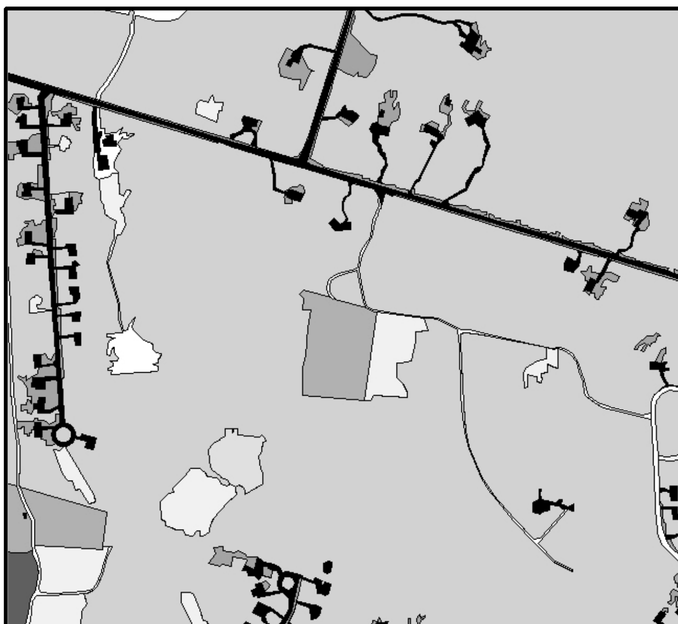
LANDSCAPE CHANGES IN THE MULLICA RIVER BASIN

1979 Map



1991 Map

PINELANDS COMMISSION
2001

Cover images show the landscape changes for a small portion of the Commission land-cover map.

LANDSCAPE CHANGES IN THE MULLICA RIVER BASIN

BY

JOHN F. BUNNELL [1], ROBERT A. ZAMPELLA [1],
RICHARD G. LATHROP [2], AND JOHN A. BOGNAR [2]

2001

[1] New Jersey Pinelands Commission
PO Box 7
New Lisbon, NJ

[2] Center for Remote Sensing and Spatial Analysis
Rutgers University
New Brunswick, NJ

INTRODUCTION

Human-induced landscape disturbances can have a substantial impact on ecosystem structure and function. These alterations can influence factors as varied as insect parasite-host interactions (Roland and Taylor 1997), plant and animal community composition and population dynamics (Fahrig and Merriam 1985, Robinson et al. 1995, Findlay and Houlahan 1997, Gibbs 1998), the probability and extent of natural disturbance (Franklin and Forman 1987, Turner et al. 1989), rates of primary production (Turner 1987, Odum and Turner 1990), runoff and erosion patterns (Leopold 1968, USDA 1986), and evaporation and heat exchange (Dow and DeWalle 2000). Quantifying the spatial and temporal characteristics of a landscape is an important step for understanding the link between landscape patterns and ecological processes (Turner 1990a, b). Two basic approaches can be used to characterize a landscape. Land cover represents the actual biophysical material on the Earth's surface. Land use depicts the way that humans utilize a portion of land or body of water. A particular land use may include several land covers.

Aerial photography and satellite imagery can be used to describe landscape conditions and assess changes on a regional, continental, and global basis (e.g., Goward et al. 1985, Tucker et al. 1985, Turner and Ruscher 1988). Because of the low cost, long history of use, and relatively high spatial and spectral resolution compared to other types of space-borne imagery, the primary satellite sensor recommended for land-cover change analysis in coastal regions of the United States is Landsat Thematic Mapper (TM) (Dobson et al. 1995). A TM image is a mosaic of 30 x 30 m pixels, or blocks, each with a color signature that corresponds to the land cover present. Although TM land-cover data is relatively coarse compared to fine-scale aerial photography, aerial photography can be used to calibrate and assess the accuracy of TM data and help transfer information across spatial scales (Iverson et al. 1989).

The Pinelands is a relatively undeveloped 450,000-ha region located on the Atlantic Coastal Plain in the southern portion of New Jersey. This acid-water, sandy-soil system supports distinct plant and animal communities that are vulnerable to changes associated with water-quality degradation from developed and agricultural landscapes (Zampella and Laidig 1997, Zampella and Bunnell 1998, Bunnell and Zampella 1999, Zampella and Bunnell 2000).

In 1979, the Pinelands Commission was established as a regional land-use planning and regulatory agency charged with the implementation of a management plan for the Pinelands National Reserve (Good and Good 1984, Collins and Russell 1988). The Commission developed a multifaceted environmental-monitoring program to assess the status and trends of selected natural resources and obtain information that can be used to periodically make changes to land-use policies and programs. Because of the relationship between land-use patterns and Pinelands biota, monitoring landscape changes provides one of the most direct measures of the impact of land-use policies on the Pinelands ecosystem.

We mapped land-cover from 1979 and 1991 aerial photography in great detail for the Mullica River basin, an area that encompasses 39% of the Pinelands. The study period represents the first 12 years of the Commission's planning effort. The basic framework of this effort is rooted in a series of Management Area designations in which land uses of different intensities are permitted. In this paper, we address three questions. First, what were the major land-cover transitions and changes in landscape structure (i.e., land-cover patch sizes) that occurred in the basin between 1979 and 1991? Second, did land-cover transitions occur in accordance with Commission Management Area designations? Third, how does the Commission's land-cover data compare to land-use data created by the New Jersey Department of Environmental Protection (NJDEP) and land-cover data generated from Landsat Thematic Mapper. The NJDEP and TM data are much less detailed than the Commission's land-cover data, but offer great promise for long-term monitoring of the Pinelands landscape.

METHODS

Study Sites

The Mullica River basin was chosen as the initial focus of the Commission's environmental-monitoring efforts because it is the largest watershed in the Pinelands and it contains a range of land-use characteristics, including a large amount of protected land (Zampella 1992). Because of the photo-interpretation effort required to map land cover within the entire basin in great detail, we used a tessellated-stratified design to generate a statistically-based subsample of the basin (Stehman and Overton 1994, Lathrop et al. 1997). From a random starting point, the basin was divided into 72 square blocks, each block was divided into nine sub-blocks, and one of the nine sub-blocks was randomly chosen to be a sample site (Figure 1). We refer to the sites as photoplots. An individual photoplot was 225 ha in size and the total areal coverage of the 72 photoplots combined was 11% (16,200 ha) of the 1,474 km^2 basin. The sample was found to be representative of the basin by comparing the percentage areas of land-use categories from an existing GIS coverage (Lathrop et al. 1997). Portions of five photoplots (1, 2, 3, 55, and 70) were outside of the basin boundary, but were included in the study because together the portions totaled only 0.1% of the basin area. The basin boundary that we used was extracted from the United States Geological Survey (USGS) 14-digit Hydrologic-Unit Code basin coverage (NJDEP 1996).

Aerial Photography

We created maps for the 72 photoplots using aerial photography from 1979 and 1991. The 1979 photographs were 1:12,000 scale true-color film positives, taken in November 1978 and March 1979 (Markhurd, Inc. for NJDEP). The 1991 photographs were 1:40,000 scale color-infrared film positives taken in March 1991 by the National Aerial Photography Program (NAPP) for the USGS. We scanned the photoplot areas from the 1991 photographs and individually rectified the resulting digital images to a Universal Transverse Mercator (UTM) base in Erdas Imagine 8.x software (Erdas Inc., Atlanta, GA, 1982-1999) using ground control points, a first-order polynomial transformation, and nearest-neighbor re-sampling. Second-order transformations were used when necessary. Ground control points were obtained from 1:24,000 scale digital black and white orthophotography from 1991 (NAPP by Markhurd, Inc. for NJDEP). Average root mean square error for the 72 photoplots was ± 2.3 m. Individual pixel size was 2 x 2 m. This process resulted in a digital geographically-referenced photograph of each photoplot for the 1991 base period.

Land-cover Mapping

Using on-screen digitizing in ArcView 3.x software (Environmental Systems Research Institute, ESRI, Inc., Redlands, CA, 1988-1992), we delineated and classified land-cover for each of the 72 photoplots from the 1991 digital photography (Figure 2). Hard-copy photographs were consulted to aid on-screen interpretation. Our classification system was modified from the National Oceanic and Atmospheric Administration's Coastal Change Analysis Program (NOAA C-CAP, Dobson et al. 1995) (Table 1). The modifications were that our developed and agricultural-land covers were somewhat more detailed and woody-land covers less detailed compared to the C-CAP classification scheme.

Developed land on the Commission map was composed of several residential and non-residential cover types, and consisted mostly of impervious covers such as structures and paved surfaces. We separated agricultural land into crop land, blueberry fields, cranberry bogs, orchards, and tree farms. Grassland covers included residential grass (lawn areas) and non-residential grass, such as athletic and recreation fields, commercial lawns, pasture land (and corrals), and roadside vegetation. Roadside vegetation consisted of herbaceous areas along paved and sand roads and varied widely in management intensity.

Other cover types, including water, barren land, herbaceous, and scrub/shrub covers, were only mapped when clearly associated with recent fire or past and present human-related land-use disturbances. These disturbances were limited to development, agricultural activities, resource extraction, and timber harvesting. Resource-extraction areas included small and large-scale sand and gravel operations. We also mapped tidal water, salt marsh, and forest cover. Tidal water and salt marsh covers were delineated using NJDEP Freshwater Wetland data from 1986 as a guide (NJDEP 1996). Forest cover included tree cover associated with any of the previously mentioned land-use disturbances and all undeveloped vegetated cover. We combined these land covers because the vast majority was forested and our primary interest was human-altered land. The minimum mapping unit was 5.0 m^2 (5×10^{-4} ha).

To generate the 1979 land-cover maps, we printed the 1991 base maps on transparent film at a scale to match the older photography. Areas of change between the two periods were identified using a light table and a 9X lens. Digital copies of the 1991 maps were created and edited on-screen to reflect 1979 conditions. For both periods, the 72 individual land-cover maps were merged into single vector (polygon) coverages. We refer to these coverages as the 1979 and 1991 Commission vector maps.

