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SPECIAL FEATURE: SCIENCE FOR OUR NATIONAL PARKS' SECOND CENTURY

Using regional bird community dynamics to evaluate ecological integrity within national parks

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Abstract. Understanding how biological communities respond to global change is important for the conservation of functioning ecosystems as anthropogenic environmental threats increase. National parks within the United States provide unique ecological and cultural resources that can help conserve biodiversity and maintain ecological integrity, especially in heavily urbanized environments. Parks within the National Capital Region (NCRN) and Mid-Atlantic (MIDN) Networks, representing federally protected areas located within a mixed landscape of rural to urban areas, have been monitoring forest and grassland birds annually to evaluate long-term trends in bird community dynamics. Given increasing rates of decline in forest- and grassland-breeding songbirds in North America, understanding community-level trends in parks will help their preservation for future generations. We used point count data collected between 2007 and 2015 from 640 sampling locations to calculate a bird community index (BCI) to infer relative estimates of ecological integrity. Our objectives were to (1) quantify BCI in 17 national parks in the mid-Atlantic region, (2) test for relationships between BCI and the proportion of forest and developed land cover types, (3) assess temporal variation in BCI, and (4) additionally test for differences in estimates of species detection probability between volunteer citizen scientists and paid observers. Mean BCI scores and ecological integrity ranks among parks ranged between 33.5 (low integrity) and 58.3 (high integrity), while the majority of parks had BCI scores ranging between 40.1 and 52.0 (medium integrity). For both networks, we found that BCI was positively related to the extent of forest cover, and for NCRN, the more heavily urbanized network, we found that BCI was negatively related to developed land cover. Assessment of temporal changes in BCI within parks indicated that BCI was stable for 12 parks, increased in four parks, and decreased in one park within our study. Lastly, we detected no differences in species detection probability between citizen scientist- and paid observer-collected data which lends support for the future comparison of bird monitoring data in regional analyses across NPS I&M Networks. The continued evaluation of ecological integrity, through measuring bird community dynamics at regional scales, is important for conserving biological diversity.

Key words: bird community index; citizen science; ecological integrity; Inventory and Monitoring; National Park Service; Special Feature: Science for Our National Parks' Second Century.

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Introduction

To mitigate current and future negative anthropogenic effects on ecosystems, the conservation of biodiversity and maintenance of ecosystem function within our landscapes will be imperative. Over the past century, the National Park Service (NPS) has played an instrumental role in large-scale conservation of biodiversity throughout the United States by protecting and managing roughly 36 million hectares of land for public use (Gorte et al. 2012). The signing of the NPS Organic Act into law in 1916 by President Woodrow Wilson marked the beginning of an important era of ecological conservation (Everhart 1972). However, given increasing threats to biodiversity and ecosystems from human population growth, industrialization, and influences of the exponential growth of technology over the past 100 years (Cardinale et al. 2012, Hansen et al. 2014), the importance of the protection and monitoring of natural areas has become strikingly apparent (Roux and Kingsford 2015).

Long-term monitoring of ecological conditions within national parks enables the assessment of the fulfillment of NPS's mission to conserve both natural and cultural resources for future generations (Fancy et al. 2009), and can provide novel insights into predicting future responses of ecosystems to environmental change (Hansen et al. 2014). However, successful conservation programs informed by long-term monitoring must overcome inherent challenges. Despite known challenges related to the influence of climate change, habitat loss, and other anthropogenic factors on migratory species, both within and outside of national park boundaries (Berger et al. 2014), long-term monitoring at regional and global scales is beneficial for describing patterns and understanding processes involving complex ecological interactions. This information can then be used to promote the quality of life for humans (Lebuhn and Droege 2015, Schmeller and Julliard 2015). Suggestions for cultivating support of conserving ecosystems include efforts in capacity building, public outreach, and education, in addition to continued long-term monitoring and population and community assessment (Berger et al. 2014).

Trade-offs between intensity and cost of biological monitoring at large spatial scales (e.g., regional or global) have motivated the development of cost-effective monitoring techniques (Caughlan and Oakley 2001), including methods for rapid assessment of biodiversity across taxa (Noss 1990, Oliver and Beattie 1996, Carlson and Schmiegelow 2002), and community-based metrics (Karr 1981, Rice 2000, Hewitt et al. 2005). Monitoring of bird communities using point count methods (Ralph et al. 1995) has proven both a cost-effective and robust measure of ecological integrity due to the relative ease of observation and detection of birds, their spatial distributions, and their inherent sensitivity to environmental change (DeGraaf and Wentworth 1986, Canterbury et al. 2000, Powell et al. 2000). For example, within the past 50 years, over 40% of Neotropical migratory songbird species have declined (Sauer et al. 2012). Causes of these declines have been linked to a synergy of habitat loss and fragmentation (Burke and Nol 2000), urbanization (Suarez-Rubio et al. 2011), pollution (Condon and Cristol 2009), and climate change (Both et al. 2009). Moreover, birds which are particularly vulnerable to broad-scale changes in the amount, arrangement, and quality of habitat required for breeding, wintering, and migration periods make them an ideal taxonomic group for biological monitoring.

The development of region- and habitat-specific bird community indices (BCI), which are analytical tools that relate bird community composition with biotic integrity, has enabled the analysis of avian monitoring data through inferential assessment of community guild structure and diversity (O'Connell et al. 1998, 2000, Bryce et al. 2002). Beyond the direct evaluation of ecological integrity thresholds, BCI analyses can be used to measure changes in patterns of ecological integrity among discrete habitat patches and through time. For example, Goodwin and Shriver (2014) found greater ecological integrity within national parks than outside of park boundaries.

These findings support the use of BCI analyses to asses relative ecological integrity and its interannual variation within national parks.

Our primary goal for this study was generally to evaluate how land use factors influence bird community diversity within 17 national parks located within the mid-Atlantic region. We used avian monitoring data collected by paid professionals and citizen scientists to calculate BCI scores (O'Connell et al. 1998, 2000). We then tested for relationships of plot-level BCI scores to the proportion of forest and developed land cover types to evaluate linkages between land cover and bird community diversity within parks. To asses interannual variation in BCI, we tested for differences between paired annual cumulative distributions of BCI scores within 17 parks. Finally, we evaluated the effects of observer type (citizen scientists and paid observers) on species detection probability.

