Title - A national assessment of green infrastructure and change for the conterminous United States using morphological image processing

Abstract - Green infrastructure is a popular framework for conservation planning. The main elements of green infrastructure are hubs and links. Hubs tend to be large areas of ‘natural’ vegetation and links tend to be linear features (e.g., streams) that connect hubs. Within the United States, green infrastructure projects can be characterized as: 1) reliant on classical geographic information system (GIS) techniques (e.g., overlay, buffering) for mapping; 2), mainly implemented by states and local jurisdictions, and; 3) static assessments that do not routinely incorporate information on land-cover change. We introduce morphological spatial pattern analysis (MSPA) as a complementary way to map green infrastructure, extend the geographic scope to the conterminous United States, and incorporate land-cover change information. MSPA applies a series of image processing routines to a raster land-cover map to identify hubs, links, and related structural classes of land cover. We identified approximately 4,000 large ($\geq$ 100 hubs) networks within the conterminous United States, of which 10 percent crossed state boundaries. We also identified a net loss of up to 1.76 million ha of links and 1.72 million ha of hubs between 1992 and 2001. Our national assessment provides a backbone that states could use to coordinate their green infrastructure projects, and our incorporation of change illustrates the importance of land-cover dynamics for green infrastructure planning and assessment.

Keywords - conservation, corridors, ecological networks, land-cover change, landscape ecology, restoration

Introduction

Green infrastructure extends the concept of built-up area needs to conservation of the natural environment (Lewis 1964; Mcharg 1969; Noss and Harris 1986; Benedict and McMahon 2002, 2006; Jongman et al. 2004; Fábos et al. 2004). It is a broadly encompassing concept because its objective is to harmonize communities with the natural systems on which they depend (Benedict and McMahon 2006). Development of community parks and recreation trails, stream restoration, storm water management, and land conservation are all within the broad scope of green infrastructure. It is viewed as a conceptual advance in environmental planning (sensu Hoctor et al. 2008) because it integrates natural systems with community well being (see also Nassuaer 2006). Though broad in scope and spatial scale, green infrastructure projects all share the common goal of sustainable land management planning (Leitão and Ahern 2002, Weber 2004, Ahern 2007).

A significant area of green infrastructure research is related to identification and mapping of ecological networks (Lewis 1964, Harris and Noss 1986, Hoctor et al. 2000, Benedict and McMahon 2002, Carr et al. 20002, Weber 2004, Weber et al. 2006, Hoctor et al. 2008). Two primary components of ecological networks are hubs and links sensu (Benedict and McMahon 2002). Hubs are areas of natural vegetation, other open space, or areas of known ecological value, and links are the corridors that connect the hubs to each other. A set of hubs connected by links constitutes a network that can be used to inform conservation-related land-use decisions.

The use of green infrastructure networks represents a strategic approach (Benedict and McMahon 2006) in that decisions about conservation, protection, and restoration can incorporate information on how potential sites fit within a network that spans a larger area (see also Opdam et al. 2006). In the US, several states and local jurisdictions have recognized the value of a green infrastructure perspective for conservation decision-making (Table 1). Lewis' (1964) greenways plan for Wisconsin was used for land acquisition (Smith 1993). In 1993, Florida instituted a greenways commission for protection and conservation of Florida natural areas (Benedict and McMahon 2006), and Hoctor et al. (2000) developed a green infrastructure network the State to meet commission needs and objectives. The network proposed by Harris and Noss (1986) was used to inform protection of the Florida panther, and also fostered formation of the Florida Greenways Commission. Maryland mapped green infrastructure (Weber et al. 2006) in response to state-mandated conservation initiatives (http://www.greenprint.maryland.gov). Many states in the U.S. have made use of green infrastructure for conservation planning (Table 1).

Although there are notable exceptions in the U.S. (e.g., Noss and Harris 1986, Carr et al. 2002, Fábos et al. 2004, Weber 2004, www.y2y.net), green infrastructure projects is that they to tend to be local or statewide endeavors (Fábos et al. 2004, Benedict and McMahon 2006, Table 1). Green infrastructure plans are better able to address the connectivity they seek to achieve when political boundaries are not considered (Fábos et al. 2004). In this paper, a nationally focused green infrastructure assessment was conducted to add the context that is lost when sub-national political boundaries are imposed. We enriched the context that a national-scale focus brings by also including temporal land-cover change. Incorporation of land-cover change is worthwhile because green infrastructure projects are plans that do not guarantee conservation by themselves. Hoctor et al. (2000), Carr et al. (2002), and Weber et al. (2006) all found that less than 50% their mapped green infrastructure networks were protected. Land-cover change is probable during green infrastructure planning, and information on it has the potential to inform decisions.

We use morphological spatial pattern analysis (MSPA) (Soille and Vogt 2009) to map green infrastructure networks for the conterminous United States. Green infrastructure mapping (e.g., Hoctor et al. 2000, Carr et al. 2002, Weber 2004, Weber et al. 2006) commonly exploits the overlay of different thematic layers first advocated by McHarg (1969) that is characteristic of geographic information system (GIS) software used today. Hubs are commonly defined through GIS overlay of several features of interest, and links are defined primarily by the river network. MSPA, which is based on concepts from mathematical morphology (Soille 2003), can be used to identify hubs and links from a single map rather than GIS overlay of several maps. We used the 2001 National Land Cover Database (NLCD) (Homer et al. 2007) and its complementary land-cover change data (Fry et al. 2009) to implement the national assessment.

