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Evaluating Temporal Changes in Landscape Heterogeneity as an Influence on Freshwater Turtle Habitat in Lancaster County, Pennsylvania

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Abstract

Human activity causes landscape changes, which in turn can influence habitat fragmentation and a loss of habitat connectivity. The purpose of this project was to evaluate temporal changes in landscape heterogeneity on potential habitat availability and accessibility for the painted turtle, *Chrysemys picta*. We hypothesized that the number of freshwater ponds has increased and that the landscape between freshwater ponds has become more heterogeneous from the 1960s to 2016 in Lancaster County, Pennsylvania. We obtained historical wetlands and land use data from the 1950s to 1970s as well as wetlands and land use data from 2011 to 2016 to show the relationship between freshwater ponds and their surrounding landscape matrix. A buffer of 1500 meters around 12 ponds was used to create 12 landscape replicates. These replicates were then analyzed for several measures of landscape division in FRAGSTATS, including the number of patches, patch density, and Landscape Division Index. The total number of ponds in each landscape at each time period was also determined in ArcGIS. Statistical analyses using paired t-tests showed that there were a greater number of patches (p = 4.47e-10), greater patch density (p = 3.63e-10), and a greater proportion of divided landscape (p = 1.57e-05) in the 2011-2016 data compared to the 1950s-1970s data. The data showed that the number of ponds increased in the entire landscape during the same period. These analyses show that in Lancaster County, the landscape has become more heterogeneous over the course of

approximately 60 years, leading to a more divided landscape. These results have implications for animals, such as the painted turtle, that rely on pond connectivity as a component of their habitat. Although the number of habitat patches has increased, increased landscape heterogeneity could lead to decreased habitat connectivity, which could negatively affect organisms by preventing them from using all of the potential habitat in the landscape.

Introduction

Human activity and development impact natural systems through habitat loss and fragmentation, which are major threats to biodiversity (Wilcove et al. 1998). Wetlands are one type of habitat that have experienced losses and fragmentation in the past. Since the mid-1700s, wetlands have been destroyed to the point that about one half of the wetlands in the continental United States have been converted to other land uses (Brinson and Malvárez 2002). Alternatively, when landscape conversion occurs, there is a loss of one kind of habitat as well as a potential gain in another. This is the case for freshwater ponds in the United States, which have experienced increases in the last century (Zedler and Kercher 2005). Freshwater ponds provide habitat for many species, so it would appear that net gains in freshwater ponds could provide benefits to certain organisms. In addition, an increase in ponds could improve connectivity in the landscape by decreasing distance between ponds, since the probability of movement decreases as distance between habitat patches increases (Roe et al. 2009).

Alternatively, properties of the habitat patches themselves are not the only factors at stake, especially in the context of a fragmented landscape due to human activity. Bender and Fahrig (2005) found that habitat patch size and isolation can be poor predictors of interpatch movement for freshwater turtles in the context of a heterogeneous landscape matrix. Landscape conversion, in addition to destroying and creating habitat, can alter the ability of an organism to move between habitat patches by altering the land use of the matrix (Bowne et al. 2006). When organisms utilize various habitat patches, movement between these patches is important for maintaining genetic diversity and allowing for the recolonization of extinct subpopulations (Stevens et al. 2006), so barriers to connectivity created by changes in the landscape matrix could potentially harm organisms.

In order to assess changes in the landscape and their predicted effect on habitat, we chose to consider freshwater ponds and the matrix between them in the context of the painted turtle, *Chrysemys picta*. Painted turtles utilize freshwater ponds as their primary habitat and can use of multiple ponds in an area (Bowne et al. 2006). Painted turtles have been found to travel up to 1500 meters between ponds, and features of the landscape including roads have been found to directly impact connectivity between ponds for painted turtles (Bowne et al. 2006).

We conducted this research in order to investigate the temporal changes in landscape and their potential effect on freshwater turtles. Data including land use and pond location were collected for two distinct time periods in northwestern Lancaster County, Pennsylvania, and then these data were analyzed for changes in landscape metrics. We hypothesized that the number of ponds in the selected region has increased, the interpond distance has decreased, and the landscape between the ponds has become more heterogeneous from the 1960s to 2016.

Materials and Methods

Ponds Data

Historical pond data were obtained through the USGS Historical Topographic Map Collection, including the three adjacent topographic quadrangles for Elizabethtown in 1964, Middletown in 1963, and Manheim in 1955. These maps were downloaded into ArcMap 10.4

and all ponds were digitized to create a map layer of polygons representing all of the ponds in the rectangular area of the topographic maps during the 1960s. Current pond data were obtained through the US Fish and Wildlife Service National Wetlands Inventory for the state of Pennsylvania in 2016, then downloaded into ArcMap 10.4. Freshwater ponds as a feature class were selected and clipped to the area of the entire extent of the three historical topographic quadrangles to create a polygon layer representing all of the ponds in that extent during 2016.

