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Maryland's Green Infrastructure Assessment: Development of a comprehensive approach to land conservation

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Abstract

Like many parts of the US, Maryland is urbanizing rapidly. The scattered pattern of low-density development consumes an excessive amount of land, fragments the landscape, displaces many native species, and disrupts ecosystem functions. Maryland's Green Infrastructure Assessment is a tool developed in the Maryland Department of Natural Resources (DNR) to help identify and rank those areas of greatest statewide ecological importance, as well as those at greatest risk of loss to development. It identifies large contiguous blocks of natural land (hubs), interconnected by natural corridors to allow animal and plant propagule dispersal and migration. Hubs and corridors were ranked within their physiographic region for a variety of ecological and development risk parameters, as well as combinations of these. Prioritization was also done on a finer scale (0.127 ha) for ecological importance and vulnerability to development, allowing a more detailed analysis for site prioritization within the network. The hub and corridor framework identified through the Green Infrastructure Assessment is being used to guide Maryland's ongoing land conservation efforts. At a multi-state scale, the green infrastructure method has been used as the framework for setting landscape ecological priorities within the Chesapeake Bay program. At a regional scale, the method has been used to rank or focus areas for state land conservation programs. Within a local government planning context, the method is now being translated into locally relevant criteria to support county-scale green infrastructure initiatives. Finally, the cell-based ranking method has been incorporated into parcel prioritization that has been used to aid state, local and private land trust conservation decision-making.

Keywords: Green infrastructure; Hub; Corridor; Natural lands; Core area; Linkage; Conservation; Maryland

1. Introduction

1.1. The importance of natural land

"Green infrastructure" is a term that describes the abundance and distribution of natural features in the landscape like forests, wetlands, and streams. Just as built infrastructure like roads and utilities is necessary

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for modern societies, green infrastructure provides the ecosystem services that are equally necessary for our well-being. Maryland's undeveloped lands—its green infrastructure provide the bulk of the state's natural support system. Ecosystem services, such as cleaning the 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, 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 Maryland residents.

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, as enumerated above, are hidden costs to society. These services meet 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 for human purposes, 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; it also takes a toll on the health of plant, animal, and human populations (Moore, 2002).

1.2. Maryland's changing landscape

The population and developed portions of Maryland have been growing rapidly. Between 1790 and 2000, Maryland's population grew from 320,000 to 5,300,000 (RESI, 1997; U.S. Census Bureau, 2001). The increase was 25.6% between 1980 and 2000 alone (U.S. Census Bureau, 2001). Maryland's population is projected to increase an additional 24.4% between 1995 and 2025 (RESI, 1997). Developed land has increased even faster than the population. Before colonization by Europeans, Maryland was 95% forested, the other 5% being marsh around Chesapeake Bay (Besley, 1916; Powell and Kingsley, 1980). By 2000, forest had decreased to 42.8% of land cover. Similarly, Maryland has lost 50% of its pre-settlement wetlands (Tiner and Burke, 1995). Developed land use reached 509,200 ha in 2000. Between 1990 and 2001, an average of 23,400 single-family residential parcels were developed in Maryland each year. The construction of these housing units consumed 84,000 ha of land or 0.30 ha of land per housing unit. The larger lots (>1 ha) tended to be in rural areas.

The Maryland Department of Planning has projected that by 2020 urban land use will increase by more than 25% from 1997 levels, and that forest cover will decrease a further 9% by 2020 from 1997 levels. Agriculture has also been projected to decrease by 9% during the same period. Wildlife habitat and migration corridors are being lost, and normal ecosystem functions are being disturbed or destroyed. Water quality has been degraded in numerous streams and rivers, as well as the Chesapeake Bay itself.

In the face of continuing urbanization, it is important that land conservation programs be directed toward conserving the most valuable of our natural assets. To identify and rank Maryland's green infrastructure, we developed a tool called the Green Infrastructure Assessment (GIA). This paper first discusses some of the scientific underpinnings of the model we developed, then describes the model and its results and potential applications, and finally suggests some future directions.

2. Scientific background

2.1. Importance of habitat fragmentation

Habitat is lost in two ways as a result of conversion to human-dominated uses. First, there is a direct reduction in the area of available habitat, which could eliminate certain habitats entirely, along with species dependent on these lost habitats (for example, woodpeckers dependent on large snages; salamanders dependent on vernal pools; brook trout dependent on clean, cool streams) (Dramstad et al., 1996).

The scattered pattern of modern development not only consumes an excessive amount of land, it fragments the landscape, leaving smaller patches of intact natural habitat and creating greater proportions of edge habitat between differing land cover types. Large areas of natural vegetation are usually more effective than small areas for protecting aquifers and watersheds, sustaining viable populations of most interior species, providing core habitat and escape cover for wide-ranging vertebrates, and allowing natural disturbance regimes (Dramstad et al., 1996). 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 replace interior species, and populations of many animals and plants become too small to persist.

The species most vulnerable to extinction in fragmented landscapes have small populations: large animals with large home ranges (e.g., top carnivores), ecological specialists (e.g., with unique habitat requirements), and species with variable populations that depend on patchy or unpredictable resources (Harris, 1984, 1989; Brown et al., 1990; Hanski, 1997; Tilman and Lehman, 1997). An extensive literature review may be found in Weber (2003).

2.2. Fundamental principles

The GIA was based on principles of landscape ecology and conservation biology, and provides a consistent approach to evaluating land conservation and restoration efforts in Maryland. It uses a computerized geographic information system (GIS) mapping approach to combine multiple layers of spatially referenced data. This approach is the descendant of the overlay method for determining development suitability pioneered by McHarg (1969), emphasizing, in this case, where development should be discouraged in order to preserve the ecological values of the land's natural state.

In something of a departure from traditional natural resources management efforts, the GIA specifically attempts to recognize: (1) a variety of natural resource values (for example, as opposed to a single species of wildlife), (2) how a given place fits into a larger system, (3) the ecological importance of open space in rural and developed areas, (4) the importance of coordinating local, state and even interstate planning, and (5) the need for a regional or landscape-level view for wildlife conservation. The concept underlying green infrastructure protection is 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. Such connection can help to offset the functional losses caused by fragmentation (Forman and Godron, 1986; Harris, 1989; Dunning et al., 1992; Dramstad et al., 1996; Anderson and Danielson, 1997; Hanski, 1997; Tilman and Lehman, 1997; Tilman et al., 1997; Van Dorp et al., 1997; Beier and Noss, 1998; Bennett, 1998; With and King, 1999; Robichaud et al., 2002; Söndgerath and Schröder, 2002; Tewksbury et al., 2002).

