Cettia diphone; breeding ecology. Journal of the Yamashina Institute of Ornithology 6:834–843.
HIGHSMITH, R. T. 1989. The singing behavior of Golden-winged Warblers. Wilson Bulletin 101:36–50.
KROODSMA, D. E. 1981. Geographic variation and functions of song types in warblers (Parulidae). Auk 98:743–751.
KROODSMA, D. E. 1988. Song types and their use: Developmental flexibility of the male Blue-winged Warbler. Ethology 79:235–247.
KROODSMA, D. E., AND J. R. BAYLIS. 1982. A world survey of evidence for vocal learning in birds. Pages 311–337 *in* Acoustic communication in birds, vol. 2. (D. E. Kroodsma and E. H. Miller, Eds.). Academic Press, New York.
LEIN, M. R. 1972. Territorial and courtship songs of birds. Nature 237:48–49.
LEIN, M. R. 1978. Song variation in a population of Chestnut-sided Warblers (*Dendroica pensylvanica*): Its nature and suggested significance. Canadian Journal of Zoology 56:1266–1283.
LUSCHI, P., AND C. D. SEPPIA. 1996. Song-type function during territorial encounters in male Cetti's Warblers *Cettia cetti*. Ibis 138:479–484.
PARK, D. S., S. KIM, AND S.-R. PARK. 1996. A song transition among the geographic populations of Bush Warbler (*Cettia diphone*). Korean Journal of Ecology 19:141–149.
PARK, D. S., AND S.-R. PARK. 1996. Does the Bush Warbler *Cettia diphone* successfully defend its territory through a particular song mode or a repertoire sequence? Korean Journal of Zoology 39:266–275.
PARK, S.-R., D. S. PARK, S. KIM, AND M. B. YOON. 1995. Playback experiments on Bush Warblers (*Cettia diphone*); their song recognition of intra- and inter-population. Korean Journal of Zoology 38:443–448.
SMITH, W. J., AND A. M. SMITH. 1992. Behavioral information provided by two song forms of the Eastern Kingbird, *T. tyrannus*. Behaviour 120:90–102.
SOKAL, R. R., AND F. J. ROHLF. 1981. Biometry. W. H. Freeman and Company, New York.
TITUS, R. C. 1998. Short-range and long-range songs: Use of two acoustically distinct song classes by Dark-eyed Juncos. Auk 115:386–393.
TRAINER, J. M. 1987. Behavioral associations of song types during aggressive interactions among male Yellow-rumped Caciques. Condor 89:731–738.
WILEY, R. H., R. GODARD, AND A. D. THOMPSON, Jr. 1994. Use of two singing modes by Hooded Warblers as adaptations for signaling. Behaviour 129:243–278.
YOON, M. B. 1995. Geographic variation of Bush Warbler (*Cettia diphone*) songs in Korea. Ph.D. dissertation, Korea National University of Education, Chungbuk, Korea.
YOON, M. B., D. S. PARK, AND S.-R. PARK. 1995. The characteristics of the alpha and beta song modes and comparison among alpha, beta mode, and inland geographic variation groups' songs of the Bush Warbler (*Cettia diphone*). Korean Journal of Behavioral Biology 4:31–42.

Received 29 June 1998, accepted 8 January 1999.
Associate Editor: E. Greene

The Auk 117(1):232–235, 2000

Use of Blocked Design Increases Efficiency of Data Collection in Field Ornithology Study

SAMUEL B. MERRILL,[1,3] GARY OEHLERT,[2] AND FRANCESCA J. CUTHBERT[1]
[1]*Department of Fisheries and Wildlife, 1980 Folwell Avenue, University of Minnesota, St. Paul, Minnesota 55108, USA; and*
[2]*School of Applied Statistics, 352 Classroom Office Building, 1994 Buford Avenue, University of Minnesota, St. Paul, Minnesota 55108, USA*

Numerous authors have addressed the need to minimize observer effects in field ornithology studies (Bart and Schoultz 1984, Balph and Romesburg 1986, Verner and Milne 1990). One approach is to train and test observers for song identification ability and hearing range (Kepler and Scott 1981, Hanowski and Niemi 1995). It is also common for ornithologists and ecologists in general to create balanced designs (having equal numbers of known effects per treatment) with observer and other effects in mind. Be-

[3] Present address: Camp Ripley Environmental Office, Post Headquarters, 15000 Highway 115, Little Falls, Minnesota 56345, USA. E-mail: samuel.merrill@dnr.state.mn.us

cause these effects are often assumed to be minimized once the design is balanced, it is not common for these variables to be treated as main effects in an analysis of variance (ANOVA). Blocked designs create additional main effects in the ANOVA for these variables. They can also be viewed as a restriction on randomization; that is, completely randomized designs have a single randomization throughout all samples, whereas blocked designs only randomize within each block (Montgomery 1991). Having blocks as main effects can reduce the error term because more of the total variability is explained, and it often increases the likelihood that other main effects will be significant. Therefore, blocked designs are usually more efficient than completely randomized designs. Efficiency in this context is defined as the proportional change in error variance between designs.

