LANDSCAPE ECOLOGICAL ASSESSMENT OF THE CHESAPEAKE BAY WATERSHED

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Abstract. The Chesapeake Bay Watershed, located in the Mid-Atlantic Region of the United States, is experiencing rapid habitat loss and fragmentation from sprawling low-density development. The bay itself is heavily stressed by excess sediment and nutrient runoff. Three states, the District of Columbia, and the federal government signed an agreement in 2000 to address these problems. The commitments included an assessment of the watershed's resource lands, and targeting the most valued lands for protection. As part of this task, the Resource Lands Assessment identified an ecological network comprised of large contiguous blocks (hubs) of forests, wetlands, and streams, interconnected by corridors to allow animal and plant propagule dispersal and migration. Hubs were prioritized by ecoregion, by analyzing a variety of ecological parameters, including: rare species presence, rarity and population viability; vegetation and vertebrate richness; habitat area, condition, and diversity; intactness and remoteness; connectivity potential; and the nature of the surrounding landscape. I found that much of the watershed was still fairly intact, although this varied dramatically by ecoregion. Current protection also varied, and an assessment of vulnerability will help focus protection efforts among the most valuable hubs and corridors.

Keywords: conservation, ecoregions, Chesapeake Bay, corridors, landscape assessment, geographic information systems

1. Introduction

The Chesapeake Bay is one of the largest estuaries in the world. It is the largest estuary in the United States, and is a major economic and recreational asset for millions of people. Undeveloped lands provide the bulk of the Chesapeake Bay watershed's natural support system. Ecosystem services, such as cleaning air, filtering and cooling water, storing and cycling nutrients, conserving and generating soils, pollinating crops and other plants, regulating climate, sequestering carbon, protecting areas against storm and flood damage, and maintaining hydrologic regimes, are all provided by the existing expanses of forests, wetlands, and other natural lands (Costanza et al., 1997; Conservation Fund, 2000). These ecologically valuable lands also provide marketable goods and services, like forest products, fish and wildlife, and recreation. They serve as vital habitat for wild species, maintain a vast genetic library, provide scenery, and contribute in many ways to the health and quality of life for Chesapeake Bay watershed residents.

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When wetlands and forest are converted for human uses, there are costs incurred that are typically not accounted for in the marketplace. The losses in ecosystem services are hidden costs to society. These services are fundamental needs for humans and other species, but in the past, the resources providing them have been so plentiful and resilient, that they have been largely taken for granted. In the face of a tremendous rise in both population and land consumption, many now realize that these natural or ecosystem services must be afforded greater consideration. The breakdown in ecosystem functions causes damages that are difficult and costly to repair, as well as taking a toll on the health of plant, animal, and human populations (Moore, 2002).

Many parts of the Chesapeake Bay watershed are urbanizing rapidly. The growing trend of urban development in the Mid-Atlantic is transforming rural areas to low-density house lots and exclusive gated communities, which give their residents a sense of space, security, and exclusivity, as well as isolating them from neighbors and unwelcome visitors. Homeowners are increasingly willing to commute long distances to their jobs in exchange for larger lots for lower prices. Development of vacation or second homes and of residences for retirees freed from the need to commute has added to sprawl. Sprawl is also encouraged by large-lot zoning (e.g., 1–20 acres).

This development has come primarily at the expense of agriculture and forest. American Forests (1999) found that average tree cover in the Chesapeake Bay watershed declined from 51% to 39% between 1973 and 1997. Natural tree cover (areas with at least 50% tree cover) declined from 55% to 38% of the total area (American Forests, 1999). Bockstael (1996) stated that land-use change due to human activity “is perhaps the single greatest factor affecting ecological resources.” Wildlife habitat and migration corridors are being lost, and normal ecosystem functions such as absorption of nutrients, recharging of water supplies, and replenishment of soil are being disturbed or destroyed. Many of the watershed’s wetlands have been altered by land conversion, filling, drainage, impoundment, logging, and urban and agricultural runoff. Water quality has been degraded in numerous streams and rivers, as well as the Chesapeake Bay itself, which is on U.S. Environmental Protection Agency’s (U.S. EPA) list of impaired waters.