Land Use Data

Historical land use data were obtained from the USGS for the Northeastern United States in 1970, then downloaded into ArcMap 10.4 and clipped to the extent of the three adjacent topographic quadrangles to create the historic land use raster layer. Current land use data were obtained from the National Land Cover Database for the entire country in 2011, then downloaded into ArcMap 10.4 and clipped to the extent of the three adjacent topographic quadrangles to create the current land use raster layer.

Analyzing Pond Number and Interpond Distance

A count of the original pond polygons and the average nearest neighbor spatial statistics tool were used to determine if the number of ponds and the distance between them changed between the historic and current time periods at the level of the entire landscape. These data were collected for the entire landscape given by the extent of the three adjacent topographic quadrangles (Figure 1). The historic and current pond layers were converted to raster and added to the respective land use raster layers. Due to differences in land use definitions for the historic and current layers, the raster categories were reclassified into the same definitions (Table 1).

Analyzing Landscape Heterogeneity

Landscape metrics including the number of patches, patch density, and Landscape Division Index were used in FRAGSTATS Version 4.2 to analyze the heterogeneity of the landscape. The number of patches corresponds to the number of distinct patches of different classes in the landscape, with a completely homogeneous landscape begin comprised of only one patch and a heterogeneous landscape consisting of many patches (McGarigal 2015). Patch density is the number of patches of a certain class over the total landscape area (McGarigal 2015). The Landscape Division Index is the proportion of the landscape that is divided, based on the probability that any two cells in the landscape are not in the same patch; a completely homogeneous landscape would have a division index of 0, whereas a completely heterogeneous landscape would have a division of 1 (McGarigal 2015).

To prepare the data for analysis in FRAGSTATS, the land use types were reclassified into patch type categories, based on the ability of turtles to pass through each landscape type (Table 2; Cosentino et al. 2008). In order to simulate landscape division at a scale that would be more relevant to individual turtles, a buffer of 1500 meters was created around 20 randomly selected ponds in the historical pond polygon layer. The 12 non-overlapping regions defined by this buffer were selected as the 12 replicate landscapes for analysis. The raster containing patch type categories were extracted to the extent of each buffer region for the historic and current data sets, then these data were run through FRAGSTATS using an eight-neighbor rule; each raster cell is compared to the four cells directly above, below, and beside it, as well as the four cells diagonal from it. Data were recorded for landscape metrics including number of patches, patch density, and landscape division index. These results were analyzed using a paired t-test in Microsoft Excel.

Results

The total count of pond number in ArcMap showed that the number of ponds in the study area increased from 252 ponds covering a total area of 623,150 m^2 in the 1960s to 402 ponds covering a total area of 1,135,630 m^2 in 2016 (Table 3). The spatial statistics analysis in ArcMap for the Average Nearest Neighbor distance showed that the average distance between ponds decreased from about 583 meters in the 1960s to about 465 meters in 2016 (Table 3).

The program FRAGSTATS was used to analyze division in the twelve 1500 meter buffer landscapes. The FRAGSTATS analyses showed that the number of patches increased from an average of 11 patches in the 1960s to an average of 62 patches in 2016 (Paired t-test, p = 4.47e-10; Table 4). Likewise, the patch density increased from an average of 1.5 patches per 100 hectares in the 1960s to an average of 8.6 patches per 100 hectares in 2016 (Paired t-test, p = 3.63e-10; Table 4). The Landscape Division Index increased from an average of 0.36 in the 1960s to an average of 0.72 in 2016 (Paired t-test, p = 1.57e-05; Table 4). A visual representation of this increase in division for one turtle-scaled landscape is displayed in Figure 2.

Discussion

Our analyses showed that the number of freshwater ponds has increased, the interpond distance has decreased, and landscape heterogeneity has increased from the 1960s to 2016 in northwestern Lancaster County. The increase in ponds and decrease in interpond distance indicates that ponds are more clustered together now than in the past, so land use change has resulted in an increase in pond habitat in northwestern Lancaster County. In addition, the increase in number of patches, patch density, and landscape division indicates that the landscape has become more heterogeneous. Therefore, painted turtle habitat patches have increased in number and aggregation, but the matrix between these habitat patches has also become more variable.

The implications of these analyses are important when considering connectivity between habitat for freshwater turtles, as well as other species. Intuitively, a highly heterogeneous landscape is expected to pose more barriers to movement for species, simply because of the increased number of boundaries between land cover types (Bender and Fahrig 2005). If those land uses present different resistance to the movement of species, than this heterogeneous landscape can impair movement. For example, the presence of roads between freshwater ponds can decrease habitat connectivity for freshwater turtles by increasing mortality of individuals that attempt to cross those roads (Bowne et al. 2006). With the landscape becoming more heterogeneous due to human activity, it is important to better our understanding of how animals move between habitat and through different land uses so that we can potentially create corridors to facilitate their movement.

