A LANDSCAPE ANALYSIS OF MIGRANT LANDBIRD STOPOVER HABITAT ON CAPE MAY PENINSULA, NEW JERSEY FROM 1972 THROUGH 1995 USING REMOTE SENSING DATA

by

ERIC PETER STILES

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ABSTRACT OF THE DISSERTATION

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Eric Peter Stiles

Dissertation Director:

Dr. Joanna Burger

Migrant landbirds are known to use a handful of critical stopover locations along the Atlantic Flyway, where they remain to increase body weight and wait for favorable weather conditions. Cape May peninsula, New Jersey has been documented as a critical fall stopover site for many migrant species. Despite the importance of stopover sites during migration, no research has examined the landscape changes affecting migrant habitat at these locations. In fall 1991, a point count study was conducted along the mid-Atlantic seaboard from New Jersey through Virginia in forest and scrub-shrub habitat. Points were randomly located in four landscapes: Bay Coast (0-1.5 km east of mean high tideline), Bay Inland (1.5-3.0 km east of mhtl), Atlantic Coast (0-1.5 km west of mhtl) and Atlantic Inland (1.5-3.0 km west of mhtl). The study found bird species richness and abundance was highest in coastal landscapes. Furthermore, species richness was greatest in coniferous forest and abundance in scrub-shrub. This study quantified landscape

changes on the Cape May peninsula from 1972 to through 1995, focusing on forest and scrub-shrub habitat types. Changes were interpreted according to the 1991 point count study findings. Land use/ land cover maps, based largely on satellite imagery, were examined from 1972/73, 1984 and 1994/95. There was a net loss of forest and scrub-shrub habitat, with an increase in development. In general, forest and scrub-shrub patches were fewer in number, but larger in area, more complex in shape and more isolated. The larger patch size was due in part to elimination of smaller patches. While larger patch size might benefit area sensitive birds, increasing patch isolation and edge effects and net reduction in available habitat could be threatening the integrity of this stopover site. An analysis of open space indicates little public ownership in the Atlantic Coast and Atlantic Inland zones. More research, including telemetry, banding and point counts, is needed to help better understand migrant landbird stopover ecology at Cape May and guide conservation efforts. Immediate protection efforts need to include aggressive open space acquisition, innovative land use policies and active habitat management on public and private lands.

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I. INTRODUCTION

Migrant landbirds use land features that change over time for stopover sites; birds have had to select areas offering suitable food, cover and shelter at these re-fueling and resting locations before continuing their perilous journey. They demonstrate site fidelity to high quality stopover locations, because birds that use these ideal feeding and resting locations experience decreased mortality rates during migration (Moore et al. 1995, Moore and Simons 1992 and Rappole 1995). However, birds must alter their stopover site selection as landscape changes alter the quality of habitats at these locations.

During the Pleistocene era, the Atlantic Flyway in New Jersey underwent major changes as shorelines grew and shrank, forests waxed and waned and an ice sheet intermittently covered large portions of the continent (Wacker 1979). Yet, many species, including migrant landbirds, survived to modern times. During the last four hundred years, European colonization on the Eastern seaboard has heralded a heightened acceleration of land use changes (Wacker 1979). Along the maritime regions of North America, these changes involved the net loss of contiguous forest with patches of scrub-shrub for agriculture or development, a pattern deleterious to high quality migrant landbird habitat (Rappole 1995).

Before the European colonization, migratory birds could select new stopover locations if climatic change decreased the quality of an existing site. With suburban sprawl, migrant landbirds have fewer choices of alternate stopover locations. Thus rapid, negative land changes may jeopardize migrant landbirds’ ability to find critical stopover locations during their annual migration (Moore et al 1995, Moore and Simons 1992).

Changes in the landscape are known to affect migrant landbirds at breeding sites (Fauth et al. 2000, Flather and Sauer 1996, Freemark et al. 1995, Howell et al. 2000, Rappole 1995, Robinson et al. 1995, Saab 1999). Avian researchers presume these same affects are present at stopover sites, but many of these assumptions remain untested (Moore et al. 1995, Moore and Simons 1992, Rappole 1995). Total area and patch size are important factors in site selection to area-sensitive species, such as the scarlet tanager (*Piranga olivacea*) (Rosenberg et al. 1999). Migrant landbirds are also susceptible to edge and shape effects through increased disturbance, predation, and parasitism in areas of close proximity to ecotones (Fauth et al. 2000, Freemark et al. 1995, Friesen et al. 1995, Howell et al. 2000, Rappole 1995, Robinson et al. 1995). Habitat fragmentation, isolation and interspersion can also play a key role in habitat use and distribution (Fauth et al. 2000, Flather and Sauer 1996, Freemark et al. 1995, Howell et al. 2000, Niles 1996, Niles et al. 1996, Parrish 1997, Saab 1999). As such, analyses of landscape effects play a key role in devising meaningful conservation plans (Freemark et al. 1995, Howell et al. 2000, Petit et al. 1995).

The Cape May peninsula is one of the most significant sites for fall migrant landbirds on the Atlantic flyway (McCann et al. 1993, Niles et al. 1996, Wiedner and Kerlinger 1990, Wiedner et al. 1992). It is an important fall stopover for American woodcock (*Scolopax minor*), over 130 Neotropical passerines, 15 raptor species, and many short distance avian migrants (Krohn et al. 1977, McCann et al. 1993, Niles et al. 1996). Wiedner et al. (1992) documented significant morning flight phenomena for migrant landbirds on Cape May peninsula, whereby birds arriving at the peninsula may reorient northwards to minimize effects of competition and predation (Alerstam 1978, Gauthreux 1978).

Using 10 minute dawn and dusk point counts from August through October 1991, McCann et al. (1993) found clear geographical and habitat patterns of fall migrant landbirds in their Virginia through Delaware coastal migratory study. McCann et al. (1993) reported that at Cape May bird species abundance is not correlated with distance to the tip of the peninsula (up to 50 km north). Niles et al. (1996) reported that fall migrant sharp-shinned hawks (*Accipiter striatus*) likewise redistribute themselves on the peninsula to improve physical condition and to wait for favorable conditions prior to continuing migration. Furthermore, Niles et al. (1996) and McCann et al. (1993) showed that species maintain strong habitat associations during the Cape May peninsula fall stopover that resemble those used while breeding.

In the McCann et al. (1993) study, a greater songbird abundance occurred at coastal landscapes (0-1.5 km from mean high tideline - mhtl) than at interior landscapes (1.5-3.0 km from mhtl). The bayside (Delaware and Chesapeake Bay) coastal landscape had a greater species richness and abundance than either the Atlantic coast or interior. Among all landscapes, species richness was greatest in coniferous forest, followed by deciduous and mixed forest and then scrub-shrub (McCann et al. 1993). Conversely, the bird abundance was highest in scrub-shrub habitats.

Although there are many studies on the phenology, distribution, and foraging of migrant landbirds at stopover sites in the United States (Moore et al. 1995, Gauthreux 1978, Moore et al. 1996, Niles et al. 1996, Parrish 1997, Alerstam 1978, Wiedner et al. 1992, and Rappole 1995), no one has investigated habitat changes in these critical areas. In this study, I quantify landscape changes pertinent to migrant landbirds from 1972 to

1995 at the Cape May peninsula, New Jersey stopover. Avian selection of optimal habitat is affected by several factors including: habitat species composition and structure, patch size, shape, and isolation, landscape heterogeneity, and number of competitors and predators present (Flather and Sauer 1996, Freemark et al. 1995, Moore et al. 1995, Moore and Simons 1992). Freemark et al. (1995) postulated that a "landscape perspective" is critical to understanding Neotropical migration. I use select landscape metrics, such as patch size and nearest neighbor, to assess changes. In this study, I ask two related questions. First, is there a change in the amount of land class types that may affect the quality of Cape May as a stopover site? Second, are there changes in the size, shape and isolation of habitat patches that may affect migrant birds? A decrease in the total amount and patch size and an increase in shape complexity and isolation of migrant landbird habitat characterize a reduction in the quality of a stopover site.

II. METHODOLOGY

Study Area

The 89,093 ha study area, which is delineated by the McCann et. al. (1993) New Jersey point count sites, consists of Cape May County and Cumberland County east of the Maurice River (Figure 1). This region offers a rich mosaic of forest, scrub-shrub, agriculture, developed and estuarine land classes bound by the Atlantic Ocean to the east and Delaware Bay to the west. Post-European colonization, human-caused land class changes through forestry, agriculture and development have dominated the landscape.

Landscape Zones

The existing New Jersey Department of Environmental Protection (NJDEP) Geographic Information System (GIS) vector coverage of the McCann et al. (1993) study area was used to define the entire landscape (Figure 1). Using ArcView 3.2 Geoprocessing module, coastal and inland landscapes were created through buffering of the mean high tide line (mhtl) GIS vector coverage used in the McCann et al. (1993) study (ESRI 1996) (Figure 1). The Atlantic Coast landscape (7,912 ha) consists of areas 0-1.5 km west of the Atlantic Ocean mhtl, and Atlantic Inland (6,802 ha) contains areas from 1.5-3.0 km west of mhtl. Likewise, the Delaware Bay Coast landscape (9,608 ha) consists of areas from 0-1.5 km east of mhtl, and Delaware Bay Inland (8,250 ha) occurs from 1.5-3.0 km east of mhtl.

Source Land Cover Classification Maps

Land cover class grid (raster) maps for 1972/73, 1984 and 1994/95 (cell size = 30m) were created using ERDAS Imagine 8.3 for the study area (Lathrop 1998) (Figures 2-5). Lathrop produced mapping using a mixture of supervised, unsupervised and GIS rule-based approach to create the land cover mapping. Image data for the classification included 1972/73 Landsat Multi-spectral Scanner (MSS) and 1984 and 1994/95 Landsat Themmatic Mapper (TM). In addition, ancillary GIS data sources, such as wetlands (e.g. National Wetlands Inventory), census block information and digital ortho-photoquads, were used to aid in classification (Lathrop 1998).

A level 1 classification was created for all time periods and a level 2 classification for 1984 and 1994/95. The 1994/95 level 1 had an overall classification accuracy of 91.10% and level 2's accuracy was 82.70% (Lathrop 1998). While accuracy was not determined for 1972/73 and 1984, it is assumed they are acceptable since the same classification method was used for the three time periods.

Level 1 mapping consisted of eight land classes: Developed, Cultivated/Grassland, Woody Land, Bare Land, Unconsolidated Shore, Estuarine Emergent Wetland, Palustrine Wetland, and Water. Note all upland forest and scrub-shrub classes have been collapsed into Woody Land. Likewise, all vegetated freshwater wetlands, including forest and scrub-shrub, have been lumped into Palustrine Wetlands.

A modification of level II mapping, comprised of 13 classes, was used for 1984 and 1994/95 to correspond with land class categories used in the McCann et al. (1993) study. Developed area was divided into Developed: Light-Unwooded, Moderate to High and Developed: Light-Wooded to discern lightly developed, forested areas which may offer suitable stopover habitat. Other classes include Deciduous (>66%) Forest, Mixed Deciduous/Coniferous (> 33% and < 66%) Forest, Coniferous (> 66%) Forest, Scrub-shrub, Cultivated, Grassland, Freshwater (non-tidal) Emergent Wetland, Bare Land, Unconsolidated Shore, Tidal Emergent Wetland, and Water. All forest and Scrub-shrub classes were also collapsed into a single Suitable cover type.

Data analysis

LANDSCAPE METRIC ANALYSIS

In accord with Freemark et al.'s (1995) recommendations, I selected landscape variables from FRAGSTATS 2.0 (McGarigal and Marks 1994) that reflect landscape composition and heterogeneity and key patch characteristics (Table 1 and Appendix 1). Class Area, Percent of Landscape and Number of Patches are indices of landscape composition. Shannon's Diversity and Evenness Indices represent landscape heterogeneity. Finally, Patch Size, Shape Index and Nearest Neighbor are important patch attributes. Shape Index, which quantifies patch shape complexity, can be used to determine edge and ecotone effects. Nearest Neighbor, which measures the distance between patches of the same class, represents landscape contiguity.

Land cover analysis was performed using FRAGSTATS 2.0 for 1972/73 and 1984 level 1 and 1984 and 1994/95 level 2 land class maps for all landscapes (coast, inland and study area) (Figures 1-5) (McGarigal and Marks 1994). FRAGSTATS 2.0 provides landscape pattern and landscape structure analysis for vector and raster coverages at the patch, class and landscape level.

Multi-temporal Landscape Metric Comparison

I compared only Percent of Landscape and Shannon's Diversity and Evenness Indices between the 1972/73 and 1984 level I land classes for each landscape pair (e.g. 1972/73 Atlantic Coast Scrub-shrub to 1984 Atlantic Coast Scrub-shrub) using Sigma Plot 4.0. Wickham and Ritters (1995) reported that these metrics were not sensitive to mapping based on differing source images with cell sizes ≤ 80 m (MSS cell size = 80 m vs. TM cell size = 30 m). However, differences in other metrics (e.g. patch size) could be confounded by the discrepancy in source image cell size.

All metrics were compared between the 1984 and 1994/95 land cover maps for each forest and Scrub-shrub landscape pair. Percent of Landscape, Number of Patches, Patch Size, Shape Index and Nearest Neighbor were graphed using Sigma Plot 4.0 (Appendix 2). Data from Patch Size, Shape Index and Nearest Neighbor are highly non-normal. I performed Mann Whitney U tests on these three variables with SAS 8.1 software (i.e. Wilcoxon rank sum test) to determine statistical significance values between landscape pairs (e.g. 1984 Atlantic Coast Scrub-shrub Patch Size vs. 1994/95 Atlantic Coast Scrub-shrub Patch Size) (SAS Institute 1987, Sokal and Rohlf 1995). I used Holm's correction to adjust P values for multiple-comparisons, which reduces family-wise Type-I error rates (Holm 1979, Rice 1989). Family (k=3) is defined as the three metrics (Patch Size, Shape Index and Nearest Neighbor) compared between land class pairs within a landscape (e.g. 1984 Atlantic Coast Scrub-shrub & 1995 Atlantic Coast Scrub shrub). Using non-parametric tests, such as Mann Whitney preserves the Type-I errors (Sokal and Rohlf 1995).