Methods

Study area

We conducted this research in 17 national parks within the National Capital Region (NCRN) and Mid-Atlantic (MIDN) Inventory and Monitoring (I&M) Networks (Table 1, Fig. 1). The NCRN consists of 11 national parks located within Washington DC, western Maryland, northern Virginia, and West Virginia that include Antietam National Battlefield Park (hereafter Antietam), Catoctin Mountain Park (hereafter Catoctin), Chesapeake and Ohio Canal National Historical Park (hereafter C&O Canal), George Washington Memorial Parkway (hereafter George Washington), Harpers Ferry National Historical Park (hereafter Harpers Ferry), Manassas National Battlefield Park (hereafter Manassas), Monocacy National Battlefield (hereafter Monocacy), National Capital Parks-East (hereafter National Capital Parks), Prince William Forest Park (hereafter Prince William), Rock Creek Park (hereafter Rock Creek), and Wolf Trap National Park for the Performing Arts (hereafter Wolf Trap) (Table 1). Within the MIDN, we sampled at Appomattox Court House National Historical Park (hereafter Appomattox), Booker T. Washington National Monument (hereafter Booker T.), Fredericksburg & Spotsylvania National Military Park (hereafter Fredericksburg), Petersburg National Battlefield (hereafter Petersburg), Richmond National Battlefield Park (hereafter Richmond), and Valley Forge National Historical Park (hereafter Valley Forge) located in Pennsylvania and Virginia (Table 1). Surveyed parks differed in area (ha) and proportion of forest and developed land cover within and surrounding the parks and are distributed across three major bird conservation regions: Appalachian Mountains (BCR 28), Piedmont (BCR 29), and New England/Mid-Atlantic Coast (BCR 30) as designated by the U.S. North American Bird Conservation Initiative Committee (2000) based on similar bird communities, habitats, and management issues (Table 1).

Data collection

We selected forest bird monitoring plots in NCRN (n = 431) parks and both forest and grassland bird monitoring plots in MIDN (n = 313) parks following a generalized random tessellation stratified (GRTS) design (Stevens and Olsen 2004) to produce a coverage for the region that is probabilistic and spatially balanced (Dawson and Efford 2006, Schmit et al. 2009). In 2014 and 2015, we surveyed 410 monitoring plots in the NCRN after the addition of 25 plots within Antietam, Monocacy, and Wolf Trap. Within MIDN parks, we selected 230 forest bird monitoring plots surveyed between 2009 and 2015 (Johnson 2014); however, not all MIDN parks collected data every year. For instance, data collection occurred in Petersburg in 2011 and 2012 only, Appomattox from 2010 to 2012, and in Richmond from 2010 to 2015 (see Table 2).

We visited monitoring locations twice each season to conduct fixed-radius circular-plot point count surveys (hereafter "point count") between 4 May and 27 July by observers trained on existing protocols for NCRN and MIDN between 20 mins before and 5 h after dawn. Observers were either paid field technicians (n = 24) for surveys in NCRN parks or citizen scientists (n = 67) in MIDN parks. All point counts were 10 mins in duration and were either divided into four 2.5-min (NCRN; Dawson and Efford 2006) or ten 1-min (MIDN; Johnson 2014) intervals depending on the network protocol. Observers recorded all individual birds for each species detected within a 0–50 m or a 0–100 m radius circle. Observers also recorded five detection covariates: temperature, humidity, wind, sky condition, and disturbance

Table 1. Respective names, four-letter alpha codes, states, coordinates (latitude and longitude), park unit areas (ha), and mean proportions of forest (For.) and developed (Dev.) land cover within 1-km buffer around bird monitoring locations for 17 national parks within the National Capital Region and Mid-Atlantic Inventory and Monitoring (I&M) Networks.

NPS I&M Network and park names	Alpha code	State	Latitude (North)	Longitude (West)	Park area (ha)	Proportion of land cover For.	Proportion of land cover Dev.
National Capital Region Network	NCRN						
Antietam National Battlefield Park†	ANTI	MD	39.474°	−77.745°	1315	0.24	0.08
Catoctin Mountain Park†	CATO	MD	39.653°	−77.464°	2490	0.91	0.06
Chesapeake and Ohio Canal National Historical Park†	CHOH	DC, MD, WV	39.601°	−77.827°	7788	0.54	0.10
George Washington Memorial Parkway§	GWMP	DC, MD, VA	38.844°	−77.0491°	3198	0.36	0.31
Harpers Ferry National Historical Park†	HAFE	MD, VA, WV	39.318°	−77.759°	965	0.77	0.09
Manassas National Battlefield Park§	MANA	VA	38.805°	−77.572°	2064	0.35	0.14
Monocacy National Battlefield§	MONO	MD	39.377°	−77.396°	667	0.22	0.15
National Capital Parks-East‡	NACE	DC	38.867°	−76.995°	4378	0.31	0.40
Prince William Forest Park§	PRWI	VA	38.585°	−77.380°	7518	0.88	0.08
Rock Creek Park§	ROCR	DC	38.967°	−77.046°	1100	0.42	0.55
Wolf Trap National Park for the Performing Arts§	WOTR	VA	38.933°	−77.266°	53	0.40	0.56
Mid-Atlantic Network	MIDN						
Appomattox Court House National Historical Park§	APCO	VA	37.379°	−78.796°	718	0.59	0.05
Booker T. Washington National Monument§	BOWA	VA	37.118°	−79.734°	97	0.61	0.05
Fredericksburg & Spotsylvania National Military Park§	FRSP	VA	38.290°	−77.530°	3440	0.71	0.09
Petersburg National Battlefield§	PETE	VA	37.244°	−77.357°	1100	0.67	0.09
Richmond National Battlefield Park§	RICH	VA	37.520°	−77.404°	930	0.47	0.09
Valley Forge National Historical Park§	VAFO	PA	40.086°	−75.452°	1403	0.35	0.09

Notes: Location of parks within Appalachian Mountains, New England/Mid-Atlantic Coastal, or Piedmont bird conservation regions (BCR) is indicated by the symbols †, ‡, and §.
† Appalachian Mountains.
‡ New England/Mid-Atlantic Coast.
§ Piedmont.

