Identifying Management Actions on DoD Installations

to Reverse Declines in Neotropical Birds

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Summary

This report investigates the utility of the National Land Cover Classification (NLCC) in predicting of the numbers of adults and young for nine bird species banded at six MAPS stations operating between 1994 and 1999 on Jefferson Proving Ground in Indiana. We also identify other types of land coverage data available for 16 U.S. Department of Defense (DoD) installations and discuss aspects of measuring the pattern and structure of these variously scaled landscape coverages in the context of species-habitat relationships. We conclude that patterns of landscape structure detected within a four-kilometer radius area of each station are good predictors of not only the numbers of birds captured, but also more importantly, their productivity levels.

We found that the numbers of adults, the numbers of young and also the ratio of young to adults increases as a function of mean woodland/forest patch size for ovenbird (*Seiurus aurocapillis*), acadian flycatcher (*Empidonax virescens*), wood thrush (*Hylocichla mustelina*), and Kentucky warbler (*Oporornis formosus*). Although these species are known to be more or less dependent upon forest interior for successful breeding, this study provides quantitative estimates of the mean woodland/forest patch size required to maximize productivity levels. Conversely, for five species normally associated with woodland/forest edge or successional habitat , northern cardinal (*Cardinalis cardinalis*), gray catbird (*Dumatella carolinensis*), white-eyed vireo (*Vireo griseus*), indigo bunting (*Passerina cyanea*), and common yellowthroat (*Geothlypis trichas*), the numbers of adults captured were highly positively correlated with the amount of woodland/forest edge in the surrounding landscape. The numbers of young of these species correlated with either the amount of edge or with other metrics such as the amount of development, the mean distance between woodland/forest patches, or the amount of successional habitat.

Most importantly, this study revealed the existence of threshold values of woodland/forest patch size above which productivity levels for four forest-interior species were maximal. This gives us insight into possible land management strategies to reverse avian population declines at the local scale by increasing their levels of productivity. For landscapes in which we know that population levels of these area-sensitive species are declining and mean

woodland/forest patch size is below these threshold levels, management actions can be taken to raise the mean patch size (i.e., by closing gaps between existing adjacent woodland/forest patches). Equally importantly, species-specific thresholds of landscape metrics can be considered in the design of forest harvesting regimes, thereby avoiding reducing productivity levels and causing local population declines.

We also intend to explore other ecological issues of management importance at a variety of spatial scales. Using detailed land use coverages of the installations provided by state or federal agencies, we can accurately measure the landscape pattern and structure at the spatial scale of the monitoring station (8-20 hectares). Although some of these land use coverages lack information on the vertical structure of the habitat, the MAPS protocol provides an assessment of the structure of the habitat(s) within the boundaries of each monitoring station (Nott et al. 2000). We hope to be able to relate these measurements to species' presence, the relative abundance of resident individuals, and productivity. This may help managers distinguish between local landscape patterns that provide source habitat for a target species and those patterns that provide sink habitat. In this way, management can utilize spatially-explicit population models to help provide suitable habitat for a suite of species and thereby maintain avian diversity and abundance on military lands.

This study shows that the MAPS protocol has great potential for both monitoring the response of bird species to landscape change, and providing data that can be used to construct landscape-level avian population or community models. These models can be used to assess the effects of proposed land management scenarios designed to restore, maintain or harvest natural resources that provide breeding habitat for a suite of neotropical landbird species.

Introduction

The Legacy Resource Management Program was established by the Congress of the United States in 1991 to provide the Department of Defense (DoD) with an opportunity to enhance the management of stewardship resources on more than 25 million acres of land under DoD jurisdiction. Since 1992, with Legacy funding, The Institute for Bird Populations (IBP) has established 78 avian monitoring stations on 20 DoD installations as part of their continent-wide Monitoring Avian Productivity and Survivorship (MAPS) program. This program represents a cooperative effort among public agencies, private organizations, and individual bird banders in North America to operate a network of over 500 constant-effort mist netting and banding stations during the breeding season.

Here we report some of the findings of the first year of a three-year project aimed at identifying management actions on Department of Defense (DoD) installations to reverse the declines of neotropical migratory birds. We gathered spatially explicit habitat data (from national datasets and local DoD sources), and historical weather data from a continent-wide network of meteorological monitoring stations, to construct a geographic information system (GIS). This system will allow us to correct for spatial variation in the effects of large-scale weather and climate and identify the landscape-level habitat characteristics associated with both low and high productivity and low and high survival rates for each target species. Using this system, we can identify generalized management strategies for altering habitat characteristics from those associated with low productivity (or low survivorship) for the target species to those associated with high productivity (or high survivorship).

In order to validate this approach, we conducted a preliminary investigation of the relationship between landscape structure and age-specific captures of nine species most commonly captured at MAPS stations on Jefferson Proving Ground in Indiana. We intend to develop these techniques to provide spatially-explicit population models that aid in the formulation and implementation of management scenarios designed to restore, maintain or harvest natural resources that provide breeding habitat for a suite of neotropical bird species.

