National Park Service
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Natural Resource Stewardship and Science

# Protocol for Monitoring Forest-Nesting Birds in National Park Service Parks

*Version 1.0 (December 2013)*

Natural Resource Report NPS/NCRN/NRR—2014/749

**ON THE COVER**
White-breasted nuthatch (*Sitta carolinensis*) in Rock Creek Park.
NPS Photo by Lisa Struckmeyer

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# Contents

Page

Figures ..... v

Tables ..... vii

Appendices ..... ix

Executive Summary ..... xi

Introduction – Protocol Overview ..... 1

Background ..... 1

Rationale for monitoring this resource ..... 1

Measureable objectives ..... 6

Sampling Design ..... 6

Background ..... 6

Counting Method ..... 6

Power Analysis ..... 8

Personnel Required and Distribution of Effort ..... 16

Data Summary and Analysis ..... 17

Supplemental Monitoring ..... 19

Literature Cited ..... 21

# Figures

Page

**Figure 1.** Contours of power (1–β) to detect trends of varying slope (y-axis) in relation to the duration of monitoring (x-axis). ..... 10

**Figure 2.** Precision of unadjusted count (solid line) for varying total count, compared to precision of binomial distance estimate of density with varying proportion ($p_1$) of birds in the 'near' category ..... 11

**Figure 3.** Cumulative counts of all species in CATO survey (total n = 2500), with cubic spline interpolation ..... 15

**Figure 4.** Distribution across species of mean number counted per 10 min, in relation to the total annual count required for 80% power to detect a 50% decline in 10 years ..... 16

# Tables

Page

**Table 1.** Bird species that regularly or occasionally nest in forests, and their documented or likely occurrence in NCRN parks.[a] ..... 3

**Table 2.** Precision of annual estimates required to detect 50% population decrease in 10 years with given power using Poisson Regression analysis of unadjusted count data[a] ..... 9

**Table 3.** Mean number of birds counted per point (Mean/Pt) ..... 12

**Table 4-1.** Correspondence between the parameters of Appendix 3 Model (3) and arguments of the R function SIMPower ..... 2

# Appendices

Page

Appendix 1: Currently Available Bird Counting Methods That Allow For Estimation of Detection Probabilities ..... 1-1

Appendix 2: Population Variation From Breeding Bird Survey Routes in Maryland ..... 2-1

Appendix 3: Simulating Point Count Data ..... 3-1

Appendix 4: Power Analysis by Simulation ..... 4-1

# Executive Summary

These documents detail the protocol for monitoring forest-nesting birds in National Park Service parks in the National Capital Region Network (NCRN). In the first year of sampling, counts of birds should be made at 384 points on the NCRN spatially randomized grid, developed to sample terrestrial resources. Sampling should begin on or about May 20 and continue into early July; on each day the sampling period begins at sunrise and ends five hours later. Each point should be counted twice, once in the first half of the field season and once in the second half, with visits made by different observers, balancing the within-season coverage of points and their spatial coverage by observers, and allowing observer differences to be tested. Three observers, skilled in identifying birds of the region by sight and sound and with previous experience in conducting timed counts of birds, will be needed for this effort. Observers should be randomly assigned to 'routes' consisting of eight points, in close proximity and, ideally, in similar habitat, that can be covered in one morning.

Counts are 10 minutes in length, subdivided into four 2.5-min intervals. Within each time interval, new birds (i.e., those not already detected) are recorded as within or beyond 50 m of the point, based on where first detected. Binomial distance methods are used to calculate annual estimates of density for species. The data are also amenable to estimation of abundance and detection probability via the removal method. Generalized linear models can be used to assess between-year changes in density estimates or unadjusted count data.

This level of sampling is expected to be sufficient to detect a 50% decline in 10 years for approximately 50 bird species, including 14 of 19 species that are priorities for conservation efforts, if analyses are based on unadjusted count data, and for 30 species (6 priority species) if analyses are based on density estimates. The estimates of required sample sizes are based on the mean number of individuals detected per 10 minutes in available data from surveys in three NCRN parks. Once network-wide data from the first year of sampling are available, this and other aspects of the protocol should be re-assessed, and changes made as desired or necessary before the start of the second field season. Thereafter, changes should not be made to the field methods, and sampling should be conducted annually for at least ten years. NCRN staff should keep apprised of new analytical methods developed for analysis of point-count data.

# Introduction – Protocol Overview

## Background

A nationwide program to monitor natural resources in national parks is being developed and implemented as part of the Natural Resource Challenge, the National Park Service's action plan for natural resource stewardship. To improve efficiency and reduce costs, the 270 park units deemed to have significant natural resources have been grouped into 32 networks, based on geography and natural resource characteristics. Each network identifies a set of physical, chemical, or biological elements or ecosystem processes that are of interest to the parks or represent their overall health or condition (i.e., vital signs), and then works with partners to develop plans and protocols to monitor them. Implementation of monitoring plans will occur as the next phase in the process.

Eleven park units in the NPS National Capital Region (Antietam National Battlefield Park [ANTI], Catoctin Mountain Park [CATO], Chesapeake and Ohio Canal National Historical Park [CHOH], George Washington Memorial Parkway [GWMP], Harper's Ferry National Historical Park [HAFE], Manassas National Battlefield Park [MANA], Monocacy National Battlefield Park [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]) comprise the National Capital Region Network (NCRN). This diverse set of parks, established to protect historical, cultural, or natural resources, consists of more than 250 tracts, ranging in area from < 1 ha to > 5,000 ha (total area > 31,000 ha). The parks are scattered across four physiographic regions (Coastal Plain, Piedmont, Blue Ridge, and Ridge and Valley), embedded in landscapes that range from highly urbanized to predominantly agricultural or forested. Forest is the predominant natural vegetation cover within the parks.

After a series of scoping meetings and workshops, in which vital signs were identified and prioritized, 21 vital signs were selected for monitoring in NCRN parks. This protocol designs a program to monitor populations of forest-nesting birds. We provide the rationale for monitoring this resource, measurable objectives, and an overview of the sampling design, with specifics detailed in Standard Operating Procedures and additional technical information, used to develop and support our recommendations, included in appendices.

## Rationale for monitoring this resource

The NCRN parks lie within the Washington, DC, metropolitan area, where suburbanization is the dominant land use trend. The associated loss, fragmentation, and degradation of forests have led to regional or local declines in populations of some forest-nesting bird species, and the forests in NCRN parks are becoming increasingly important to preservation of the region's avifauna. At the same time, these forests are facing several threats, including heavy browsing pressure from white-tailed deer (*Odocoileus virginianus*), tree diseases or insect pests, and invasive exotic plants, that affect their structure, condition, and composition, reducing their quality as habitat for some bird species. In addition, birds that nest in urban areas, including the NPS parks in and near Washington, are vulnerable to the mosquito-borne West Nile Virus (Kilpatrick et al. 2007), which may be impacting populations of some species. Although NPS generally does not actively manage park habitats for birds or other wildlife, efforts are being made to control insect pests (e.g., mosquitoes, gypsy moth) or invasive plants in some NCRN parks, and options currently are

being considered to reduce the density of deer in CATO and ROCR because of their heavy impacts on forest understory vegetation and tree regeneration.

Considerable data exist on the distribution and abundance of breeding birds in the National Capital Region. Bird count or presence data were collected for several projects, including inventories and other bird surveys in NCRN parks (e.g., Brewer 2001, Dawson and Gough 2001, Gates and Walters 2003, Sinclair et al. 2004, Bates et al. 2005), the Prince George's County (MD) Forest Bird Survey (Dawson et al. 1993), Montgomery County (MD) Bird Survey Project (Darr and Dawson, in prep.), Patuxent Research Refuge Breeding Bird Survey (Bystrak et al., unpublished), DC Birdscape (Hadidian et al. 1997) and Birdscape II (Katju and Dawson, unpublished), and the Northern Virginia Bird Survey (The Audubon Society of Northern Virginia [formerly Fairfax Audubon Society], unpublished). Field methods varied among these surveys, but all provide information on the spatial distribution and habitat associations of forest birds in the region.

Over 90 bird species that regularly or occasionally nest in forests (Table 1) have been documented in NCRN parks (Brewer 2001; Dawson and Gough 2001; Gates and Walters 2003; Sinclair et al. 2004; Bates et al. 2005; Dawson, pers. obs.). Forests in NCRN parks also host many bird species during the winter months and during periods of migration. However, because birds are generally more mobile and not territorial during these seasons, it is difficult to design a meaningful long-term survey of their status and trends.

Several of NCRN's forest-nesting bird species have been designated as priorities for continental or regional conservation efforts (e.g., Rich et al. 2004), and thus should be focal species for monitoring efforts, to the extent possible. Wood Thrush (scientific names in Table 1), Prairie Warbler, Cerulean Warbler, Prothonotary Warbler, Worm-eating Warbler, and Kentucky Warbler have been included on the Partners in Flight Watchlist (Rich et al. 2004). Multiple reasons for concern exist across their ranges, and management or other on-the-ground conservation actions are considered necessary to reverse long-term population declines or sustain vulnerable populations (Rich et al. 2004).

**Table 1.** Bird species that regularly or occasionally nest in forests, and their documented or likely occurrence in NCRN parks.[a]

| pecies | Scientific Name | ANTI | CATO | CHOH | GWMP | HAFE | MANA | MONO | NACE | PRWI | ROCR | WOTR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Great Blue Heron | *Ardea herodias* | Po[b] | — | Po | Po | Po | Po | Po | Po | Po | — | — |
| Green Heron | *Butorides virescens* | Po | — | Po | Po | Po | Pr[c] | Po | Pr | Po | Po | Po |
| Black Vulture | *Coragyps atratus* | — | — | Po | Po | Po | Po | Po | Po | — | Po | — |
| Turkey Vulture | *Cathartes aura* | Po | Po | Pr | Po | Po | Po | Po | Po | Po | Po | — |
| Wood Duck | *Aix sponsa* | Pr | | Pr | Pr | Co[d] | Co | Pr | Pr | Po | Po | Co |
| Bald Eagle | *Haliaeetus leucocephalus* | — | — | Co | Po | Po | Po | — | Co | — | — | — |
| Cooper's Hawk | *Accipiter cooperii* | Po | Po | Po | Po | Po | Po | Po | Po | Po | Po | Po |
| Red-shouldered Hawk[e] | *Buteo lineatus* | Po | Po | Pr | Po | Po | Pr | Po | Pr | Po | Po | Pr |
| Broad-winged Hawk | *Buteo platypterus* | — | Co | Po | Po | Po | — | — | Po | Po | Po | |
| Red-tailed Hawk | *Buteo jamaicensis* | Co | Pr | Pr | Po | Po | Pr | Po | Pr | Po | Po | Po |
| Ruffed Grouse | *Bonasa umbellus* | — | Po | Po | — | — | — | — | — | — | — | — |
| Wild Turkey | *Meleagris gallopavo* | Pr | Pr | Po | Po | — | Co | Po | Co | Po | — | — |
| American Woodcock | *Scolopax minor* | Po | — | Po | Po | Po | Po | Po | Po | Po | — | — |
| Mourning Dove | *Zenaida macroura* | Co | Co | Pr | Pr | Po | Co | Pr | Pr | Po | Pr | Pr |
| Black-billed Cuckoo | *Coccyzus erythropthalmus* | — | — | Po | — | — | — | — | — | — | — | — |
| Yellow-billed Cuckoo | *Coccyzus americanus* | Pr | Co | Pr | Po | Po | Pr | Po | Pr | Po | Po | Po |
| Eastern Screech-Owl | *Otus asio* | Pr | Co | Pr | Po | Po | Po | Po | Pr | Po | Pr | Po |
| Great Horned Owl | *Bubo virginianus* | Co | Po | Pr | Po | | Co | Po | Co | Po | Po | Po |
| Barred Owl | *Strix varia* | Pr | Pr | Pr | Po | | Po | Po | Pr | Po | Po | Po |
| Whip-poor-will | *Caprimulgus vociferus* | | Po | Po | Po | Po | Po | — | Po | Po | — | — |
| Ruby-throated Hummingbird | *Archilochus colubris* | Po | Pr | Pr | Pr | Po | Po | Po | Po | Po | Pr | Po |
| Red-headed Woodpecker | *Melanerpes erythrocephalus* | Co | — | Po | — | — | Po | Po | — | — | — | — |
| Red-bellied Woodpecker[e] | *Melanerpes carolinus* | Co | Co | Pr | Pr | Co | Co | Pr | Co | Co | Pr | Pr |
| Downy Woodpecker | *Picoides pubescens* | Co | Co | Pr | Pr | Pr | Co | Pr | Pr | Co | Pr | Pr |
| Hairy Woodpecker | *Picoides villosus* | Pr | Co | Pr | Pr | Po | Co | Pr | Pr | Po | Pr | Po |
| Northern Flicker | *Colaptes auratus* | Co | Co | Pr | Pr | Po | Co | Pr | Pr | Po | Pr | Pr |
| Pileated Woodpecker | *Dryocopus pileatus* | Co | Co | Pr | Pr | Po | Pr | Pr | Pr | Po | Po | Co |
| Eastern Wood-Pewee | *Contopus virens* | Pr | Co | Pr | Pr | Co | Pr | Pr | Co | Pr | Pr | Pr |
| Acadian Flycatcher[e] | *Empidonax virescens* | Pr | Co | Pr | Pr | Po | Co | Pr | Co | Po | Pr | Pr |
| Least Flycatcher | *Empidonax minimus* | — | — | Po | — | — | — | — | — | — | — | — |
| Eastern Phoebe | *Sayornis phoebe* | Pr | Co | Pr | Pr | Po | Co | Pr | Co | Co | Pr | Co |
| Great Crested Flycatcher | *Myiarchus crinitus* | Pr | Co | Pr | Pr | Pr | Co | Pr | Co | Po | Pr | Po |
| Eastern Kingbird | *Tyrannus tyrannus* | Co | — | Pr | Pr | Po | Co | Pr | Co | Po | Pr | Po |
| White-eyed Vireo[e] | *Vireo griseus* | Co | — | Pr | Co | Po | Pr | Pr | Pr | Po | Po | Po |
| Yellow-throated Vireo[e] | *Vireo flavifrons* | — | Co | Pr | Po | Po | Pr | Pr | Po | Po | Po | — |
| Warbling Vireo | *Vireo gilvus* | Pr | — | Pr | Pr | Pr | — | Pr | Pr | — | — | — |
| Red-eyed Vireo | *Vireo olivaceus* | Pr | Co | Pr | Pr | Pr | Co | Pr | Pr | Pr | Pr | Po |