Change detection analysis

A multi-date change detection using post-classification comparison was performed for the 1972/73-1984 and 1984-1994/95 land cover maps (Figure 6). Grid coverages were first reclassified to provide unique from-to class value combinations for change detection analysis (ESRI 1996, Dobson et al. 1995, Jensen 1986, Jensen et al. 1993). Using ArcView 3.2 with Spatial Analyst 1.1, two change maps, identifying to and from land cover types, were produced using Map Calculator to subtract each grid pair (i.e. 1984 and 1994/95) (ESRI 1996). Changes were quantified for each from-to (i.e. 1984 Forest: Deciduous to 1995 Developed) class in a change matrix (Dobson et al. 1995, Jensen 1986, Jensen et al. 1993).

The fate of 1984 Suitable land cover patches were determined for 1995. 1984 Suitable land cover patches were categorized into 1-10, 11-50, 51-100 and 101-1000 ha size classes. ArcView 3.2 with Spatial Analyst 1.1 was used to determine what percentage of the land cover remained classified as Suitable in 1995 from the 1984 patches.

III. RESULTS

1972/73 – 1984 Landscape Metric Comparison

The amount of suitable migrant landbird habitat, defined as Woody Land and Palustrine Wetland, declined from 1972 to 1984. Woody Land and Palustrine Wetland Percent of Landscape Area decreased in all landscapes (Figure 7). The decrease of Woody Land was greatest in the Delaware Bay Coast landscape, and, among the landscapes, the Atlantic Inland contained the highest percent of Woody Land in 1972 and 1984. Woody Land decreased by 2.44% and Palustrine Wetland by 1.61% in the study area (Figure 8).

Developed and Cultivated/Grassland land cover increased in all landscapes (Figure 7). The Atlantic Coast landscape had the greatest Percent of Landscape Area for these land cover types in 1972 and 1984. Cultivated/Grassland increased by a greater amount than Developed in all landscapes; Cultivated/Grassland increased by 2.38% and Developed by 1.26% in the study area (Figure 8).

Shannon's Diversity and Evenness Indices increased in all zones from 1972/73 to 1984, which indicates that area became more evenly distributed among the land classes (Table 2) (McGarigal and Marks 1994). This increase is partially due to the decrease in migrant landbird habitat and increase in Developed and Cultivated/Grassland area.

1972/73 – 1984 Change Detection Analysis

The land class matrix quantifies changes in habitat types between 1972/73 and 1984 for the entire study area (Table 3). Out of 23,155 ha classified as Woody Land in 1972, 18,378 ha remained unchanged in 1984. From 1972 to 1984, 1,821 ha were reclassified as Development, 2,145 ha as Cultivated/Grassland and 672 ha as Palustrine Wetlands.

Between 1972/73 and 1984, 19,520 ha of Palustrine Wetlands remained the same. 948 ha were reclassified as Estuarine Emergent Wetland and 614 ha as Woody Land. Similarly, 311 ha of Palustrine Wetland in 1972 were retyped as Cultivated/Grassland and 452 ha as Developed in 1984.

For Developed lands, 5,011 ha were the same for 1972 and 1984. 1,701 ha were relabeled as Cultivated/Grassland and 486 ha as Woody Land in 1984. The majority of new Developed areas in 1984 came from areas classified as Woody Land (1,821 ha) and Cultivated/Grassland (1,175 ha) in 1972. Of the 6,350 ha classified as Cultivated/Grassland in 1972, 3,957 ha remained in 1984. 970 ha were recategorized as Woody Land in 1984.

1984 – 1994/95 Landscape Metric Comparison

The amount of forest land class decreased from 1984 to 1995. Deciduous forest Percent of Landscape increased and mixed and coniferous forest decreased in all landscapes, yielding a net loss of forested land (Figures 7 and 8). Scrub-shrub Percent of Landscape declined in inland landscapes and increased in the coastal and study area landscapes (Figures 7 and 8). The inland landscapes had the greatest percent of forest, and the coast landscapes contained the greatest percent of Scrub-shrub.

The developed land classes Percent of Landscape increased for all landscapes (Figures 7 and 8). The Atlantic Coast landscape, followed by the Delaware Bay Coast, continued to contain the largest percent of developed land. Cultivated and Grassland

Percent of Landscape decreased in all landscapes (Figures 7 and 8). The Atlantic landscapes had the greatest loss of Grassland.

Shannon's Diversity and Evenness Indices increased in all landscapes, except for Atlantic Coast in which both variables decreased (Table 4). An increase in these indices indicates that the proportion of land distributed among land classes became more uniform (McGarigal and Marks 1994). Conversely, the Atlantic Coast exhibited an increasing uneven distribution of area among the land classes. In general, the loss of forest, Cultivated and Grassland area combined with growth of developed lands resulted in a more even distribution of area among land classes.

Forest and Scrub-shrub land classes, in general, had fewer patches that were larger, more complex in shape and further apart. Forest, Scrub-shrub and Suitable classes showed a marked decrease in the number of patches from 1984 to 1995 for all landscapes (Figure 9). Scrub-shrub had the greatest decrease in patch number. Deciduous forest patch number declined the least, with patch number actually increasing in the Atlantic Coast landscape.

Patch Size was larger for forest and Scrub-shrub land classes in 1995 than 1984 (Figure 10). All pair-wise comparisons of patch size for these land classes, except Atlantic Inland scrub-shrub, were significantly different ($p<.05$, Table 5). Deciduous forest patch size increased noticeably in all landscapes except the Atlantic Coast. Mixed forest patch size increased in all landscapes except for the entire study area. Coniferous forest and scrub-shrub patch size increased in all landscapes.

Shape Index values for forest and scrub-shrub land classes were generally greater and therefore more complex in 1995 (Figure 11). All pair-wise comparisons of Shape

Index were significantly different ($p<.05$) except for Atlantic Inland scrub-shrub (Table 5). Deciduous forest and scrub-shrub had marked increases in Shape Index for all landscapes. Coniferous forest had the smallest Shape Index increase in the Atlantic Coast, and mixed forest Shape Index increased slightly in all landscapes.

Forest and scrub-shrub patches generally possessed greater Nearest Neighbor distances in 1995 (Figure 12). All pair-wise comparisons of Nearest Neighbor were significantly different ($p<.05$) except for Atlantic Coast and study area deciduous forest and Atlantic Inland Scrub-shrub (Table 5). Nearest Neighbor distance for deciduous forest tended to remain stable, and its patches actually became closer in the Atlantic Coast landscape. Mixed and coniferous forest and scrub-shrub, except for the Delaware Bay Coast Scrub-shrub, had patches that were further apart.

1984 – 1994/95 Change Detection Analysis

The change detection matrix quantifies changes in land class type from the 1984 to 1994/95 maps for the study area (Table 6). The matrix shows a great amount of forest areas was reclassified as a different forest type in 1995. 18,990 ha of mixed forests (FM) remained unchanged from 1984 to 1995; 4,403 ha and 2,077 ha were respectively reclassified as Forest: Deciduous (FD) and Forest: Coniferous (FC) in 1995. 704 ha of FM was recategorized as Developed: Light-Unwooded, Moderate-High (DM), 549 ha as Developed: Light-Wooded (DL) and 183 ha as Scrub-shrub.

Of the 5,109 ha of 1984 deciduous forest, 2,681 ha remained unchanged in 1995. The largest change was 1,778 ha reclassified as mixed forest. Only 2,845 ha mapped as coniferous forest in 1984 remained in 1995. 3,209 ha and 165 ha were respectively classified as mixed and deciduous forest. Additionally, 149 ha were relabeled as DM and 144 ha as DL.

219 ha of Scrub-shrub were unchanged in 1995. Land classified as forest in 1984 contributed a significant 271 ha to Scrub-shrub in 1995. Conversely, 218 ha were reclassified as forest in 1995.

5,517 ha of Developed: Light-Unwooded, Moderate-High remained in 1995, and 537 ha were re-assigned to the DL land class. Likewise, 1,417 ha of Developed: Light-Wooded remained in 1995; 566 ha were reclassified as DM. 458 ha of Cultivated lands were typed as DM in 1995; 2,767 ha were unchanged. 202 ha of Cultivated areas were reclassified to mixed forest and 119 ha as Grassland.

Of the 4,713 ha of Grassland in 1984, 1,375 ha and 385 ha were respectively reassigned to DM and DL; 1,084 ha remained in 1995. 956 ha were reassigned to mixed forest and 366 ha to deciduous forest. Of the 648 ha classified as Freshwater Emergent Wetland in 1984, 213 ha remained in 1995. 104 ha and 89 ha were respectively recategorized as mixed and deciduous forest. 24 ha was classified Scrub-shrub in 1995.

Areas classified as Suitable in 1984 tended to remain Suitable in 1995 if they were located in larger patches (Figure 13). Only 51.3% of Suitable area lying in 1 to 10 ha patches in 1984 remained in 1995. In contrast, 82.8% of Suitable land cover lying in 101 to 1,000 ha patches in 1984 remained in 1995. The majority of the small patches classified as forest and Scrub-shrub in 1984 were reclassified as developed, Cultivated and Grassland in 1995.

Land in smaller Suitable patches in 1984 were less likely to be classified as Suitable in 1995 than land in larger patches (Figure 13). Only 51% of land contained in 1 to 10 ha Suitable patches in 1984 remained unchanged in 1995. Of the land in 1984 Suitable patches ranging from 11 to 100 ha, 71% remained suitable in 1995 and 83% of lands in 101 to 1000 ha 1984 Suitable patches were unchanged in 1995.

IV. DISCUSSION

Changes in the landscape are presumed to affect the quality of avian stopover sites (Freemark et al. 1995, Moore et al. 1995, Moore and Simons 1992, Petit et al. 1995, Rappole 1995). Landscape-level effects have been documented for these same species at breeding sites (Fauth et al. 2000, Flather and Sauer 1996, Friesen et al. 1995, Howell et al. 2000, Robinson et al. 1995, Rosenberg et al. 1999, Saab 1999). Habitat loss, fragmentation, and isolation may act to reduce the viability of key stopover locations where birds need to increase fitness and wait for better weather conditions prior to continuing their journey to breeding or wintering grounds. There is no formula to determine how exactly the loss of critical habitat will affect parameters such as weight gain rate and survivorship. Yet, denigration of key stopover locations has been identified as a threat to many Neotropical landbirds (Moore et al. 1995, Moore and Simons 1992, Rappole 1995).

With the advent of satellite imagery, Geographic Information System and remote sensing analysis software and the field of landscape ecology, researchers now have tools necessary to quantify landscape changes over time. This analysis can in turn be used to help guide important conservation efforts such as land management, habitat protection and land use policy decisions.

Analysis of landscape changes in the study area and other landscapes clearly show that there was a loss of migrant landbird habitat from 1972 to 1995. The amount of forest decreased and Scrub-shrub remained relatively stable from 1984 to 1995. Additionally, patch level dynamics show increasing patch size which could benefit area-sensitive species. However, the increase in patch complexity and isolation that could negatively effect migrant landbirds. Future land changes will continue to decrease the quality of the site as a stopover. Immediate conservation efforts and research is needed to help mitigate this negative trend.

1972/73 to 1984 Level 1 Landscape Changes

From 1972 to 1984, every landscape exhibited a net loss of migratory landbird stopover habitat in the form of Woody Land and Palustrine Wetland. The large, intact inland forests of northern Cape May County and Cumberland Counties partially moderated landscape area changes. The Delaware Bay landscape, where McCann et al. (1993) found the greatest avian species richness and abundance, showed the greatest combined loss of Woody Land and Palustrine Wetland. Likewise, the Atlantic Inland, Atlantic Coast and Delaware Bay Inland zones showed a substantial decrease in Woody Land, which is heavily used by migrants.

The loss of migrant landbird habitat was coupled with the growth of Cultivated/Grassland and Developed land classes. The Cultivated/Grassland areas, increasing more than Development, had particularly notable expansions in the Atlantic Inland and Delaware Bay Coast. The greatest increase in Developed areas was found in the Atlantic Coast landscape, which was expected since it represents desirable land close to the popular beach communities. These land cover types offer, at best, marginal habitat to most migrant landbirds who are looking for insects and berries for food and vegetation for cover (Moore et al 1995, Moore and Simons 1992, Niles 1996, Parrish 1997).

The conversion of Woody Land to Developed and Cultivated/Grassland detected in the change matrix represents a typical pattern of habitat alteration. Surprisingly, a fair amount of Palustrine Wetland was reclassified as Developed. Since wetlands are more difficult (e.g. fill and septic requirements) to develop than upland sites, this change was not expected.

Some of the land cover changes quantified in the change detection matrix may represent classification errors of wrongly excluding (omission) and including (commission) areas. For example, 1,701 ha of Developed lands in 1972 were reclassified as Cultivated in 1984, which may represent errors of omission and commission more than real-world land changes. Also, the retyping of Palustrine Wetland to Woody Land may indicate either a change in hydrology or more likely classification errors of omission and commission. The boundaries between some land classes may not be distinct. The ecotone between developed and grassland offers a good illustration. A house or building may be adjacent to a large turf farm. During classification, one must decide where developed ends and grassland begins with the best information (e.g. ancillary data sets) available.

1984 to 1994/95 Level 2 Landscape Changes

The landscapes, in general, exhibited a loss in the amount of migrant landbird habitat. The increase in development continued to reduce the quality of the stopover by decreasing the amount of forest and Scrub-shrub. Also, the loss of coniferous and mixed forest was partially offset by a gain in deciduous forest. However, since McCann et al. (1993) found the greatest species richness in coniferous forest, the net loss of coniferous forest might not be negated by a similar gain in deciduous forest.