Methods

Data

Land cover is a foundation of green infrastructure network mapping (Hoctor et al. 2000, Carr et al. 2002, Weber 2004, Weber et al. 2006). We used NLCD land-cover change data (Fry et al. 2009) to map green infrastructure networks and change in network structure for the conterminous United States. The NLCD land-cover change product was developed for temporal comparisons of the 2001 NLCD (Homer et al. 2007) and the 1992 NLCD (Vogelmann et al. 2001). The NLCD land-cover change data includes an eight-class legend (water, ice, urban, bare ground, forest, shrubland, agriculture, wetland) at a spatial resolution of 0.9ha/pixel (30 X 30 meters pixels). The early and late dates of the NLCD land-cover change data are ca. 1992 and ca. 2001, respectively (Fry et al. 2009), covering an approximate 10-year period.

We chose forest and wetland as our focal classes for green infrastructure network mapping, setting all other classes to background. We chose forest and wetland because forests are an important resource of the United States. Assessments of forest are common because of their importance (e.g., Riitters et al. 2004), and landscape factors such as size and connectedness are important factors of such assessments (Noss 1999, Riitters et al. 2004). Our use of green infrastructure for forest assessment is consistent the forest frontiers study (see Noss 1999). We included wetland along with forest because the NLCD land-cover change data (Fry et al. 2009) did not distinguish between woody and emergent wetlands. Wetlands, in addition to forest, are an important land-cover class for green infrastructure network mapping (Hoctor et al. 2000, Carr et al. 2002, Weber 2004, Weber et al. 2006).

MSPA and green infrastructure network mapping

After reclassifying a raster land-cover map into foreground (forest and wetland) and background (all other classes), MSPA uses a series of image processing routines to identify hubs, links (corridors), edges, and other features that are relevant to green infrastructure assessments (Vogt et al. 2007). The green infrastructure elements identified by MSPA include core, islet, bridge, loop, branch, edge, and perforation (Soille and Vogt 2009) (Table 2). In the terminology of green infrastructure, core is equivalent to hub, and bridge is equivalent to link or corridor. MSPA processing starts by identifying core, which is based on the connectivity rule used to define neighbors and the value used to define edge width (Soille and Vogt 2009). Connectivity can be set to either four (cardinal directions only) or eight neighbors. Edge width affects the minimum size of core and the number of pixels classified as core (Figure 1). Increasing edge width increases the minimum size of core, reducing the number of pixels classified as core. The 'loss' of core that results from increasing edge width results in gains for all other classes, not just edge (Table 3). Increasing edge width can change core to islet if the area of core is small, and core to bridge if the area of core is narrow (see Figure 1). We used eight-neighbor connectivity and edge values of one (1), two (2), and four (4) for this analysis. The physical distance (width) of edge translates to 30, 60, and 120 meters (m) for values one (1) two (2) and four (4), respectively, as a result of the native 30-meter pixel size of the Landsat TM imagery used to produce the NLCD (Homer et al. 2007). Edge width can be set to any multiple integer of the pixel resolution (http://forest.jrc.ec.europa.eu/biodiversity/GUIDOS/).

Additional GIS processing was needed to organize MSPA features (i.e., core, bridge, and related elements) into the ecological networks of disjunct core areas connected by bridges that are the heart of green infrastructure. Connectivity among disjunct areas of core was determined using common raster GIS routines that group adjacent and like-classified pixels, assigning each group a unique identifier. The output of the grouping routine is the raster equivalent of a vector (i.e., polygon) map where each unique occurrence of a particular class (e.g., core) has a unique identifier. Raster grouping was done for maps core only and maps of core and bridge combined. Comparison of the two maps yields the number of core areas, the proportion of core areas that are connected to at least one other core area, and the number of core areas in a given network. Summary of the grouped bridge and core map yields the overall size of a network of connected core areas (excluding edges, branches and loops). We then overlaid the network maps on a map of state boundaries to determine where and how many networks crossed state borders.

Comparison of MPSA output with other green infrastructure networks

Our green infrastructure networks naturally differ of other published networks (e.g., Hoctor et al. 2000, Carr et al. 2002, Weber et al. 2006) because we rely solely on land cover and do not include the other layers of information that can be included when GIS overlay routines are used. To quantify the differences, we compared our network maps to the Maryland (Weber et al. 2006) and southeast US (Carr et al. 2002) networks. The comparison provides insight into the role and importance of land cover in green infrastructure network mapping. We used the 1992 component of the NLCD land-cover change data (Fry et al. 2009) for the comparisons because the Maryland (Weber et al. 2006) and Southeast US networks (Carr et al. 2002) were based on NLCD 1992 (Vogelmann et al. 2001). While the NLCD 1992 (Vogelmann et al. 2001) was based on somewhat different mapping methods than the NLCD 2001 (Homer et al. 2007) and the NLCD land-cover change data (Fry et al. 2009), the comparisons are based on land-cover sources that are as similar as possible (Table 4).