**Table 2 (continued).** Bird species that regularly or occasionally nest in forests, and their documented or likely occurrence in NCRN parks.[a]

| pecies | Scientific Name | ANTI | CATO | CHOH | GWMP | HAFE | MANA | MONO | NACE | PRWI | ROCR | WOTR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Blue Jay* | *Cyanocitta cristata* | Pr | Co | Pr | Pr | Po | Co | Pr | Pr | Po | Pr | Co |
| American Crow | *Corvus brachyrhynchos* | Co | Co | Pr | Pr | Po | Co | Pr | Pr | Po | Pr | Po |
| Fish Crow | *Corvus ossifragus* | Po | — | Pr | Pr | Po | Po | Po | Co | Po | Po | Po |
| Common Raven | *Corvus corvax* | — | Po | Po | — | Po | — | — | — | — | — | — |
| Tree Swallow | *Tachycineta bicolor* | Co | — | Pr | Po | Po | Po | Po | Co | Po | — | — |
| Carolina Chickadee | *Poecile carolinensis* | Co | Co | Pr | Pr | Pr | Co | Pr | Co | Po | Pr | Pr |
| Black-capped Chickadee | *Poecile atricapillus* | — | Po | Pr | — | — | — | — | — | — | — | — |
| Tufted Titmouse | *Baeolophus bicolor* | Co | Co | Pr | Pr | Pr | Co | Pr | Co | Co | Pr | Co |
| White-breasted Nuthatch | *Sitta carolinensis* | Pr | Co | Pr | Pr | Po | Co | Pr | Pr | Pr | Pr | Co |
| Brown Creeper | *Certhia americana* | — | Po | Po | — | — | — | — | — | — | — | — |
| Carolina Wren[e] | *Thryothorus ludovicianus* | Co | Co | Pr | Pr | Pr | Co | Pr | Co | Po | Pr | Co |
| House Wren | *Troglodytes aedon* | Co | Pr | Pr | Pr | Po | Pr | Pr | Pr | Po | Pr | Pr |
| Blue-gray Gnatcatcher | *Polioptila caerulea* | Co | Co | Pr | Pr | Po | Co | Pr | Co | Pr | Pr | Po |
| Eastern Bluebird | *Sialia sialis* | Co | Co | Pr | Pr | Pr | Co | Pr | Co | Po | Po | Co |
| Veery | *Catharus fuscescens* | — | Co | Po | Po | Po | — | — | — | — | Po | — |
| Wood Thrush[f] | *Hylocichla mustelina* | Co | Co | Pr | Pr | Co | Pr | Pr | Co | Pr | Pr | Co |
| American Robin | *Turdus migratorius* | Co | Co | Pr | Pr | Po | Co | Pr | Co | Pr | Pr | Co |
| Gray Catbird | *Dumetella carolinensis* | Co | Pr | Pr | Pr | Po | Co | Pr | Pr | Po | Pr | Po |
| Northern Mockingbird | *Mimus polyglottos* | Co | Po | Pr | Pr | Po | Co | Pr | Pr | Po | Pr | Po |
| Brown Thrasher[e] | *Toxostoma rufum* | Co | Pr | Po | Po | Pr | Co | Pr | Pr | Po | Po | Po |
| European Starling | *Sturnus vulgaris* | Co | Pr | Pr | Pr | Po | Co | Pr | Pr | Po | Pr | Po |
| Cedar Waxwing | *Bombycilla cedrorum* | Pr | Po | Pr | Po | Po | Po | Pr | Po | Po | Po | Po |
| Blue-winged Warbler | *Vermivora pinus* | — | — | Po | — | — | — | — | — | — | — | — |
| Northern Parula | *Parula americana* | — | Pr | Pr | Pr | Po | Co | Pr | Pr | Po | Pr | Po |
| Yellow Warbler | *Dendroica petechia* | — | — | Po | Po | Po | Po | Po | Pr | — | — | — |
| Chestnut-sided Warbler | *Dendroica pensylvanica* | — | Pr | Po | — | — | — | — | — | — | — | — |
| Yellow-throated Warbler[e] | *Dendroica dominica* | — | — | Pr | Po | Po | — | — | Po | — | — | — |
| Pine Warbler[e] | *Dendroica pinus* | Pr | — | Po | Po | — | Co | — | Pr | Pr | Po | Po |
| Prairie Warbler[f] | *Dendroica discolor* | Pr | — | Po | Po | Po | Co | Po | Po | Po | — | — |
| Cerulean Warbler[f] | *Dendroica cerulea* | — | Co | Pr | Po | — | — | — | — | — | — | — |
| Black-and-white Warbler | *Mniotilta varia* | — | Co | Po | Po | — | Po | Po | Po | Po | Po | |
| American Redstart | *Setophaga ruticilla* | — | Co | Pr | — | Po | Po | Po | Co | — | — | — |
| Prothonotary Warbler[b] | *Protonotaria citrea* | — | — | Pr | Po | — | — | — | Co | — | — | — |
| Worm-eating Warbler[f] | *Helmitheros vermivorus* | — | Co | Pr | Po | Pr | Po | Pr | Co | Po | — | — |
| Ovenbird | *Seiurus aurocapillus* | — | Co | Pr | Pr | Po | Co | Po | Co | Pr | Pr | Pr |
| Louisiana Waterthrush[e] | *Seiurus motacilla* | Pr | Co | Pr | Pr | Pr | Co | Pr | Co | Pr | Pr | Po |
| Kentucky Warbler[f] | *Oporornis formosus* | — | Co | Pr | Pr | — | Pr | Pr | Co | Po | Po | — |
| Common Yellowthroat | *Geothylpis trichas* | Pr | | Pr | Pr | — | Co | Pr | Co | Pr | Pr | Po |

**Table 2 (continued).** Bird species that regularly or occasionally nest in forests, and their documented or likely occurrence in NCRN parks.[a]

| pecies | Scientific Name | ANTI | CATO | CHOH | GWMP | HAFE | MANA | MONO | NACE | PRWI | ROCR | WOTR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hooded Warbler[e] | *Wilsonia citrina* | — | Co | Po | Po | — | — | — | Co | Pr | Po | — |
| Yellow-breasted Chat | *Icteria virens* | Co | — | Po | Po | — | Pr | Po | Pr | Po | Po | Po |
| Summer Tanager | *Piranga rubra* | — | — | — | — | — | — | — | Po | Po | — | — |
| Scarlet Tanager | *Piranga olivacea* | Pr | Co | Pr | Pr | Pr | Co | Pr | Pr | Co | Pr | Po |
| Eastern Towhee[e] | *Pipilo erythrophthalmus* | Co | Co | Pr | Pr | Po | Co | Pr | Co | Pr | Pr | Pr |
| Chipping Sparrow | *Spizella passerina* | Co | Co | Pr | Pr | Po | Co | Pr | Pr | Po | Po | Co |
| Song Sparrow | *Melospiza melodia* | Co | — | Pr | Pr | Pr | Co | Pr | Pr | Po | Pr | Po |
| Northern Cardinal | *Cardinalis cardinalis* | Co | Co | Pr | Pr | Pr | Co | Pr | Co | Pr | Pr | Pr |
| Rose-breasted Grosbeak | *Pheuticus ludovicianus* | — | — | Po | — | — | — | — | — | — | — | — |
| Blue Grosbeak | *Guiraca caerulea* | Co | — | Po | Po | — | Co | Pr | Co | Po | — | Po |
| Indigo Bunting[e] | *Passerina cyanea* | Co | Pr | Pr | Pr | Co | Co | Pr | Co | Po | Pr | Po |
| Red-winged Blackbird | *Agelaius phoeniceus* | Co | — | Pr | Co | Po | Co | Pr | Co | Po | Po | Po |
| Common Grackle | *Quiscalus quiscula* | Co | Pr | Pr | Pr | Co | Po | Pr | Pr | Po | Pr | Pr |
| Brown-headed Cowbird | *Molothrus ater* | Co | Co | Pr | Pr | Po | Co | Pr | Co | Po | Pr | Po |
| Orchard Oriole | *Icterus spurius* | Co | Po | Pr | Po | Po | Co | Pr | Co | Po | Po | Pr |
| Baltimore Oriole | *Icterus galbula* | Co | Pr | Pr | Pr | Pr | Co | Pr | Pr | Po | Po | Po |
| American Goldfinch | *Carduelis tristis* | Co | Pr | Pr | Pr | Po | Co | Pr | Pr | Po | Pr | Co |

**Sources:** Robbins 1996; Hadidian et al. 1997; Brewer 2001; Dawson and Gough 2001; Gates and Walters 2003; Sinclair et al. 2004; Bates et al. 2005; Katju and Dawson unpublished data; Dawson personal observation.

**Notes:**

a. Some species associated with successional habitats are included because their habitats are generally not distinguished from forest in available land cover data (NLCD).

b. Po = nesting possible.

c. Pr = nesting probable.

d. Co = nesting confirmed.

e. Stewardship Species, Eastern Deciduous Forest Biome (Rich et al. 2004).

f. Partners in Flight Watchlist Species.

Thirteen other species have been designated as Stewardship Species for the Eastern Deciduous Forest Biome (Rich et al. 2004), because a high proportion of their global population nests within the biome. Of these, management action is recommended to maintain populations of Brown Thrasher and Eastern Towhee, both of which need or use shrub/successional habitats or disturbed areas within forests or along forest edges, and long-term planning is recommended for Red-shouldered Hawk, Red-bellied Woodpecker, Acadian Flycatcher, White-eyed Vireo, Yellow-throated Vireo, Carolina Wren, Yellow-throated Warbler, Pine Warbler, Louisiana Waterthrush, Hooded Warbler, and Indigo Bunting.

Some of the priority species are relatively common at present, and distributed throughout the NCRN parks (e.g., Wood Thrush, Red-bellied Woodpecker, Acadian Flycatcher, Carolina Wren; Table 1). Others are sparsely or patchily distributed, in part because they have more specific habitat requirements. Prothonotary Warblers, for example, are associated with swamps or river margins, and occur only in the parks bordering the Potomac or Anacostia Rivers (i.e., CHOH,

GWMP, NACE; Table 1). In contrast, Worm-eating Warblers associate with dry slopes, on ridges or in ravines. We develop a sampling design that assesses the status and trends of as many as possible of these species in NCRN parks, while providing information on the dozens of other forest-nesting bird species, some of which may need conservation or management action in the future.

## Measureable objectives

1. Obtain annual estimates of density and/or indices of abundance for forest-nesting bird species, including those designated as priorities for conservation efforts, across parks in the NCRN network.
2. Estimate long-term trends in density/abundance across parks in the NCRN network.

## Sampling Design

### *Background*

Populations of forest-nesting birds will be sampled and monitored at points on the grid developed for sampling terrestrial vital signs in NCRN parks (Koenen 2005). The grid of points spaced at 250-m intervals was generated and clipped with park boundaries in ArcGIS (Environmental Systems Research Institute, Redlands, CA). A Generalized Random-Tessellation Stratified (GRTS) design (Stevens and Olsen 2004) was applied to all 4683 points on the grid, giving each an equal probability of selection and producing an ordered list of randomly selected points that is spatially balanced. Working within this design, once the desired sample size of points for a vital sign has been determined, the set of points comprising the sample starts at the top of the ordered list and works downward until the target number of points is reached. The point grid was overlaid on mapped land cover data for the region (National Land Cover Data 1992, U.S. Geological Survey); points located in deciduous forest, evergreen forest, mixed forest, or woody wetlands comprise the set of forest points (n = 3495; n = 2962, when points on easement or other non-federal lands within park boundaries [e.g., CHOH and Piscataway Park/NACE] are excluded).

The sampling design for forest-nesting birds is constrained not only by the GRTS design, but by the desire to obtain network-wide measures of abundance or density for a wide variety of bird species, some of which are sparsely or patchily distributed. Because of the inherent heterogeneity of the NCRN parks, we believe that sampling at a large number of points from the GRTS frame is necessary to provide adequate coverage of particular habitats used by priority species. More intensive sampling at a smaller number of points risks missing some species altogether. Efficiently accomplishing this necessitates adopting a count-based sampling method, rather than using territory mapping or a capture-mark-recapture approach (e.g., Efford 2004, Efford et al. 2004) to estimate species' densities.

### *Counting Method*

In recent years, considerable discussion and research has focused on improving methods to assess bird abundance from count data. Traditional methods that use raw counts of birds heard or seen to index abundance are now often viewed as inadequate for drawing inferences about changes in abundance or density over time or space, because the probability of detecting birds can vary with observer, time of day or season, weather conditions, habitat, or other factors. Incomplete detection of birds creates a potential for artifactual variation due to variation in the

detection probability rather than in population size or density. Consequently, field methods that allow for estimation of detection probabilities are strongly recommended (e.g., Fancy and Sauer 2000, Lancia et al. 2005) so that counts can be adjusted to obtain 'absolute' estimates of bird density or abundance; these include distance sampling (Buckland et al. 2001), double-observer counts (Nichols et al. 2000), and removal or time of detection sampling (Farnsworth et al. 2002, Alldredge et al. 2007). However, these methods each have a set of assumptions that can be difficult to meet, and require more complex data collection procedures, putting additional burdens upon (and requiring additional skills of) observers. We reviewed (see appendix 1) the 'absolute' counting methods that currently are available, considering their suitability and feasibility for monitoring forest birds in NCRN parks, based in part on personal experience in using these methods in field surveys of forest-nesting birds.

The goal for forest bird monitoring in NCRN is to obtain a precise annual measure of species-specific population density that can be used to track changes in density over time. This goal does not in itself require an estimate of absolute density (only a relative measure is needed), although absolute estimates have some desirable properties, particularly robustness to systematic variation in detection probability caused by changing observers and counting conditions. However, density estimation causes a loss of precision compared to analysis of raw counts (e.g., Skalski and Robson 1992, and see below). It is unclear yet whether the greater robustness of density estimates to extraneous variation in detectability justifies the cost in precision.