3. Development of the Green Infrastructure Assessment

3.1. Study area

The Green Infrastructure Assessment was carried out within the state of Maryland, plus adjacent land up to the nearest paved road or major river in neighboring states. In western Maryland, we used the state boundary, which is not a natural boundary, in situations where blocks of forest extended far into Pennsylvania, but not far into Maryland.

The Maryland landscape ranges from the Atlantic Ocean to the Appalachian Mountains, spanning five physiographic regions (Coastal Plain, Piedmont, Blue Ridge, Ridge and Valley, and Appalachian Plateau). Each region is defined by unique geology and varying climate, and thus, different assemblages of flora. The state is important geographically, since it is at the southern limit of many northern plant and animal species and at the northern limit of many southern plant and animal species (Williams, 1991).

3.2. Identification of green infrastructure hubs

Hubs in the green infrastructure network represent the most ecologically important large natural areas remaining in Maryland. Maintaining them as open space and being careful about what sort of development happens around them are vital to retaining the state's biological diversity in the face of continued human transformation of the landscape. Hubs are areas critical to many species and/or to particular life stages of multiple species—interior forest, for example, is essential for nesting success for many species of songbirds, while state-designated sensitive species areas represent the presence of one or more rare, threatened or endangered species of plant or animal or other unique natural community. Large blocks of contiguous forest are necessary, too, to support forestry as a continuing, and regionally very important, economic activity.

Hubs contain one or more of the following:

- areas containing sensitive plant or animal species;
- large blocks of contiguous interior forest (at least 100 contiguous hectares, plus a 100 m transition zone);
- wetland complexes with at least 100 ha of unmodified wetlands;
- streams or rivers, and their associated riparian forest and wetlands, with aquatic species of concern; with representative populations of the full suite of native fish, amphibians, and reptiles (complementary watersheds from Southerland et al., 1998); with rare coldwater or blackwater ecosystems; or with anadromous fish spawning areas;
- conservation areas already protected by the public (primarily by the Maryland Department of Natural Resources or the federal government) and by private organizations like the Nature Conservancy or Maryland Ornithological Society.

In the GIA model, these features were identified from GIS data like land cover/land use, streams, wetlands, roads, protected lands, and biological survey results. Intensive human land uses (development, agriculture, and quarries) and major roads were excluded; natural areas less than 40 contiguous hectares were dropped; adjacent forest and wetland was added to the remaining hubs; and the edges were smoothed to eliminate narrow tendrils. Buffers (up to 175 m) were added around potential migration paths, wetlands, streams, and shorelines within hubs. Fig. 1 diagrams the hub delineation process.

3.3. Linking hubs with corridors

Corridors in the green infrastructure network are linear features, at least 350 m wide, linking hubs together to allow animal and plant propagule movement between them. The hope behind maintaining this pattern is 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 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 method used to identify possible corridors. To function effectively, corridors should be wide enough to provide interior conditions for habitat specialists (for example, favorable microclimate, protection from edge predators and invasive non-native species), and to protect the hydrology and water quality of streams and wetlands within them.

Corridor identification and delineation were based on many sets of data, including land cover/land use, wetlands, roads, streams, slope, floodplains, aquatic resources from the Maryland biological stream survey (MBSS), and fish blockages. Linkages were tailored to three different ecotypes: terrestrial, wetland, and aquatic. For each of these ecotypes, core areas were identified within hubs, and a "corridor suitability" layer was created based on land cover, stream presence, riparian area width, aquatic community condition, presence or absence of roads, slope, and land management "impedance" to animal and plant propagule movement. 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.

After creating a composite impedance or suitability layer for each ecotype, we used a GIS technique called least-cost path 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

