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Field Validation of a Conservation Network on the Eastern Shore of Maryland, USA, Using Breeding Birds as Bio-Indicators

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Abstract Maryland's Green Infrastructure (GI) is a network of large, intact natural areas (hubs), interconnected by linear swaths of riparian or upland vegetation (corridors). The GI serves significant ecological functions and provides the bulk of the state's natural support system. This study examined whether the GI as mapped does, in fact, identify Maryland's most ecologically valuable forested lands, using forest interior dwelling birds (hereafter called "forest birds") as bio-indicators. We conducted bird point counts within forest both inside and outside of hubs on Maryland's Eastern Shore. We also collected a wide variety of habitat data. We found that both the condition of a forest and its surrounding landscape influenced the bird communities. On average, forest bird richness was significantly higher within hubs; furthermore, almost all sites with at least five forest bird species present were in hubs. Forest bird richness and abundance were highest in undisturbed, mature broadleaf forest with wetlands and streams nearby. We detected a significant relationship between forest bird richness and the ecological score of a finer-scale landscape assessment, focused on "cells" of about 0.1 ha in size. This field study also validated the Rapid Field Assessment (RFA) protocol developed in 2001 to assess, on the ground, the relative condition of individual sites or properties within the GI. Forest bird richness and abundance were positively correlated with the RFA community scores. Our results underscore the importance of maintaining regional biological diversity by retaining large blocks of forest, especially mature forest containing streams and wetlands.

Keywords Conservation planning · Forest condition · Forest interior birds · Green Infrastructure · Rapid field assessment · Maryland

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Introduction

Defining and Mapping GI

"Green Infrastructure" is a term for networks of natural ecosystems, such as forests, wetlands, and streams (Benedict and McMahon 2006). These areas provide important ecosystem services, including cleaning the air, filtering and cooling water, storing and cycling nutrients, conserving and generating soils, pollinating crops and other plants, regulating climate, protecting areas against storm and flood damage, maintaining hydrology, providing habitat for resident and migratory wildlife, maintaining a vast genetic library, providing products like timber and fish, and providing recreational opportunities and scenery (Costanza and others 1997). In an effort to identify the state's most important remaining natural areas and provide a consistent framework for land conservation, the Maryland Department of Natural Resources (DNR) developed the Green Infrastructure Assessment (GIA) in the late 1990s (Weber and others 2006b). Based on principles of landscape ecology and conservation biology, the GIA identifies and evaluates a Green Infrastructure (GI) network of large natural "hubs" and interlinking "corridors" of natural land.

Large natural patches, e.g., hubs in the GI, support a larger variety of habitats than small patches, are more likely to be colonized by new species, support larger populations which are less vulnerable to extinction, and support animals that require large home ranges (Dramstad and others 1996; Hanski 1997; Harris 1984; Tilman and Lehman 1997). In the Maryland GIA, hubs were defined as containing one or more of the following:

(1) Large blocks of contiguous interior forest. Based on habitat requirements for forest interior birds listed in Bushman and Therres (1988), the size threshold set in the GIA was 100 hectares, plus an interior-edge transition zone of 100 meters.
(2) Large wetland complexes, with at least 100 hectares of unmodified wetlands.
(3) Sensitive animal and plant habitats in patches at least 40 hectares in size, including rare, threatened, and endangered species locations; unique ecological communities; and colonial waterbird nesting sites.
(4) Streams and rivers, and their associated riparian forest and wetlands, containing one or more of the following: aquatic species of concern; key populations of native fish, amphibians, or reptiles; rare coldwater or blackwater ecosystems; or important for anadromous fish.
(5) Existing protected areas (e.g., state parks and forests, National Wildlife Refuges, and Nature Conservancy preserves) with at least 40 hectares of contiguous natural land.

Corridors in the GI are linear features connecting hubs together to help animals and plant propagules move between suitable habitats. Retaining connectivity, as appropriately sited and configured corridors can accomplish, can help to offset the functional losses caused by habitat fragmentation (Anderson and Danielson 1997; Beier and Noss 1998; Bennett 1998; Söndgerath and Schröder 2002). In the GIA, corridors were generally at least 335 meters wide, and followed the best ecological or "most natural" routes between hubs. Typically these were forested stream valleys or ridge lines. Developed areas, major roads, and other unsuitable features were avoided by the assessment methodology (Weber and others 2006b).

Maps of Maryland's GI were developed in a Geographic Information System (GIS) model based on satellite imagery (captured by the United States Geological Survey between 1991 and 1993, with 30 m resolution), road and stream locations, biological data, and other information (see Weber and others 2006b for details). The results were reviewed by scientists, local government officials, and conservation groups. Natural areas in the GI comprise 33% of the state's land area, but contain most of its important ecological features, including 90% of interior forest (Weber and others 2006b).

Applying the GIA to Conservation Planning

As of 2004, only about 30% of Maryland's GI (not including gaps) was protected from potential loss to urban types of development (Herrmann 2005), i.e., it was either owned by public or private conservation organizations managing it for its natural values, or it was under conservation easement. Thus, a major purpose of assessing the landscape systematically was to provide guidance for future public and private conservation efforts. To assist in this effort, the landscape was divided into "cells" about 0.1 ha in size (corresponding to the land cover resolution), and each cell was assessed for a variety of ecological parameters (Table 1). Both regional and local factors were used to rank the cells, with the understanding that each cell both contributes energy and matter to the surrounding landscape, and is controlled by larger-scale processes. The overall cell ecological score was half dependent on landscape context, e.g., hub or corridor condition and importance, and half dependent on local site conditions, e.g., vegetation type and disturbance (see Weber and others 2006b for more details).