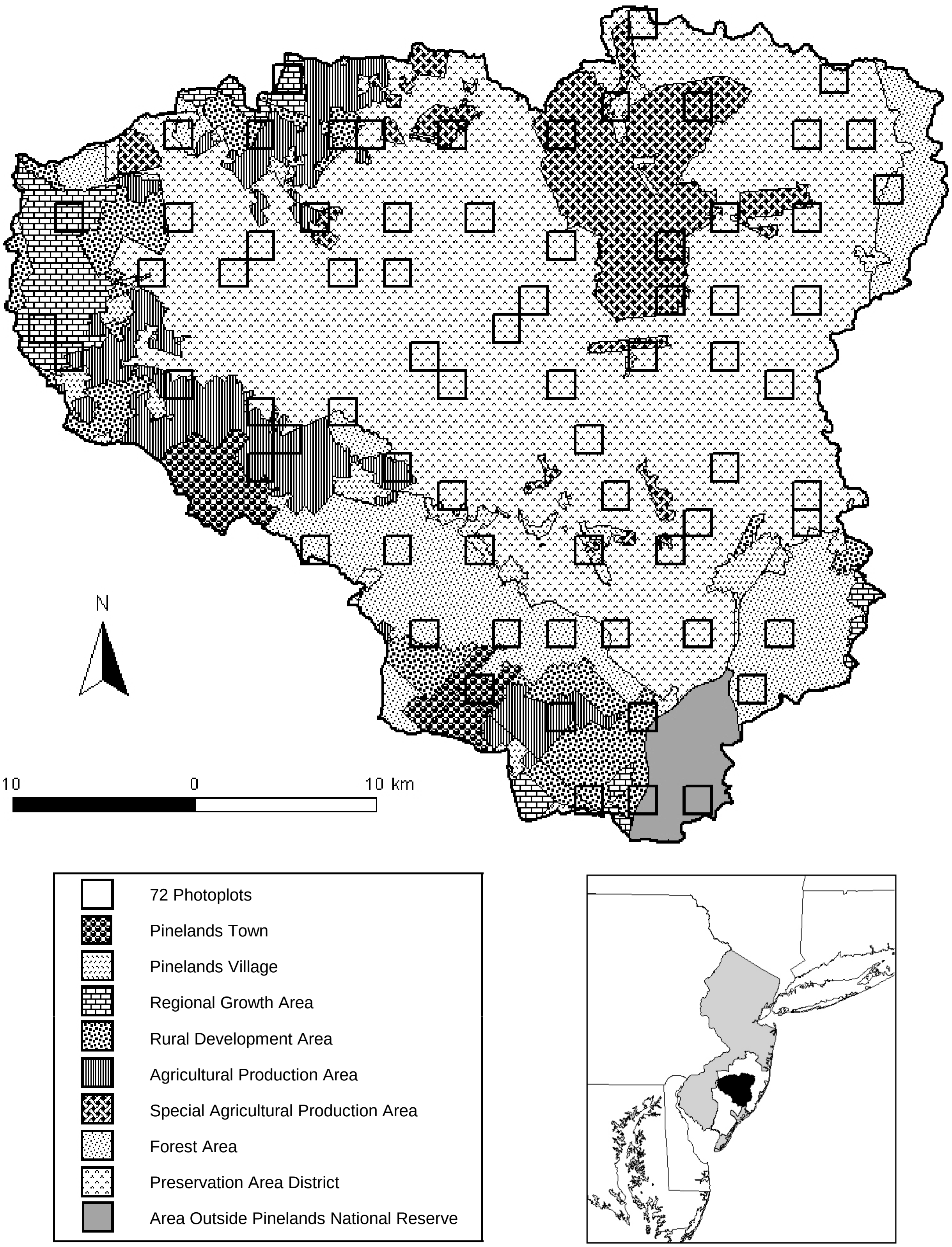


Figure 1. Regional location of the Pinelands National Reserve in New Jersey (inset) and the distribution of 72 photoplots and Commission Management Areas in the Mullica River basin.

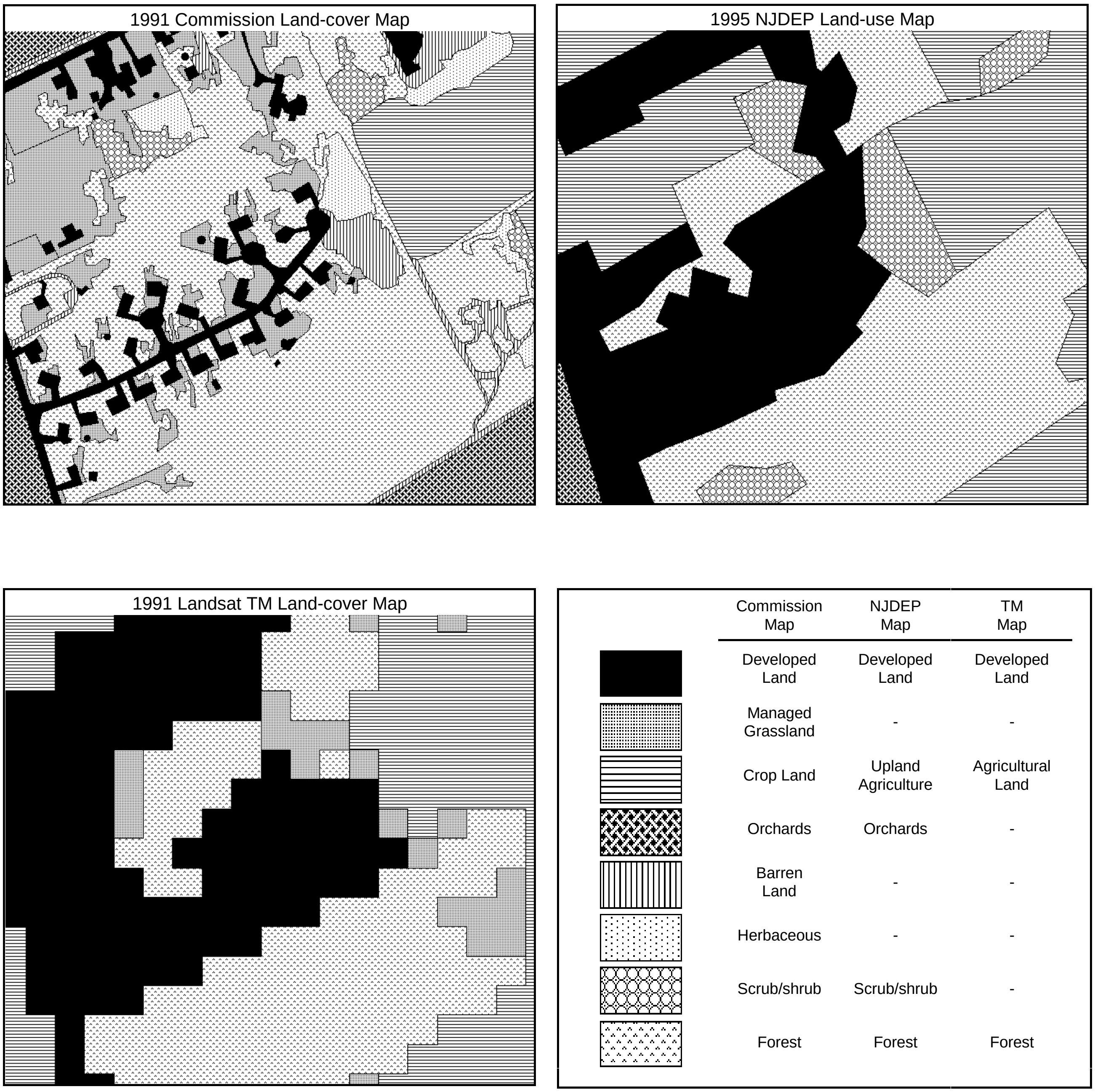


Figure 2. Pinelands Commission map, New Jersey Department of Environmental Protection (NJDEP) map, and Landsat Thematic Mapper (TM) map for a small portion of one Mullica River basin photoplot. The key shows land-use and land-cover types present in each map. For scale, each TM pixel is 30 x 30 m in size. See Table 1 for details on the classification scheme for each map.

Using ArcView software and Spatial Analyst 1.1 (ESRI, Inc., 1998), we converted the 1979 and 1991 vector maps to raster, or pixel, format. The raster process divided both vector maps into ~162 million 1 x 1-m pixels and assigned each pixel the dominant cover type. The use of such a small pixel allowed us to retain the detail of the original vector maps. We refer to these two maps as the Commission raster maps.

Data Analysis

Landscape Changes between 1979 and 1991

Landscape Composition and Structure. We used the 1979 and 1991 Commission vector maps to compare landscape composition and structure between the two periods. For each photoplot, we calculated the mean, median, and first and third quartile patch sizes, the number of patches, and the total land-cover area for twelve major land-cover types and for all cover types combined. The twelve cover types were developed land, managed grassland, barren land, crop land, orchards, blueberry fields, cranberry bogs, herbaceous, scrub/shrub, forest, salt marsh, and water (Table 1). To determine if there were differences in landscape structure between periods, we used the Wilcoxon matched-pairs test on a photoplot by photoplot basis to compare the summary attributes for the twelve cover types and for all types combined. Separate groups of Wilcoxon tests were completed for each attribute. Although trends in median values should reflect overall patch size trends, we included the first and third quartiles in the analysis to determine whether there were also differences in the smaller and larger patches between periods. Land-cover area and number of patch values were projected to the entire basin by dividing the photoplot-based values by 0.11 because the photoplots represented 11% of the basin area.

Land-cover Transitions. Using ArcView software with Spatial Tools 3.3 (Hooge and Eichenlaub 1997), we completed a post-classification pixel-to-pixel change-detection procedure between the 1979 and 1991 Commission raster maps (Dobson et al. 1995, Jensen 1996). This procedure resulted in a transition matrix between 1979 and 1991 for each 1 x 1-m pixel for the twelve major land-cover types (Table 1). Geographic registration of the raster maps prior to the change-detection procedure was not necessary because both maps originated from the same source.

Pinelands Land Management Area Analysis. The Commission's land-allocation system separates the Mullica River basin into eight management areas that differ with respect to land-use capability (Figure 1). In general, the Preservation Area District and, to a large extent the Forest Area, were designed to protect natural resources and encourage little development or agricultural-land use. The Agricultural Production and Special Agricultural Production Areas, were structured to encourage farming and discourage development unrelated to agricultural activities. Pinelands Villages, Pinelands Towns, Regional Growth Areas, and Rural Development Areas were designed to accommodate various intensities of development. The 1979 to 1991 period corresponds to the first twelve years of Commission land-use regulation in the Pinelands. To evaluate whether landscape changes occurred in the appropriate management areas (Pinelands Commission Land Capability Map, November 1999), we used ArcView software to partition the 1979 to 1991 land-cover transition matrix by management area. These results were analyzed graphically.

Comparison of Commission Map with Other Maps

NJDEP Land-use Map Comparison. We used the NJDEP land-use vector map for the Mullica River basin for three separate analyses (1995/97 Land Use/Land Cover Update, released 2001) (Figure 2). This medium-resolution land-use map was generated from aerial photographs from 1986 (Markhurd, Inc. for NJDEP), integrated with a freshwater wetland coverage, and updated using digital photography from 1995/97 (NAPP for USGS). During the update process, the minimum mapping unit was reduced from 1 ha to 0.4 ha and the percentage of impervious surface was estimated for each land-use polygon. Impervious surface consisted of paved and built-up land and was visually estimated at 5% intervals from 0 - 100%. Because the vast majority of the Mullica River basin over-flight occurred in 1995 and not 1997, the NJDEP map generally reflects 1995 land-use conditions in the basin. The NJDEP classification system is based on Anderson et al. (1976) (Table 1).

For the first analysis, we used the 1991 Commission raster map to quantify the land-cover composition of NJDEP land-use classes and subclasses. Using ArcInfo 8.x (ESRI, Inc., Redlands, CA, 1982-2000)

Table 1. Commission land-cover types and related Landsat and NJDEP classes found within 72 photoplots in the Mullica River basin. Commission and Landsat classifications were modified from the NOAA Coastal Change Analysis Program (Dobson et al. 1995). For Commission forest, scrub/shrub, herbaceous, barren-land, and water cover types, disturbances included development, agricultural activities, resource extraction, timber harvests, and fire. The NJDEP classification scheme follows Anderson et al. (1976). NJDEP names given in parentheses are abbreviations used in figures.