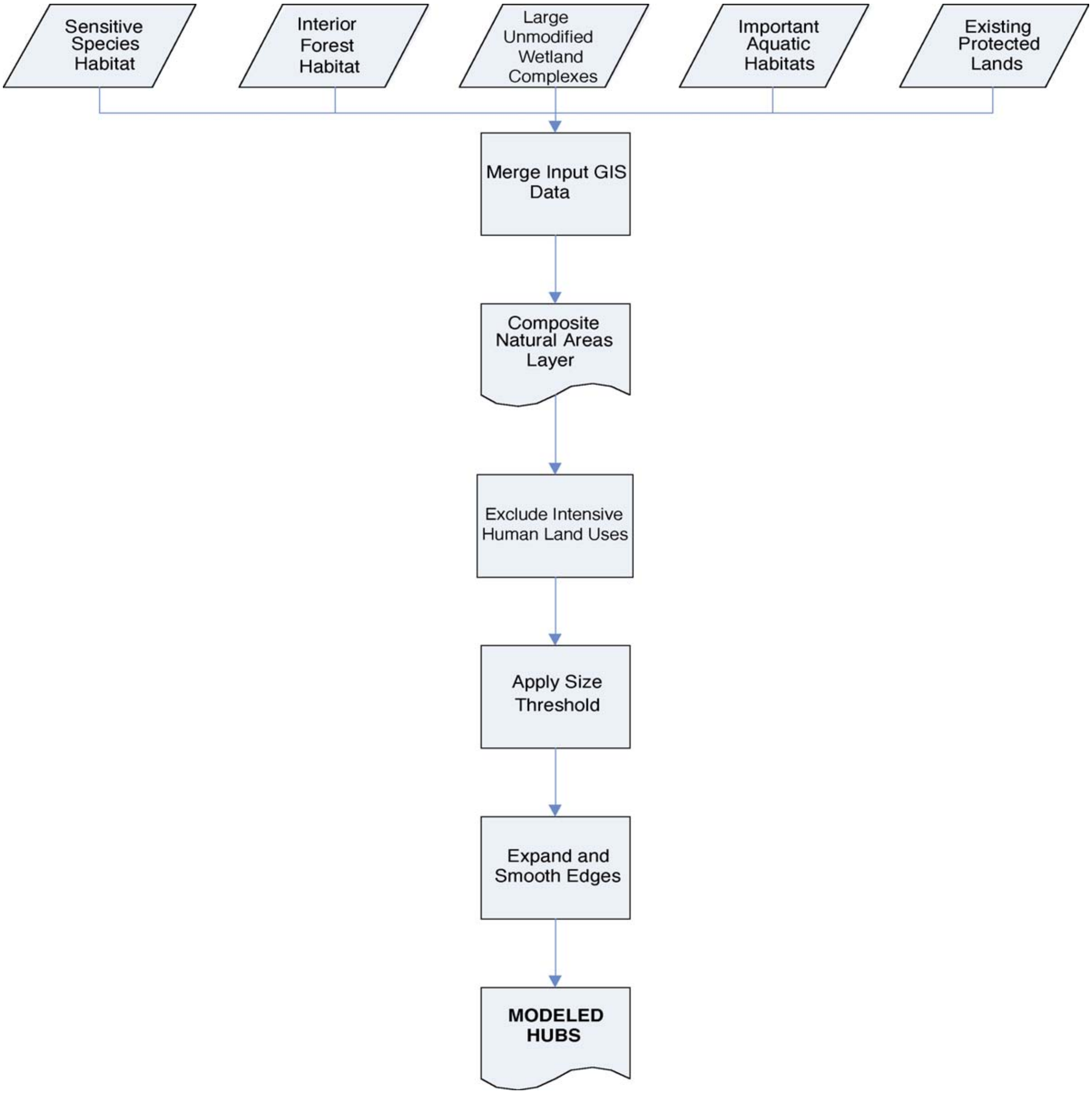

Fig. 1. Hub delineation process.

habitat (like forest and wetlands), was the least-cost path. The corridor delineation process is diagramed in Fig. 2.

In general, corridor preference, based on literature reviews, was given to healthy streams with riparian forest (e.g., Harris, 1984; Forman and Godron, 1986; Brown et al., 1990). Other good wildlife corridors included ridge lines, valleys, and upland forest. Urban areas, roads, and other unsuitable features were avoided. Since Maryland historically was dominated by forest (Besley, 1916; Powell and Kingsley, 1980), the terrestrial connections link large areas (at least 40 ha) of interior upland forest within hubs. Wetland linkages were between wetlands of special state concern (WSSC) or large, unmodified wetlands (at least 40 ha) within hubs. These core wetlands were best linked by natural waterways and wetlands. Salt marshes were also linked by estuaries and bays, which were not included explicitly in the analysis. Core areas for fresh-water aquatic communities were rivers or streams with high biotic integrity, within hubs determined previously. These were best linked by natural waterways with riparian forest cover or adjacent wetlands, and without blockages to fish migration.

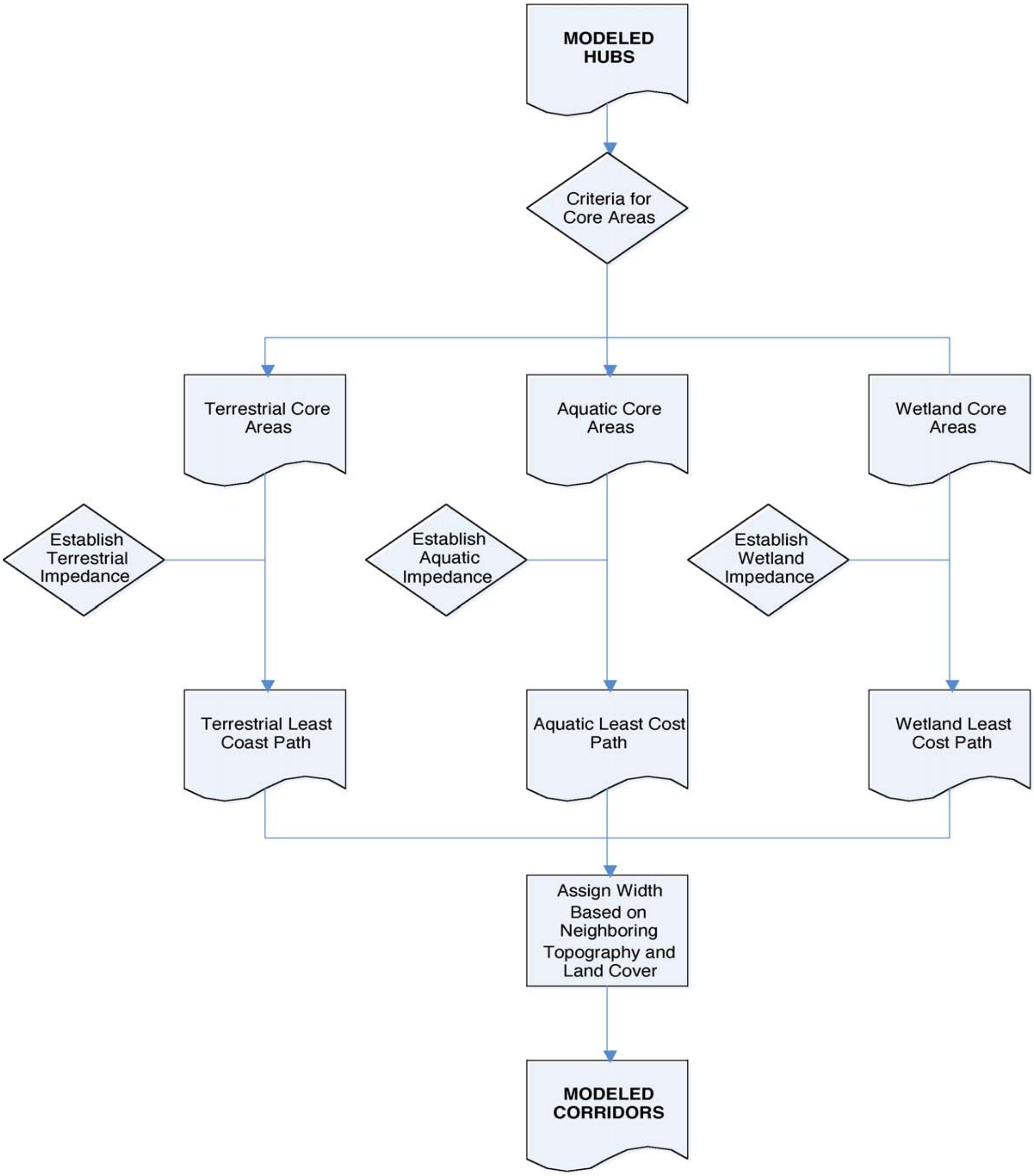

Fig. 2. Corridor delineation process.