Recommended Method

We propose a hybrid monitoring design for NCRN forest birds. We recommend that point-count data be recorded in two distance classes ('near' and 'far') to allow density estimation using the half-normal binomial distance model (Buckland et al. 2001). This approach greatly simplifies the task of measuring distances: it is necessary only to determine if detected birds are within or beyond a specified distance. It yields a measure of detectability, expressed either as the distance at which the probability of detection is 0.5, or the effective radius of detection (Buckland et al. 2001), allowing observer- or habitat-specific calculations of area sampled. There is a slight loss of efficiency relative to the half-normal model applied to ungrouped detection distances, and it is not possible to test the goodness of fit, but the binomial model is considered to effectively estimate relative density, although estimates of absolute density may be biased (Buckland et al. 2001). Possibly, a weak estimate of absolute density may serve as a better index (measure) than a count with no adjustment for varying detection probability. This view is expressed by Buckland (1987) in relation to binomial counts, and is implicit in the various other attempts to refine point counts (e.g., Nichols et al. 2000, Farnsworth et al. 2002). We therefore also advocate adopting a sampling design that reduces variation in detectability to the extent possible so that the resulting count data also can be analysed by Poisson regression using generalized linear models (McCullagh and Nelder 1989) or Hierarchical Bayes methods (e.g., Link and Sauer 2002, Royle and Dorazio 2006).

Additionally, we recommend that each count be 10 minutes in length, subdivided into four 2.5-min time intervals, with birds recorded in both the distance and time interval where first detected. Although this count duration is considerably longer than recommended for distance sampling (Buckland et al. 2001, appendix 1), it offers some advantages. First, it will likely increase the number of detections of "rare" species (see Dawson et al. 1995), which may sing less frequently than birds with near neighbours, while expending relatively little extra effort (i.e.,

time). For more common species, where increased count length increases the probability of birds moving, resulting in double-counting, the count data easily can be subset for distance analysis to include only detections from the first one or two time intervals (i.e., 2.5 min or 5 min). Second, it also allows for estimation of detection probability and abundance/density using the removal method outlined in Farnsworth et al. (2002) or by distance-removal methods (Burnham et al. 2004), when they are more fully developed. Because the robustness of the combined method to pooling across observers and habitats is still in doubt (Efford and Dawson 2009.), we use binomial distance estimates and unadjusted counts in the power analyses presented below.

### *Power Analysis*

Background

The intensity of monitoring must be sufficient to deliver adequate precision. Precision is adequate when a statistical test has a high probability of detecting significant change in population density, given that change has occurred. This is expressed as the 'power' of the comparison, denoted 1–β. Power depends on the magnitude of the actual change ('effect size') and also on the value of α, the chosen probability of rejecting the null hypothesis by chance. We conducted simulation analyses to assess power for forest bird monitoring in NCRN, nominating an effect size of 50% population decrease in 10 years. One-sided tests are more powerful than two-sided tests if only one direction of change is of interest, but we focus on two-sided tests because both increases and declines likely are of interest. Conventional targets for power are 80% and 90%. In monitoring analyses, the conventional α level of 0.05 is sometimes increased to 0.1 (e.g., Purcell et al. 2005) or 0.2 (Gibbs et al. 1998) to increase power at the expense of more frequent 'false alarms'. In our analyses, designs that yielded 80% power for α = 0.05 yielded 90% power for α = 0.1.

Annual Population Variation

Population variation about the trend line (temporal 'process variance') is an important determinant of power (e.g., Hatch 2003, Thomas et al. 2004a). We obtained indicative estimates of population variation for 46 of the bird species that nest in forests in NCRN parks by analyzing annual indices of abundance derived from data collected along Breeding Bird Survey routes surveyed in Maryland during 1966–2004 (Sauer et al. 2005, appendix 2). The measure we use is the standard deviation of the residuals of logged index values from the loglinear regression line $\hat{\sigma}(y_i)$. We assume that process variance dominates sampling error in the larger survey. Species other than Carolina Wren ($\hat{\sigma}(y_i) = 0.38$) and Yellow-billed Cuckoo ($\hat{\sigma}(y_i) = 0.28$) fall close to the median $\hat{\sigma}(y_i) = 0.10$ (appendix 2), which we used for the power simulations reported here.

Precision of Annual Estimate

Within-year precision is a further determinant of power to detect a temporal trend, and one that relates directly to sampling effort. The coefficient of variation $\mathrm{CV}(\hat{D})$ of each annual index or estimate is a convenient measure of within-year precision. (We use $\hat{D}$ here for both density estimates and unadjusted counts). We approach the power analysis for binomial distance in two stages: determine the within-year CV required to detect trend, and then determine how to achieve that CV by distance sampling.

To achieve our target (detection of 50% population decrease in 10 years), the TRENDS software (Gerrodette 1987, 1991) indicates a minimum value of $\mathrm{CV}(\hat{D}) = 0.17$ for the first year. We set $\mathrm{CV(D)} \propto 1/\sqrt{\mathrm{D}}$, which applies, at least approximately, to both binomial distance estimates and Poisson regression. Essentially identical results were obtained for $\alpha = 0.05$, $1-\beta = 0.8$ and $\alpha = 0.10$, $1-\beta = 0.9$. Very similar results are derived by Thomas et al. (2004a, Fig. 5.6, with $\lambda = 0.5^{0.1} = 0.93$) for the assumption of constant CV. This criterion for precision makes no direct allowance for process variance.

Power calculations for unadjusted count data are outlined in appendices 3 and 4. Trend was estimated by Poisson regression allowing for overdispersion (i.e., by fitting a generalized linear model with log link and variance proportional to the expected value, using the 'quasipoisson' family in the R programming language and statistical package, http://www.r-project.org/). The null hypothesis of no trend was rejected when the reduction in deviance from adding a 'year' effect to the model was significant by an F-test. Dispensing with observer effects and spatial structure, this analysis yields the target $\mathrm{CV}(\hat{D})$ shown in Table 2. In the absence of process variance, the values nearly match those from TRENDS. With realistic process variance, the target is $\mathrm{CV}(\hat{D}) = 0.14$. The power target is arbitrary; more subtle persistent trends may be detected with the same effort by monitoring for longer (Figure 1).

**Table 3.** Precision of annual estimates required to detect 50% population decrease in 10 years with given power using Poisson Regression analysis of unadjusted count data[a].

| | | | Required: | |
|---|---|---|---|---|
| **α** | **1–β** | **Process Variance** | **Total birds counted in year 1** | $CV(\hat{D})$ |
| 0.05 | 0.8 | None | 35 | 0.17 |
| 0.1 | 0.9 | None | 35 | 0.17 |
| 0.05 | 0.8 | $\sigma(y_i) = 0.1$ | 49 | 0.14 |
| 0.1 | 0.9 | $\sigma(y_i) = 0.1$ | 48 | 0.14 |

a. All tests are two-sided. Power estimated by Monte Carlo simulation with the R function **`simPower`** (appendix 4). Corresponding $\mathrm{CV}(\hat{D})$ estimated as $1/\sqrt{\text{count}}$.

How many birds must be counted to achieve CV(D) = 0.14?

We focus now on how to achieve $\mathrm{CV}(\hat{D}) = 0.14$ with binomial distance sampling and analysis. The precision of a distance estimate based on point counts is

$$\mathrm{CV}(\hat{D}) = \sqrt{\frac{\hat{V}(n)}{n^2} + \frac{\hat{V}(\hat{h}(0))}{[\hat{h}(0)]^2}}\,, \qquad (1)$$

where n is the total number of birds counted and h(0) is the slope of the tangent to the density function at distance r = 0 (Buckland 1987:365). For counts alone, the expression reduces to $\sqrt{\frac{\hat{V}(n)}{n^2}}$. If animals are distributed completely at random, then $\hat{V}(n) = n$, and $\mathrm{CV}(n) = \frac{1}{\sqrt{n}}$. If birds are spatially 'overdispersed' (i.e., clumped) this underestimates the actual CV and other estimates are preferred (e.g., Burnham et al. 1980, Buckland 1987).

The second term in (1) depends on details of the distance analysis. In the case of binomial distance sampling, the only other parameter is the proportion $p_1$ of detections in the 'near' distance class, which varies with the distance threshold. Precision is greatest for $p_1 \approx 0.8$, but there is remarkably little variation for $p_1$ in the range 0.5 to 0.9 (Figure 2).

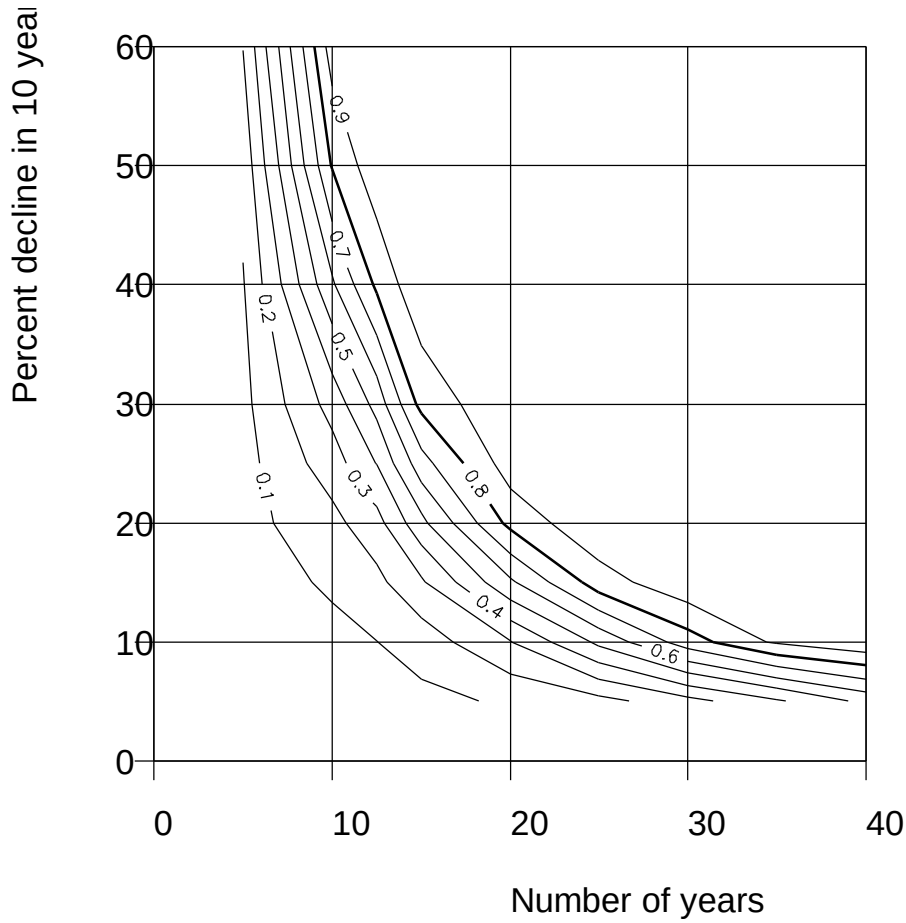


**Figure 1.** Contours of power (1–β) to detect trends of varying slope (y-axis) in relation to the duration of monitoring (x-axis). Sampling effort each year was held constant at the level required to yield 80% power to detect a 50% decline in 10 years (Table 2). The contour for 80% power (1- β = 0.8) is emphasized (visible when zoomed in). Results by linear interpolation from a grid of output values, each based on 5000 replicates in **`simPower`** (appendix 4): Poisson regression fitted by quasi-likelihood; two-sided tests with α = 0.05 and process variation $\sigma(y_i) = 0.1$. Sustained declines of 20% per 10 years may be detected with 80% power after 20 years.

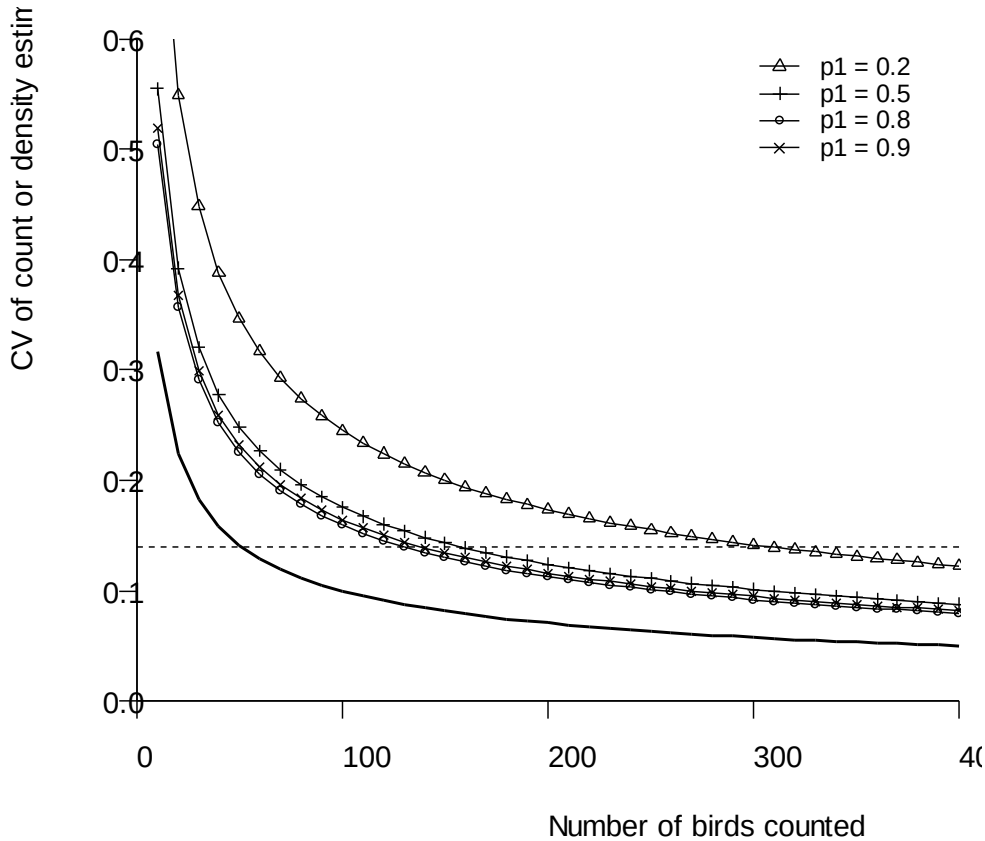


**Figure 2.** Precision of unadjusted count (solid line) for varying total count, compared to precision of binomial distance estimate of density with varying proportion ($p_1$) of birds in the 'near' category. Dashed horizontal line indicates a target CV of 0.14, sufficient to provide power of 0.8 for detecting a trend leading to 50% change over 10 years. Precision of unadjusted count is Poisson variance conditional on placement of the sampling points. Precision of binomial distance estimates used the asymptotic formula for a half-normal detection function (Buckland 1987).