1979 and 1991 Commission Land-cover Types	1991 Landsat Thematic Mapper Land-cover Types	1986 and 1995 NJDEP Land-use Classes
● Developed land • Residential development, including houses/driveways, outbuildings, and swimming pools • Nonresidential development, including buildings/asphalt, paved roads, railroads, campground vehicles, and junkyards/ storage areas	● Developed land (% impervious and barren land) • Light: wooded (25 - 50%) • Light: unwooded (25 - 50%) • Moderate (50 - 75%) • High (> 75%)	● Developed land, excluding recreational lands and athletic fields • Rural density residential development • Low density residential development • Medium density residential development • High density residential development • Nonresidential development, including commercial/services, industrial, transportation/communication/utilities, and other urban uses
● Crop land, including crop land, turf fields, and gardens ● Orchards • Tree farms ● Blueberry fields ● Cranberry bogs, including bogs and reservoirs	● Agricultural land ● Vines/Bushes	● Upland agriculture, excluding orchards/vineyards/nurseries/horticultural areas ● Orchards/vineyards/nurseries/horticultural areas ● Wetland agriculture
● Managed grassland • Residential grass (lawns) • Nonresidential grass, including pastures/ corrals, recreation land, athletic fields, commercial lawns, and roadside vegetation ● Herbaceous, including several unmanaged disturbance-related herbaceous covers	● Grassland, including managed and unmanaged herbaceous areas	● (Recreation land) Recreation land, athletic fields, and managed wetlands ● Herbaceous wetlands ● Old Fields (< 25% brush covered)
● Forest, including undeveloped vegetated land and several disturbance-related tree covers ● Scrub/shrub, including several disturbance-related scrub/shrub covers	● Forest, including seven forest types ● Scrub/shrub, including two scrub/ shrub types	● (Forest) Upland forest and wetlands, excluding scrub/shrub subclasses and tidal, herbaceous, disturbed, and managed wetlands ● (Scrub/shrub) Upland forest and wetlands composed of scrub/shrub subclasses and excluding tidal, herbaceous, disturbed, and managed wetlands
● Barren land • Residential barren land • Nonresidential barren land, including several disturbance-related barren-land covers • Sand roads • Fire breaks	● Barren land, including barren land and areas with < 25% vegetated cover	● Barren land, including extractive mining, altered lands, transitional areas, undifferentiated barren lands, and disturbed wetlands
● Salt marsh	● Salt marsh, including unconsolidated shore and emergent wetlands	● Tidal wetlands, including saline marshes
● Water, including tidal water, retention basins, impoundments, irrigation ponds, ditches/canals, and other disturbance-related water cover	● Water, including unconsolidated shore and emergent wetlands	● Water and tidal waters

and ArcView software, we clipped land-use polygons from the NJDEP map to the 72 photoplots, and determined the percentage land-cover composition of Commission land-cover types in NJDEP land-use classes and subclasses (Table 1). Because the 1991 Commission map represented a period roughly midway between 1986 and 1995, the composition of NJDEP land-use classes was determined for both years. We analyzed these results graphically.

For the second analysis, we compared the impervious-surface estimates from the 1995 NJDEP map to the amount of developed land in the 1991 Commission map. When the NJDEP polygons were clipped to the photoplot boundaries, polygons distributed along the edges were severed. Some of these severed polygons contained impervious surface. We do not know whether the actual impervious portions of those polygons were included or excluded from the photoplots, but because a large number of polygons (1073) with an impervious-surface estimate were within the photoplot boundaries, we assume that inclusion and exclusion errors were similar. The original percentage estimates were used to re-calculate the amount of impervious area for each polygon, and these area values were summed for each five percent impervious-surface estimate interval. Using Arcview software, we summed the amount of developed land from the 1991 Commission map for each impervious-surface interval. Developed land represented impervious surface in the Commission map. We used Pearson product-moment correlation to assess the relationship between the total amount of impervious area from the NJDEP map and the Commission map for each impervious-surface estimate interval. We also calculated the difference between the Commission and NJDEP totals for each impervious-surface estimate interval, and used Pearson correlation to evaluate the association between this difference and the number of NJDEP polygons in the estimate interval. We did this to determine if the magnitude of the difference between the two maps was related to the number of polygons in which an estimate was made.

The NJDEP land-use data also identified which land-use polygons changed between 1986 and 1995. For the third analysis, we evaluated changes that occurred in the basin during this nine-year period. Transition matrices for eight major NJDEP land-use classes were generated for the entire basin and for the Pinelands National Reserve portion of the basin between the two years. The eight land-use types were developed land, upland agriculture (including orchards), wetland agriculture, barren land, upland forest (upland forest and scrub/shrub subclasses), water, wetlands (wetland forest and scrub/shrub subclasses), and tidal water and wetlands.

Landsat Thematic Mapper Comparison. A hybrid multispectral-classification technique that incorporated supervised, unsupervised, and rule-based GIS approaches was used to classify TM imagery of the Mullica River basin from 1991 (Figure 2). Details on image processing and classification procedures are given in Lathrop et al. (1997). The classification process resulted in a map of the basin with a land-cover type assigned to each 30 x 30-m pixel. The classification scheme follows that for the C-CAP (Table 1).

We used ArcView software to generate land-cover profiles for the 72 photoplots from the TM map. Using different approaches, we compared the TM profiles to the Commission vector and raster maps from 1991. On a photoplot by photoplot basis, we used the Wilcoxon matched-pairs test to determine if there were overall differences in the total area of eight land-cover types between the Commission vector map and TM map. The eight cover types included in this analysis were developed land, agricultural land, vines/bushes, grassland, woody land, barren land, salt marsh, and water (Table 1). We collapsed individual developed covers into one developed type for both maps because different methods were used to delineate these areas. For the Commission map, orchards and tree farms were included with crop land, cranberry bogs and blueberry fields were combined into a vines/bushes type, and herbaceous and managed grassland covers were collapsed into grassland because the TM classification did not distinguish between these individual cover types. Forest and scrub-shrub covers were pooled into a woody-land cover because, on the Commission map, scrub-shrub cover was only delineated when it was associated with human-related disturbance or fire, whereas all scrub-shrub cover was mapped during the TM classification.

Each 30 x 30-m TM pixel covered nine-hundred 1 x 1-m Commission raster-map pixels. To quantify the land-cover composition of individual TM cover types, we used ArcView software to determine the area of the twelve Commission raster-map cover types in each TM cover type. All twelve original TM types were analyzed, along with the combined developed-land type (Table 1). We calculated the percentage composition of the Commission raster-map covers in each TM type and analyzed these results graphically.

Statistics

We applied the sequential Bonferroni significance-level adjustment to groups of related Wilcoxon matched-pair tests (Rice 1989). The alpha level was 0.05 for all statistical tests. Summary statistics were generated using Intercooled Stata 6.0 (Stata Corp., College Station, TX, 1999). All statistical analyses were completed using Statistica 5.5 (Statsoft, Inc., Tulsa, OK, 2000).

RESULTS

Landscape Changes between 1979 and 1991

Landscape Composition and Structure

Based on the Commission maps, forest cover represented about 75% of the Mullica River basin in both periods (Figure 3). The other eleven cover types each totaled less than 5% of the basin. The combined area of developed-land, managed-grassland, agricultural-land, and barren-land cover types covered 13% and 15% of the basin in 1979 and 1991, respectively.

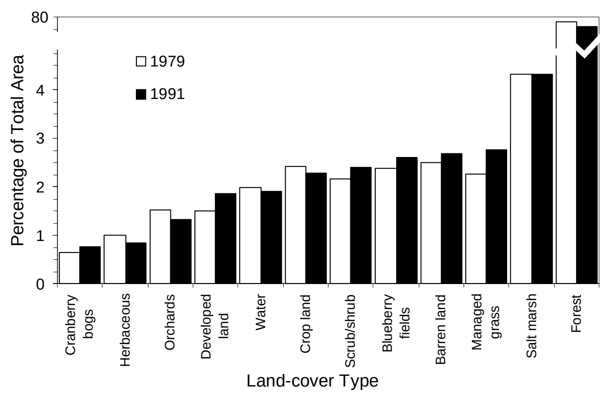


Figure 3. Land-cover composition in 72 photoplots for 1979 and 1991 in the Mullica River basin.

Approximately 80% of all patches were less than 0.5 ha in both periods. Salt marsh and forest land represented the largest patches (Table 2). These were the only two covers with patches greater than 75 ha (maximum patch size is an entire photoplot or 225 ha). Salt marsh patches were generally larger than forest patches, but much fewer in number. Agricultural patches were larger than those for the remaining cover types, and blueberry and cranberry patches were larger than crop land and orchard patches. Developed and managed grassland patches were the smallest of all cover types. Sixty percent of the total number of patches in both periods were classified as developed land, managed grassland, and barren land, approximately 30% of the total were vegetated (forest, scrub/shrub, and herbaceous), and the remaining 10% were composed of agricultural land, salt marsh, and water.

We found a significant difference in several cover types between 1979 and 1991 (Table 2). The total area and the number of developed-land, managed-grassland, and barren-land patches increased due to the increase in the residential and non-residential cover types, fire breaks, and paved and sand roads (Figure 4). Managed grassland displayed the greatest increase in total area due mostly to the relatively large increase in residential lawns in the basin.

The loss in total agricultural area between periods was small (6 ha). Crop land and orchards decreased and blueberry fields increased in area, but the differences were not significant (Figure 4, Table 2). Of all twelve cover types, only crop land and orchards showed a decrease in the number of patches between the two years. The trend for crop land was significant (Table 2). Although the area and the number of patches increased for cranberry bogs, the statistical

Table 2. Summary statistics and results of Wilcoxon matched-pairs tests for individual land-cover types and all types combined in the Mullica River basin. Tests were completed on summary statistics in 72 photoplots between 1979 and 1991. The 72 photoplots represented 11% of the basin area. Mean patch size was not included in the Wilcoxon tests but is provided for comparison. Attributes significant at the Bonferroni adjusted significance level (α = 0.05, k = 11 tests for all attributes except total land area, where k = 10 tests) are indicated with a box. The initial *p*-level, the number of photoplot pairs in which the land cover was present (*n*), and the median attribute value for both periods are given. Land-cover area and the number of patches were projected as basin-wide values by dividing the photoplot-based number by 0.11. Cranberry bogs and salt marsh covers were not included in the Wilcoxon tests because of the low *n* for cranberry bogs and lack of change between periods for salt marsh.