Patch level changes indicate a mixture of negative and positive effects on migrant landbirds. Migrant landbird habitat Patch Size increased. Note part of this increase is the loss of small forest and Scrub-shrub patches from 1984 to 1995. This increase could act to improve habitat for area-sensitive species. Little is known about area effects on migrant landbirds at a stopover, but many of these species are subject to area effects on breeding grounds (Rosenberg et al. 1999). However, patches were typically further apart, which acts to isolate and fragment migrant landbird habitat. On average, birds need to fly further between patches to find suitable food and cover. This could result in increased predation and energetic costs by forcing birds to move through poor habitats (Moore et al. 1995, Moore and Simons 1992).

Patches also became increasingly complex in shape; amount of edge increases with shape complexity. So even though patches were larger, edge effects increased. While fragmented landscapes, characterized by a high percentage ecotones, may have the greatest amount of avian diversity (Howell et al. 2000, Saab 199), they can also reduce the patch quality through increased predation and disturbance (Friesen et al. 1995).

The land class change matrix quantified significant reclassification to and from Scrub-shrub, forest, Grassland and Freshwater Emergent Wetland, which would be expected through succession and human activities involving land clearing. Surprisingly, a greater amount of Tidal Emergent Wetlands were recategorized as forest or Scrub-shrub than forest and Scrub-shrub were reclassified as Tidal Emergent Wetland. These changes occurred at forest-estuarine ecotones. Recent salt-water intrusion is thought to be killing forest and scrub-shrub adjacent to Tidal Emergent Wetlands, so this type of change due to succession would be unexpected. A large amount of forest was reclassified to another forest type between 1984 and 1995. This trend might be due in part to change in forest composition and/or errors of omission and commission.

Small patches of Suitable (forest and scrub-shrub) were lost at a greater rate than large patches. These smaller areas, the majority of which were surrounded by development and agriculture, were converted to these land cover types in 1995. With fewer small parcels to clear, human land alteration will begin affecting larger patches.

Projected Landscape Changes

As evident from the 1972 to 1984 and 1984 to 1995 land class change matrices, developed classes draw heavily from forested, Grassland and Cultivated land classes. Grassland and Cultivated areas, which require little clearing and fill, may represent a more cost-effective means of developing land. The amount of grassland declined by almost 50% from 1984 to 1995. As remaining Grasslands and farmland are squeezed for development, vegetated areas will offer the only alternative. Forest and Scrub-shrub lands would then be cleared for either development or new Cultivated lands or Grasslands. As more forest and scrub-shrub is lost, I would expect distance between patches to increase, shape complexity to increase and patch size to become smaller.

Four programs may temper this loss of migrant landbird habitat. In 1998, Governor Whitman authorized Green Acres, a state government program, to protect a million more acres of open space by 2007 (NJSA 8C-1 et seq.). Protection can occur through easements, development rights and direct purchases. This will help augment the existing open space areas managed by state, federal and non-profit conservation agencies and groups (Figure 14). Also, state and federal wetlands statutes will protect the study area's many forested wetlands. In addition most sections of the study area fall under one of two regulatory programs, the Pinelands Protection Act (Collins and Russell 1988) and Coastal Area Facilities Review Act (NJSA 13:19-1 et seq.), which regulate and limit development.

Conservation Needs

Development and conversion of forest and Scrub-shrub to Grassland and farmland will continue to threaten key forest and Scrub-shrub migrant landbird habitat. Land purchasers should work with avian biologists to identify key parcels for protection through state, federal, local or non-profit conservation ownership. Considerations need to include land cover types, patch sizes, distance to other quality habitat types and other protected lands and proximity to mean high tideline. McCann et al. (1993) found bird species richness and abundance to be highest in the Coastal zones. Furthermore, coniferous forest supported the greatest species richness and Scrub-shrub contained the highest abundance. By adding to existing protected lands, one can act to increase patch size, decrease distance between patches and reduce edge effects from development. Of the 40,301 ha of scrub-shrub and forest in the study area, 15,190 ha are within open space areas (Figure 14). Note, almost no land is protected through open space in either Atlantic landscape, making it a key area for immediate land acquisition.

Land managers need to actively manage for scrub-shrub habitat because this land cover type provides a critical food and cover source for migrants. McCann et al. (1993) found the greatest bird abundance in this habitat type. Parrish (1997) documented the importance of scrub-shrub fruit as a food source for migrants. This ephemeral habitat type relies upon a regular disturbance regime by land managers for maintenance and/or establishment. Open space managers should also provide and promote high quality ecotourism opportunities to help create an advocacy group for stopover habitat conservation.

Water conservation will be key in the future as the demand from the local aquifer outpaces the recharge rate on the Cape May peninsula (Spitz 1998). Currently, two communities (Cape May and West Cape May) on the Cape May peninsula are obtaining water from a desalination plant (NJDEP 1998). With continued development, salt-water intrusion could continue to encroach in local ground-water and tidal streams (Spitz 1998). Salt-water encroachment could be lethal to forest and Scrub-shrub in freshwater wetlands and areas adjacent to estuarine ecotones. The encroachment could be heightened by the projected sea level rise (Nordstrom 1986).

Innovative state, county and local land use regulations could help minimize development impacts through setting standards. Through use of such tools as clustered housing and greenways, communities can help ensure the maintenance of migrant habitat (Stiles 1998). Additionally, communities could require development to utilize beneficial vegetation with minimum lot coverage standards (NJDEP 1998).

Regional land use planning would greatly enhance conservation of migrant landbird habitat at the Cape May peninsula. New Jersey's municipal-based planning system hampers the ability to effectively implement landscape-level efforts such as establishment of Greenways, corridors, and complimentary zoning. Yet, this is needed to truly conserve this diminishing natural resource.

Land protection, habitat management and land use policies should be updated periodically to reflect the current knowledge of stopover ecology. Further research can and should help refine these policies (Petit et al. 1995).

Conclusions

Land changes will continue to reduce the quality of the Cape May peninsula stopover. The loss of forest and Scrub-shrub with decreasing patch size and increasing isolation and shape complexity will diminish already dwindling migrant landbird habitat resources. Aggressive open space purchase, focused land management and innovative land use planning can act to mitigate these losses.

Future research should concentrate on three areas: assessment/GIS tools, land cover change and avian habitat use. Wickham and Ritters (1995) showed that certain landscape metrics, including percent of landscape and diversity and evenness metrics, were not sensitive to differences in source images if the image pixel size was ≤ 80 m. However, they did not examine the effect of pixel size on patch-level metrics such as Patch Size, Shape Index and Nearest Neighbor. Research is needed to determine if other metrics are sensitive to differences in pixel size.

Continued analysis of land cover and migrant landbird trends will be important to assessing impacts to migrants and success of conservation efforts. Long-term monitoring, including point counts, bird banding and land use changes, is needed as an early warning for changes to species abundance, richness, behavior and habitat at the stopover. In addition, studies should examine use of habitat by migrant landbirds. The process of habitat selection by migrant landbirds and their movement at the peninsula is still not understood.

Table 1. Landscape metric statistics summary (from McGarigal and Marks 1994). These metrics are used to quantify multi-temporal land cover changes at the Cape May peninsula, New Jersey for migrant landbirds.

Statistic Name	Statistic Abbreviation	Patch Variable	Class Variable	Landscape Variable
Area Metrics				
Class Area	CA		x	
Percent of Landscape	%LAND		x	
Total Landscape Area	TLA			x
Patch Density & Size Metrics				
No. of Patches	NumP		x	x
Patch Size[1]	PS	x		
Shape Metrics				
Shape Index[1]	SI	x		
Diversity & Interspersion Metrics				
Nearest Neighbor Distance[1]	NN	x		
Shannon's Diversity Index	SDI			x
Shannon's Evenness Index	SHEI			x

[1] Summary Statistics (e.g. median and quartiles) of these variables yield class and landscape variables.

Table 2. Shannon's Diversity and Evenness Indices for 1972/73 and 1984 landscapes at Cape May peninsula, New Jersey.

Landscape	1972/73 Shannon's Diversity Index	1984 Shannon's Diversity Index	1972/73 Shannon's Evenness Index	1984 Shannon's Evenness Index
Atlantic Coast	1.66	1.68	.80	.81
Atlantic Inland	1.54	1.61	.74	.83
Delaware Bay Inland	1.28	1.37	.62	.70
Delaware Bay Coast	1.65	1.72	.79	.83
Study Area	1.72	1.78	.83	.86

Table 3. 1972/73 to 1984 land class change matrix (ha) for the Cape May peninsula, New Jersey study area.

	1984 Land Cover Classes							
1972 Land Cover Classes	Developed	Cultivated/ Grassland	Woody Land	Bare Land	Unconsolidated Shore	Estuarine Emergent Wetland	Palustrine Wetland	Water
Developed	5,010.76	1,700.89	485.94	95.28	157.43	42.59	87.27	64.52
Cultivated/ Grassland	1,175.09	3,956.52	969.98	71.98	13.92	57.42	93.73	10.92
Woody Land	1,820.74	2,145.25	18,337.71	145.24	4.82	20.84	671.77	8.10
Bare Land	98.55	310.95	96.64	265.45	0.00	5.55	34.22	77.71
Unconsolidated Shore	104.56	14.01	24.48	23.21	322.51	54.78	51.05	82.90
Estuarine Emergent Wetland	64.16	16.74	144.42	72.80	84.18	17,333.97	317.23	2,675.78
Palustrine Wetland	452.36	311.04	614.34	195.20	45.96	947.77	19,519.72	270.64
Water	44.41	13.83	15.74	28.67	110.47	980.62	144.05	5,974.55

Table 4. Shannon's Diversity and Evenness Indices for 1984 and 1994/95 landscapes at Cape May peninsula, New Jersey.

Landscape	1984 Shannon's Diversity Index	1994/95 Shannon's Diversity Index	1984 Shannon's Evenness Index	1994/95 Shannon's Evenness Index
Atlantic Coast	2.12	2.01	.83	.79
Atlantic Inland	1.90	1.99	.74	.78
Delaware Bay Inland	1.71	1.84	.67	.72
Delaware Bay Coast	2.10	2.15	.82	.84
Study Area	2.07	2.10	.81	.82

Table 5. Statistical significance of pair-wise landscape metric comparison using Mann Whitney test with Holm's correction for family-wise error. Family is defined as the 3 metrics (Patch Size, Shape Index and Nearest Neighbor) compared between land class pairs within a landscape (e.g. 1984 Atlantic Coast Scrub-shrub & 1995 Scrub-shrub). Statistically significant p-values (p<.05) are bolded.

Landscape	**Land Class**	**Variable**	**P value**	**Holm's Correction P Value**
Atlantic Coast	Dec Forest	Patch Size	**<.0001**	**<.0001**
		Shape Index	**<.0001**	**<.0001**
		Nearest Neighbor	.5084	.5084
	Mix Forest	Patch Size	**<.0001**	**<.0001**
		Shape Index	**<.0001**	**<.0001**
		Nearest Neighbor	**.0005**	**.0005**
	Con Forest	Patch Size	**<.0001**	**<.0001**
		Shape Index	**.0017**	**.0017**
		Nearest Neighbor	**<.0001**	**<.0001**
	Scrub Shrub	Patch Size	**<.0001**	**<.0001**
		Shape Index	**<.0001**	**<.0001**
		Nearest Neighbor	**<.0001**	**<.0001**
Atlantic Inland	Dec Forest	Patch Size	**<.0001**	**<.0001**
		Shape Index	**<.0001**	**<.0001**
		Nearest Neighbor	**.0155**	**.0155**
	Mix Forest	Patch Size	**.0026**	**.0078**
		Shape Index	**.0222**	**.0410**
		Nearest Neighbor	**.0205**	**.0410**
	Con Forest	Patch Size	**<.0001**	**<.0001**
		Shape Index	**<.0001**	**<.0001**
		Nearest Neighbor	**<.0001**	**<.0001**
	Scrub Shrub	Patch Size	.3153	.3153
		Shape Index	.1526	.3053
		Nearest Neighbor	**.0004**	**.0013**
Del Bay Inland	Dec Forest	Patch Size	**<.0001**	**<.0001**
		Shape Index	**<.0001**	**<.0001**
		Nearest Neighbor	**.0002**	**.0002**
	Mix Forest	Patch Size	**<.0001**	**<.0001**
		Shape Index	**<.0001**	**<.0001**
		Nearest Neighbor	**.0058**	**.0058**
	Con Forest	Patch Size	**<.0001**	**<.0001**
		Shape Index	**<.0001**	**<.0001**
		Nearest Neighbor	**<.0001**	**<.0001**

Table 5. (cont'd)

Landscape	**Land Class**	**Variable**	**P value**	**Holm's Correction P Value**
Del Bay Inland	Scrub Shrub	Patch Size	**.0006**	**.0011**
		Shape Index	**.0093**	**.0093**
		Nearest Neighbor	**<.0001**	**<.0001**
Del Bay Coast	Dec Forest	Patch Size	**<.0001**	**<.0001**
		Shape Index	**<.0001**	**<.0001**
		Nearest Neighbor	**.0083**	**.0083**
	Mix Forest	Patch Size	**<.0001**	**<.0001**
		Shape Index	**<.0001**	**<.0001**
		Nearest Neighbor	**<.0001**	**<.0001**
	Con Forest	Patch Size	**<.0001**	**<.0001**
		Shape Index	**<.0001**	**<.0001**
		Nearest Neighbor	**<.0001**	**<.0001**
	Scrub Shrub	Patch Size	**<.0001**	**<.0001**
		Shape Index	**<.0001**	**<.0001**
		Nearest Neighbor	**.0064**	**.0064**
Study Area	Dec Forest	Patch Size	**<.0001**	**<.0001**
		Shape Index	**<.0001**	**<.0001**
		Nearest Neighbor	.5787	.5787
	Mix Forest	Patch Size	**<.0001**	**<.0001**
		Shape Index	**<.0001**	**<.0001**
		Nearest Neighbor	**<.0001**	**<.0001**
	Con Forest	Patch Size	**<.0001**	**<.0001**
		Shape Index	**<.0001**	**<.0001**
		Nearest Neighbor	**<.0001**	**<.0001**
	Scrub Shrub	Patch Size	**<.0001**	**<.0001**
		Shape Index	**<.0001**	**<.0001**
		Nearest Neighbor	**<.0001**	**<.0001**

Table 6. 1984 to 1994/95 land class change matrix (ha) for the Cape May peninsula, New Jersey study area.

