction observed of 1 percent, 2 percent,...,5 percent forest cover loss (based on table 1.4.1 "Confidence intervals for binomial distribution" of Snedecor and Cochran (1967)) (fig. 4). Keep in mind that a 1 percent error in estimating change is equal to 29 square miles of forest land in the state of Connecticut. Before we leave the results of plot-based estimates of forest loss, consider that as the number of plots decrease, the ability to estimate small change is diminished. In a county like New Haven, CT, with 180,000 acres of forest land, a 1-percent loss would not be detected 75 percent of the time due to the low number (30) of forested plots.

Comparison of the NOAA/Earthsat Change Map with FIA Estimates

A summary of the forested Landsat pixels that changed in the 5-year period from 1995 to 2000 according to the NOAA/Earthsat change map of New York indicates that out of 15,817 square miles of forest, 251 square miles (1.5 percent) were lost to other land cover types. The average size of change was 1 acre with a range of 1/4 acre to 8,000 acres. Most of the change ranged from 1 to 38 acres. It is difficult to compare these results with forest change based on FIA plot data because the last periodic FIA survey of New York by the Forest Service was in 1993. The three northern FIA survey units in New York are contained within the NOAA mapped area and cover 67 percent of the acreage. Between 1980 and 1993 this area had a net increase of 143,000 acres of forest land, for a gain of 1.8 percent or 210 square miles (Alerich and Drake 1995).

In both the satellite-based estimate and FIA plot-based estimate, the map error and sampling error, respectively, are about the same magnitude as the change. The error matrix provided with the NOAA/Earthsat map estimates that the classification accuracy of forest land on the year 2000 map is 95 percent (96 percent correct omission error and 95 percent correct commission error) based on 750 ground truth plots, of which 200 plots were on forest land. This is a high level of accuracy not often exceeded in Landsat image based maps. Even though the forest loss estimate is smaller than the map error rate for forest land, experience shows that certain types of change should be accurately depicted, such as forest land to residential housing, commercial, and industrial areas. The NOAA map indicates that 16 square miles (0.01 percent) were lost to urbanization. Furthermore, the map shows the location and size of likely forest-loss patches.

Comparison of Forest Change Estimation: FIA Plots vs. Landsat Pixel Algebra Maps

Our forest loss map, based on an algebraic comparison of pixel brightness values of two Landsat scenes, shows a forest canopy loss of 3,547 acres in Monmouth County, New Jersey, between 1991 and 1997. The corresponding FIA estimate shows a net loss of 7,000 acres out of 90,300 acres of forest land from 1987 to 1999 (Griffith and Widmann 2001). If the rate of forest loss was evenly distributed over each of the 12 years, these two estimates are in close agreement. Based on aerial photo comparison and the complete classification redundancy of the combined three image inputs to the satellite map, it is highly likely that the estimates of "loss of forest canopy" are accurate even though accuracy was not formally assessed. This method of classification does not necessarily allow a final estimate of how much forest land is converted to other land cover types because the area of lost forest canopy may regenerate back into a closed canopy forest, as it might after fire or harvesting.

In adjacent Ocean County, New Jersey, the Landsat map estimated a forest canopy loss of 2,047 acres (1991–1997). FIA estimates a 42,000-acre gain (1987–1999), up from a forested area of 204,000 acres in 1987. Since FIA reports only net forest change, the 2,047 acres of possible forest loss would be difficult to detect. Furthermore, the FIA estimate has a sampling error of about 8 percent, so sampling error alone would not allow for accurate detection of a 2,000-acre loss of forest land.

Conclusions

The authors reject the hypothesis that the density of FIA plots, 1 plot per 6,000 acres, does not permit accurate estimates of forest land loss if the area lost is low—1 to 5 percent of the total forest area. This rejection, however, requires that the number of plots is reasonably large, which in the FIA survey program also means a reasonably large survey area. It does seem paradoxical that a sample that covers only 0.017 percent of the area can detect and accurately estimate a small amount of change, but one of the properties of statistics is that it only requires there be a large absolute number of plots, not a large sample relative to the population. However, in small counties that have few plots, accurate estimates of forest loss are not possible. This also limits the ability of FIA plots to provide useful information on the spatial distribution of forest loss.

So, accurate FIA plot-based state estimates of forest loss are possible, even if the percentage loss is low. Of course, if the estimate is only of net forest change, the important measurement of forest loss is not likely to be obtained. In sufficiently large areas, such as at the State level, the FIA program could add forest area loss to its list of reported estimates. Landsat-derived forest change maps can provide both quantitative and spatial information on how, where, and why forest land is lost. Map error and the inability of moderate resolution imagery to classify seedling/sapling covered forest areas will continue to degrade the accurate interpretation of these forest cover maps. However, satellite imagery can be an efficient tool for small and large area forest assessments, especially in those frequently found cases in the East where forest land is lost to urbanization, roads and freeways, and reservoirs.

The NOAA/Earthsat change map seems to be a high-quality map asset for analyzing landscape changes. State and Federal land management agencies may wish to consider using it to provide large area land cover change information. The authors find, as many have before, that Landsat can be used quickly, simply, and robustly to detect forest area loss.

The USDA Forest Service Forest Inventory and Analysis program will continue to explore the use of remote sensing to augment the ability to determine the extent, condition, and trends of forest land.

Acknowledgments

The authors wish to thank Greg Koeln, Eleanore Meredith, Dave Cunningham, and Francois Smith of Earthsat Corp. and Mark Finkbeiner of NOAA for providing the NOAA/Earthsat change maps of New York and helping us evaluate their contents.

Literature Cited

Alerich, C.; Drake, D. 1995. Forest statistics for New York: 1980 and 1993. Resour. Bull. NE-132. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 249 p.

Brooks, R.; Kitteredge, D.; Alerich, C. 1993. Forest resources of southern New England. Resour. Bull. NE-127. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 71 p.

Gessler, P.; Grey, D.; Hoppus, M. 1998. Change detection using remotely-sensed data: a USDA Forest Service training course manual. Salt Lake City, UT: U.S. Department of Agriculture, Forest Service, Remote Sensing Applications Center. 50 p.

Griffith, D.; Widmann, R. 2001. Forest statistics for New Jersey: 1987 and 1999. Resour. Bull. NE-152. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 70 p.

Hansen, M.; Frieswyk, T.; Glover, J.; Kelly, J. 1992. The east-wide forest inventory data base: users manual. Gen. Tech. Rep. NC-151. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station. 48 p.

Huntsburger, David; Billingsley, Patrick. 1977. Elements of statistical inference. Boston, MA: Allyn and Bacon, Inc. 385 p.

Jensen, J.R. 1996. Introductory digital image processing. Upper Saddle River, NJ: Prentice Hall. 318 p.

NOAA Coastal Services Center/Coastal Change Analysis Program (C-CAP). 2002. C-CAP Great Lakes 1995-2000 land cover metadata. Charleston, SC: NOAA Coastal Change Analysis Program (C-CAP). Available at: http://www.csc.noaa.gov.

Snedecor, George W.; Cochran, William G. 1967. Statistical methods. 6th ed. Ames, IA: Iowa State University Press.