Another approach to account for observer and other known effects is to add covariates to the model. The difference between use of blocks and use of covariates is that covariates are not measured until data collection occurs. We used blocking because we could isolate our anticipated sources of variation at the design stage. Covariates are useful for features that cannot be known before data collection. For example, wind speed or temperature could affect bird activity. These variables would not be known until data collection and thus would be candidates for covariates. It is also worthwhile to note that variance reduction via covariates is more dependent on discovering and modeling a linear relationship (between covariate and response) than is a model based on blocks.

Relative to efficient designs, inefficient sampling designs require more samples to detect effects of the same size. Thus, inefficiency can result in a reduction in the number of species and/or locations that researchers can study. This reduction amounts to a decreased ability to do research of generalized applicability at the landscape scale and among groups of species.

Blocked designs have been recommended for ornithological research, but most applications have been directed at behavioral versus habitat-based studies (see Kamil 1988). Few studies have quantified the increase in information gained by blocking on known effects. We quantified these increases for a habitat-based study of bird abundance and diversity and examined how even with a balanced design, substantial observer and time effects can exist in the data.

Methods.—We analyzed data from Merrill et al. (1998) with formulas for relative efficiency of blocked versus completely randomized designs. Merrill et al. (1998) examined bird species diversity and abundance in northern Minnesota in clearcuts with and without patches of quaking aspen (*Populus tremuloides*) left standing. Birds were surveyed over a six-week period from 26 May to 6 July 1993. The study employed a blocked design with eight-minute point counts of singing birds, and response variables were bird species diversity, density of foraging and nesting guilds, and density of individual bird species. The treatment effect had four levels and examined avian response to characteristics of residual timber left standing on the clearcuts; results from Merrill et al. (1998) are not discussed here.

Each sampling location was surveyed three times. We anticipated variation due to seasonality, time of day, and observer, so we created a design that balanced for these effects. The six-week sampling period was divided into three blocks of two weeks each. Sampling times were set between 0500 and 0600, 0600 and 0700, and 0700 and 0800. We randomized when and by whom a count was made with the restrictions that (1) each clearcut was counted once during each time of day, (2) each clearcut was counted once during each two-week period, (3) each clearcut was counted twice by one observer and once by the other, (4) each clearcut group had an equal number of clearcuts counted by each observer, (5) each two-week period had the same number of counts by each observer, (6) each time of day had the same number of counts by each observer, and (7) each time of day had the same number of counts from each week.

The following was used for comparing efficiency of the design in Merrill et al. (1998) with the same design minus the blocks on observer, week, and hour (i.e. as a completely randomized design):

$$1 + \frac{\dfrac{SS_{\text{observation error}} + SS_{\text{blocks}}}{df_{\text{observation error}} + df_{\text{blocks}}} - MS_{\text{plot error}}}{MS_{\text{plot error}}} \quad (1)$$

This formula was applied to all variables from Merrill et al. (1998) with significant week, hour, or observer effects (two diversity indices, total number of species, total number of individuals, three nesting guilds, 10 single species, and unknown species). Data were analyzed using MACANOVA (Oehlert and Bingham 1993), which is a program designed for analysis of complex multifactorial designs. All variables in Merrill et al. (1998) except the diversity indices were modeled with Poisson regression instead of ANOVA. We modeled variables with ANOVA to facilitate quantification of relative efficiencies. Use of ANOVA instead of Poisson regression did not change the results. Throughout, means are reported ± SD.

Results.—Use of the relative efficiency formula produced values for 18 response variables from Merrill et al. (1998) analyzed with a blocked design and the same data analyzed as a completely randomized design. On average, 17.8 ± 10.7% more information per unit effort resulted from the blocked versus the completely randomized design (Table 1). For blocks on observer, the mean increase was 5.3 ± 6.5% (range

TABLE 1. Estimated percent increases in sample size needed in a completely randomized design to achieve the same power as a blocked design for data from Merrill et al. (1998). Values also represent the percent decrease in error variance for each response variable listed for each blocking factor used.

