science for a changing world

2006 GIO/Center of Excellence in Geographic Information Systems

A Landscape Indicator Approach to the Identification and Articulation of the Consequences of Land-Cover Change in the Mid-Atlantic Region, 1973–2001

By E. Terrence Slonecker, Lesley E. Milheim, and Peter R. Claggett

Open-File Report 2009-1187

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
KEN SALAZAR, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

U.S. Geological Survey, Reston, Virginia: 2009

For product and ordering information:
World Wide Web: http://www.usgs.gov/pubprod
Telephone: 1-888-ASK-USGS

For more information on the USGS—the Federal source for science about the Earth, its natural and living resources, natural hazards, and the environment:
World Wide Web: http://www.usgs.gov
Telephone: 1-888-ASK-USGS

Suggested citation:
Slonecker, E.Terrence, Milheim, Lesley E., and Claggett, Peter R., 2009, A landscape indicator approach to the identification and articulation of the consequences of land cover change in the Mid-Atlantic region, 1973-2001: U.S. Geological Survey Open-File Report 2009-1187, 41 p. [http://pubs.usgs.gov/of/2009/1187/].

Contents

Figures

Tables

A Landscape Indicator Approach to the Identification and Articulation of the Consequences of Land-Cover Change in the Mid-Atlantic Region, 1973–2001

By E. Terrence Slonecker, Lesley E. Milheim, and Peter R. Claggett

Abstract

Landscape indicators, derived from land-use and land-cover data, hydrology, nitrate deposition, and elevation data, were used by Jones and others (2001a) to calculate the ecological consequences of land-cover change. Nitrate loading and physical bird habitat were modeled from 1973 and 1992 land-cover and other spatial data for the Mid-Atlantic region. Utilizing the same methods, this study extends the analysis another decade with the use of the 2001 National Land Cover Dataset. Land-cover statistics and trends are calculated for three time periods: 1973–1992, 1992–2001 and 1973–2001. In addition, high-resolution aerial photographs (1 meter or better ground-sample distance) were acquired and analyzed for thirteen pairs of adjacent USGS 7.5 minute quadrangle maps in areas where distinct positive or negative changes to nitrogen loading and bird habitat were previously calculated.

During the entire 30 year period, the data show that there was extensive loss of agriculture and forest area and a major increase in urban land-cover classes. However, the majority of the conversion of other classes to urban occurred during the 1992–2001 period. During the 1973–1992 period, there was only moderate increase in urban area, while there was an inverse relationship between agricultural change and forest change. In general, forest gain and agricultural loss was found in areas of improving landscape indicators, and forest loss and agricultural gain was found to occur in areas of declining indicators related to habitat and nitrogen loadings, which was generally confirmed by the aerial photographic analysis.

In terms of the specific model results, bird habitat, which is mainly related to the extent of forest cover, declined overall with forest extent, but was also affected more in the decline of habitat quality. Nitrate loading, which is mainly related to agricultural land cover actually improved from 1992–2001, and in the overall study, mainly due to the conversion of agriculture to forests and urban.

The high-resolution imagery analysis was significant in that it confirmed, at a very local level, the specific land-cover changes that were driving the landscape metrics and model results that were calculated from moderate resolution land-cover data and models. These were generally subtle changes in patch size of agriculture, forest, and urban areas, but had substantial effects on bird habitat and nitrogen loadings. This analysis of high-resolution imagery demonstrates and confirms the important ability of moderate-resolution land-cover data to capture significant landscape-level activity that is directly related to specific metrics of ecological significance. It also

demonstrates consistent landscape-scale relationships between data derived from high-resolution, moderate-resolution and landscape-model sources.

Finally, many of the areas of improvement and decline in bird habitat and nitrogen loadings appear to be potentially regional in nature and likely reflect some local trend in landscape activity. Although the use of ecoregions as sampling units has been criticized in recent years, these results show that basic changes in Level 1 land-cover categories, such as forest and agriculture, may still reflect ecoregional patterns and considerations at some scale of mapping and analysis. This is a potentially important area for future landscape-indicator research. This and other follow-on research opportunities are discussed.

Introduction

The advancement of geographic science in the area of land-surface status and trends and land- cover change is at the core of the U.S. Geological Survey (USGS) current geographic scientific-research agenda (McMahon and others, 2005). The dynamics of change on the earth's surface, and its causes, consequences and drivers, relate to several strategic goals of the Geographic Analysis and Monitoring (GAM) Program (GAM, 2006), the Geographic Information Office (GIO) (Siderelis and others, 2005), the Geographic Discipline (McMahon and others, 2005), the USGS (2000) and the Department of Interior strategic goals (USDOI, 2006).

Of the successful scientific development of land-cover related activities, such as the North American Landscape Characterization (NALC) program, the Multi-Resolution Land Cover Consortium (MRLC) , the National Land Cover Data (NLCD) programs (Vogelman and others, 2001; Homer and others, 2004), the development of the CART-based Land Cover mapping tools (Yang and others, 2003a), and the land-cover change (Yang and others, 2003b) and land-cover trends (Loveland and others, 2001) programs, perhaps the least developed or articulated aspect of USGS land-cover research has been in the identification and analysis of the consequences of land-cover change.

Research has shown clear evidence that changes in land use and land cover have significant impacts on a variety of environmental, ecological, economic, and social conditions and processes (O'Neal and others, 1997; Loveland and others, 2001). Land-cover change affects the pattern and process and form and functioning of ecosystems, including their ability to provide essential ecological goods and services, which in turn affect the economic, public health, and social benefits that these ecosystems provide (Turner, 1989). The consequences of change are both direct and indirect and are manifested at a range of spatial and temporal scales (Foley and others, 2005). One of the great scientific challenges ahead of modern science is to understand and calibrate the effects of land-use and land-cover change and the complex interaction between human and biotic systems at a variety of natural, geographic, and political scales. Improving understanding and knowledge of the consequences of land-use and land-cover change is an important goal of the science strategy for geographic land-use and land-cover change research and the USGS mission (McMahon and others, 2005).

Understanding the dynamics of land-cover and land-use change requires an increased understanding of the complex nature of human-environmental systems and will require a suite of scientific tools that include traditional geographic data and analysis methods, such as remote sensing and geographic information systems (GIS), as well as new and innovative approaches to understanding the dynamics of complex systems (Gallant and others, 2004). One such approach that has gained much recent scientific attention is the landscape-indicator, or landscape-assessment approach that has been developed with the emergence of the science of Landscape Ecology (Golley, 1987).

The Landscape-Indicator Approach

Because of the increasing need to monitor ecosystem health and the traditionally high costs associated with field-based monitoring, alternatives to and adaptations of the traditional monitoring approach have been developed using moderate-resolution remotely sensed data, standard geographic data, and derivative products (Turner, 1989). Termed the "landscape approach," this alternative applies a combination of concepts from landscape ecology, hydrology, and geography in conjunction with remotely sensed and other spatial data and GIS technology to the assessment landscape and ecological condition (O'Neill and others, 1997; Jones and others, 2000; Pitchford and others, 2000). The landscape approach relies on

- Geographic analysis of spatially explicit patterns of ecological characteristics (for example, riparian zones near streams) to interpret ecological conditions;
- Concepts from the field of landscape ecology, relating changes in landscape patterns to changes in ecological processes;
- Hierarchy theory that analyzes the consequences of landscape change on ecosystems at multiple scales;
- Spatially explicit digital data and maps of biophysical characteristics and human use to interpret landscape patterns relative to ecological conditions; and
- Inclusion of humans as part of the environment.

Implementing the landscape approach typically starts with the acquisition and/or development of a series of moderate resolution (~30 meter, 1:100,000 scale) base geographic data in a GIS format including

- Land use/land cover in raster format representing one or more time periods,
- Streams and hydrology in a vector format,
- Roads and transportation in a vector format,
- Normalized Difference Vegetation Index (NDVI) derived from satellite imagery,
- A digital elevation model,
- In place monitoring data from field sampling or a monitoring network, such as USGS stream gauges,
- Any other special GIS data layers targeted for a specific ecological condition.

Once the data are assembled, a variety of landscape extent and pattern metrics are calculated based on hypotheses about what metrics are most relevant to the ecological conditions under study. Landscape metrics include such measurements as average forest patch size, number of patches, patch contagion, and percentage of stream miles buffered by forests. The selected landscape metrics serve as a set of independent variables that are then related statistically to measurements of ecological conditions serving as the dependent variables (for example, Index of Biological Integrity, species diversity, in-stream nutrient concentration). These statistical tests are called landscape models. Statistically significant and explainable relationships between one or more landscape metrics and measurements of ecological condition become landscape indicators that can then be used to infer ecological condition in places where the condition has not been directly measured. All landscape indicators are based on landscape models, but not all models have the statistical strength and logic supporting them to serve as valid landscape indicators.

Consequences in the Mid-Atlantic region

The Mid-Atlantic region of the Eastern United States is defined by the land and near-coastal area that includes all of Standard Federal Region III and parts of regions II and IV. States completely covered are: Pennsylvania, Maryland, Delaware, Virginia, and West Virginia. Also included are parts of New Jersey, New York, and North Carolina (USEPA, 1997; Jones and others, 1997). In terms of consequences research, a key application of landscape indicators was performed by Jones and others (2001b). Land cover and land-cover change was calculated for the Mid-Atlantic region from NALC, MRLC, and NLCD datasets for the 1973–1992 time period. Typical landscape applications compute landscape metrics and indicators based on natural or administrative (for example, watershed or county) reporting units and attempt to explain variability in the dependent variable based on multiple regression. In this application, land-cover data were aggregated and resampled into 120-meter pixels, and land-cover statistics and metrics were computed on a per pixel basis throughout the study area. Using specific ecological models of bird habitat and nitrogen loading, the landscape-datasets were used to calculate changes in land cover, landscape metrics, and indicators and to statistically relate these to the bird habitat and nitrogen-loading model inputs. Results of the model outputs were calculated in spatially explicit 25 km2 grid cells (5 by 5 km) for the study area. Using spatial-analysis and statistical-clustering techniques, indicator values were developed for positive and negative changes for habitat and nitrogen individually and in combination. Figure 1 shows an example of the results of landscape evaluation of both bird-habitat quality and total nitrogen loading trends and shows positive and negative statistical relationships and their spatial pattern across the Mid-Atlantic region.

What is most interesting about this approach is that it reveals patterns and relationships that are not intuitive or readily apparent from our knowledge of the landscape phenomenology. In the example in figure 1, southern New York, western Pennsylvania and north-central West Virginia all show significant improvement in nitrogen loading, while south central Pennsylvania and north central Maryland show declines. There is no readily apparent reason for these patterns to appear.

For this research effort, we propose expanding on the work by Jones and others (2001a, 2001b) by (1) updating the analysis to cover the historical period from 1992 through 2001 by using the 2001 NLCD, and (2) acquiring high-resolution imagery (1 meter or better ground-sample distance) of areas in the target time periods to determine the detailed translation of land-use and land-cover change and potential causal factors that are the focus of any decision support scenario. Articulation of specific land-use changes is central to the understanding of overall consequences and to the likely paths of effective corrective action.

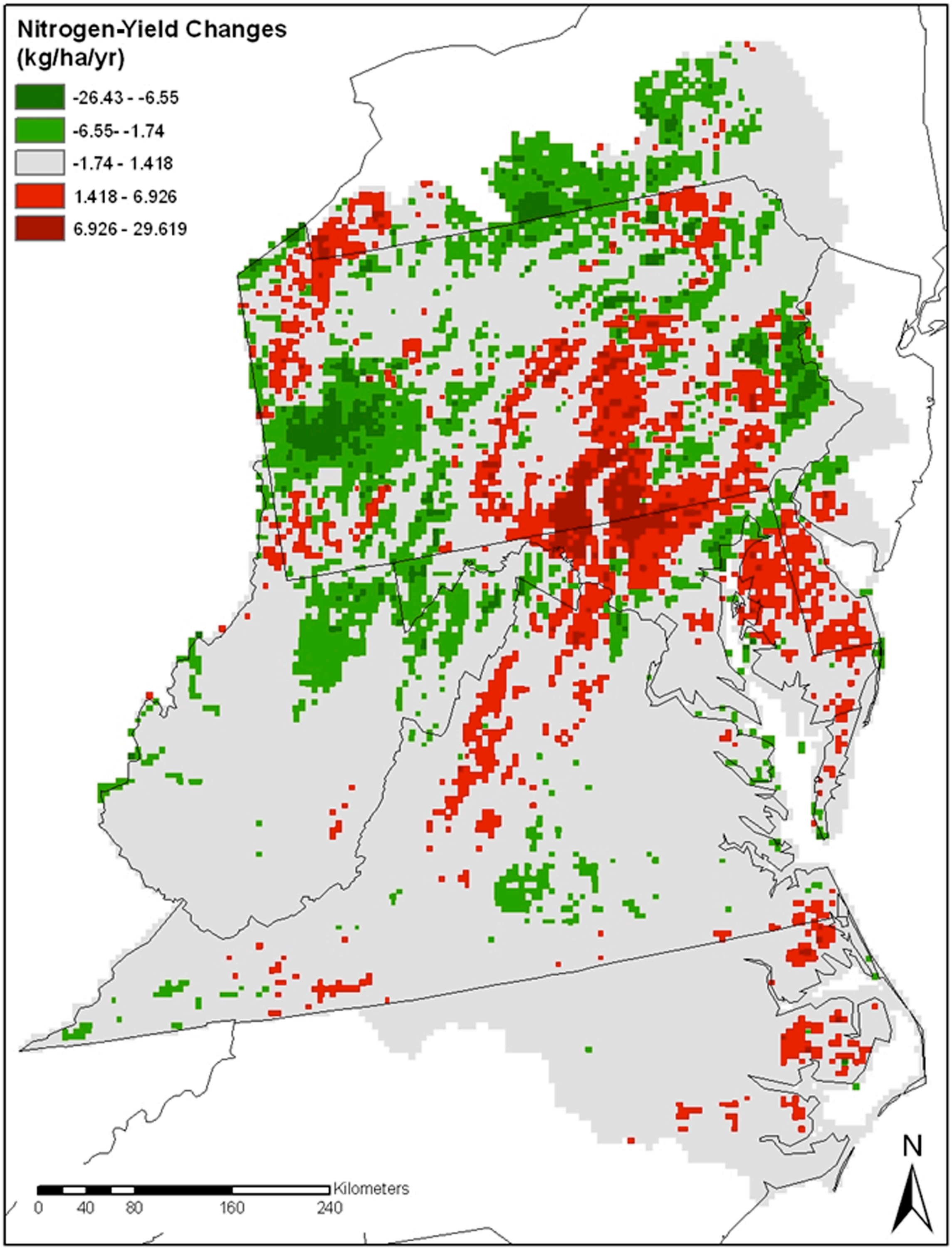

Figure 1. Spatial pattern of nitrogen yield changes across the Mid-Atlantic region from 1973–1993. Changes are depicted by 25-km2 grid cells and are in kilograms/hectare/year (kg/ha/yr). This represents a real and measureable consequence of land-cover change that has a direct effect on ecological health and environmental quality (Jones and others, 2001b).