(such as ambient noise from traffic or aircraft). To compare data quality collected by citizen scientists (n = 16) and paid observers (n = 3), both citizen scientists and paid observers conducted point count surveys in Fredericksburg and Valley Forge at the same forest (n = 69) and grassland (n = 44) bird monitoring plots in 2015. All aspects of data collection were identical between network protocols except the difference in interval length (2.5 vs. 1 min) used by paid and citizen scientist observers, respectively, and the days on which monitoring locations were visited. While we did not expect a priori to find differences between observer types, based on results from previous studies (review in Lewandowski and Specht 2015), we felt it important to conduct this analysis to evaluate any potential observer-type bias that could arise in larger-scale regional analyses using data collected across multiple national park networks.

Data analyses

We used monitoring data from all plots surveyed annually to estimate plot-level BCI scores using guild assignments and ranking from a previously developed BCI for the Mid-Atlantic

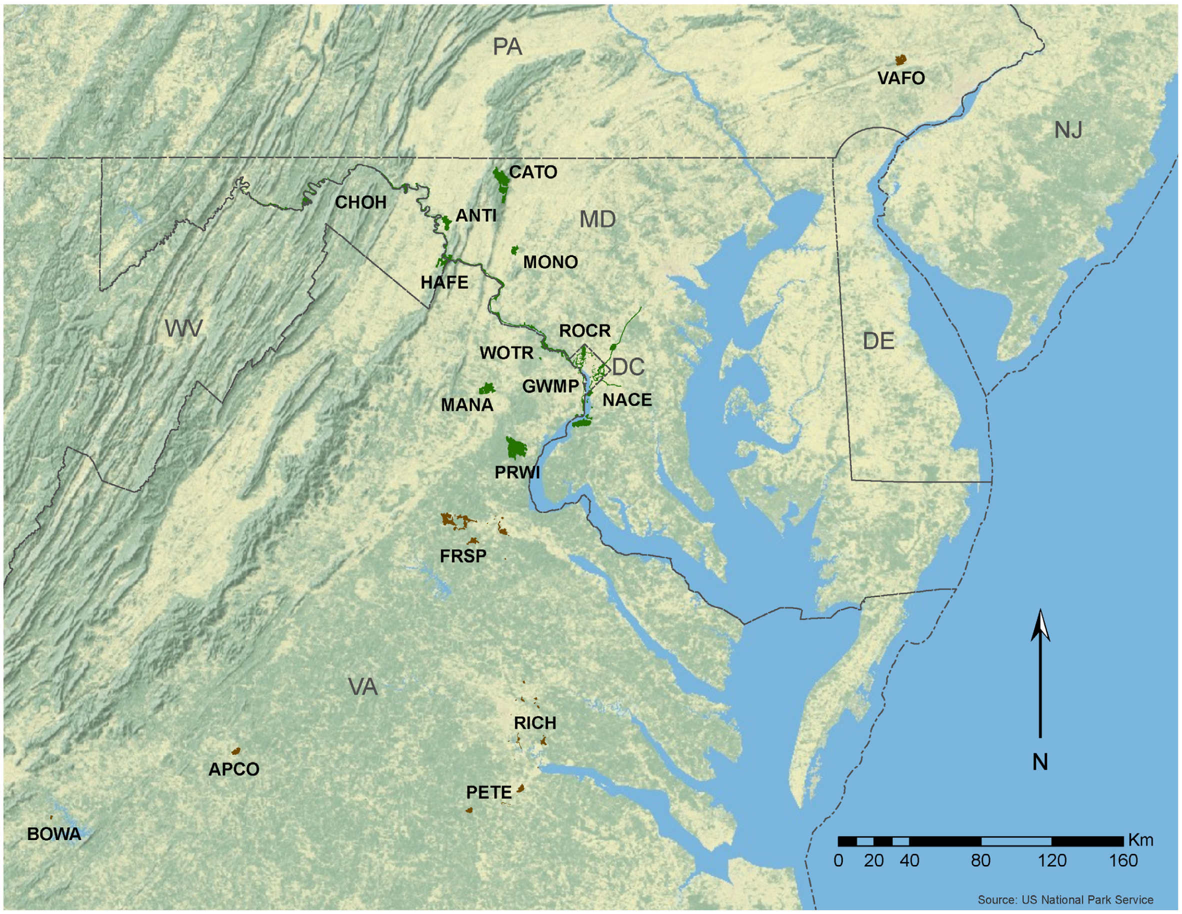

Fig. 1. Map showing 17 national parks (indicated by four-letter codes) located in PA, MD, Washington DC, VA, and WV, where bird monitoring occurred from 2007 to 2015 within the Mid-Atlantic United States. National parks within the National Capital Region Network (NCRN; shown in green) include: Antietam National Battlefield Park (ANTI), Catoctin Mountain Park (CATO), Chesapeake and Ohio Canal National Historical Park (CHOH), George Washington Memorial Parkway (GWMP), Harpers Ferry National Historical Park (HAFE), Manassas National Battlefield Park (MANA), Monocacy National Battlefield (MONO), National Capital Parks-East (NACE), Prince William Forest Park (PRWI), Rock Creek Park (ROCR), and Wolf Trap National Park for the Performing Arts (WOTR). Mid-Atlantic Network parks (shown in brown) include the following: Appomattox Court House National Historical Park (APCO), Booker T. Washington National Monument (BOWA), Fredericksburg & Spotsylvania National Military Park (FRSP), Petersburg National Battlefield (PETE), Richmond National Battlefield Park (RICH), and Valley Forge National Historical Park (VAFO).