To evaluate parcels for potential acquisition, a tiered approach was adopted, beginning with desktop, GIS-based assessment (looking at the amount of GI in the parcel, the average cell score, proximity to existing protected lands, and the parcel's contribution to the network), and proceeding to aerial or drive-by verification of this assessment. Properties passing the initial GIS and aerial or drive-by screening were then assessed using a Rapid Field Assessment (RFA) protocol, which considered forest, wetland, and stream ecosystems on-site, and their quality and condition, as well as areas needing restoration. The RFA was developed and calibrated using data from sites representing a wide range of abiotic conditions, community types, and disturbance regimes. Natural communities at these sites were evaluated for their plant community structure and composition; wildlife habitat values; hydrology, presence, type, and intensity of human disturbances; and presence and extent of invasive species. Site conditions affecting community parameters, like rocky soils or exposed ridge tops, were noted and considered when rating the community. Numeric site scores were grouped into four categories (Excellent, Good, Fair, or Poor) based on thresholds observed in the calibration data (Table 2). Details are available in Weber (2003).

Table 1 Parameters used to calculate the GI cell ecological score

Hub parameters	Corridor parameters
Rare species occurrences, weighted by rarity and population viability	Ecological ranking of hubs connected
Area of Delmarva fox squirrel habitat	Variety of ecosystem types connected
Fraction in mature natural vegetation communities	Corridor length and area
Area of natural heritage areas	Number of corridor breaks
Mean fish index of biotic integrity	Number and type of road and railroad crossings
Mean benthic invertebrate index of biotic integrity	Percent of corridor with natural cover
Presence of brook trout	Habitat conditions within the corridor
Anadromous fish index	Surrounding land use
Area of other unmodified wetlands	
Length of streams in interior forest	Local Parameters
Number of stream sources and junctions	Land cover
Number of vegetation community types	Rare species occurrences
Number of wetland types	Proximity to designated natural areas of concern
Number of soil types	Vegetation community type and successional stage
Area of highly erodible soils	Proximity to streams, and condition of streams
Proportion of interior natural area in hub	Within floodplain
Area of upland interior forest	Within interior forest
Area of wetland interior forest	Proximity to unmodified wetlands
Number of physiographic regions in hub	Proximity to development
Topographic relief	Distance to roads, weighted by road type
Remoteness from major roads	Soil erodibility
Surrounding buffer suitability	
Interior forest within 10 km of hub periphery	
Marsh within 10 km of hub periphery	
Patch shape	
Proximity to other hubs	

Table 2 Site rating developed for the RFA to assess natural community condition

Site Rating	Examples
Excellent	Old-growth or mature forest dominated by late-successional species, and with diverse composition and structure. Community could be early successional if subject to repeated natural disturbances (e.g., beach dunes, river scours). No signs of recent human disturbance or exotic species in majority of community or site (>95% undisturbed).
Good	Regenerating forest with natural composition, >30 yrs old. Could be signs of human disturbance, but not recent, and they are not significantly affecting hydrology, species composition, or animal movement. No major ditches, few invasive exotics, no roads present.
Fair	Dominated by saplings or early successional native trees (e.g., *Liquidambar styraciflua* or *Pinus virginiana*); or old fields. Restoration needs might include tree planting, removal of exotic species, addressing minor stream erosion, minor ditch filling, removing trash, culling animal overpopulations (e.g., deer, hogs), etc.
Poor	Dominated by human land uses: pine plantations, row crops, clearcuts, etc. Might contain numerous logging roads or ditches. Might be dominated by exotic species. Streams may be unstable or major erosion occurring on site. Restoration needs might include clearing and revegetation, road retirement, major ditch filling, major road-stream retrofits, or major stream restoration. Neighboring land uses might require perpetual active management.

Ratings were quantified by comparing on-site data to data collected from reference sites. Developed or strip-mined areas were excluded from consideration

Importance of Field Validation of the GIA

Stokes and Morrison (2003) highlighted problems encountered when projects rely on GIS maps that have not been field verified to plan conservation efforts. Even when models are based on credible scientific theories, there may be inconsistencies with the real world. It is essential that a GIS model be ground-truthed so that the status, trends, and losses of land can be identified (Stokes and Morrison 2003). Field validation can provide evidence that the GIA methodologies are sound, suggest improvements, and answer whether the GI maps are useful tools for identifying the state's most ecologically valuable lands.

Using Birds as Bio-Indicators

Bird guilds can be used effectively to assess the general health of ecosystems (e.g., Blair 1996; Canterbury and others 2000; O'Connell and others 2000; Padoa-Schioppa and others 2006; Reynaud and Thioulouse 2000). In particular, forest interior dwelling bird species (hereafter called "forest birds") can be useful to assess the health of forest ecosystems (Canterbury and others 2000; O'Connell and others 2000). Forest birds are defined as birds that require large forest areas to breed successfully and maintain viable populations (Jones and others 2000). Many are sensitive to edge effects like increased nest predation and brood parasitism (Gates and Giffin 1991). Forest birds are considered "umbrella species:" their survival needs encompass those of many other plant and animal species (Jones and others 2000). Important forest microhabitats include riparian areas and seasonal wetlands. In addition, 80% of the forest birds known to breed in Maryland are neotropical migrants, a guild of birds that is experiencing serious population declines (Sauer and others 2007). Although neotropical migrants are affected by stressors on their wintering grounds and migratory routes, they are also dependent on suitable breeding habitat.