Materials and Methods

The study examined the spatial concordance of landscape indicators in the Mid-Atlantic region of the United States consisting of southern New York, Pennsylvania, western New Jersey, Delaware, Maryland, West Virginia, Virginia, and northern North Carolina (fig.2). The landscape indicators examined were nitrogen load and bird-habitat quality, which were modeled from existing spatial data. Digital land-cover maps were acquired and processed to identify temporal changes in the indicators of bird habitat quality and temporal changes in total nitrogen load. The methodology used is comprised of three major steps (1) acquire and process land-cover data for three time periods, (2) run total nitrogen-load and bird-habitat-quality models using the land-cover data, and (3) compare the land-cover changes and the model outputs across time periods and themes (total nitrogen load and bird habitat).

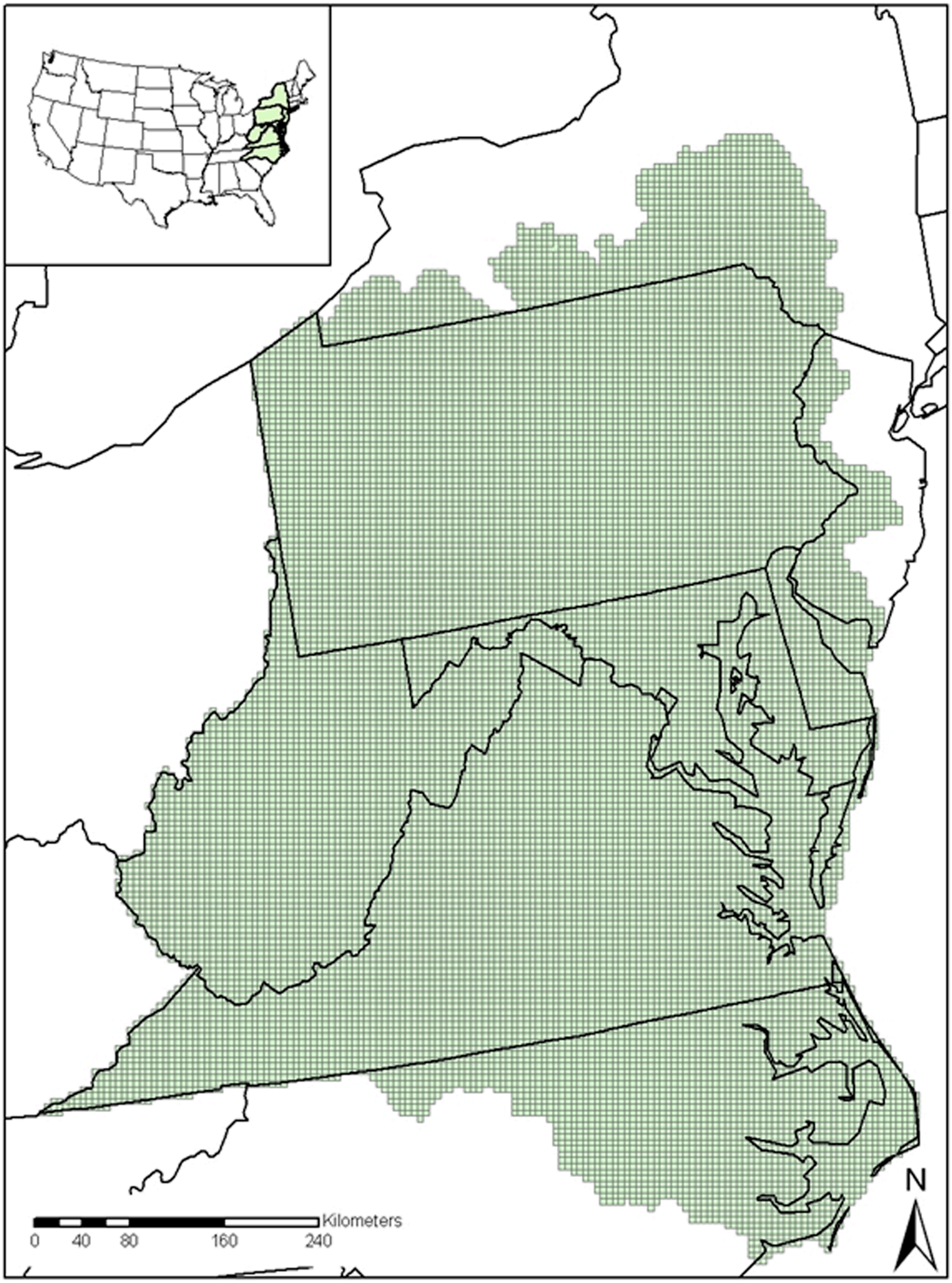

Figure 2. The Mid-Atlantic region study area encompassing Pennsylvania, Delaware, Maryland, Virginia, West Virginia, and portions of North Carolina, New Jersey, and New York.

Models

The study used a landscape computation program known as ATtILA (Analytical Tools Interface for Landscape Assessments) to calculate the metrics of land cover and two models to calculate the landscape indicators, one for nitrogen load and one for bird-habitat quality. ATtILA (http://www.epa.gov/nerlesd1/land-sci/attila/index.htm) is an extension to ArcView [developed by Environmental Systems Research Institute (ESRI)] used to calculate common landscape metrics across all types of landscapes at local, regional, and national scales.

The models used to calculate the landscape indicators were implemented using the model builder in ArcGIS for consistency of calculation over each land-cover dataset. The model for nitrogen load was taken from Jones and others (2001a)

$$\mathrm{Ln}(N) = 0.02114alc + 0.00175nd - 1.58487, \qquad (1)$$

where N is nitrogen yield (kg/ha/yr), alc is the percentage of agricultural land cover and nd is the nitrate deposition (kg/yr * 100).

The bird-habitat-quality model, used by Jones and others (2001b; adapted from O'Connell and others, 2000) is also repeated here. The model characterizes the relationship between bird community index scores and land cover. The model first classifies bird habitat into three strata: good, moderate, and poor, based on the percentage of forest cover. Areas with greater than 80 percent forest were classified as good; areas with less than 41 percent were classified as poor; while areas between 41 percent and 80 percent were classified as moderate. Areas classified as poor were further characterized by the percentage of urban or percentage of agricultural cover. Areas with greater than 33 percent urban land cover were classified as poor-urban, and areas with greater than 50 percent agriculture were classified as poor-agriculture. Poor areas that did not meet the poor-urban or poor-agriculture criteria were classified as poor-other. This application of the bird-habitat-quality model produces five classes: good, moderate, poor-urban, poor-agriculture, and poor-other.

Data

Four types of data are required for this study:

1. Polygons that define the areal units over which all calculation are performed. The areal units used for calculation were defined as a tessellation of 25-km^2 grid cells (5 by 5 km).
2. An atmospheric nitrate-deposition dataset for use in calculating nitrogen load. The atmospheric nitrate-deposition dataset was created as the mean of model-based estimate maps of wet nitrate deposition for 1987 and 1993 (http://www.epa.gov/emap/html/cdrom/index.html).
3. Land-cover datasets from which the land-cover percentages are calculated. Temporal land-cover datasets were acquired to represent the early 1970s, the early 1990s, and the early 2000s nominally referred to as NALC 1973, MRLC 1992, and NLCD 2001. The 1970s land-cover data were created from the Landsat MSS data acquired as part of the NALC program. The 1990s land-cover data were acquired from the MRLC program which created a national land-cover dataset using Landsat TM data. Jones and others (2001a) resampled the 1970s and 1990s datasets to 120-meter pixel resolution and classified the land-cover datasets into six land-cover classes. The land-cover classes are water; forest, including forested wetland; agriculture; emergent wetland; urban; and bare ground. Also, the urban areas of the 1970s and 1990s land-

cover datasets were calibrated so that urban areas of the former dataset were not lost in the latter due to changing tree density (Jones and others, 2001b). In accordance with the earlier process, NLCD 2001 was also acquired from the MRLC program, resampled to 120-meter resolution, reclassified to the six land-cover classes, and calibrated so that urban areas in earlier land-cover datasets were not lost.

4. An additional and final component of this research effort involves the analysis of high-resolution imagery of a sample of the key areas of landscape change. Land-use and land-cover change based on satellite imagery is computed from a variety of different methods and techniques that all depend on derivative analytical products, such as spectral-reflectance signatures, image texture, statistical clustering, and, as in this case, derived-landscape metrics. However, all are, to some extent, limited by the instantaneous field of view, or pixel size, of the satellite remote-sensing platform. In this case, the Landsat MSS and Landsat TM sensors have pixel sizes of 60 and 30 meters, respectively, and this effects the spatial and spectral parameters of land-use and land-cover change products derived from these systems. Further, there are a number of confounding factors, such as seasonal change in temperate vegetation, which can lead to errors in thematic-mapping categories. Even major land-use and land-cover mapping programs, such as the NLCD, that are derived with sophisticated algorithms and complex statistical probabilities, have an overall thematic-mapping accuracy rate of between 70-80 percent (Stehman and others, 2003).

Because of this, and because of the nature of landscape indicators in this type of analysis, an evaluation of the actual landscape change, or lack of it, as derived from high-resolution imagery, might be insightful for future utilization of landscape-indicator types of analytical techniques. To do this, we selected a series of test areas corresponding to the major positive and negative changes in the nitrogen-loading and bird-habitat results previously reported in Jones and others (2001a) and further extended earlier in this paper.

Figure 3 shows the target areas identified for high-resolution analysis based on the areas of change previously computed from landscape metrics. Specific areas were selected using USGS 7.5 minute quadrangle sheet pairs to facilitate historical imagery research. A search of government and commercial sources of historical imagery was conducted to identify appropriate imagery in the 1970, 1990, and 2000 time frames for each area. Generally a spatial resolution of 2 meters and a temporal envelope of plus or minus 2 years of the target date were sought. Table 1 lists the target area quadrangles and the dates and sources of imagery acquired. Analog imagery was scanned at a minimum of 15 microns and geo-registered to a Digital Ortho Quarter Quad (DOQQ) base for analysis in a GIS environment.

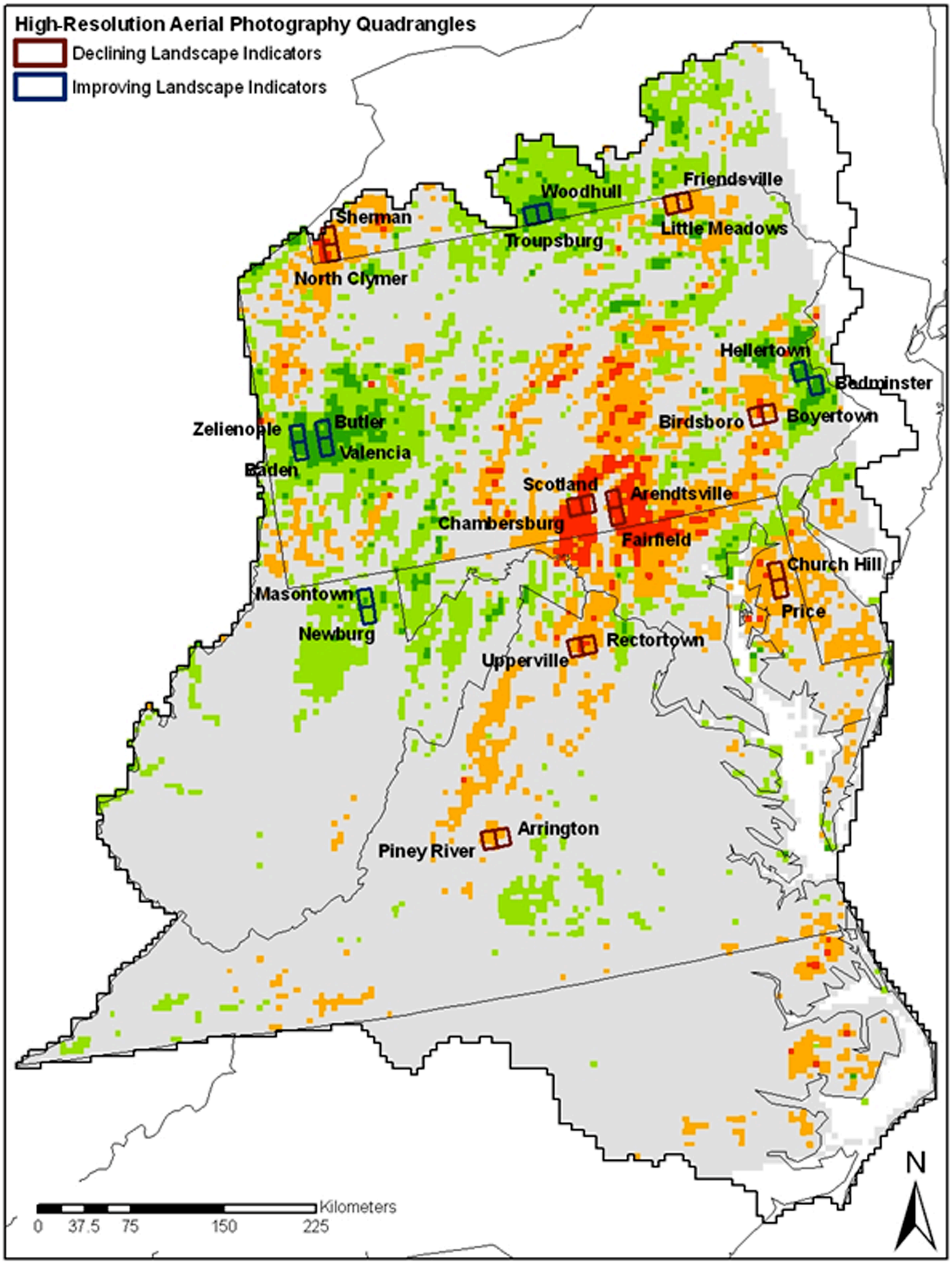

Figure 3. Areas selected for high-resolution imagery analysis. Quad pairs selected based on improving/declining landscape-indicator patterns for Jones and others (2001b).

Table 1. High-resolution imagery test areas. The dates and sources of all aerial photos used in the evaluation of Landsat-based land cover and land-cover change.

