# Land-use Change in the Atlantic Coastal Pine Barrens Ecoregion

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# LAND–USE CHANGE IN THE ATLANTIC COASTAL PINE BARRENS ECOREGION

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ABSTRACT. Information on the rates, characteristics, and drivers of land-use change are vital for addressing the impacts and feedbacks of change on environmental processes. The U.S. Geological Survey's Land Cover Trends project is conducting a consistent, national analysis of the rates, causes, and consequences of land-use change. In this article we assess change in the Atlantic Coastal Pine Barrens ecoregion from 1973 to 2000. Urban lands expanded by more than 900 square kilometers during the study period. Land-use change in the ecoregion followed the tenets of "Forest Transition Theory" (FTT) prior to the study period, but forest lands experienced consistent declines from 1973 to 2000. Increasing government regulation during the study period, consistent with concept of the "Quiet Revolution" (QR), mitigated forest loss during the latter half of the study period. Generalized theories, including FTT and the QR, are valuable, but local and regional determinants of comparative land rents ultimately drive land-use change at this scale. *Keywords: change, land cover, land use, pine barrens, trends.*

Land-use and land-cover (LULC) change is the primary modifier of the landscape, ultimately affecting a broad range of socioeconomic, biological, climatic, and hydrologic systems. Information on the rates, characteristics, and drivers of change are needed if we are to address the impacts and feedbacks of LULC change on environmental processes. LULC change is inherently a local event (Sohl, Gallant, and Loveland 2004), and LULC change data are necessary at the local to regional scale if we are to understand the cumulative impacts at multiple scales. Given that the characteristics of LULC change can vary dramatically among regions, LULC data that capture the uniqueness of each region are essential (Gallant and others 2004; Sohl, Gallant, and Loveland 2004). Although researchers have conducted innumerable LULC-change studies, without common spatial, temporal, and thematic frameworks it is difficult for LULC scientists to understand the linkages between different LULC analyses and develop generalized and widely applicable LULC theory.

The U.S. Geological Survey's (USGS's) Land Cover Trends project focuses on understanding the rates, trends, patterns, causes, and consequences of contemporary LULC change in the conterminous United States (Loveland and others 2002). It uses a consistent framework to provide estimates of LULC change by ecoregion, providing the basis for telling the unique story of change for eighty-four different Environmental Protection Agency (EPA) Level III ecoregions (Omernik 1987).[1] Its results also fulfill the need for a regionally stratified, national-scale analysis of LULC change (Gallant and others 2004; Sohl, Gallant, and Loveland 2004; Loveland and Acevedo 2007).

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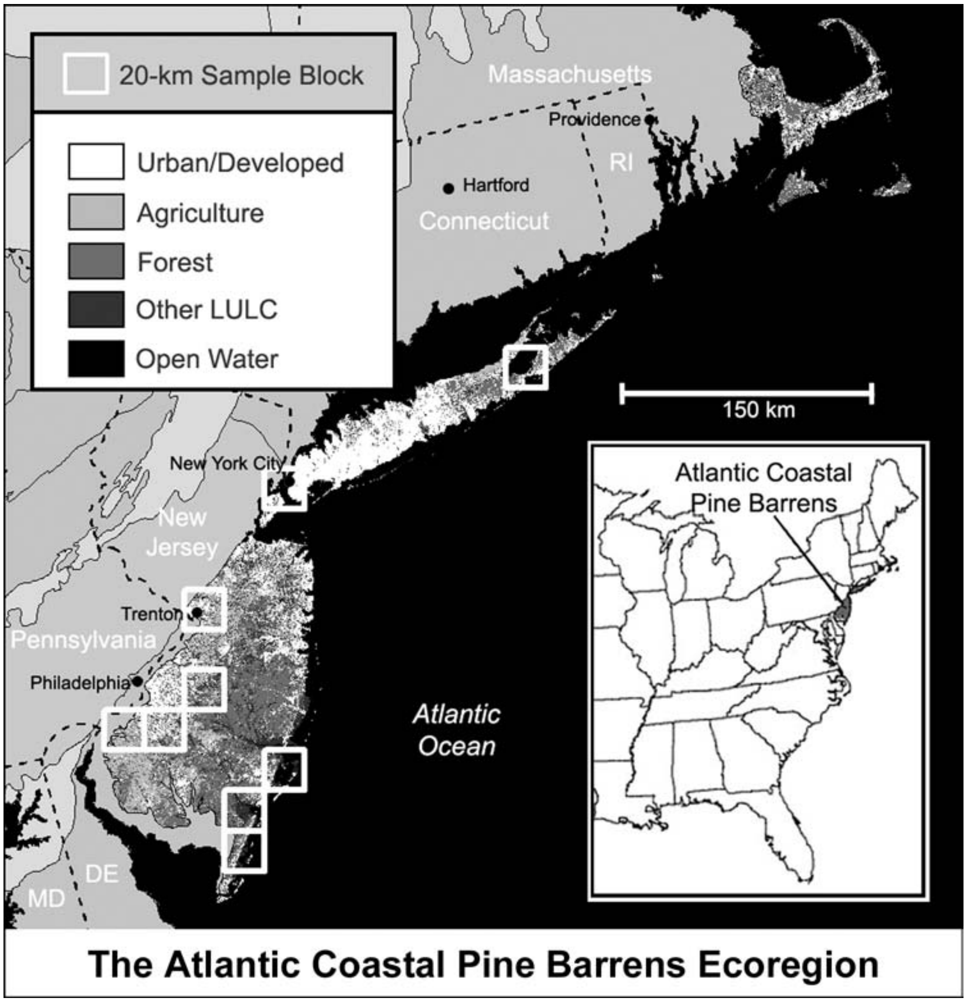


FIG. 1—The Atlantic Coastal Pine Barrens ecoregion. The randomly selected, 20-by-20-kilometer sample blocks used to analyze land-use and land-cover change in the ecoregion are indicated as hollow squares. Early-1990s land-use and land-cover change are depicted within the ecoregion boundaries. *Sources:* Vogelmann, Sohl, and Howard 1998; Loveland and others 2002. (Cartography by Terry L. Sohl)

In this article we examine LULC change from 1973 to 2000 in one ecoregion, the Atlantic Coastal Pine Barrens, a relatively small area covering parts of New Jersey, New York, and Massachusetts that once comprised unique habitats, including pitch pine and scrub oak, cedar swamps, and maritime grasslands (Figure 1). Despite major conservation efforts (Good and Good 1984; Mason 1992), however, urbanization and urban sprawl encroached on significant parts of the ecoregion (Dinerstein and others 2010). The Land Cover Trends project methodology provides data to quantify these changes, capturing contemporary rates and patterns of land-cover change. Within the context of these data, we look at the primary driving forces of recent LULC change in the ecoregion and relate the changes to the theoretical constructs of "Forest Transition Theory" (FTT) and the "Quiet Revolution" (QR).