Results

The number of distinct core areas ranged from 1.7×10^6 (edge width = 120m) to 7.5×10^6 (edge width = 30m) (Table 4). A small proportion of core areas were not connected to another core area, and that proportion decreased as edge width increased. The number of networks of connected core also decreased as edge width increased, decreasing from approximately 820,000 (edge width 30m) to approximately 93,500 (edge width = 120m (Table 4). The sheer number of networks is an indicator of fragmentation (Riitters et al. 2002, Wickham et al. 2008). If forests were not fragmented, the number of core areas would not decline by orders of magnitude with very small increases in edge width, there would be few networks, and areally small networks (e.g., 2 to <10 core areas) would not comprise the majority of networks.

An objective of many green infrastructure network mapping projects is to document where connectivity exists as a means to combat the potentially harmful effects of fragmentation (Hoctor et al. 2000, Carr et al. 2002, Weber 2004, Weber et al. 2006). The context contributed by a national perspective can be used to extend connectivity mapping beyond state boundaries. The number of networks with at least 100 core areas that crossed state boundaries increased from 313, to 407, to 467, for edge widths of 120m, 60m, and 30m, respectively (Figure 2). Depending on edge width, the state-spanning networks comprise 10% to 15% of the total number of networks with at least 100 core areas.

Core and bridge green infrastructure elements were temporally dynamic (Figure 4). Most areas of the conterminous U.S. experienced a net change in either core, bridge, or both elements for both values of edge width. Net loss of core and bridge dominated nationally (Table 5), with net losses for both elements occurring in approximately 40 percent of the 120x120 km summary units. Net loss of core and bridge characterized the eastern United States, the Pacific Northwest, and much of the four-corner States (Arizona, New Mexico, Utah, Colorado). For edge with equal to 60m, average net losses of core were 413 ha for summary units with net losses of core, and average net losses of bridge were 378 ha for summary units with net losses of bridge. Net gains in core and bridge characterized the Great Plains, portions of the Midwest, and southern Texas. Average net gains in core (edge width = 60m) were 144 ha for summary units with net gains in core, and average net gains in bridge (edge width = 60m) were 52 ha for summary units with net gains in bridge. The spatial patterns of change in core and bridge for edge width equal to 30m and 120m were similar to those depicted in Figure 4.

Although not all bridge loss breaks connectivity within a network, the data can be used to locate where bridge losses have resulted in network fragmentation. Bridge loss in southwest Georgia, for example, disconnected a 20,000 ha portion a 1,036,000 ha network (Figure 5). The disruption of network connectivity illustrates how local-scale land-cover changes can have broader-scale consequences (Wickham et al. 2007a, b, 2008). A very small loss of forest and wetland occurred in a pattern that broke connections within a larger network. Such patterns suggest that the local-scale characteristics of many land-use decisions (Foster and Foster 1999, Sampson and Decoster 2000) are probably made without regard to their broader-scale context.

Comparison of our networks with those for the southeastern United States (Carr et al. 2002) and Maryland (Weber et al. 2006) show the impact of choices regarding data and models for delineation of green infrastructure networks (Table 6). Our models relied solely on land cover whereas the Maryland and southeastern US models incorporated several other sources of information in addition to land cover. The proportion of Maryland and southeastern US hubs and corridors that are labeled as background by MSPA reflect differences in modeling choices the use of the additional information in Maryland and the southeastern US studies. Nevertheless, the strong agreement (e.g., 75% of the southeastern US network is also labeled as one of the six MSPA classes) shows the importance of land cover in developing green infrastructure networks.

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Discussion

Using MSPA to map the elements of green infrastructure, we identified 1.7 to 7.5 million areas of core and 93,000 to 820,000 networks depending on the width used to define the edge around core. Most of the networks were small, with a comparatively small percentage of spatially extensive networks. The distribution of ‘many small but few large’ networks is evidence of fragmentation (e.g., Riitters et al. 2002, Wickham et al. 2008), and the appeal and motivation for using green infrastructure for conservation (Noss and Harris 1986, Hoctor et al. 2000, Carr et al. 2002, Weber et al 2006). The local-scale character of green infrastructure planning and implementation can be enriched by broadening their geographic perspective and ignoring political boundaries, which may foster a more comprehensive approach to prevention of further fragmentation of the natural environment (e.g., Noss and Harris 1986, Fábos 2004). Approximately 10-15 percent of the large forested-wetland networks ($\geq$ 100 core areas) crossed state boundaries.

Temporal analysis of land cover (i.e., change) added another useful source of information for green infrastructure assessment and planning. Land-cover is dynamic rather than static (Dobson et al. 1995), indicating that temporal change should be incorporated into green infrastructure planning where possible. Our temporal analysis indicated that losses of core and bridge green infrastructure elements were substantial over the approximate 10-year period. The dynamic character of land cover and the low proportions of green infrastructure that are actually protected (see Hoctor et al. 2000, Carr et al. 2002, Weber et al. 2006) suggest that land-cover change has the potential to alter plans for conservation of unprotected green infrastructure.