Highlands (see O'Connell et al. 1998 for extensive details) that corresponded closely with the suite of forest bird species detected within NCRN and MIDN parks. To compute BCI scores, species detected at each plot were first categorized into specialist or generalist guild memberships within non-mutually exclusive functional (e.g., foraging behavior), compositional (e.g., migratory or resident), and structural (e.g., nest placement and habitat preference) guilds (Table 3). We then calculated the relative proportions of each guild category occurring at each plot and assigned corresponding numerical scores for each guild category. Higher BCI scores at monitoring plots resulting from higher proportions of species occurrence within specialist guilds are indicative of greater biotic integrity (i.e., areas with minimal human disturbance), due to corresponding

Table 2. Total number of sampling locations (n), annual counts of unique species detected, and mean (SE) bird community index (BCI) scores for 17 national parks within the National Capital Region and Mid-Atlantic Inventory and Monitoring (I&M) Networks.

NPS I&M Network and park names	n	Year										BCI
		2007	2008	2009	2010	2011	2012	2013	2014	2015	Total	
National Capital Region Network	431	112	118	104	122	115	106	110	120	118	166	
Antietam National Battlefield Park	12	47	48	35	43	44	34	41	53	54	82	42.7 (0.91)
Catoctin Mountain Park	49	60	46	41	52	49	50	57	53	49	93	53.8 (0.32)
Chesapeake and Ohio Canal National Historical Park	76	91	87	74	91	86	85	89	87	85	136	48.8 (0.28)
George Washington Memorial Parkway	20	64	63	60	69	63	59	59	57	60	114	48.0 (0.52)
Harpers Ferry National Historical Park	21	50	64	55	52	53	52	59	52	48	99	51.3 (0.51)
Manassas National Battlefield Park	19	60	61	57	65	61	59	59	74	57	112	46.9 (0.45)
Monocacy National Battlefield	15	28	23	28	23	31	28	21	57	52	76	43.5 (0.85)
National Capital Parks-East	49	63	76	62	68	67	63	64	69	64	113	46.3 (0.54)
Prince William Forest Park	145	66	73	64	68	66	67	62	66	61	111	55.6 (0.18)
Rock Creek Park	19	55	46	41	51	51	42	35	38	39	83	45.1 (0.71)
Wolf Trap National Park for the Performing Arts	6	8	8	9	9	9	11	18	30	28	45	46.2 (1.82)
Mid-Atlantic Network	316	–	–	69	84	113	85	87	81	84	147	
Appomattox Court House National Historical Park	32	–	–	–	40	36	34	–	–	–	52	47.9 (0.95)
Booker T. Washington National Monument	16	–	–	37	46	41	41	47	38	38	66	51.2 (0.98)
Fredericksburg & Spotsylvania National Military Park	59	–	–	53	53	52	50	53	47	51	87	52.7 (0.34)
Petersburg National Battlefield	71	–	–	–	–	88	40	–	–	–	92	48.8 (0.65)
Richmond National Battlefield Park	62	–	–	–	54	39	50	58	47	49	79	47.7 (0.70)
Valley Forge National Historical Park	76	–	–	47	55	55	51	54	60	58	87	44.4 (0.41)

life-history requirements for survival and reproduction of specialists (Wiens 1989, Noss 1990, Karr and Chu 1997). Finally, the scores for functional, compositional, and structural guilds were summed for each plot (see Table 3 for example calculation) and were averaged to estimate mean annual BCI scores per park. Higher scores indicate higher ecological integrity. Plots were assigned ecosystem integrity categories corresponding to the following ranges of BCI scores: highest integrity (60.1–77.0), high integrity (52.1–60.0), medium integrity (40.1–52.0), and low integrity (20.0–40.0) (O'Connell et al. 1998).

Table 3. Response guilds (from O'Connell et al. 1998) used in calculating bird community index (BCI) scores and an example calculation of a BCI score at an idealized survey location where species (n = 23) were detected.

					Example BCI calculation		
Integrity element	Guild category	Response guild	Specialist	Generalist	n = 23	Proportion	Rank
Functional	Trophic	Omnivore		X	8	0.35	4
Functional	Insectivore	Bark prober	X		2	0.09	3
Functional	Insectivore	Ground gleaner	X		1	0.04	1.5
Functional	Insectivore	Upper-canopy forager	X		1	0.04	2
Functional	Insectivore	Lower-canopy forager	X		5	0.22	2.5
$Total_{Functional}$							13
Compositional	Population limiting	Nest predator/ brood parasite		X	3	0.13	3.5
Compositional	Origin	Exotic		X	0	0.00	5
Compositional	Migratory	Resident		X	10	0.43	2
Compositional	Migratory	Temperate migrant		X	3	0.13	4
Compositional	Number of Broods	Single brooded	X		12	0.52	3
$Total_{Compositional}$							17.5
Structural	Nest Placement	Canopy nester	X		8	0.35	4.5
Structural	Nest Placement	Shrub nester		X	4	0.17	4
Structural	Nest Placement	Open-ground nester	X		0	0.00	1
Structural	Nest Placement	Forest-ground nester	X		2	0.09	3
Structural	Primary Habitat	Forest generalist		X	14	0.61	2.5
Structural	Primary Habitat	Interior forest obligate	X		4	0.17	3
$Total_{Structural}$							18
Bird Community Index Score							48.5

Note: The overall BCI score is calculated by summing the $Total_{Functional}$, $Total_{Compositional}$, and $Total_{Structural}$ rank scores.

To determine the effects of landscape context on park BCI scores and land cover variables, we calculated the proportion of land cover types within a 1 km radius circular buffer around each monitoring plot in ArcGIS 10.2 (ESRI 2015), Geospatial Modeling Environment (ver. 0.7.2 RC2; Beyer 2012), using the 2011 National Land Cover Data (NLCD) layer (Homer et al. 2012). We summed the proportions for each of the NLCD land cover classes (NLCDV21, NLCDV22, NLCDV23, NLCDV24) to create a generalized "developed" land cover category and (NLCDV41, NLCDV42, NLCDV43) to create generalized "forest" land cover category. We used linear mixed-effects models in the R package "lme4" (Bates et al. 2014) and subsequent parametric bootstrapping (nsim = 1000) in the "pbkrtest" package (Halekoh and Højsgaard 2014) to test for relationships between BCI score and the fixed effects of proportion of forest and developed land cover from 2012 National Land Cover Data, within a 1-km buffer around monitoring plots using data from both NCRN and MIDN. We included park unit, year, and plot as random effects in all models.