From Buckland et al. (2001: 245), we have the following approximate expression for the number of sampling points k required for $\mathrm{CV}(\hat{D}) = 0.14$, given a mean count per point of m: $k = b / 0.14^2 / m$. The constant b reflects the shape of the detection function; a value of 3.0 is suggested (Buckland et al. 2001). Thus, for a species counted at 1.0 per point on average, 153 points should be counted to provide $\mathrm{CV}(\hat{D}) = 0.14$. A similar estimate may be obtained from Figure 2. In general, about three times as many detections are required for binomial distance estimation as for analysis of unadjusted count data. For $p_1 \geq 0.5$, only marginal gains in precision are expected from full distance analysis, the real benefits of which lie in more accurate modelling of detection functions than can be done with binomial distance data (Buckland 1987 Table 1; Buckland et al. 2001).

<u>Distance Threshold</u>

Choice of an inappropriate threshold distance to separate the 'near' and 'far' distance classes may cause $p_1 << 0.5$ for many species, and this is definitely to be avoided for its effect on precision (Figure 2). Data from breeding bird surveys in NACE and CATO (Table 3) suggest that 50 m is a suitable threshold for many species. There is virtually no species for which a 50-m

threshold is demonstrably too large ($p_1$ >> 90%). Several species do show $p_1 < 0.5$ for a 50-m threshold. However, we do not advise the use of a larger threshold because distances greater than 50 m are generally difficult to estimate accurately in forest.

**Table 4.** Mean number of birds counted per point (Mean/Pt)

| Species | NACE | | CATO | | | CHOH | MEAN/ 10-min |
|---|---|---|---|---|---|---|---|
| | Mean/pt | p50 | Mean/pt | p25 | p50 | Mean/pt | |
| Red-eyed Vireo | 1.66 | 0.48 | 2.67 | 0.16 | 0.42 | 0.79 | 1.712 |
| American Crow | 2.51 | 0.13 | 0.58 | 0.00 | 0.04 | 1.42 | 1.660 |
| Northern Cardinal | 1.56 | 0.69 | 0.53 | 0.20 | 0.52 | 1.11 | 1.184 |
| Tufted Titmouse | 1.45 | 0.68 | 0.66 | 0.16 | 0.48 | 0.77 | 1.032 |
| Wood Thrush[b] | 0.73 | 0.42 | 1.99 | 0.09 | 0.23 | 0.32 | 0.988 |
| Common Grackle | 1.44 | 0.39 | 0.01 | 1.00 | 1.00 | 1.11 | 0.988 |
| Acadian Flycatcher[b] | 0.87 | 0.60 | 1.04 | 0.11 | 0.35 | 0.65 | 0.897 |
| Carolina Wren[b] | 1.33 | 0.57 | 0.23 | 0.14 | 0.27 | 0.67 | 0.817 |
| Carolina Chickadee | 1.34 | 0.80 | 0.32 | 0.23 | 0.77 | 0.49 | 0.766 |
| Red-bellied Woodpecker[b] | 0.68 | 0.32 | 0.58 | 0.11 | 0.36 | 0.56 | 0.658 |
| Eastern Wood-Pewee | 0.35 | 0.49 | 1.02 | 0.09 | 0.33 | 0.45 | 0.625 |
| European Starling | 1.20 | 0.31 | 0.00 | 0.00 | 0.00 | 0.49 | 0.623 |
| Blue-gray Gnatcatcher | 0.62 | 0.96 | 0.20 | 0.32 | 0.89 | 0.60 | 0.538 |
| Scarlet Tanager | 0.30 | 0.56 | 1.15 | 0.18 | 0.42 | 0.11 | 0.494 |
| American Goldfinch | 0.79 | 0.60 | 0.14 | 0.31 | 0.62 | 0.35 | 0.465 |
| American Robin | 0.54 | 0.61 | 0.24 | 0.22 | 0.48 | 0.38 | 0.426 |
| Indigo Bunting[b] | 0.45 | 0.51 | 0.05 | 0.00 | 0.00 | 0.56 | 0.420 |
| Blue Jay | 0.44 | 0.37 | 0.62 | 0.09 | 0.21 | 0.19 | 0.418 |
| Downy Woodpecker | 0.53 | 0.68 | 0.25 | 0.17 | 0.58 | 0.24 | 0.364 |
| Cedar Waxwing | 0.52 | 0.52 | 0.23 | 1.00 | 1.00 | 0.18 | 0.326 |
| Gray Catbird | 0.51 | 0.78 | 0.21 | 0.40 | 0.75 | 0.18 | 0.315 |
| Great Crested Flycatcher | 0.22 | 0.49 | 0.32 | 0.13 | 0.47 | 0.29 | 0.302 |
| Eastern Towhee[b] | 0.47 | 0.50 | 0.37 | 0.03 | 0.34 | 0.06 | 0.294 |
| Mourning Dove | 0.31 | 0.50 | 0.18 | 0.12 | 0.47 | 0.29 | 0.291 |
| White-breasted Nuthatch | 0.24 | 0.81 | 0.34 | 0.22 | 0.78 | 0.16 | 0.255 |
| Brown-headed Cowbird | 0.30 | 0.75 | 0.27 | 0.20 | 0.72 | 0.15 | 0.250 |
| Red-winged Blackbird | 0.43 | 0.31 | 0.00 | 0.00 | 0.00 | 0.19 | 0.228 |
| Pileated Woodpecker | 0.08 | 0.03 | 0.35 | 0.09 | 0.24 | 0.20 | 0.221 |

**Table 5.** Mean number of birds counted per point (Mean/Pt) (continued)

| Species | NACE | | CATO | | | CHOH | MEAN/ 10-min |
|---|---|---|---|---|---|---|---|
| | Mean/pt | p50 | Mean/pt | p25 | p50 | Mean/pt | |
| Baltimore Oriole | 0.13 | 0.51 | 0.01 | 0.00 | 0.00 | 0.36 | 0.209 |
| Northern Parula | 0.26 | 0.53 | 0.03 | 0.00 | 0.33 | 0.22 | 0.195 |
| Northern Flicker | 0.13 | 0.32 | 0.18 | 0.12 | 0.35 | 0.17 | 0.175 |
| Yellow-billed Cuckoo | 0.13 | 0.54 | 0.09 | 0.13 | 0.38 | 0.23 | 0.174 |
| Song Sparrow | 0.15 | 0.43 | 0.001 | 0.00 | 0.00 | 0.26 | 0.169 |
| House Wren | 0.16 | 0.40 | 0.06 | 0.00 | 0.00 | 0.16 | 0.147 |
| American Redstart | 0.001 | 0.00 | 0.39 | 0.14 | 0.49 | 0.06 | 0.146 |
| Louisiana Waterthrush[b] | 0.04 | 0.40 | 0.16 | 0.07 | 0.33 | 0.16 | 0.133 |
| Hooded Warbler[b] | 0.13 | 0.51 | 0.28 | 0.04 | 0.35 | 0.001 | 0.126 |
| Wood Duck | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.24 | 0.113 |
| Hairy Woodpecker | 0.09 | 0.51 | 0.21 | 0.35 | 0.80 | 0.03 | 0.110 |
| Yellow-throated Vireo[b] | 0.01 | 0.25 | 0.22 | 0.19 | 0.38 | 0.07 | 0.104 |
| Fish Crow | 0.18 | 0.30 | 0.00 | 0.00 | 0.00 | 0.08 | 0.098 |
| Common Yellowthroat | 0.16 | 0.58 | 0.00 | 0.00 | 0.00 | 0.10 | 0.098 |
| Eastern Phoebe | 0.05 | 0.72 | 0.06 | 0.00 | 0.17 | 0.12 | 0.090 |
| Cerulean Warbler[b] | 0.00 | 0.00 | 0.20 | 0.05 | 0.21 | 0.06 | 0.089 |
| Warbling Vireo | 0.04 | 0.31 | 0.00 | 0.00 | 0.00 | 0.16 | 0.087 |
| Kentucky Warbler[b] | 0.14 | 0.43 | 0.11 | 0.20 | 0.50 | 0.001 | 0.081 |
| Pine Warbler[b] | 0.14 | 0.64 | 0.00 | 0.00 | 0.00 | 0.07 | 0.078 |
| Northern Mockingbird | 0.19 | 0.32 | 0.00 | 0.00 | 0.00 | 0.02 | 0.072 |
| Prothonotary Warbler[b] | 0.11 | 0.48 | 0.00 | 0.00 | 0.00 | 0.07 | 0.071 |
| Eastern Kingbird | 0.12 | 0.61 | 0.00 | 0.00 | 0.00 | 0.06 | 0.067 |
| Worm-eating Warbler[b] | 0.05 | 0.5 | 0.07 | 0.57 | 0.86 | 0.06 | 0.065 |
| Chipping Sparrow | 0.06 | 0.39 | 0.03 | 0.00 | 0.33 | 0.04 | 0.050 |
| N. Rough-winged Swallow | 0.06 | 0.57 | 0.00 | 0.00 | 0.00 | 0.07 | 0.049 |
| White-eyed Vireo[b] | 0.12 | 0.44 | 0.00 | 0.00 | 0.00 | 0.02 | 0.046 |
| Veery | 0.00 | 0.00 | 0.15 | 0.00 | 0.57 | 0.001 | 0.045 |
| Orchard Oriole | 0.09 | 0.49 | 0.00 | 0.00 | 0.00 | 0.03 | 0.044 |
| Yellow Warbler | 0.03 | 0.25 | 0.00 | 0.00 | 0.00 | 0.07 | 0.042 |
| Eastern Bluebird | 0.05 | 0.68 | 0.00 | 0.00 | 0.00 | 0.05 | 0.038 |
| Ruby-throated Hummingbird | 0.06 | 0.95 | 0.02 | 1.00 | 1.00 | 0.03 | 0.037 |
| Yellow-throated Warbler[b] | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.07 | 0.032 |

**Table 5.** Mean number of birds counted per point (Mean/Pt) (continued)

| Species | NACE | | CATO | | | CHOH | MEAN/ 10-min |
|---|---|---|---|---|---|---|---|
| | Mean/pt | p50 | Mean/pt | p25 | p50 | Mean/pt | |
| Yellow-breasted Chat | 0.06 | 0.41 | 0.00 | 0.00 | 0.00 | 0.02 | 0.029 |
| Black-capped Chickadee | 0.00 | 0.00 | 0.001 | 0.00 | 0.00 | 0.06 | 0.028 |
| Red-shouldered Hawk[b] | 0.05 | 0.11 | 0.00 | 0.00 | 0.00 | 0.02 | 0.026 |
| Blue Grosbeak | 0.08 | 0.46 | 0.00 | 0.00 | 0.00 | 0.00 | 0.025 |
| Belted Kingfisher | 0.001 | 0.00 | 0.01 | 1.00 | 1.00 | 0.05 | 0.025 |
| Tree Swallow | 0.03 | 0.80 | 0.00 | 0.00 | 0.00 | 0.03 | 0.023 |
| Wild Turkey | 0.00 | 0.00 | 0.04 | 0.00 | 0.00 | 0.02 | 0.022 |
| Green Heron | 0.02 | 0.50 | 0.00 | 0.00 | 0.00 | 0.03 | 0.022 |
| Red-tailed Hawk | 0.01 | 0.00 | 0.04 | 0.00 | 0.25 | 0.00 | 0.016 |
| Brown Thrasher[b] | 0.04 | 0.56 | 0.00 | 0.00 | 0.00 | 0.003 | 0.016 |
| Turkey Vulture | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.009 |
| Black-and-white Warbler | 0.001 | 0.00 | 0.02 | 0.50 | 0.50 | 0.00 | 0.007 |
| Prairie Warbler[b] | 0.003 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.006 |
| Black-billed Cuckoo | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.005 |
| Rose-breasted Grosbeak | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.001 | 0.004 |
| Common Raven | 0.00 | 0.00 | 0.001 | 0.00 | 0.00 | 0.01 | 0.003 |
| Summer Tanager | 0.003 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.001 |
| Ovenbird | 0.45 | 0.35 | 0.98 | 0.05 | 0.14 | 0.01 | 0.448 |

**Notes:**

a. NACE (10-min counts conducted in 1999, Dawson and Gough 2001), CATO (12-min counts conducted in 2002, Bates et al. 2005), and CHOH (5-min counts conducted in 1995, 1998, and 2001; Gates and Walters 2003). The proportion of birds detected within 50 m (p50) is shown for NACE and the proportion within 25 m (p25) and 50 m (p50) for CATO. Counts from CATO and CHOH were standardized to 10-min count length before overall mean (MEAN/10-min) was calculated.

b. Bird species that are priorities for conservation efforts (Rich et al. 2004).

How Many Point Counts?

Average counts of forest-nesting bird species are available from recent surveys in NACE, CATO, and CHOH (table 3). These surveys differed in count duration, skill level of observers, and timing. We adjusted counts from CATO (12 min) and CHOH (5 min) to a standard duration of 10 min used in the surveys in NACE (Figure 3).

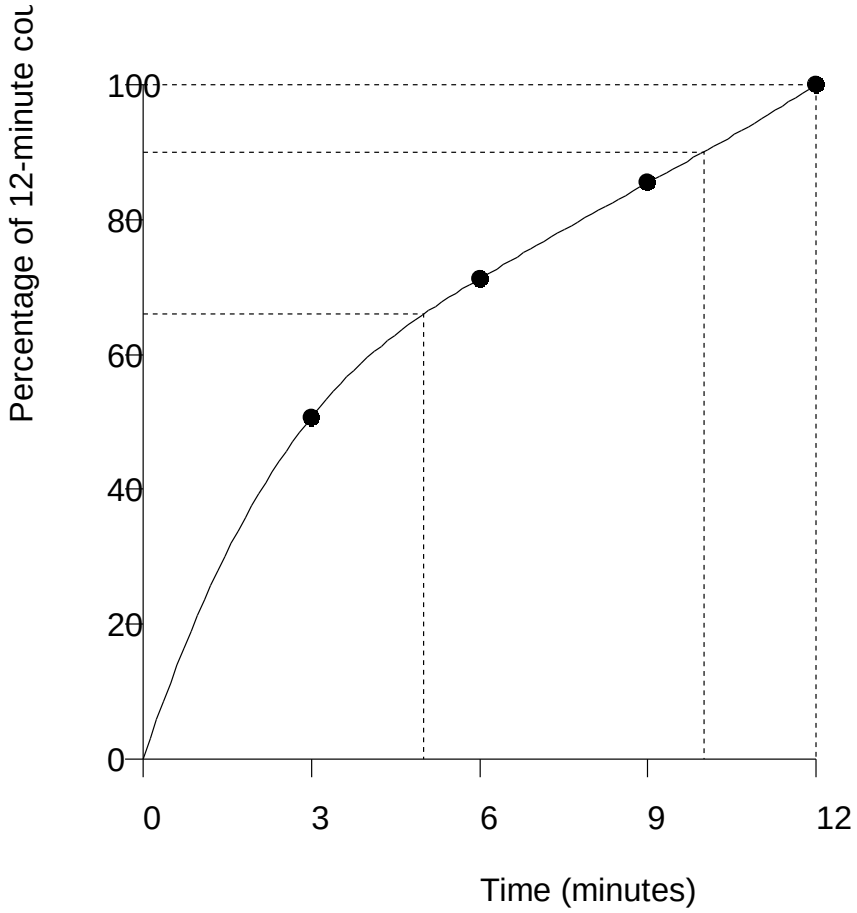


**Figure 3.** Cumulative counts of all species in CATO survey (total n = 2500), with cubic spline interpolation. Predicted counts are 66.0% of 12-min total after 5 min and 90.0% after 10 min.