Future land-cover change is sometimes modeled as part of green infrastructure planning. Carr et al. (2002) and Weber et al. (2006) used existing GIS layers to model the relative risk of urbanization. The risk analysis was then used to guide preservation decisions (e.g., unprotected hubs and links with high urbanization risk were assigned a higher priority for protection than counterparts with lower urbanization risk). Such models only consider one of many possible driving forces of land-cover change (e.g., see Clagget et al. 2004), and do not include some of the benefits that measured land-cover change offers. Loss of green infrastructure elements can be used to guide restoration. Loss of bridges (e.g., Figure 5), for example, has the potential to be used to prioritize restoration based on re-establishing lost connectivity. Without temporal information, restoration is based on geographic gaps in green infrastructure. Adding land-cover change to geographic gaps enriches the main source of information that would be used to inform restoration decisions. Likewise, gains in green infrastructure could be used to re-assess preservation priorities. Protection priorities for two otherwise equal areas might change over time because of differential gains in green infrastructure.

The different perspectives on green infrastructure taken by MSPA and GIS overlay represent opportunities for integration. Green infrastructure projects typically emphasize size by applying areal thresholds to define hubs, and then rely on river networks and other linear features to determine connectedness. Hubs are typically large, buffers are often set at a fixed width, and links are not necessarily comprised of ‘natural’ vegetation throughout their length (Hoctor et al. 2000, Carr 2002, Benedict and McMahon 2006, Weber et al. 2006). Rather than size, MSPA emphasizes interior and connectedness. MSPA defines hubs based on interior, which is defined by a user-specified edge width, and links can not have gaps in ‘natural’ vegetation (if ‘natural’ vegetation classes only are used to define foreground). Comparison of output from the two approaches can be used to examine the relative roles of interior and size for defining hubs, the importance of uninterrupted ‘natural’ vegetation throughout a corridor’s length, the value of using a range of widths for examining edge effects (Harper et al. 2005, Laurance 2008), and for distinguishing possible differences between interior (perforation) and exterior edge effects.

Connections between structural and functional connectivity is one example of integration that is highlighted by considering the different perspectives of MSPA and green infrastructure networks mapped using classical GIS overlay techniques. One of the striking results of the comparisons of MSPA to the other networks is the large proportion of Maryland corridors that do not contain forest or wetland (Table 6). Maryland corridors were identified with a view toward those places in the landscape that should promote functional connectivity, whereas MSPA corridors were generated from the perspective of structural connectivity. While functional connectivity is the ultimate objective of green infrastructure network mapping, it is as yet unclear how structural connectivity factors into promoting and enhancing that objective (Simberloff et al. 1992, Beier and Noss 1998). There is evidence, however, that structural connectivity promotes functional connectivity. Haddad and Tewkbury (2006) point out corridor studies should focus on habitat specialists, suggesting that functional corridors should be comprised of the species' habitat. Robichaud et al. (2002), Belisle and Desrochers (2002), Tewksbury et al. (2002), and Levey et al. (2005) all found that corridors promoted connectivity, and in each case the corridor and habitat land cover were the same. Dixon et al. (2006) found that dense urban land use and an interstate appeared to be barriers in a corridor connecting central and northern Florida black bear populations. Green infrastructure reports also commonly point out the additional environmental benefits beyond habitat and functional connectivity conservation (e.g., Weber 2004, Hoctor et al. 2008) that are mainly of function of conservation of 'natural' lands. Water quality is often cited as one of these benefits, and the structural 'connectivity' provided by having riparian vegetation adjacent to streams is a recognized need for water quality maintenance (Peterjohn and Correl 1984, Nakano and Murakmi 2001, Sweeney et al. 2004). Streams are an important component of MSPA, Maryland, and southeastern US corridors, and the relationship between riparian vegetation and water quality indicates the structure and function are tightly linked for many of the additional environmental benefits of green infrastructure (Weber 2004, Hoctor et al. 2008).

MSPA, Maryland, and the southeastern US networks were also different in there selection of corridor width. MSPA corridors ranged in width from 30m to 120m, Maryland corridors were fixed at 350m (Weber et al. 2006), and southeastern US corridor width was dependent on the inputs into their least-cost-path analysis. Field studies of corridor width show similar variability. Field studies showing positive corridor effects had corridor widths ranging from 25m (Tewksbury et al. 2002) to 100m wide (Robichaud et al. 2002) to 150m wide (Mech and Hallet 2000). Interestingly, Levey et al. (2005) found that it was the contrast (i.e., edge) between the corridor and the surrounding land cover that provided the conduit between habitat patches, suggesting that corridor presence rather width may be a determining factor, at least for some species.