1984 Land Cover Classes	1995 Land Cover Classes: Dev1	Dev2	Cult	GR	FD	FM	FC	SS	Bare	US	TEW	FE	Water
Dev1	5,516.91	536.99	40.04	110.47	41.95	108.93	13.65	12.56	29.12	29.94	33.03	10.10	43.59
Dev2	566.39	1,416.52	11.19	25.30	34.67	139.05	20.38	4.91	4.37	2.18	7.19	8.10	3.09
Cult	458.28	31.76	2,767.15	118.85	63.06	202.20	27.76	3.46	38.13	1.27	14.65	25.30	4.28
GR	1,374.65	385.02	111.48	1,083.54	366.19	955.96	100.01	19.02	268.36	8.74	12.56	12.56	15.02
FD	93.82	59.24	25.84	117.12	2,681.06	1,777.51	63.52	45.23	66.34	7.46	40.04	113.02	18.93
FM	704.34	548.92	240.06	409.32	4,403.15	18,989.45	2,076.82	182.64	239.51	24.75	277.73	199.29	49.32
FC	148.79	144.33	46.50	47.32	164.80	3,208.50	2,844.50	42.77	49.23	6.83	122.58	40.22	7.01
SS	32.21	13.47	10.56	13.01	26.48	142.51	48.87	218.77	23.39	19.20	44.95	32.40	7.01
Bare	73.44	6.73	5.28	125.03	28.67	70.25	23.39	10.56	393.58	46.50	32.31	23.66	58.42
US	225.41	6.28	0.18	19.75	3.28	9.56	7.01	34.85	15.20	1,808.55	1,619.72	31.40	662.58
TEW	120.94	15.83	11.28	11.83	210.21	374.19	84.27	135.32	27.76	1,502.33	16,578.67	32.67	338.25
FE	7.64	4.64	2.91	5.19	88.63	104.20	24.39	24.12	25.12	38.40	50.60	212.67	59.15
Water	81.99	3.19	0.91	5.73	4.28	18.47	8.65	6.83	51.32	740.93	244.06	19.84	4,274.48

Class	**Qualifier**
Dev1	Developed: High, Moderate and Light (Unwooded)
Dev2	Developed: Light (Wooded)
Cult	Cultivated
GR	Grassland
FD	Forest: Deciduous
FM	Forest: Mixed Deciduous/Coniferous
FC	Forest: Coniferous
SS	Scrub-Shrub
Bare	Bare Land
US	Unconsolidated Shore
TEW	Tidal Emergent Wetlands
FE	Freshwater Emergent Wetlands
Water	Water

Figure 1. Map of study area and landscape zones: Cape May peninsula, New Jersey. The point count locations and landscapes are taken from the 1991 migrant landbird study (McCann et al.1993). Coastal landscapes are 0-1.5 km from mean high tidelines(mhtl) and inland landscapes are 1-5-3.0 km from mhtl.

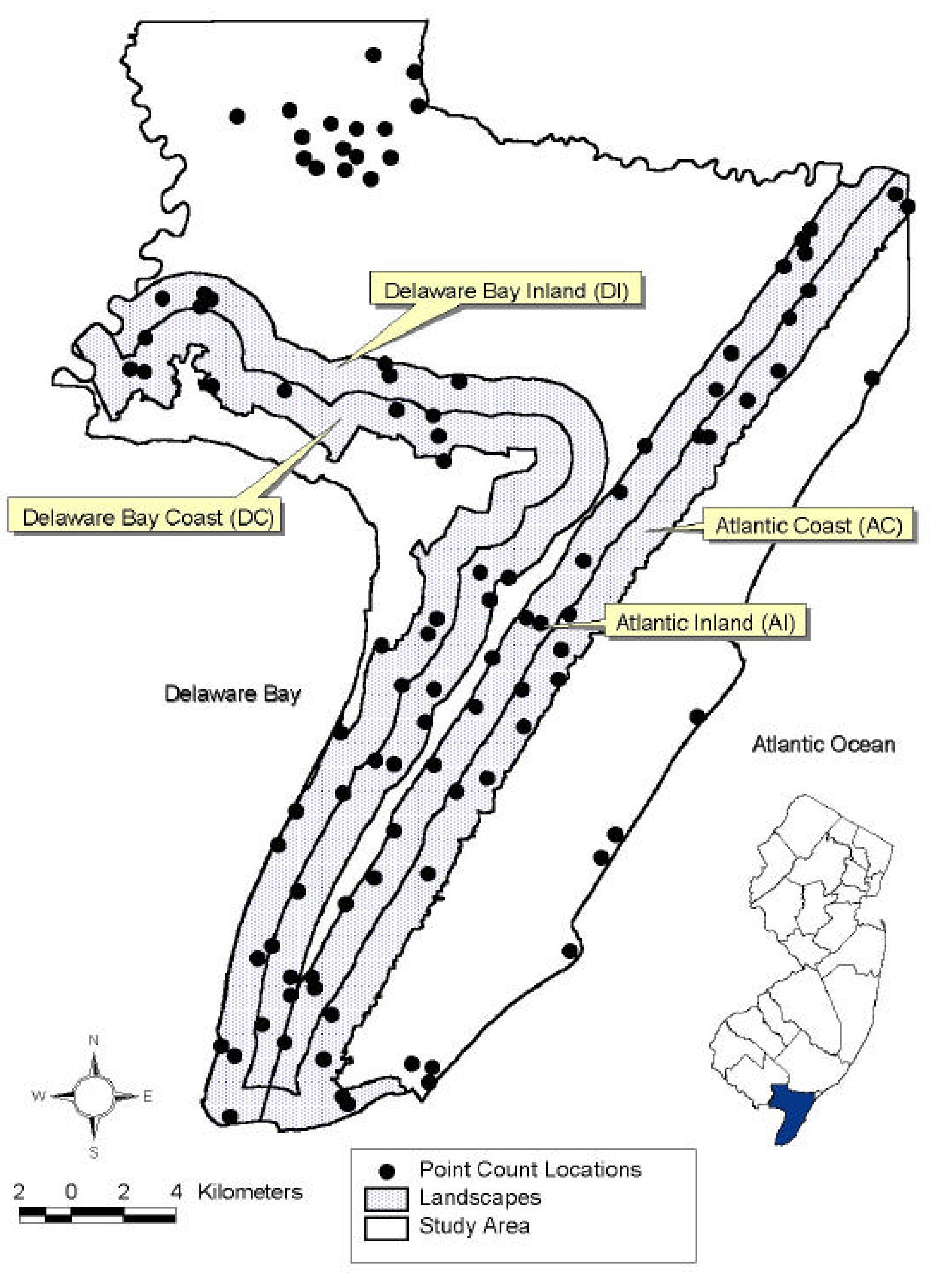


Figure 2. 1972/73 land use/ land cover map – level 1 at Cape May peninsula, New Jersey. The map includes the landscapes being examined for land cover change.

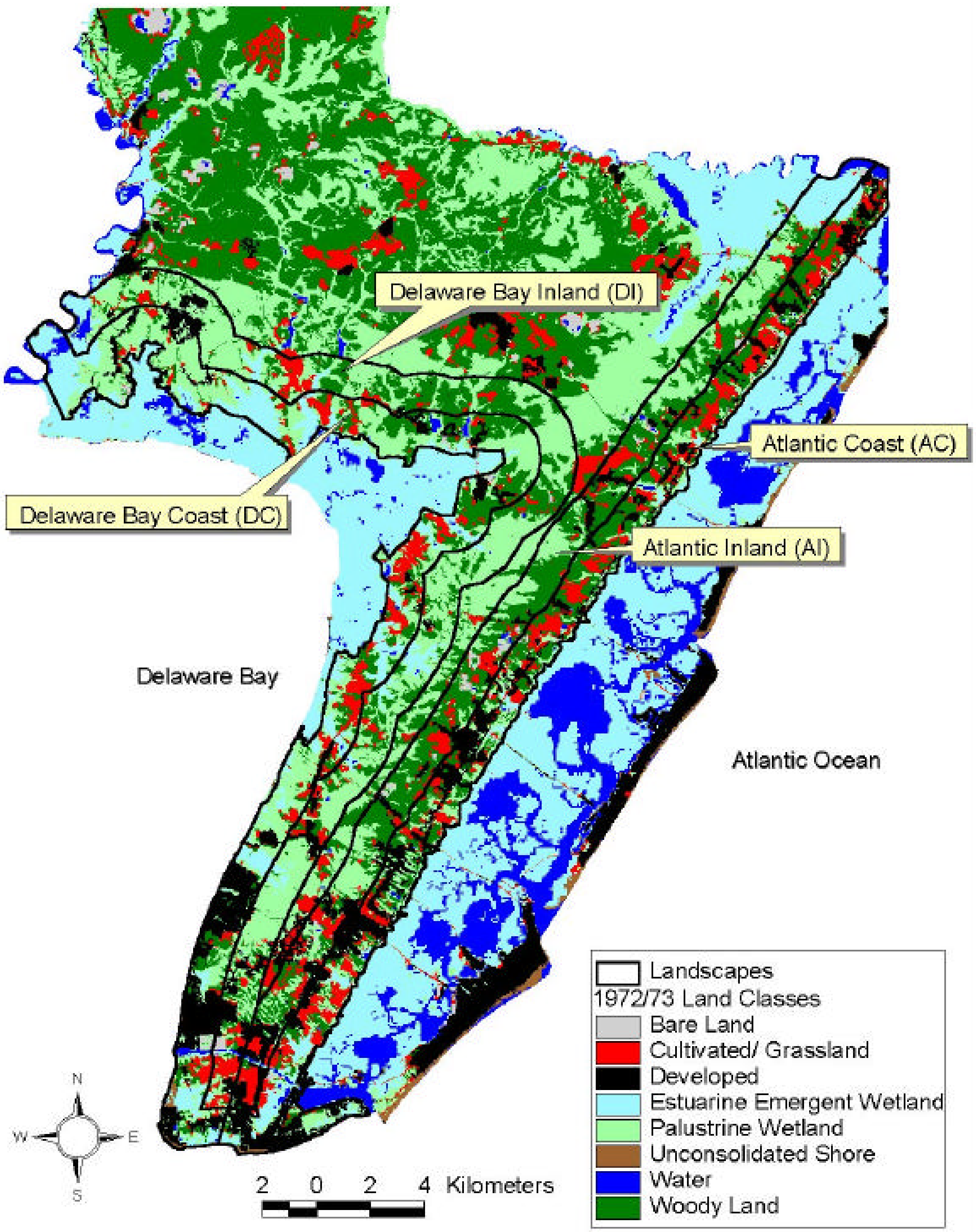


Figure 3. 1984 land use/ land cover map – level 1 at Cape May peninsula, New Jersey. The map includes the landscapes being examined for land cover change.

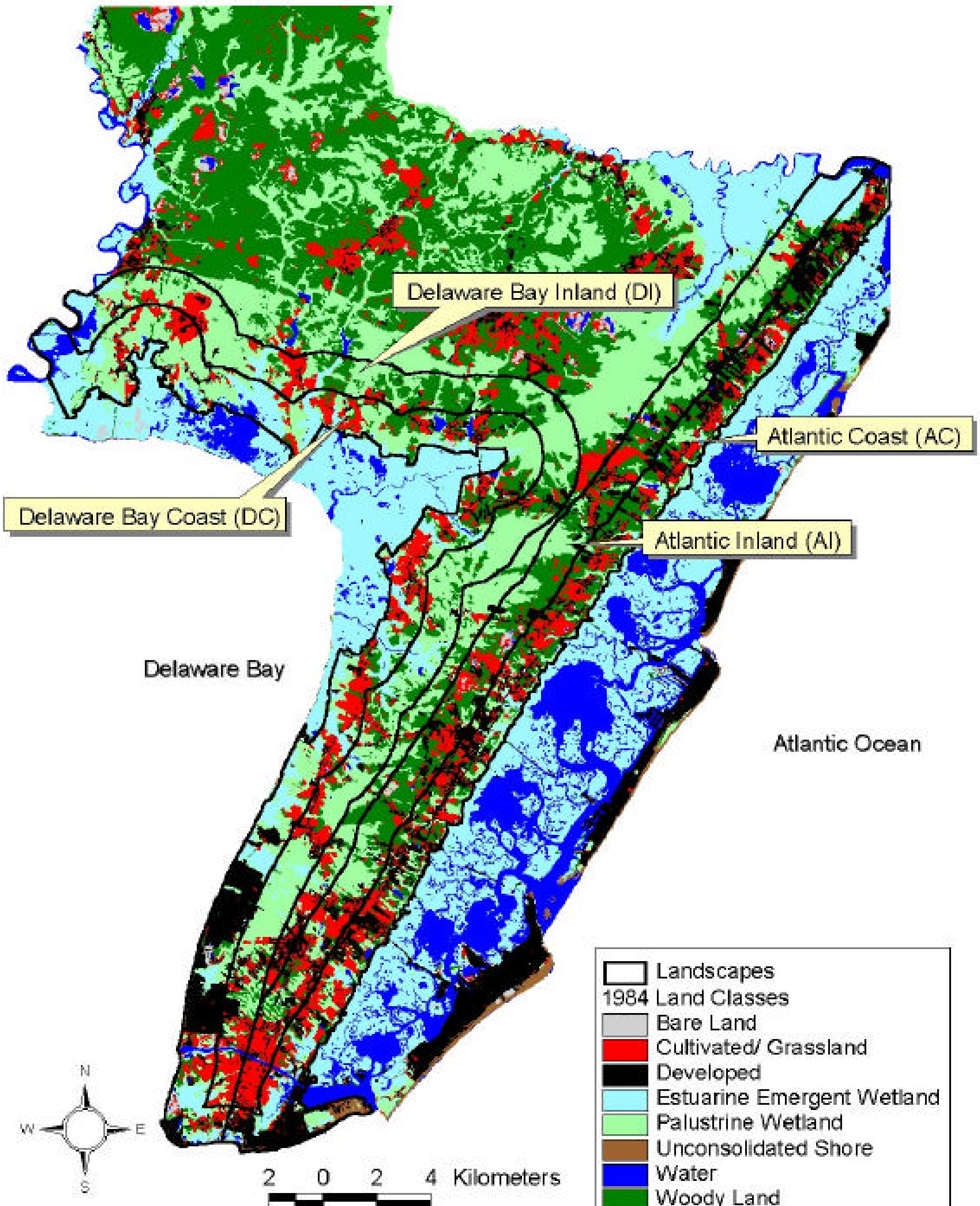


Figure 4. 1984 land use/ land cover map – level 2 at Cape May peninsula, New Jersey. The map includes the landscapes being examined for land cover change.