Test area	1970s image date	1970s image source	1970s image type	1990s image date	1990s image source	1990s image type	2000s image date	2000s image source	2000s image type
Arendtsville-Fairfield	Mar-71	USGS	BW	Apr-94	PA_DOQQ	BW	4-Jun	NAIP	CIR
Arrington-Piney River	Nov-68	USGS	BW	Apr-94	VA_DOQQ	CIR	3-May	NAIP	Color
Baden-Zelienople	Apr-72	USGS	BW	Apr-93	USGS	BW	4-Jun	NAIP	CIR
Bedminister-Hellertown	May-68	USGS	BW	Mar-92	USGS	BW	4-Jun	NAIP	CIR
Birdsboro-Boyertown	May-68	USGS	BW	Mar-92	USGS	BW	4-Jun	NAIP	CIR
Butler-Valencia	Apr-72	USGS	BW	Apr-92	USGS	BW	4-Jun	NAIP	CIR
Chambersburg-Scotland	May-68	USGS	BW	Apr-92	USGS	BW	4-Jun	NAIP	CIR
Church Hill-Price	Sep-70	USGS	CIR	Apr-92	USGS	CIR	5-Jun	NAIP	Color
Friendsville-Little_Meadows	Jan-73	USGS	BW	Apr-92	USGS	BW	4-Jun	NAIP	CIR
Newburg_Masontown	Apr-76	USGS	BW	Apr-93	USGS	BW	Apr-97	WV_DOQQ	CIR
North-Clymer_Sherman	May-71	Lockwood	BW	Apr-94	USGS	CIR	4-Apr	NY_DOQQ	Color

Processing

The study followed a similar protocol to that used by Jones and others (2001b). Land-cover datasets were acquired, resampled, reclassified, and calibrated so that prior urban areas were not lost, for each of the three time periods. The ATtILA extension was then used to calculate the percentage of each of the six land-cover classes within each of the grid cells for each land-cover dataset. The nitrogen load and bird-habitat-quality models processed the land-cover percentages to estimate the nitrogen load and bird-habitat quality, respectively. Temporal differences in nitrogen load were calculated for 1973–1992, 1992–2001, and 1973–2001; temporal changes in bird-habitat quality were also calculated for these time periods. The temporal differences for each landscape indicator (nitrogen load and bird habitat) were compared to evaluate the spatial pattern of change and were compared across themes to determine the concordance of changes in both landscape indicators over time and space.

Historical imagery triplets were analyzed visually in a GIS environment. Each test area was manually analyzed for the predominant land-use pattern and compared to subsequent years of analysis for identification of the vectors and patterns of major change land-use types. Figure 4 shows an example of the imagery triplet of 1970s, 1990s, and 2000 imagery of the area of Zelienople, Pennsylvania.

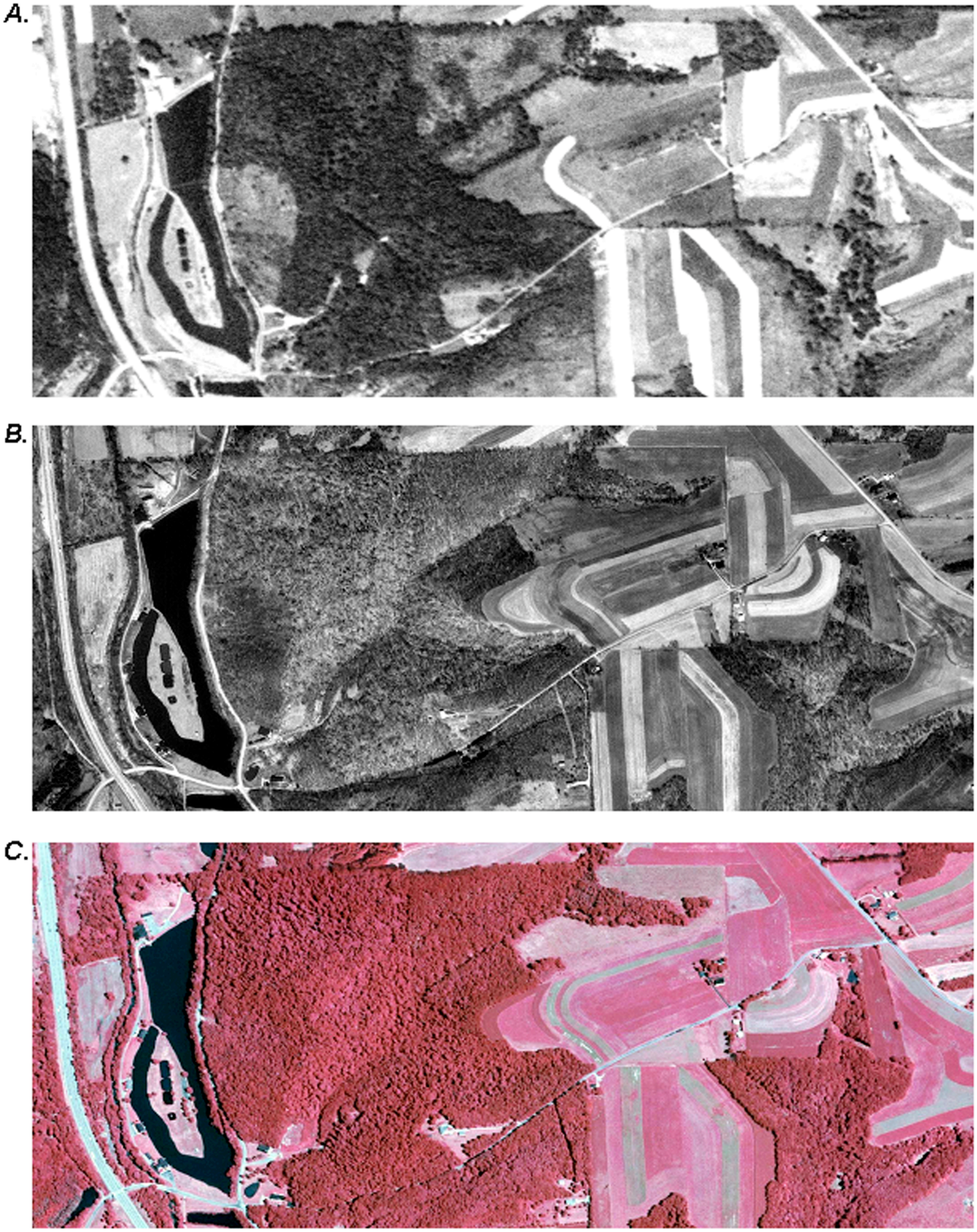

Figure 4. Example of a temporal imagery triplet. A portion of the study area near Zelienople, Pennsylvania, demonstrating land-cover change through time. A, 1972; B, 1993; and C, 2004. Photo scale is approximately 1:13,800.

Results

Changes in Land Cover and Landscape Metrics

Landscape Change

For all three study dates, the Mid-Atlantic region is largely agriculture and forest (table 1), but urban land use increases from approximately 3.5 percent in 1973 to 4.8 percent in 1992 and 9.8 percent in 2001. Table 1 presents the total area for each land cover class and change in land cover for each of the three time periods (1973–1992, 1992–2002, and 1973–2001) examined. The land-cover classes most affected are forest, agriculture and urban. For the nineteen year period between 1973 and 1992, there were small losses of agricultural land to water, forest, barren and urban. In the nine year period between 1992 and 2001, there was a large increase in the rate of change in forest, agriculture and urban land cover. The urban growth rate grew eight-fold from 0.069 percent per year in the 1973–1992 time period to 0.55 percent per year in the 1992–2001 time period. Regionally, the urban growth from agriculture was twice that from forest.

Table 2. Temporal and areal summary of land-cover change by land-cover classification.

Land-cover class	Land-cover area, in km^2			Land-cover change, in km^2			Percent change		
	1973	1992	2001	1973–1992	1993–2001	1973–2001	1973–1992	1993–2001	1973–2001
Water	30,224	32,313	31,546	2,089	-767	1,322	0.48	-0.18	0.30
Forest	269,882	271,230	260,113	1,348	-11,117	-9,769	0.31	-2.55	-2.24
Agriculture	114,190	103,073	94,659	-11,117	-8,414	19,531	-2.55	-1.93	-4.48
Wetlands	4,339	3,878	4,093	-461	215	-246	-0.11	0.05	-0.06
Barren	1,698	4,110	2,470	2,412	-1,640	772	0.55	-0.38	0.18
Urban	15,478	21,206	42,929	5,728	21,723	27,451	1.31	4.98	6.30

The maps in figures 5 and 6 show detailed land cover for 1973, 1992, and 2001 in metropolitan Washington, D.C., and southeastern metropolitan Pittsburgh, Pennsylvania, areas. These examples highlight the changing land cover between forest, agriculture, and urban areas.

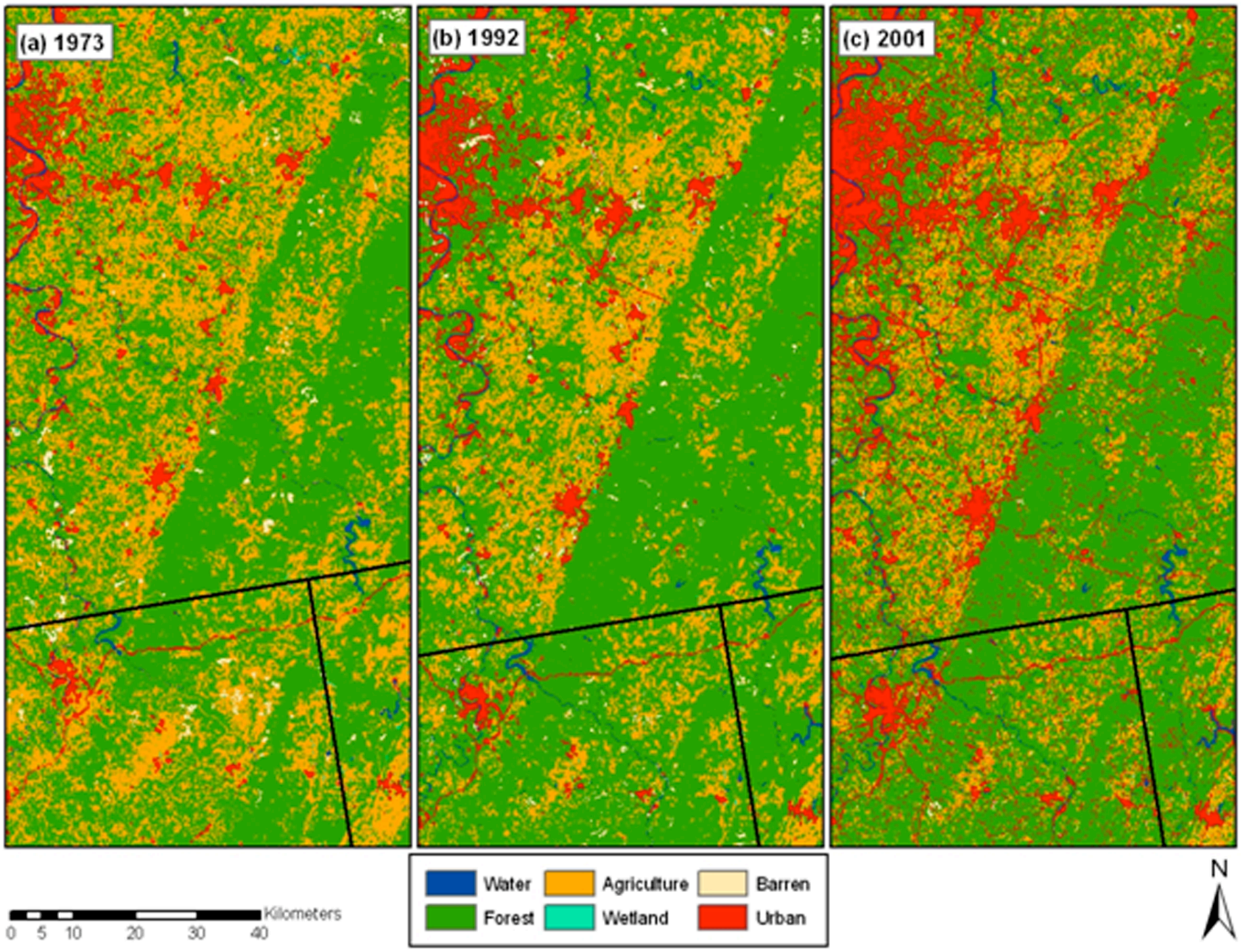

Figure 5. Spatial distributions of areas of land cover for the southeastern metropolitan Pittsburgh, Pennsylvania, area A, 1973; B, 1992; and C, 2001.

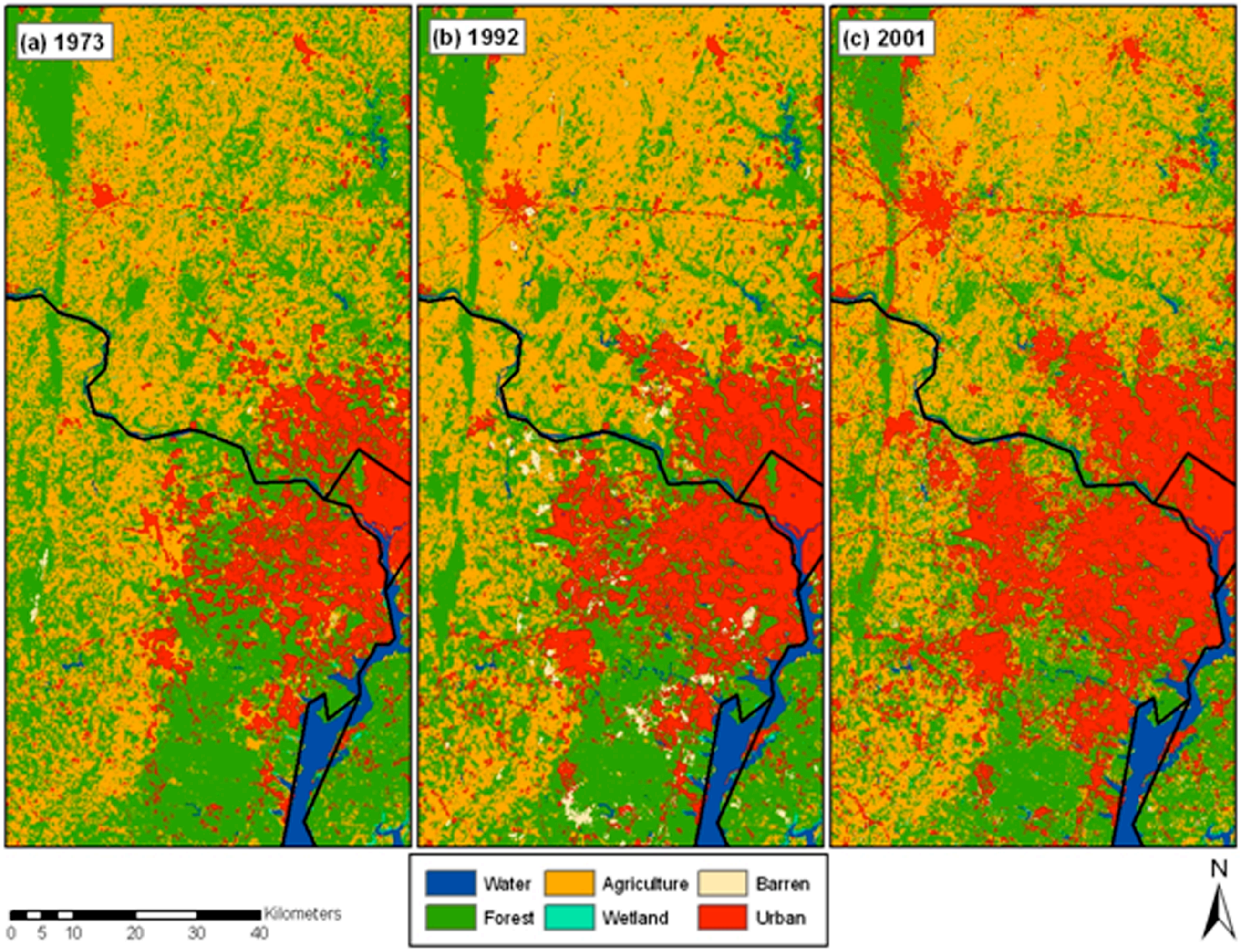

Figure 6. Spatial distributions of areas of land cover for the metropolitan Washington, D.C., area A, 1973; B, 1992; and C, 2001.