		Mean Patch Size		Median Patch Size			First Quartile Patch Size			Third Quartile Patch Size			Total Land Cover Area			Number of Patches		
Land-cover Type	*n*	1979 (ha)	1991 (ha)	Initial *p*-level	1979 (ha)	1991 (ha)	Initial *p*-level	1979 (ha)	1991 (ha)	Initial *p*-level	1979 (ha)	1991 (ha)	Initial *p*-level	1979 (ha)	1991 (ha)	Initial *p*-level	1979 (ha)	1991 (ha)
Developed Land	50	0.09	0.09	0.695	0.04	0.04	0.286	0.02	0.02	0.004	0.07	0.07	0.000	2222	2744	0.000	22506	28089
Managed Grassland	43	0.16	0.16	0.531	0.07	0.08	0.128	0.03	0.03	0.484	0.17	0.18	0.000	3322	4076	0.000	23470	28935
Barren Land	69	0.50	0.45	0.629	0.15	0.14	0.084	0.07	0.05	0.013	0.40	0.40	0.001	3691	3944	0.001	8821	9839
Crop Land	25	0.68	0.69	0.234	0.41	0.54	0.039	0.15	0.26	0.396	0.68	1.06	0.023	3575	3356	0.003	2428	1964
Orchards	15	0.54	0.48	0.117	0.59	0.35	0.612	0.20	0.20	0.678	0.73	0.71	0.507	2250	1946	0.575	1128	1118
Blueberry Fields	13	0.93	0.95	0.059	0.69	0.71	0.080	0.36	0.35	0.398	1.35	1.19	0.790	3500	3839	0.374	2419	2519
Cranberry Bogs	6	1.27	1.59	-	0.84	1.21	-	0.43	0.60	-	1.65	2.06	-	952	1130	-	700	773
Herbaceous	45	0.25	0.19	0.014	0.14	0.12	0.099	0.06	0.05	0.127	0.31	0.22	0.111	1486	1226	0.043	3428	3683
Scrub/shrub	51	0.38	0.31	0.410	0.18	0.20	0.554	0.09	0.08	0.150	0.46	0.43	0.621	3195	3529	0.122	4747	5265
Forest	69	10.17	7.57	0.002	0.54	0.45	0.016	0.08	0.07	0.000	3.81	3.39	0.003	113851	112366	0.000	19178	22824
Salt Marsh	7	23.32	23.32	-	12.73	12.73	-	0.94	0.94	-	24.18	24.18	-	6360	6360	-	227	227
Water	45	0.31	0.27	0.039	0.16	0.15	0.084	0.08	0.07	0.300	0.35	0.30	0.619	2910	2797	0.012	2446	2846
All Cover Types	72	0.44	0.40	0.005	0.16	0.15	0.280	0.07	0.06	0.000	0.47	0.39	-	-	-	0.000	91498	108084

significance of this change could not be determined because the number of photoplot pairs was too low (n = 6) to complete the matched-pairs tests (Sokal and Rohlf 1987). Salt marsh cover was not tested because it did not change between periods (Figure 4).

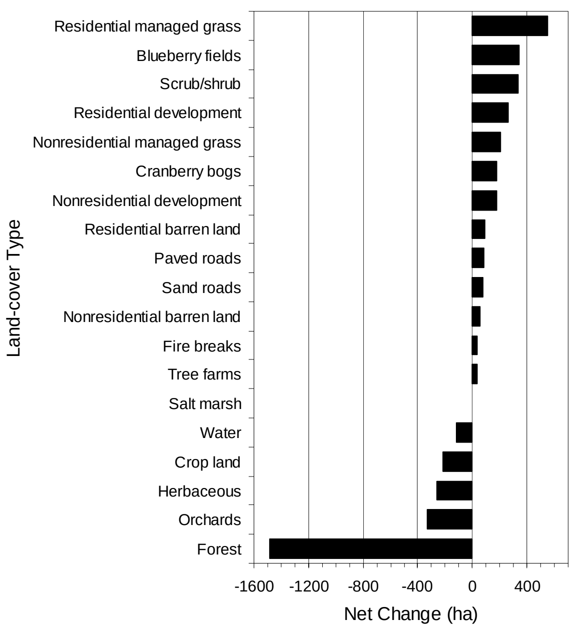


Figure 4. Estimated net change in land-cover area between 1979 and 1991 in the Mullica River basin. Change values are basin-wide numbers that have been extrapolated from 72 photoplots (11% of the basin).

The change in forest land between 1979 and 1991 represented the largest overall decrease in area (Figure 4). For this cover type, we found a significant increase in the number of patches and a significant decrease in total area and the median and third quartile patch-sizes (Table 2). Based on median photoplot values, there was a 19% increase in the number of patches and a 17% decrease in median forest-land patch size. We also found a significant increase in the number of patches and a significant decrease in median and third quartile patch size for all cover types combined. Although not included in the statistical analysis, mean patch size also decreased between periods for forest land and all cover types combined. Differences for scrub/shrub cover, herbaceous cover, and water cover between periods were not significant. We found no significant differences for the first quartile patch-size values (which represent the smallest patches) between periods for any cover type.

Land-cover Transitions

Retention values, which represent the amount of a land-cover type that did not change between 1979 and 1991, ranged from 49% - 100% (Table 3). Besides salt marsh, which did not change during the period, herbaceous cover had the lowest percentage retention and cranberry bogs the highest (99%). Based on the 72 photoplots, 5.3% of the basin area was estimated to have changed cover type between periods. These changes included several transitions estimated to be greater than 100 ha. For agricultural cover types, about one-quarter of the orchard land was converted to crop land and a small amount was converted to blueberry fields. A small amount of barren-land cover was also converted to blueberry fields. For the majority of the barren land converted to blueberry fields, the heavy machinery was visible preparing the land on the 1979 photography. About 20% of the 1979 crop land was converted to orchards and managed grassland. A small percentage of the crop land succeeded to scrub/shrub cover.

We found several other successional changes between periods estimated to be greater than 100 ha (Table 3). Approximately one-third of the herbaceous cover in 1979 was converted to scrub/shrub cover and forest cover in 1991. About one-third of the scrub/shrub cover was also converted to forest cover during this period. A large percentage of the total area that changed from herbaceous to scrub/shrub cover, herbaceous to forest cover, and scrub/shrub to forest cover occurred in abandoned agricultural fields and other fields. Between 1979 and 1991, the total amount of herbaceous and scrub/shrub cover that succeeded to forest cover was similar to the amount of forest cover that was converted to herbaceous and scrub/shrub cover. The vast majority of the latter transition occurred as a result of fire and timber harvests.

There was a net decrease of forest land between 1979 and 1991 (Figure 4). The majority of the developed land, managed grassland, and barren land created between 1979 and 1991 originated from forest land. Conversion of various previously disturbed covers accounted for the additional increase in these three covers. Compared to crop land, orchards, and blueberry fields, the percentage of new cranberry bogs created from forest land was high (Table 3). All new bogs were established in abandoned bogs that had succeeded to forest cover prior to 1979. The conversion of water to scrub/shrub also occurred in abandoned bogs.

Table 3. Transition matrix for land-cover types between 1979 and 1991. The top number (bolded) is the percentage area (± 1 SD) and the bottom number is the total area (ha) for cover-type transitions and the basin totals. Data were generated from 72 photoplots (11% sample of the basin) and land-cover area totals were projected to the entire basin by dividing site-based values by 0.11. Retention values are on the diagonal and represent the percentage and area of a land-cover type that did not change between 1979 and 1991.

1979 Land-cover types	1991 Land-cover types: Developed land	Managed grassland	Barren land	Crop land	Orchards	Blueberry fields	Cranberry bogs	Herb-aceous	Scrub/shrub	Forest	Salt marsh	Water	1979 Mullica basin net total
Developed land	**97.7** 2171	**0.6** 13	**0.9** 20	**-** -	**<0.1** 1	**-** -	**-** -	**0.1** 3	**0.5** 10	**0.1** 3	**-** -	**-** -	**1.5 (± 3.2)** 2222
Managed grassland	**1.6** 55	**92.6** 3077	**1.1** 38	**0.3** 10	**0.5** 15	**0.4** 13	**-** -	**1.3** 45	**1.1** 37	**1.0** 33	**-** -	**-** -	**2.3 (± 4.2)** 3322
Barren land	**2.9** 108	**1.9** 69	**85.5** 3156	**0.3** 13	**0.2** 8	**4.6** 169	**0.1** 2	**0.8** 29	**2.2** 82	**1.0** 38	**-** -	**0.5** 19	**2.5 (± 2.1)** 3691
Crop land	**0.6** 22	**6.1** 218	**1.1** 39	**73.1** 2614	**13.4** 478	**1.2** 42	**<0.1** 1	**1.0** 37	**3.2** 116	**0.2** 9	**-** -	**-** -	**2.4 (± 7.0)** 3575
Orchards	**0.1** 1	**1.7** 39	**0.9** 20	**27.5** 618	**61.7** 1388	**6.1** 137	**-** -	**1.3** 30	**0.3** 8	**0.3** 8	**-** -	**-** -	**1.5 (± 5.9)** 2250
Blueberry fields	**-** -	**0.5** 16	**0.9** 33	**0.1** 2	**0.1** 2	**95.8** 3352	**0.6** 20	**0.6** 22	**1.1** 38	**0.3** 12	**-** -	**0.1** 3	**2.4 (± 9.0)** 3500
Cranberry bogs	**-** -	**-** -	**0.4** 3	**-** -	**-** -	**-** -	**99.4** 946	**-** -	**-** -	**-** -	**-** -	**0.3** 3	**0.6 (± 3.0)** 952
Herbaceous	**2.0** 30	**2.5** 38	**3.0** 44	**1.8** 27	**-** -	**3.4** 51	**-** -	**48.7** 725	**21.1** 314	**15.2** 226	**-** -	**2.1** 31	**1.0 (± 1.9)** 1486
Scrub/shrub	**0.5** 18	**2.2** 70	**1.5** 49	**1.1** 36	**1.0** 33	**0.8** 24	**0.4** 12	**2.3** 73	**59.2** 1893	**30.7** 981	**-** -	**0.2** 6	**2.2 (± 3.0)** 3195
Forest	**0.3** 340	**0.5** 536	**0.4** 498	**<0.1** 35	**<0.1** 21	**<0.1** 47	**0.1** 134	**0.2** 227	**0.8** 922	**97.5** 111056	**-** -	**<0.1** 35	**77.3 (± 26.7)** 113851
Salt marsh	**-** -	**-** -	**-** -	**-** -	**-** -	**-** -	**-** -	**-** -	**-** -	**-** -	**100** 6360	**-** -	**4.3 (± 16.8)** 6360
Water	**-** -	**<0.1** 1	**1.5** 45	**-** -	**-** -	**0.1** 3	**0.5** 15	**1.2** 35	**3.8** 109	**<0.1** 1	**-** -	**92.8** 2699	**2.0 (± 5.2)** 2910
1991 Mullica basin net total	**1.9 (± 3.9)** 2744	**2.8 (± 5.2)** 4076	**2.7 (± 1.9)** 3944	**2.3 (± 6.7)** 3356	**1.3 (± 4.6)** 1946	**2.6 (± 10.5)** 3839	**0.8 (± 3.5)** 1130	**0.8 (± 1.4)** 1226	**2.4 (± 4.0)** 3529	**76.3 (± 26.5)** 112366	**4.3 (± 16.8)** 6360	**1.9 (± 5.1)** 2797	**100** 1474 km^2

Pinelands Management Area Analysis

Ninety-eight percent of the Mullica River basin falls within the Pinelands National Reserve and is under Commission jurisdiction (Figure 1). Fifty-five percent of this portion of the basin is Preservation Area District (Figure 5). The other seven management areas total less than 13% each. Although the basin-wide percentage of most management areas is similar to that in the photoplot-based sample, extrapolation of photoplot-based results must be made with caution because the sample was not specifically designed to be representative of the management areas in the basin.