The required number of 10-min counts depends on the expected mean number per count for each species and the target total annual number of birds counted (i.e., if you expect a mean of 1 bird per 10-min count, then count data are needed from 49 points for Poisson regression of unadjusted count data, or from 153 points for binomial distance analysis). These are combined graphically in Figure 4.

It is immediately obvious that some bird species are detected too seldom to be surveyed by point counts, mostly because of known peculiarities of their biology. The 'tail' of 10 species with mean count per point < 0.02 would require >2000 10-min counts per year, which is almost certainly impractical. A further group of 17 species, including three of the priority species, with mean count of 0.02–0.05, would require >1,000 10-min counts per season. A cluster of eight priority species have mean counts in the range 0.065 (Worm-eating Warbler) to 0.133 (Louisiana

Waterthrush), and we propose the sampling design for NCRN be sized to monitor these. This leads to a requirement for approximately 49/0.065 = 754 10-min counts per year. Exclusive reliance on binomial distance methods reduces from 52 to 30 the number of species (and from 14 to 6 priority species) for which this effort is predicted to meet the power target (80% power to detect 50% decline in 10 years).

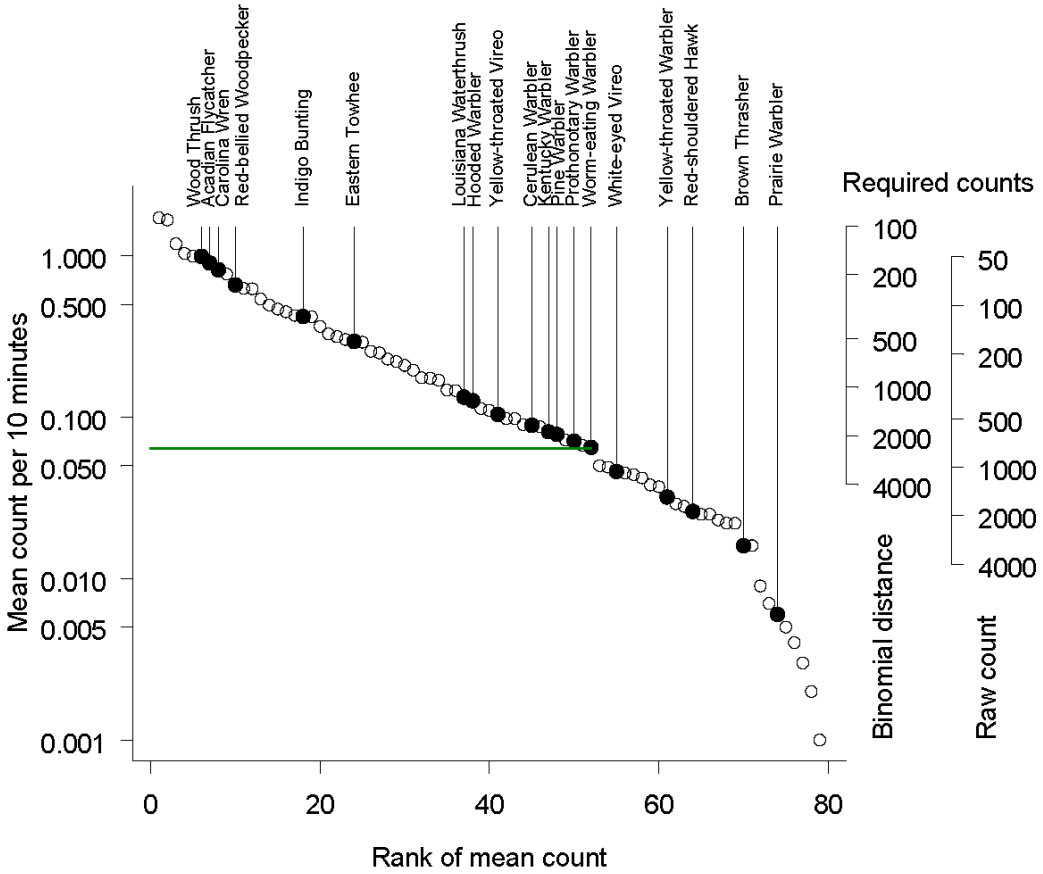


**Figure 4.** Distribution across species of mean number counted per 10 min, in relation to the total annual count required for 80% power to detect a 50% decline in 10 years. Required total annual count (scaled bars on right) is shown for both binomial distance analysis ('near-far') and a Poisson regression analysis of unadjusted (raw) count data (assumptions as in Table 2 and Figure2). Data from three previous studies (CATO, NACE, CHOH) were standardized to 10-min counts based on time-of-detection data from CATO (5-min count x 1.36; 12-min count x 0.90). Species of conservation priority are identified. A design with 754 10-min point-counts each year is likely to have the required power for about 50 species (horizontal line), including 14 of the 19 priority species, assuming the analysis is based on unadjusted count data.

### *Personnel Required and Distribution of Effort*

**Three observers** will be needed to conduct the required number of point-counts (754) during the roughly six-week period in late May through early July when nearly all forest birds in the National Capital Region are settled on territories and actively vocalizing. The target number of counts can be obtained in one of two ways: by sampling 754 points once, or by making repeat visits to a smaller number of points. Although the first option allows for greater sampling of the spatial variation in NCRN, we recommend the second, specifically sampling 377 points twice during each year, with each point counted once in each half of the field season. This option balances the within-season coverage of points to increase the number of detections for species

whose detectability dwindles or increases through the breeding season. It also allows the coverage to be spatially balanced among observers, and for differences among observers to be tested.

The points in the GRTS sample are widely dispersed, and the limited time available for sampling (six weeks each year, mornings only) demands that they be sampled as efficiently as possible. Travel times can be greatly reduced by visiting points in close proximity in succession on one morning rather than in the random sequence generated by the GRTS design. We call such convenient groups of points 'routes' (cf BBS and Purcell et al. 2005, though note that, unlike in these surveys, points in the NCRN GRTS design are independent). If possible, routes should be in the same habitat, so that they can be used also as units of analysis. When points are grouped in this way, routes become the units for allocation of observers to visits (i.e., all points on a route are visited by the same observer on the same morning). It is highly desirable that all routes be comprised of a constant number of points. If this is not the case, then care must be taken in analyses to allow for the size of each route (e.g., by using 'weights' in Poisson regression models, Chambers and Hastie 1993). **Therefore, we round up to 384 the recommended number of points to sample, grouped into 48 routes of 8 points (the expected average number of points that can be visited and counted in one morning), each counted twice, or 768 10-min counts.**

To achieve balanced coverage of routes/points by observers, the two visits to routes/points should be made by different observers, and all observers should conduct the same number of 10-min counts (768/3 = 256). We provide (SOP, Section ii) a scheme that randomly assigns observers to route-visits, and recommend that it be adhered to so that observer variation can be assessed. In formal statistical terms, this design does not allow an estimate of the within-observer variance for repeat visits to a site. However, there is evidence from the point count literature that such variation is Poisson or nearly so (i.e., variance/mean ratio in the range 1 to 2), and the benefit of direct estimation is minimal.

All first visits to points should be completed during the first three weeks of the field season, with second visits made during the final three weeks. The order in which routes are surveyed should be spatially balanced to the extent possible; e.g., don't visit and count all points in PRWI on consecutive days, but distribute visits to routes throughout each half of the field season. It also is desirable to balance the time of coverage within the morning, so that points counted in late morning on the first visit are counted at an earlier time on the second visit. However, we recognize that logistics may render impossible the balanced coverage of points with respect to time of day and season.

### *Data Summary and Analysis*

Pilot Year

The first year of sampling should be viewed as a pilot year. Data collected in this year should be analysed with respect to observer differences, species coverage, and precision (examples and R programming language code are provided in SOP, Section iv). The results will allow informed adjustments to the design for later years, but beyond this point changes should be minimized. Note that the term 'pilot' does not imply a token effort. In fact, the effort in year 1 should be greater than is likely to be sustainable, so as to provide the best possible basis for finalizing the

subsequent design. High precision in the first year's data will also be beneficial ultimately for measuring long-term trend.

The first year's effort will provide solid data and experience to re-evaluate some aspects of the design that are at present slightly speculative. Specifically:

- The proposed staffing level may not be sufficient to complete the desired number of counts during the time available for sampling (i.e., mornings during late May to early July).

- For the priority bird species and others that are relatively uncommon, the rates of gain in detections with successive time intervals should be examined to assess whether they justify a count duration of 10 minutes.

- The actual, presently unknown, distribution of species across the NCRN will have consequences for the mean number of individuals counted for species. Counts may also be affected by the skill levels of observers. Mean counts for species from the pilot year should be used to review monitoring targets by updating Figure 4, and either increasing or decreasing the sampling effort in subsequent years, as considered appropriate.

- Bird monitoring schemes are vulnerable to variation in skill level and performance among observers. The binomial distance method is intended to address this problem. Its performance should be evaluated by comparing observer differences in unadjusted (raw) counts with observer differences in density estimates: if binomial distance methods are effective, then the resulting observer-specific density estimates should be more similar than those based on unadjusted counts.

- Measurements of between-route variance may prompt some fine tuning of the design. Although a random route effect was provided for in the simulation model used for power analysis (appendix 3), we had no field data to indicate its magnitude, and we ignored it when estimating power. Hierarchical Bayes methods (e.g., Link and Sauer 2002) can be used to fit such a random effect. Otherwise, habitat covariates may prove important. One possible scenario is that a habitat of importance to one or more of the priority species is under-sampled by the GRTS sample, with the result that monitoring has inadequate power for these species. This may justify redistributing part of the sampling effort to increase the list of species with adequate data; e.g., adding more samples in CHOH could increase the number of points at which Cerulean Warbler, Prothonotary Warbler, Yellow-throated Warbler, and other species are counted. The key is congruence among several species, as resources are unlikely to be sufficient to support monitoring targeted at individual species.

<u>Analysis of Year-to-Year Changes and Long-term Trend</u>

Annual density estimates for bird species are calculated following the methods for binomial models described in Buckland (1987) and Buckland et al. (2001, Section 6.6.1); code in the R programming language (http://www.r-project.org/) is provided in Section iv of the SOP. The default is to use data from all sampled points to produce an annual network-wide estimate of density. However, for bird species that are relatively common, it may be possible to obtain

density estimates for the larger parks, for parks within the same landscape (i.e., urban, suburban, agricultural, forested), or for clusters of points or routes. Recording bird detections within time intervals also allows for estimation of species' abundances and detection probabilities by the removal method (Farnsworth et al. 2002), using Program CAPTURE (model $M_b$, White et al. 1982). In summary, NCRN staff should keep alert to new methods being developed for analysis of point count data (e.g., Royle and Dorazio 2006).

For basic between-year(s) analyses, a log-linear trend should be fit to the density estimates or unadjusted counts using a generalized linear model with log-link and variance proportional to the mean, fitted by quasi-likelihood (see R code and example in Section iv of SOP). If the precision of the estimates varies between years, the inverse variance estimates ($1/SEdensity^2$) should be used as weights (e.g., Thomas et al. 2004a: 81). In the longer term (> 10 years), it may be appropriate to fit nonlinear trajectories using generalized additive models (e.g., Fewster et al. 2000). In the GRTS design, each point on the grid has an equal probability of being selected for sampling, so inferences about density and population change can be made to the entire network.

Forest vegetation characteristics also will be sampled at all or most of the bird sampling points. When these data become available, the methods of Royle et al. (2004) can be used to identify vegetation covariates that significantly influence point-specific bird abundances and to adjust estimates of density accordingly. We do not describe other analyses of bird and vegetation data here. Note however that distance sampling and alternative methods for estimation of density do not produce point-specific estimates, but estimate density or abundance across a set of points. For bird species that are relatively common, density estimates from clusters of points can be related to forest vegetation characteristics sampled at the same set of points. Otherwise, vegetation characteristics can be used as explanatory variables in regression analyses, with point-specific unadjusted counts or presence/absence as the response variable.

### Supplemental Monitoring

Although we ruled out capture-mark-recapture as a monitoring method for NCRN, banding studies provide estimates of density (e.g., Efford et al. 2004) and other demographic parameters (e.g., annual adult survival, recruitment, productivity), which when monitored over space and time can provide insights to the mechanisms driving population change. As such, they provide a nice complement to count-based methods. Therefore, we recommend that NCRN staff provide encouragement and support to licensed banders who are interested in initiating studies of breeding birds in NCRN parks. If banders follow the protocols developed by the MAPS (Monitor Avian Productivity and Survival) program (DeSante et al. 2004, http://www.birdpop.org), administered by the Institute for Bird Populations, the data can also contribute to regional or national estimates of demographic parameters and population trends. However, note that the number and density of nets recommended in the MAPS protocol ($\leq$ 10 nets per 8 ha, more only with sufficient personnel and few birds) is generally too small to yield sufficient data for station/site-specific estimates. In a mist-netting study conducted in June 2005 on a forested site on the Patuxent Research Refuge in nearby Laurel, MD (Dawson and Efford, unpublished data), bird capture rates were extremely low. We found that both captures and re-captures of birds could be increased considerably by increasing the number of nets without increasing the area sampled (i.e., by increasing the density of nets), with negligible extra effort involved in checking them. An alternative is to establish multiple banding sites in similar habitat or strata, and pool

data across sites. With this approach, we recommend that at least three sites be located in parks within the same landscape (i.e., urban, suburban, agricultural, forested).