Landscape coverage data for DoD installations

Land managers and GIS specialists of each of 14 DoD installations in the eastern and central United States provided land use/land cover (LULC) data. In general these coverages are delimited by the boundaries of each installation and contain detailed information such as the relative densities of different tree species, the mean canopy height, or forest stand age. Although the information provided by the classifications used in continent-wide or state coverages such as the National Land Cover Classification (NLCC) project (Bara 1994) or Gap Analysis Project (GAP) lack such detail, they do cover those areas within and adjacent to military installations. Land use on these adjacent lands can influence the dynamics of avian populations breeding on the DoD installations. For instance, intensive cattle grazing around an installation might attract cowbirds to breeding habitat within the installation. Where no direct correlates exist between the two types of datasets, local LULC cover classifications can be grouped to match those classifications defined in the regional NLCC (Table 1) or GAP databases describing the areas surrounding the installations. In this way it will be possible to assess the accuracy of the regional coverages. The MAPS program also conducts a habitat assessment within the boundaries of its monitoring stations, which in conjunction with GPS data, provides a further source of ground-truthing of these coverage databases. A summary of the landscape coverages available for each of 16 installations is provided (Appendix 1:Table A) in the details of a tour of 14 of these installations conducted in 1999 and 2000.

Table 1. National Land Cover Classification (NLCC) System Key – (Rev. July 20, 1999)

Code	Classification	Code	Classification
Water		***Shrubland***	
11	Open Water	51	Shrubland
12	Perennial Ice/Snow	***Non-natural Woody***	
Developed		61	Orchards/Vineyards/Other
21	Low Intensity Residential	***Herbaceous Upland***	
22	High Intensity Residential	71	Grasslands/Herbaceous
23	Commercial/Industrial/Transportation	***Herbaceous Planted/Cultivated***	
Barren		81	Pasture/Hay
31	Bare Rock/Sand/Clay	82	Row Crops
32	Quarries/Strip Mines/Gravel Pits	83	Small Grains
33	Transitional	84	Fallow
Forested Upland		85	Urban/Recreational Grasses
41	Deciduous Forest	***Wetlands***	
42	Evergreen Forest	91	Woody Wetlands
43	Mixed Forest	92	Emergent Herbaceous Wetlands

Identifying useful landscape level metrics

The Institute for Bird Populations secured a software grant through Environmental Systems Research Institute (ESRI) Incorporated and acquired ArcView GIS, Spatial Analyst, and Image Analysis software packages. This allows multiple source, scale and type of GIS coverages to be merged and analyzed. In addition, Patch Analyst (Elkie et al. 1999), based on the older Fragstats software (McGarigal and Marks, 1994), is incorporated into this software suite. Patch Analyst calculates 25 landscape metrics associated with raster-based coverages (grid themes) and 21 metrics associated with vector-based coverages (shape themes). These metrics are listed in Table 2.

Table 2. Categorized landscape pattern and structure statistics provided by Patch Analyst (McGarigal and Marks, 1994). Abbreviations and descriptions of the metrics are also provided.

Spatial statistic	Abbreviation	Brief description
Area Metrics		
Class area	CA	Total area of a cover type
Total landscape area	TLA	Total area of landscape
Patch Density & Size		
No of patches	NumP	Number of cover type patches
Mean patch size	MPS	Mean area of patches
Median patch size	MedPS	Median area of patches
Patch size CV	PSCoV	Coefficient of variation of patch areas
Patch size standard deviation	PSSD	Standard deviation of patch areas
Edge Metrics		
Total edge	TE	Sum of perimeters of patches
Edge density	ED	Amount of edge relative to TLA
Mean patch edge	MPE	Mean of perimeters of patches
Shape Metrics		
Mean shape index	MSI	Index of shape complexity
Area-weighted MSI	AWMSI	MSI weighted by total area
Mean perimeter-area ratio	MPAR	Simple index of shape complexity
Mean patch fractal dimension	MPFD	Fractal dimension of patch shapes
Area-weighted MPFD	AWMPFD	MPFD weighted by patch area
Diversity & Interspersion Metrics		
Mean nearest neighbor distance	MNN	Measure of patch isolation
Mean proximity index	MPI	Degree of isolation/fragmentation
Interspersion juxtaposition index	IJI	Measure of patch adjacency
Shannon’s diversity index	SDI	Measure of relative class diversity
Shannon’s evenness index	SEI	Patch distribution and abundance
Core Area Metrics		
Total core area	TCA	Total area of core areas
Mean core area	MCA	Average size of core patches
Core area standard deviation	CASD	Standard deviation of core areas
Core area density	CAD	Relative distribution of core areas
Total core area index	TCAI	TCA weighted by total area