A major premise underlying the GIA is that natural lands within the GI network are more valuable ecologically than natural lands outside of the GI. In this study, in order to test this hypothesis, we collected species-level data inside and outside of GI hubs. Because the vast majority of Maryland's GI network is composed of large blocks of contiguous interior forest, we collected data within forest interior habitats. We focused our data collection on the presence and abundance of forest birds inside and outside of GI hubs on Maryland's Eastern Shore. We also collected data on other species of birds and a wide range of local habitat variables and landscape features inside and outside of GI hubs.

The general questions we wished to address with this field validation included: (1) Does the GI model accurately predict good habitat for forest birds? (Specifically, is forest bird richness or abundance in hub interior forest higher than forest bird richness or abundance in interior forest outside of hubs?) (2) Is there a detectable relationship between forest bird richness or abundance and GI cell-based ecological rank? (3) How does forest bird richness and abundance correlate with the forest community RFA developed for the GIA? (4) How can the forest community RFA protocol be changed to better assess suitable local habitat for forest birds?

Methods

Study Area

This study was conducted on Maryland's Eastern Shore (see Fig. 1). This region, especially the southern portion, is a shifting mosaic of forest ages and types. The land cover upon which the GI was based was from circa 1992, supplemented by 1997 land use data. Since then, extensive logging of forests (mostly pine plantations) and, conversely, regrowth of former logged areas, has changed the landscape.

Site Selection

In order to test if GI hubs are more likely to be used by forest birds than other interior forest blocks, point counts were conducted in interior forest blocks both inside and outside of GI hubs. Interior forest was defined as >100 m from the forest edge. Point counts were conducted in interior forest blocks located in one of three categories: interior forest >100 ha in GI hubs; interior forest <100 ha in GI hubs; and interior forest <100 ha outside of GI hubs (all forest patches >100 ha were included in the GI). Because these habitats vary significantly in their vegetative and faunal composition, site selection was stratified so as to include roughly equal numbers of sites in both coniferous and deciduous forests. Interior forest blocks were selected at random from public lands or private lands that we had permission to access. All forest blocks sampled were a minimum of 4 ha. Sample sites are shown in Fig. 1.

The number of bird point counts and accompanying habitat surveys conducted in a given forest block was assigned according to the size of the block (Lynch and Whigham 1984; Robbins and others 1989). One point count was used in blocks of <60 hectares, two in blocks of 60–100 ha, three in blocks of 100–200 ha, and four in blocks >200 ha. When more than one study site was selected per forest block, each site was established at least 250 m away from any other sites to reduce the risk that the same individual birds might be observed at different point count locations. All sites were situated at a maximum distance, and at least 150 m, from an edge.

Before conducting surveys, we verified that the sites were actually within intact interior forest. Verification was done either by helicopter or on the ground. Many potential sites had been recently clearcut, thinned, or were inaccessible; these sites were dropped from the study. Some of the