The corridors identified by the least-cost path analysis were assigned a width according to the neighboring topography and land cover. Where corridors followed streams, we buffered the streams 175 m on each side (after Brown et al., 1990). Thus, the corridor would contain 150 m of interior conditions along its path, and 100 m of edge transition on either side. If the floodplain exceeded this distance, the corridor was defined by the 100-year floodplain, up to a maximum of 300 m from the stream. Where floodplain data were unavailable, we used ridge-to-ridge distance. Where corridors were not along streams, we buffered the least-cost path a distance of 175 m on each side. The width of corridors was then extended to account for compatible landscape features, such as adjacent forest or wetlands. "Nodes" were defined as patches of interior forest, plus their edge transition; unmodified wetlands, with an upland buffer; sensitive species areas; or conservation areas along linkages between hubs. Only natural cover was included. Nodes serve as "stepping stones" or "rest stops" for wildlife movement along corridors, making successful crossings between hubs more likely. For mapping purposes, nodes were added to their associated corridors.

3.4. Delineation of compatible land use buffers

A buffer of low-intensity land use was identified around the entire green infrastructure network. This buffer was defined as existing natural land, silviculture, agriculture, or lawns up to one mile from hubs or corridors, or to the nearest major road. This buffer was not included in the county-level maps in Maryland Greenways Commission (2000), but could be used to help guide agricultural preservation activities. From an ecological perspective, preserving agriculture could protect the green infrastructure from high-intensity disturbances associated with urban development. From an economic perspective, it could protect an agriculture base from disappearing into urban sprawl. And from an aesthetic perspective, a protected agricultural buffer area could maintain large swaths of rural landscape.

3.5. Review, evaluation and revision

Green infrastructure model output was reviewed by field ecologists and county planners, and compared to a forest reserve system proposed for Baltimore County (see Baltimore County Department of Environmental Protection and Resource Management, 1996). Hub locations were largely consistent with existing natural areas according to these sources, although some small features and undigitized rare species locations were missed. Field investigations on Maryland's Eastern shore showed that the model did not adequately identify mowed areas along ditches. These often failed to show up on satellite imagery. Further, the stream files missed many first-order streams and ditches. When these are adequately mapped, as was done by Tiner et al. (2000) for the Nanticoke and Coastal Bays watersheds, the model, especially its restoration component, will be revised.

Maps of green infrastructure model output were reviewed by county planning and parks and recreation departments. If recommended additions contained at least 40 ha of contiguous natural area (forest, wetland, beach), or if they were adjacent to modeled hubs or corridors, they were added to the proposed network. Some riparian corridors were added or adjusted. Additions to mapped green infrastructure stemming from county comments totaled 14,143 ha (an increase of 1.32%).

Conversely, model reviewers suggested several areas for deletion. Most of these were areas that had been developed since the model source data were acquired. In a few other cases, proposed corridors were too carved up into parcels to make implementing a protection program feasible, and alternative routes were suggested that were more easily protected. Most of the 23 subtractions were in the fast-growing central and southern portions of the state. As a result, 3677 ha were subtracted from the model output.

Further additions came from the Baltimore County greenway model (see Baltimore County Department of Environmental Protection and Resource Management, 1996). Finally, ecologically significant areas digitized by the Maryland DNR Heritage Division were added if they were adjacent to, but not entirely within, modeled hubs or corridors. Maps reflecting all of these changes were published in the Maryland Atlas of Greenways, Water Trails, and Green Infrastructure (Maryland Greenways Commission, 2000).

Later additions to the network came from a multistate landscape model tailored for the Delmarva peninsula. Model discrepancies were compared to aerial photographs, and if the areas were primarily forest or wetland, they were added to the green infrastructure. Most of these were interstate connections between hubs

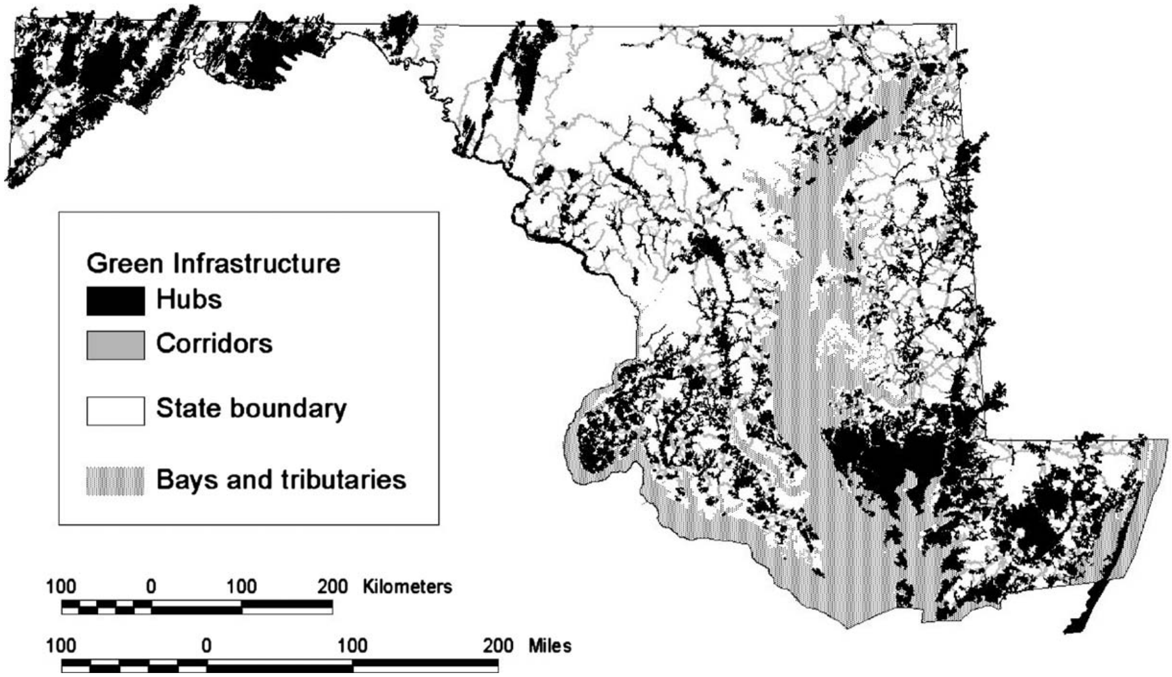

Fig. 3. Maryland's Green Infrastructure network.

in Maryland and Delaware. We also added estuarine marsh along the Coastal Bays identified by the Delmarva model but not the GIA model. These wetlands were partially drained by human activities, but nevertheless identified by Tiner et al. (2000) as having high potential for fish, shellfish, and water bird habitat. They also had high potential for nutrient transformation, sediment and other particulate retention, coastal storm surge detention, and shoreline stabilization (Tiner et al., 2000). Fig. 3 depicts the green infrastructure after all of these modifications were incorporated.