Additionally, NCRN staff should endorse and cooperate with efforts by others to survey forest bird populations in the National Capital Region. For example, bird populations in Washington, D.C., were sampled in the mid 1990s at points on the DC Birdscape grid (points spaced at 500-m intervals across the entire city, Hadidian et al. 1997). The grid was partially re-sampled in 2003 for DC Birdscape II (Katju and Dawson, unpublished), and there are tentative plans to finish the sampling in the upcoming breeding season, and possibly in future years. This survey, along with the ongoing Northern Virginia Bird Survey sponsored by The Audubon Society of Northern Virginia, provide additional information on the spatial distribution, abundance, and population changes of birds in urban and suburban parks managed by NPS, giving some perspective to results from the NCRN GRTS sample.

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# Appendix 1: Currently Available Bird Counting Methods That Allow For Estimation of Detection Probabilities

## Distance Sampling

Distance sampling has been widely advocated as a solution to the problem of incomplete detection (e.g., Buckland et al. 2001, Rosenstock et al. 2002, Ellingson and Lukacs 2003, Norvell et al. 2003, Buckland submitted). For counts made at points, the observer records the distances to birds seen or heard during a 'snapshot moment' or fixed, short time period. Either at the time of the count or during analysis, records beyond a fixed radius are discarded. The smoothed distribution of detection distances is used to estimate the number of birds present, but not detected, within the fixed radius (Buckland et al. 2001).

The main assumptions of the distance method for point counts are:

All birds directly above the point are detected.

A 'snapshot' is obtained, so that all birds are detected as if stationary.

Distance measurements are accurate, or detected birds are recorded in the correct distance interval.

Meeting these assumptions is difficult at best, especially in forests, where birds can be concealed by vegetation and most detections are aural, not visual. 'Mark-recapture distance-sampling' methods have been suggested for situations where the detection of animals at the point cannot be guaranteed, using either a sample of marked animals and measuring the proportion detected or counts from two observers, where the observations of one (or each) observer provide a 'marked' sample for the other, to estimate absolute detection probabilities in a distance-sampling framework (Laake and Borchers 2004); however, these methods have yet to be widely tested and are mostly not applicable to point counts. Breaches of assumption 2 can be alleviated somewhat by setting a count duration that is short (e.g., 5 min or less) or by focusing the counting effort on a pre-defined subset of species of interest and ignoring others. Distance measurements can be improved by enlisting observers who are skilled or trained in perceiving birds and estimating distances, and equipped with laser or optical rangefinders (though note that rangefinders can only measure distances to clear targets, not those obscured by foliage, so are of limited use at many points in forest). However, it remains that in forest most estimates of distance are to the perceived, not necessarily actual, locations of birds, so of questionable accuracy. In an experiment involving recorded bird songs broadcast from known locations, Simons et al. (2005) found that observers tend to overestimate distances to 'birds' within 30 m and underestimate distances to 'birds' more than 30 m away, and the ability of observers to perceive and locate birds is greatly influenced by ambient noise, including traffic, wind, and stream noise, and even the number and diversity of birds vocalizing nearby. Although recording detected birds within intervals of distance simplifies the task of measuring distances, it still can be extremely difficult to accurately assign birds to the proper interval, especially those at some distance from the observer.

## Double-Observer and Removal Models

'Double-observer' (Nichols et al. 2000) and 'removal' (Farnsworth et al. 2002) methods have been advanced as alternatives to distance methods for bird point counts. In general, we believe that, unless safety or other constraints require that observers work in pairs, double-observer methods are an inefficient use of resources, doubling the cost of field data collection or halving the number of points that can be sampled. In removal sampling, the counting period is sub-divided into time intervals, and the observer tallies birds in the interval when first detected. The numbers of birds first detected in successive time intervals are used to estimate population size and the probability of detection, as the product of the probability that a bird sings during the count and the probability that it is detected given that it sings.

Removal estimates are highly sensitive to heterogeneity of detection probability due to distance from the observer. Farnsworth et al. (2002) attempted to allow for this by fitting simple mixture models, but this approach is ineffective at removing the bias. Combining distance and removal methods is a more promising approach as it potentially eliminates bias due to distance-related decline in detection. The method was mentioned by Farnsworth et al. (2002), and theory for a combined model was given by Burnham et al. (2004). We (unpublished) implemented the method for count data where distances to birds were recorded in intervals, and tested it on simulated data and on field data collected simultaneously in distance intervals (0-25 m, 25-50 m, 50-75 m, 75-100 m) and time intervals (0-3 min, 3-6 min, 6-9 min, 9-12 min) in the Catoctin Mountains, Frederick County, Maryland (CATO and the nearby Frederick City Watershed Cooperative Wildlife Management Area, Bates et al. 2005). The method shows promise with simulated data, but some weaknesses have been uncovered. Standard methods for model selection (AIC: Akaike Information Criterion, Burnham and Anderson 1992) reject the distance-removal model in favor of simpler (distance-only) models when data are sparse. When fitted to field data there is a consistent pattern of poor model fit in some distance-time classes that requires further investigation ((unpublished). We therefore believe it is premature to advocate the method for general use.

## Occupancy Methods

Bird monitoring usually aims to describe changes in population size or density. An alternative is to describe changes in the proportion of habitat patches that are occupied (i.e., 'occupancy') by species of interest. On a single survey all species that occupy a patch may not be detected, but rigorous statistical methods exist to estimate overall occupancy rates for species (MacKenzie et al. 2002). These methods are relatively easy to apply: it is simply necessary to make a series of independent surveys over a short period of time, recording whether or not a species is detected. Measurement of occupancy rather than density therefore has some appeal, especially for species with sparse populations (MacKenzie et al. 2004, 2005).

We do not advocate occupancy methods for NCRN for two reasons. First, the Network does not comprise a natural set of discrete habitat patches, and the park units that can be described as patches are extremely heterogeneous in shape and size. Second, although occupancy can be estimated from data on bird occurrence at points on a grid (results interpreted as 'proportion of area occupied'), this does not yield a meaningful parameter for monitoring. This is because the probability of detecting a species at a point varies both with the scale of bird movements within a territory or home range, and with the distance at which birds are detected by visual or auditory cues. Point 'occupancy' therefore confounds the population parameter that we wish to monitor

(i.e., density) with observational and behavioral variables that depend in unknown ways on habitat, observer skill, population density, or other factors. No method exists to adjust point 'occupancy' for these effects.

# Appendix 2: Population Variation From Breeding Bird Survey Routes in Maryland

We analysed data from Breeding Bird Survey (BBS) routes conducted in Maryland during 1966 to 2004 to estimate the inherent population variation $\sigma(y_i)$ for 46 of the bird species that nest in forests in NCRN parks. Annual index values (residuals from route regressions using regional trends) were obtained from the BBS website (Sauer et al. 2005). For each species we calculated the standard error of the estimate for a linear trend fitted by least squares to the logged data. The method provides only an approximate upper bound for $\sigma(y_i)$, because the BBS data include sampling error (although probably much less than the proposed NCRN counts because of the large number of counts, approximately 2500 3-min counts per year, i.e., 50 routes, each with 50 3-min stops/counts), and because of differing spatial scale (the area sampled by Maryland BBS routes is greater than NCRN). It is also possible that this analysis is biased by the route regression analysis. However, we wish to use historical patterns of variation only as a general indication of what may apply in the future, so greater accuracy appears unnecessary.

The logged indices are plotted on the following pages to illustrate the range of trends found in different species. Each graph is scaled between 10% and 100% of the maximum index value for the species. Although a surprising number of species show sustained trends, these were seldom outside the range ±20% per 10 years (0.8<Trend10<1.2, Figure 1a). Carolina Wren ($\hat{\sigma}(y_i) = 0.38$) and Yellow-billed Cuckoo ($\hat{\sigma}(y_i) = 0.28$) show exceptional variation around a log-linear trend. Other species are clustered around the median $\hat{\sigma}(y_i) = 0.10$ (Figure 1b).