Fig. 2—High-value nursery products are sold in many portions of the Atlantic Coastal Pine Barrens ecoregion. (Photograph by Thomas Loveland, March 2002)

## The Atlantic Coastal Pine Barrens Ecoregion

The Atlantic Coastal Pine Barrens ecoregion covers about 16,000 square kilometers of the coastal plain—roughly the southern half of New Jersey, New York's Long Island, and Massachusetts's Cape Cod, Martha's Vineyard, Nantucket, and nearby islands (see Figure 1). It is the second smallest of the eighty-four EPA Level III ecoregions (Omernik 1987). Rainfall averages around 122 centimeters per year, but the soil is sandy, extremely porous, and drains very quickly. The soils are generally dry, except where the Cohansey-Kirkwood Aquifer intersects the surface, resulting in the bogs and swamps (Canace and Sugarman 2009). A wide variety of relatively rare ecological community types exist here, among them pitch-pine–scrub-oak barrens, cedar swamps and sphagnum bogs, coastal plain salt ponds and dune systems, and unique maritime grasslands.

Fire is a major natural disturbance factor that influences the composition of vegetation in the Atlantic Coastal Pine Barrens ecoregion (Little 1979; Mason 1992; Russell 1994). In the absence of disturbance, the vegetation cover likely would become dominated by oaks and other hardwoods (Little and Moore 1949; Buell and Cantlon 1950). However, fires often sweep across the land, giving the advantage to species able to survive and even thrive after a conflagration (Mason 1992). Pitch pine is the dominant pine in the mixed pine-oak forests due to its ability to regenerate quickly. Other fire-tolerant species, such as bracken fern, which regenerates from its root stocks, are common in the ecoregion. Sediment cores from lakes in the region indicate an abundance of pitch-pine pollen, providing evidence that this habitat had been present in some form for thousands of years (Parshall and Foster 2002; Parshall and others 2003).

Parts of the ecoregion represent some of the best-preserved habitat in the eastern United States, partially because the generally poor soils in the ecoregion restrict many agricultural activities. Suitability for agriculture is especially limited in parts of the New Jersey portion of the ecoregion, where acid-loving blueberries and cranberries are often the only crops grown in quantity. However, portions of Long Island and scattered locations in the New Jersey portion of the ecoregion possess rich soil capable of supporting other forms of agriculture (Figure 2). Suffolk County, on the eastern half of Long Island, is New York's leading county in wholesale value of agricultural products, producing nursery products—cut flowers, potted plants, bedding plants—vegetables, fruits and berries, and sod and turf grass, as well as having significant grape and wine industries (USDA 2012).

Although parts of the Pine Barrens are relatively well preserved, other parts of the ecoregion are among the most highly developed areas on the face of the earth. Significant development of urban and suburban housing, retirement communities, commercial and industrial zones, and vacation homes has occurred throughout the ecoregion, especially on the western half of Long Island, Cape Cod, and the New Jersey Shore (Sohl 2008).

## Historical Land–Use and Land–Cover Change, 1700s–1970

Early settlement took place around the periphery of the Atlantic Coastal Pine Barrens ecoregion (Wacker 1979), while settlers used the pine barrens habitat for resource extraction, especially timber. Settlers established sawmills in the region as early as 1704 (Defebaugh 1906–1907), with rot-resistant white cedar used for shingling, ship building, and fence building (Muntz 1959). The nearby cities of New York and Philadelphia provided a market for large quantities of timber products. Pitch pine provided a source of wood for construction and furniture, with the resin used for naval stores. As lumbermen depleted woodlands near New York City and Philadelphia, the Pine Barrens became a primary source of fuelwood (Wacker 1979), a resource that also fed new industries. Well before the Industrial Revolution an iron industry flourished in the New Jersey portion of the ecoregion (Braddock-Rogers 1930). The ecoregion's "bog-iron" industry depended on iron deposits in swamps, in bogs, and along riverbanks (Crerar, Knox, and Means 1979). Forests provided timber with which to make charcoal for powering the iron furnaces and forges, and lime required in the smelting process came from clam and oyster shells found on nearby shorelines. The bog-iron industry reached its peak between 1812 and 1840 but ended by the 1860s because higher-grade iron deposits discovered in Pennsylvania and elsewhere were much easier to utilize (Braddock-Rogers 1930). Glass industries also took advantage of the natural resources of the Pine Barrens. The availability of high-quality sand and trees for fuel, plus the proximity of the Philadelphia and New York City markets, made glassmaking a viable industry until about 1890 (Lee and Hauck 1943).

Beginning in the 1850s, railroads helped to encourage truck farming, fruit farming, and tourism. Berry agriculture replaced rural industries in many areas, with cranberry production beginning with the first human-made cranberry bog in New Jersey in 1835 (RCE 2006). By 1916, a commercially profitable domestic blueberry agriculture developed in the region (Good and Good 1984). Portions of the ecoregion with richer soils provided substantial quantities of fresh fruits and vegetables to New York City and Philadelphia, but farmers began to abandon marginal agricultural lands in the region around 1850 (Hall and others 2002). Cultivated cropland in the region peaked around 1880 (Figure 3), as railroads and improved transportation networks allowed agriculture on the better soils west of the Appalachians to supply the New York City and Philadelphia markets (Waisanen and Bliss 2002). Between 1910 and 1940, the area of improved farmland dropped by one-third to one-half (Lee and Hauck 1943). Because of the abandoned agricultural land, forest cover in the region gradually increased during the twentieth century (Scheller and others 2008).

The enormous demand for wood through the nineteenth century, clearing of land for agriculture, and uncontrollable forest fires drastically changed the landscape from its prehistoric form (Berger and Sinton 1985). The frequency of fires initially increased in the region after European settlement, due to the use of fire for clearing land and to accidental ignitions (Parshall and others 2003; Howard and others 2005; Scheller and others 2008). However, active fire suppression in the twentieth century reduced the frequency of fires and altered the composition of vegetation in the region. The unique pitch-pine–scrub-oak habitat declined as a result of fire-suppression activities, while fire-intolerant oak, other hardwood species, and white pines increased (Little 1979; Forman and Boerner 1981; Motzkin, Patterson, and Foster 1999; Luque 2000; Jordan, Patterson, and Windisch 2003).

Land used for urban development in the ecoregion concentrated in major urban centers through the early twentieth century. Since 1920, population growth and urban development have steadily pushed outward from the major urban centers. The "core" New York counties around central New York City—Bronx, Kings, Queens, and New York—each had more than 1 million residents by 1930. Population in these counties increased until the automobile-dominated era after World War II, when urban development concentrated in suburbs of the major cities (Figure 4). The greater New York City / northern New Jersey metropolitan area encroached from the north into central New Jersey, while the Philadelphia urban area pushed into the ecoregion from the west as the New Jersey suburbs expanded. The western and central sections of Long Island became extensive suburbs of New York City, with both Nassau and Suffolk counties reaching more than 1 million residents each by 1970. The pace of growth in these counties started to level off after 1970, but very strong growth continued in the New Jersey portion of the ecoregion (see Figure 4). In addition to suburban growth, Atlantic City and other resort communities were established on many of the barrier islands along the New Jersey shore, and commercial activities associated with seasonal resorts quickly became a critical