3.6. Ranking hubs by relative ecological importance

Protection of many natural resources outside the green infrastructure may not need special conservation attention—they can and should be addressed by various regulatory programs, such as wetland, steep slope or floodplain regulations and ordinances; endangered species protection; stream protection and restoration; project reviews or zoning. But in order to use the green infrastructure network in statewide conservation targeting, there needs to be a method of ranking the significance of the individual components.

Hubs, which were separated by major roads and/or intervening human land uses, were evaluated and ranked within their physiographic region for a variety of ecological parameters. Physiographic regions have a characteristic geology and climate, which shapes the ecosystems and communities within them. We wanted to recognize the best examples of ecosystems in each of these regions, ensuring that ecosystems adapted to different climates and substrates were represented in the top ranking hubs.

We then calculated a wide variety of statistics for each hub. Twenty-seven parameters (see Table 1) were selected and given an importance weighting according to feedback from biologists and natural resource managers; literature reviews; minimization of redundancy, area dependence, and spatial overlap; balancing different ecotypes; data reliability; and examination of output from different combinations. None of the parameters were highly correlated (>80%). The highest correlation was between area of upland forest and interior forest streams (75%).

Table 1
Parameters and weights used to rank overall ecological significance of each hub within its physiographic region

Parameter	Weight
Heritage and MBSS element occurrence rank (occurrences of rare, threatened and endangered plants and animals; weighted according to their global or range-wide rarity status; state-specific rarity status; and population size, quality, or viability)	12
Area of Delmarva fox squirrel habitat	3
Fraction in mature and natural vegetation communities	6
Area of natural heritage areas	6
Mean fish Index of Biotic Integrity	1
Mean benthic invertebrate Index of Biotic Integrity	1
Presence of brook trout	2
Anadromous fish index	1
Proportion of interior natural area in hub	6
Area of upland interior forest	3
Area of wetland interior forest	3
Area of other unmodified wetlands	2
Length of streams within interior forest	4
Number of stream sources and junctions	1
Number of vegetation types	3
Topographic relief (standard deviation of elevation)	1
Number of wetland types	2
Number of soil types	1
Number of physiographic regions in hub	1
Area of highly erodible soils	2
Remoteness from major roads	2
Area of proximity zone outside hub	2
Nearest neighboring hub distance	2
Patch shape	1
Surrounding buffer suitability	1
Interior forest within 10 km of hub periphery	1
Marsh within 10 km of hub periphery	1

Hubs were ranked within their physiographic region from best to worst for each parameter in Table 1. We calibrated these rankings by converting to percentiles (percentile = rank × 100/maximum rank). We wanted to know how each hub compared to other hubs with similar climate and geology. For example, did a hub contain more interior forest than most other hubs in the physiographic region? Did it contain more rare species? Did it contain a wider diversity of vegetation and soil types? Was it more intact? Was it closer to other hubs? To derive a composite ecological ranking, the percentiles for the 27 ecological parameters were multiplied by an importance weighting (Table 1), and added together for each hub. The importance weightings were a function of the parameter's utility and data reliability. Some parameters were area-dependent (e.g., area of interior forest), some were area-independent (e.g., proportion of interior natural area), and some were inversely area-dependent (the larger the hub, the less important metrics of isolation are). Relative weightings were adjusted by contrasting model output from different combinations. We used non-parametric ranking because we lacked information needed to evaluate thresholds (e.g., what density of stream sources or junctions is desirable?), or to standardize parameters (e.g., comparing area of wetlands to length of streams). Keeping in mind that all hubs are ecologically significant, the hubs were then divided into three tiers by their composite ecological score: tier 1 comprised the top 33% of hubs; tier 2, the middle 33%; and tier 3, the bottom 33%.

3.7. Ranking corridor segments by relative ecological importance

Corridors were also evaluated and ranked within their physiographic region for a variety of ecological parameters (Table 2). Nodes were considered part of their corridors. There were two tiers of corridors, depending upon the ranking of the hubs they connected.

Because corridors often intersected, they were separated into segments for comparative analysis of alternative linkages between hubs. Many of the ecological parameters used to rank corridor segments were similar to those used to rank hubs. However, the parameter weights emphasized more what the corridors linked, and how effective that linkage was. Corridor condition was also important. Corridors with breaks, road crossings (especially if they were major roads), or insufficient width were considered more difficult for wildlife and seeds to traverse. Corridor length was also a factor, although we had to use area as a proxy. Shorter connections were deemed preferable if quality was otherwise equal.

As with hubs, we ranked corridor segments from highest to lowest for each parameter in Table 2, within their physiographic region and size class. We converted these rankings to percentiles, and multiplied the percentile for each parameter by its importance weight (Table 2). The linear combination of weighted percentiles ranked corridor segments from highest to lowest within their physiographic region and size class. As with hubs, we used non-parametric ranking because we lacked information needed to evaluate thresholds.

Table 2
Parameters and weights used to rank overall ecological significance of each corridor segment within its physiographic region

Parameter	Weight	Percentage of score (%)
Does corridor link hubs in top ecological tier?	8	14.5
Top ecological ranking of hubs connected by corridor	4	7.3
Mean upland impedance	4	7.3
Mean wetland impedance	4	7.3
Mean aquatic impedance	4	7.3
Total area	1	1.8
Number of corridor breaks	4	7.3
Road crossings, weighted by road type	8	14.5
Percent of gap area	2	3.6
Sum of rare species scores	2	3.6
Area of Delmarva fox squirrel habitat	1	1.8
Fraction in mature and natural vegetation communities	2	3.6
Fish Index of Biotic Integrity	1	1.8
Benthic invertebrate Index of Biotic Integrity	1	1.8
Presence of brook trout	1	1.8
Area of upland interior forest	1	1.8
Area of wetland interior forest	1	1.8
Area of other unmodified wetlands	1	1.8
Length of streams within interior forest	1	1.8
Area of highly erodible soils	1	1.8
Mean distance to the nearest primary or secondary road	1	1.8
Surrounding buffer suitability (within 100 m of hub)	2	3.6

If the hubs that a corridor links are lost, the corridor cannot function as a linkage. Thus, corridor segments that link existing protected lands should be a higher priority for spending limited acquisition or easement funds. These segments were selected manually in arc view, and annotated accordingly.

3.8. Ranking hubs and corridors by relative risk of development

We ranked hubs within their physiographic region from highest to lowest for the development risk parameters listed in Table 3 and converted these rankings to percentiles. We multiplied these percentiles by the parameter importance value, and added these together to give an overall ranking from highest to lowest risk of development. Rankings were both for the entire state and within each physiographic region. As with ecological data, we used non-parametric ranking, because we lacked information needed to evaluate thresholds. All hubs were considered ecologically important, and all should receive protection, but the above parameters could be used for relative rankings.