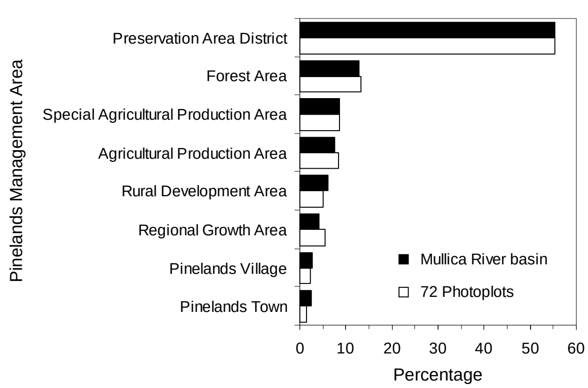


Figure 5. Percentage composition of Pinelands Management Areas for 72 photoplots and for the entire Mullica River basin.

The type of land-cover changes were consistent with the management areas in which the transitions occurred (Figure 6). Although there were increases in developed land and managed grassland in all eight management areas, the largest gains occurred in Regional Growth and Rural Development Areas. The increase in managed grassland in the Preservation Area District was due to the conversion of crop land to pasture land near the edge of this area in the northwestern portion of the basin. Barren land increased in the Special Agricultural Production Area and Preservation Area District due to agricultural activities and the expansion of resource-extraction areas. The decrease in barren land in Agricultural Production Areas was due mostly to the creation of blueberry fields. Barren land decreased in Regional Growth Areas from the development of land cleared prior to 1979.

Major agricultural transitions were limited to Regional Growth Areas, Agricultural Production Areas, and Special Agricultural Production Areas (Figure 6). There was a conversion of crop land to orchards in Regional Growth Areas. An opposite trend was observed in Agricultural Production Areas. Blueberry fields and cranberry bogs were created in Agricultural Production Areas and Special Agricultural Production Areas, respectively.

Herbaceous cover was lost in all management areas except the Special Agricultural Production Areas and Pinelands Villages (Figure 6). There were very small increases in herbaceous cover in these two management areas. Scrub/shrub cover was lost to developed land, managed grassland, and crop land in Regional Growth Areas and succeeded to forest land in abandoned-cranberry bogs and timber-harvest areas in the Special Agricultural Production Areas. The relatively large gain in scrub/shrub in the Preservation Area District was due to forest loss from fire and timber harvests. Forest was lost to developed land and managed grassland in Rural Development Areas and increased in Pinelands Towns due to succession of herbaceous and scrub/shrub cover in abandoned fields. The small loss of water cover in the Preservation Area District was mostly due to flooded abandoned bogs being drained.

Comparison of Commission Map with Other Maps

NJDEP Land-use Map Comparison

The comparison of the Commission land-cover types and NJDEP land-use classes showed that the composition of all NJDEP land-use classes was similar for 1986 and 1995 (Figure 7). All of the NJDEP land-use classes were composed of several Commission land-cover types.

The comparison confirmed the high, medium, low, and rural density classifications assigned to residential land use by the NJDEP (Figure 7). All four NJDEP residential land-use subclasses included some non-residential developed cover, which was mostly structures (with associated asphalt) and paved roads. The amount of total managed-grassland cover delineated on the Commission map was fairly constant among the four NJDEP residential land-use subclasses. About two-thirds of the NJDEP nonresidential-developed land-use subclass area was classified as nonresidential-development and managed-grassland cover on the Commission map. The nonresidential development in this land-use

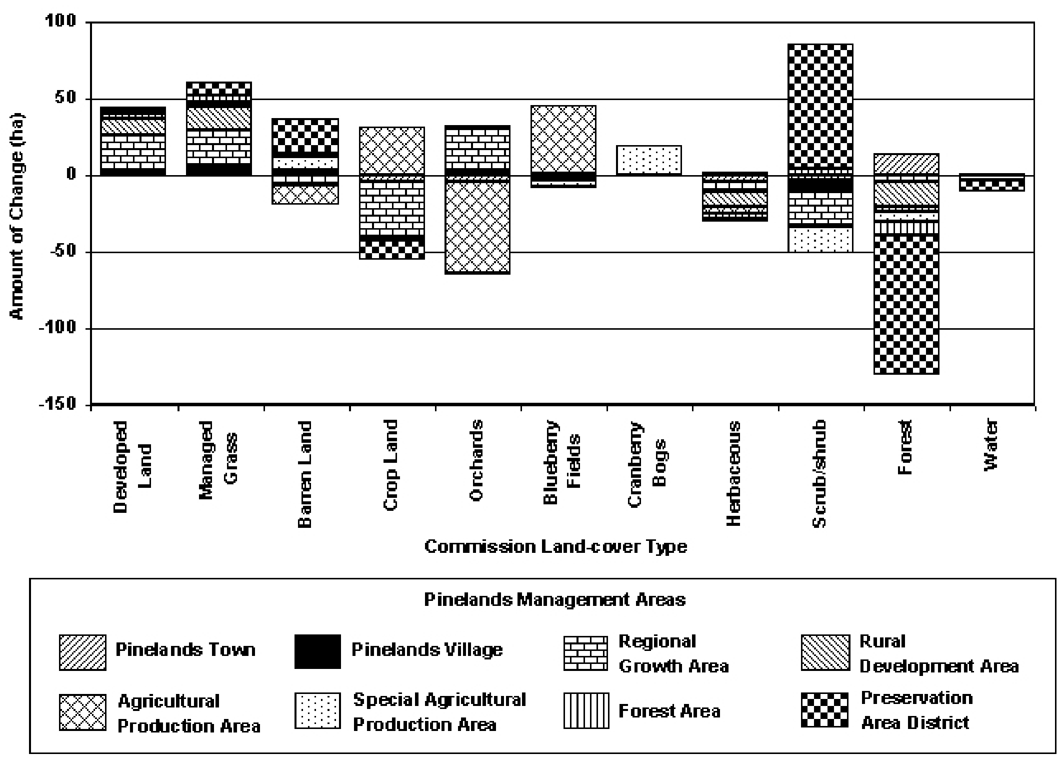


Figure 6. Changes in land-cover area by Pinelands Management Area between 1979 and 1991 in 72 photoplots in the Mullica River basin.

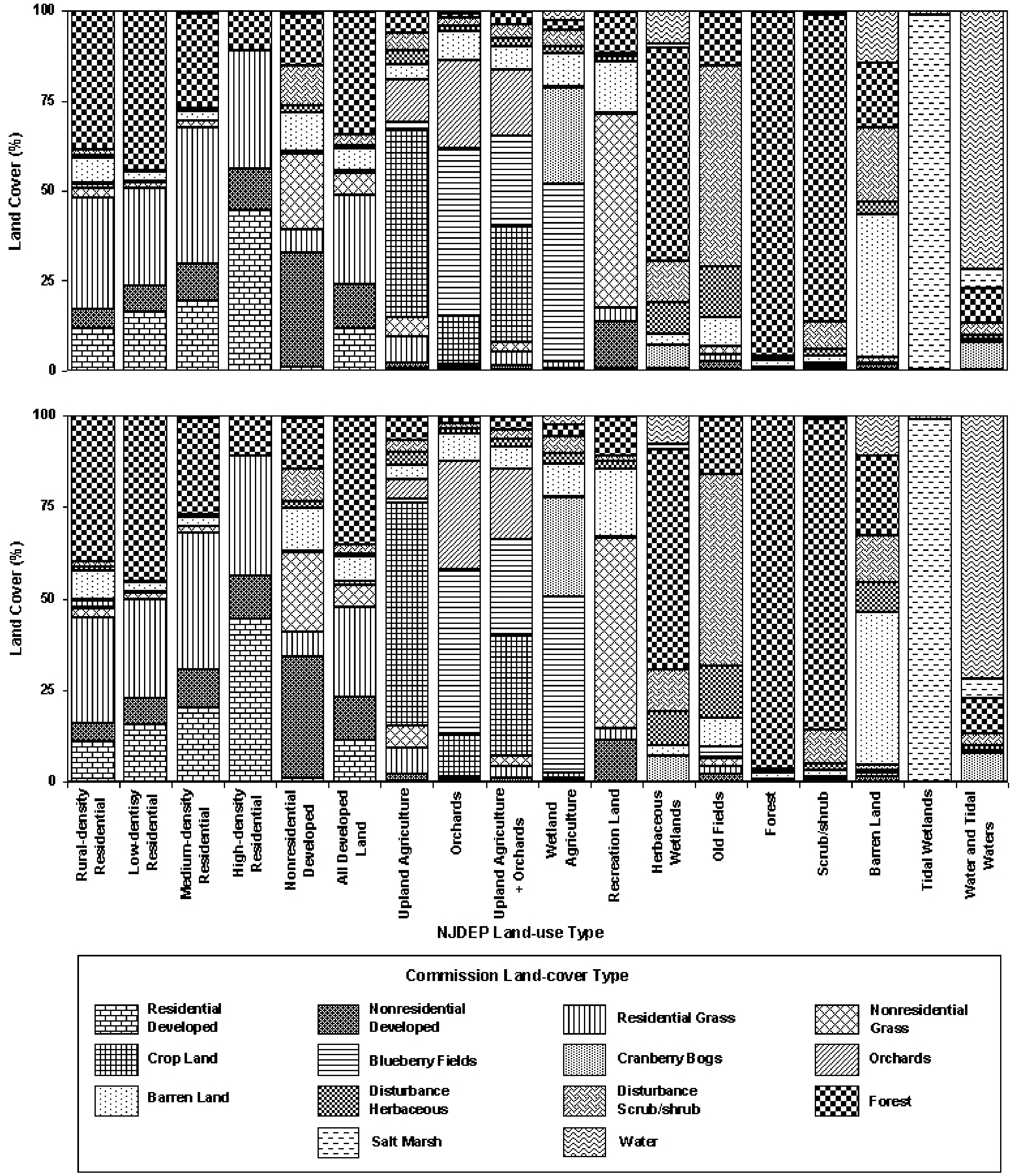


Figure 7. Land-cover composition of 1986 (top) and 1995 (bottom) NJDEP land-use types in 72 photoplots in the Mullica River basin. Refer to Table 1 for details regarding Commission and NJDEP classifications.

subclass was about half structures and half paved roads. Twenty-three percent of the total area designated as developed land by the NJDEP was classified as developed-land cover on the Commission map. The NJDEP recreation land, athletic field, and managed wetland land-use subclasses were composed mostly of managed-grassland, developed-land, and barren-land cover. These three Commission cover types were primarily associated with recreation areas such as athletic fields, campgrounds, and parks.