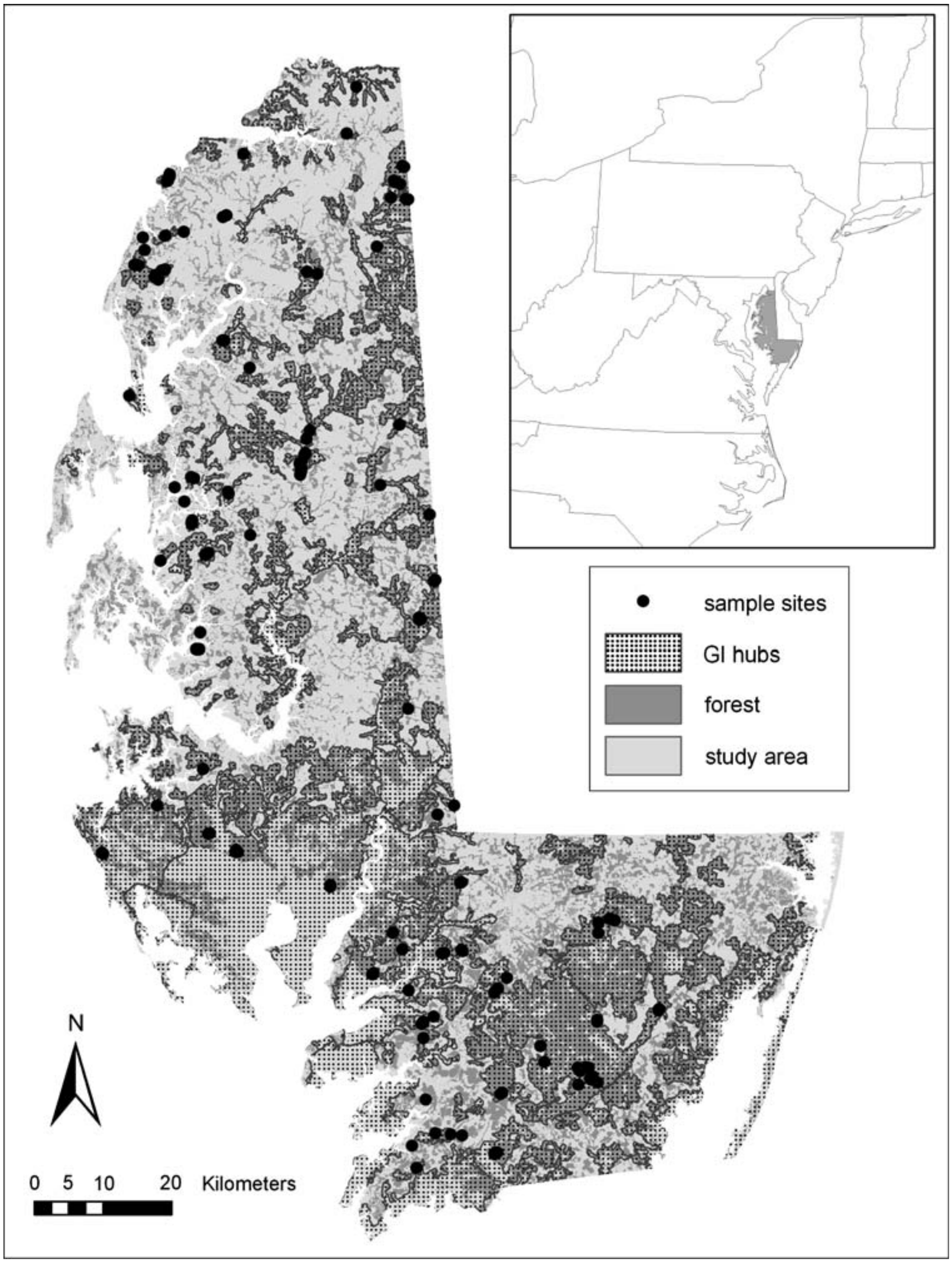

Fig. 1 Location of study sites, forest, and GI hubs on Maryland's Eastern Shore

coastal forest stands in Dorchester County had been killed by sea level rise. We also limited the study to woods past the sapling stage (>10 cm DBH).

We used Global Positioning System (GPS) receivers to find our pre-assigned point count locations. If necessary, we adjusted our pre-assigned sites in the field so that we were at least 150 m from the nearest forest edge.

Bird Survey Protocol

We used a point count protocol that was based on protocols from similar avian studies (MCWRU 1994; Nichols and others 2000; Ralph and others 1995; Robbins and others 1989). All point counts were conducted by P. J. Blank. All birds were recorded during a 10 minute time period using simultaneous 50-m radius and unlimited-distance point counts. In 50-m radius point counts, all birds seen or heard within 50 m of the observer were recorded. In unlimited-distance counts, all birds seen or heard at any distance from the observer were recorded. We used both techniques to allow for comparisons between our data and those of other studies that have used 50-m radius point counts or unlimited-distance counts.

No distinction was made between males and females in the field. Because our focus was on breeding birds, family groups consisting of an adult and first-year juveniles were counted as one individual bird. Birds flying over the site but not seen using the site were not included in the data analysis, but a note was made of them. Individual birds were not recorded twice if they were determined to be heard from two different locations. Every effort was made to avoid tuning out birds (missing some birds while concentrating on others).

Counts were conducted once between May 20 and July 19, 2003. These dates were chosen to be sure that our counts fell within the safe-dates of most forest breeding birds, after migrants were gone, and before breeding males stopped singing. Analyses for ovenbirds were conducted on observations only between May 20 and July 8, and for worm-eating warblers only between May 20 and June 13, because we felt that observations outside of these dates were not reliable indications of the presence or absence of these species (due to lack of vocalizations).

Wind direction, wind intensity, cloud cover, and estimated temperature were recorded at each site. Counts were not conducted on rainy or windy days or in excessively hot conditions. Counts were done between sunrise and 10:00 am.

Vegetation Survey Protocol

At each sampling site, we collected vegetation data within the 50-m radius point count area. The center point of the vegetation plot was the same as where the point count had been conducted. Information collected within the 50-m radius plot included: percent visible human disturbance; type of disturbance; and presence or absence of streams, wetlands, springs, headwaters, seeps, or vernal pools. The presence of perennial water and wetlands, and evidence of repeated natural disturbances or stresses within 100 m of the center point were also noted.

Vegetation surveys were conducted using modified versions of the James and Shugart (1970) and Martin and others (1997) methods. At each point count location, at least one 11.3-m radius circular subplot (0.04 ha) was surveyed intensively to obtain detailed vegetation data. Sites that contained only one forest community type within the 50-m radius plot were sampled by using one subplot centered where the point count had been conducted at the center of the 50-m radius plot. If more than one community was found to exist within the 50-m radius plot, separate subplots were set up in the approximate center of each representative community type. For example, if two forest community types (e.g., upland and wetland, or deciduous and pine) were found within the 50-m radius plot, then two sampling subplots were surveyed. The locations of any additional subplots (including distance and direction) were noted on a map.

Within each 11.3-m radius sub-plot, the percent of leaf cover at the center of the plot was measured using a densiometer. The top heights of the canopy, the sub-canopy, and the shrub layer were measured using a Haga altimeter. The percent cover of canopy and subcanopy trees, shrubs, mosses, lichens, litter, woody debris, and bare ground was visually estimated within the following categories: absent, 1–5%, 6–25%, 26–50%, 51–75%, or 76–100%. The presence or absence of trees with natural or excavated cavities, pit and mound structures, and downed logs greater than 20-cm diameter at breast height (DBH) were recorded. Depth of leaf duff and humus layer was estimated at the center of the subplot. Percent cover of any exotic species was recorded, and the species, number, and DBH of all canopy and subcanopy trees were noted.

Within 5 m of the center of each circular subplot, data on tree saplings, shrubs, and vines were recorded. The species name and count of the number of shrubs and tree saplings (<10 cm DBH and >1 m tall) were noted. Estimates of the percent cover of vines, the percent of trees with vines, cover of the herbaceous layer, and the count of tree seedlings (<1 m tall) were made. All data sheets used in the study are online in Weber and others (2006a).