To characterize how changes in bird species composition affect BCI through time, we estimated cumulative distribution functions (CDF) of BCI scores, which convey the probability that a given park unit will contain monitoring plots less than or equal to a given BCI score threshold. This is a useful way within a probabilistic framework, to evaluate temporal changes in BCI and compare BCI among parks. To compute CDF, we used the "cont.analysis" function and subsequently the "cont.cdftest" function in the R package "spsurvey" (Kincaid and Olsen 2015). We then tested for differences in CDFs between selected years (α = 0.10) within each park.

To compare observer-type effects on detection probability for both forest and grassland species, we first analyzed count data from two repeated visits using N-mixture models with the "pcount" function (Royle 2004) with observer type and visit as detection covariates and park unit as a site covariate in the R package "unmarked" (Fiske and Chandler 2011). These models can be used to estimate true unobserved abundance as: N_{it} ~ Pois (λ_{it}), where N is the unobserved true abundance at site i, at time t, which is a function of the Poisson distribution, in which the mean is equal to the variance, with a mean of λ at site i, at time t. The above model is then nested within and influences the model describing the detection process: y_{ijt} ~ Binom (N_{it}, p_{ijt}), where y_{ijt} is the observed abundance at site i, during visit j, at time t which is a function of a binomial random variable with the parameters N_{it} (true abundance at site i, at time t) and p_{ijt} (detection probability, p at site i, during visit j, at time t) (Royle 2004, Kéry et al. 2005). We then used linear mixed-effects models in the "lme4" package (Bates et al. 2014) that included species and park unit in models as random effects, observer type (i.e., citizen scientist or paid observer) as a fixed effect, and detection probability as the response variable. All statistical analyses were conducted in R (version 3.2.1) (R Development Core Team 2015), and we report means ± SE, unless indicated otherwise.

Results

Mean annual BCI scores ranged between 33.5 (no SE; Wolf Trap in 2011) and 58.3 ± 0.39 (Prince William in 2015) within the NCRN parks and between 42.7 ± 1.08 (Valley Forge in 2010) and 54.2 ± 2.25 (Booker T. in 2010) within MIDN parks. The range of BCI estimates among parks spans the range of O'Connell's (1998) broad rankings from low (20.0–40.0) to high (52.1–60.0) integrity. Overall, BCI scores for Prince William and Catoctin indicated that these parks had "High" ecological integrity rankings (Fig. 2). Bird community index scores for Fredericksburg and Booker T. indicated intermediate ecological integrity between "High" and "Medium" integrity rankings. Parks with BCI scores corresponding to "Medium" ecological integrity rankings included the following: C&O Canal, George Washington, Harpers Ferry, Manassas, Monocacy, National Capital Parks, Rock Creek, Appomattox, Petersburg, Richmond, and Valley Forge (Fig. 2). Finally, BCI scores from Wolf Trap indicated the most variation among years which included both "Low" and "Medium" ecological integrity rankings (Fig. 2).

Mean annual BCI scores were positively related to the proportion of forest land cover within a 1 km radius buffer around monitoring plots (PBtest: likelihood ratio test statistic = 44.9, nsim = 1000, $P < 0.001$) and negatively related to developed land cover (PBtest: likelihood ratio test statistic = 10.4, nsim = 1000, $P < 0.01$) within the NCRN (Fig. 3A). In the MIDN, we found a positive relationship between BCI and the proportion of forest land cover (PBtest: likelihood ratio test statistics = 5.82, nsim = 1000, $P < 0.05$), but we found no significant relationship between BCI scores and developed land cover (PBtest: likelihood ratio test statistics = 0.28, nsim = 1000, $P = 0.65$; Fig. 3B).

When comparing cumulative distributions of BCI between paired years (i.e., year 1 and most recent year of monitoring) within each park, we found differences suggesting further utility in using BCI for tracking finer-resolution temporal changes in ecological integrity driven by annual changes in bird community composition. Within the NCRN, we found increases in cumulative distributions of BCI between 2007 and 2015 in ANTI (Wald-F = 6.17, df = 2, 16, $P < 0.05$), C&O Canal (Wald-F = 12.59, df = 2, 148, $P < 0.001$), and Prince William (Wald-F = 5.53, df = 2, 257, $P < 0.01$), and decreasing cumulative distribution of BCI in George Washington (Wald-F = 2.86, df = 2, 47, $P < 0.10$; Fig. 4). In the MIDN, we found cumulative distribution of BCI increased between 2010 and 2012 for Appomattox (Wald-F = 3.17, df = 2, 38, $P < 0.10$; Fig. 4). We found similar cumulative distributions of BCI scores for the remaining NCRN and MIDN parks between compared years (Wald-$F < 2.17$, $P > 0.12$, in all tests; Fig. 4).

Among all observers and across species, detection probability (mean ± SE) was 0.18 ± 0.25 within forest and 0.15 ± 0.10 grassland monitoring locations. We found no significant relationship between observer type and detection probability within forest (PBtest: likelihood ratio test statistic = 2.47, nsim = 1000, $P = 0.13$) or grassland (PBtest: likelihood ratio test statistic = 0.20, nsim = 1000, $P = 0.67$) monitoring plots. Within Fredericksburg and Valley Forge in 2015, observers detected 73 and 69 unique species within forest and grassland monitoring plots, respectively (Table 4). Of all the species detected, 56 species (81%) were detected at both forest and grassland monitoring plots (see Appendix S1 for lists of detected species by habitat type). While we did