Potential species-specific relationships with landscape pattern and structure

Measurements of landscape pattern and structure may provide determinants of the presence/absence or abundance of a species. Individual organisms may respond to threshold values of one or more of the landscape pattern and structure metrics for single or multiple classes of patch (cover types). Let us consider a species that requires a minimum area of interior forest in which to nest. We may find that nesting densities of this species across a landscape to be a multivariate function of the number of patches in a given area, their shape and the amount of core area (patch area minus a buffer zone) they contain. Other species may forage on the edges of forest and scrub, in which case the values of edge metrics may be important. A species may inhabit one particular habitat type and avoid crossing gaps of other habitat types; the distribution of these gaps across the landscape is indicated by the mean nearest neighbor metric. Conversely, a species may nest in one habitat type but forage in another adjacent habitat type. The first step in identifying management actions that can potentially reverse declines in bird populations is to establish relationships between species-specific productivity indices (or adult survivorship estimates) obtained from analysis of MAPS data and the aforementioned landscape pattern and structure metrics.

Many landscape-level studies have demonstrated the effects of landscape structure and habitat coverage on avian populations and communities at a variety of spatial scales from 1km^2 up to 625km^2 (Askins and Philbrick 1987, van Dorp and Opdam 1987, Villard et al. 1999, Drolet et al. 1999). The choice of an appropriate spatial resolution is crucial (Wiens et al. 1987), and may be determined by the territorial (nesting and/or foraging) or dispersal behavior of target species (Pearson 1993, Addicot et al. 1987). In this study we assume that the constant effort mist-netting protocol adopted by MAPS (DeSante et al. 1995, 1998, 1999, 2000) effectively samples numbers of both local breeders and, later in the season, dispersing young and adults from the surrounding area (e.g., 4-kilometer radius).

Landscape level determinants of avian productivity at Jefferson Proving Ground

In this study we investigated the relationships between species-specific productivity levels, derived from the numbers of individual adults and young captured during 3600 hours of mist-netting effort (1994-1999), and the values of landscape metrics associated with a 4km radius area surrounding each MAPS station (Figure 1). The results are consistent with expected habitat preferences for the nine species included in the study. Generally, productivity and abundance of four forest interior species correlated positively with landscape metrics indicative of high forest cover, while numbers of scrub or forest-edge preferring species correlated positively with the amount of forest and woodland edge in the landscape. Notwithstanding the simple regression analyses conducted in this study, we report quantitative relationships that not only provide specific land management information for Jefferson Proving Ground, but can also be used to assess the potential avian conservation value of military lands to these species.