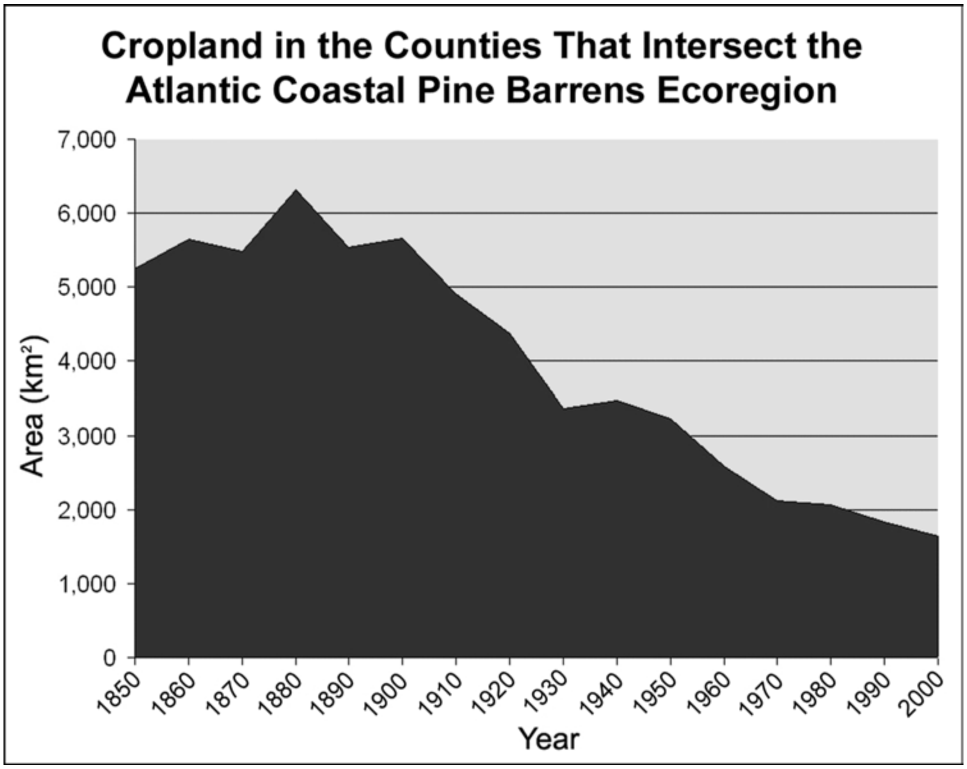


FIG. 3—The extent of cropland in all of the counties that intersect the Atlantic Coastal Pine Barrens ecoregion. In the nineteenth century, forests were cleared for agricultural land use, with total cropland in these counties reaching a peak of more than 6,000 square kilometers by 1880. As agricultural production in the United States shifted westward, abandonment of agricultural land resulted in a recovery of forest land. *Source:* Waisanen and Bliss 2002. (Graph by Terry L. Sohl)

component of the regional economy. Resort development also impacted Cape Cod, Martha's Vineyard, and eastern Long Island, as did the establishment of retirement villages.

## Measuring Rates of Contemporary Land–Use and Land–Cover Change, 1973–2000

The Land Cover Trends project used nine 20-by-20-kilometer sample blocks to generate estimates of contemporary LULC change in the Atlantic Coastal Pine Barrens ecoregion for the 1973–2000 period (see Figure 1). We developed estimates of change by mapping LULC for five dates—1973, 1980, 1986, 1992, and 2000—using ten thematic classes:

- Developed: High- or low-density residential, commercial, industrial, or transportation land uses.
- Cropland and pasture: Cultivated and uncultivated croplands, hay lands, pasture, orchards, vineyards, and confined livestock operations.

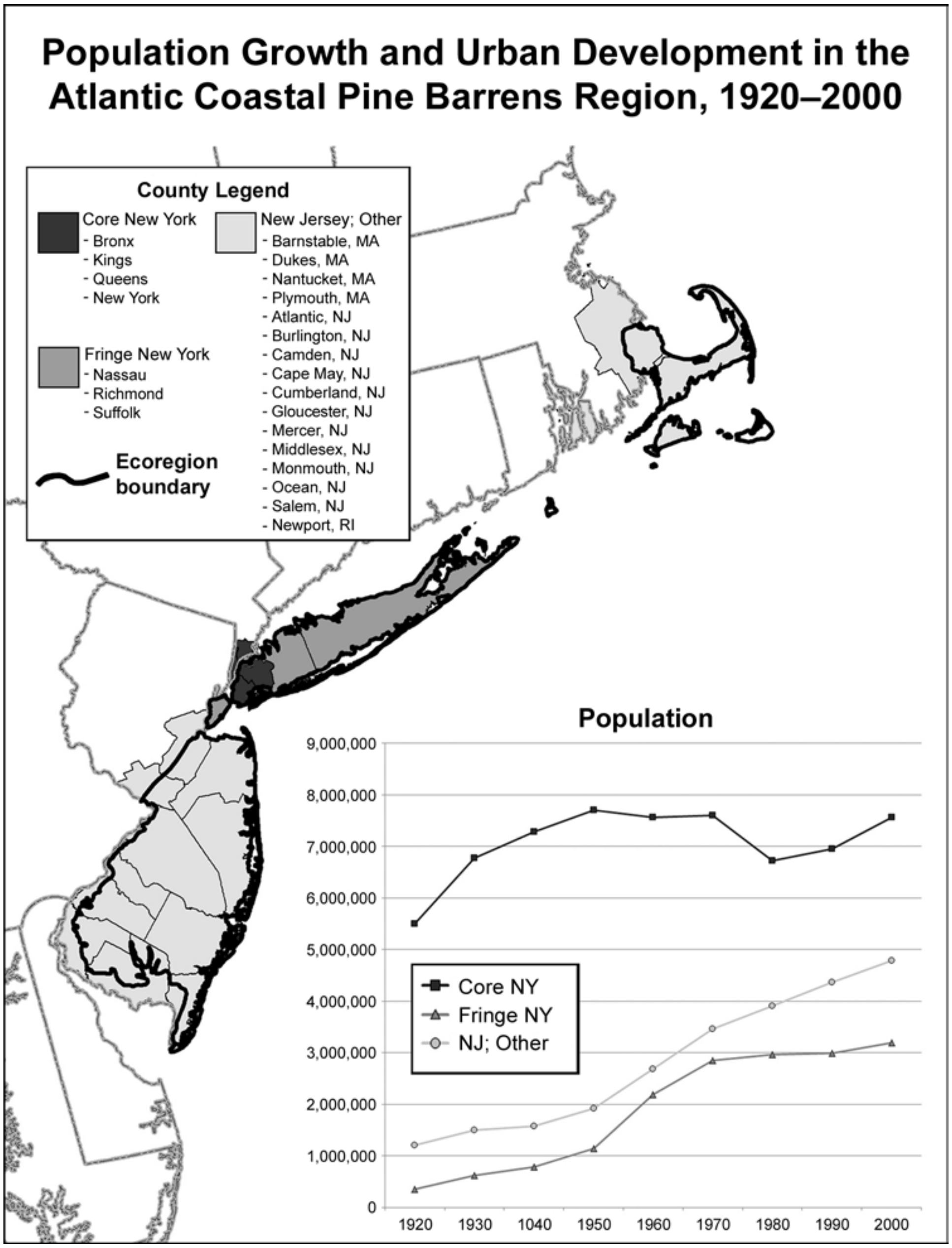


FIG. 4—During the first half of the twentieth century, populations in the Atlantic Coastal Pine Barrens ecoregion increased most rapidly in the "core" New York counties in and around New York City. After World War II, populations in these counties stayed relatively constant, while "fringe" New York counties and the New Jersey portion of the ecoregion experienced rapid population growth as urban development concentrated in the suburbs of New York City and Philadelphia. The rate of growth declined in New York counties after 1970 but remained very strong in the rest of the ecoregion. *Source:* Forstall 1995. (Cartography and graph by Terry L. Sohl)

- Forests and woodland: Land where the tree-cover density is greater than 10 percent.
- Shrubland/grassland: Vegetated land where grasses, forbs, or shrubs compose at least 10 percent of the area.
- Wetland: Lands where water saturation is the determining factor in soil characteristics, vegetation types, and animal communities.
- Water: Areas persistently covered with water, such as streams, canals, lakes, reservoirs, bays, or oceans.
- Natural barren: Land that comprises natural occurrences of soils, sand, or rocks where less than 10 percent of the area is vegetated.
- Mined lands: Quarries, overburden, leach, tailings, or other significant surface expression of mining activities.
- Mechanically disturbed: Forest clear-cutting, earthmoving, scraping, chaining, reservoir drawdown, or other related human-induced changes
- Nonmechanically disturbed: Natural disturbances, including wind, floods, fire, and other related sources.