Table 3
Parameters and weights used to rank overall development risk of each hub within its physiographic region

Parameter	Importance	Weight
Mean level of protection from development	High	5
Percent of hub in inside designated priority funding areas	High	3
Percent of hub with existing or planned sewer service	High	3
Population growth or loss 1990–2000	Medium	2
Number of parcel centroids in the hub, divided by hub area	Low	1
Commuting time to urban centers	Low	1
Land demand from proximity to Washington, DC, and Baltimore	Medium	2
Mean market land value	Medium	2
Mean distance to nearest major road	Medium	2
Area of waterfront property	Medium	2
Mean proximity to preserved open space	Medium	2

Corridor segments were ranked using the same development risk parameters as hubs (Table 3). Corridors tend to cross more private land parcels than hubs, and may be at greater risk of development. This is especially important because loss of part of the corridor, if the break is significant, destroys the effectiveness of the entire linkage.

3.9. Ranking individual cells by relative ecological importance

The Maryland landscape was also analyzed at a finer scale, to allow a more detailed site comparison and prioritization. Individual "grid cells" were pixels determined by the resolution of the satellite imagery we used (Landsat Thematic Mapper). The cells were squares corresponding to an area of 0.127 ha. The cell rank was based on both its local significance and its landscape context.

Each cell is a part of a larger landscape; it both contributes energy and matter to the larger system, and is controlled by the larger system. There are no isolated ecosystems. We gave a higher weighting to cells in the green infrastructure hub-corridor network, because

Table 4
Local ecological parameters and weighting for cell-based ecological score.

Parameter	Weight	Value range
Rare plant and animal element occurrences	4	0–200
Delmarva fox squirrel habitat	6	0 or 60
Proximity to natural heritage areas	5	0–100
Proximity to other heritage areas	3	0–60
Land cover	4	0–40
Proximity to development	4	0–40
Distance to nearest road, weighted by road type	1	0–40
Highly erodible soils	2	0–20
Proximity to unmodified wetlands	4	0–40
Interior forest	4	0–40
Proximity to high integrity streams	6	0–60
Proximity to low integrity streams	2	0–20
Proximity to other streams or in 100 year floodplain	4	0–40
Proximity to stream nodes	1	0–10

they contributed to the integrity of the network, and were potentially better functioning and more resilient as a part of a larger natural system. For example, a forested cell within a hub may have greater species richness, fewer human disturbances, and fewer exotic species than a forested cell in a small, isolated woodlot outside the green infrastructure network.

Where a cell fell within a hub or a corridor, it received a score according to the composite ecological percentile of that hub or corridor within its physiographic region (see Tables 1 and 2). Cells in hubs were given a slightly higher rating than cells in corridors, because they were generally felt to be in better condition.

Table 4 lists local ecological parameters, their relative weighting, and their value range after weighting. To combine these parameters, we first multiplied the parameters by their importance weight. Then, for each cell, we selected the maximum value for the four weighted stream parameters, and the maximum for each of the two weighted heritage parameters. We added these to the other weighted parameters to derive an overall local ecological score. These overall scores were then calibrated by converting to equal-area percentile rankings.

To combine local and landscape ecological scores, both of which were on a scale between 0 and 100, we compared model output from different combinations of local and landscape weightings, to field data and expert knowledge. Weighting local conditions and landscape context equally gave the best results. Hub and corridor delineations were apparent, and continuous gradients of environmental conditions were also apparent. The final cell ecological score varied between 0 and 100, with 100, most valuable ecologically, 0, least valuable ecologically.

3.10. Rank individual cells by relative risk of development

As with ecological value, we created a fine-scale, cell-based, model of development risk. The parameters and weights are listed in Table 5. We reclassified the model to an equal-area percentile distribution on developable land: cells with a score of 0 were considered the least likely to be developed, and 100 the most likely. These were only relative scores, rather than specific predictions of which cells will be developed in a particular year. Scores should be averaged within areas of at least 40 ha.

We later compared this model to field-validated locations of green infrastructure loss to development between 1997 and 2000 (Weber and Aviram, 2002). Of these developed areas, 64% had a mean risk score between 50 and 100, and 36% had a risk 0–49. A better cell risk threshold was 45, 75% had scores of 45–100; 90% of developed areas had a risk >25. The development risk model was a useful, but not infallible, predictor. Decisions to develop a parcel depend on the

Table 5
Parameter importance weights for cell-based development risk models

Parameter	Weight
Level of protection from development	6
Inside priority funding areas, or with existing or planned sewer service	4
Population growth or loss 1990-2000	1
Parcel size, interpolated from property view centroids	1
Commuting time to town centers	1
Land demand from proximity to Washington, DC, and Baltimore	2
Market land value per acre, interpolated from property view centroids	2
Distance from primary roads	2
Distance from secondary roads	1
Waterfront property	2
Proximity to preserved open space	2

intentions of the landowner and developers, which cannot always be predicted by models. However, the development risk model performed better than random chance, and by using suitable thresholds, can help focus protection efforts. For example, hubs and corridors with their unprotected portion averaging above 45 for development risk are 3 times more likely to be developed than hubs and corridors averaging below 45, if 1997–2000 trends continue. The >25 threshold can be used with even more confidence (90%). Landowner intentions, local knowledge, and signs of development pressure identified through field study should be taken into account when considering protection of individual parcels.

4. Results and application of the Green Infrastructure Assessment

4.1. Composition of Maryland's green infrastructure network

Within state boundaries, Maryland's green infrastructure is comprised of 719,300 ha of hubs and 102,380 ha of corridors in natural land cover (forest, wetland, and bare rock/sand/clay), totaling 821,700 ha. Open water was excluded from these calculations. In addition, altered open areas (agriculture, lawns, quarries, and cleared lands) comprise 151,980 ha in the potential green infrastructure land network. These "gaps" represent areas that could perhaps be restored to a natural cover type. Developed areas (10,214 ha) were excluded from these calculations: they are usually difficult to restore, although many state parks and some privately owned rural properties contain abandoned (usually ruined) buildings.