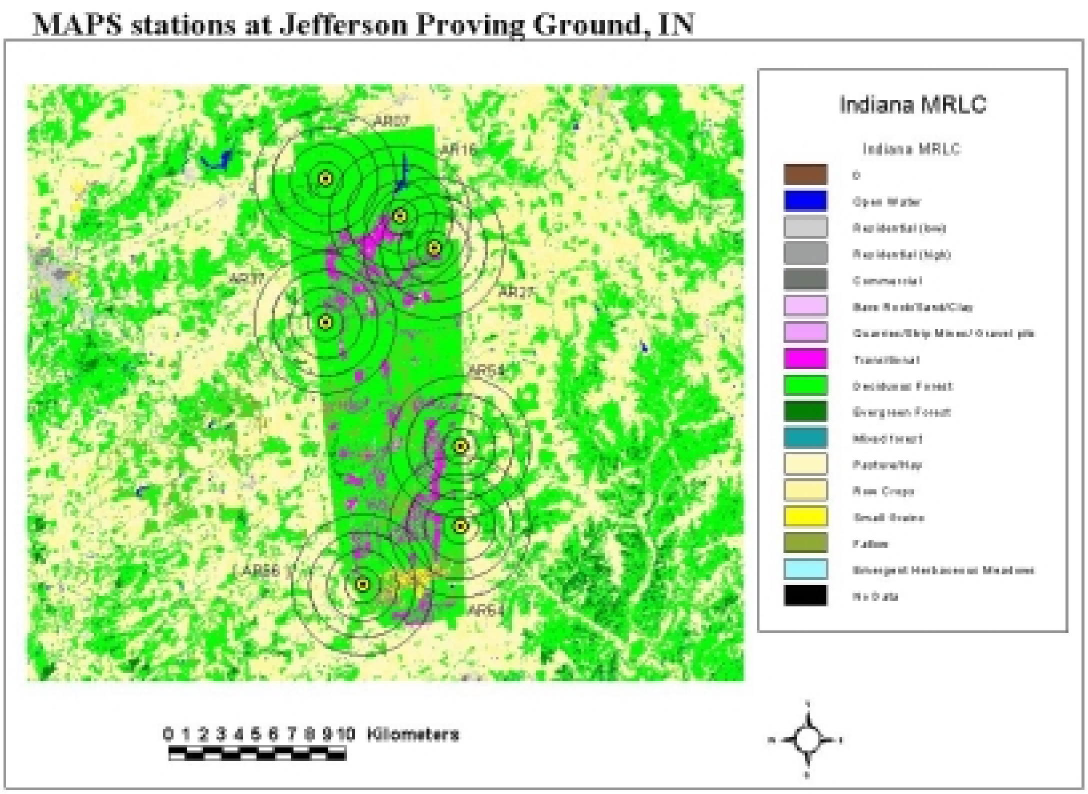

Figure 1. National Land Cover Classification (NLCC) map of the area within and surrounding Jefferson Proving Ground, Indiana. The locations of seven Monitoring Avian Productivity and Survivorship (yellow bulls-eyes) stations are shown surrounded by one to four kilometer radii. Five stations operated each breeding season since 1994. Station AR66 (in brackets) closed in 1995 to be replaced by station AR64 (adjacent to AR66) in 1996.

Methods

The MAPS constant-effort mist netting protocol recommends that at each station ten 12m mist nets are located within the central 8 hectares of a 20 hectare study plot and are operated for six hours following sunrise. Each station is visited on one day within sequential ten-day periods throughout the breeding season (May to August) up to a maximum of 10 periods (equivalent to 600 hours mist-netting per year). All birds caught are banded, aged, sexed and released. Annual numbers of adult and young captures are expressed relative to 600 hours mist-netting per year, which over six years (1994-1999) represents 3600 net hours.

The following steps were followed to establish the relationships between bird captures and landscape metrics describing 4-kilometer radii areas (30m resolution over a 50 km^2 area) surrounding MAPS stations at Jefferson Proving Ground, Indiana:

1. We plotted locations of six MAPS stations on the Indiana NLCC land coverage map.
2. We defined 4-kilometer radius areas around each of six MAPS station locations (a map of these areas is shown in Figure 1). We analyzed the structure and pattern of each cover type within these areas using Arcview (Environmental Systems Research Institute 1996) and Patch Analyst, version 2.2 (Elkie et al. 1999). The results are shown in Table 3.
3. We counted the number of adult and young captures (pooled across 1994-1999) of nine bird species. We adjusted these counts to individuals caught per 3600 net hours because actual total hours of operation varied from station to station because of inclement weather and unforeseen circumstances (e.g., Area 64 only operated for 4 of 6 years, so numbers of adults and young were multiplied by 1.5). See Table 4.

Table 3. Values of selected landscape metrics for six MAPS stations located at Jefferson Proving Ground, IN. Percentage cover of six metrics are: WOFOCOV%: Woodland/Forest, CROP/GRASS%: crops and grassland, TRAN%: transitional habitat, ME/WW%: meadow and wet woodland, DEVEL%: developed land, WATER%: standing water. Other metrics reported are: SDI: Shannon's diversity of coverage types, and SEI: Shannon's evenness of coverage types, WMPS: mean deciduous forest/woodland patch size (ha), WOFOEDGE: Woodland/forested edge (m/ha), WOFOMNN: Woodland/Forest mean nearest neighbour distance.

			STATION					
Metric	Type	Units	AR64	AR27	AR54	AR31	AR16	AR07
WOFOCOV%	Cover	%	54.08	60.66	61.21	65.5	77.91	89.17
CROP/GRASS%	Cover	%	30.08	26.34	26.03	23.9	8.69	6.22
TRAN%	Cover	%	8.95	9.95	9.05	9.26	10.72	3.3
ME/WW%	Cover	%	5.02	2.57	3.44	1.14	1.37	1.21
DEVEL%	Cover	%	1.73	0.19	0.23	0.19	0.23	0.03
WATER%	Cover	%	0.14	0.29	0.04	0.01	1.08	0.07
SDI	Diversity		1.48	1.23	1.22	1.14	0.88	0.6
SEI	Evenness		0.58	0.51	0.51	0.49	0.37	0.27
WMPS	Patch size	(ha)	12.31	21.32	18.15	18.54	39.17	82.45
WOFOEDGE	Edge	(m/ha)	115.91	77.35	101.27	94.25	65.62	66.08
WOFOMNN	Neighbor	(m)	40.36	55.63	44.63	44.3	48.06	45.51

Table 4. The numbers of individual adults (Adults) and young birds (Young) for nine species (four forest-interior species and five edge/successional species), captured at six MAPS stations on Jefferson Proving Ground, Indiana. Numbers of birds are corrected to represent expected numbers of captures from 600 hours annual effort (1994-1999). Species codes (Code) are provided by the Bird Banding Laboratory, Patuxent, Maryland.