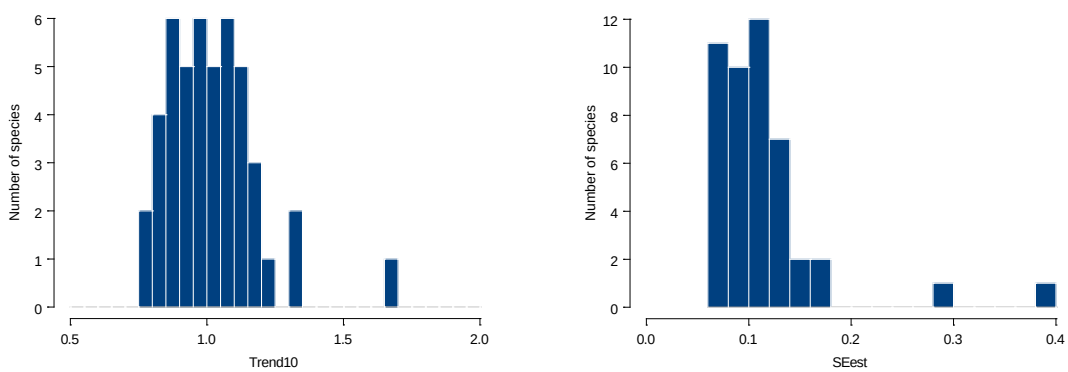
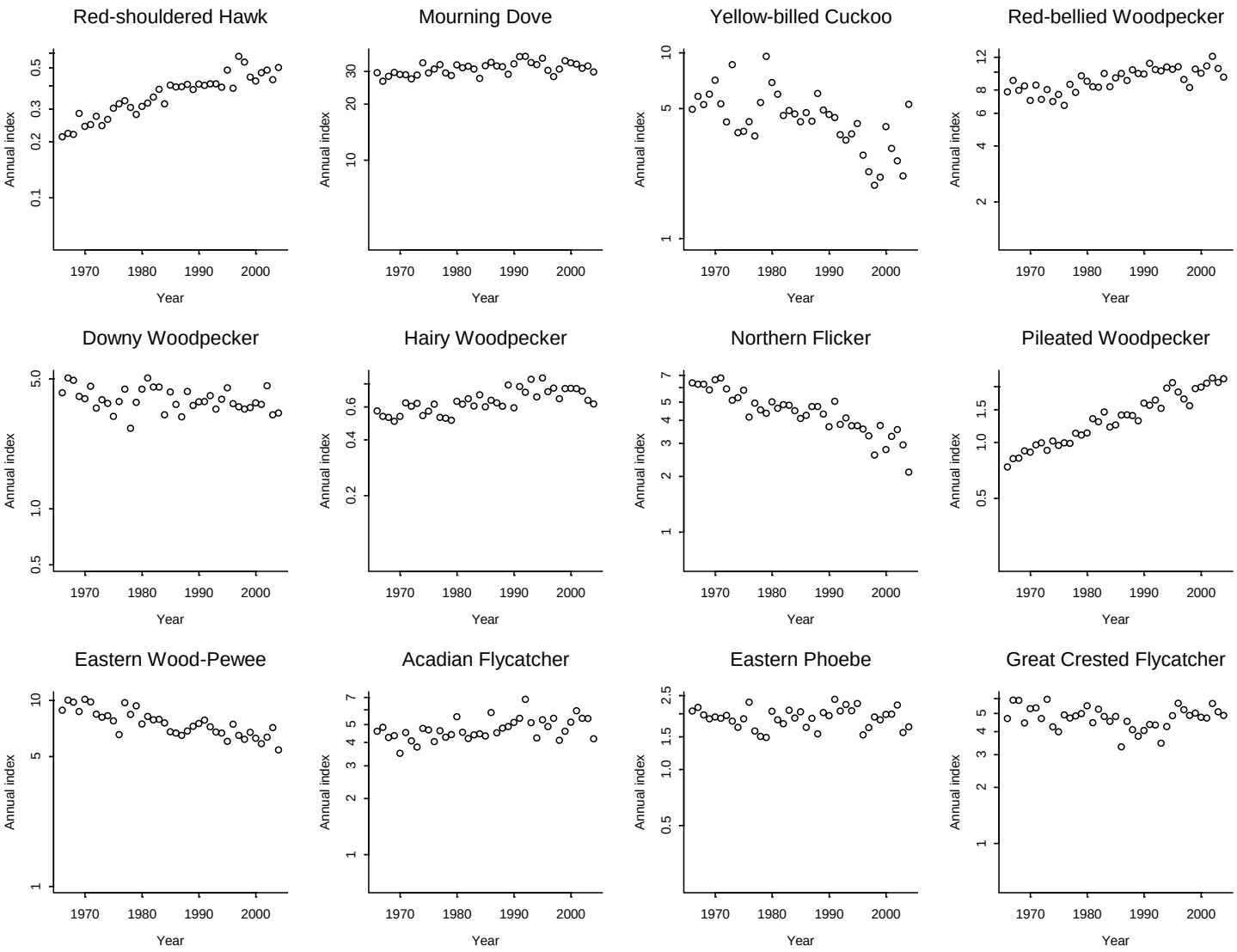
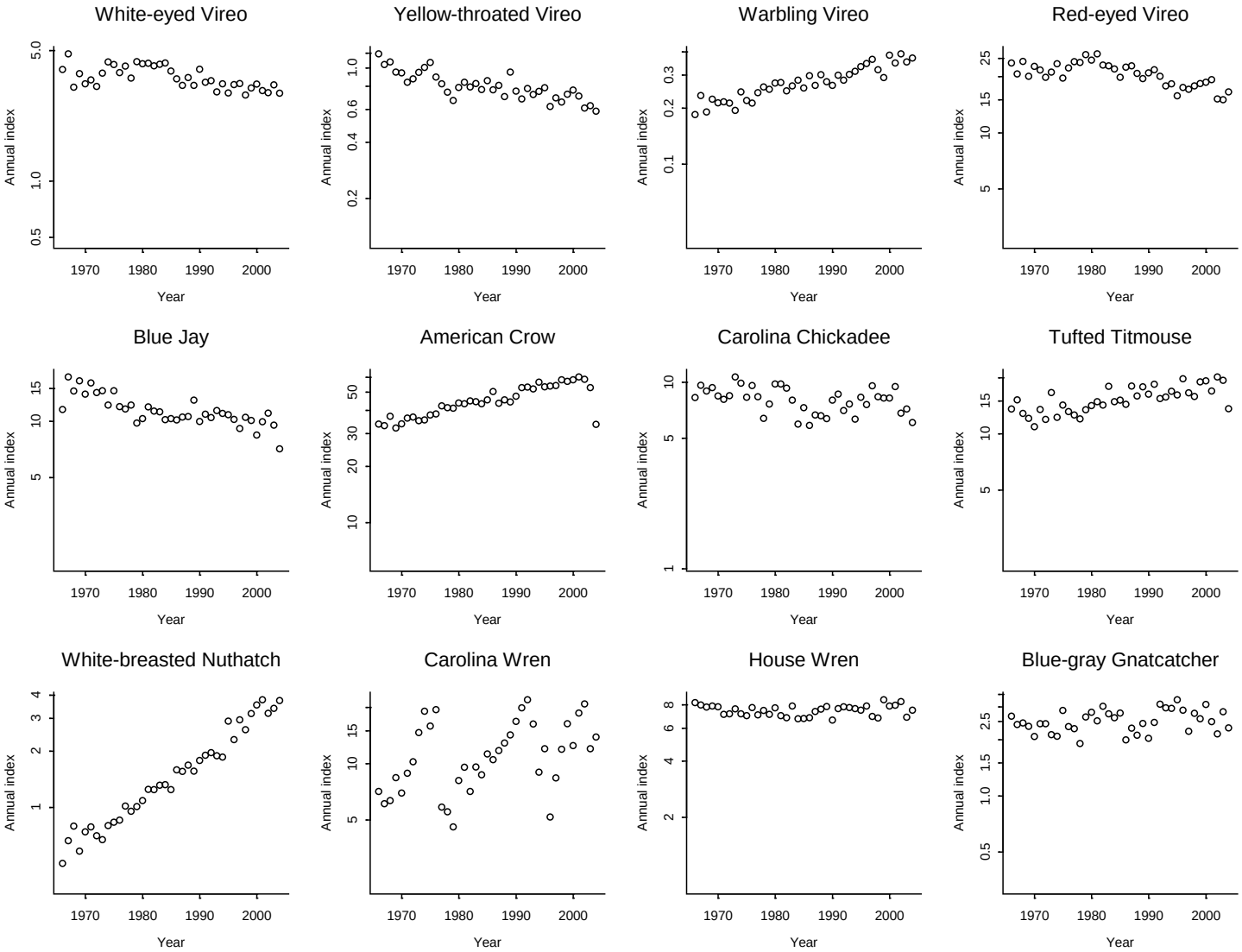
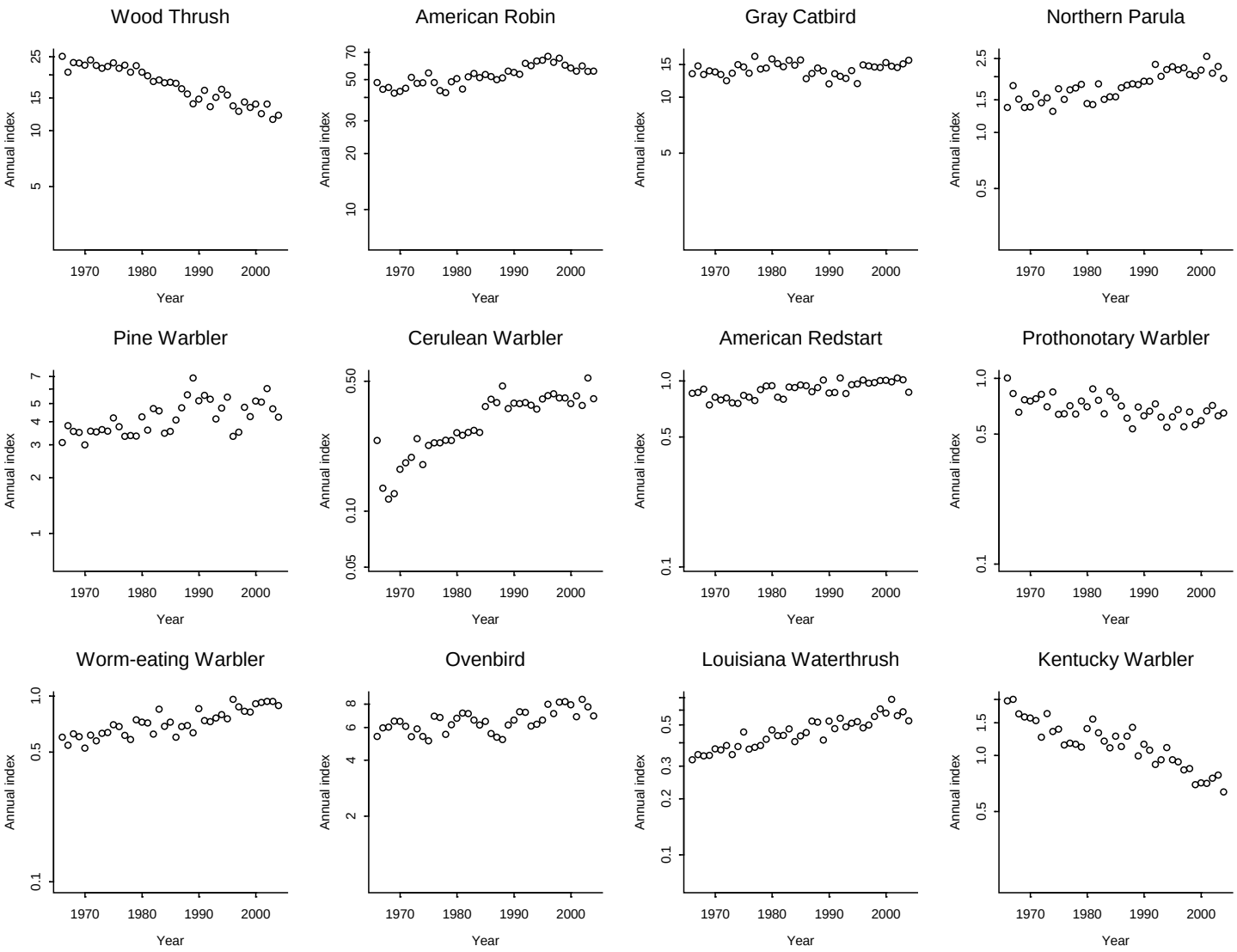
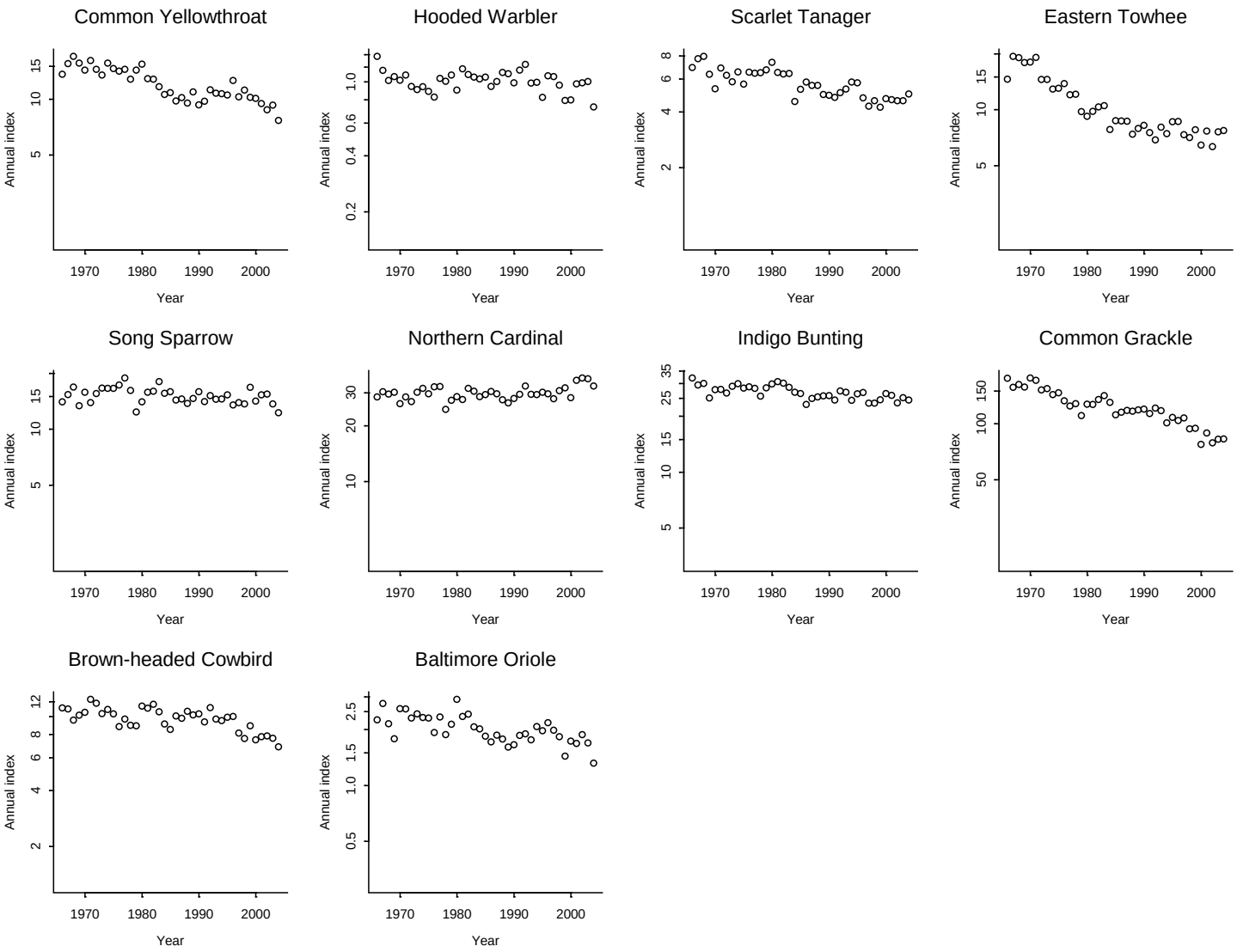



**Figure 1**. Log-linear trend analysis for 46 forest-nesting bird species surveyed by BBS in Maryland, 1966 to 2004. (a) Slope *b*, converted to multiplicative change per 10 years; Trend10 = exp(*b**10), and can be interpreted as expected population after 10 years as fraction of initial population. (b) SE of estimate.


Red-shouldered Hawk
Mourning Dove
Yellow-billed Cuckoo
Red-bellied Woodpecker
Downy Woodpecker
Hairy Woodpecker
Northern Flicker
Pileated Woodpecker
Eastern Wood-Pewee
Acadian Flycatcher
Eastern Phoebe
Great Crested Flycatcher
Annual index
Year
1970
1980
1990
2000


White-eyed Vireo
Yellow-throated Vireo
Warbling Vireo
Red-eyed Vireo
Blue Jay
American Crow
Carolina Chickadee
Tufted Titmouse
White-breasted Nuthatch
Carolina Wren
House Wren
Blue-gray Gnatcatcher
Annual index
Year
1970
1980
1990
2000


Wood Thrush
American Robin
Gray Catbird
Northern Parula
Pine Warbler
Cerulean Warbler
American Redstart
Prothonotary Warbler
Worm-eating Warbler
Ovenbird
Louisiana Waterthrush
Kentucky Warbler
Annual index
Year
1970
1980
1990
2000


Common Yellowthroat
Hooded Warbler
Scarlet Tanager
Eastern Towhee
Song Sparrow
Northern Cardinal
Indigo Bunting
Common Grackle
Brown-headed Cowbird
Baltimore Oriole
Annual index
Year
1970
1980
1990
2000

# Appendix 3: Simulating Point Count Data

We used simulated data to assess the power of point-count designs to detect trend, and to test methods of analysis. We distinguish a 'process' (or 'state') model and an 'observation' (or 'sampling') model. This allows for inherent annual and spatial variation (both are forms of process variance) and for sampling variance (e.g., Hatch 2003, Purcell et al. 2005). Process variance and observer-related variation in detection are generated as log-normal random effects.

The models actually fitted for analysis will typically be simpler than those used to generate the data, and include random effects only via an overdispersion parameter (Purcell et al. 2005). If desired, random effects may be fitted using Hierarchical Bayes (e.g., Link and Sauer 2002) in software such as WinBUGS or S+ Bayes, or with generalized linear mixed models fitted by penalized quasi-likelihood (e.g., glmmPQL in the MASS library of Venables and Ripley for R and S-Plus).

We assume counts are made at the same fixed set of points each year. Points are grouped by habitat and/or proximity into 'routes'. Each route may be visited and counted more than once. Repeat visits are by different observers (see below for allocation of observers to visits). The panel of observers may change between years.

Population density is expected to vary among routes (driven by habitat or other spatial variation) and between years (including both random and systematic effects). Systematic between-year change is assumed to be linear on a log scale, with a slope that may vary among routes.

The process model for density at a point on route $j$ in year $i$ is

$$D_{ij} = \exp(a + d_j + b_j(i-1) + y_i) \qquad (1)$$

where

- $a$ — intercept ($\ln(D)$ in the absence of other effects)
- $d_j$ — route effect — Normal(mean=0, SD=$\sigma(d_j)$)
- $b_j$ — route-specific trend — Normal(mean=0, SD=$\sigma(b_k)$)
- $y_i$ — year effect — Normal(mean=0, SD=$\sigma(y_i)$).

  WARNING: year effects are assumed to be uncorrelated.

The observation model for the number $C_{ij}$ counted on route $j$ in year $i$ is

$$C_{ij} = \sum_k c_{ijk} \text{ Poisson}[n\beta D_{ij} \exp(\varepsilon_k)] \quad (2)$$

where

- $n$ — number of points per route

$\beta$ proportionality constant between counts and density [E(count) = $\beta$D].

$c_{ijk}$ = 1 if observer $k$ counts route $j$ in year $i$,

$c_{ijk}$ = 0 otherwise.

$\varepsilon_k$ observer effect — Normal(mean=0, SD=$\sigma(\varepsilon_k)$).

[**Note:** this formulation assumes counts are aggregated across all visits to a route in a particular year. Full modelling of observer effects requires that visits be distinguished.]

Combining (1) and (2):

$$\text{count}_{ij} = \sum_k c_{ijk} \text{ Poisson}[\exp(a_0 + d_j + b_k(i-1) + y_i + \varepsilon_k)] \quad (3)$$

where $a_0$ is ln(count) in the absence of random effects and trend ($a_0 = a + \ln(n) + \ln(\beta)$).

Setting particular SD to zero collapses this model into various models considered by Purcell et al. (2005). Variation among counts is assumed to be Poisson, conditional on year, route and observer.