Our choices for MSPA modeling also affected our results, and hence comparisons with the Maryland (Weber et al. 2006) and southeastern US green infrastructure networks (Carr et. al. 2002). Roads are identified reliably in the NLCD 2001 (Homer et al. 2007) and the NLCD land-cover change data (Fry et al. 2009) because of the modeling used to derive NLCD 2001 land cover (Homer et al. 2004). Use of NLCD 2001 (Homer et al. 2007) resulted in the 'fragmentation' of networks that might have been mapped as connected if land-cover data with a less well defined road network had been used. The effects of roads are an important ecological topic (Forman and Alexander 1998, Trombulak and Frissell 2001), and there are few places in the US that are not within a 'road effect' zone of some type (Riitters and Wickham 2003). Still, there is insufficient information to determine which classes of roads (rural, interstate) should be allowed to disconnect networks (see Clevenger and Wiezchowski 2006). Absent this information, we permitted all roads identified in the NLCD 2001 (Homer et al. 2007) to disconnect networks. Use of land-cover data with a less well defined road network would have resulted in fewer networks (Table 4). The NLCD 1992 (Vogelmann et al. 2001), which was the primary source of land-cover data for the Maryland (Weber et al. 2006) and southeastern US green infrastructure networks (Carr et al. 2002), is a land-cover data source with a less well defined road network. Setting aside effects of temporal land-cover change, there probably would have been more similarity between MSPA and Maryland and southeastern US green infrastructure networks if NLCD 2001 (Homer et al. 2007) had had a less well defined road network.

Whereas our choice of land-cover data increased the number of networks because of the well-articulated road network, our choice of eight-neighbor connectivity to define MSPA classes (see Methods) had the opposite effect. Use of eight-neighbor connectivity to define connectivity classes increases connectivity among core areas by treating corner only adjacency as connected. Four-neighbor connectivity would treat corner only adjacency as not connected, which would have resulted in a greater number of networks (Table 4).

Choice of spatial extent was also an important source of differences between our results using MSPA and those relying on classical GIS overlay (Riitters 2005). Hoctor et al. (2000), Carr et al. (2002), and Weber et al. (2006) were able to incorporate more detailed information, and hence more precision, into their modeling because they were focused on smaller spatial extents. Shifting to a national extent changes the modeling perspective from precision to generality and realism (Riitters 2005). Generality and realism were achieved by relying on a nationally consistent land-cover database (NLCD 2001) (Homer et al 2007), which was consistent with previous green infrastructure mapping efforts that relied on a similar land-cover dataset (1992 NLCD) as a foundational data set (Carr et al. 2002, Weber 2004, Weber et al. 2006). Incorporation of temporal change in land cover and mapping green infrastructure networks using three different edge widths also added realism.

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List of Tables

Table 1: Green Infrastructure Initiatives. The Conservation Fund site lists several initiatives that in total demonstrate the local to statewide perspective that characterizes green infrastructure projects. (All URLs were accessed on November 13, 2008)

The Conservation Fund:	www.greeninfrastructure.net
Florida:	www.greeninfrastructure.net/florida_profile
Maryland:	www.dnr.state.md.us/greenways/gi/overview/overview.html www.dnr.state.md.us/greenways/greenprint/greenprint.html
New Jersey:	www.gardenstategreenways.org
North Carolina:	www.onencnaturally.org/pages/CPT_Details.html
Virgina:	www.dcr.virginia.gov/natural_heritage/vclna.shtml
New England:	www.umass.edu/greenway
Southeast:	www.geoplan.ufl.edu/epa

Table 2: Definition of MSPA classes

Core:	Foreground pixels surrounded on all sides by foreground pixels.
Islet:	Foreground pixels that do not contain core.
Bridge:	Foreground pixels that connect two or more disjunct areas of core.
Loop:	Foreground pixels that connect an area of core to itself.
Branch:	Foreground pixels that extend from an area of core, but do not connect to another area of core.
Edge:	Pixels that form the transition zone between foreground and background.
Perforation:	Pixels that form the transition zone between foreground and background for interior regions of foreground. Consider a group of foreground pixels in the shape of a doughnut. The pixels forming the inner edge would be classified as perforations, whereas those forming the outer edge would be classified as edge.

Table 3: MSPA class proportions for edge width equal to 30m and 60m.

Class	**Edge = 30m**	**Edge = 60m**	**Edge = 120m**
Branch	0.037	0.056	0.051
Edge	0.134	0.143	0.095
Islet	0.021	0.045	0.091
Core	0.731	0.579	0.361
Bridge	0.030	0.104	0.327
Loop	0.019	0.048	0.062
Perforation	0.028	0.025	0.013

Table 4: Core and network summary statistics for edge width equal to 30m, 60m and 120m. Networks are defined as two or more disjunct core areas connected by bridges. Core is referred to as isolated if it is not connected to another core.

Core and Network Descriptions	**Edge = 30**	**Edge = 60**	**Edge = 120**
Number of core areas	7,526,919	3,913,313	1,692,407
Number of connected core areas	6,078,757	3,457,735	1,498,338
Number of isolated core areas	1,446,558	455,758	98,754
Number of networks	820,431	333,990	93,526
Number of networks with $\geq$ 2 but $<$ 10 core areas	750,170	293,661	76,253
Number of networks with $\geq$ 10 but $<$ 100 core areas	65,657	36,804	15,291
Number of networks with $\geq$ 100 but $<$ 1000 core areas	4,236	3,162	1,819
Number of networks with $\geq$ 1000 core areas	368	273	163

Table 5: Net change (ha) in bridge and core classes. Net loss of bridge increased with edge width and net loss of core decreased with edge width because of the effect of edge width choice on the MSPA classes (see Figure 1 and Table 3).