Overall land-cover change in the Mid-Atlantic region between 1972 and 2001 is extensive (fig. 7), affecting approximately 28 percent of the landscape (table 3). Land-cover change is dispersed throughout the region with greater concentration along the coastal areas of Delaware, Maryland, Virginia, and North Carolina, western New Jersey, central New York, and southeastern and western Pennsylvania and lesser concentration in the Appalachian highlands of central Pennsylvania, western Virginia, and West Virginia.

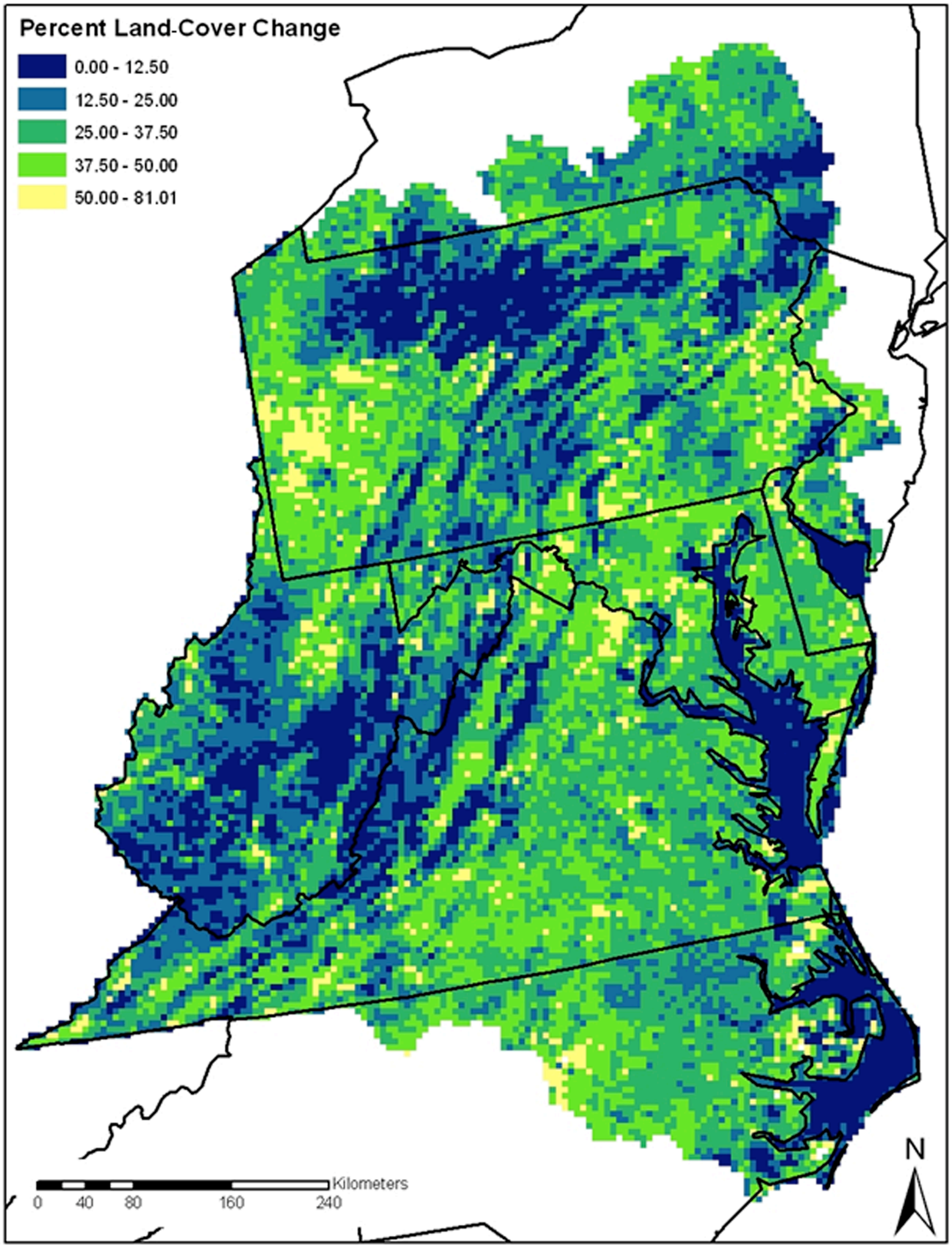

Figure 7. Spatial distribution of land-cover change in the Mid-Atlantic region 1973–2001**.**

Table 3. Temporal and areal summary of land-cover change by land-cover classification.

Time period of change	Area of change, in km²	Percent change
No change	312,686	71.75
1973–1992	47,637	10.93
1992–2001	46,386	10.64
1973–1992 and 1992–2001	29,103	6.68
Total	435,811	100.00

Bird-Habitat Change

Bird-habitat quality is based mainly on the availability of forest-land cover and, therefore, reflects the changing landscape to a degree. Forest-land cover declined by more than 2 percent between 1973 and 2001 (table 3). Analysis of bird-habitat quality (table 4) shows an overall reduction in good and moderate bird-habitat quality of approximately 2 and 1.5 percent, respectively, and an increase in poor-urban bird-habitat quality of 3 percent.

For clarity, only the direction of bird-habitat change was depicted spatially. Figure 8 shows the spatial improvements (green) and declines (black) in bird-habitat quality for 1973–1992, 1992–2001, and 1973–2001. The tan background identifies areas of minimal or no change. The 1973–1992 time period shows widespread areas of improving bird habitat in western Pennsylvania, northeastern West Virginia, and southeastern Virginia and decline in the developing Appalachian corridor and the Delmarva Peninsula.

The 1992–2001 time period shows general decline in bird habitat. The 1973–2001 time period shows widespread declines in bird-habitat quality in approximately half of the Mid-Atlantic region, with minimal bird-habitat improvements in western Pennsylvania.

Table 4. Bird-habitat quality for 1973, 1992, and 2001.

	Area, in km²			Change, in km² Annualized change (km2/yr)			Percent change Annualized percent change		
	1973	1993	2001	1973–1993	1993–2001	1973–2001	1973–1993	1993–2001	1973–2001
Good	137,608	151,040	129,313	13,432	-21,727	-8,295	3.21	-5.19	-1.98
				672	-2,716	-296	0.16	-0.65	-0.07
Moderate	209,066	189,489	202,973	-19,577	13,484	-6,093	-4.67	3.22	-1.45
				-979	1,685	-218	-0.23	0.40	-0.05
Poor - Urban	10,358	14,550	23,119	4,192	8,569	12,762	1.00	2.05	3.05
				210	1,071	456	0.05	0.26	0.11
Poor - Agriculture	44,141	46,732	41,062	2,591	-5,670	-3,079	0.62	-1.35	-0.73
				130	-709	-110	0.03	-0.17	-0.03
Poor - Other	15,737	15,099	20,442	-638	5,344	4,706	-0.15	1.28	1.12
				-32	668	168	-0.01	0.16	0.04

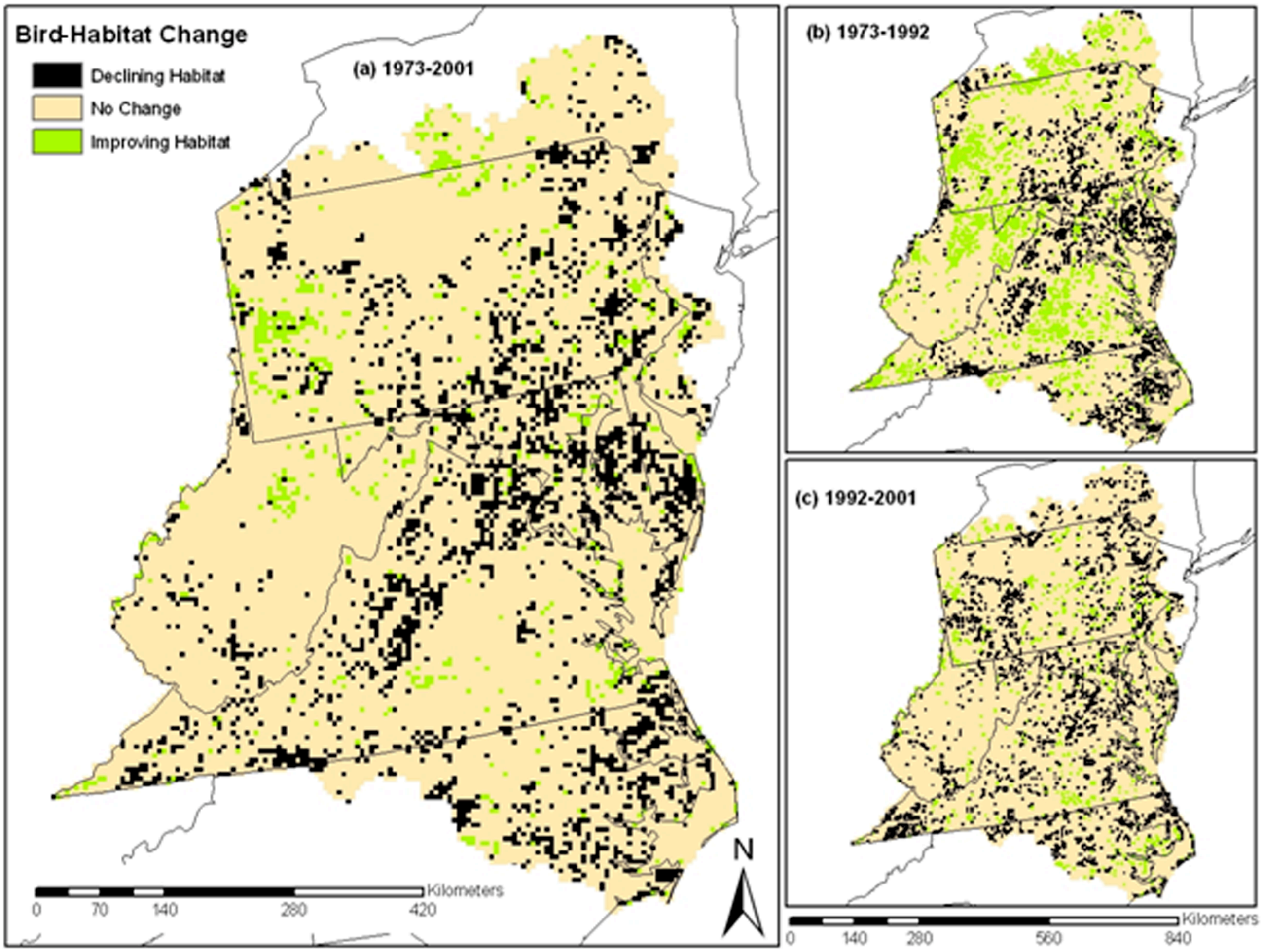

Figure 8. Bird-habitat condition A, 1973–1992; B, 1992–2001; and C, 1973–2001.

Nitrogen-Load Change

The study did not examine the effects of yearly atmospheric nitrate deposition on nitrogen loading, only the effects of land cover change, specifically the change in the amount of agriculture. Between 1973 and 2001 agricultural land cover declined by approximately 4.5 percent (table 2). During this same period, the regional analysis shows a small mean decrease (approximately -1 kg/ha/yr) in nitrogen loading, therefore, an improvement in this landscape indicator. Change in nitrogen load condition is shown in figure 9 as widespread improvement in southwestern Pennsylvania into northern West Virginia, southern New York into central and eastern Pennsylvania and south-central Virginia and smaller areas of decline along the southeastern Pennsylvania-Maryland border, the Delmarva Peninsula, and two small areas along the northeastern and northwestern Pennsylvania-New York border. The area showing a reduction in nitrogen load is more than twice that of the area with increasing nitrogen load, which is consistent with the reduction in agricultural land cover.

Despite the overall consistency between the reduction in agriculture and in nitrogen load, spatial patterns of improving and declining nitrogen-load conditions vary considerably over time. Large areas of improving nitrogen-load conditions occur in western Pennsylvania, northern West Virginia, and southern New York, and declining nitrogen load conditions occur in northwestern Pennsylvania, southeastern Pennsylvania into the Appalachian corridor, eastern North Carolina, and the Delmarva Peninsula between 1973 and 1992. During 1992–2001 there are small areas of declining nitrogen-load conditions in northeastern, central, and eastern Pennsylvania and the Delmarva Peninsula, and a scattering of declining nitrogen-load conditions in northern and southwestern Virginia. The declining nitrogen-load conditions of 1973–1992 largely appear to change to improving conditions in 1992–2001.

This latter change, especially along the Pennsylvania-Maryland border and central Maryland, appears to contradict widely accepted estimates of approximately 173,000 acres of agricultural loss in Maryland between 1982 and 1997 (USDA, 1992). These dates fall within each of the study's time period and may cause some confusion in interpreting our results. We investigated other potential sources for this conflict and found that (1) these results are consistent with the land-cover datasets, (2) the atmospheric wet nitrate deposition is greater in the northern Mid-Atlantic region and strongly influences the pattern of nitrogen loading, (3) the number of grid cells showing agricultural losses were comparable between the two time periods, whereas the number of grid cells showing agricultural gains in 1973–1992 mostly contained gains of 1-km^2 or greater, while those in 1992–2001 mostly contained gains of less than 1-km^2, and (4) these smaller changes of the 1992–2001 time period are missed by the map-classification scheme. Of these sources of conflicts, the amount of atmospheric wet nitrate deposition strongly influences the pattern of improvement and decline in nitrogen loading.