Most of conservation work is focused on loss of habitat for key species, but landscape conversion does not always mean that the new land use is completely unusable by all species. In the context of this study, landscape changes occurred that involved an increase in freshwater ponds, therefore indicating a potential increase in viable habitat for freshwater turtles like the painted turtle. Similarly, increased planting of forests as bioenergy crops, paired with harvesting methods such as clear-cutting and thinning, has been projected to provide more habitat for shrub-loving species due to an increase in development of dense, shrubby vegetation in these situations (Tarr et al. 2017). Therefore, it is important to consider what land use conversion is occurring and how the loss of habitat for some species might mean the gain in habitat for others.

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Tables and Figures

Table 1: Reclassifications of historic and current land use features, with NP indicating land uses that were not present in the data.

LULC Historical Classes	NLCD 2011 Classes	New Classes
Residential, commercial and services, industrial, transportation, communication, utilities, mixed urban or built-up land, other urban or built-up land	Developed open space, developed low intensity, developed medium intensity, developed high intensity	Urban/Developed
Cropland and pasture, orchards, groves, vineyards, nurseries ornamental, confined feeding operations	Pasture/Hay, Cultivated crops	Agricultural
Herbaceous rangeland	Grassland/Herbaceous	Herbaceous
NP	Shrub/scrub	Shrub/scrub
Deciduous forest land	Deciduous forest	Deciduous forest
NP	Evergreen forest	Evergreen forest
NP	Mixed forest	Mixed forest
Streams and canals, lakes, reservoirs	Open water	Water
NP	Woody wetlands	Woody wetlands
NP	Emergent herbaceous wetlands	Emergent herbaceous wetlands
Strip mines, quarries, gravel pits	Barren land (rock/sand/clay)	Barren

Table 2: Reclassifications of land cover into patch type based on similarity to pond habitat, with increasing numbers indicating decreasing similarity.

Land Use	Patch Type Reclassification
Pond	1
Water, Woody wetlands, Emergent herbaceous wetlands	2
Herbaceous, Deciduous forest, Evergreen forest, Mixed forest, Shrub/scrub	3
Agricultural	4
Barren	5
Urban/Developed	6

Table 3: Number of ponds and interpond distance in the historic and current time periods at the entire landscape scale.

Time Period	Number of Ponds	Interpond Distance (m)
Historic	252	583
Current	402	465

Table 4: Mean values for landscape metrics in the historic and current time periods at the turtle-landscape scale.

Metric	Historic	Current	*p*-value
Number of Patches	11.08 ± 5.82	62.33 ± 10.92	4.47e-10
Patch Density (patches/100 ha)	1.52 ± 0.79	8.55 ± 1.46	3.63e-10
Landscape Division Index	0.36 ± 0.28	0.72 ± 0.18	1.57e-05