	Bridge			**Core**		
	Edge = 30m	**Edge = 60m**	**Edge = 120m**	**Edge = 30m**	**Edge = 60m**	**Edge = 120m**
Loss	-883,095	-2,356,461	5,226,849	-3,893,266	-2,571,131	1,137,684
Gain	199,455	594,145	1,637,227	2,169,859	1,667,573	958,434
Net	-686,640	-1,762,316	-3,589,622	-1,723,407	-903,558	-179,251

Table 6: Comparison of MSPA networks (edge = 60m) with the Maryland and southeastern US networks. Comparisons show the percentage of the Maryland and southeastern US networks in each of the MSPA classes. Comparisons were based on the 1992 NLCD in the NLCD land cover change data (Fry et al. 2009). Background is used as the label for all non-forest and non-wetland land cover. The Maryland network data are distributed as two classes (hub and corridor). The southeastern US network data are distributed as one class that combines hub and corridor. The distribution of percentages for edge widths equal to 30 and 120m would follow the patterns in Table 3, except for the background class. Background percentages would remain constant. Maryland data were downloaded from http://dnrweb.dnr.state.md.us/gis/data. The southeastern US data were downloaded from http://www.geoplan.ufl.edu/epa

	MSPA							
Maryland	Background	Branch	Edge	Islet	Core	Bridge	Loop	Perforation
Hub	22.6	2.3	12.2	0.4	50.4	7.6	3.3	1.3
Corridor	46.2	4.6	13.4	1.8	21.0	9.9	2.7	0.3
Hub+Corridor	26.3	2.7	12.4	0.6	45.7	8.0	3.2	1.2
Southeast US								
Hub+Corridor	25.0	1.9	9.0	0.5	51.0	6.9	3.7	1.9