			STATION					
Species	Code	Age	AR64	AR27	AR54	AR31	AR16	AR07
Forest interior species								
Ovenbird	OVEN	Adults	16.55	39.86	32.35	7.23	35.88	90.39
Seiurus aurocapillis		Young	0.00	6.39	0.00	0.00	17.76	31.10
Acadian Flycatcher	ACFL	Adults	4.13	25.24	13.03	17.00	50.69	97.42
Empidonax virescens		Young	0.00	0.00	1.26	0.00	6.55	13.69
Wood Thrush	WOTH	Adults	24.35	61.54	38.21	14.16	49.33	94.15
Hylocichla mustelina		Young	5.48	9.36	16.09	1.26	22.93	30.32
Kentucky Warbler	KEWA	Adults	24.66	62.23	23.01	25.04	61.87	92.09
Oporornis formosus		Young	3.96	11.79	10.09	8.22	41.91	31.03
Edge/Successional species								
Northern Cardinal	NOCA	Adults	49.11	25.54	20.90	34.49	24.45	16.00
Cardinalis cardinalis		Young	12.38	1.09	3.41	8.75	3.58	6.12
Gray Catbird	GRCA	Adults	108.11	14.89	103.74	40.03	9.41	19.34
Dumatella carolinensis		Young	33.18	1.25	10.07	4.61	0.00	2.02
White-eyed Vireo	WEVI	Adults	80.33	6.54	76.45	42.54	3.12	6.06
Vireo griseus		Young	13.19	1.25	6.07	16.05	1.05	0.00
Indigo Bunting	INBU	Adults	86.70	40.34	17.44	59.56	2.53	4.34
Passerina cyanea		Young	2.04	2.19	1.26	1.39	3.82	0.00
Common Yellowthroat	COYE	Adults	137.72	5.68	94.94	56.96	16.70	0.00
Geothlypis trichas		Young	34.64	8.90	16.70	13.02	0.00	1.29

4. We correlated numbers of adults and young caught at each station with values of landscape metrics for those stations and identified the relationships with the highest correlation coefficients (i.e., those landscape metrics that explained most of the variation in the abundance data). We fitted log-linear regression models to each relationship and reported the correlation coefficient and the probability associated with them (Table 5).
5. For the four forest dependent species we plotted the relationship between the numbers of individual adults and young captured against deciduous woodland/forest patch size (Figure 2A). This metric provided the most powerful determinant of the number of captures of both adults and young in all cases except for that of Kentucky warbler young. However, the correlation between the number of Kentucky warbler young and deciduous woodland/forest patch size was still high and significant (r=0.71, P<0.05).

Table 5. Landscape level determinants of the number of adult and young individual birds of nine species (four forest interior species and five edge/successional species) caught between 1994 and 1999 at six MAPS stations located on Jefferson Proving Ground, Indiana. R-values are given for the strongest correlation along with the probability levels associated with linear regressions of the numbers of birds against the corresponding landscape metric (P<0.10 given in italics). WMPS: mean deciduous forest patch size (ha), CROP/GRASS%: percentage cover of crops and grassland, DEVEL%: percentage cover of developed land, WOFOEDGE: woodland/forested edge (m/ha), WOFOMNN: Woodland/Forest mean nearest neighbour distance, TRAN%: percentage cover of transitional habitat.

	ADULTS			YOUNG		
SPECIES	METRIC	*r*	*P*-value	METRIC	*r*	*P*-value
Forest interior species						
Ovenbird	WMPS	0.92	<0.01	WMPS	0.97	<0.01
Acadian Flycatcher	WMPS	0.99	<0.001	WMPS	0.98	<0.001
Wood Thrush	WMPS	0.86	<0.05	WMPS	0.86	<0.05
Kentucky Warbler	WMPS	0.88	<0.05	CROP/GRASS%	-0.94	<0.01
Edge/successional species						
Northern Cardinal	DEVEL%	0.88	<0.05	WOFOMNN	-0.84	<0.05
Gray Catbird	WOFOEDGE	0.92	<0.01	DEVEL%	0.96	<0.005
White-eyed Vireo	WOFOEDGE	0.96	<0.005	WOFOEDGE	0.80	*<0.10*
Indigo Bunting	WOFOEDGE	0.79	*<0.10*	TRAN%	0.83	<0.05
Common Yellowthroat	WOFOEDGE	0.96	<0.005	WOFOEDGE	0.96	<0.005

Using these data two further steps were taken to establish quantitative relationships between productivity for each of the four forest-interior species and mean woodland/forest patch size:

6. To establish the relationships between species-specific productivity and deciduous woodland/forest patch size we calculated the ratio of young to adults at regular intervals along the fitted lines. The resulting plots are shown in Figure 2B. This method was utilized to circumvent the problems associated with using the raw data; for example dividing a finite number of young by zero adults would result in a reproductive index of infinity. Low capture rates may also bias the reproductive indices calculated from the raw data; if by chance only one adult and two young were caught a reproductive index of 2.0 would result. Future research may identify or develop more sophisticated methods to deal with this problem.
7. To compare tolerances to mean patch size across species we identified the 45 degree inflexion points in each of the productivity plots and the corresponding mean patch size associated with each inflexion point.

Results

For all nine species, high and significant levels of correlation were apparent between the numbers of adults or young captured and one or more landscape metrics calculated for a four kilometer radius area surrounding the MAPS stations. Not surprisingly, the amount and pattern of woodland/forest best explained the abundance of both adults and young of the four forest-interior species but other metrics such as the amount of woodland/forest edge best explained the abundance of the five edge/successional species. These relationships are described in detail below.