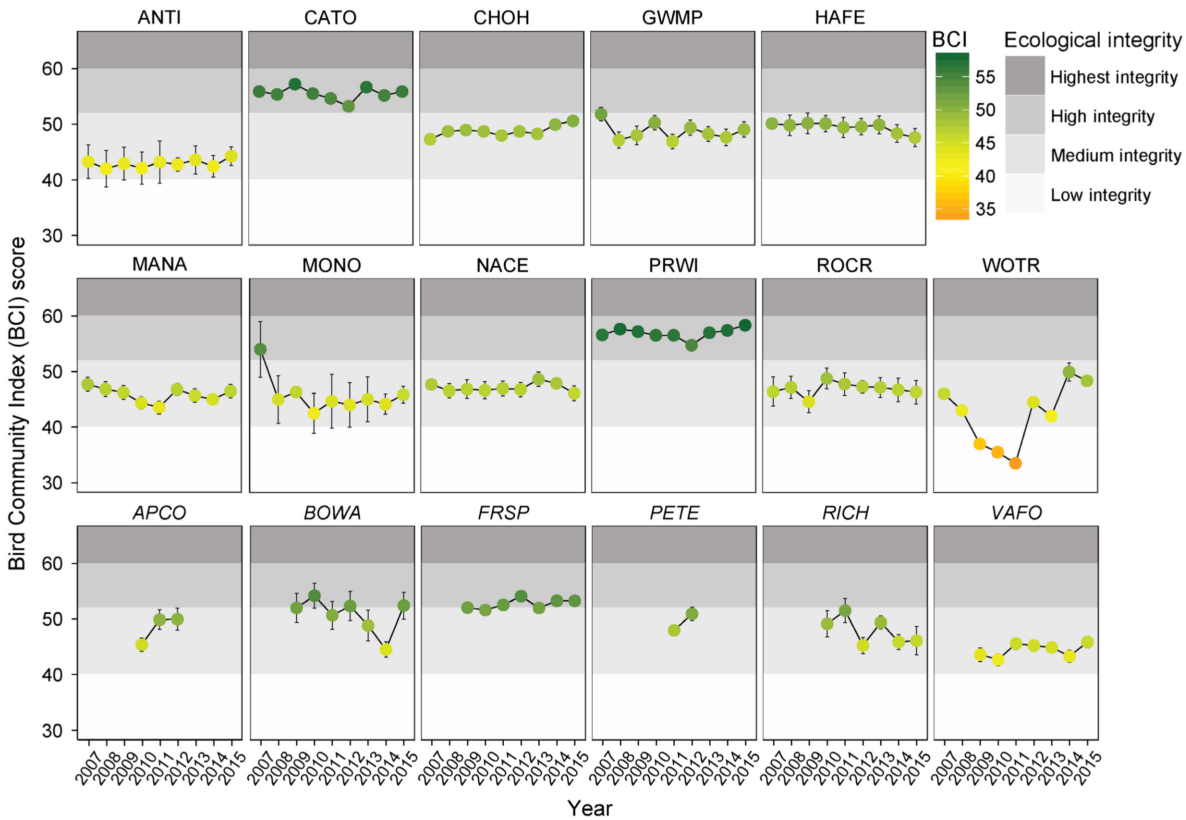

Fig. 2. Annual bird community index (BCI) scores (mean ± SE) in 17 national parks estimated using nine years of data (2007–2015) from Forest Bird Monitoring Protocols within 11 National Capital Region parks and six Mid-Atlantic Network parks. Italicized and regular four-letter park codes indicate Mid-Atlantic and National Capital Region Network parks, respectively. Continuous color ramp and gray background bars indicate BCI scores and ecological integrity ranking, respectively. Note different values among x-axes.

not formally test for differences in the mean number of species detected between observer types, we found that including both forest and grassland habitat types, citizen scientists detected 16 more unique species than paid observers.

Discussion

Using bird community-derived BCI estimates, we found that 17 national parks in the mid-Atlantic United States have medium-to-high ecological integrity and that changes in bird community diversity are driven by regional land cover patterns. Additionally, this study lends further support for how NPS I&M Networks charged with continual monitoring of natural resources within parks (Fancy et al. 2009), are able to meet increasing demands to measure and evaluate ecological performance (Gaston and Jackson 2008), particularly in relation to effects from increasing urbanization and anthropogenic global environmental change (Turner 2010). Our results support findings from a previous study that applied a BCI approach (O'Connell et al. 2003) and found BCI scores for eight parks within the highly urbanized NCRN were positively related to forest land cover and were greater when compared with surrounding unprotected lands (Goodwin and Shriver 2014). However, our study goes further in using nine years of data (as opposed to a single year) to demonstrate how spatiotemporal variation in BCI provides insight into ecological change at both regional and local scales through time. Given current and future needs for understanding how established linkages between ecological integrity and anthropogenic change