List of Figures

Fig. 1

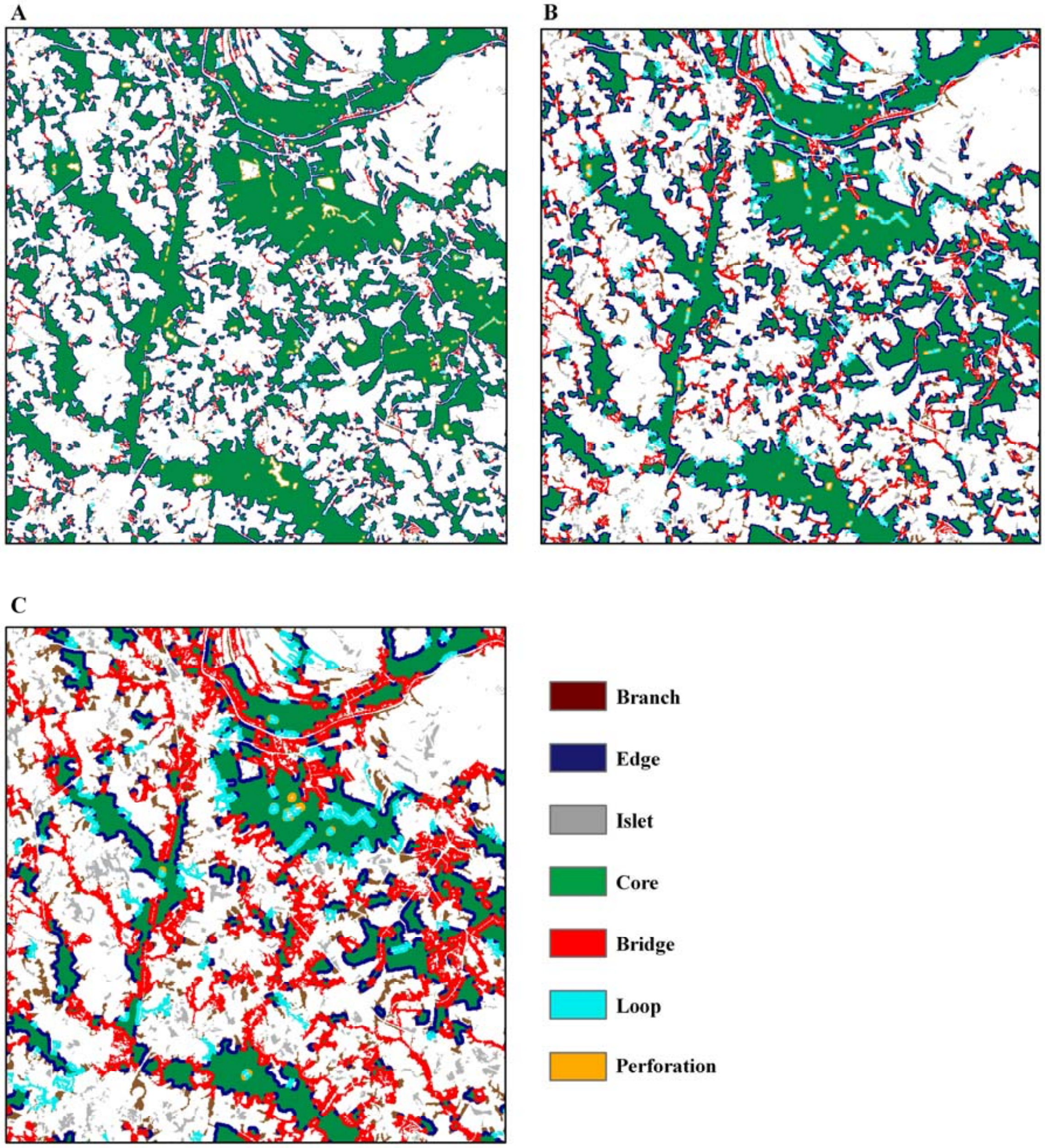


Fig. 2

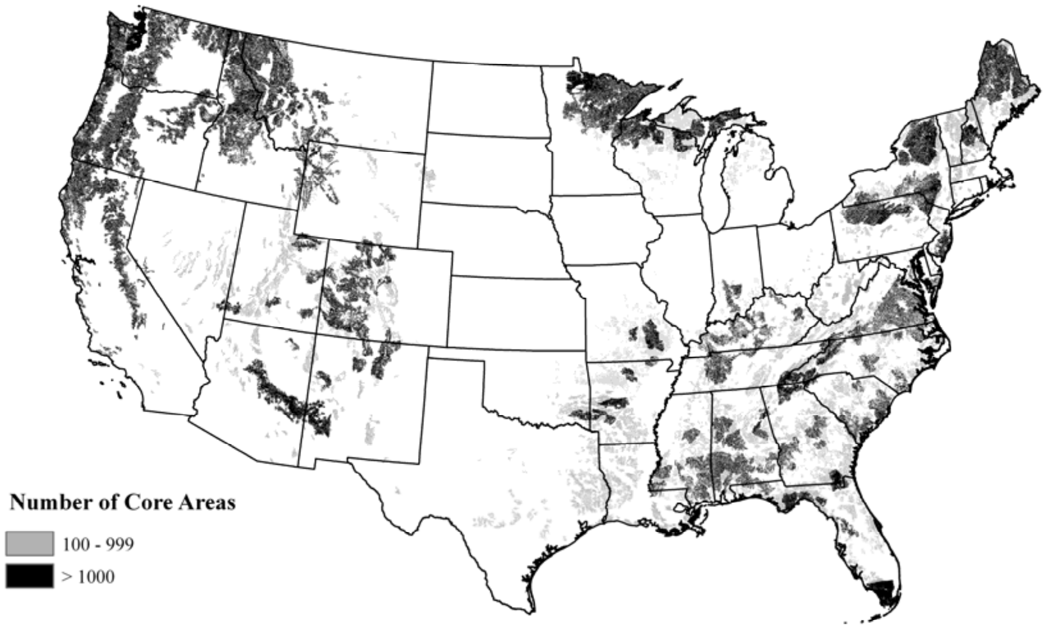
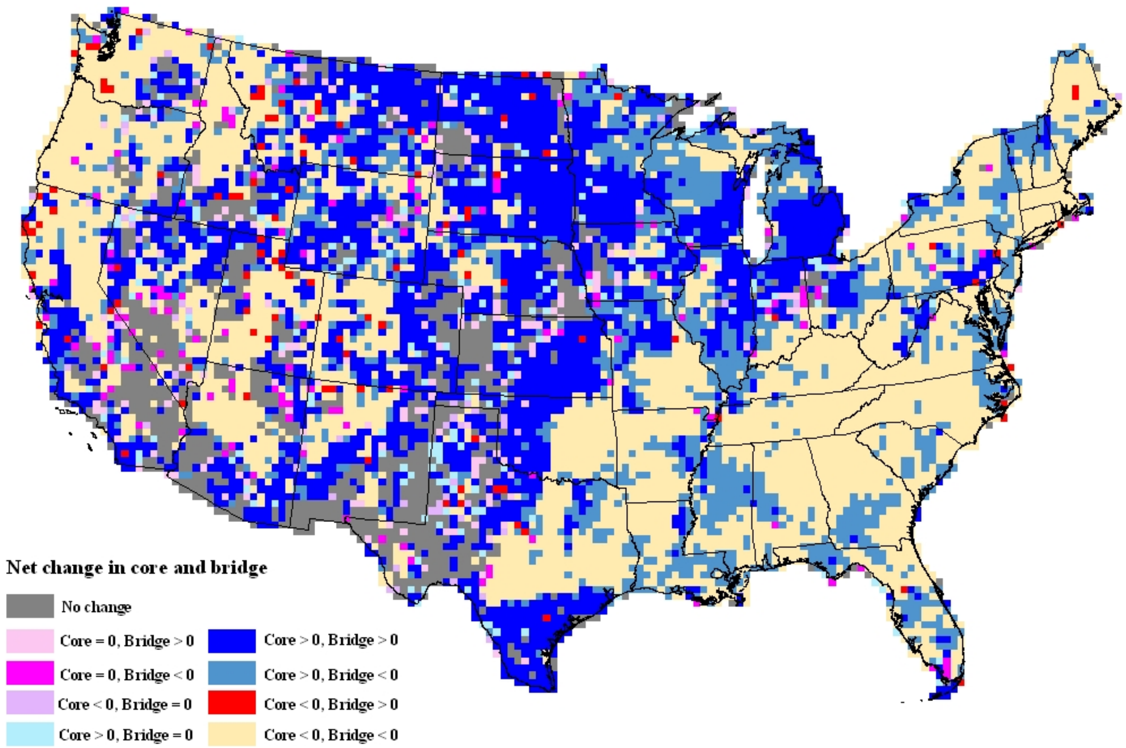