Forest-interior species

Overall, the forest-interior species, ovenbird, acadian flycatcher, wood thrush, and Kentucky warbler showed a strongly significant positive relationship ($P<0.05$) between the number of adult individuals captured and mean deciduous woodland/forest patch size (WMPS). This same relationship held for numbers of young in each these four species, except that numbers of young Kentucky warblers were most highly correlated (but negatively) with the percentage cover of crop/grassland (CROP/GRAS%). However, to allow comparisons to be made between adults and young, we used the WMPS metric that also significantly and positively correlated with the number of Kentucky warbler young ($r=0.71$, $P<0.05$). The top four panes (A) of Figure 2 show the data points and fitted relationships (linear-log regressions) for numbers of adults and young captured among the four species that normally breed in the forest or woodland interior.

The lower four panes (B) of Figure 2 show, for each species, a positive asymptotic relationship between productivity levels and mean woodland/forest patch size. These results are similar to those presented by other studies of "forest-interior species" habitat relationships (review by Villard 2000), in which for example, the reproductive success of ovenbirds increases with forest patch size (e.g., Porneluzi et al. 1993). Of the four species, ovenbird shows the strongest dependence upon contiguous forest with a mean patch size of around 30 ha., compared to 20 ha. for the other three species. Again, this result is supported by the literature (Yahner 1993). Burke and Noll (1998) reported that the minimum forest patch size necessary to hold high-quality ovenbird habitat was 80-hectares with a 20-hectare core area. For ovenbirds (and acadian flycatchers) the positive relationship between numbers of adult captures and deciduous woodland patch size is well documented (Gibbs and Faaborg 1990). They, and also Villard (1993), found higher proportions of paired ovenbirds in contiguous forest than in isolated fragments suggesting that breeding success would be higher in areas where woodland/forest patches are larger and less fragmented. Gibbs and Faaborg (1990) suggest that the ovenbird’s dependence upon forest-interior may be driven by a requirement for moisture-dependent ground-dwelling arthropods that are less abundant closer to the drier forest edges. In this study, young ovenbirds were only caught at the three (of the six) stations where the percentage cover and mean deciduous woodland patch size were greatest (>20ha). For wood thrush, we would also expect increasing adult abundance with patch size (Galli et al. 1976, and Lynch 1987), and increasing nest success with patch size (Hoover 1992). Similar relationships have been shown for Kentucky Warbler (e.g., Whitcomb et al. 1981).

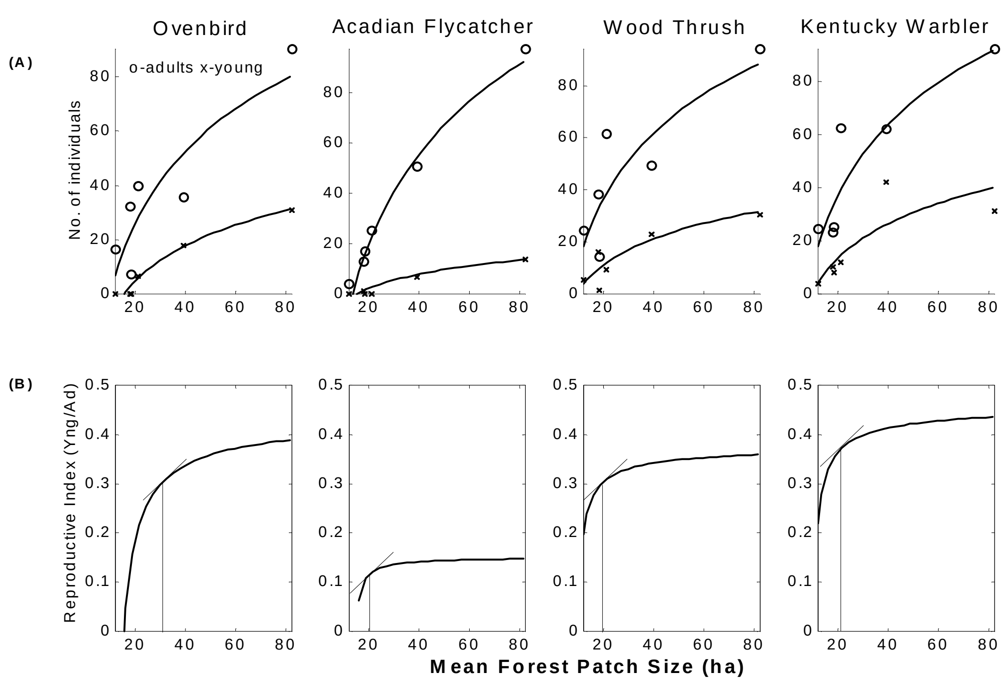

Figure 2. (A) Numbers of individual adult (o) and young (x) birds of four forest interior species captured per 3600 net-hours at six MAPS stations operated during 1994-1999 on Jefferson Proving Ground, Indiana, as a function of mean forest patch size in the 4-kilometer radius area surrounding each station. (B) Relationship between reproductive index (young/adult) and mean forest patch size at Jefferson Proving Ground for these four species (obtained from the linear-log regressions shown in A).