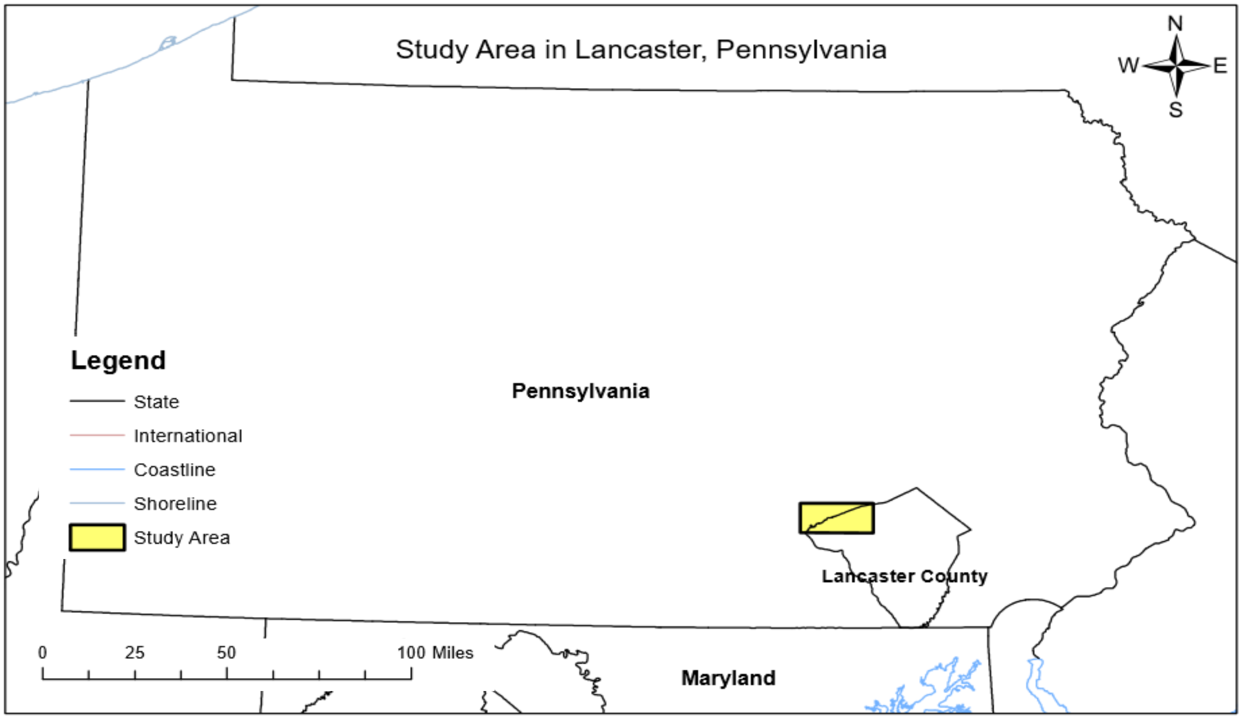

Figure 1: Map of the location and spatial extent of the study area in Lancaster County, Pennsylvania. State Boundary data from ArcGIS. Lancaster County Boundary data from Pennsylvania Spatial Data Access.

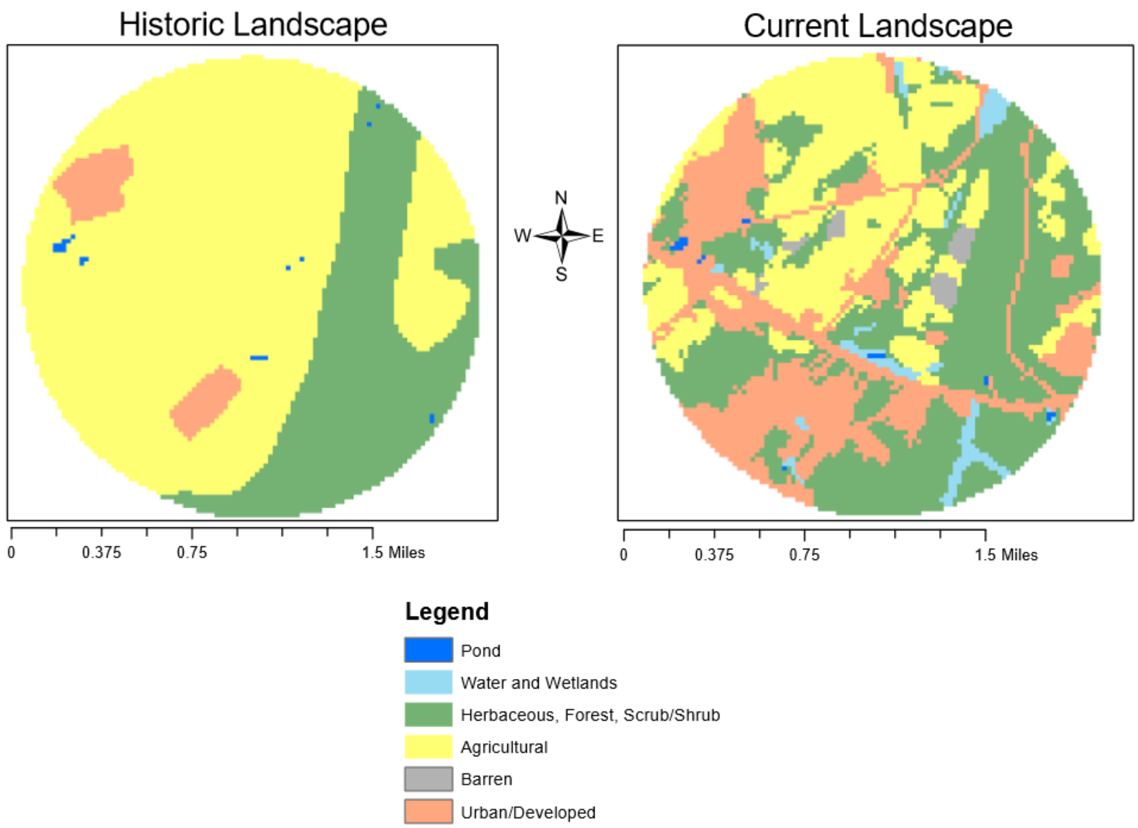

Figure 2: Map comparing landscape division between the historic (1960s-1970s) and current (2011-2016) time periods for the same geographic location. Land uses described in the figure legend are based on connectivity classifications from Table 2. Historic data was obtained from the USGS Historical Topographic Map Collection in the 1960s and USGS Land Use of Northeastern United States in 1970. Current data was obtained from the US Fish and Wildlife Service National Wetlands Inventory in 2011 and National Land Cover Database in 2016.