The scattered pattern of modern development not only consumes an excessive amount of land, it fragments the landscape. Sorrell (1997) states, "the end result of fragmentation is often a patchwork of small, isolated islands of habitat in a sea of developed land." Numerous studies have shown the negative ecological effects of forest fragmentation in the landscape. Some generalist or ecotone species, like white-tailed deer and raccoons, can benefit from fragmentation. But according to Sorrell (1997), habitat fragmentation is perhaps the greatest worldwide threat to forest wildlife, and the primary cause of species extinction. Yahner (1988), Hansen and Urban (1992), Donovan et al. (1995), and Robinson et al. (1995) showed that fragmentation and increased edge have reduced the distribution and abundance of forest birds and other wildlife species throughout North America. As forest areas are divided and isolated by roads and development, interior habitat decreases, human disturbance increases, opportunistic edge species and invasive exotics replace native interior species, and populations of many animals and plants become too small to persist.

Each native species is uniquely adapted to transform and channel energy in an ecosystem, and each plays a role in ecosystem functioning. Ecosystems with higher diversity are generally more efficient (Odum, 1983). For example, diverse communities are more likely to contain species able to utilize different amounts and combinations of limiting resources like nutrients or light; and more likely to have symbiotic relationships. As species are lost from an ecosystem or landscape, those that depend on them for food, pollination, or other needs, also begin to disappear. Many interconnections among species are not even known. Ecosystem resilience to stresses is dependent on species composition and diversity. Diverse communities are more likely to contain species tolerant to disturbances like flooding, drought, or pests; and the spread of pests is slower when host species are separated by non-host species.

Three states, the District of Columbia, and the federal government signed an accord in 2000 to address these problems within the Chesapeake Bay watershed; this is known as the "Chesapeake 2000 Agreement." The commitments included an assessment of the watershed's resource lands, including forests and farms, emphasizing their role in the protection of water quality and critical habitats, as well as cultural and economic viability, and targeting the most valued lands for protection. This assessment, designated the Resource Lands Assessment (RLA), was begun in 2002. The study discussed in this paper addresses the identification of significant habitats, one of the facets of the RLA effort. Managers must first know where important ecological resources are before they can be appropriately protected.

The RLA habitat assessment was based on principles of landscape ecology and conservation biology, and provides a consistent approach to evaluating land conservation and restoration efforts in the Chesapeake Bay watershed, as well as a prototype for state and local governments to develop their own assessments. The concept underlying the RLA was to link large, contiguous blocks of ecologically significant natural areas (hubs) with natural corridors that create an interconnecting network of natural lands across the landscape. Large areas of natural habitat are usually more effective than small areas for protecting water, sustaining viable populations of most interior obligates, providing core habitat for large ranging species, and permitting natural disturbance regimes (Bushman and Therres,1988; Brown et al., 1990; Dramstad et al., 1996; Hanski, 1997; Tilman and Lehman, 1997). When such areas are decreased in size or isolated, plant and animal populations, which fluctuate in size, are more likely to go locally extinct (MacArthur and Wilson, 1967; Harris, 1984; Harris, 1988; Dramstad et al., 1996; Hanski, 1997). Corridors allow wildlife to pass more easily between habitat blocks, thus increasing available habitat and animal populations (Forman and Godron, 1986; Harris, 1989). They also ease dispersal of native plant pollen and seeds (Tilman et al., 1997; van Dorp et al., 1997; Tewksbury et al., 2002). Corridors linking habitat patches in a landscape are essential for many organisms to recolonize unoccupied sites, and for the persistence of metapopulations in fragmented landscapes (Dunning et al, 1992; Anderson and Danielson,1997; Tilman et al., 1997; van Dorp et al., 1997; Beier and Noss, 1998; Bennett, 1999; With and King, 1999; Robichaud et al., 2002; Söndgerath and Schröder, 2002; Tewksbury et al., 2002).