This study confirms that both the productivity and the numbers of adult and young ovenbirds and acadian flycatchers captured are dependent on deciduous woodland patch size. Kentucky warblers and wood thrushes are reported to be more tolerant to forest fragmentation on breeding grounds than some other warbler species (Gibbs and Faaborg 1990, Whitcomb et al. 1981). Correspondingly, we showed that the levels of correlation for these two species are lower than those for the acadian flycatcher and ovenbird. Interestingly, the numbers of young Kentucky warblers are best correlated inversely with the amount of crop and grassland present in the landscape, and positively with the amount of woodland/forest edge (per hectare). This may reflect the fact that this species is a frequent host for brown-headed cowbird (*Molothrus ater*) parasitism, the levels of which increase as a function of both the degree of fragmentation and proximity to forest edge (Donovan et al. 1997). Hawrot and Neimi (1996) describe how different relationships between these two metrics can be used to define the type of edge that dominates the landscape, and to which species' may differentially respond.

Edge/successional species

The northern cardinal is a common garden bird and in this study the numbers of adults were positively associated with development, but the numbers of young negatively correlated with the mean gap size between woodland/forest patches (Table 5). This suggests that cardinals are found in greater numbers in developed areas but that good breeding habitat would include forested patches with narrow gaps between them.

The remaining four species, recognized as edge or scrub species, show a strongly increasing relationship between adult captures and the amount of woodland/forested edge (Table 5). Not surprisingly, high numbers of both adult and young white-eyed vireos and common yellowthroats are associated with landscapes in which the amount of woodland/forested edge is high. Gray catbirds appear to prefer woodland/forested edges but are more productive in areas with some development (DEVEL%) where they are commonly observed. Indigo bunting adults are also more numerous in landscapes with lots of woodland/forested edge but more young are detected in landscapes with higher proportions of transitional land (this category includes old field, regenerating forest, and shrubland).

Discussion

The American Bird Conservancy designated Jefferson Proving Ground a Globally Important Bird Area in 1998 to help protect a population of Henslow's sparrow (*Ammodramus henslowii*) that inhabits some grasslands within the boundaries of the installation. It is, important to note, however, that Jefferson Proving Ground, like so many DoD installations in eastern and central North America, also represents a considerable acreage of contiguous woodland and forest in an otherwise developed or agricultural landscape (Figure 1). The potential of these installations to provide breeding habitat for populations of neotropical migratory birds, especially for those area-sensitive or edge avoiding species that are dependent upon large patches of woodland or forest, is illustrated in this study. Villard (2000), however, reviewed area sensitivity and edge avoidance issues for several landbird species and cautioned against widespread application of oversimplified landscape analyses to management problems. He also argued for careful consideration of the role of small habitat fragments in metapopulation dynamics as refugia for non-breeding individuals, and further argued against focusing conservation efforts on single species.

The results of this study suggest that analysis of MAPS data in combination with landscape coverage data can provide a useful method for identifying multiple species-habitat relationships. The MAPS protocol has several advantages over other methods of collecting demographic data for this purpose. First, analysis of banding data allows for direct estimation of survival, recruitment, and the annual population growth rate (lambda). Second, it represents a standardized protocol that is applied continent-wide to determine the presence/absence and breeding status of many species in the avian community associated with each station. Third, it provides estimates of adult abundance, and using appropriate mark-recapture models, estimates of species-specific proportions of resident adult individuals (DeSante et al. 1995, Nott and DeSante in press, Pradel 1996, Pradel et al. 1997). Fourth, this study suggests that reproductive indices derived from constant-effort banding data represent a reliable relative measure of species-specific breeding success across the landscape surrounding the monitoring sites. It is also important to note that other methods of obtaining breeding densities and measures of reproductive success (e.g., using spatially-extensive spot mapping in conjunction with nest monitoring protocols) require considerably more effort.

Combined analysis of MAPS and landscape data will provide spatially-explicit population models to allow installation managers (and other land managers) to formulate and implement management actions and conservation plans. These efforts are primarily intended to reverse the observed declines in avian populations on military installations (and elsewhere) while allowing the installations to continue to serve their military mission. However, spatially-explicit population models of this sort can also be used to help maintain avian populations and assess the effects of proposed land use changes (e.g., timber harvesting regimes or new construction) on landbird populations.