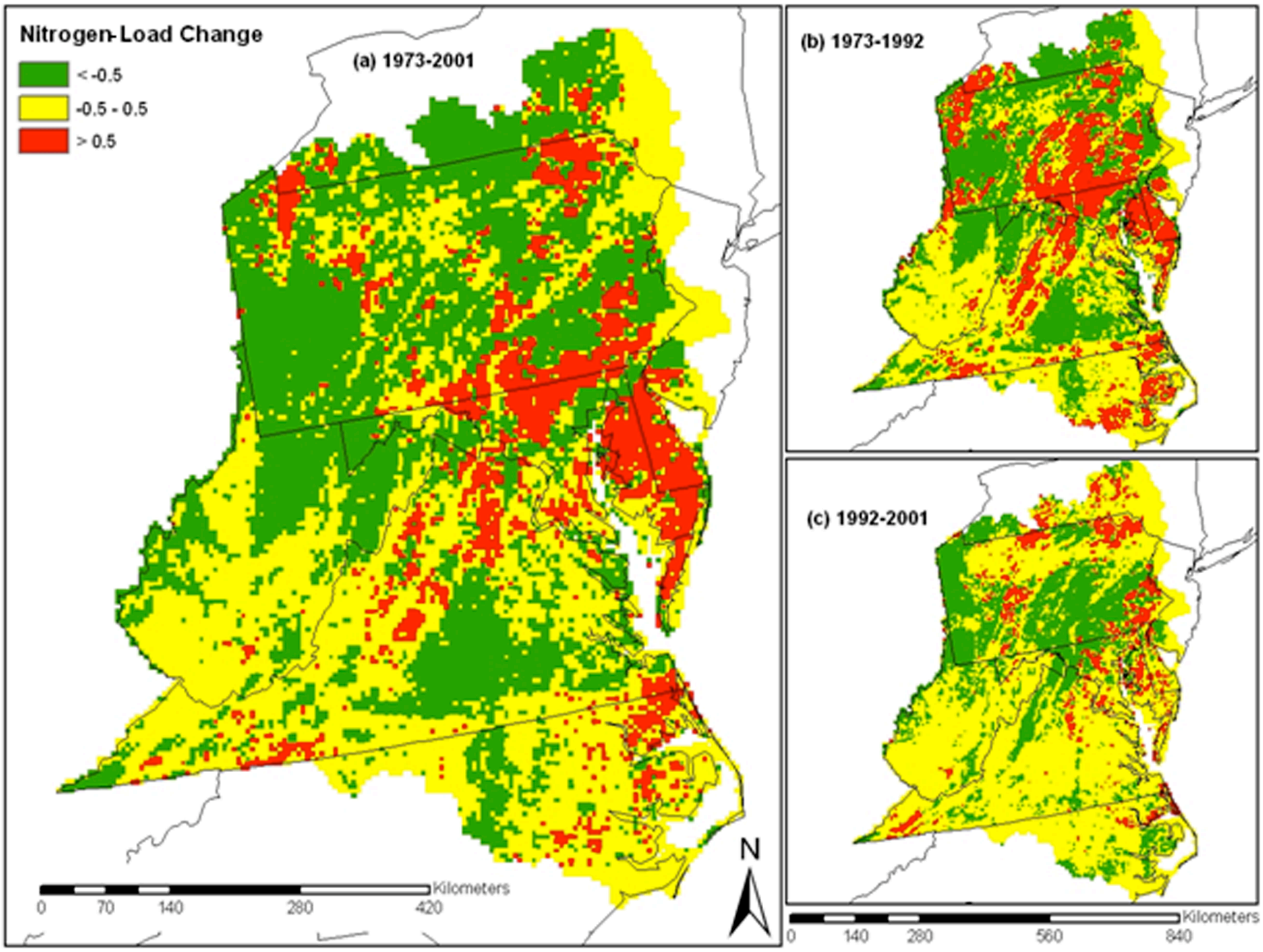

Figure 9. Nitrogen-load condition for A, 1973–1992; B, 1992–2001; and C, 1973–2001.

Spatial Concordance of Nitrogen Loads and Bird-Habitat Quality

Spatial analysis of the model results revealed areas of coincident improvement or decline in bird-habitat quality and nitrogen loading to streams. Table 5 summarizes the total area of improvement or decline in both landscape indicators. In 1973–1992 more area showed evidence of improvement than decline for both models, while in 1992–2001 more area declined than improved, although there was less change overall for this shorter time period. During the 1973–2001 time period, the area subject to improvement and decline was similar, although spatially differentiated.

Table 5. Summary of concordant landscape-indicator improvement or decline in the Mid-Atlantic region, 1973–2001.

	1973–1992		1992–2001		1973–2001	
	Area (km^2)	Percent	Area (km^2)	Percent	Area (km^2)	Percent
Improving indicators	46,850	11.24	13,600	3.26	37,600	9.02
Declining indicators	32,850	7.88	26,625	6.39	36,450	8.74
Mixed indicators or no change	337,175	80.88	376,650	90.35	342,825	82.24
Total	416,875	100.00	416,875	100.00	416,875	100.00

Figure 10 shows the spatial distribution of concordant improving or declining landscape patterns and figure 11 shows both the concordant and nonconcordant areas of bird-habitat quality and nitrogen loadings. In the 1973–1992 time period, there were three large clusters of improving bird habitat and declining nitrogen load in south-central New York into north-central Pennsylvania, western Pennsylvania into northern West Virginia, and south-central Virginia. This time period also identifies many smaller areas of improving landscape indicators throughout the Mid-Atlantic region. Between 1992 and 2001, the areas of joint improvement or decline were mostly dispersed through the region with modest clusters of decline in west-central Pennsylvania, and southwestern and eastern Virginia.

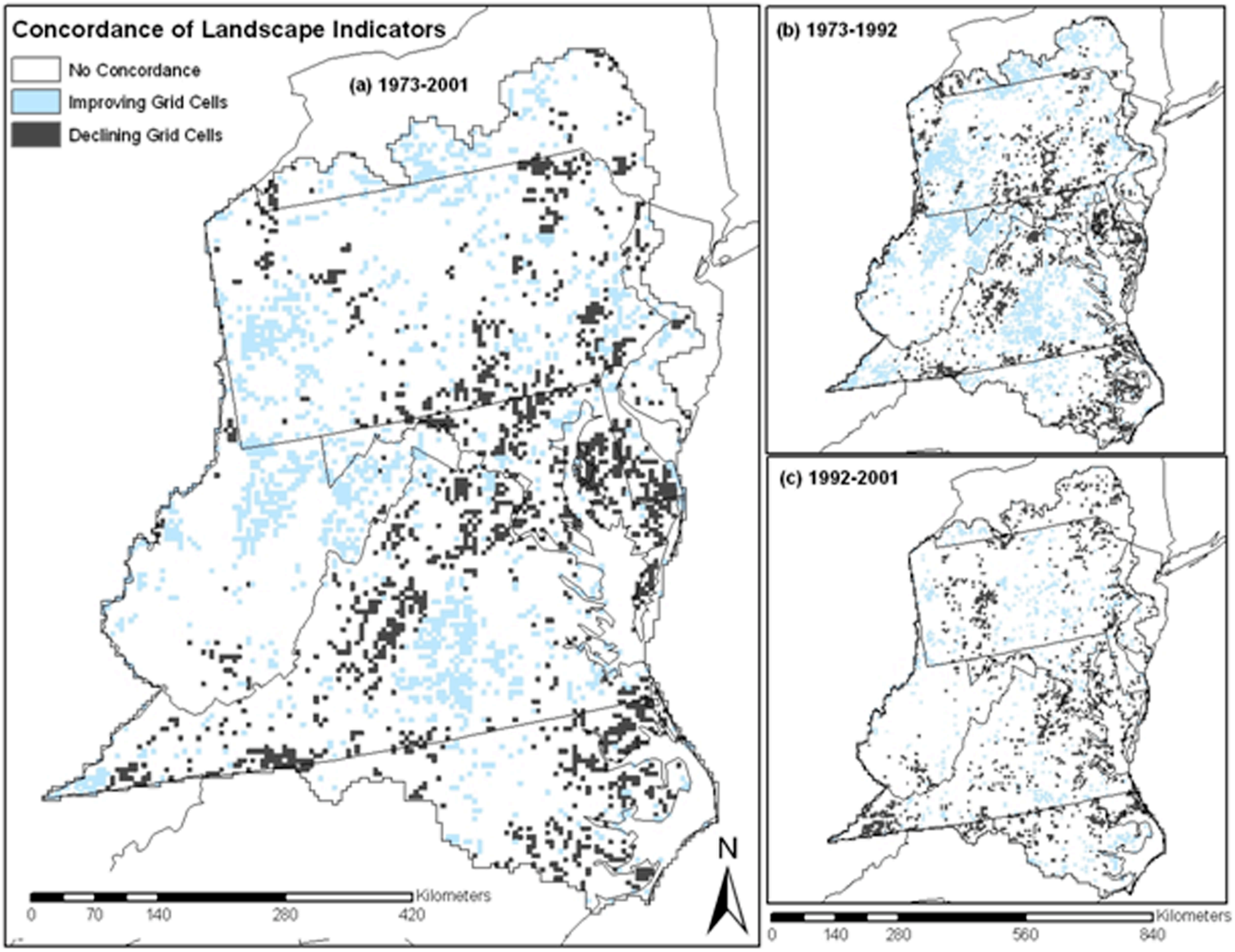

Figure 10. Concordance of landscape indicators (bird habitat and nitrogen load) in the Mid-Atlantic region *A,* 1973–1992; *B,* 1992–2001; and *C,* 1973–2001.

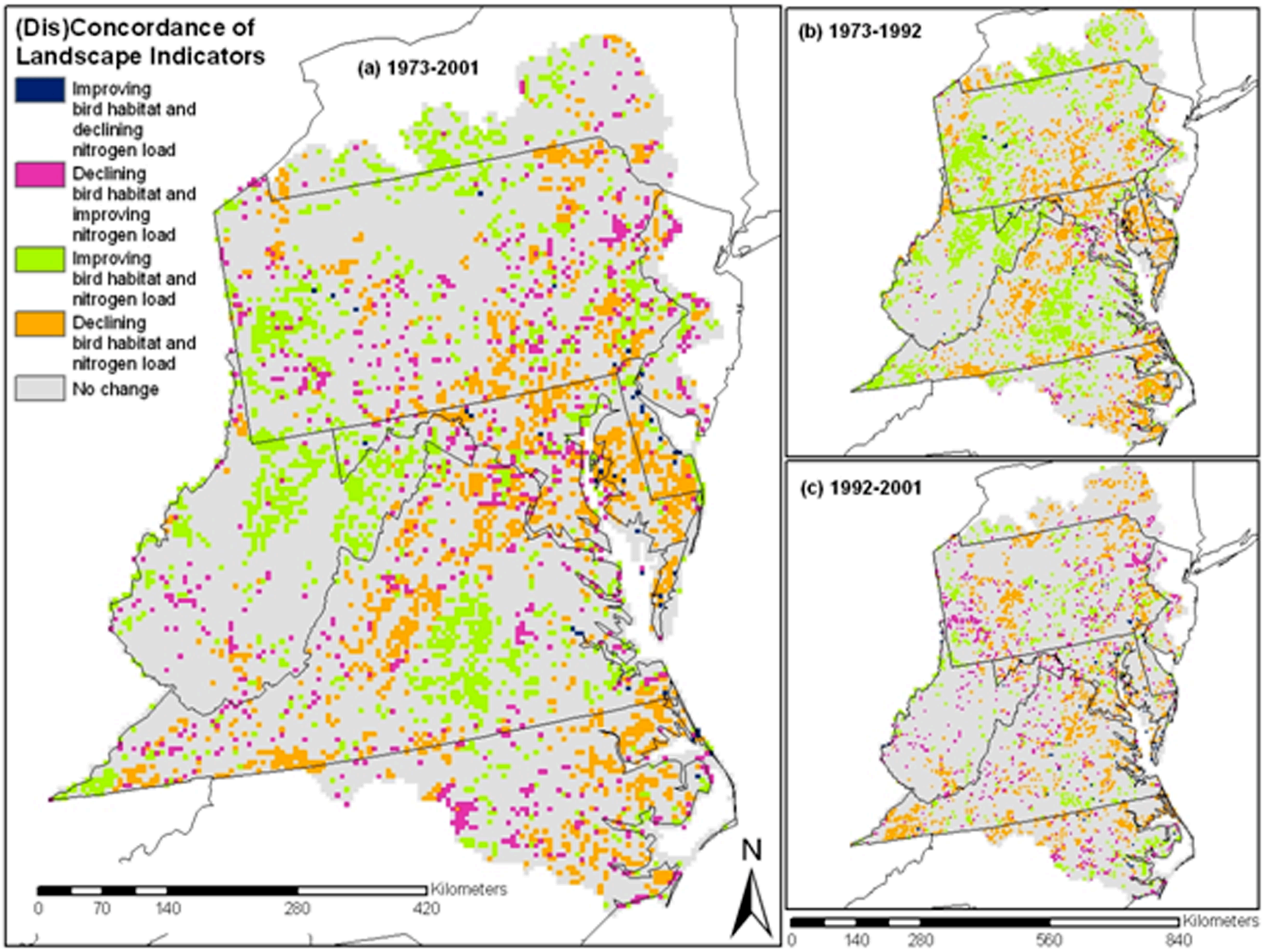

Figure 11. Concordance of landscape indicators (bird habitat and nitrogen load) in the Mid-Atlantic region *A,* 1973–1992; *B,* 1992–2001; and *C,* 1973–2001.

Statistics and Landscape Patterns of Change

In the entire period of the study, very distinct patterns of change can be detected both visually from the high-resolution imagery, as well as from the general land-cover statistics as computed from the Landsat-based land-cover data. Appendix A shows the area and percentage change for 6 classes of land cover for the periods 1973–1992, 1992–2001, and 1973–2001.

In the 13 test areas, urban land cover increased throughout the 30-year period, but at very different rates between to two study periods. From 1973–1992 there was an average increase in urban land cover of approximately 1 percent. From 1992–2001 there was an average increase in the 13 test areas of more than 8 percent, showing a dramatic increase in urbanization in the 1990s.

The other predominant patterns of change involve forest and agriculture. Although both forest- and agriculture-land covers were reduced by 7.0 and 1.9 percent, respectively, during the 1973–2001 period, in every case there was an inverse relationship between the gain and loss. When forests were gained, agriculture was lost, and when agriculture was gained, forests were lost. This was also true for 1973–1992 period. Further, the forest/agriculture change was related to positive or negative change in the combined consequence indicators. When the combined indicators were improving, forests were gained and agriculture was lost, and when the combined indicators were declining, agriculture was gained and forests were lost.

Patterns of Change 1973–1992

Figure 4 shows an example of a temporal imagery triplet through time and demonstrates the subtle but apparent patterns in land-cover change. The most predominant pattern of change in the 1973–1992 period is the near reciprocal increase or decrease in forests and agriculture. Without exception in the 1973–1992 time period, if the bird habitat and nitrogen loadings were improving, then forests were gained and agriculture was lost. Conversely, if the bird habitat and nitrogen loadings were declining in quality, then forests were lost and agriculture was gained.

This is clearly seen in the data both visually and statistically. Figure 12 shows an example from the Baden, Pennsylvania, quad. The conversion of agriculture to forest cover is subtle but apparent. Likewise, figure 13 shows the conversion of forests to agriculture in the area of Ardentsville, Pennsylvania. The change between agriculture to forests displays a strong inverse statistical relationship with an $r2 = .99$ ($p < .01$). Also during this period, there was an average increase in urban- land cover of just more than one percent, but almost no correlation between urban change and forest/agricultural change ($r2 = .08$, $p < .01$).