The analysis that follows is therefore primarily focused on LULC change as defined by the thematic classification system. Note that we used an intensive, manual interpretation process to classify LULC change for each sample block, utilizing not only Landsat MSS and TM but also historical aerial photography (Loveland and others 2002).[2]

The footprint of change in the eco–region–that is, the percentage of area that changed at least one time from 1973 to 2000—was 5.8 percent (Table I). Although 5.4 percent of the ecoregion area changed just once during the four distinct time periods, only 0.4 percent of the ecoregion changed multiple times. Overall rates of LULC conversion were low compared with those in other ecoregions of the eastern United States (Figure 5).

TABLE I—PERCENTAGE OF THE ATLANTIC COASTAL PINE BARRENS ECOREGION TOUCHED BY LAND–USE AND LAND–COVER CHANGE, 1973–2000

| NUMBER OF CHANGES | PERCENTAGE OF THE AREA CHANGED |
|---|---|
| 1 | 5.4 |
| 2 | 0.3 |
| 3 | 0.1 |
| 4 | 0.0 |
| Total | 5.8 |

Temporally, overall change was relatively stable over each of the four time intervals, varying from 1.4 percent to 1.7 percent of the ecoregion area (Table II). When normalized to account for varying time-interval lengths, annual rates of change peaked during the 1980–1986 time period and were lower but generally equivalent for the other three time intervals.

In contrast to the relatively low overall rates of LULC conversion in the Atlantic Coastal Pine Barrens compared with those in other eastern U.S. ecoregions, in terms of urban development the area is one of the most dynamic eastern ecoregions. More than 4.7 percent of the ecoregion—covering more than 900 square kilometers—converted to urban development between 1973 and 2000 (Table III). Similar

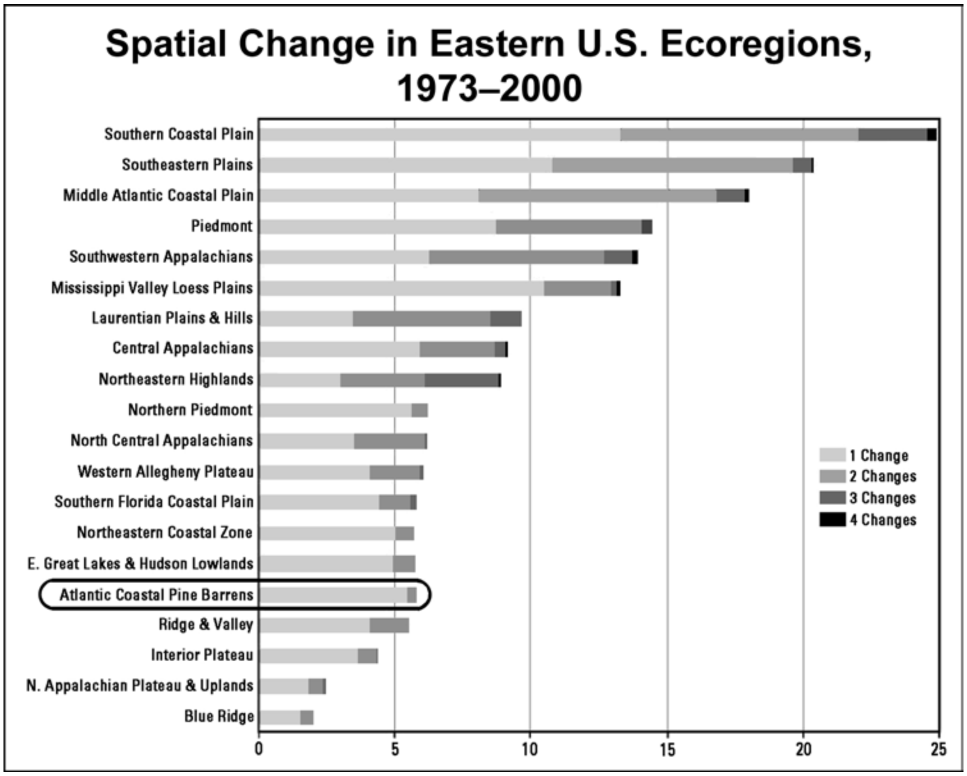


FIG. 5—The overall spatial change in all eastern U.S. ecoregions, as measured by the Land Cover Trends project. Each bar chart shows the proportion of the ecoregion that experienced LULC change on one, two, three, or four dates. *Source:* Modified from Loveland and Acevedo 2007. (Graph by Kristi L. Sayler, U.S. Geological Survey)

TABLE II—OVERALL ESTIMATES OF LAND–USE AND LAND–COVER CHANGE AND OF NORMALIZED ANNUAL CHANGE IN THE ATLANTIC COASTAL PINE BARRENS ECOREGION, 1973–2000[a]

| TIME PERIOD | ESTIMATED PERCENTAGE OF CHANGE | STANDARD ERROR | LOWER BOUNDARY | UPPER BOUNDARY | AVERAGE ANNUAL PERCENTAGE OF CHANGE |
|---|---|---|---|---|---|
| 1973–1980 | 1.5 | 0.6 | 0.9 | 2.0 | 0.2 |
| 1980–1986 | 1.7 | 0.6 | 1.2 | 2.3 | 0.3 |
| 1986–1992 | 1.4 | 0.5 | 0.9 | 1.9 | 0.2 |
| 1992–2000 | 1.6 | 0.8 | 0.8 | 2.4 | 0.2 |

[a] The margin of error is at the 85 percent level.

increases in developed land use are found in the adjacent Northern Piedmont ecoregion (Auch and others 2012), which, along with the Pine Barrens ecoregion, covers much of the northeastern U.S. Megalopolis.