Maryland's green infrastructure contains:

- 33% of Maryland's total land area (39% when gaps are included);
- 63% of Maryland's forest land, including 90% of the State's interior forest;
- 87% of Maryland's remaining unmodified wetlands;
- 91% of Maryland's streams within interior forests;
- 99.7% of Maryland's natural heritage areas;
- 88% of Maryland's occurrences of rare, threatened, or endangered species;
- 89% of Maryland's steep slopes ($\geq$25%);
- only 44% of Maryland's highly erodible soils;
- 60% of Maryland's highly erodible soils with forest cover (retaining forest on highly erodible soil protects against erosion and stream sedimentation);
- 89% of Maryland's streams with brook trout (690 of 770 km);
- 73% of stream survey sites with high Index of Biotic Integrity (IBI) scores or with imperiled aquatic species;
- 90% of Maryland's areas identified as high quality forest interior bird habitat.

In general, the green infrastructure model is relatively efficient at capturing most of the state's biodiversity and natural resources. However, it missed some areas, such as isolated natural heritage elements, some streams and their riparian buffers (and many poorly buffered streams), some steep slopes, and some wetlands. The model performed most poorly at capturing highly erodible soils, many of which are not forested.

4.2. Current protection level and risk of development

As of 2000, only 26% of Maryland's green infrastructure natural land cover was protected from development by federal, state, or local public ownership; by private conservation organizations like the Nature Conservancy or the Izaak Walton League; or by conservation easements held solely or jointly by the Maryland Environmental Trust. Furthermore, only 13% of hub natural cover, and less than 1% of corridor natural cover, was in areas managed primarily for natural values, using the GAP management criteria from Scott et al. (1993).

Because of the degree to which they are currently unprotected, hubs were ranked from highest to lowest for the development risk parameters as described above. While all hubs are considered ecologically important, initial conservation efforts might be directed toward those at the greatest risk of loss to development. A hub's risk of development can be combined with its ecological score to help prioritize conservation efforts.

4.3. Defining focus areas

In pursuing conservation actions, we need to balance flexibility (the ability to respond to opportunity

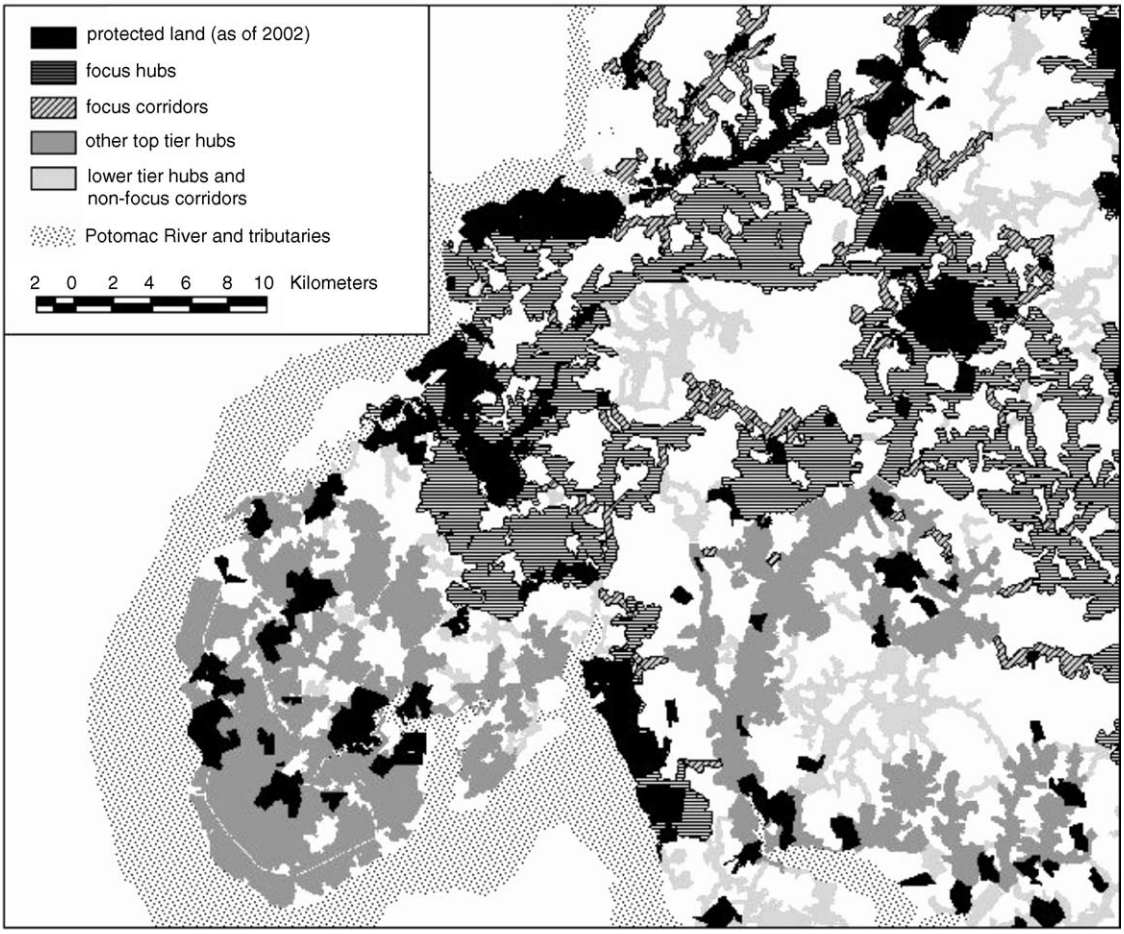

Fig. 4. Sample version of protection focus areas for a portion of southern Maryland, based on composite ecological ranking, development risk on unprotected land, and locations of existing protected lands (as of 2002).

that arises) and focus on what is most valuable to protect. To help focus protection efforts, we combined the ecological and risk ranks of hubs and corridors. We examined several combinations. It will not help if purchases or easements are scattered, and the remaining portions of the hubs or corridors are developed. One version of these focus areas (Fig. 4) featured:

- hubs in the top ecological tier (composite ecological rank in the top third of hubs in the physiographic region), and with their unprotected portion in the top 50% for development risk either statewide or within their physiographic region;
- corridors linking the above hubs, and in the top 50% for development risk;
- corridors linking existing protected green infrastructure land, and in the top 50% for development risk.

More narrowly defined focus areas were also considered, looking at various ecological and risk rank combinations. Thematically based focus areas are currently under development, tailoring hub and corridor targeting to particular programmatic interests (e.g., biodiversity, water quality, forestry, or recreation).