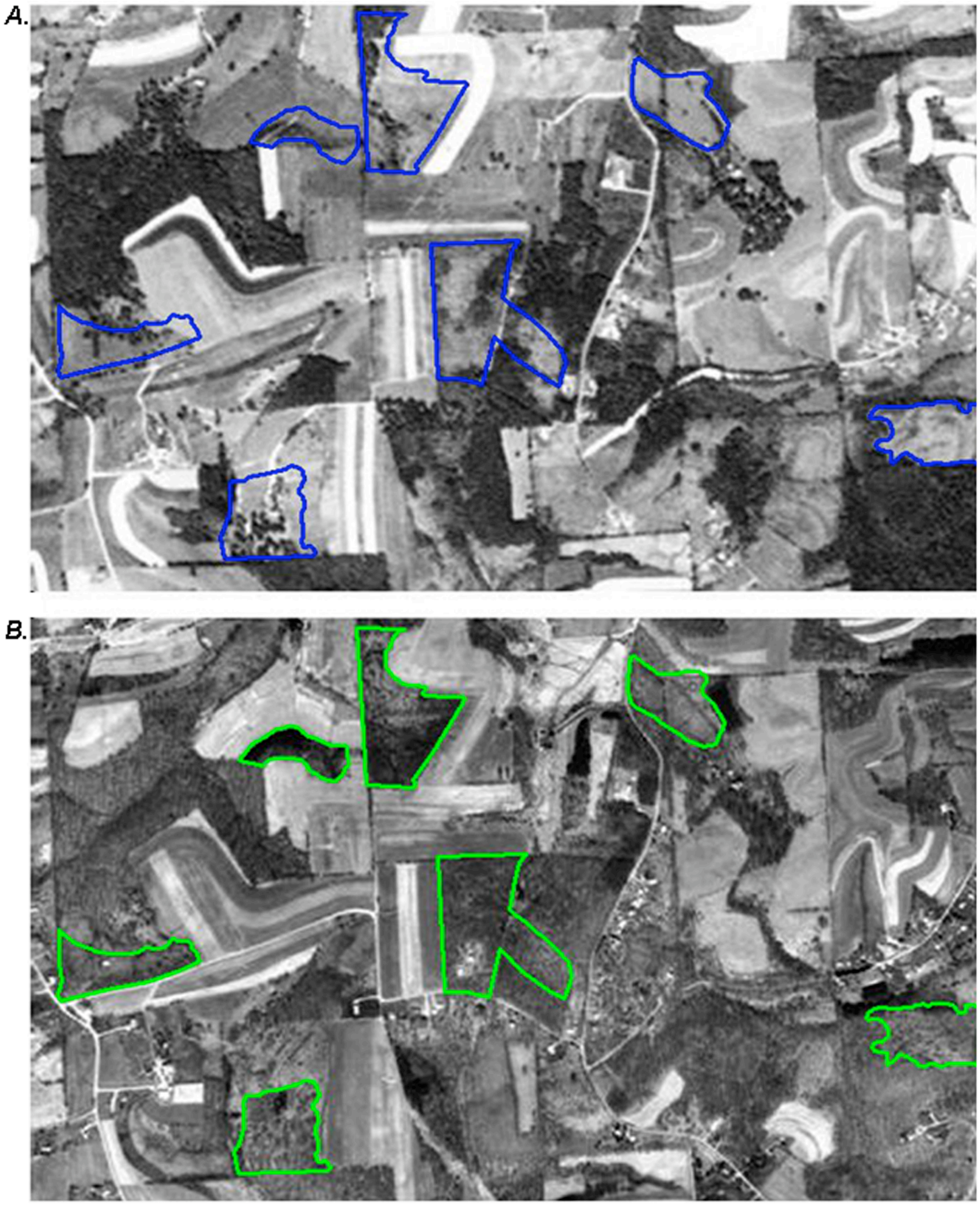

Figure 12. Subtle but substantial patterns of aforestation that occurred in the Baden, Pennsylvania, area between A, 1972 and B, 1993. Photo scale is approximately 1:13,000.

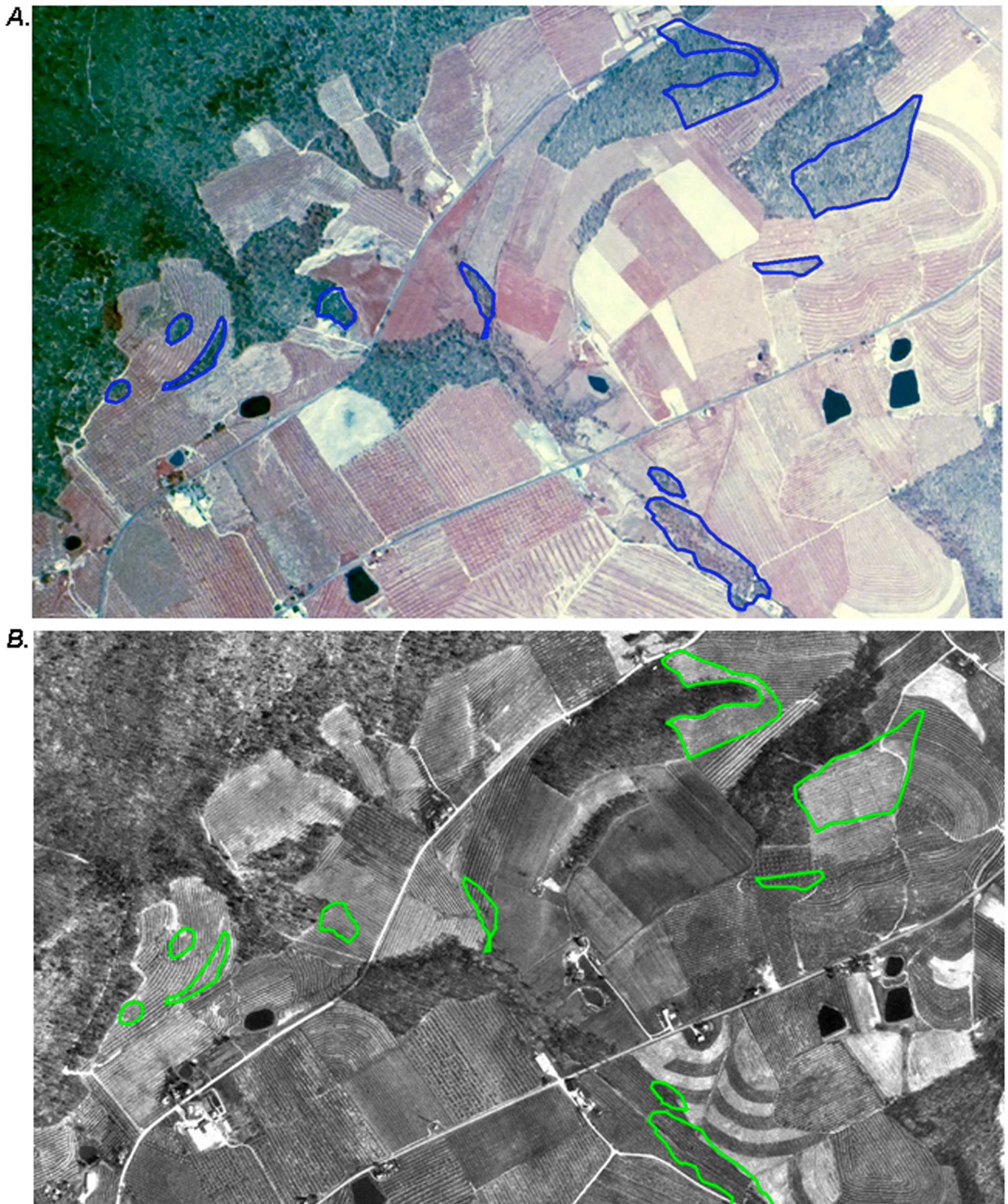

Figure 13. The typical of pattern of urban/suburban growth from A, 1993 to B, 2002 in the area of Bedminster, Pennsylvania. Photo scale is approximately 1:17,500.

Patterns of Change 1992–2001

The period from 1992–2001 was different from the period of 1973–1992. Throughout the Mid-Atlantic study area, the predominant land-cover change was urban expansion. In all 13 test areas there was an increase in urban-land cover ranging from 1 to 17 percent with an average increase of 7.5 percent. The expansion of residential and other forms of urban land use is readily apparent in figure 14 showing urban expansion between 1993 (top) and 2002 (bottom) in the area of Bedminster, Pennsylvania.

During this period, there was a general loss of both forest and agriculture with an average of 3.7 percent each. Agricultural land-cover change was more closely related ($r2 = .44$, $p < .01$) to urban increase than forest change ($r2 = .02$, $p < .01$). However, the sum of the agriculture or forest gain or loss was highly correlated with urban gain ($r2 = .98$, $p < .01$), indicating that both forests and agriculture were being transformed into urban-land uses.

The bird habitat and nitrogen loadings for this time period showed much weaker patterns of improvement and, in general, a greater amount of decline in habitat, primarily because of the loss of forest area (figs. 5 and 6). For the nitrogen loadings, there is a general improvement in this indicator, especially in south-central Pennsylvania and north-central Maryland, due largely to the conversion of agriculture-to urban-land use (fig. 6).

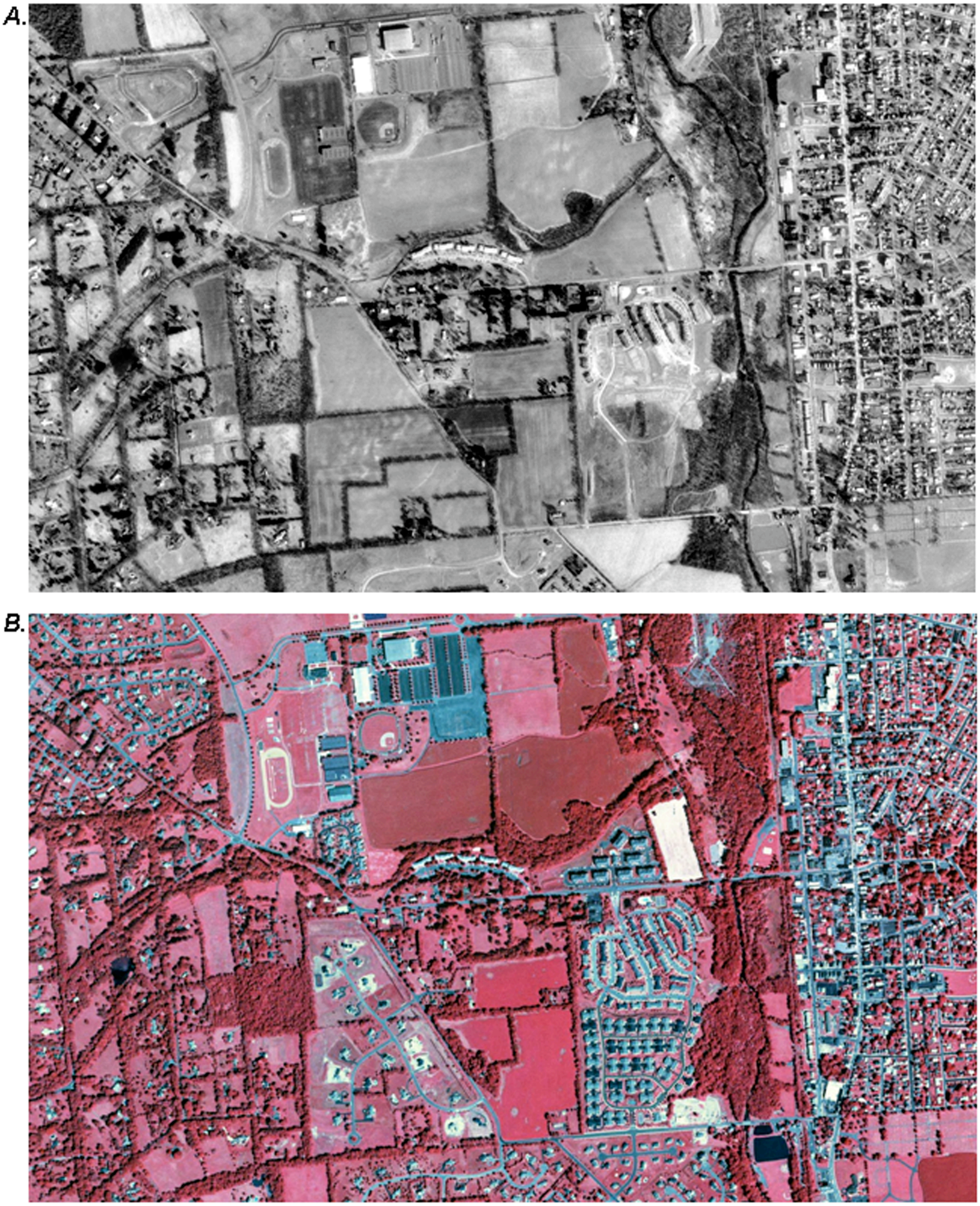

Figure 14. The typical of pattern of urban/suburban growth from A, 1993 to B, 2002 in the area of Bedminster, Pennsylvania. Photo scale is approximately 1:17,500.

Discussion

Evaluation of the use of landscape indicators is limited by the metrics and models used to estimate landscape indicator change and the spatial and temporal scales of the land cover underlying the model calculations. This study updates an earlier study of bird habitat and nitrogen-load models of environmental health in the Mid-Atlantic region to include 1992–2001. We focus on (1) the comparability of results for the concordance of and the individual landscape indicators during the two time periods, (2) how those results reflect actual changes reported at a finer spatial scale, and (3) the challenges of interpretation of these results.

The concordance between improving and declining landscape indicators is generally spatially consistent although intensity varies across the time periods. The concordance of changes from 1973–1992 shows large clustered improvements in both bird habitat and nitrogen load, with fewer and looser clusters of decline. The concordance of changes from 1992–2001 shows a more dispersed decline with fewer improvements. Overall, the 19-year concordance of changes from 1973–1992 appears to dominate those of 1992–2001 (9 years). Concordant declining landscape indicators occur on a possible ecoregional basis (Omernick, 1987) in the Northern Appalachian Plateau and Uplands, northern Ridge and Valley, Blue Ridge, Piedmont and Northern Piedmont ecoregions, and the Middle Atlantic Coastal Plain. Concordant improving landscape indicators occur in the Western Allegheny Plateau, northern Central Appalachians, central Ridge and Valley and Northern Piedmont ecoregions. Table 6 and figure 15 identify the primary land-cover changes for each ecoregion. The cyclic nature of some land-cover changes may be responsible for the resultant pattern of improvement and decline within the same ecoregions and for the observed spatial and temporal differences, but it is apparent that there are definite clusters and patterns of consequence indicators that occur within specific ecoregional boundaries.

Table 6. Land-cover change from 1973–2001 by ecoregion within the Mid-Atlantic region (USGS, 2008).