Approximately two-thirds of the NJDEP upland-agriculture land-use class, excluding orchards, were classified as blueberry fields, orchards, and crop land on the Commission map (Figure 7). About one-half of the NJDEP wetland-agriculture land-use subclass was composed of blueberry fields and one-quarter was cranberry bogs. The NJDEP orchard subclass was also about one-half blueberry-field cover. Thirty-two percent of the total blueberry-field area in the 1991 Commission map was classified as wetland agriculture in the NJDEP map, whereas 68% was mapped as upland agriculture and orchards.

Based on the Commission map, the NJDEP barren land-use class was composed primarily of barren land, forest, scrub/shrub, and water covers (Figure 7). These Commission cover types were generally associated with resource-extraction activities. The NJDEP herbaceous-wetland subclass and the total area covered by upland-forest scrub/shrub and wetland scrub/shrub subclasses were characterized as being dominated by forest cover because all undeveloped vegetated land was classified as forest land on the Commission map. The NJDEP old-field land-use class was predominantly herbaceous, scrub/shrub, and forest cover. Although this land use was defined as being < 25% brush cover in the Anderson et al. (1976) classification scheme, it was dominated by scrub/shrub cover. There was good correspondence between areas classified by the Commission as forest and areas mapped by NJDEP as upland forest and wetlands, excluding scrub/shrub cover. Areas designated as water by the Commission corresponded to areas mapped as water and tidal waters by the NJDEP. As mentioned previously, the 1986 NJDEP Freshwater Wetland data were used as a guide for the delineation of salt marsh on the 1991 Commission map. The cranberry-bog cover included in the NJDEP water and tidal waters class was due to the classification of cranberry reservoirs and bogs as cranberry bogs on the Commission map (Table 1).

We found a strong positive relationship between the amount of developed land depicted on the Commission map and the amount of impervious-surface cover in the NJDEP map for each impervious-surface estimate interval ($r = 0.99$, $p < 0.05$) (Figure 8). Although this indicated that the visual estimates of impervious surface in the NJDEP map were accurate, there were small differences between the two maps at each estimate interval. Compared to developed land in the Commission map, impervious-surface estimates tended to be lower in NJDEP polygons that were classified as 5% to 50% impervious and higher in those estimated at 55% to 100% impervious cover (Figure 8 inset). The greatest differences between the two maps were 10.6 ha at the 15% interval and 8.8 ha at the 20% interval. The magnitude of the difference between the Commission developed-land total and the NJDEP impervious-surface total was related to the number of polygons in the estimate interval ($r = 0.80$, $p < 0.05$). Of all the NJDEP polygons in the photoplots with impervious surface present, 83% were within the first four estimate intervals (5-20%) and 90% were < 2.0 ha. These results indicate that the differences between the Commission developed-land totals and the NJDEP impervious-surface totals were at least partly due to the large number of small polygons with impervious surface present.

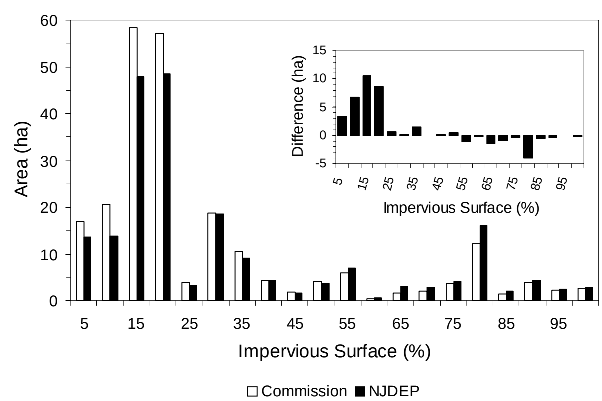


Figure 8. Total amount of developed land depicted on the 1991 Commission map and the amount of impervious surface depicted on the 1995 NJDEP map for each impervious-surface estimate interval. The difference (Commission developed land minus NJDEP impervious surface) for each estimate interval is shown in the inset.

Based on the 1995 NJDEP map for the whole basin, 23% of the NJDEP developed land-use area was designated as impervious surface by the NJDEP. As mentioned previously, the comparison of the

Commission map to the NJDEP map in the 72 photoplots indicated that 23% of the NJDEP developed-land use was actually developed cover.

NJDEP Land-use Transitions

NJDEP land-use transitions from 1986 through 1995 within the Pinelands National Reserve and the entire basin, including the small area located outside the Reserve, were similar (Tables 4 and 5). Retention values were generally high and ranged from 60% for the barren-land use to 100% for the tidal waters and wetlands use. The majority of the land-use changes during this period occurred with barren land, upland agriculture, developed land, and upland forest. Most of the barren-land conversion was to forest and developed-land uses. The transition of barren land to forest land occurred primarily in resource-extraction areas. Although a small amount of upland agriculture was converted to developed land, the greatest change in the upland-agriculture use was succession to upland-forest land. Conversely, upland-forest land was lost to upland agriculture, barren land, and developed land, with the largest amount being converted to developed land. In both the Pinelands National Reserve and the entire basin, developed land created from upland agriculture and forest land between 1986 and 1995 was predominantly residential development. The amount of residential versus nonresidential development created from barren land during the nine-year period was similar.

Landsat Thematic Mapper Comparison

We found a significant difference in total area between the Commission map and TM map for several cover types (Figure 9). Compared to the Commission map, the amount of barren-land, grassland, and woody-land (shrub/scrub and forest) cover was lower in the TM map, and the amount of developed-land and agricultural-land cover was higher. Differences in water, vines/bushes, and salt marsh cover were not significant.

Table 4. Transition matrix for major NJDEP land-use classes between 1986 and 1995 in the Pinelands National Reserve portion of the Mullica River basin. Transition values represent the percentage of the land-use area in each year.

	1995 Land-use class								1986 Mullica basin net total (ha)
1986 Land-use class	Upland agriculture	Wetland agriculture	Barren land	Upland forest	Developed land	Water	Wetlands	Tidal water and wetlands	
Upland agriculture	92.3	0.0	0.3	5.0	2.3	0.0	0.0	0.0	10281.8
Wetland agriculture	0.0	98.3	0.0	0.0	0.0	0.0	1.6	0.0	2315.3
Barren land	3.4	0.0	61.6	27.1	5.1	2.8	0.0	0.0	775.2
Upland forest	0.3	0.0	0.2	98.5	1.0	0.0	0.0	0.0	74338.4
Developed land	0.2	0.0	0.1	1.0	98.7	0.0	0.0	0.0	7516.1
Water	0.0	1.2	0.4	0.0	0.0	98.0	0.4	0.0	1809.4
Wetlands	0.0	0.3	0.0	0.0	0.1	0.0	99.6	0.0	38916.1
Tidal water and wetlands	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	7956.7
1995 basin total (ha)	9758.4	2429.2	673.4	74041.5	8439.6	1804.5	38802.9	7959.6	1,439 km^2

Table 5. Transition matrix for major NJDEP land-use types between 1986 and 1995 in the entire Mullica River basin. Transition values represent the percentage of the land-use area in each year.

	1995 Land-use class								1986 Mullica basin net total (ha)
1986 Land-use class	Upland agriculture	Wetland agriculture	Barren land	Upland forest	Developed land	Water	Wetlands	Tidal water and wetlands	
Upland agriculture	92.0	0.0	0.3	5.1	2.5	0.0	0.0	0.0	10380.8
Wetland agriculture	0.0	98.0	0.0	0.0	0.3	0.0	1.6	0.0	2323.2
Barren land	3.2	0.0	60.8	26.5	6.7	2.7	0.0	0.0	822.0
Upland forest	0.3	0.0	0.2	98.3	1.1	0.0	0.0	0.0	75870.6
Developed land	0.2	0.0	0.1	1.0	98.7	0.0	0.0	0.0	7960.9
Water	0.0	1.2	0.4	0.0	0.0	98.0	0.4	0.0	1857.3
Wetlands	0.0	0.3	0.0	0.0	0.1	0.0	99.6	0.0	39866.3
Tidal water and wetlands	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	8312.6
1995 basin total (ha)	9822.4	2430.5	719.2	75415.7	9092.2	1853.8	39744.6	8315.3	1,474 km^2

Sixty-one percent of all developed-land cover delineated on the Commission map was included as developed land in the TM map. Total developed land was significantly higher in the TM map compared to the Commission map because of the large amount of managed-grassland and forest cover present in the TM developed type (Figure 10). The land-cover composition of the TM developed type was similar to that for the NJDEP developed-land class (Figures 7 and 10). Total developed land in the TM map was separated into four developed types (high, moderate, low:wooded, and low:unwooded) based on the amount of impervious and barren-land cover present (Table 1). The comparison with the Commission map showed that the amount of developed cover in each of the four TM developed types was slightly underestimated (Figure 10).

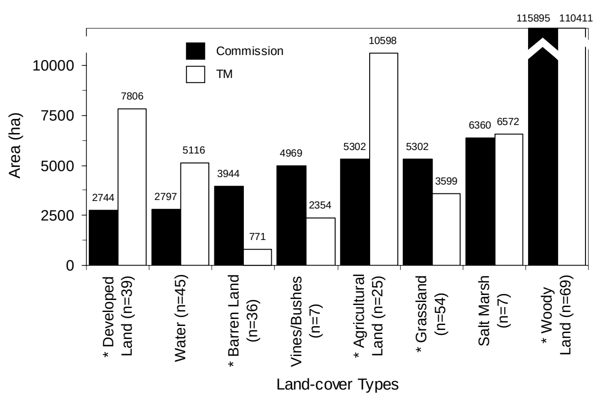


Figure 9. Commission and Landsat Thematic Mapper (TM) land-cover area totals for the Mullica River basin in 1991. Commission data are basin-wide values that have been extrapolated from seventy-two photoplots that represented 11% of the basin. TM data are the actual basin-wide values. The total number of hectares is given above each bar. Based on the results of Wilcoxon tests between matched photoplot pairs, land-cover types with an asterisk indicate a significant difference after sequential Bonferroni significance-level adjustment (k = 8 tests, $p < 0.004$ for the five significant results). The number of photoplot pairs with the cover type present (n) is in parenthesis.

Grassland cover was significantly lower in the TM map compared to the Commission map because herbaceous and managed grassland together comprised a relatively small proportion of the TM grassland type and the majority of the managed-grassland cover from the Commission map was included in the four TM developed types (Figure 10). Forest, scrub/shrub, and barren land were the dominant cover types in the TM grassland type. The barren-land cover present in the TM grassland type was mostly non-residential barren land, sand roads, and fire breaks. The scrub/shrub cover in the TM grassland type was associated with resource-extraction areas and burned areas. A small percentage of the TM grassland type was composed of developed-land cover, which was mostly non-residential structures and paved roads.