2. Study Area

The RLA includes the Pennsylvania, Maryland, Delaware, Virginia, West Virginia, and District of Columbia portions of the Chesapeake Bay watershed (i.e., New York was excluded). Large blocks of habitat that fell only partly within the watershed were included in their entirety. A portion of the analysis, on the Delmarva peninsula, was performed earlier (Delmarva Conservation Corridor - DCC), and served as a pilot study, as did the Green Infrastructure Assessment (GIA) in Maryland (see Weber and Wolf, 2000; Weber, 2003).

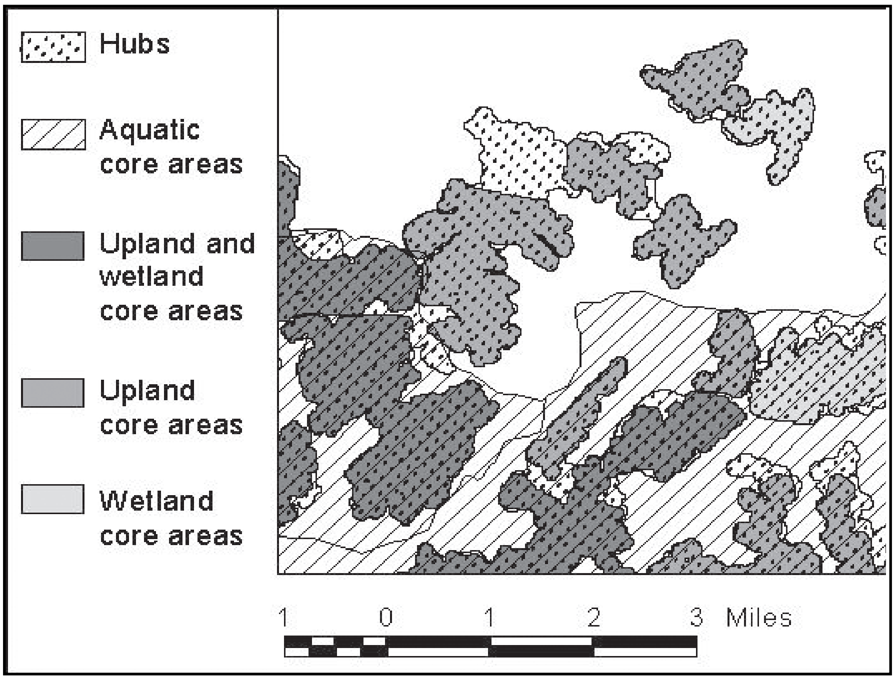

Figure 1. Examples of core areas and hubs in a subset of the study area.

3. Identification of Core Areas and Hubs

To construct the RLA habitat model, we used geographic information systems (GIS) techniques with data such as land cover, road and stream locations, biological surveys, etc. We began the analysis by identifying the least disturbed areas in the Chesapeake Bay watershed. These "core areas" are thought to provide breeding habitat for native wildlife and suitable conditions for native plants. Terrestrial (upland or wetland) core areas were defined as blocks of forest, wetland, nearshore open water, beach, or bare rock at least 100 m from the nearest anthropogenic land cover, road or active railroad, or powerline corridor, and at least 100 acres in size. A terrestrial core area was defined as a wetland core area if it contained at least 50% wetland in its interior, or if it contained at least 100 acres of unmodified wetlands. All terrestrial core areas not designated as wetland core areas were defined as upland core areas. In addition, terrestrial core areas with at least 50% upland forest in their interior, or with at least 100 acres of upland interior forest, were designated as upland core areas. Thus, some terrestrial core areas could be defined as both wetland and upland core areas.

Aquatic core areas were defined as watersheds with <10% impervious surface, >66.6% forest cover (from Scheuler, 2002), >66.6% forested or marsh stream banks (from Scheuler, 2002), and no acid mine drainage. These were watersheds likely to have mostly unimpaired streams. The smallest watersheds delineated consistently within the Chesapeake Bay area were federal 11-digit hydrologic unit code (HUC 11) watersheds (mostly 4th-order drainages, with a mean size of 352 km^2). 159 of 505 HUC 11 watersheds in the study area (31%) met the aquatic core criteria.