Data Analysis

Birds were designated as either forest birds or nonforest birds based on Bushman and Therres (1988), Freemark and Collins (1989), and Jones and others (2000). Forest bird richness and abundance within each forest block were calculated by using the mean of the observations from point counts within the same block. Forest bird presence and abundance were compared to a broad suite of local and landscape habitat variables. Habitat variables were examined for co-linearity. At sites where more than one vegetation subplot was surveyed, an area-weighted average was used to obtain a single value for each habitat variable.

Univariate analyses were performed using Chi-square tests, analyses of variance (ANOVAs), Kruskal-Wallis Multiple-Comparison Z-Value tests, Tukey-Kramer Multiple-Comparison Tests, and linear regressions, depending on the type of data (e.g., discrete or continuous). Multivariate analyses were performed using Stepwise Regression and All Possible Regressions. In some cases, variables were transformed to increase normality or decrease variation. Statistical significance was set at $p = 0.05$.

Data on canopy and subcanopy trees from the 11.3-m radius subplots were used to classify forest community types at each site. Sites were organized into four forest categories: broadleaf, coniferous, mixed, and pine plantations. Broadleaf sites were defined as subplots with >75% broadleaf trees in the canopy layer. Coniferous sites were defined as subplots with <25% broadleaf trees in the canopy, and <50% broadleaf trees in the subcanopy. Mixed sites were defined as subplots with <75%, but >25% broadleaf trees in the canopy, or >50% broadleaf trees in the subcanopy. Pine plantations were stands of pine trees (here, *Pinus taeda*) of similar age and size in straight rows. Composition of canopies and subcanopies was determined by calculating the total DBH of all broadleaf and coniferous trees within each subplot. Statistical analyses were conducted using Number Cruncher Statistical Systems (Hintze 2001).

We gave each site a community score and habitat rating (Excellent/Good/Fair/Poor) based on the RFA protocol described in the introduction. Table 3 lists the RFA variables and relative weights. Variable definitions and value groupings are in Weber and others (2006a).

Results

We conducted point counts at 134 locations in 94 different forest blocks and among 8 different forest types on Maryland's Eastern Shore during the summer of 2003 (Fig. 1). Table 4 lists the number of points sampled inside and outside GI hubs, inside and outside forest blocks >100 ha, and by forest type (broadleaf, coniferous, and mixed). Some blocks contained more than one type of forest. Overall, we observed a total of 66 bird species and recorded a total of 2336 individual birds (excluding flyovers not using the site).

Table 3 RFA variables used to rate forest communities for conservation value

Variable	Percent of total score
Disturbance intensity	8.2
Area affected by anthropogenic disturbances	12.2
Area of exotic invasive plants	8.2
Presence and type of wetlands	6.5
Presence and type of streams	6.5
Presence of ponds or vernal pools	3.3
Presence of headwaters, springs, or seeps	3.3
Canopy dominated or co-dominated by nut-producing trees	4.9
Number of native dominant or co-dominant canopy trees	2.4
Number of woody species	3.3
Evenness of woody species	3.3
Tree seedling recruitment	6.5
Size class of canopy species (diameter measure)	13.1
Stand stratification (no. of layers with >25% areal) coverage)	3.3
Snags >20-cm dbh	3.3
Tree cavities present	3.3
Leaf duff and humus depth	2.1
Pit and mound structure present	3.3
Number of herbaceous species	1.6
Evenness of herbaceous species	1.6

Forest Birds and GI Hubs

During point counts, we detected 16 of the 24 species of forest birds known to breed on Maryland's Eastern Shore (Table 5). Forest bird richness was higher within hubs than outside hubs for all forest types combined (Table 6). Pine plantations were the least favored forest type, with forest birds generally being absent altogether from pine plantations outside of hubs.

Figures 2 and 3 show the number of forest birds counted inside and outside of GI hubs using 50-m and unlimited-distance observations, respectively. The average number of all bird (i.e., not just forest) species recorded at each unlimited distance point count was 11, and the average number of individual birds observed at each site was 17.4. Detailed statistics for the unlimited-distance observations may be found in Weber and others (2006a). Eleven GI hub sites contained between 6 and 9 different forest bird species in unlimited-distance counts, whereas no sites outside of GI hubs had greater than 5 forest bird species. Twenty-nine percent of hub sites contained at least 5 forest bird species (11% were >5) while only 9% of nonhub sites contained 5.

Forest Birds and GI Cell Ecological Score

We conducted point counts and vegetation surveys in 32 different GI hubs and evaluated the GIA's ability to predict areas of high ecological value by comparing cell rank scores with our forest bird observations. There was a significant positive relationship between forest bird richness within 50-m plots and the mean cell ecological score within the same area ($r = 0.27$, $p < 0.005$) (Fig. 4). Forest bird richness was significantly higher at sites with a mean cell score of 85–100 than those scoring <85 ($p < 0.005$, $f = 8.36$, $df = 133$).

There was also a significant positive relationship between forest bird abundance within 50-m plots and the mean cell ecological score within this area ($r = 0.20$, $p < 0.05$). Forest bird abundance was significantly higher at sites with a mean cell score of 85–100 than <85 ($p < 0.05$, $f = 4.42$, $df = 133$).