The TM agricultural type included 92% of all crop-land cover and 94% of all orchard cover present in the Commission map. However, agricultural land was significantly higher in the TM map compared to the Commission map because three-quarters of all blueberry-field cover from the Commission map was included as agricultural land rather than vines/bushes in the TM map (Figure 10). The majority of these blueberry fields were from the west-central part of the basin near Hammonton. Although the TM vines/bushes type included most of the remaining blueberry-field cover and two-thirds of the cranberry-bog cover present in the Commission map, vines/bushes cover was lower in the TM map versus the Commission map due to the exclusion of that large amount of blueberry-field cover from the TM vines/bushes type. The lack of significance for the difference in vines/bushes cover between the two maps may have been due to the low number of photoplot pairs ($n = 7$) with this cover combination in common. The barren-land cover in the TM agricultural-land and vines/bushes types was primarily sand-road cover. Sand roads are a common feature in Pinelands agricultural areas.

Barren land was significantly lower in the TM map compared to the Commission map because barren-land cover from the Commission map was present in several other TM cover types (Figure 10). Most of the barren-land cover that was included in TM types other than the TM barren-land type was cleared lots, sand roads, and fire breaks. Only about one-third of the TM barren-land type was classified as barren-land cover on the Commission map. The composition of the TM barren-land type was similar to that for the NJDEP barren land-use class (Figures 7 and 10). As with the NJDEP barren-land class, the majority of the Commission cover types present in the TM barren-land type was associated with resource-extraction activities. Approximately half of all barren-land cover that was associated with resource-extraction operations in the Commission map was included in the TM barren-land type.

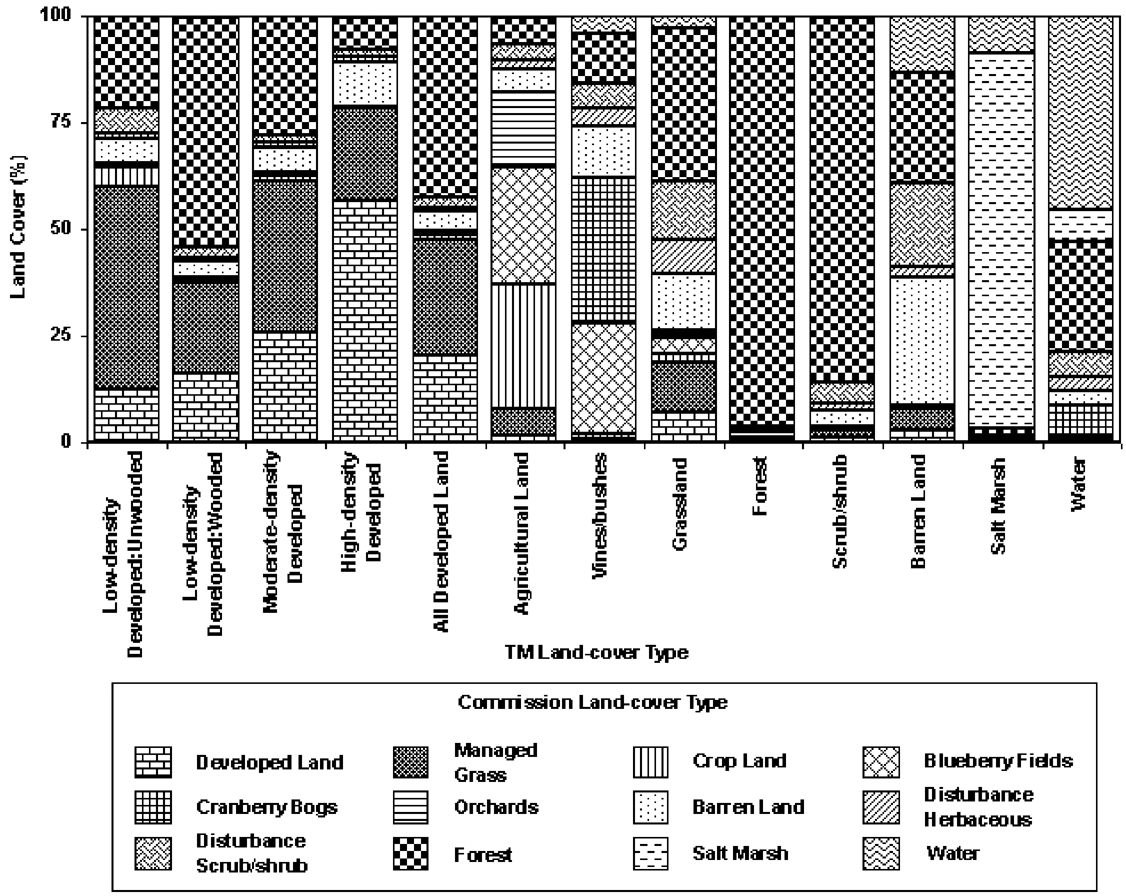


Figure 10. Land-cover composition of 1991 Landsat Thematic Mapper (TM) cover types in 72 photoplots in the Mullica River Basin. Refer to Table 1 for details regarding Commission and TM classifications.

Total woody land was significantly lower in the TM map versus the Commission map due to the amount of forest cover included in other TM cover types (Figure 10). Based on the Commission map, TM forest and scrub/shrub types were both characterized as being predominantly forest cover. The scrub/shrub type was characterized as forest cover mostly due to large areas in three photoplots being classified as forest in the Commission map and as scrub/shrub in the TM map. One area that appeared as mixed tree and scrub/shrub cover was harvested prior to 1979 and the other two areas were located in upland portions of the Pine Plains. The Pine Plains are dominated by short-stature pine and oak species (Good et al. 1979). Although we found no significant difference between the two maps for water cover, over half of the TM water type was composed of forest land and other covers combined. We found good agreement between the TM and Commission map salt marsh types.

Discussion

Landscape Changes between 1979 and 1991

Our results indicate that the major landscape changes that occurred in the basin between 1979 and 1991 were the loss of forest land to development and associated cover types and the conversion of one agricultural type to another. We observed a general shift from crop and orchard farming to berry farming. Both blueberry and cranberry farming is almost exclusively limited to the Pinelands in New Jersey and, based on U.S. crop rankings from 1997, (http://www.usda.gov/nass/pubs/ranking/crank97.htm), the state ranked second and third in the nation for blueberry and cranberry production, respectively. The gain in land area for berry farming corresponded to an overall increase in statewide production volume for both blueberries and cranberries between 1979 and 1991 (Pinelands Commission 2000).

Results from the analysis of landscape structure indicated that fragmentation of forest land and the landscape as a whole occurred during the period. Patches became smaller and more numerous. The results for the whole landscape reflect both the trends found for forest land, which dominated the landscape, and the increase in the number of patches for almost all cover types, especially development-related covers. The gain in area for paved and sand roads also played a role in the structural changes because new roads partitioned areas of forest into smaller patches.

Similar structural changes have been reported for forest land in other studies in the Pinelands. Using Landsat imagery from 1972 and 1988, Luque et al. (1994) compared landscape changes in the northeastern half of the Pinelands National Reserve to those in an area that extended further north and east that was not under Commission jurisdiction. They concluded that the decrease in the mean patch size and increase in the number of patches for forest land both inside and outside the Reserve were due to fragmentation. Results from a larger-scale study that used Landsat data from 1972, 1976, 1982, and 1988 throughout the entire National Reserve indicated that similar structural alterations occurred for forest land (Luque 2000a). It is especially noteworthy that the structural changes reported in these two studies were revealed using satellite imagery re-sampled to a very large (80 x 80 m) pixel.

The agreement between land-cover transitions and Pinelands Management Areas indicated that landscape changes corresponded with Commission management patterns. The larger increases in development-related covers were limited to management areas where growth is encouraged. Agricultural transitions occurred in areas designed to accommodate these land uses. Resource-extraction and timber-harvest operations were concentrated in the Special Agricultural Area and Preservation Area District.

Although significant landscape changes occurred in the basin, the overall percentage land-cover composition was similar in 1979 and 1991. The lack of large differences between the 1986 and 1995 NJDEP characterizations indicated that little additional change in land-cover composition occurred during the four years following 1991. These similarities emphasize the large percentage of forest land in the basin and the fact that more than half of the watershed is designated Preservation Area District, which is considered to be protected land.

Comparison of Commission Map with Other Maps

The NJDEP land-use characterization and impervious-surface analysis results are important because this map is a statewide GIS coverage that has many applications. Impervious-land cover has also been recently recognized as a major indicator of the status of environmental conditions (Arnold and Gibbons 1996). Field verification of over 40,000 polygons throughout New Jersey was completed to correct photo-interpretation errors and verify signatures during the NJDEP map-update process, but no formal accuracy assessment was reported for polygon classification or impervious-surface estimates in the metadata (1995/97 Land Use/Land Cover Update, released 2001). Although we only evaluated the Mullica River basin portion of the map, which represents about 7.5% of the state, our land-use characterization results lend credence to the quality of the photo-interpretation. The results of the impervious-surface analysis strongly suggest that the NJDEP impervious-surface estimates accurately represented developed land throughout the basin and that the 72-photoplot sample adequately characterized the NJDEP developed land-use.

The only notable inconsistencies between the Commission and NJDEP map classifications were with agricultural lands. We do not know whether the disparity associated with orchards and crop land was due to interpretation error or the different time periods in which the covers and uses were mapped (1979 and 1991 versus 1986 and 1995). The inclusion of blueberry fields in the two different NJDEP land-use types was due to the integration of a wetland coverage into the original 1986 land-use map. During the integration process, wetland classes took precedence over land-use classes and effectively separated all land uses into upland and wetland categories (1995/97 Land Use/Land Cover Update, released 2001).

The NJDEP characterization not only emphasized the difference between land-cover and land-use, but also indicated how these data can be used together to create models that better quantify the impacts of human-related land-use disturbance on ecosystem function. For example, Dow and DeWalle (2000) point out the need to supplement land-use data with detailed land-cover information, such as the amount of impervious surface, lawns, and forest cover present in developed-land uses, so that water and energy balances can be estimated more accurately. With the results of our characterization, the various cover types present in the developed uses can be assigned different levels of permeability and irrigation estimates could be generated for the managed-grassland covers in order to obtain more precise estimates of runoff, evaporation, and heat exchange than those derived from impervious-surface area or land-use data alone.

Satellite imagery has potential for widespread application to environmental monitoring (Westman 1987, Roughgarden et al. 1991). In the Pinelands and other areas of the state, several recent studies have used Landsat imagery to characterize land-cover conditions and measure landscape change (Luque et al. 1994, Royle and Lathrop 1997, Luque 2000a and b, Lathrop 2000, Stiles 2001). In our study, we found that TM and Commission map land-cover totals differed for several major cover types in the basin, and that developed, grassland, and agricultural covers were the most difficult to accurately classify from TM imagery. With respect to the amount of developed and barren-land cover present in the individual TM developed types, the differences between the Commission map and the TM map were minor and reasonable considering the size of a TM pixel and the amount of spectral mixing possible from the large number of relatively-small patches often found in developed areas. However, future TM classifications should attempt to incorporate the large amount of managed grassland associated with the developed landscape. In addition to the forest cover present, the TM grassland type seemed to be a catch-all for a variety of partially vegetated land covers.