Fig. 3


Richmond, VA
Petersburg, VA
Norfolk, VA
Virginia
North Carolina
Edenton, NC
Chowan R.
Albemarle
Sound
Greenville, NC
25 12.5 0 25 Kilometers

Fig. 4


Net change in core and bridge
No change
Core = 0, Bridge > 0
Core = 0, Bridge < 0
Core < 0, Bridge = 0
Core > 0, Bridge = 0
Core > 0, Bridge > 0
Core > 0, Bridge < 0
Core < 0, Bridge > 0
Core < 0, Bridge < 0

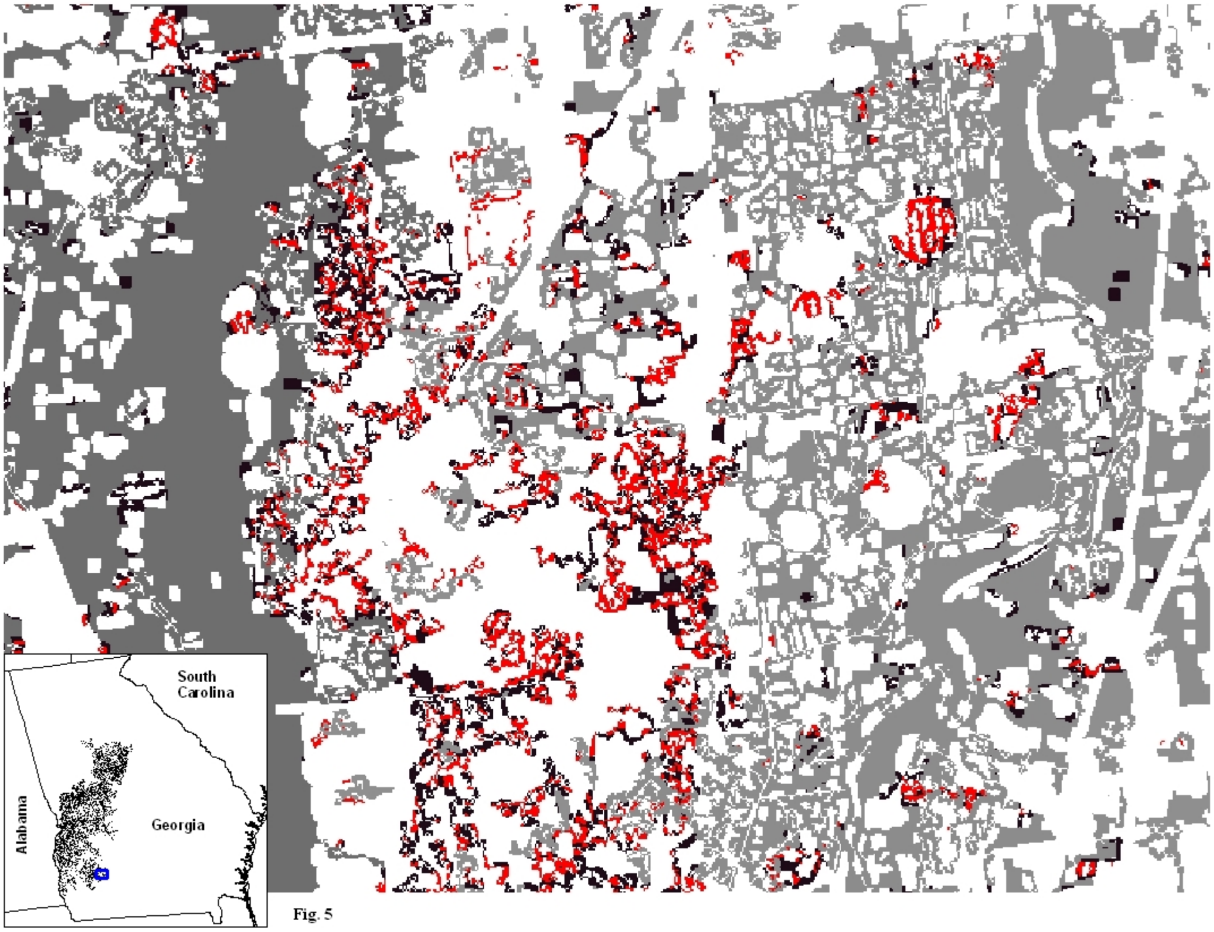


Fig. 5