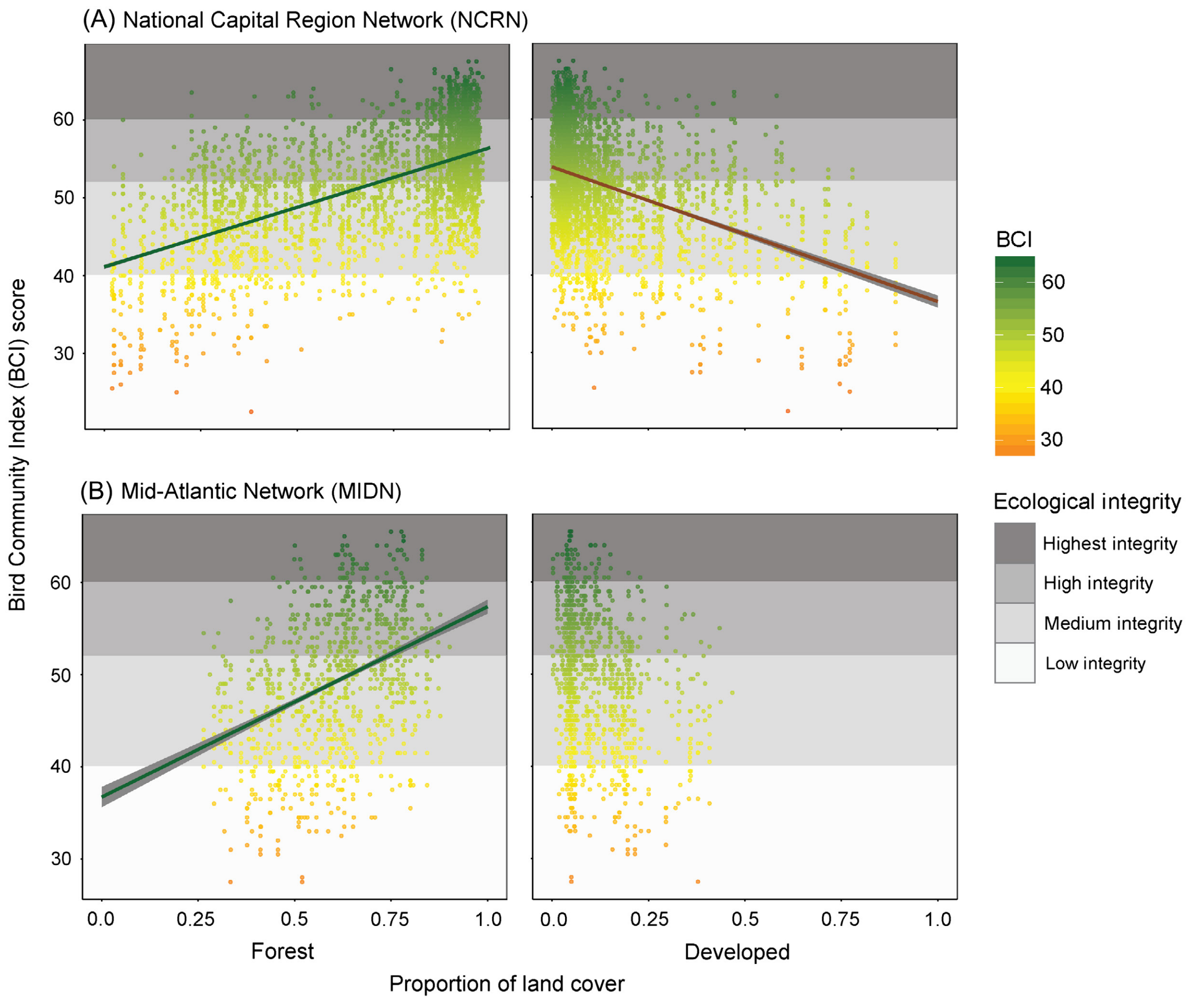

Fig. 3. Linear relationships between the proportion of forest and developed land cover within a 1-km radius buffer around point count survey plots and mean annual bird community index (BCI) scores at each plot within 17 national parks consisting of (A) 11 National Capital Region parks ($n = 324$) and (B) six Mid-Atlantic Network parks ($n = 228$). Plots showing linear trend lines and 95% CIs are significantly correlated. Continuous color ramp and gray background bars indicate BCI scores and ecological integrity ranking, respectively.

(e.g., via increasing urbanization), regional BCI analyses provide a comprehensive tool in evaluating and predicting how ecological integrity may change over time (Parrish et al. 2003, Tierney 2009).

Among the 17 national parks within this study, BCI scores and corresponding ecological integrity rankings differed among parks. However, we found that both parks with high ecological integrity located in less urbanized areas (e.g., Catoctin, Fredericksburg, and Prince William) and parks with medium ecological integrity, located in more heavily urbanized areas (e.g., George Washington, National Capital Parks, Rock Creek, and Wolf Trap), remained relatively stable through time. In a few cases, however, the addition of monitoring plots in 2014 within Monocacy and Wolf Trap has likely influenced mean annual BCI scores. For example, the wide variation in mean annual BCI scores seen in Wolf Trap is largely due to there being only one sampling location there from 2007 to 2013, and scores from 2014 onward are perhaps more representative of ecological integrity in Wolf Trap. Additionally, size-dependent effects not explicitly examined in this study likely contribute to protected areas'

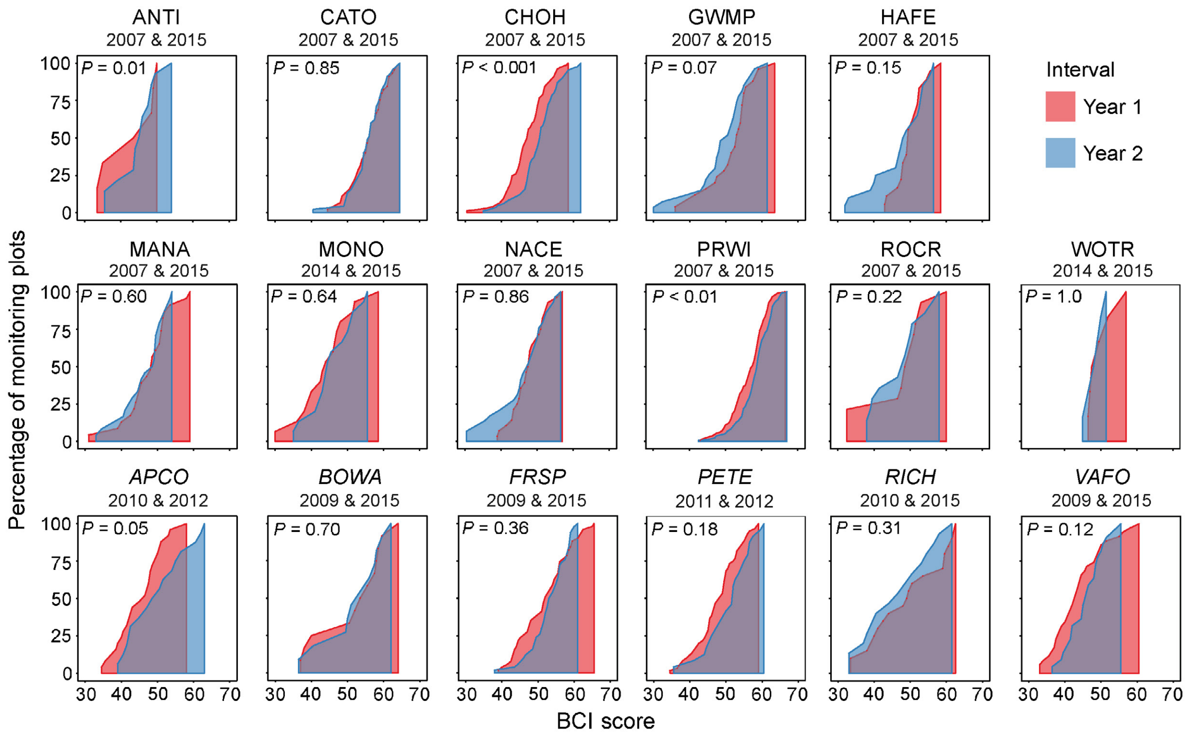

Fig. 4. Comparison of cumulative distribution functions between two years calculated from annual bird community index (BCI) scores at each plot within 17 national parks. National Capital Region Network parks are indicated by non-italicized four-letter park codes, and six Mid-Atlantic Network park codes are italicized. Paired year comparisons show year 1 (red) and year 2 (blue) within each park and are indicated under four-letter park codes in gray text. Plots with *P*-values shown in black text were found to be significantly different.

ability to sustain ecosystem integrity (Shafer 1995, Donnelly and Marzluff 2004, Maiorano 2008). In our study, park size may influence observed variation in BCI scores among, as well as within parks. For example, the following smaller-sized parks: Booker T. (97 ha), Monocacy (667 ha), and Richmond (930 ha divided among several discrete subunits) all exhibited a relatively higher degree of variation in annual mean BCI scores among parks.