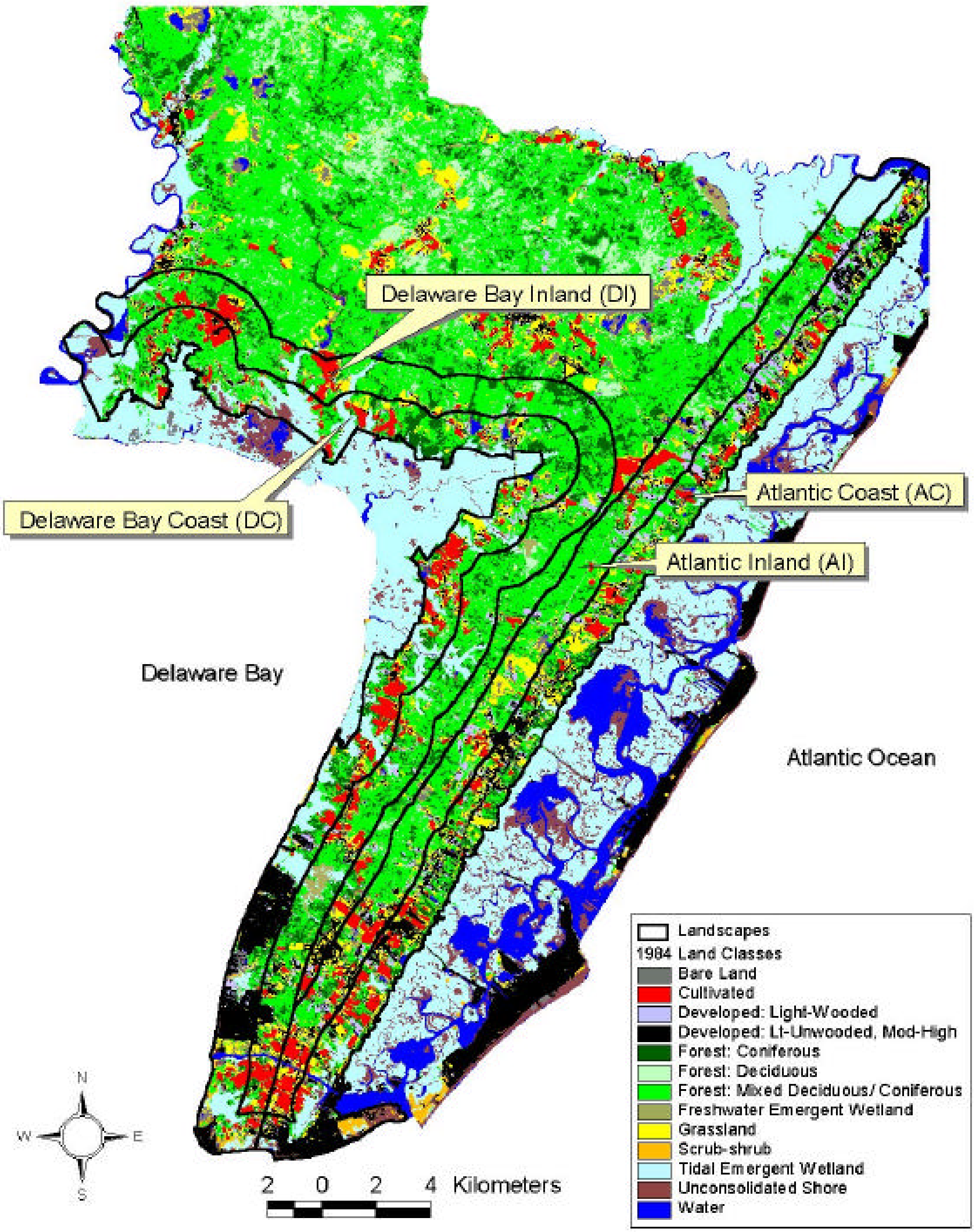


Figure 5. 1994/95 land use/ land cover map – level 2 at Cape May peninsula, New Jersey. The map includes the landscapes being examined for land cover change.

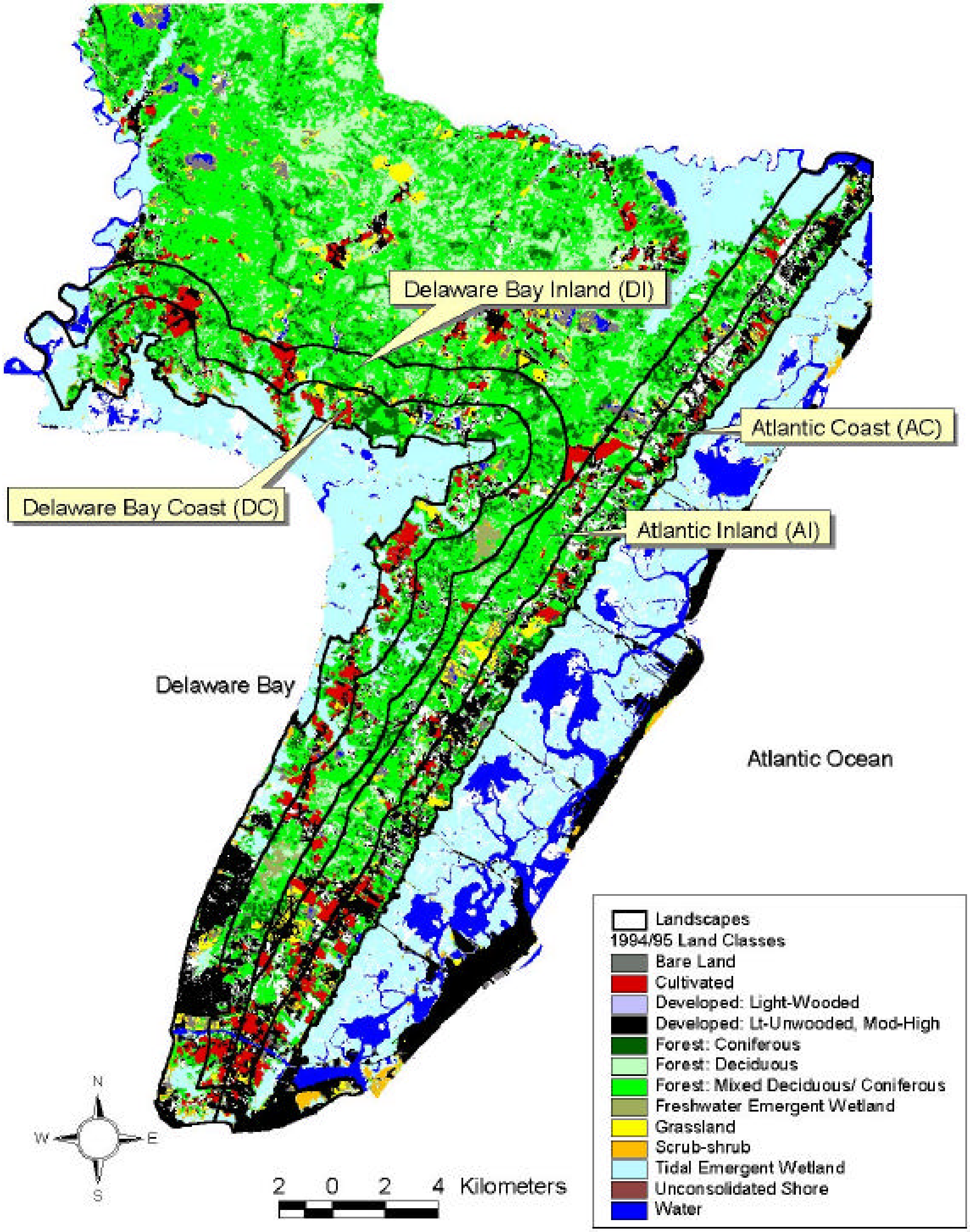


Figure 6. Multi-date change detection using post-classification comparison at Cape May peninsula, New Jersey (Dobson et al. 1995).

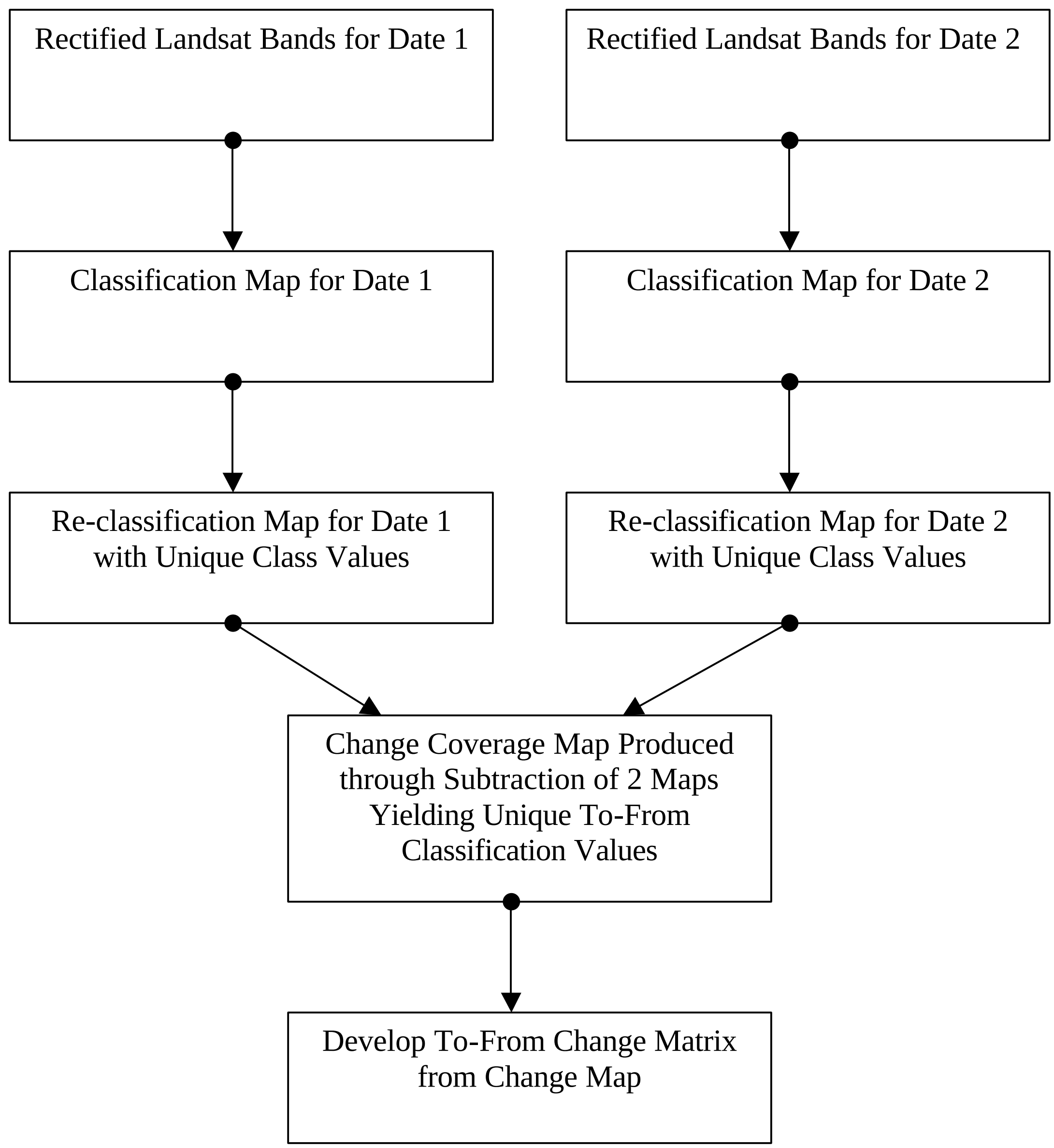


Figure 7. Percent of Landscape Area by land class: 1972-1984 level 1 and 1984-1995 level 2 at Cape May peninsula, New Jersey. Migrant landbird habitat is defined as Woody Land and Palustrine Wetland (level 1) and forest and Scrub-shrub (level 2).