Hubs were defined as natural areas containing one or more core areas, bounded by major roads or anthropogenic land cover >100 m; thus, hubs were slightly fragmented aggregations of core areas, containing largely suitable matrix conditions. Figure 1 shows the relationship between core areas and hubs in a portion of southern Maryland.

4. Ranking of Hubs

Much of the study area (56.6% of the land) fell within hubs. The Appalachians and central Virginia retained much of their forest cover, although the valley, Piedmont, and coastal plain regions north of Richmond were more fragmented. To more narrowly define conservation priorities, we assessed the relative importance of each hub, looking at a wide variety of attributes, and considering the hub's context in its ecoregion.

Ecoregions are areas with general similarities in ecosystems and in the type, quality, and quantity of environmental resources (Woods et al., 1996). Woods et al. (1996) mapped ecoregions within U.S. EPA Region 3. Ecological regions can be identified through the analysis of the patterns and the composition of biotic and abiotic phenomena that affect or reflect differences in ecosystem quality and integrity (Wiken, 1986; Omernik, 1987, 1995). Ecoregional delineation was based on climate, elevation, land use/land cover, land form, potential natural vegetation, soil, structural/bedrock geology, and surficial/Quaternary geology (Woods et al., 1999). Expert judgement was applied to this data to form the regions (Woods et al., 1999). Because they contain different abiotic conditions, different ecoregions tend to support different plant and animal communities. We decided that the RLA conservation network should be representative, and contain the best examples of each ecosystem type.

We identified the ecoregion that each hub fell within, and calculated various ecological indicators of importance or quality. These indicators were filtered, weighted, and combined to create an overall ecological rank for each hub, both within the entire study area and within their ecoregion. We tested the hub variables for autocorrelation (using Spearman ranks), and in the Coastal Plain of Maryland west of the Chesapeake Bay, compared them to the hub ecological rankings of the Maryland GIA, where RLA and GIA hubs closely overlapped (65 cases). The GIA went through an extensive review process (see Weber, 2003); thus, we were more confident in its predictions than the evolving RLA model.

We selected and weighted RLA hub variables by considering their correlation with GIA hub rankings, correlation with other RLA variables, expert judgement of their biological importance, data reliability, minimization of spatial overlap, and importance in "All Possible Regressions" models. Hintze (2001) explains All Possible Regressions; we ran numerous models to see which variables created a best overall fit with GIA rankings. Cluster analyses were unable to group the data coherently.

We then ranked the hubs (as percentiles) from best to worst for the retained parameters (Table I), and multiplied the percentile ranks by the parameter's importance weighting. This gave a composite ecological percentile rank for each hub both within its ecoregion and within the study area as a whole. Hubs ranking in the top third (by quantile, not by area) either within their ecoregion, or within the entire study area, were designated "top tier hubs". Most of these ranked within the top third of both. Hubs ranking in the middle third within their ecoregion were designated "middle tier hubs." Finally, hubs ranking in the bottom third within their ecoregion were designated "bottom tier hubs."

5. Identification of Corridors

Corridors in the RLA are linear features, at least 1100 ft (335 m) wide, linking hubs together to facilitate animal and plant propagule movement between them. The hope behind maintaining this pattern was that there will be enough populations of species in the discrete hubs within a region that any localized extinction will be offset by movement between hubs, with recolonization of the hub that experienced the extinction. The corridors delineated in many cases follow prominent features like streams

Table I. Parameters and weights used to score RLA hubs.