Figure 6 shows urban development peaking during the 1980–1986 time period, with an average of just over 40 square kilometers converted to developed uses annually, followed by significant declines in development rates to approximately 32 square

TABLE III—PERCENTAGE OF COVERAGE IN EACH LAND–COVER CLASS IN THE ATLANTIC COASTAL PINE BARRENS ECOREGION, WITH TRENDS AND TESTS OF TREND SIGNIFICANCE, 1973–2000

| | Water | Developed | Mechanically Disturbed | Mined Lands | Natural Barren | Forests and Woodland | Shrubland/ Grassland | Cropland and Pasture | Wetland |
|---|---|---|---|---|---|---|---|---|---|
| 1973 | 16.9 | 25.5 | 0.2 | 0.4 | 0.8 | 23.3 | 0.1 | 17.4 | 15.3 |
| 1980 | 17.0 | 26.5 | 0.0 | 0.5 | 0.8 | 22.8 | 0.1 | 17.0 | 15.2 |
| 1986 | 17.0 | 27.8 | 0.1 | 0.6 | 0.8 | 22.2 | 0.2 | 16.2 | 15.2 |
| 1992 | 17.0 | 28.9 | 0.1 | 0.6 | 0.8 | 21.9 | 0.1 | 15.4 | 15.2 |
| 2000 | 17.1 | 30.2 | 0.1 | 0.6 | 0.8 | 21.5 | 0.1 | 14.5 | 15.1 |
| 1973–2000 | 0.1 | 4.7 | –0.1 | 0.2 | 0.0 | –1.8 | 0.0 | –2.9 | –0.2 |
| *P*, paired t-test | 0.22 | <0.01 | 0.43 | 0.04 | 0.47 | <0.01 | 0.78 | 0.05 | 0.04 |

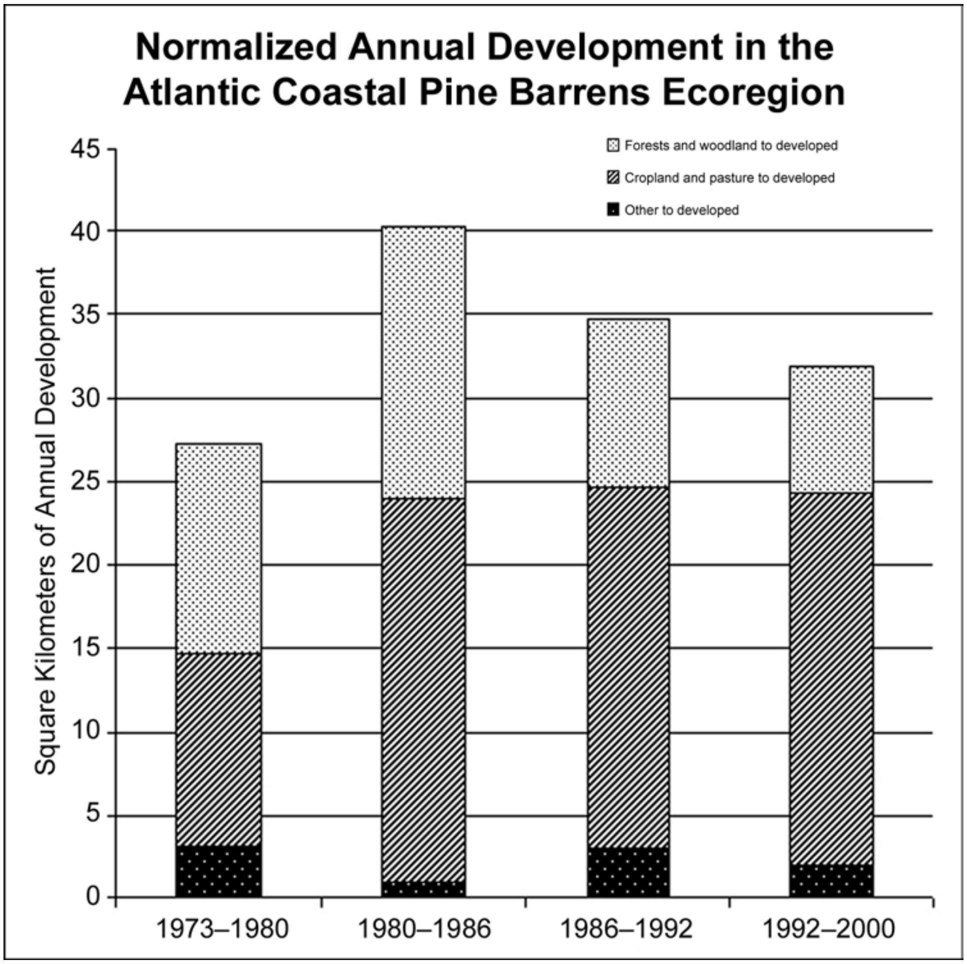


FIG. 6—Normalized annual development in square kilometers for the Atlantic Coastal Pine Barrens ecoregion. Total annual development peaked during the 1980–1986 time period and declined through the last two time periods. Urban development of agricultural land remained at a relatively stable rate through the last three time periods, but the rate of development of forest land dropped substantially. (Graph by Terry L. Sohl)

kilometers annually by the 1992–2000 time period. Conversion of cropland and pasture (530 square kilometers) and of forests and woodlands (310 square kilometers) makes up the vast majority of urban development, and results show statistically significant declining trends for each (see Table III). Rates of development of cropland and pasture, and of forests and woodland, are very similar during the 1973–1980 time period (see Figure 6). However, subsequent time periods show an obvious shift in this balance, with rates of development in forests and woodland peaking and then significantly declining after the 1980–1986 time period. Rates of development in cropland and pasture remain nearly constant during the last three time periods, despite a significant decline in overall development rates.

## Drivers of Contemporary Land–Use and Land–Cover Change, 1973–2000

Historical LULC change prior to the Land Cover Trends study period reveals a landscape that largely followed the tenets of FTT (Mather 1992; Mather and Needle 1998). Based largely on empirical evidence from European and North American forest histories, FTT predicts general stages of forest use as economic development occurs in a region: Initial economic development rapidly depletes forests and woodland, through clearing for agricultural and other uses and through exploitation of forest products for fuelwood, industrial purposes, and lumber. Eventually, a region reaches a point of minimum forest cover. With maturation of the economy and technological innovation, cropland and pasture concentrate in areas of large expanses of highly fertile land, while biophysical constraints—soil, water, and climate—in more marginal lands result in abandoned fields and regeneration of forest cover. These U-shaped forest-cover trends seem to fit the Atlantic Coastal Pine Barrens ecoregion. Cutting of forests and woodland for agricultural uses, along with the extensive fires, decimated forest habitats by the late 1800s. Cropland and pasture in the ecoregion peaked around 1880 but then began to decline as the Midwest and Great Plains became the agricultural breadbasket of the United States (see Figure 3). Abandoned agricultural lands naturally regenerated to forest cover, resulting in the predicted U-shaped temporal curve.

However, as the Land Cover Trends data show, the Atlantic Coastal Pine Barrens ecoregion experienced consistent declines in forest cover during the 1973–2000 time period, in conjunction with concurrent declines in agricultural land and significant increases in developed land. A similar pattern existed in the eastern United States as a whole, with forests and woodlands experiencing overall declines from 1973 to 2000 (Drummond and Loveland 2010). With the continued downward trend in forest cover, the FTT temporal trajectory clearly does not sufficiently describe contemporary forest-cover trends in this region. In 2007 Arild Angelsen attempted to reconcile the generalized temporal curve of forest cover in FTT with the von Thünen model of relative agricultural and forest land rent. Angelsen noted that FTT focuses on the temporal trend of forest change, whereas the von Thünen model focuses on the spatial component of change. In 2008 Robert Walker noted that the concept of FTT was not originally designed to be applied to small areas. FTT generally applies even to the relatively small spatial extent of the Atlantic Coastal Pine Barrens, but only through the mid-twentieth century. At the spatial and temporal scale of our analysis, it is the unique regional and local characteristics of the ecoregion that drive both comparative land rents among LULC classes and contemporary LULC trends.