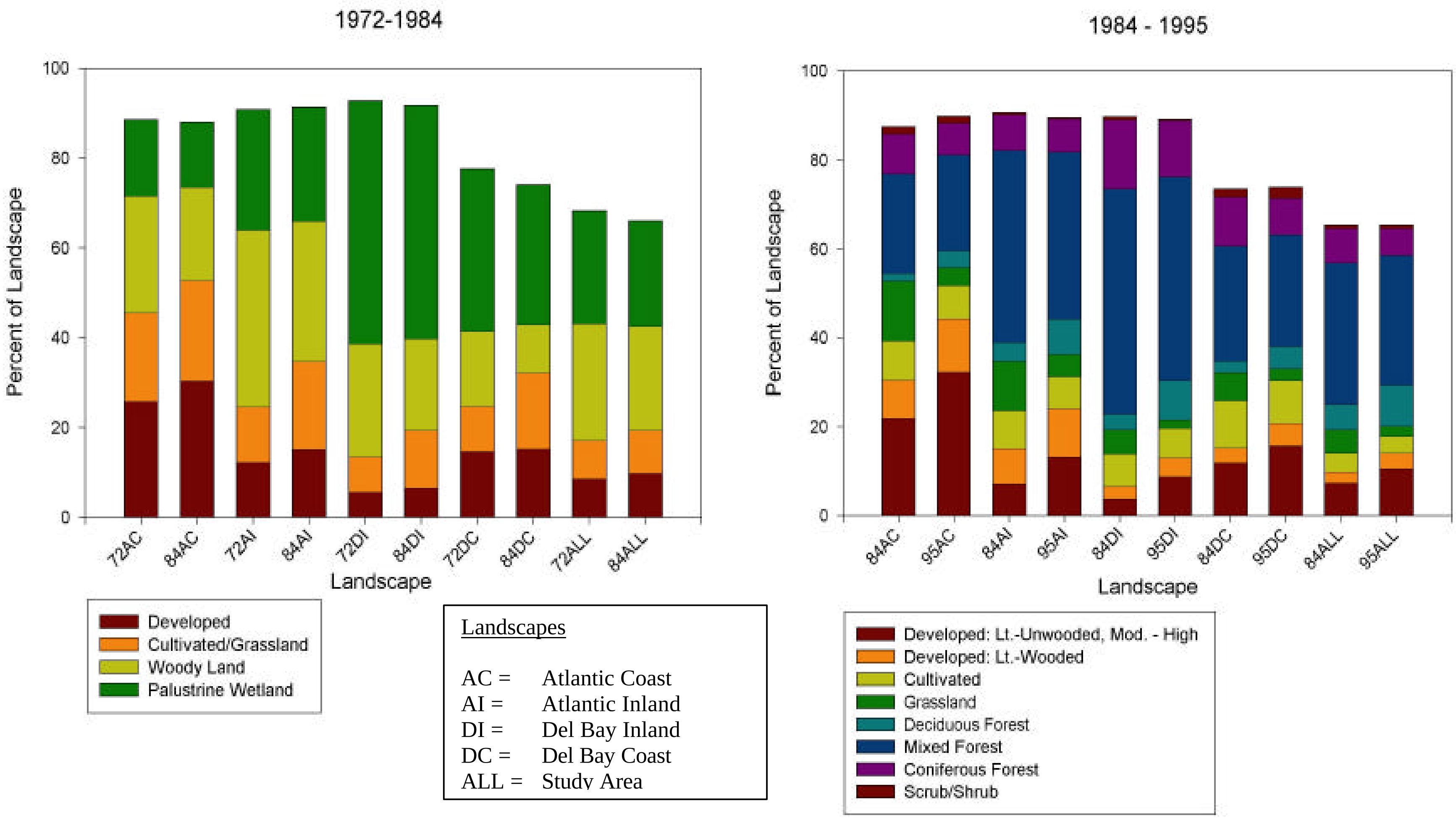
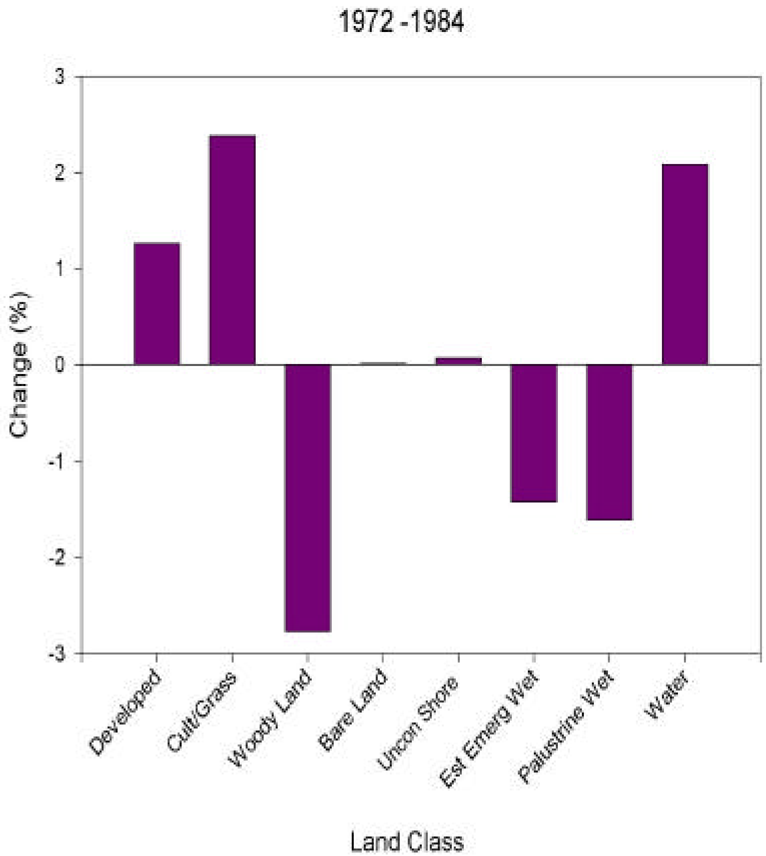
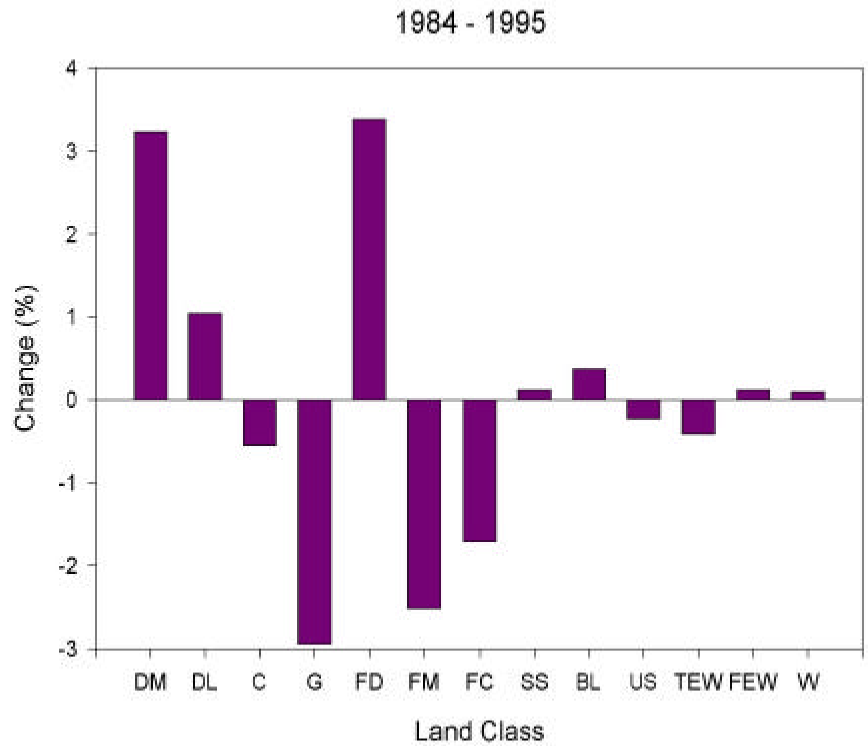


Figure 8. Percent of land class change in the study area: 1972 to 1984 level 1 and 1984 to 1995 level 2 at Cape May peninsula, New Jersey.





DM = Dev: Lt-Unwooded, Mod-High
DL = Dev: Lt-Wooded
C = Cultivated
G = Grassland
FD = Forest: Deciduous
FM = Forest: Mixed
FC = Forest: Coniferous
SS = Scrub-shrub
BL = Bare Land
US = Unconsolidated Shore
TEW = Tidal Emerg Wet
FEW = Fresh Emerg Wet
W = Water

Figure 9. Number of Patches within land classes by landscape for forest, Scrub-shrub and Suitable: 1984 and 1995 level 2 at Cape May peninsula, New Jersey.

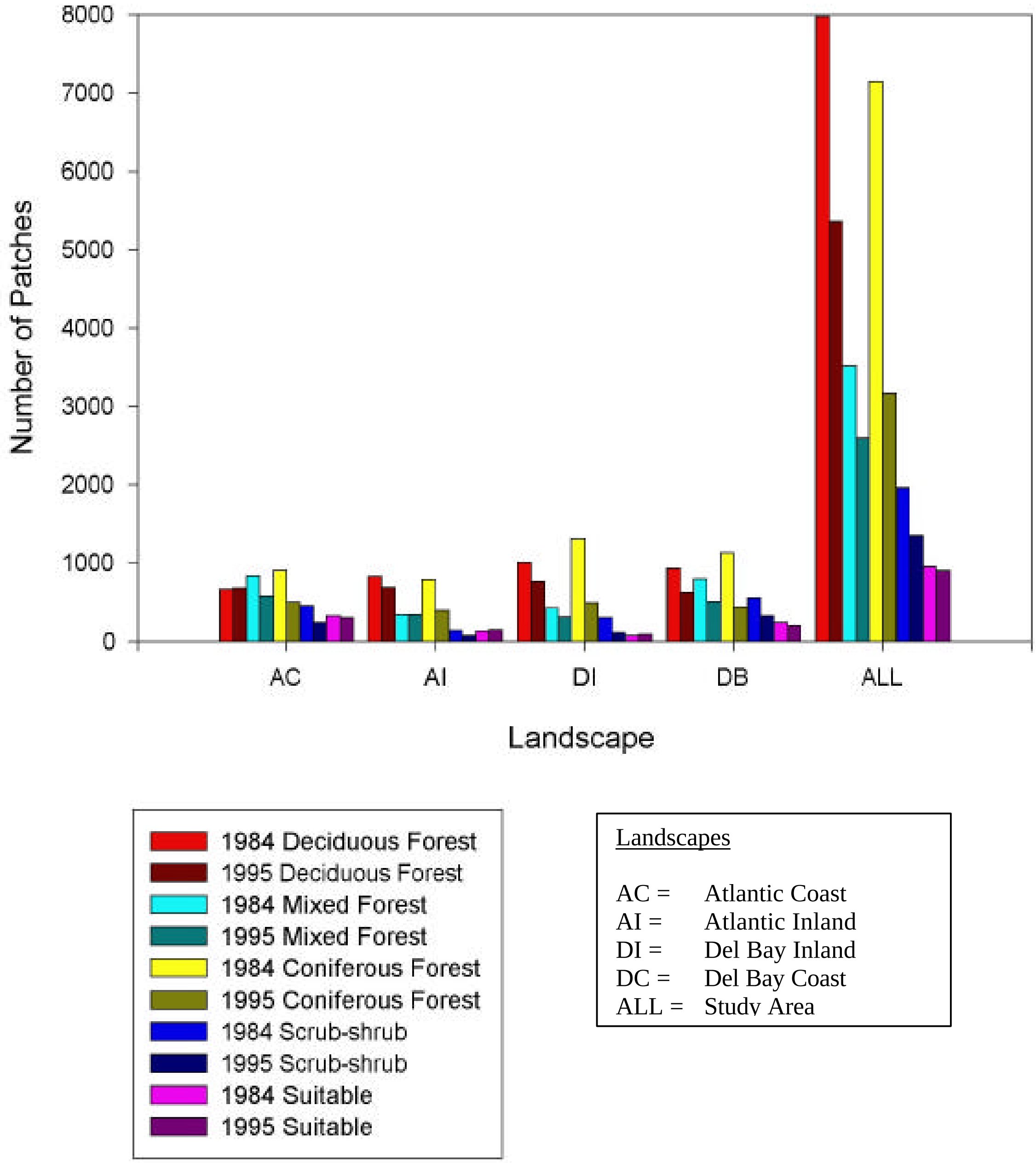
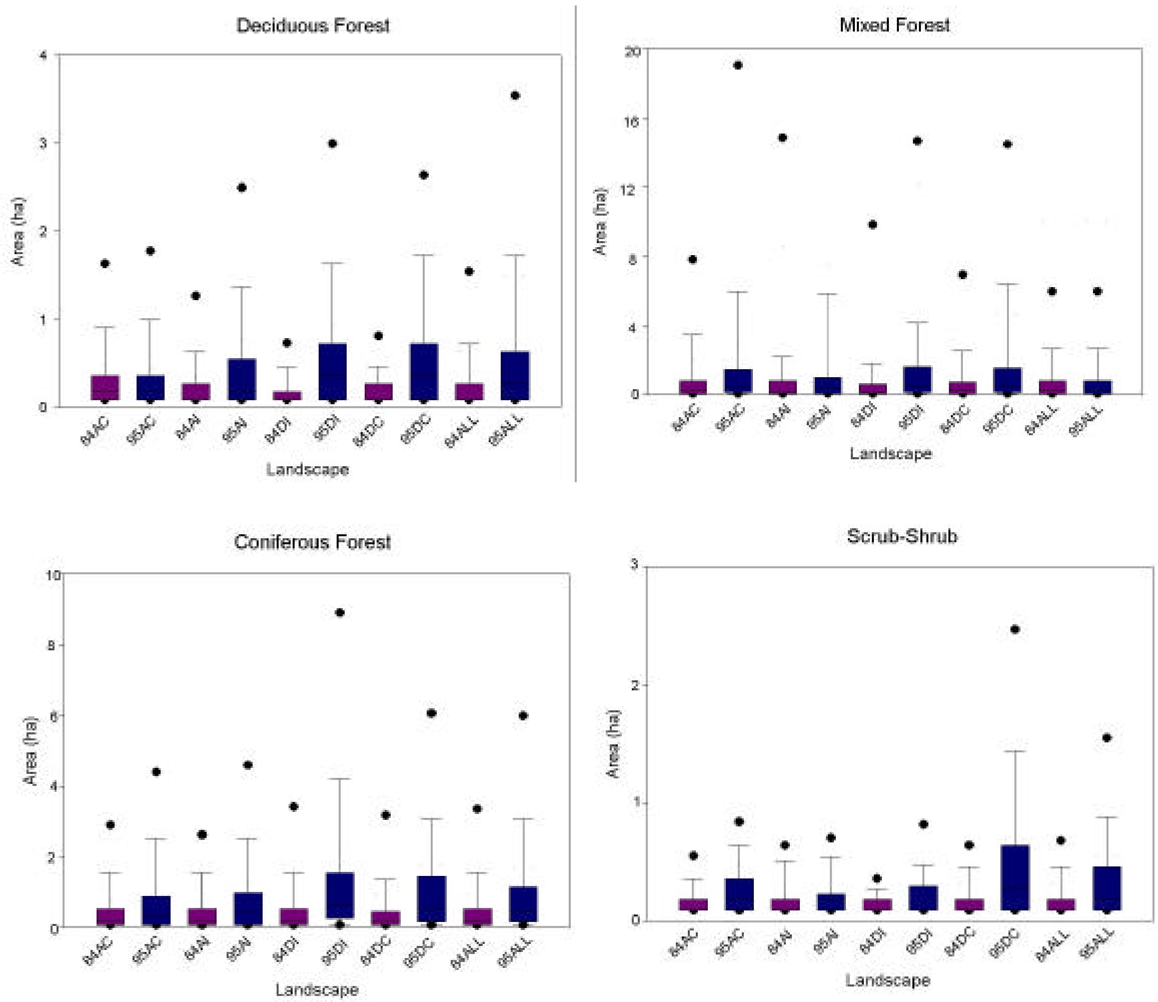