Table 4 Final distribution of study sites among forest types and locations

Forest type and location	Number of points	Number of forest blocks	Min. forest block size (ha)	Max. forest block size (ha)	Mean forest block size (ha)
Broadleaf forest in blocks with ≥100 ha of interior forest, and within GI hubs	29	16	288	1552	629
Coniferous forest in blocks with ≥100 ha of interior forest, and within GI hubs	30	18	260	1957	706
Mixed forest in blocks with ≥100 ha of interior forest, and within GI hubs	14	10	288	1323	783
Broadleaf forest in blocks with <100 ha of interior forest, and within GI hubs	21	16	26	232	131
Coniferous forest in blocks with <100 ha of interior forest, and within GI hubs	4	3	83	232	164
Mixed forest in blocks with <100 ha of interior forest, and within GI hubs	3	3	73	205	130
Broadleaf forest outside GI hubs	18	16	43	235	99
Coniferous forest outside GI hubs	9	7	41	1839	355
Mixed forest outside GI hubs	6	5	66	315	140

Forest Birds and Individual Variables

Several individual variables were significantly related to forest bird richness (Weber and Blank 2008, in prep). Forest bird richness was higher at sites where disturbance was minimal (<5% of area); broadleaf trees were dominant; seasonally, semipermanently, or permanently flooded wetlands were present; perennial water, including streams, ponds, or permanently flooded wetlands, was present; canopy height was >26 m; mean canopy DBH was >40.6 cm; and tree saplings were less abundant (<1910/ha). Forest bird richness was also positively correlated (linear regressions, $p < 0.05$) with canopy tree richness, the length of streams within 1 km, and the area of wetlands within 1 km. Canopy height, presence and area of nearby wetlands, the inverse of sapling density, the length of streams within 1 km, and dominance by broadleaf trees were the most important variables in a multiple regression model (Weber and Blank, in prep). The majority (73%) of unlimited-radius plots with at least five species of forest birds were in forest blocks with at least 120 ha of interior forest.

Forest Birds and GI RFA

We gave each site a community score and habitat rating (Excellent/Good/Fair/Poor), based on the RFA protocol, and combined it with the site's location either within or outside the GI hubs (Table 7). A linear regression between raw categorization and forest bird richness was significant at the 0.05 level. This was also true for forest bird abundance.

Both forest bird richness and abundance were higher in forest communities with Excellent or Good GI field ratings, compared to communities with Fair or Poor ratings (Table 7). Forest bird richness and abundance did not significantly differ between hub and nonhub sites rated Excellent versus Good, but these differed significantly from sites rated Fair or Poor. Aggregating ratings, mean forest bird richness at excellent and good sites was 2.14, and for fair and poor sites it was 1.14 ($df = 134, f = 22.81, p < 0.001$). Mean forest bird abundance at Excellent and Good sites was 2.71, and for Fair and Poor sites it was 1.38 ($df = 134, f = 59.97, p < 0.001$).

Our analysis indicates that both local and landscape condition are important to forest birds. However, we could not tell whether one was more important than the other. Sites within hubs and rating Excellent or Good had significantly higher forest bird richness and abundance than sites rating Fair or Poor, whether in a hub or not.

Modifications to the GI RFA

Our study suggested several modifications to the RFA protocol (Table 8). The disturbance score was modified, combining intensity and affected area. Exotic plant dominance was included in this. Because forest bird richness and abundance were correlated with the presence of seasonally, tidally, or permanently flooded wetlands, this variable was given a strong weighting. Canopy height was given a weight equivalent to mean canopy tree diameter at breast height (DBH). Canopy species dominance was replaced by richness, which was both easier to measure and better correlated with forest bird richness. Lastly, we added sapling density.

Table 5 Forest Interior Dwelling Birds known to breed on Maryland's Eastern Shore[a] and those recorded during our study

Common name	Scientific name	Species observed	Number of observations (50-m radius)	Number of observations (unlimited-radius)
Red-shouldered hawk	*Buteo lineatus*	X	1	2
Broad-winged hawk	*Buteo platypterus*			
Barred owl	*Strix varia*	X[b]		
Whip-poor-will	*Caprimulgus vociferus*			
Hairy woodpecker	*Picoides villosus*	X	10	14
Pileated woodpecker	*Dryocopus pileatus*	X	9	19
Acadian flycatcher	*Empidonax virescens*	X	48	63
Brown creeper	*Certhia americana*			
Veery	*Catharus fuscescens*			
Wood thrush	*Hylocichla mustelina*	X	28	67
Yellow-throated vireo	*Vireo flavifrons*	X	6	11
Red-eyed vireo	*Vireo olivaceus*	X	43	88
Northern parula	*Parula americana*	X	3	7
Black-throated green warbler	*Dendroica virens*			
Black-and-white warbler	*Mniotilta varia*	X	1	4
American redstart	*Setophaga ruticilla*	X	2	2
Prothonotary warbler	*Protonotaria citrea*	X	10	18
Worm-eating warbler	*Helmitheros vermivorus*	X	6	13
Swainson's warbler	*Limnothlypis swainsonii*			
Ovenbird	*Seiurus aurocapillus*	X	43	81
Louisiana waterthrush	*Seiurus motacilla*	X	3	6
Kentucky warbler	*Oporornis formosus*	X	1	2
Hooded warbler	*Wilsonia citrina*	X[b]		
Scarlet tanager	*Piranga olivacea*	X	15	43

[a] Sources: Bushman and Therrres (1988), Robbins (1996), Jones and others (2000)

[b] Observed while walking to or from study sites, but not observed during point counts

Table 6 Forest bird richness (in 50-m radius plots), by forest type, inside and outside GI hubs

Forest type	Number of forest blocks	Mean forest bird richness in hubs	Mean forest bird richness outside hubs
Broadleaf	48	2.33	1.53
Mixed	18	1.88[a]	1.00
Broadleaf or mixed	66	2.20[a]	1.40
Natural coniferous	13	1.73	1.00
Pine plantations	17	1.26[a]	0.10
All coniferous	30	1.49[a]	0.36
ALL FOREST	81	1.92[a]	1.15