For the eastern United States as a whole, Mark Drummond and Thomas Loveland postulate that land-use intensification, urban expansion, and diminished capacity for agricultural land abandonment characterize the recent stage of net forests and woodland loss (2010), a pattern that also fits the Atlantic Coastal Pine Barrens ecoregion. Farmers abandoned marginal cropland and pasture in much of the eastern United States as the center of agricultural production shifted to the Midwest and Great Plains (Waisanen and Bliss 2002). The resulting increase in forests and woodland owing to abandonment more than offset the losses in forest land cover due to urban development or other LULC changes. In recent decades, however, the rate at which forests and woodland in the eastern United States have been abandoned has declined as the pool of marginal agricultural land parcels has declined (Drummond and Loveland 2010). This is especially true in the Atlantic Coastal Pine Barrens ecoregion. Given the typically poor agricultural soils and low land rents for large-scale agricultural cultivation, cropland and pasture land use were already largely confined to high-quality agricultural areas by the beginning of our study period. Combined with the intense development pressure in the region and the long land-use history in the region, which had allowed for the development of "mature" land-use patterns, it is likely that by 1973 little "marginal" agricultural land was still being used for agriculture. Indeed, the Land Cover Trends results show a lack of agricultural land abandonment in this ecoregion between 1973 and 2000, with only 28 square kilometers of agricultural land reverting to forest over the entire study period. Widespread abandonment of agricultural land simply did not drive forest expansion in the FTT framework in this period.

The unique characteristics of regional geography led to widespread urban development in the ecoregion and to contemporary declines in forests and woodland. New Jersey's growth was historically dependent on urban and industrial spillover from nearby New York City and Philadelphia, with growth largely associated with the extension of transportation systems and along the emerging beltway cities (see Figure 4) (Brown and others 2005). The region also experienced dramatic increases in retirees and retirement communities, as well as expanding recreational opportunities. By the start of this study period, Ocean County, New Jersey, had become a magnet for retirement communities (Mason 1992), accounting accounted for nearly 70 percent of the entire state's population growth in the 1970s (Forstall 1995; OCDP 2010). In 1981 Ocean County had twenty-six retirement communities; in 1999, seventy-nine, with a total of 56,186 units (OCDP 2010). The age structure of the region began to change: The town of Manchester, New Jersey, for example, had a median age of sixty-eight by 1990 (OCDP 2010). Increased populations, especially of retired persons with large amounts of free time, also resulted in a greatly increased demand for recreation centers, including golf courses and beaches (Figure 7). The legalization of gambling at Atlantic City in 1976 created more pres-sure to develop adjacent pinelands areas in New Jersey and along major highways linking Atlantic City and Philadelphia (Russell 1994).

Population and development pressure and associated high land rents for commercial and residential land uses led to high levels of urban development in the ecoregion. The resulting cutting of forests and woodland resulted in a departure in forest land-cover trends from what the FTT predicted. All of New Jersey's counties with land in the ecoregion grew at a rate faster than the state average during the 1970s (Collins and Russell 1988). Suburbanization also continued in eastern Long Island, especially around the Hamptons, where large-lot rural subdivisions were

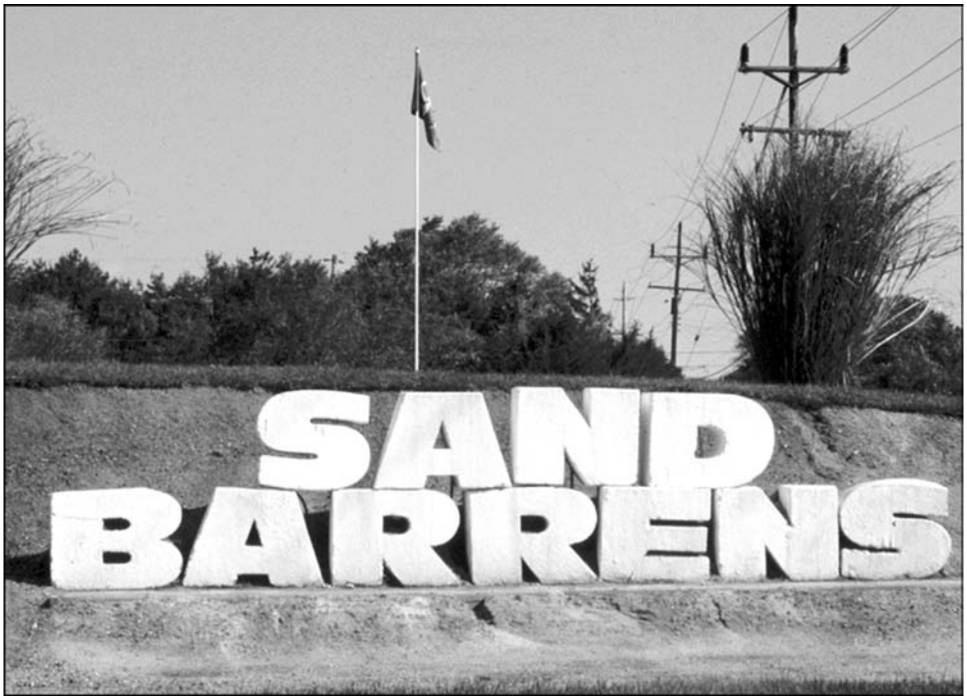


FIG. 7—Recreational uses, such as golf courses and vacation homes, are an important driving factor of land-use and land-cover change in many parts of the Atlantic Coastal Pine Barrens ecoregion. (Photograph by Thomas Loveland, March 2002)

common. The population on Cape Cod also grew rapidly, as Barnstable County more than doubled its population (96,000–222,000) between 1970 and 2000 (Forstall 1995). As we noted above, the rate of annual urban development in the ecoregion peaked in the 1980–1986 period, with subsequent declines in urbanization rates primarily associated with decreased development of forests and woodland (see Figure 6).

Even with the constant drop in forests and woodland during the study period, greater forest losses were likely without the effects of the QR. In 1971 Fred Bosselman and David Callies proposed the concept of the QR in a report commissioned for President Richard Nixon's Council on Environmental Quality. The report supported Nixon's proposed Land Use Policy Act of 1971, an unsuccessful bill that would have provided federal assistance to states to develop policies for dealing with land-use issues of regional or state concern. Bosselman and Callies served as both "advocates and prophets" for the QR (Bronin 2008), stating that some issues, including environmental protection, transcend the ability of local government to manage and that a revolution was needed to shift land-use planning and control from the local level to states. A basic and innovative tenet of the QR was the recognition of land as not only a commodity but also as a resource, where land has intrinsic value–scenic beauty or biodiversity support, for example—other than the capability to generate income for its owner (Bosselman and Callies 1971). They stated that the QR had already begun and predicted that it would continue. In 2008 Sara Bronin argued that the QR had not occurred nationally, largely due to fierce desire for local government to maintain control of land-use decisions. In 1992 Robert Mason agreed that few new statewide or regional initiatives during the latter half of the 1970s were consistent with the concept of the QR. However, Mason also stated that the QR had worked in the case of the establishment of the Pinelands National Reserve, a driver of the changing characteristics of urban development in the ecoregion.