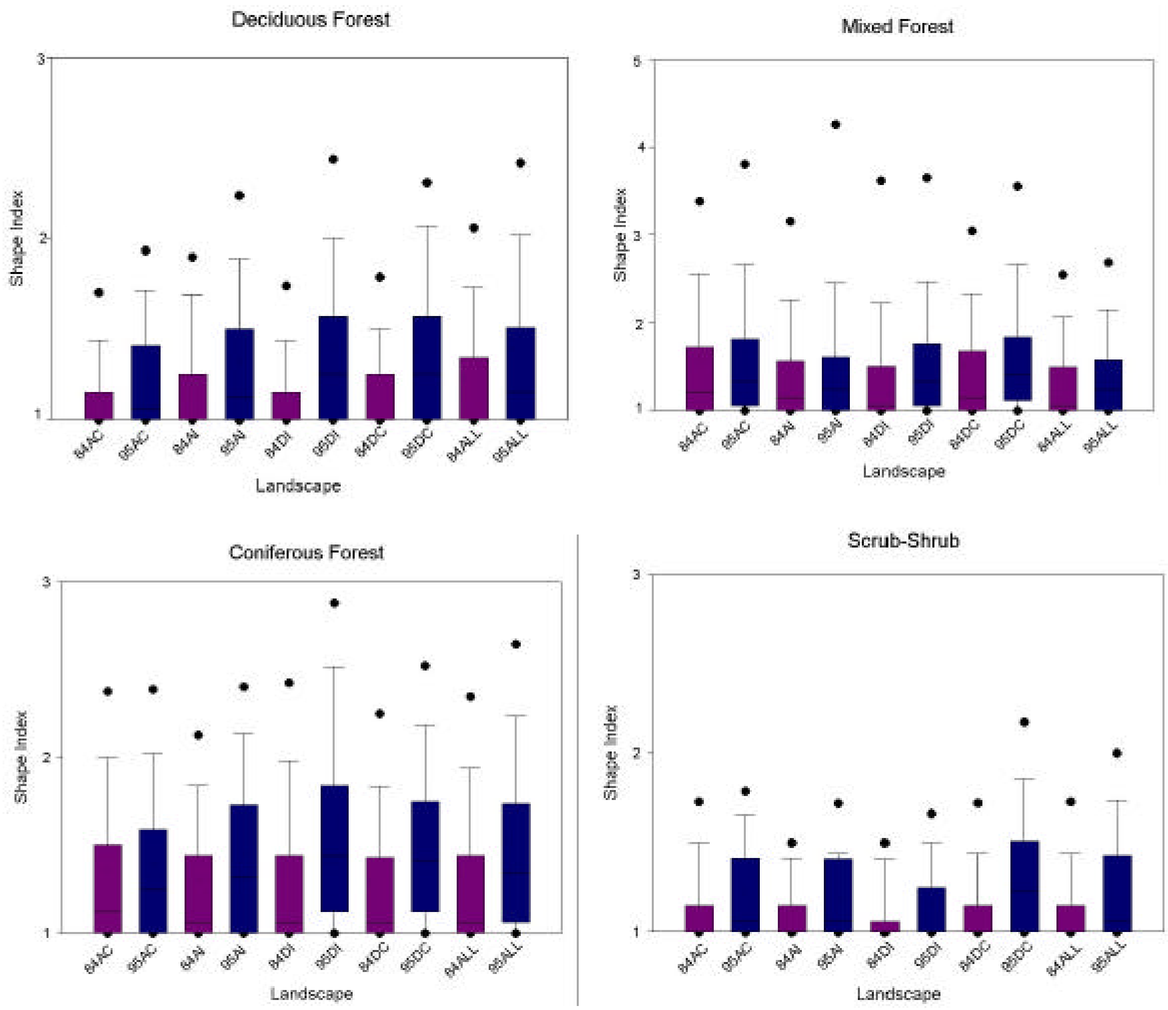
Figure 10. Patch Size distribution by landscape for forest and Scrub-shrub land classes: 1984 and 1995 level 2 at Cape May peninsula, New Jersey.



Landscapes

AC = Atlantic Coast
AI = Atlantic Inland
DI = Del Bay Inland
DC = Del Bay Coast
ALL = Study Area

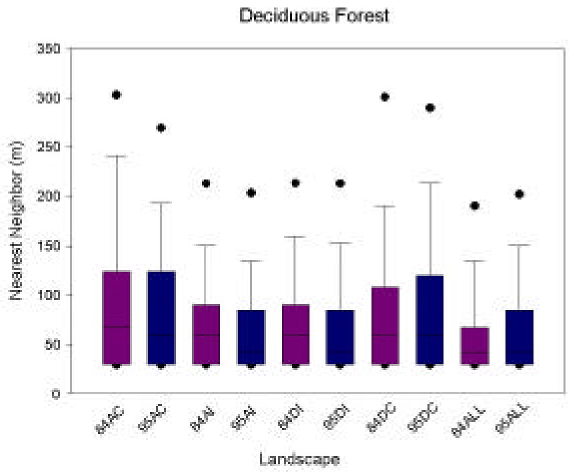
Figure 11. Shape Index distribution by landscape for forest and Scrub-shrub land classes: 1984 and 1995 level 2 at Cape May peninsula, New Jersey.

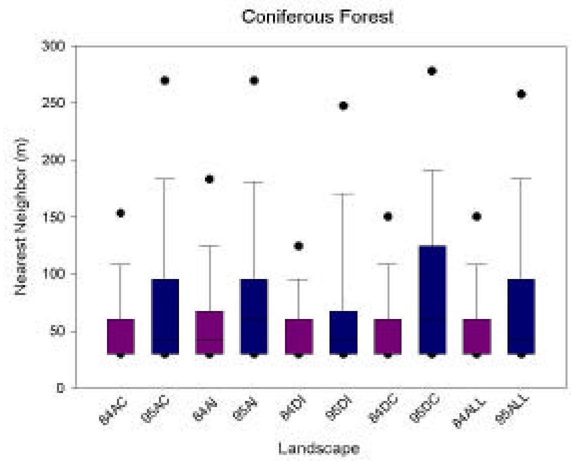


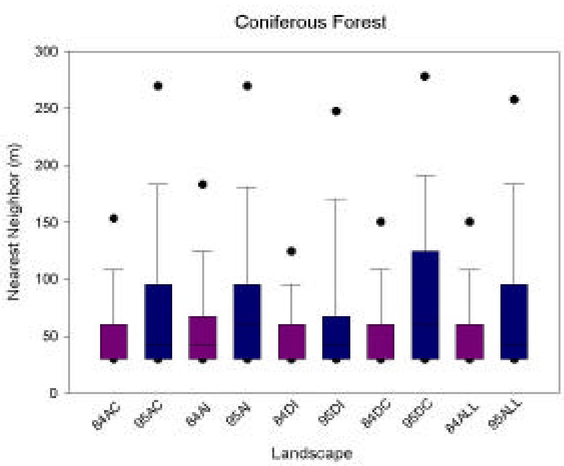
Landscapes

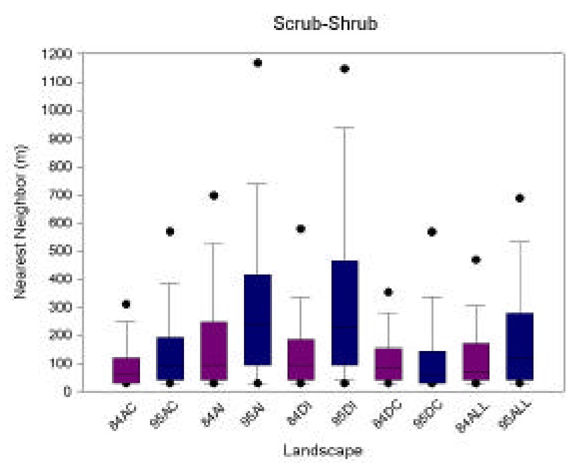
AC = Atlantic Coast
AI = Atlantic Inland
DI = Del Bay Inland
DC = Del Bay Coast
ALL = Study Area

Figure 12. Nearest Neighbor distribution by landscape for forest and Scrub-shrub land classes: 1984 and 1995 level 2 at Cape May peninsula, New Jersey.









Landscapes

AC = Atlantic Coast
AI = Atlantic Inland
DI = Del Bay Inland
DC = Del Bay Coast
ALL = Study Area

Figure 13. Percent of Suitable land cover, which remained in 1995 from 1984 Suitable patches at Cape May peninsula, New Jersey. Suitable is defined as forest and Scrub-shrub classes combined. Analysis was performed according to 1984 patch size classes for the study area.

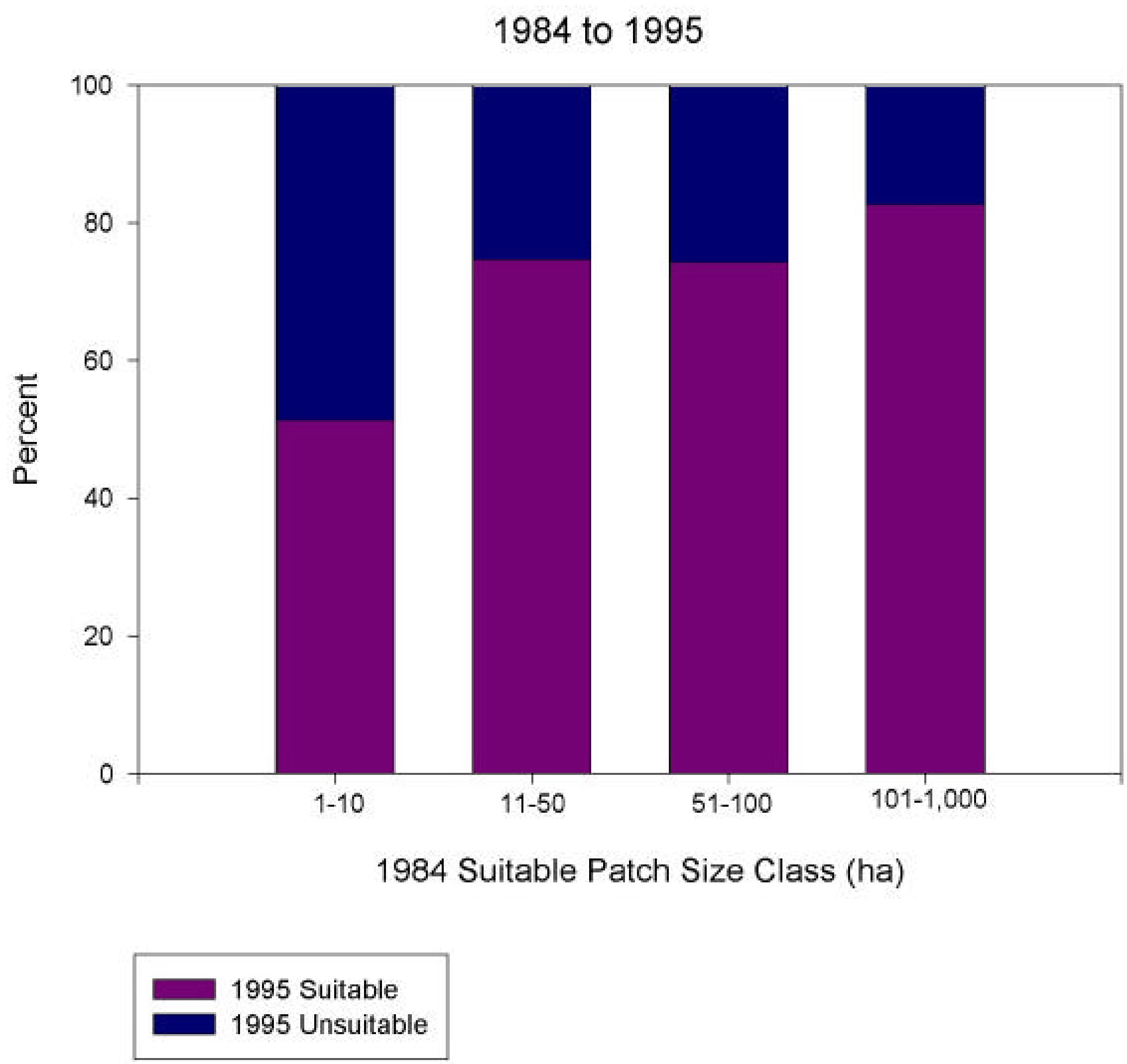
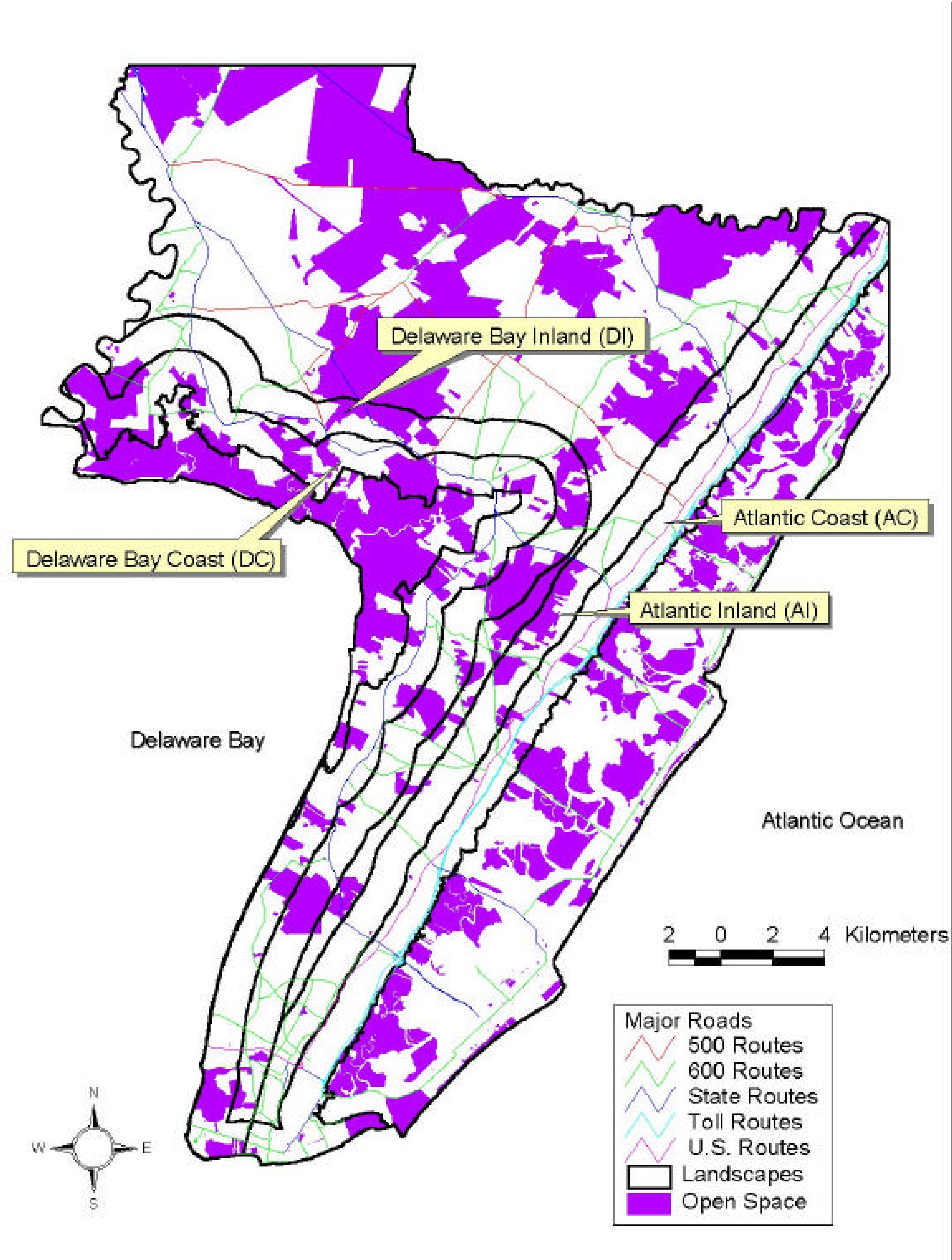