[a] statistically significant difference whether the forest block was in a hub or not (ANOVA, $p < 0.05$)

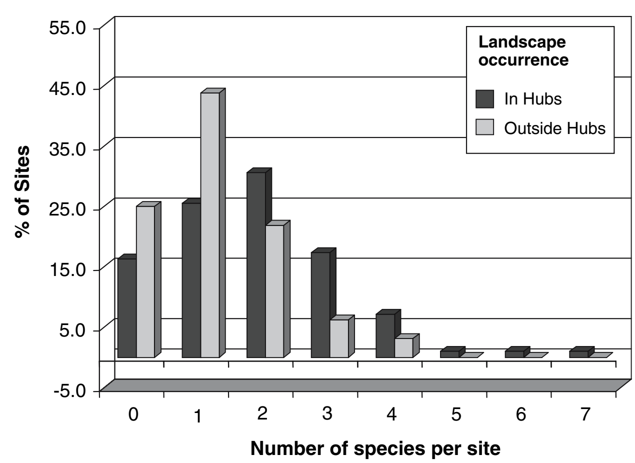

Fig. 2 Number of forest interior bird species counted inside and outside of GI hubs using 50-m fixed radius point counts

We recomputed forest community scores and ratings using this revised protocol, and compared them to forest bird richness and abundance in the corresponding plots. The revised community score and rating had a higher correlation to both forest bird richness and abundance (Table 9). It especially improved discrimination between Excellent and Good sites in terms of richness and abundance of forest birds (Table 10).

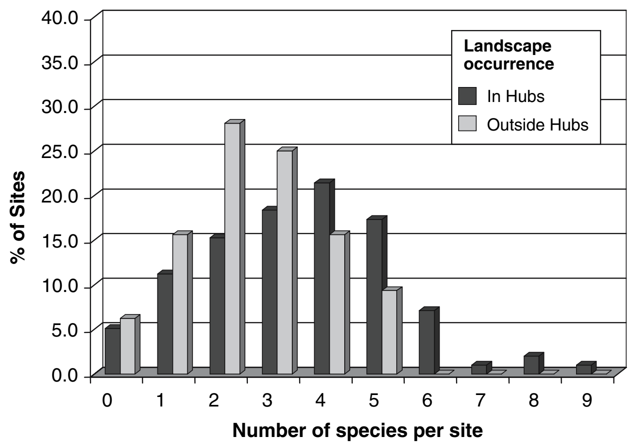

Fig. 3 Number of forest interior bird species counted inside and outside of GI hubs using unlimited-distance point counts

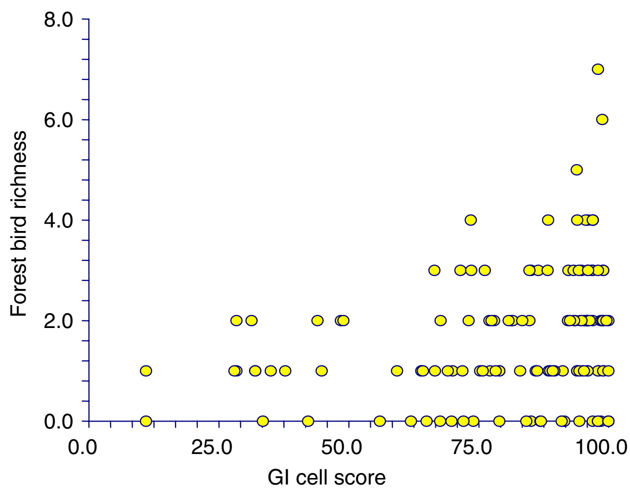

Fig. 4 Forest bird richness within 50-m plots versus mean GI cell ecological score in the same area

Discussion

We found that forest bird richness was generally higher within GI hubs than in nonhub forest. Sites with the highest richness were all located in hubs. Our results underscore the importance of maintaining regional biological diversity by retaining large blocks of forest, especially mature forest containing streams and wetlands. Protecting such areas (i.e., Green Infrastructure) will help more area-sensitive species than will protecting isolated woodlots and allowing the landscape to be further fragmented. These findings agree with similar studies of avian response guilds in forested landscapes (Freemark and Collins 1989; Robbins and others 1989) and are consistent with the recommendations of Partners in Flight to identify and maintain large blocks of forest habitat in the Mid-Atlantic Coastal Plain (Watts 1999). Yet, Maryland's GI forest is fast disappearing: over 6000 ha were lost to development between 1997 and 2000 (Weber and Aviram 2002), in addition to areas logged for timber or wood pulp.

Our study validated the GI GIS and field assessments, but also suggested improvements for Maryland's GIA. Although, on average, hubs contained more species of forest birds than nonhub forest, some sites within hubs had few forest birds present. Some of these sites were pine plantations, which future GI maps should not identify as core habitat. But not all cases could be explained by available habitat. Our study also demonstrated the need to update GIS maps in rapidly changing landscapes; many of our preliminary sites had been clearcut.