Ecoregion	Land Cover Change
Blue Ridge	Small transition from forest to developed (urban expansion and exurban development) and cyclic forest harvesting.
Central Appalachians	Transition from forest to mining (1992–2000) and return to grassland/shrubland and forest from mining or agriculture.
Middle Atlantic Coastal Plain	Large changes; mostly cyclic forest clear-cutting and regrowth and urban development from forest, agriculture and wetlands.
Northern Appalachian Plateau and Uplands	Relatively stable with abandonment of agriculture and return to grassland/shrubland and forest.
Northern Piedmont	Transition from agriculture and forest to developed and from agriculture to forest.
Piedmont	Large changes; cyclic forest harvesting and agriculture-forest, transition from forest and agriculture to developed.
Ridge and Valley	Cyclic transition between forest and agriculture and forest harvesting.
Western Allegheny Plateau	Transition from forest to mining and return to grassland/shrubland and forest from mining or agriculture.

The evaluation becomes more challenging when examining the individual landscape indicators. Bird-habitat quality is determined by a rule-based model that evaluates the proportion of forest, urban- and agricultural-land cover. The bird-habitat model results are visualized as a qualitative grid of improving or declining habitat quality. Alternatively, nitrogen load is estimated using the proportion of agriculture and the atmospheric wet nitrate deposition grid and is visualized as a continuous variable over a similar grid. Therefore, the qualitative bird-habitat quality determines the distribution of concordant grid cells and not the joint classification of two continuous landscape indicators. Bird-habitat quality shows patterns of improvement and decline for 1973–1992 followed by a more generalized decline 1992–2001 very similar to the concordant results shown above.

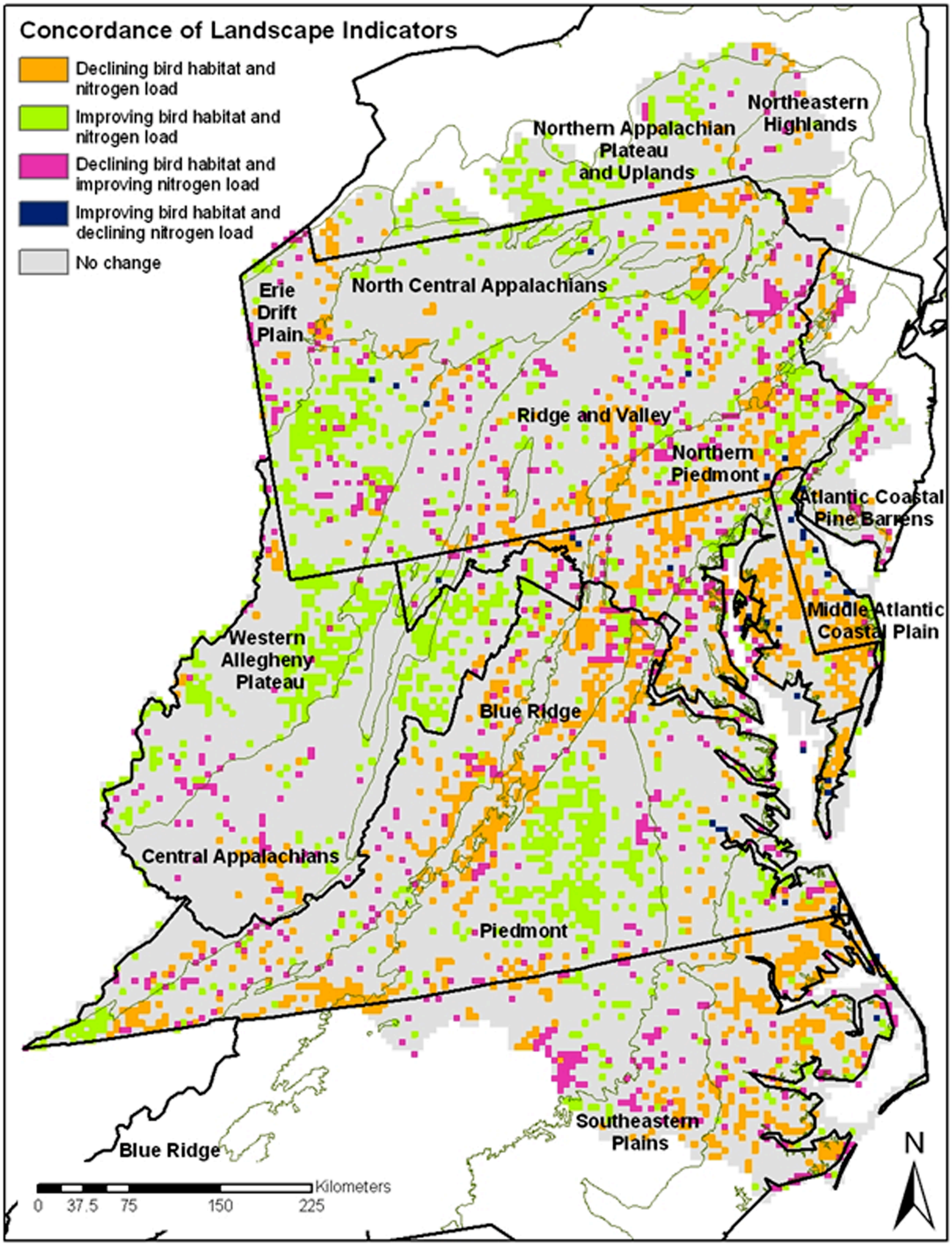

Figure 15. Improving and declining Landscape Indicators during the entire 1973–2001 period and their spatial relationship to ecoregional boundaries.

The nitrogen-load model estimates nitrogen-loading values from the proportion of agricultural-land cover and atmospheric wet nitrate-deposition data to produce a finer-grained visualization of nitrogen loading. Nitrogen load shows an extreme increase in the Appalachian region during 1973– 1992 versus a widespread reduction during 1992–2001. These differences may be attributed to many factors:

- actual spatial and temporal differences including effects from the cyclic nature of some land-cover change,
- differences between the classes and methodology used to produce the individual land-cover datasets,
- use of models based on a unique land-cover dataset,
- focus on agriculture and (de)forestation,
- failure to reflect the changing level of urbanization, and
- an artifact of the temporal periods (19 versus 9 years).

The differences between land-cover datasets did not become apparent until the release of the NLCD 2001 following the completion of the first study. The change in methodology and land-cover classification results in differences in the representation of land cover between MRLC 1992 and NLCD 2001 and, presumably, the classification of the NALC 1973 imagery. These differences in classification most likely alter the changes observed in the landscape indicators making cross-dataset comparisons unreliable. This consideration makes the observation of ground-level changes most important (See discussion below.)

The models were based on data used in the earlier study. Specifically, the nitrogen-load model was fit to the land cover as classified in the MRLC. This model calibration identified the proportion of agriculture as a land cover significant in nitrogen loading. Recent research has linked the amount of urbanization to increases of nitrogen loading (Valiela and others, 2004). Land-cover trends in the Mid-Atlantic vary between the 1973–1992 and 1992–2001 time periods, but, overall, there is a loss largely of forest and agriculture and a corresponding increase in developed and disturbed, which may be the precursor to more development or part of the forestry cycle. For the nitrogen model, this trend from agriculture-to developed-land cover may be significant for the estimation of nitrogen loading.

Despite these dataset challenges, the consistency of concordance across the time periods demonstrates the utility of landscape indicators in illuminating areas of potentially significant change of the landscape and ecosystem functions. The use of multiple landscape indicators potentially alleviates the bias that any one landscape indicator might introduce to such research. Nonetheless, consistently classified historical land-cover datasets would greatly improve the potential for evaluating consequences of landscape changes.

The high-resolution imagery analysis served to confirm and articulate the specific landscape changes that were captured in the Landsat-based land-use and land-cover data. The high-resolution analysis confirmed the subtle, yet statistically significant gain and loss in forest and agricultural patch size and the conversion of both of these into urban land uses. This also confirmed the driving forces in the two consequences models, forest gain and loss driving habitat and agricultural gain and loss driving nitrogen, with conversion to urban affecting both, depending on the time frame involved.

Accuracy of Landscape-Indicator Change

While the accuracy of the 1973 NALC dataset in the Mid-Atlantic region has not been reported in the literature, a study of land-cover trends in Mexico reports an overall accuracy of 60 percent (Lyon, 2004). The 1992 NLCD has overall accuracy of 61 percent in the Mid-Atlantic region (Stehman and others, 2003), and the overall accuracy of the 2001 NLCD nationally is estimated to be around 84 percent (Homer and others, 2007). The accuracy of land-cover change estimates derived from differencing two independently produced land-cover maps, such as the 1992 and 2001 NLCD, equals the product of their individual accuracies (Stow and others, 1980). Therefore, the expected accuracy of land-cover change between 1992 and 2001 is about 51 percent at the 0.8 ha minimum mapping unit (MMU) scale. Moreover, the accuracy of land-cover maps decreases with increasing spatial heterogeneity and decreasing patch size (Smith and others, 2002), such as characterizes suburban landscapes in the Mid-Atlantic where urban growth is most prevalent.

These overall accuracy values would appear to invalidate the use of these data for change detection purposes. As described in Jones and others (2001b), however, we attempted to maximize comparability among the three land-cover datasets and minimize the effect of class confusion, mixed pixels, and positional errors by reclassifying the data to Anderson Level 1 classification (for example, urban, forest, agriculture), resampling the raw 60 m resolution NALC and 30 m resolution NLCD data to 120 m, and by computing the landscape indicators at the aggregate 25-km^2 scale. Generally, land-cover accuracies increase with increases in the minimum mapping unit (Knight and Lunetta, 2003).

In Landsat-derived land-cover datasets, the forest-cover class typically has the highest accuracy of all classes due to its distinct spectral signature. Changes in both the nitrogen and bird-habitat indicators resulted mainly from changes in forest cover. This characteristic increases our confidence in the landscape indicator trends. The low correlation between urban change and forest/agricultural change is nonintuitive, but supported by the analysis of high-resolution imagery. Urban areas, particularly new, low-density developments are easily confused with agriculture. Older urban areas with mature forest canopy may be spectrally confused with forest. Therefore, it is possible that agricultural areas transitioning to forest and forested areas transitioning to agriculture could be the result of urbanization. Additional analysis of the high-resolution imagery would be required to verify this hypothesis.

Recommendations for Further Research

This work has demonstrated that beyond the mechanics and metric of identifying changing pixels or polygons, the policy-relevant consequences of LULC change can be identified, modeled, articulated, and verified using the land-cover mapping data and tools available from the suite of data products and procedures available from the geographic sciences at the USGS. In some ways, consequences represent environmental and social issues that are more likely to garner political and economic interest than just the change statistics of land cover. Some areas of potential further research follow.

Additional Consequences Issues and Landscape Indicator Data

The successful application of the nitrogen and bird-habitat models could be extended to other types on consequence issues such as sedimentation, phosphorus loading, soil loss, heavy metal contamination, and other environmental consequences and issues. The degree to which this can be done depends on the quantitative relationships between these sorts of environmental themes and processes, and spatially explicit biophysical data.

Retroactive Land-Cover Mapping

The advances in land-cover mapping methods that utilize sophisticated statistical methods, such as Classification and Regression Tree (CART) methods, have made it possible to reclassify and improve old land-cover datasets and make them thematically and spatially consistent with existing land-cover data (USGS, 2008). This has been successfully implemented on a limited basis with the MRLC 1992 and the NLCD 2001 datasets (USGS, 2008). However, it could conceivably be extended back to the NALC and LUDA/GIRAS datasets of the early 1970s and could even be used, with early Thematic Mapper data, to develop an early or mid 1980s dataset. With the ongoing development of the NLCD, it is conceivable that we could retroactively map 5 decades of spatially and thematically consistent land-use and land-cover data. The benefits of such an effort could be significant for understanding historical and temporal patterns of landscape change and their consequences.

One of the obvious shortcomings of this research was the lack of a 1980s dataset which would have helped define the temporal patterns at least on a decadal level. The only point here is that spatial and temporally consistent land-cover data can be developed and would provide a great potential for understanding land-cover change through time.

Ecoregional Research

There appears to be a potentially strong and significant relationship between the spatial patterns of landscape indicators, change through time, and an ecoregional setting. The USGS Land Cover Trends project is focused on understanding the rates, trends, causes, and consequences of contemporary U.S. land-use and land-cover change, and it performs this historical analysis based on Omernick's ecoregions (USGS, 2007; Omernick, 1987). Although there has been an on-going debate among researchers in recent years about the use of ecosystem boundaries as sampling units (Loveland and others, 2002; Riitters and others, 2006; USGS, 2007), there nonetheless appears to be some basic relationship between ecoregions and the direction and disposition of landscape indicators, as evidenced in figure 14. Clear patterns of improved bird habitat spatially correlate with the Piedmont, the Western Allegheny Plateau and the Northern Appalachian Plateau and Uplands. While declines in bird-habitat quality and nitrogen loading are strongly associated with the Middle Atlantic Coastal Plain, the Northern Piedmont, and the Blue Ridge ecoregions.

Even though there has been some criticism of using ecoregions as sampling units, there remains validity in the approach, especially when the primary drivers are major land-cover themes, such as forest and agriculture. In this study we found that complex models of bird-habitat quality and nitrogen loading, translated into land-cover changes in forest and agricultural area, and that these changes could be articulated as subtle patterns of changes in landscape patterns on high-resolution imagery. When there is a simple stratification by major land-cover class, the ecoregional approach may still offer some insight into regional patterns, and this aspect deserves further investigation.

References Cited

Ebert, D.W, and Wade, T.G., 2004, ATtILA user's guide: Washington, D.C., U.S. Environmental Protection Agency, EPA/600/R-04/083, [http://www.epa.gov/nerlesd1/land-sci/attila/manual/userman.htm#app4 last accesses August 26, 2009].

Foley, J.A., DeFries, R., Asner, G.P., Barford, C., Bonan, G., Carpenter, S.R., Chapin, F.S., Coe, M.T., Daily, G.C., Gibbs, H.K., Helkowski, J.H., Holloway, T., Howard, E.A., Kucharik, C.J., Monfreda, C., Patz, J.A., Prentice, I.C., Ramankutty, N., and Snyder, P.K., 2005, Global consequences of land use: Science, v. 309, p. 570–574.

Gallant, A.L., Loveland, T.R., Sohl, T.L., and Napton, D.E., 2004, Using a geographic framework for analyzing land cover issues: Environmental Management, 34: 89–110.

GAM, 2006, Draft geographic analysis and monitoring program, 5–year program plan, August 11, 2006: Reston, Virginia, U.S. Geological Survey.

Golley, F.B., 1987, Introducing landscape ecology: Landscape Ecology, v. 1, no. 1, p. 1-3.

Homer, C., Huang, C., Yang, L., Wylie, B., and Coan, M., 2004, Development of a 2001 national land-cover database for the United States: Photogrammetric Engineering and Remote Sensing, v. 70, no.7, p. 829-840.

Homer, C., Dewitz, J., Fry, J., Coan, M., Hossain, N., Larson, C., Herold, N., McKerrow, A., Van Driel, J. N., and Wickham, J., 2007, Completion of the 2001 national land cover database for the conterminous United States: Photogrammetric Engineering and Remote Sensing, v. 7, no. 4, p. 337-341.