Hub Parameter	Weight
Rare species occurrences in the hub, weighted by their rarity and population condition or viability (MD and VA only)	8 in MD, 5 in VA
Number of native vertebrate species modeled in the hub (PA only)	8
Number of native vertebrate species modeled in the hub (VA only)	3
Number of neotropical migrant bird species observed in the hub	4
Area of upland interior forest	4
Area of wetland interior forest	4
Area of other wetlands	3
Length of streams within interior forest in the hub	4
Fraction of the hub in mature and natural vegetation communities	4
Number of ecoregions in the hub	2
Number of different vegetation alliances in the hub	1
Number of wetland types (from NWI)	2
Number of stream sources and junctions	1
Topographic relief (standard deviation of elevation) in the hub	1
Number of different soil types (from STATSGO)	1
Percent of interior natural area in the hub	4
Mean distance to nearest major road	2
Mean distance to nearest paved road	2
Mean distance to nearest paved road, unpaved road, railway, or powerline	1
Distance to nearest neighboring hub, transformed by multiplying by -1	2
Acres of forest outside the hub, but within 1 km	2
Acres of unmodified wetlands outside the hub, but within 1 km	2
Acres of core area outside the hub, but within 1 km	2
Acres of forest outside the hub, but within 10 km	1
Acres of unmodified wetlands outside the hub, but within 10 km	1
Acres of core area outside the hub, but within 10 km	1
Percent hub area outside the hub, but within 10 km	1

or ridges. In other locations they may be less intuitive, based rather on remaining pathways of upland natural vegetation in a landscape dominated by human modification. An effort was made to avoid roads and urban areas in the methodology used to identify possible corridors. To function effectively, corridors should be wide enough to provide interior conditions for habitat specialists (favorable microclimate, protection from edge predators and invasive exotics, etc.), as well as protecting the hydrology and water quality of contained streams and wetlands.

Corridor identification and delineation were based on many sets of data, including land cover, vegetation type, wetlands, roads, streams, slope, acid mine drainage, urban proximity, and land management. Linkages were tailored to three different ecotypes: upland, wetland, and aquatic. For each of these ecotypes, we identified core areas to link, and created a "corridor suitability" layer based on land cover, road, slope, and other "impedances" (Table II). Impedance, which is the inverse of suitability, measures the degree to which the landscape parameter inhibits wildlife use and movement. For example, urban land cover has a much higher impedance than forest. For aquatic organisms such as fish and mussels, water is required.

Upland linkages connected upland core areas, as defined earlier. In general, linkage preference was given to streams with wide riparian buffers (from Harris, 1984; Forman and Godron, 1986; Brown et al., 1990; and Forman, 1995). Other good linkages included ridge lines, valleys, and forest. Urban areas, roads, and other unsuitable features were avoided. Wetland linkages connected large wetland complexes within wetland core areas. Linkage preference was given to riparian wetlands. Tidal marshes were linked by bays and tributaries. Finally, aquatic linkages connected stream reaches in hubs that ran at least 0.5 km within interior forest. These were best linked by natural waterways with riparian forest cover or adjacent wetlands, and without acid mine drainage.

Table II. Suitability variables for upland, wetland, and aquatic corridors.

Ecotype	Corridor suitability variables
Upland	land cover (forest preferred); vegetation type (mature communities preferred); adjacency to water; forest >100 m from edge; presence of rare species or communities; proximity to urban development; road presence and type; water >150 m from land; slope; land management; presence and ranking of hubs.
Wetland	land cover (wetlands preferred); vegetation type; distance to water; forest >100 m from edge; presence of rare species or communities; proximity to urban development; road presence and type; water >150 m from land; slope; land management; presence and ranking of hubs.
Aquatic	presence of water (required); stream type (natural streams preferred over ditches or canals); road-stream crossings; riparian width; acid mine drainage; presence of rare species or communities; proximity to urban development; land management; presence and ranking of hubs.

We calculated two sets of corridors, the first between core areas in top tier hubs, and the second linking core areas in lower tier hubs, both to other lower tier hubs, and to the top tier network. In retrospect, separating corridors by hub tier was not worth the extra computer time.

After creating a composite impedance or suitability layer for each ecotype, we used a GIS technique called least-cost path (LCP) analysis to determine the best ecological paths between core areas, and thus, hubs. Here, cost refers to the difficulty for wildlife to traverse the landscape along a particular route. The pathway between two given core areas with the fewest obstacles (like roads and development), and the most favorable habitat (like forest and wetlands), was the LCP. LCPs included riparian, upland, and mixed connections. A mixed connection might be an overland linkage across watersheds between two streams, which obviously would benefit terrestrial more than aquatic organisms.