Allocation of observers to routes is determined by the $c_{ijk}$. We can model the $c_{i.k}$ by allowing observers to 'drop out' with a random binomial probability $P_k$ at the end of each year. For example, in a 10-year study with 20% random turnover ($P_k$ = 0.2) in the observer panel per annum:

| | Year *i* | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Observer *k*** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** |
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 2 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 5 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| 7 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 |

[Observer 3 replaces Observer 2 in year 3, but participates only 1 year before dropping out.]

Appendix 4 describes the Monte Carlo simulation method for estimating power and contains R functions for models (1) and (3).

# Appendix 4: Power Analysis by Simulation

The R function **`simPower`** generates random count datasets from the model in appendix 3 and performs a Poisson regression analysis on each. Output is a table of estimated power (proportion of simulated datasets for which a trend is detected) for each combination of the levels of the input variables.

```
simPower <- function (
     initialN=1, SDyear=0, SDrte=0, SDtrnd=0, SDobs=0, Pnewobs=1, trend10=0.5,
     nyear = 10, nroute=48, nvisit=2, nobs=2,
     nrep  = 1000, margins=NULL, ...)
```

The first seven arguments of **simPower** match parameters in appendix 3 Model (3) as shown in the table below. The next four arguments (nyear, nroute, nvisit, nobs) define the design, where the total number of counts in a year is 'nroute * nvisit', conducted by 'nobs' different observers. 'nrep' is the number of replicate simulations to be performed. 'margins' defines which of the first 11 arguments should appear as margins in the output table. e.g., margins=c(6,10) if initialN and nvisit have been specified at multiple levels. If margins=0, the output table automatically will include all dimensions with multiple levels. If margins=NULL, no summary table is produced and the results of each regression are output. '…' indicates other arguments to be passed to `simPoissonRegression`:

alpha α-level for test of slope (default = 0.05)

one.sided true (T) if a 1-sided test is to be performed (default = F)

HA sign of trend for alternative hypothesis in case of a 1-sided test (default = –1)

obs.term true (T) if 'observer' should be included as a term in the regression model (default = F) [Note: 'route' is included whenever nroute>1]

qusi true (T) if dispersion parameter to be estimated (i.e., use quasi-likelihood to fit Poisson regression; otherwise assume dispersion parameter=1) (default = T)

agg true (T) if counts should be summed over visits for analysis (default = F)

allow.revisit true (T) if observers may count a route on more than one visit in a particular year (otherwise each visit must be by a different observer) (default = F)

**Table 6-1.** Correspondence between the parameters of Appendix 3 Model (3) and arguments of the R function SIMPower

| Model 3 | simPower | Description |
|---|---|---|
| $\log(a_0)$ | initialN | Expected count per route-visit in the absence of other variation |
| $\sigma(y_i)$ | SDyear | Variation in log (density) between years |
| $\sigma(d_j)$ | SDrte | Variation in log (density) between routes |
| $\sigma(b_k)$ | SDtrnd | Variation in log-linear trend in density between routes |
| $\sigma(\varepsilon_k)$ | SDobs | Variation in log count between observers |
| $P_k$ | Pnewobs | Annual probability of observer dropout |
| $E(b_k)$ | trend10 | Mean trend (expected population after 10 years as fraction of initial population) |

## Example of usage

```
simPower (initialN      = c(1, 5),
          SDyear        = 0,
          SDrte         = 0,
          SDtrnd        = 0,
          SDobs         = 0,
          Pnewobs       = 0,
          trend10       = c(1.0, 0.9, 0.8, 0.7, 0.6, 0.5),

          nyear         = 10,
          nroute        = 48,
          nvisit        = 2,
          nobs          = 3,

          nrep          = 1000,
          alpha         = 0.05,
          qusi          = T,
          one.sided     = F,
          obs.term      = F,
          agg           = F,
          allow.revisit = F)


Elapsed minutes  24.57

        Trend10=1 Trend10=0.9 Trend10=0.8 Trend10=0.7 Trend10=0.6 Trend10=0.5
InitN=1     0.054       0.073       0.154       0.296       0.481       0.744
InitN=5     0.052       0.154       0.532       0.881       0.993       1.000
```

## Interpretation of example

In the absence of trend (Trend10=1), the proportion of simulations yielding a significant result is close to the nominal alpha level (0.05) regardless of the expected initial count. This is what we would like.

The 10-year trend for which power is 80% may be obtained by linear interpolation, given an initial expected count of 5 per route-visit (InitN=5):

```
approx(x=c(0.532,0.881), y=c(0.8,0.7), xout=0.8)$y

[1] 0.7232092
```

This represents a decline of 1–0.723 = 28% in 10 years. Power to detect a decline of 50% or less does not reach the 80% threshold for species with an initial count of 1.0.

The example does not include any process variance (SDyear=0, SDrte=0, SDtrnd=0), observer variance (SDobs=0), or observer turnover (Pnewobs=0). In practice we therefore expect the actual power of the test to be less than calculated.

### R functions for power analysis of Poisson regression for point counts.

**`simPower`** Conducts power analysis of Poisson regression test for trend, using data generated under appendix 3 Model (3)**.** Arguments of **`simPower`** correspond to parameters of appendix 3 Model (3).

**`simulated.density`** Generates route- and year-specific population densities using appendix 3 Model (1)

**`allocate.routes`** Simulates a panel of observers with random annual turnover, and assigns routes and visits to the observers active in each year

**`simulated.count`** Applies the observation model appendix 3 Model (2) to generate random count data sets. Calls **`simulated.density`** and **`allocate.routes`.**

**`simPoissonRegression`** Performs Poisson regression (with optional overdispersion) on a randomly generated dataset from **`simulated.count.`** Called by **`simPower`**.

Cut and paste all functions into the R command window. Tip 1: R may be downloaded from http://cran.r-project.org/

Tip 2: R is case-sensitive.

```
#################################################################
############################

simulated.density <- function (nyear, nroute, trend10, sig.yr=0,
sig.rte=0, sigbj=0)

{

  # make data frame for each visit to each route in each year
  output  <- expand.grid(year=1:nyear, route= 1:nroute)


  # redefine rnorm function to allow for zero SD
  rnorm0  <- function (n,sd) if (sd>0) rnorm(n,sd=sd) else
rep(0,n)
```

```
  # random effects
  randj   <- rnorm0(nroute, sig.rte)                          #
route effect
  randbj  <- log(trend10) / 10 + rnorm0(nroute, sigbj)      #
route-specific trend
  randi   <- rnorm0(nyear, sig.yr)                             #
year effect


  # expected density per point
  # density(ij) ~ exp(dj + bj.(i-1) + yi)
  output$dlambda <- exp (
                 randj  [output$route] +                    #
route
                 randbj [output$route] * (output$year-1) +  #
route-specific trend
                 randi  [output$year]                       #
year (process error)
                )
  list(randi=randi, randj=randj, randbj=randbj, density=output)
}


##################################################################
############################


allocate.routes <- function (nroute=12, nvisit=1,  nobs=1,
nyear=4, Pnewobs=1, allow.revisit=F)


# Count each route 'nvisits' times in each year
# Use a different observer each visit unless 'allow.revisit'=T
# Observers are assigned to visits at random
# Where possible each observer conducts the same number of
counts in a year
# Observers drop out between years with probability Pnewobs

{
  if ((nobs < nvisit) & !allow.revisit) stop ('Not enough
observers')
  if (nobs==1) {obs <- array(dim=c(nroute, nvisit, nyear));
obs[,,] <- 1 }
  else {


  # Generate matrix of observers and the years they were present
```

```
  obs.mat <- matrix (nr=nyear, nc=nobs)
  for (i in 1:nobs) obs.mat[,i] <- cumsum(c(1,runif(nyear-
1)<Pnewobs))
  if (nobs>1) for (i in 2:nobs) obs.mat[,i] <- obs.mat[,i] +
obs.mat[nyear,i-1]


  # Set up a data frame of observer combinations
  alloc         <- expand.grid (lapply(rep(nobs, nvisit), seq,
from=1))
  if (!allow.revisit) {
    no.repeats  <- apply(apply(alloc, 1, duplicated),2,sum)==0
    alloc       <- alloc[no.repeats,]
  }
  nperm         <- nrow(alloc)  # factorial(nobs) / factorial
(nobs-nvisit)
  multiples     <- nroute/nperm
  if (multiples != round(multiples))
  warning (paste('Unbalanced observers: nroute should be
multiple of',nperm))

  # Randomly order observer combinations, enough for all routes
in all years; then lookup
  temp          <- as.vector(sapply(rep(nperm,
multiples*nyear),sample))
  obs           <- array(unlist(alloc[temp,]), dim=c(nroute,
nyear, nvisit))


  # Convert to actual observer numbers, allowing for year, and
output
  for (y in 1:nyear) obs[,y,] <- obs.mat[y, obs[,y,]]
  obs[,,]       <- order(unique(as.vector(obs)))[obs] # number
chronologically
  obs           <- aperm(obs, c(1,3,2))
  }


  dimnames(obs) <- list(paste('Route', 1:nroute, sep=''),
                        paste('Visit', 1:nvisit, sep=''),
                        paste('Year',  1:nyear,     sep=''))
  obs
}
##################################################################
############################
```

```
simulated.count <- function (initN=1, sig.obs=0, nyear=10,
nroute=7, nvisit=1, nobs=1,
                  Pnewobs=1, agg=F, allow.revisit=F, trend10=1,
sig.yr=0, sig.rte=0, sigbj=0)
{
  output     <- expand.grid (year=1:nyear, route= 1:nroute,
visit=1:nvisit)
  density    <- simulated.density (nyear=nyear, nroute=nroute,
trend10=trend10, sig.yr=sig.yr,
                                  sig.rte=sig.rte,
sigbj=sigbj)$density
  Dij        <- merge (output, density, sort=F)$dlambda

  # Observers
  if (nobs>1) {
    obs      <- allocate.routes (nroute, nvisit, nobs, nyear,
Pnewobs, allow.revisit)
    output$observer <- obs[cbind(output$route, output$visit,
output$year)]
  } else output$observer <- rep(1,nrow(output))
  rnorm0     <- function (n,sd) if (sd>0) rnorm(n,sd=sd) else
rep(0,n)
  rand.obs   <- rnorm0 (max(output$observer), sig.obs)


  # Count per route ~ Poisson (exp(a0 + ln(Dij) + Ek))
  lambda     <- exp (
                log(initN) +                                #
constant
                log(Dij)   +                                #
state
                rand.obs[output$observer]                   #
observer
               )
  output$count <- rpois(nrow(output), lambda)


  if (agg) # sum over visits within a route
  {
    output <- aggregate (output$count,
                         list(as.factor(output$year),
as.factor(output$route)),
                         sum)
    names(output) <- c('year','route','count')
  }
  output
}
```

```
#################################################################
############################

simPoissonRegression <- function (in1 = c(0.1, 0.3, 0.0, 0.0,
0.0, 1.0, 0.5, 10, 48, 2, 2),
        alpha=0.05, one.sided=F, HA= -1, obs.term=F, qusi=T,
agg=NULL, allow.revisit=NULL)

# HA=-1 implies alternative hypothesis is decrease
{
  dat <- simulated.count(
    initN   = in1[1],
    sig.yr  = in1[2],
    sig.rte = in1[3],
    sigbj   = in1[4],
    sig.obs = in1[5],
    Pnewobs = in1[6],
    trend10 = in1[7],
    nyear   = in1[8],
    nroute  = in1[9],
    nvisit  = in1[10],
    nobs    = in1[11]
  )


  form <- 'count ~'
  if (obs.term & !is.null(dat$observer)) {
    form         <- paste(form, 'observer +')
    dat$observer <- as.factor(dat$observer)
  }
  if (nlevels(dat$route)>1) {
    form         <- paste(form, 'route +')
    dat$route    <- as.factor(dat$route)
  }
  form <- as.formula(paste (form, 'year'))

  if (qusi) fam <- quasipoisson # overdispersed
  else      fam <- poisson
  g1     <- glm   (formula=form, family=fam, data=dat)

  b.hat  <- as.numeric(coef(g1)['year'])
  p      <- anova(g1,test='F') ['year', 'Pr(>F)']
  if (one.sided) H0 <- (sign(b.hat) != HA) | ((p/2) > alpha)
  else           H0 <- (p > alpha)
```

```
  c(b.hat=b.hat, p=p, H0=H0)    # only use H0, but useful to
save trend and p
}
##################################################################
#####################


simPower <- function (initialN = c(0.1,1), SDyear=0, SDrte=0,
SDtrnd=0, SDobs = 0,
     nyear = 10, nroute=48, nvisit=2, nobs=2, Pnewobs=1, trend10
= 0.5,
     nrep  = 1000, margins=0, ...)
{
  start <- proc.time()[3]
  # sequence of fields in 'temp' is critical as rows are input
to simPoissonRegression
  temp <- expand.grid(initialN, SDyear, SDrte, SDtrnd, SDobs,
Pnewobs, trend10,
                      nyear, nroute, nvisit, nobs,
                      1:nrep)


  test <- apply(temp, 1, simPoissonRegression, ...)
  cat('\n Elapsed minutes ', round((proc.time()[3]-start)/60,2),
'\n \n ')


  if (!is.null(margins)) {
    temp <- array(
       test['H0',],
       dim      = c(length(initialN), length(SDyear),
length(SDrte), length(SDtrnd),
                    length(SDobs), length(Pnewobs),
length(trend10), length(nyear),
                    length(nroute), length(nvisit),
length(nobs), nrep),
       dimnames = list( paste('InitN=',   initialN, sep=''),
                        paste('SDyear=',  SDyear,   sep=''),
                        paste('SDrte=',   SDrte,    sep=''),
                        paste('SDtrnd=',  SDtrnd,   sep=''),
                        paste('SDobs=',   SDobs,    sep=''),
                        paste('Pnewobs=', Pnewobs,  sep=''),
                        paste('Trend10=', trend10,  sep=''),
                        paste('NYears=',  nyear,    sep=''),
                        paste('NRoute=',  nroute,   sep=''),
                        paste('NVisit=',  nvisit,   sep=''),
                        paste('NObserv=', nobs,     sep=''),
                        NULL)
```

```
     )
    if (margins==0) margins <- (1:11)[dim(temp)[-12] > 1]
    if (length(margins)==0) margins <- 1
    1-apply(temp, margins, mean, na.rm=T)   # power
  }
  else test   # full results
}
################################################################
############################
```

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NPS 800/123437, January 2013

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