In our regional comparison of BCI scores from the NCRN and MIDN, not surprisingly, we found positive relationships between the proportion of forest cover and BCI in both networks. However, the negative relationship of developed land cover and BCI, that we found within the NCRN and not within the MIDN, is likely due to differences in the amount of developed land cover between the two networks. Interestingly, the relationships we observed between increased developed land cover and ecological integrity in NCRN may foreshadow similar effects in other areas as urbanization increases. The dominant land cover type within the NCRN landscape is developed land (Masek et al. 2000), with forest bird monitoring plots having upwards of 75% developed land cover within a 1-km radius buffer, whereas the percent of developed land cover around MIDN monitoring plots did not exceed 50%. In general, our findings suggest that despite increasing rates of urbanization and consequent negative influence on avian bird communities, national parks exhibited relatively stable ecological integrity over the duration of the study. However, continued monitoring and evaluation of BCI would be required to evaluate the ability of national parks to sustain ecological integrity over the long term. Additionally, from an avian conservation perspective, national parks with relatively high and stable BCI scores are providing critical breeding habitat, and hence, supporting a

Table 4. Numbers of unique species detected and unique shared species (detected by both observer types) overall (Total) and within forest and grassland monitoring plots (*N*) by citizen scientist and paid observers within Fredericksburg & Spotsylvania National Military Park (FRSP) and Valley Forge National Historical Park (VAFO) from 14 May to 8 July 2015.

Habitat type (*N*)	Observer type	FRSP	VAFO	Total
Forest (69)	Citizen scientist	49	51	64
	Paid observer	45	46	56
	Shared	38	41	47
	Total	56	56	73
Grassland (44)	Citizen scientist	33	58	64
	Paid observer	31	49	56
	Shared	22	45	48
	Total	42	63	69

greater proportion of species designated within specialist trophic, compositional, and functional guilds.

When we tested for pairwise differences in the cumulative distributions of BCI scores between two years within each park, our results supported qualitative findings of within-park stability of ecological integrity, with 12 of 17 parks showing no change in BCI cumulative distributions between years. In the five parks where significant differences between cumulative distributions of BCI scores were detected between compared years, we found that all parks, except for George Washington, showed an improvement in BCI scores over time. Potential drivers of such improvement that would promote the occupancy of species belonging to specialist guilds may include park-level management efforts in controlling and removing invasive species, targeted management for diversity in forest seral stages or unique habitat types, or implementing deer management strategies. Beyond the basic evaluative benefits of using a BCI approach to detect changes in ecological integrity over time within parks, data collected by I&M Networks can provide valuable information to help guide park units' proposed plans for future management and improvement of biological and cultural resources, establishment of proposed ecological integrity thresholds, and the tailoring of management strategies to meet proposed goals.

Another important finding from this study was that we found no difference in detection probability estimates between paid professional and citizen scientist observers. While our analysis was constrained to using data collected within Fredericksburg and Valley Forge in 2015, these results which were corroborated using data from both forest and grassland monitoring plots are promising and lend support for future regional analyses among NPS I&M Networks that incorporate citizen scientist observers into monitoring efforts. Furthermore, these findings give us confidence in our ability to conduct meaningful regional analyses (e.g., comparing BCI scores among parks across I&M Networks). The integration of citizen scientist observers into monitoring protocols can be valuable for engaging public interest and support of national parks and enhancing, in this case, both natural and cultural resources. However, care should be taken in the training and oversight of volunteering citizen scientist observers, particularly given the potential for volunteer turnover and differences in skill levels, to ensure adherence to monitoring protocols in order to maintain high data quality standards.

Over the next century, national parks are poised to be strongholds of ecological integrity and biological diversity conservation. In light of increasing threats to ecosystem function and stability driven by anthropogenic landscape and environmental change, national parks can provide critical counterpoints by maintaining ecosystem integrity. Although we found positive correlations between BCI and forest land cover similar to previous studies comparing bird community dynamics and land cover data (Boulinier et al. 2001, Goodwin and Shriver 2014, Pierson et al. 2016), it is important to note that using the proportion of forest land cover alone may not provide a suitable metric to guide management decisions. Future use of integrated multitaxa indices may also help improve our power to assess ecological integrity. For instance, Medeiros et al. (2015) found that an integrated plant and bird index were more accurate in estimating ecological integrity within tropical forest fragments. Not surprisingly, our findings illustrate how BCI scores influenced by stochasticity in species' population dynamics vary both spatially and temporally (e.g., interannual variation) among parks we sampled. This spatiotemporal sensitivity driven, in part, by annually observed changes in bird community composition has the potential to track finer-resolution changes in ecological integrity, as opposed to the proportion of forest cover alone. However, consideration of long-term responses of bird communities to habitat loss and land cover change should include assessment of differential time-lag responses within bird communities among functional guilds (Uezu and Metzger 2016).

Perhaps just as critical as the long-term commitment to the protection and maintenance of national parks, is the sustainability of long-term monitoring programs. We encourage future integrated analyses using I&M data across multiple networks to investigate large-scale regional ecological patterns. Novel insights that can be gleaned through analyzing long-term monitoring data, such as NPS I&M Networks are designed and charged to collect, will prove important in helping us understand, predict, and adapt to shifting environmental conditions that can help guide future sustainable human development.

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