Next, three reviewers manually inspected the computer-generated LCPs. We preferred corridors with few or no breaks, few or no major road crossings, sufficiently wide and unfragmented, and with suitable habitat (or at least marginal). Riparian or forested ridgeline or valley corridors were preferable. Most stream corridors were retained because of their multiple benefits and greater chance of protection. The reviewers flagged LCPs that traversed major roads, urban areas (unless along a stream), or wide extents of open water (unless connecting streams), or if they appeared redundant. Where multiple LCPs connected two core areas, we selected the best. Although multiple pathways provide redundancy against disturbance or conversion to anthropogenic land use (which Weber and Aviram (2002) found beneficial in Maryland), we deleted marginal or poor linkages if better ones existed connecting the same core areas. In some cases, the reviewers also added alternative pathways that were superior to computer-generated connections between given core areas or hubs, or if computer LCPs had to be deleted.

The remaining linkages were then assigned a width according to the neighboring topography and land cover. Where corridors followed streams, we buffered streams 550 ft (168 m) on each side (after Brown et al., 1990). Thus, the corridor would contain 500 ft (150 m) of interior conditions along its path, and 300 ft (100 m) of edge transition on either side. Floodplain data was unavailable for most of the study area, but we widened stream corridors to include adjacent slopes, up to the ridge. Where linkages were not along streams, we buffered them a distance of 550 ft (168 m). The width of corridors was then extended to account for compatible landscape features, such as adjacent forest or wetlands, out to the nearest road. Figure 2 shows the resulting hub-corridor network in the Chesapeake Bay watershed, excluding New York.

6. Current Protection Status of RLA Network

After adding the DCC hubs and corridors, we assessed the relative protection of the Chesapeake Bay hub-corridor network by ecoregion. Our files of protected lands were not up to date, and varied by state