A significant shift in land-use control from the local level to the state impacted LULC patterns in the ecoregion, consistent with the concept of the QR. Mason stated that one factor often regarded as a precondition for strong state-level land-use legislation is a threat—real or perceived—to the land resource (1992). Multiple perceived threats to the pine barrens habitat existed just prior to and during our study period. In 1967 a study by the Philadelphia Academy of Natural Sciences stated that habitats of the pine barrens were of "national significance" and were in danger (McCormick 1970), leading the U.S. Department of Interior to develop a report outlining potential conservation strategies (Mason 1992). Urban encroachment from three sides in southern New Jersey by the late 1970s raised concerns of possible contamination of the large aquifer found there, with New Jersey Governor Brendan Byrne pushing for regional water-quality standards. Legalized gambling in Atlantic City raised concerns about possible associated development of nearby pine barrens habitats (Russell 1994). In response to these and other perceived threats, state and federal governments worked together to create the Pinelands National Reserve, the nation's first such reserve, to help control urban development and preserve pine barrens habitat (Collins and Russell 1988). The federal National Parks and Recreations Act of 1978 established the reserve, and at the state level the Pinelands Protection Act of 1979 provided for implementation of the federal bill. The Pinelands Commission, which Governor Byrne established, was responsible for the creation and execution of a Comprehensive Management Plan (CMP). The original CMP, published in 1980, established Core and Peripheral Protection Areas to balance ecological concerns with development goals (Pinelands Commission 1980; Good and Good 1984). The core preservation zone allowed existing land uses to continue but greatly limited new development. The peripheral portions of the reserve, such as those near Philadelphia, Atlantic City, and the more populated areas to the north, allowed more moderate development.

The United Nations Educational, Scientific, and Cultural Organization designated the New Jersey Pinelands as a "biosphere reserve" in 1983. Several studies have provided evidence that the biosphere approach and the protections that the CMP established were successful in preserving pine barrens ecosystems. Robert Yaro and Tony Hiss pointed to the frequency of building permits awarded in protection areas as evidence of the approach's success (1996). William Frey cited the implementation of the biosphere reserve as a primary driver of regional redistribution of rural populations, with less development in protected areas (1987). Robert Walker and William Solecki found that the 1975–1986 spatial pattern of LULC change in the Pinelands National Reserve was consistent with the biosphere model and with the CMP's intended growth patterns (1999). Sandra Luque, Richard Lathrop, and John Bognar found that development restrictions were successful in slowing but not stopping landscape change in the Pinelands National Reserve, with most development occurring prior to establishment of the reserve (Luque, Lathrop, and Bognar 1994; Luque 2000). The Land Cover Trends results presented here are not localized to the reserve. However, decreasing urban development of forested land in the ecoregion as a whole is due in part to the success of the CMP and is in accordance with increased state—and federal—control of land-use policy, as Bossel-man and Callies and the QR predicted in had 1971.

Much of the discussion of drivers of LULC change has focused on the New Jersey portion of the ecoregion and the impact of the National Pinelands Reserve and Biosphere Reserve, but changes in development patterns in the ecoregion as a whole are also an artifact of many other regional processes and policies (Walker and Solecki 1999). Throughout the region, a growing environmental movement pressured local and state governments to protect the region's unique ecosystems. Environmentalists in southern New Jersey joined together to form a political force for Pine Barrens preservation (Berger and Sinton 1985). In Ocean County residents created the Pinelands Cultural Society to preserve natural habitats (Berger and Sinton 1985). In the wake of unprecedented growth in the 1980s, the Cape Cod Commission Act declared that its region's unique natural, coastal, historical, and cultural values were threatened, leading to the implementation of a regional land-use policy for Cape Cod. In New York, the Long Island Pine Barrens Society, formed in 1977, eventually pushed the New York State Assembly to pass the Long Island Pine Barrens Protection Act in 1993, ensuring the preservation of more than 22,000 hectares.

Although the effectiveness of each of these groups varied, the combined local, state, and federal efforts to protect pine barrens habitat led urban-development pressure to shift to agricultural lands during the study period. John Fraser Hart noted that the urban-rural fringe is characterized by high-priced agricultural land, with price almost entirely dependent on location, not inherent suitability for agriculture (1991). W. Patrick Beaton noted the effects of the establishment of the reserve on increasing land values in and around it (1991). As land values rose in the region, many farmers sold their land for development; others switched from vegetables to more highly valued nursery stock, flowers, or sod for economic survival (Hart 1991). Urban development encroached on agricultural land use in Long Island (Figure 8), as well as on Cape Cod, to the extent that the American Farmland Trust Organization in 1977 listed the region as one of the top twenty most threatened agricultural areas in the country.

The LULC impacts of the unique regional driving forces in the ecoregion are evident when comparing our results with other regional LULC studies. Although we show a trend toward lower rates of urban development of forested lands in the ecoregion, John Hasse and Richard Lathrop noted that the largest LULC change in New Jersey as a whole between 1986 and 1995 was development of forested land (2003). They demonstrated that most loss of the "forest core" was either in northern

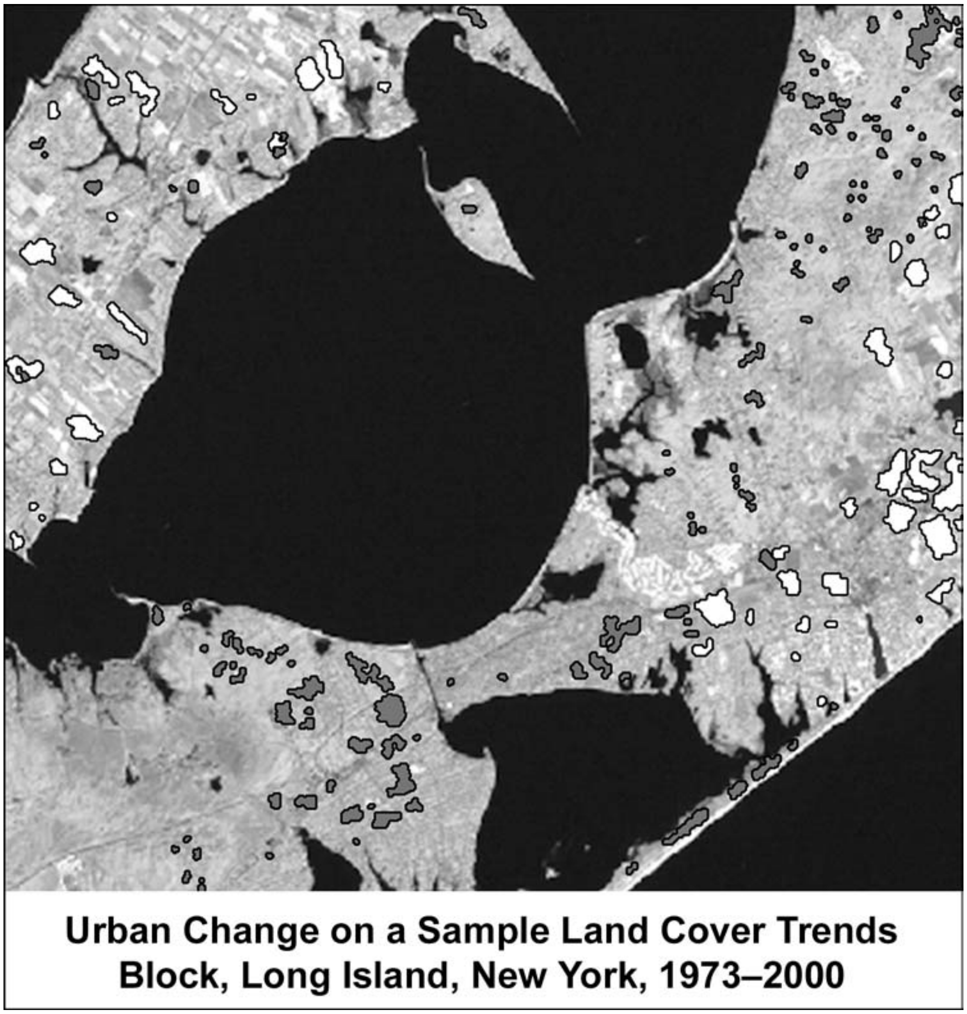


FIG. 8—Urban change on a Land Cover Trends 20-by-20-kilometer sample block on Long Island from 1973 to 2000. White polygons are agricultural lands lost to urban development, and dark grey polygons are other land-use types lost to development. Loss of agricultural land to development is a major concern in many parts of the Atlantic Coastal Pine Barrens ecoregion. (Cartography by Terry L. Sohl)