4.4. Conservation targeting

Two state administrations have now accepted the green infrastructure as a vital element in Maryland's land protection efforts. In 2001 the General Assembly, at the initiative of the governor, enacted the GreenPrint program, a multi-year, multi-million dollar authorization to protect, through acquisition of easement or fee interest, priority lands in the green infrastructure where there were willing sellers. GreenPrint differed from on-going land protection initiatives (Program Open Space dates to 1969 and the Maryland Agricultural Land Preservation Foundation to 1977) by focusing on important natural lands, rather than lands with potential recreational or agricultural uses, or identified habitats of particular rare species, which were the focus of the earlier programs. Before severe budget constraints curtailed the program, some US$46 million were expended to protect roughly 12,000 ha. The current administration has used the analyses described here as the basis for its land conservation priority, protecting the watershed of the Chesapeake Bay.

In implementing potential land acquisition projects, a parcel evaluation method (see Weber, 2003) was developed out of the ranking methods of the Green Infrastructure Assessment that is now routinely employed prior to State action on any land conservation proposal. This method consists of four tiers:

Tier 1: Identification of candidate properties for acquisition, either proactively in focus areas (hubs and corridors that are highly significant ecologically, and under significant threat from development); or opportunistically from existing pools of willing sellers and other sources. The parcel boundaries are then digitized from tax maps.

Tier 2: GIS assessment of the property to determine if the project contains green infrastructure as delineated by the GIA model; the amount, percentage, and ecological significance (using the cell ecological rank) of green infrastructure present; proximity to existing protected lands and contribution to further protection of the green infrastructure hub or corridor the property lies in; an overall ecological score for the project; and the presence of other conservation features on the property.

Tier 3: For those properties rating highly in tier 2, a cursory or “drive-by” field visit to areas easily accessible by roads or trails, to verify the Green Infrastructure Assessment model, identify potential restoration needs, and estimate the threat of development the property faces if fee or easement acquisition is not pursued. This step was performed by helicopter for areas on the eastern shore and southern Maryland.

Tier 4: In some cases, a detailed field assessment. This assessment maps all natural communities on the site; collects data for each community; rates each community according to its ecological condition; gives the property an overall ecological field rating based on an area-weighted sum of community conditions; accounts for high-quality natural communities on site, which may make a property more desirable; accounts for impacted or heavily degraded communities on site, which may make a property less desirable; identifies restoration needs on the site; and helps identify easement or management requirements.

4.5. Restoration targeting

Although composed primarily of natural ecosystems, the green infrastructure network contains a variety of environmental conditions, including some areas that are heavily degraded. Land cover “gaps” are developed, agricultural, mined, or cleared lands within the green infrastructure network that could be targeted for restoration. These were evaluated for their potential restoration to forest, wetland, or riparian buffers, by examining watershed condition, landscape position, local features, ownership, and programmatic considerations. Gaps with hydric soils were probably once wetlands, and could be restored as such. Reforestation of gaps along streams would not only benefit wildlife, but improve water quality and stream stability.

We also evaluated a variety of other types of restoration needs within the green infrastructure network. For example, 18,000 ha of wetlands in Maryland were identified as ditched by the National Wetlands Inventory (NWI), including about 9700 ha in the green infrastructure. We set priorities among these by considering watershed condition, landscape context, wetland area and class (i.e., riparian versus non-riparian), and proximity to wetland-dependent rare species.

Stream restoration or remediation includes not only inadequate buffers (addressed as land cover gaps), but such actions as restoring stream morphology, restoring in-stream habitat, reducing nutrient and sediment loading, and controlling acid mine drainage and other point source pollution. We examined ditches and channelized streams in the Nanticoke and Coastal Bays watersheds (identified by Tiner et al., 2000) in a pilot study. These were prioritized for restoration efforts by considering watershed and landscape context, potential nutrient transport from agricultural operations, and potential area and functional importance of hydrologically impaired wetlands.

Stream blockages prevent fish migration, decreasing fish diversity, abundance, and biomass upstream, and removing vital spawning habitat from anadromous species (Kenney et al., 1992). Fish blockages were identified by DNR field surveys. In addition, we identified potential blockages where roads crossed streams, without bridges. We assumed that most non-bridge crossings were culverts. Not all of these may be fish blockages, and conversely, fish blockages may occur away from roads, but field verification would be required. Each field-identified fish blockage and road-stream crossing was ranked by considering the watershed's importance to freshwater and anadromous fish, the length of stream habitat isolated by the blockage, and the severity of the blockage.

Similarly, roads have numerous negative effects on terrestrial wildlife and ecosystems (Yahner, 1988; Brown et al., 1990; Mladenoff et al., 1995; Forman and Hersperger, 1996; Schiller and DeLille, 1997; Elliott, 1998; U.S. Forest Service, 1999; Haskell, 2000). Underpasses beneath roads and railroads can facilitate wildlife passage from one side to the other, and partially mitigate the impact of roads on population viability (U.S. Department of Transportation - Federal Highway Administration, 2000). We identified where roads and railroads cross green infrastructure hubs or corridors, and ranked places for later field verification and examination for potential underpasses. Priority was given to road locations in the center of high ranking hubs or corridors, bridges (which may already provide suitable crossing, or may do so with modification), roads with higher widths and traffic, and stream or wetland crossings.

5. Conclusions

The Green Infrastructure Assessment is a work in progress. We anticipate altering the models as more recent or more accurate land cover, stream, and wetland data become available. We also plan to incorporate habitat boundaries around occurrences of species of concern, and adjust model methods using data and habitat relationships from field surveys (such as a study of forest interior breeding birds we conducted in 2003) and from the predicted distribution of native vertebrate species from the Mid-Atlantic Gap Analysis Project (GAP).

These caveats aside, Maryland's Green Infrastructure Assessment has proven a useful tool for both conservation and restoration efforts in the state. The GIA project was Maryland's first attempt to take a consistent, statewide look at the ecological resources of the state and their vulnerability to development based on the best available data. Because it was developed with real data pertaining to Maryland, and extensively reviewed by professionals in the planning and conservation fields statewide, it has gained a large measure of acceptance at all levels of government in the state.

The concept has particular relevance to state and local land planning authorities. Green infrastructure data have been incorporated into major planning activities in some counties and regional planning organizations. The ability to rank elements of the network at multiple spatial scales has proven to be a valuable tool in conservation and restoration decision-making. Furthermore, the ecosystem-based (as opposed to a single-species) approach employed has made the assessment relevant to multiple conservation and restoration programs operating at multiple levels of government. It has been incorporated into Maryland's Strategic Forest Lands Assessment and served as a prototype for green infrastructure efforts in the Delmarva peninsula (the Delmarva Conservation Corridor), the Chesapeake Bay Watershed (the Resource Lands Assessment), various Maryland counties, and the state of Virginia (the Virginia Conservation Lands Assessment), among others.

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