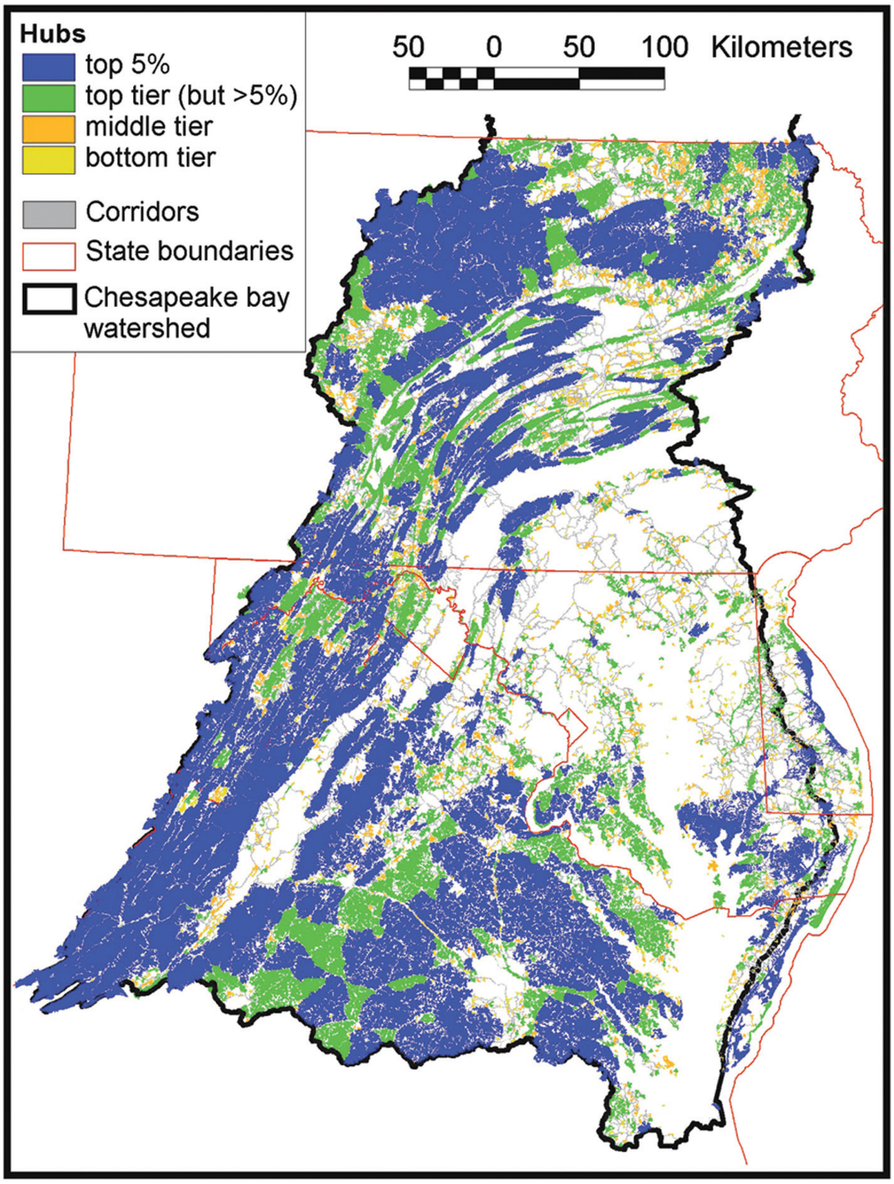

Figure 2. Resource Lands Assessment hub-corridor network for the Chesapeake Bay watershed (New York not included).

(Pennsylvania 1998, Maryland 2000, Delaware 2000 or earlier, Virginia 2001 or earlier, West Virginia unknown). However, a simple overlay of protected lands was useful to visually identify where hubs and corridors were protected. Hubs within the Piedmont and Coastal Plain regions were underprotected compared to those in the Appalachians, presumably because they are more easily farmed, and have higher population densities and land costs. Of the 36 ecoregions, only four had over 50% of their hubs and corridors protected, and over half were <10% protected.

7. Restoration Opportunities in the RLA

Although composed primarily of natural ecosystems, the RLA network contains a variety of environmental conditions, including some areas that are heavily degraded. Land-cover "gaps", which are agricultural, mined, cleared, or developed lands within hubs or corridors, could be targeted for restoration: converting to wetlands or forests with composition, functions and processes resembling native natural conditions. These human-generated gaps are logical starting points when attempting to identify opportunities for landscape restoration actions; they offer a chance to improve the overall network while simultaneously addressing water quality or specific habitat concerns. Weber (2003) describes how gaps in Maryland's green infrastructure network were prioritized for restoration efforts, according to their relative ecological benefits, reclamation ease, and programmatic considerations. Other types of targeting included wetland restoration, stream remediation, ditch filling, removal of stream blockages, constructing road or railroad underpasses, erosion control, removal of invasive species, and changing management practices incompatible with ecosystem functioning.

8. Future Steps

The RLA is an ongoing project. The hub-corridor habitat model will be integrated with other watershed assessments, including priorities for water quality protection, cultural and heritage protection, and resource economics, as well as their risk of loss to development. The results of these assessments will be distributed by the Chesapeake Bay Program, with the hope that planners and managers can focus their limited resources on the most important areas.

The RLA habitat model could benefit from future revisions and additions. We were unable to obtain rare species occurrences and modeled vertebrate distributions for all the states in the study area. In addition, more recent land cover and delineated habitat for rare species would improve the model. LCP delineation will be revised in future RLA models. The programs took too long to run (up to four computers over two weeks each), and the output too long to review (over two weeks). This reflects the large size of the study area. Furthermore, the computer-generated LCPs were often unsatisfactory, and numerous edits were required. In the future, cover types will be more differentiated, and much greater weighting given to interior forest and wetland. Fewer parameters should be used, to reduce computation time. Corridors can also be evaluated and ranked, as was done for Maryland's GIA. Core areas within hubs can also be ranked. Finally, a fine-scale assessment, such as the cell-based targeting developed in Maryland, would help planners evaluate the importance of individual parcels. The Maryland Department of Natural Resources expanded on such an assessment to develop a protocol for selecting and prioritizing parcels for acquisition from willing sellers, incorporating property tracking, mapping and GIS support, desktop ecological evaluation, and field assessment into a single integrated system.

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