Although agricultural cover for the most part was correctly classified in the TM map, orchards, cranberry bogs, and crop land were classified more accurately than blueberry fields. Blueberry fields contain rows of very short bushes that are typically separated by bare sand areas. Because the leaf-off TM image used to classify the basin was from March (Lathrop et al. 1997), it is possible that the spectral signature for blueberry fields was similar to that of some early-season crop land due to the bare land often present in both types of fields. A bare land signature in the Pinelands generally appears bright from the sandy soils, especially in upland areas, where the majority of the basin's blueberry-field cover was located.

Most of the barren-land cover included in the TM developed, grassland, agricultural, and vines/bushes types was composed of cleared lots, sand roads, and fire breaks, which may be too small or narrow to be adequately captured by the 30 x 30-m TM pixel. Similarly, the presence of forest cover in the TM water type is at least partly due to the sinuosity of water-body shorelines and narrowness of small impoundments. A large percentage of the scrub/shrub, forest, and water cover included in the TM barren-land type was associated with resource-extraction operations. Portions of these covers may have been classified as barren land because areas that contained < 25% vegetation were considered barren in the TM map (Table 1). Our finding that salt marsh was accurately classified in the TM map is important for C-CAP because one of the primary objectives is to monitor changes in wetland land-cover in coastal regions of the United States (Dobson et al. 1995).

The accuracy of Landsat-derived maps can be determined through various assessment protocols, but many evaluations compare groups of like pixels (e.g., a 3 x 3 pixel region) to large homogenous areas on the ground to generate a quantitative error matrix for each cover type (Congalton and Green 1999). A 3 x 3 region in a TM image is an 8100 m^2 area. Although valuable, this approach characterizes the accuracy of cover types using only the larger polygons in the image and ignores single pixels, smaller groups of pixels, ecotone areas, and linear and diagonal features (Congalton and Green 1999). These heterogeneous areas are difficult to classify with satellite imagery because of the mixture of spectral signatures present within and among individual pixels. Statistical relationships between the proportions of different land-cover types in mixed pixels and the spectral signatures of those pixels can be used to develop spectral-mixture models to improve classification accuracy (Settle and Drake 1993).

Although not a quantitative accuracy assessment, the characterization that we completed was unique in that it included all classified TM pixels present in the photoplots and provided a detailed composition of every TM type. This kind of comparison can identify the cover types in any region that are difficult to classify and assist with the formulation of approaches to address problem areas. However, we do not advocate the use of such characterization methods in lieu of statistically-rigorous accuracy-assessment procedures, but rather recommend both techniques to improve image classification and the long-term monitoring potential of satellite-based imagery.

ACKNOWLEDGMENTS

We thank Barry Moraller and Roman Senyk for scanning aerial photographs, Dan Dombroski of the New Jersey Geological Survey for the use of 1978/79 aerial photographs, and Larry Thornton from NJ Department of Environmental Protection for the in-house usage of their digital orthophotography to obtain ground-control points. Portions of this report were developed using New Jersey Department of Environmental Protection Geographic Information System digital data. This study was supported by the National Park Service and the Pinelands Commission.

LITERATURE CITED

Anderson, J. R., E. E. Hardy, J. T. Roach, and R. E. Witmer. 1976. A land use and land cover classification system for use with remote sensor data. U.S. Geological Survey Professional Paper 964.

Arnold, C. L., Jr. and C. J. Gibbons. 1996. Impervious surface coverage: the emergence of a key environmental indicator. Journal of the American Planning Association 62:243-258.

Bunnell, J. F. and R. A. Zampella. 1999. Acid water anuran pond communities along a regional forest to agro-urban ecotone. Copeia 1999:614-627.

Collins, B. R. and E. W. B. Russell. 1988. Protecting the New Jersey Pinelands. Rutgers University Press, New Brunswick, New Jersey, USA.

Congalton, R. G. and K. Green. 1999. Assessing the accuracy of remotely sensed data: principles and practices. Lewis Publishers, New York, New York, USA.

Dobson, J. E., E. A. Bright, R. L. Ferguson, D. W. Field, L. L. Wood, K. D. Haddad, H. Iredale III, J. R. Jensen, V. V. Klemas, R. J. Orth, and J. P. Thomas. 1995. NOAA coastal change analysis program (C-CAP): guidance for regional implementation. NOAA Technical Report NMFS 123.

Dow, C. L. and D. R. DeWalle. 2000. Trends in evaporation and Bowen ratio on urbanizing watersheds in eastern United States. Water Resources Research 36:1835-1843.

Fahrig, L. and G. Merriam. 1985. Habitat patch connectivity and population survival. Ecology 66:1762-1768.

Findlay, C. S., and J. Houlahan. 1997. Anthropogenic correlates of species richness in southeastern Ontario wetlands. Conservation Biology 11:1000-1009.

Franklin, J. F. and R. T. T. Forman. 1987. Creating landscape patterns by forest cutting: ecological consequences and principles. Landscape Ecology 1:5-18.

Gibbs, J. P. 1998. Distribution of woodland amphibians along a forest fragmentation gradient. Landscape Ecology 13:263-268.

Good, R. E., N. F. Good, and J. W. Andresen. 1979. The Pine Barren Plains. Pages 283-295 *in* R. T. T. Forman, editor. Pine Barrens: ecosystem and landscape. Academic Press, New York, New York, USA.

Good, R. E. and N. F. Good. 1984. The Pinelands National Reserve: an ecosystem approach to management. Bioscience 34:169-173.

Goward, S. N., C. J. Tucker, and D. G. Dye. 1985. North American vegetation patterns observed with the NOAA-7 advanced very high resolution radiometer. Vegetatio 64:3-14.

Hooge, P. N. and B. Eichenlaub. 1997. Animal movement extension to arcview. ver. 1.1. Alaska Biological Science Center, U.S. Geological Survey, Anchorage, Alaska, USA.

Jensen, J. R. 1996. Introductory digital image processing: a remote sensing perspective, 2nd ed., Prentice Hall, Upper Saddle River, New Jersey, USA.

Iverson, L. R., E. A. Cook, R. L. Graham. 1989. A technique for extrapolating and validating forest cover across large regions: calibrating AVHRR data with TM data. International Journal of Remote Sensing, 10:1805-1812.

Lathrop, R. G., J. A. Bognar, R. A. Zampella, and J. F. Bunnell. 1997. Monitoring landscape change in the New Jersey Pinelands National Reserve. Proceedings of the 1997 ACSM/ASPRS Annual Convention, April 7-10, 1997, Seattle, Washington 4:88-95.

Lathrop, R. G. 2000. Land cover change analysis project: 1972 - 1984 - 1995. Center for Remote Sensing and Spatial Analysis, Rutgers University, New Brunswick, New Jersey, USA.

Leopold, L. B. 1968. Hydrology for urban land planning - a guidebook on the hydrologic effects of urban land use. U.S. Geological Survey Circular 554.

Luque, S. S., R. G. Lathrop, and J. A. Bognar. 1994. Temporal and spatial changes in an area of the New Jersey Pine Barrens landscape. Landscape Ecology, 9:287-300.

Luque, S. S. 2000a. Evaluating temporal changes using Multi-spectral Scanner and Thematic Mapper data on the landscape of a natural reserve: the New Jersey Pine Barrens, a case study. International Journal of Remote Sensing, 21:2589-2611.

Luque, S. S. 2000b. The challenge to manage the biological integrity of nature reserves: a landscape ecology perspective. International Journal of Remote Sensing, 21:2613-2643.

NJDEP (New Jersey Department of Environmental Protection) 1996. New Jersey Geographic Information System CD-ROM series 1, volumes 1 - 4.

Odum, E. P. and M. G. Turner. 1990. The Georgia landscape: a changing resource. Pages 137-164 *in* I. S. Zonneveld and R. T. T. Forman, editors. Changing landscapes: an ecological perspective. Springer-Verlag, New York, New York, USA.

Pinelands Commission. 2000. Long-term economic monitoring program 2000 annual report. New Lisbon, New Jersey, USA.

Rice, W. R. 1989. Analyzing tables of statistical tests. Evolution 43:223-225.

Robinson, S. K., F. R. Thompson III, T. M. Donovan, D. R. Whitehead, and J. Faaborg. 1995. Regional forest fragmentation and the nesting success of migratory birds. Science 267:1987-1990.

Roland, J. and P. D. Taylor. 1997. Insect parasitoid species respond to forest structure at different spatial scales. Nature 386:710-713.

Roughgarden, J., S. W. Running, and P. A. Matson. 1991. What does remote sensing do for ecology? Ecology 72:1918-1922.

Royle, D. D. and R. G. Lathrop. 1997. Monitoring hemlock forest health in New Jersey using Landsat TM data and change detection techniques. Forest Science 43:327-335.

Settle, J. J. and N. A. Drake. 1993. Linear mixing and the estimation of ground cover proportions. International Journal of Remote Sensing 14:1159-1177.

Sokal, R. R. and F. J. Rohlf. 1987. Introduction to biostatistics. W. H. Freeman and Company, New York, New York, USA.

Stehman, S. V. and W. S. Overton. 1994. Environmental sampling and monitoring. Pages 263-306 *in* G. P. Patil and C. R. Rao, editors. Handbook of statistics, Volume 12. Elsevier Science, The Netherlands.

Stiles, E. P. 2001. A landscape analysis of migrant landbird stopover habitat on Cape May peninsula, New Jersey, from 1972 through 1995 using remote sensing data. Masters Thesis. Rutgers University, New Brunswick, New Jersey, USA.

Tucker, C. J., J. R. G. Townshend, and T. E. Goff. 1985. African land-cover classification using satellite data. Science 227:369-374.

Turner, M. G. 1987. Land use changes and net primary production in the Georgia, USA, landscape: 1935 to 1982. Environmental Management 11:237-247.

Turner, M. G. and C. L. Ruscher. 1988. Changes in landscape patterns in Georgia, USA. Landscape Ecology 1:241-251.

Turner, M. G., R. H. Gardner, V. H. Dale, and R. V. O'Neill. 1989. Predicting the spread of disturbance across heterogenous landscapes. Oikos 55:121-129.

Turner, M. G. 1990a. Landscape changes in nine rural counties in Georgia. Photogrammetric Engineering and Remote Sensing 56:379-386.

Turner, M. G. 1990b. Spatial and temporal analysis of landscape patterns. Landscape Ecology 4:21-30.

USDA. 1986. Urban hydrology for small watersheds. U.S. Department of Agriculture, Soil Conservation Service. Technical Release 55.

Westman, W. E. 1987. Monitoring the environment by remote sensing. Trends in Ecology and Evolution 2:333-337.

Zampella, R. A. 1992. Long-term Pinelands monitoring program. Task 1: study area selection. New Jersey Pinelands Commission, New Lisbon, New Jersey, USA.

Zampella, R. A. and K. J. Laidig. 1997. Effect of watershed disturbance on Pinelands stream vegetation. Journal of the Torrey Botanical Society 124:52-66.

Zampella, R. A. and J. F. Bunnell. 1998. Use of reference-site fish assemblages to assess aquatic degradation in Pinelands streams. Ecological Applications 8:645-658.

Zampella, R. A. and J. F. Bunnell. 2000. The distribution of anurans in two river systems of a Coastal Plain watershed. Journal of Herpetology 34:210-221.