Figure 14. Open space (2000) within the Cape May peninsula study area: non-profit, local, state and federal lands.



Appendix 1. Definition of level 1 and 2 land cover classes. Level 1 mapping produced for 1972 and 1984 and Level 2 mapping produced for 1984 and 1995.

Level 1 Classes

Developed	Includes Developed: Light-Wooded and Developed: Light-Unwooded, Moderate to High classes. Light, moderate and high refer to the development density.
Cultivated/Grassland	Includes all cultivated and grassland classes. Cultivated includes row and non-row crops. Grassland includes both managed and unmanaged grasslands.
Woody Land	Includes all upland forest and scrub-shrub classes.
Bare Land	Includes all upland areas with bare ground (e.g. exposed substrate).
Unconsolidated Shore	Includes exposed substrate in a wetland (e.g. mud flat or beach).
Estuarine Emergent Wetland	Includes tidal wetland areas with emergent vegetation.
Palustrine Wetland	Includes any vegetated, non-tidal wetland.
Water	Includes tidal and non-tidal bodies of water

Level 2 Classes

Developed: Light-Unwooded Moderate-High	Includes development of light density without an intact forest canopy and development of moderate to high Density.
Developed: Light-Wooded	Includes light intensity development with an intact forest canopy.
Cultivated	Includes all row and non-row crop lands.
Grassland	Includes managed and unmanaged grassland.
Forest: Deciduous	Includes upland and wetland forest areas in which deciduous trees comprise >66% of the canopy.
Forest: Mixed	Includes upland and wetland forest areas in which deciduous trees comprise between 33% and 66% of the canopy.

Appendix 1. (cont’d)

Level 2 Classes (cont’d)

Forest: Coniferous	Includes upland and wetland forest areas in which coniferous trees comprise >66% of the canopy.
Scrub-shrub	Includes wetland and upland scrub-shrub.
Bare Land	Includes all upland areas with bare ground (e.g. exposed substrate).
Unconsolidated Shore	Includes exposed substrate in a wetland (e.g. mud flat or beach).
Tidal Emergent Wetland	Includes tidal wetland areas with emergent vegetation.
Freshwater Emergent Wetland	Includes non-tidal wetland areas with emergent Vegetation
Water	Includes tidal and non-tidal bodies of water

Appendix 2. Landscape metric definitions, excerpted from McGarigal and Marks (1994).

$$\textbf{CLASS AREA} = \sum_{j=1}^{n} \textbf{patch}_{ij}\ \textbf{size (m}^2\textbf{) of class i/10,000}$$

Units: Hectares.

Range: CA > 0, without limit.

CA approaches 0 as the patch type becomes increasingly rare in the landscape. CA equals the total landscape area when the entire landscape consists of a single patch type; that is, when the entire image is comprised of a single patch.

Description: CA equals the sum of the areas (m^2) of all patches of the corresponding patch type, divided by 10,000 (to convert to hectares); that is, total class area.

$$\textbf{\% OF LANDSCAPE} = \left(\sum_{j=1}^{n} \textbf{patch}_{ij}\ \textbf{size (m}^2\textbf{) of class i/total landscape area (m}^2\textbf{)}\right)\textbf{*100}$$

Units: Percent

Range: $0 < \%LAND \leq 100$

%LAND approaches 0 when the corresponding patch type (class) becomes increasingly rare in the landscape. %LAND = 100 when the entire landscape consists of a single patch type; that is, when the entire image is comprised of a single patch.

Description: %LAND equals the sum of the areas (m^2) of all patches of the corresponding patch type divided by the total landscape area (m^2), multiplied by 100 (to convert to a percentage); in other words, %LAND equals the percentage the landscape comprised of the corresponding patch type.

Appendix 2. (cont'd)

TOTAL LANDSCAPE AREA = area of the landscape/10,000

Units: Hectares

Range: TA > 0, without limit.

Description: TA equals the area (m^2) of the landscape, divided by 10,000 (to convert to hectares). TA excludes the area of any background patches within the landscape.

NUMBER OF PATCHES = number of patches of class i

Units: None.

Range: NP ≥ 1, without limit.

NP=1 when the landscape contains only 1 patch of the corresponding patch type; that is, when the class consists of a single patch.

Description: NP equals the number of patches of the corresponding patch type (class).

AREA [PATCH SIZE] = area of patch (m^2)/10,000

Units: Hectares

Range: AREA > 0, without limit

The range in AREA is limited by the grain and extent of the image, and in a particular application, AREA may be further limited by the specification of a minimum patch size that is larger than the grain.

Description: AREA equals the area (m^2) of the patch, divided by 10,000 (to convert to hectares).

Appendix 2. (cont'd)

SHAPE INDEX = (.25*patch perimeter (m))/(patch size(m^2))$^{.5}$

Units: None

Range: SHAPE ≥ 1, without limit

Shape = 1 when the patch is square (raster) and increases without limit as patch shape becomes more irregular.

Description: SHAPE equals patch perimeter (m) divided by the square root of patch area (m^2), adjusted by a constant to adjust for a square standard (raster).

NEAREST NEIGHBOR = Distance to next nearest patch of same type (class)

Units: Meters

Range: NEAR > 0, without limit

Description: NEAR equals the distance (m) to the nearest patch of the same type, based on the shortest edge-to-edge distance.

SHANNON'S DIVERSITY INDEX = $-\sum_{i=1}^{m} (P_i * \ln P_i)$

P_i = proportion of the landscape occupied by patch type (class) i

Units: None

Range: SHDI ≥ 0, without limit.

SHDI = 0 when the landscape contains only 1 patch (i.e. no diversity). SHDI increases as the number of different patch types (i.e. patch richness) increases and/or the proportional distribution of area among patch types becomes more equitable.

Description: SHDI equals minus the sum, across all patch types, of the proportional abundance of each patch type multiplied by that proportion.

Appendix 2. (cont'd)

SHANNON'S EVENNESS INDEX $= -\sum_{i=1}^{m} (P_i * \ln P_i) / \ln m$

P_i **= proportion of the landscape occupied by patch type (class) i**

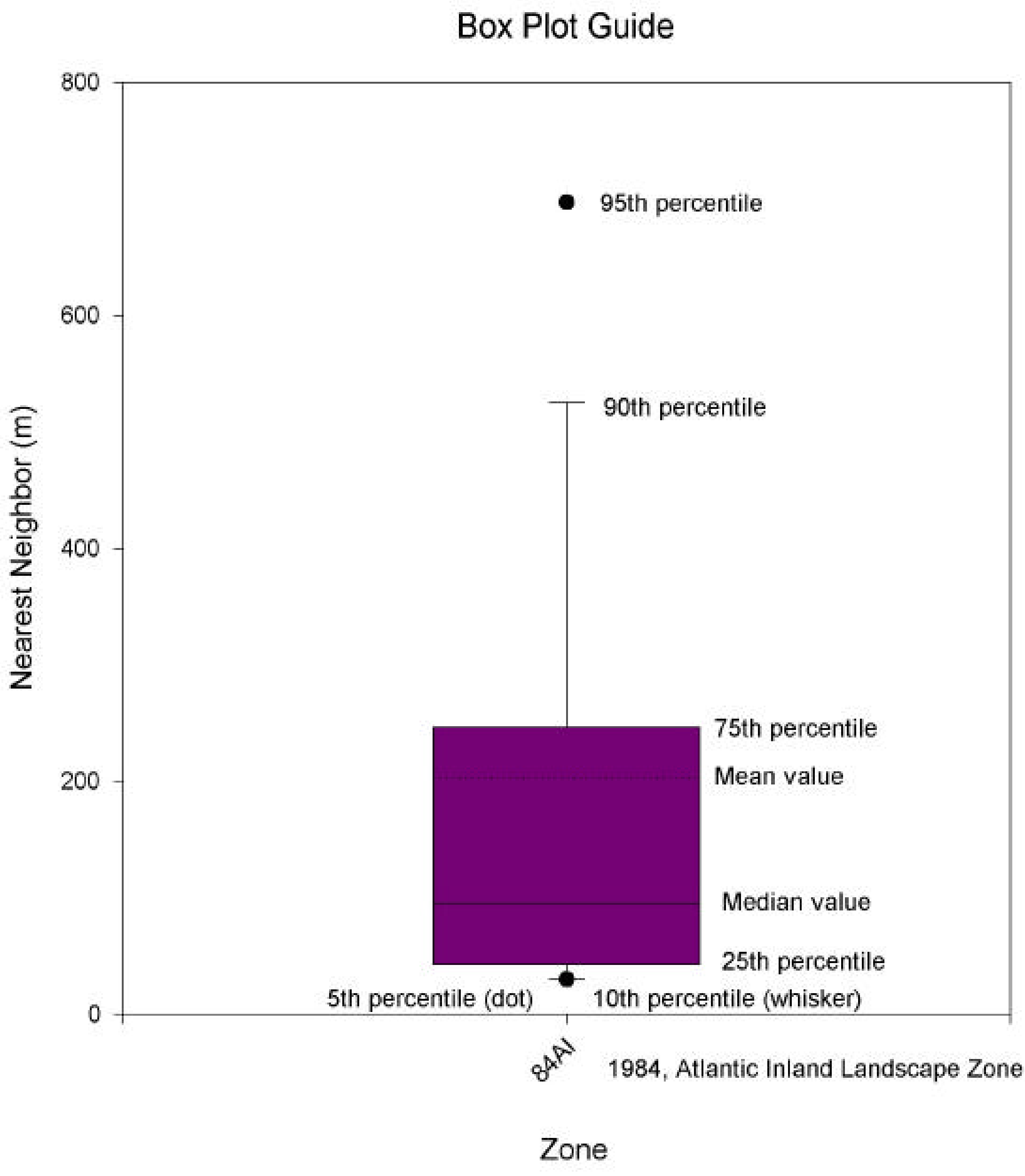
Units: None

Range: $0 \leq SHEI \leq 1$

SHEI = 0 when the landscape contains only 1 patch (i.e. no diversity) and approaches 0 as the distribution of area among the different patch types becomes increasingly uneven (i.e. dominated by 1 type). SHEI = 1 when distribution of area among patch types is perfectly even (i.e. proportion abundances are the same).

Description: SHEI equals minus the sum, across all patch types, of the proportional abundance of each patch type multiplied by that proportion, divided by the logarithm of the number of patch types. In other words, the observed Shannon's Diversity Index divided by the maximum Shannon's Diversity Index for that number of patch types.

Appendix 3. Example box-plot generated using SigmaPlot 4.0. These plots used for patch size, shape index and nearest neighbor.



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