Jones, K.B., Neale, A.C., Nash, M.S., Van Remortel, R.D., Wickham, J.D., Riitters, K.H., and O'Neill, R.V., 2001a, Predicting nutrient and sediment loadings to streams from landscape metrics—A multiple watershed study from the United States Mid-Atlantic region: Landscape Ecology, v. 16, p. 301-312.

Jones, K.B., Neale, A.C., Wade, T.G., Wickham, J.D., Cross, C.L., Edmonds, C.M., Loveland, T.R., Nash, M.S., Riiters, K.H., and Smith, E.R., 2001b, The consequences of landscape change on ecological resources—An assessment of the United States Mid Atlantic region, 1973–1993: Ecosystem Health, v. 7, p. 229-242.

Jones, K.B., Riitters, K.H., Wickham, J.D., Tankersley, R.D., Jr, O'Neill, R.V., Chaloud, D.J., Smith, E.R., and Neale, A.C., 1997, An ecological assessment of the United States Mid-Atlantic region—A landscape atlas: Washington, D.C., U.S. Environmental Protection Agency, USEPA/600/R-97/130.

Jones, K.B, Williams, L.R., Pitchford, A.M., Slonecker, E.T., Wickham, J.D., O'Neill, R.V., Garofalo, D., Riitters, K.H., Kepner, W.G., and Goodman, I.A., 2000, A national assessment of landscape change and impacts to aquatic resources, a 10-year research strategy for the landscape sciences program: U.S. Environmental Protection Agency, EPA/600/R-00/001.

Knight, J.F., and Lunetta, R.S., 2003, An experimental assessment of minimum mapping unit size: IEEE Transactions on Geoscience and Remote Sensing, v. 41, no. 9, p. 2132-2134.

Loveland, T.R., Sohl, T.L., Sayler, K., Gallant, A., Dwyer, J., Vogelmann, J.E., and Zylstra, G.J., 2001, Land cover trends—rates, causes, and consequences of late-twentieth century U.S. land cover change: EPA Journal, p. 1-52.

Loveland, T.R., Sohl, T.L., Stehmen, S.V., Gallant, A., Sayler, K., and Napton, D.E., 2002, A strategy for estimating the rates of recent United States land cover change: Photogrammetric Engineering and Remote Sensing, v. 68, p. 1091-1099.

Lyon, J.G., US/Mexico study—Denver, Colo., Nalc/Mexico land cover mapping results-implications for assessing landscape conditions: Monitoroing Science and Technology Symposium, September 20-24, 2004.

McMahon, G., Benjamin, S.P., Clarke, K., Findley, J.E., Fisher, R.N., Graf. W.L., Gunderson, L.C., Jones, J.W., Loveland, T.R., Roth, K.S., Usery, E.L., and Wood, N.J., 2005, Geography for a changing world—A science strategy for the geographic research of the U.S. Geological Survey, 2005–2015: Sioux Falls, SD, U.S. Geological Survey Circular 1282, 76 p.

O'Neill, R.V., Hunsaker, C.T., Jones, K.B., Riitters, K.H., Wickham, J.D., Schwartz, P.M., Goodman, I.A., Jackson, B.L., and Baillargeon, W.S., 1997, Monitoring environmental quality at the landscape scale: Bioscience, v. 47, no. 8, p. 513-519.

Omernick, J.M., 1987, Ecoregions of the conterminous United States: Annals of the Association of American Geographers, v. 77, no. 1, p. 118-125.

Pitchford, A.M., Denver, J.M., Olsen, A.R., Ator, S.W., Cormier, S., Nash, M.S., and Mehaffey, M.H., 2000, Testing landscape indicators for stream condition related to pesticides and nutrients: Landscape Indicators for Pesticides Study for Mid-Atlantic Coastal Streams (LIPS-MACS), U.S. Environmental Protection Agency, EPA/600/R-00/087., 87 p.

Riitters, K.H., Wickham, J.D., and Wade, T,G., 2006, Evaluating ecoregions for sampling and mapping land-cover patterns: Photogrammetric Engineering and Remote Sensing, v. 72, no. 7, p. 781-799.

Siderelis, K., DeLoatch, I., DeMulder, M., Garie, H., Naftzger, M., Pierce, R., and Ponce, S., 2005, The National Geospatial Programs Office: A plan for action: U.S. Geological Survey Open-File Report 2005-1379, 58 p.

Smith, J.H., Wickham, J.D., Stehman, S.V., and Yang, L., 2002, Impacts of patch size and land-cover heterogeneity on thematic image classification accuracy: Photogrammetric Engineering and Remote Sensing, v. 68, no. 1, p. 65-72.

Stehman, S.V., Wickham, J.D., Smith, J.H., and Yang, L., 2003, Thematic accuracy of the 1992 National Land-Cover Data (NLCD) for the Eastern United States—Statistical methodology and regional results: Remote Sensing of Environment, v. 86, p. 500-516.

Stow, D.A., Tinney, L.R., and Estes, J.E., 1980, Deriving land use/land cover change statistics from Landsat—A study of prime agriculture land: Proceedings of the 14th International Symposium on Remote Sensing of Environment 2:1227-1237.

Turner, M.G., 1989, Landscape ecology—The effect of pattern on process: Annual Reviews of Ecological Systems, v. 20, p. 171-197.

United States Department of Agriculture, National Agricultural Statistics Service, 1992, The census of agriculture: Highlights of Agriculture, 1992 and 1987 Maryland [http://www.agcensus.usda.gov/Publications/1992/State_and_County_Highlights/datafile/mdst.txt last accesses August 26, 2009].

United States Department of the Interior, 2006, U.S. Department of Interior GPRA strategic plan fiscal year 2007–2012—August 2006, DRAFT: U.S. Department of the Interior, Washington, D.C., 80 p. [http://www.doi.gov/ppp/Strategic%20Plan%20FY07-12/strat_plan_fy2007_2012.pdf last accesses August 26, 2009].

United States Environmental Protection Agency, 1997, Environmental Monitoring and Assessment Program (EMAP), Research Strategy: Office of Research and Development Report, EPA/620/R-98/001, Washington, D.C., 18 p.
United States Geological Survey, 2000, U.S. Geological Survey Strategic Plan 2000–2005: Reston, Virginia, U.S. Geological Survey, 25 p. [http://www.usgs.gov/science_strategy/stratplan_00/index.html last accesses August 26, 2009].
United States Geological Survey, 2007, USGS land cover trends project peer review report—External peer review of the USGS land cover trends research project: Panel Report, 23 August 2007: Reston, Virginia, U.S. Geological Survey, 15 p. [http://landcovertrends.usgs.gov/documents/USGS_LCT_peer_report.pdf last accesses August 26, 2009].
United States Geological Survey, 2008, National Land Cover Database (NLCD) 1992/2001 Retrofit Land Cover Change Product Multi-zone Download Site: Multi-Resolution Land Characteristics Consortium database available online at http://www.mrlc.gov/multizone.php last accesses August 26, 2009.
Valiela, I., Geist, M., McClelland, J., and Tomasky, G., 2000, Nitrogen loading from watersheds to estuaries—Verification of the Waquoit Bay nitrogen loading model: Biogeochemistry, v. 48, no. 3, p. 277-293.
Volgelman, J.E., Howard, S.M., Yang, L., Larson, C.R., Wylie, B.K., and Van Driel, N., 2001, Completion of the 1990s National Land Cover Data Set for the conterminous United States from Landsat thematic mapper data and ancillary data sources: Photogrammetric Engineering and Remote Sensing, v. 67, no. 6, p. 650-662.
Yang, L., Huang, C., Homer, C., Wylie, B., and Coan, M., 2003a, An approach for mapping large-area impervious surfaces—Synergistic use of Landsat 7 ETM+ and high spatial resolution imagery: Canadian Journal of Remote Sensing, v. 29, no. 2, p. 230-240.
Yang, L., Xian, G., Klaver, J., Deal, B., 2003b, Urban land-cover change detection through sub-pixel imperviousness mapping using remotely sensed data: Photogrammetric Engineering and Remote Sensing, v. 69, no.9, p. 1003-1010.

Appendix A.

Land-cover change statistics for the 13 quad-pair high-resolution test areas.

	Land Cover Class	Land Cover Change (km2)			Percent Change		
		1973–1992	1992–2001	1973–2001	1973–1992	1992–2001	1973–2001
Arendtsville - Fairfield	Water	1,475	-125	1,350	0.29	-0.02	0.26
	Forest	-141,100	-4,425	-145,525	-27.27	-0.86	-28.13
	Agriculture	13,850	-30,050	107,800	26.65	-5.81	20.84
	Wetlands	-350	1,575	1,225	-0.07	0.30	0.24
	Barren	100	6,475	6,575	0.02	1.25	1.27
	Urban	2,025	26,550	28,575	0.39	5.13	5.52
Arrington Piney River	Water	2,800	725	3,525	0.53	0.14	0.66
	Forest	-132,575	-26,975	-159,550	-24.96	-5.08	-30.04

	Agriculture	121,000	-9,375	111,625	22.78	-1.76	21.01
	Wetlands	150	-150	0	0.03	-0.03	0.00
	Barren	3,625	-4,225	-600	0.68	-0.80	-0.11
	Urban	5,000	40,000	45,000	0.94	7.53	8.47
Baden	Water	-3,300	1,550	-1,750	-0.65	0.30	-0.34
- Zelienople	Forest	107,175	-16,500	90,675	21.06	-3.24	17.82
	Agriculture	-124,450	-58,350	-182,800	-24.45	-11.46	-35.92
	Wetlands	100	-100	0	0.02	-0.02	0.00
	Barren	2,125	-2,225	-100	0.42	-0.44	-0.02
	Urban	18,350	75,625	93,975	3.61	14.86	18.46
Bedminister	Water	11,000	-3,125	7,875	2.15	-0.61	1.54
- Hellertown	Forest	134,050	-75,675	58,375	26.24	-14.81	11.43
	Agriculture	-141,825	49,575	-92,250	-27.77	9.71	-18.06
	Wetlands	-8,950	3,925	-5,025	-1.75	0.77	-0.98
	Barren	7,725	-2,475	5,250	1.51	-0.48	1.03
	Urban	-2,000	27,775	25,775	-0.39	5.44	5.05
Birdsboro	Water	3,425	-1,275	2,150	0.67	-0.25	0.42
- Boyertown	Forest	-78,275	-36,950	-115,225	-15.29	-7.22	-22.50
	Agriculture	58,300	-9,275	49,025	11.38	-1.81	9.57
	Wetlands	0	2,325	2,325	0.00	0.45	0.45
	Barren	3,100	-2,125	975	0.61	-0.41	0.19
	Urban	13,450	47,300	60,750	2.63	9.24	11.86
Butler	Water	175	525	700	0.03	0.10	0.14
- Valencia	Forest	113,850	-15,800	98,050	22.38	-3.11	19.27
	Agriculture	-126,975	-70,975	-197,950	-24.95	-13.95	-38.90
	Wetlands	0	175	175	0.00	0.03	0.03
	Barren	825	-3,025	-2,200	0.16	-0.59	-0.43
	Urban	12,125	89,100	101,225	2.38	17.51	19.89
Chambersburg	Water	1,400	-75	1,325	0.27	-0.01	0.26
- Scotland	Forest	-136,475	11,875	-124,600	-26.50	2.31	-24.20
	Agriculture	124,750	-83,500	41,250	24.22	-16.21	8.01
	Wetlands	-75	575	500	-0.01	0.11	0.10
	Barren	2,400	-2,375	25	0.47	-0.46	0.00
	Urban	8,000	73,500	81,500	1.55	14.27	15.83
Church Hill	Water	3,875	-2,850	1,025	0.74	-0.55	0.20
- Price	Forest	-77,700	-14,075	-91,775	-14.92	-2.70	-17.62
	Agriculture	71,350	10,650	82,000	13.70	2.04	15.74
	Wetlands	-50	975	925	-0.01	0.19	0.18
	Barren	950	-75	875	0.18	-0.01	0.17
	Urban	1,575	5,375	6,950	0.30	1.03	1.33
Friendsville -	Water	2,850	-475	2,375	0.57	-0.10	0.48

Little_Meadows	Forest	-48,250	-31,675	-79,925	-9.66	-6.34	-15.99
	Agriculture	46,000	16,200	62,200	9.21	3.24	12.45
	Wetlands	0	1,175	1,175	0.00	0.24	0.24
	Barren	-650	-225	-875	-0.13	-0.05	-0.18
	Urban	50	15,000	15,050	0.01	3.00	3.01
Newburg - Masontown	Water	1,650	700	2,350	0.32	0.14	0.45
	Forest	109,475	-26,125	83,350	21.13	-5.04	16.09
	Agriculture	-114,925	-7,425	-122,350	-22.18	-1.43	-23.62
	Wetlands	-500	-550	-1,050	-0.10	-0.11	-0.20
	Barren	3,375	-6,025	-2,650	0.65	-1.16	-0.51
	Urban	925	39,425	40,350	0.18	7.61	7.79
North-Clymer _Sherman	Water	-450	-50	-500	-0.09	-0.01	-0.10
	Forest	-110,800	13,750	-97,050	-22.24	2.76	-19.48
	Agriculture	111,050	-32,800	78,250	22.29	-6.58	15.70
	Wetlands	50	1,475	1,525	0.01	0.30	0.31
	Barren	-375	25	-350	-0.08	0.01	-0.07
	Urban	525	17,600	18,125	0.11	3.53	3.64
Rectortown -Upperville	Water	-50	950	900	-0.01	0.18	0.17
	Forest	-128,250	17,875	-110,375	-24.56	3.42	-21.13
	Agriculture	122,375	-44,150	78,225	23.43	-8.45	14.98
	Wetlands	0	0	0	0.00	0.00	0.00
	Barren	100	-100	0	0.02	-0.02	0.00
	Urban	5,825	25,425	31,250	1.12	4.87	5.98
Troupsburg -Woodhall	Water	150	50	200	0.03	0.01	0.04
	Forest	154,575	-40,500	114,075	30.99	-8.12	22.87
	Agriculture	-155,225	21,425	-133,800	-31.12	4.30	-26.83
	Wetlands	0	500	500	0.00	0.10	0.10
	Barren	-75	25	-50	-0.02	0.01	-0.01
	Urban	575	18,500	19,075	0.12	3.71	3.82

Abbreviations and Acronyms

ATtILA Analytical Tools Interface for Landscape Assessments.
BW Black and White.
CART Classification and Regression Tree.
CIR Color Infrared.
DOQQ Digital Ortho Quarter Quad.
GAM Geographic Analysis and Monitoring Program.
GIO Geographic Information Office.
GIS Geographic Information Systems.
LUDA Land Use Data Analysis.
LULC Land Use and Land Cover.
MRLC Multi Resolution Land Cover Consortium.
MSS Multi Spectral Scanner.
NALC North American Landscape Characterization.
NDVI Normalized Difference Vegetation Index.
NLCD National Land Cover Database.
TM Thematic Mapper.
USDOI United States Department of the Interior.
USGS United States Geological Survey.