Conclusion

Combining demographic data and landscape coverage data allowed us to model productivity and abundance as a function of mean woodland/forest patch size for four forest-interior species experiencing widespread population declines. Both the productivity levels and numbers of captures of these species clearly reflect the landscape pattern and structure within 4-kilometer radius areas of the MAPS stations located on Jefferson Proving Ground. Moreover, these relationships revealed species-specific threshold values above which productivity was high. This in itself provides valuable information for land managers. We are encouraged by the clarity of these results and hope to replicate these kinds of relationships for other installations. However, we emphasize that this is a preliminary study and we need to further investigate the relationships described here. For instance, this study used a simplistic approach by identifying a single dominant landscape determinant of the numbers of adults and young. With more data points it will be possible to apply multiple regression, PCA or other techniques to explain more of the spatial variance in population and productivity levels (sensu Hawrot and Niemi 1996).

We also intend to explore other ecological issues of management importance at a variety of spatial scales. Using detailed land use coverages of the installations provided by state or federal agencies, we can accurately measure the landscape pattern and structure at the spatial scale of the monitoring station (perhaps 250m radii). Although some of these land use coverages lack information on the vertical structure of the habitat, the MAPS protocol provides an assessment of the structure of the habitat(s) within the boundaries of each monitoring station (Nott 2000). We hope to be able to relate these measurements to species' presence, the relative abundance of resident individuals, and productivity. This may help managers distinguish between local landscape patterns that provide source habitat for a target species and those patterns that provide sink habitat. In this way, management can utilize spatially-explicit population models to help provide suitable habitat for a suite of species and thereby maintain avian diversity and abundance on military lands.

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Appendix 1: Tour of DoD installations operating MAPS stations

A total of 14 of the 16 major Department of Defense (DoD) installations within the eastern and central United States upon which MAPS avian monitoring stations are operated were visited in the months of July 1999 and June 2000. Natural resource management staff of each installation were either met in person or otherwise contacted in order to:

a) schedule (or obtain) the precise locations (using geographic positioning systems {GPS}) of MAPS stations,
b) obtain GIS coverage data (or other maps) and historical habitat management data for each installation, and
c) discuss wildlife conservation plans and current land management practices pertaining to the individual installations.

The status of GIS coverage data for these installations is shown in Table A. Regional GIS based land use/land cover (LULC) data are available for all 16 installations. Most of these coverages are provided by the National Land Cover Data (NLCD), specifically by the 30m resolution Multi-Resolution Land Characterization (MRLC) Consortium (Bara 1994). This is a partnership including the United States Geological Survey, Environmental Protection Agency, the United States Forest Service, and the National Oceanic and Atmospheric Administration. These data are publicly available as the National Land Cover Classification (NLCC) dataset covering the contiguous 48 United States.

Local GIS datasets were also obtained that covered the entire extent of most DoD installations. These datasets exist mainly as vector coverages (shapefiles) that define the extent of discrete patches of land cover types. In many cases these datasets include database information describing conservation areas, age and type of forested stands, developed areas, and recreational areas. Other layers describe topography, roads, fencelines, streams and rivers. Copies of all these coverages now reside on storage medium associated with The Institute for Bird Population’s geographic information system (MAPSGIS).

Table A. Summary of status (to June 2000) of geographic information pertaining to U.S. Department of Defense installations upon which Monitoring Avian Productivity and Survivorship (MAPS) are located. This information includes the name of the installation, and the month within which each installation was visited. The identity of the regional land use/land cover (LULC) database(s) incorporating the installation is identified. The existence and type of local LULC coverage is also indicated.

Installation	State	Visit	LULC #1	LULC #2	Local LULC
Patuxent River Naval Air Warfare Station	MD	07/1999	MD-NLCC	n/a	Stand-specific shapefile
Indian Head Naval Surface Warfare Center	MD	07/1999	MD-NLCC	VA-NLCC	none
Dahlgren Naval Surface Warfare Center	VA	07/1999	VA-NLCC	MD-NLCC	Stand-specific shapefile
Fort Belvoir	VA	07/1999	VA-NLCC	MD-NLCC	Stand-specific shapefile
Fort A.P. Hill	VA	07/1999	VA-NLCC		Stand-specific shapefile
Oceana Naval Air Station	VA		VA-NLCC	NC-NLCC	
Fort Bragg	NC		NC-NLCC	n/a	
Jefferson Proving Ground	IN	07/1999	IN-NLCC	n/a	Stand-specific shapefile
Crane Naval Weapons Support Center	IN	07/1999	IN-NLCC	n/a	Stand-specific shapefile
Fort Knox	KY	07/1999	KY-NLCC	IN-NLCC	none
Fort Leavenworth	KS	07/1999	KS-NLCC	MO-NLCC	none
Fort Riley	KS	07/1999	KS-NLCC	n/a	none
Fort Leonard Wood	MO	07/1999	MO-NLCC	n/a	Stand-specific shapefile
Fort Hood	TX	06/2000	TX-NLCC	n/a	Stand-specific shapefile
Camp Bowie	TX	06/2000	TX-NLCC	n/a	Stand-specific shapefile
Camp Swift	TX	06/2000	TX-NLCC	n/a	Stand-specific shapefile