Based on habitat requirements for forest interior birds listed in Bushman and Therres (1988), forest blocks with at least 100 ha of interior forest were defined as being inside GI hubs. We found no significant differences in forest bird richness and abundance between hub and nonhub sites rated Excellent or Good, implying that some sites with less than 100 ha of interior forest and in Excellent or Good condition may provide adequate habitat for forest birds. However, we were unable to determine a size threshold lower than 100 ha that may sustain the highest mean richness and abundance of forest birds. The type and age of forest, proximity to wetlands and streams, forest block size, and inclusion in areas meeting GI hub criteria were all significantly related to forest bird richness. A conservation network subsequently developed for the state of Delaware (Weber 2007) therefore defined "core forest areas" as large

Table 7 Forest bird richness and abundance, GI (RFA) site rating, and whether the site was in a hub

Category	Category description	Number of sites	Mean forest bird richness	Significantly different from category[a]	Mean forest bird abundance	Significantly different from category[a]
A	Sites within hubs and rating Excellent or Good	55	2.33	B, D	2.8	B, D
B	Sites within hubs and rating Fair or Poor	43	1.26	A	1.51	A
C	Sites outside hubs and rating Excellent or Good	15	1.47		2.4	
D	Sites outside hubs and rating Fair or Poor	17	0.94	A	1.18	A

[a] Differences between categories were examined with Tukey-Kramer Multiple-Comparison Tests ($p < 0.05$)

Table 8 Modified RFA variables used to rate forest communities for conservation value

Variable	Percent of total score
Disturbance score	27.8
Presence and type of wetlands	7.9
Presence and type of streams	7.9
Presence of ponds or vernal pools	3.2
Presence of headwaters, springs, or seeps	3.2
Canopy dominated or co-dominated by nut-producing trees	4.8
Number of native canopy trees	2.4
Number of woody species	3.2
Tree seedling recruitment	4.8
Size class of canopy species (diameter measure)	7.9
Height at top of canopy layer	7.9
Stand stratification (no. of layers with >25% areal coverage)	3.2
Number of tree saplings	3.2
Snags >20 cm dbh	3.2
Tree cavities present	3.2
Leaf duff and humus depth	2.4
Pit and mound structure present	2.4
Number of herbaceous species	1.6

blocks of forest (at least 100 ha) containing at least 50%, or 100 ha of, mature broadleaf forest (except coastal areas historically dominated by conifers), as well as meeting other criteria like containing wetlands or perennial streams.

The GI cell ecological score, which incorporates both landscape and site factors, was a useful predictor of forest bird habitat. Sites with high scores tended to have high forest bird richness and abundance. Because 90% of the state's interior forest is within the GI, the cell ecological score is helpful to narrow conservation decisions.

Site-level habitat assessment is most accurately performed in the field. The RFA, especially with our recommended improvements, is not only a systematic method to rate ecosystem condition, but can also identify good wildlife habitat. Forest sites approaching reference standards also tended to support a greater number of interior bird species.

Table 10 Original and revised RFA ratings versus forest bird richness

RFA rating	Number of plots	Mean number of forest birds	Standard error
Original RFA rating			
All	134	1.66	
Excellent	13	2.15	0.33
Good	57	2.14	0.16
Fair	35	1.43	0.20
Poor	29	0.79	0.22
Revised RFA ratings			
All	134	1.66	
Excellent	26	2.69	0.23
Good	59	1.78	0.15
Fair	18	1.28	0.27
Poor	31	0.81	0.21

Although during our point counts we only detected 16 out of 24 species of forest birds known to breed on the Eastern Shore, we felt that detecting two thirds was good considering the number of sites we visited. Of the eight species we did not detect during point counts, five have very few confirmed nesting attempts in our study area (Robbins and Blom 1996), two were seen in hubs outside of our point counts (Table 5), and one (*Caprimulgus vociferus*) generally sings only at night.

We acknowledge that single observer point counts are inherently prone to error. Research has shown that a variety of factors influence detection probability during point counts, including observer identity and skill, bird species, and local habitat characteristics (Nichols and others 2000; Pendleton 1995). In addition, factors such as wind speed, forest density, humidity, and the bird's orientation may have influenced our results. To avoid inter-observer biases, all the point counts in this study were conducted by the same person. Although many studies try to estimate the total number of males, or the total number of breeding pairs, in a given area, we did not distinguish between males and females during our point counts. This resulted in higher counts per species when females and males were both observed compared to when only males were observed. We do not believe this to be a major problem because the vast majority of the birds we recorded were singing males.

Table 9 Comparison of original and revised RFA scores and ratings to forest bird richness and abundance. ($df = 134$ for all tests)

Test	Original RFA scores	Revised RFA scores	Original RFA ratings	Revised RFA ratings
Spearman correlation with forest bird richness	0.4312	0.4927	0.4257	0.4896
Linear regression r^2 with forest bird richness	0.1790[a]	0.2164[a]	0.1602[a]	0.2264[a]
Spearman correlation with forest bird abundance	0.4490	0.4805	0.4228	0.4614
Linear regression r^2 with forest bird abundance	0.1841[a]	0.1955[a]	0.1518[a]	0.1986[a]

[a] significant at $p < 0.05$

Conclusions

We found that both forest condition and its surrounding landscape influenced the bird communities on Maryland's Eastern Shore. More species of forest birds were found within Green Infrastructure hubs than in forest outside hubs. This implied that hubs provide better habitat than nonhub forest for at least some species of conservation concern. Forest bird richness and abundance were highest in undisturbed, mature broadleaf forest with wetlands and streams nearby. We detected a significant relationship between forest bird richness and the cell-based ecological score, which combines landscape and site-scale GIS data. This field study also validated the RFA protocol developed to assess conditions on the ground. Forest bird richness and abundance were positively correlated with the RFA community scores and ratings. This study suggests improvements in both the landscape and field assessment procedures used for GI analyses in addition to the need for regularly updating the GI maps to reflect recent changes in land cover.

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