New Jersey outside the ecoregion or in other regions outside the Pinelands National Reserve. Luque analyzed 1972–1988 LULC change within the reserve (2000), finding that most of the change from forest to nonforest took place before the reserve was established and that after it was created, most development occurred either beyond its borders or in areas designated for agricultural production. Our results, as well as the results of these other studies, provide evidence of the effectiveness of conservation approaches in the ecoregion.

This discussion has focused on the changing patterns of urban development of agricultural and forest land because other forms of LULC conversion in the Atlantic

TABLE IV—THE MOST COMMON LAND–COVER CONVERSIONS IN THE ATLANTIC COASTAL PINE BARRENS ECOREGION, AND ANNUAL RATES OF CONVERSION FOR EACH, 1973–2000

| CLASS OF LAND COVER | | | | | |
|---|---|---|---|---|---|
| FROM | TO | AREA ($km^2$) | STANDARD ERROR ($km^2$) | ECOREGION (%) | ANNUAL RATE OF CONVERSION ($km^2$) |
| | | *1973–1980* | | | |
| Forests and woodland | Developed | 88 | 28 | 0.46 | 12.6 |
| Cropland and pasture | Developed | 81 | 47 | 0.42 | 11.6 |
| Mechanically disturbed | Developed | 22 | 11 | 0.11 | 3.1 |
| Forests and woodland | Mined lands | 12 | 5 | 0.06 | 1.7 |
| | | *1980–1986* | | | |
| Cropland and pasture | Developed | 138 | 54 | 0.72 | 23.0 |
| Forests and woodland | Developed | 98 | 20 | 0.51 | 16.3 |
| Forests and woodland | Mined lands | 17 | 8 | 0.09 | 2.8 |
| Cropland and pasture | Forests and woodland | 10 | 4 | 0.05 | 1.7 |
| | | *1986–1992* | | | |
| Cropland and pasture | Developed | 130 | 43 | 0.68 | 21.7 |
| Forests and poodland | Developed | 61 | 16 | 0.32 | 10.2 |
| Mechanically disturbed | Developed | 14 | 11 | 0.07 | 2.3 |
| Cropland and pasture | Mechanically disturbed | 9 | 7 | 0.05 | 1.5 |
| | | *1992–2000* | | | |
| Cropland and pasture | Developed | 179 | 83 | 0.93 | 22.4 |
| Foresst and woodland | Developed | 61 | 11 | 0.32 | 7.6 |
| Mechanically dsturbed | Developed | 12 | 8 | 0.06 | 1.5 |
| Cropland and pasture | Mechanically disturbed | 8 | 7 | 0.04 | 1.0 |

Coastal Pine Barrens were generally minor. As Table III shows, temporal trends in the water, natural barrens, and shrubland/grassland were statistically insignificant. The mechanical disturbed class, most often used to represent areas of clear-cut forests, constitutes a tiny portion of the landscape, indicating that commercial timber harvest is not an appreciable economic activity in the ecoregion. The mining class makes up a small portion of the landscape but has undergone a moderate and statistically significant increase during contemporary times (Table IV). Note that the majority of nonfuel minerals mined in the ecoregion are sand, gravel, and crushed stone used in construction, with most of the remainder being industrial sand and gravel. This increase in mining lands is correlated with the overall increased urban area. In 2002 the USGS specifically stated that large-scale capital projects, such as major road-widening and road-realignment projects, and an active construction sector contributed to the majority of mining activities in New Jersey and New York.

## Generalized Theory Alone Is Inadequate to Describe Land Change in the Pine Barrens

Land-use and land-cover estimates from the Land Cover Trends project serve as important baseline data for exploring and analyzing regional driving forces of change. Land Cover Trends results indicate relatively low overall rates of LULC conversion from 1973 to 2000 but with significant trends in increasing urbanization and concurrent declines in agriculture and forestry. Historical—pre-1973—LULC trends in the ecoregion followed the generalized temporal curve for forest cover that FTT described, but development pressures and associated high land rents for commercial and residential land uses resulted in declines in forest cover throughout the study period, a result at odds with FTT. Regardless of the tenets of FTT, as Hart stated (1991), urban expansion always wins in matters of land use, for owners of agricultural or forest land cannot pay urban prices for land. Although a broad geographical theory such as FTT may be applicable at certain temporal or spatial scales, what is evident is that the local and regional driving forces affecting the relative changes in land rent that ultimately drive LULC change at the regional scale.

Without the effects of the Quiet Revolution, overall forest declines might have been even greater. Although the widespread shifts from local to state control of land-use policy that the QR predicted have generally not occurred in the United States, state and federal policy and the establishment of the Pinelands National Reserve have affected LULC trends in the Atlantic Coastal Pine Barrens ecoregion. As Bosselman and Callies predicted in their introduction to the QR (1971), increased state control of land-use policy was necessary to protect the unique pine barrens habitat. Establishment of the reserve has led to decreased rates of forest conversion to urban land uses.

We note that the generalizability of FTT has come under scrutiny, with Stephen Perz faulting FTT for failing to account for processes that operate at multiple scales and for attempting to create a grand, universal theory of forest change (2007). Perz pushed for interdisciplinary studies of land-use and land-cover change rather than a focus on development of grand, universal theory. In contrast, Walker, in a defense of FTT, referred to interdisciplinary thought as a "seductive ether" that distracts geographers from the "simplicities of Occam's razor" (2008, 139). We have shown that general tenets of broad geographical theories, such as FTT and the QR, do show applicability to describing LULC change in the Atlantic Coastal Pine Barrens at certain temporal or spatial timelines and scales but cannot by themselves adequately characterize LULC change in the region. Generalized theories such as FTT or the QR are critical to the evolution of geographical thought. However, we believe we do not currently have enough consistent, widespread, local and regional analyses of LULC change to support and improve the development of widely applicable, generalized geographical theories of LULC change. Consistent, comparable local studies, including the "seductive ether" of interdisciplinary analyses, are important for improving our understanding of local-to-regional LULC dynamics. The story of change in the Atlantic Coastal Pine Barrens ecoregion rep-resents but one regional story of contemporary LULC change. The Land Cover Trends project, with its consistent analysis of regional LULC change across the conterminous United States, provides a suite of regional LULC stories to support the development and improvement of generalized theories of LULC science.

## Notes

1. For a complete description of the methodology used in the Land Cover Trends project, see Loveland and others 2002.

2. For additional information on our sampling and mapping methodology, see Loveland and others 2002; Stehman and others 2003.

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