Response variable	Blocking factors			Sum
	Observer	Week	Hour	
Shannon index	14.5	17.6	0.0	30.6
Total number of species	7.0	19.0	0.6	25.7
Tree-nesting birds	6.4	6.0	3.2	15.1
Shrub-nesting birds	0.5	20.0	0.0	19.1
Brillouin index	0.0	12.0	0.6	11.6
Total number of individuals	0.0	11.0	0.7	10.5
Ground-nesting birds	4.2	1.3	0.0	5.2
Alder Flycatcher (*Empidonax alnorum*)	0.1	19.0	0.0	17.7
Least Flycatcher (*Empidonax minimus*)	1.1	0.2	1.2	2.4
Red-eyed Vireo (*Vireo olivaceus*)	0.0	40.3	4.0	42.1
Winter Wren (*Troglodytes troglodytes*)	5.5	0.0	2.3	6.6
Veery (*Catharus fuscescens*)	0.0	6.5	6.1	12.1
Nashville Warbler (*Vermivora ruficapilla*)	0.0	21.3	12.3	31.6
Chestnut-sided Warbler (*Dendroica pensylvanica*)	7.2	1.9	0.6	9.4
Black-and-white Warbler (*Mniotilta varia*)	20.0	7.7	1.3	27.9
American Redstart (*Setophaga ruticilla*)	11.2	7.9	0.0	17.7
Mourning Warbler (*Oporornis philadelphia*)	0.0	9.7	0.2	9.5
Unknown	17.3	2.6	5.9	24.8
Mean	5.3	11.3	2.2	17.8

0.0 to 20.0%). For blocks on week, the mean increase was 11.3 ± 10.2% (range 0.0 to 40.3%). For blocks on hour, the mean increase was 2.2 ± 3.2% (range 0.0 to 12.3%).

Discussion.—It is important to distinguish between blocking and balancing a sampling design. Many field ecologists balance their designs regularly (distribute known effects equally across treatment units), which reduces bias in their results. The need exists, however, to go one step further and treat these balancing factors as blocking factors. This entails including them as main effects in the ANOVAs where possible. Until this is done, variation in the data caused by these effects might be spread evenly among treatments, but it remains in the mean-squared error term of the ANOVA. Because this is the term against which treatment effects will be tested, treatment effects are less likely to be significant, even with a perfectly balanced design, than they are with a blocked design. In general, the larger the effects that are blocked upon, the greater the increase in accuracy of treatment effect estimates once a blocked design is utilized.

Other methods of compensating for time of day and other biases have been used and recommended (e.g. Hill et al. 1984, Palmeirim and Rabaça 1994), but many of them require complex statistical procedures and are difficult to interpret. Our study illustrates the potential value of blocking on known effects of unknown magnitude. The mean increase in information per unit data in this study was 17.8%, and for the Shannon diversity index, a commonly used measure of bird communities, it was 30.6%. Efficiency as defined here is not identical to statistical power, because an increase in sample size would increase power but not necessarily information per unit data However, increased efficiency will represent increased power, because the likelihood of detecting differences with the same number of replicates will increase (as a result of decreased error variance). Therefore, the number of samples required to achieve adequate power (i.e. 0.8; Steidl et al. 1997) will be substantially lower.

Ten response variables from Merrill et al. (1998) had significant observer effects. Eight of these were greater for observer 1 than for observer 2, including total number of species, the Shannon index, and several single species. These results provide a framework for analyzing differences between observer experience, hearing ability, and frequency of errors in bird identification. In many instances, less-experienced observers will report more species and more individual birds. This is usually attributed to double-counting and misidentification of song variation from a single bird during a survey period. In Merrill et al. (1998), observer 1 was the more experienced observer but reported significantly more species and individuals. Midway through the fieldwork, it was discovered that observer 2 had trouble hearing higher frequencies. It is possible that this discrepancy in hearing ability accounted for a large portion of the difference in the number of birds detected. Had the hearing ability of both observers been equivalent, observer 2 may have reported more birds than observer 1. Importantly, variation due to this discrepancy did not decrease precision in estimates of the treatment effects because it was removed from ANOVA through the blocked design. The blocked design also allowed careful inspection of the direction and magnitude of observer bias for each species. This can be useful for detecting interactions between observer and time of day (Blake et al. 1991) or between observer and number of weeks into the breeding season (i.e. inexperienced observers may become more familiar with certain songs and report fewer misidentifications as the season progresses).

For field studies conducted during the early morning hours in the breeding season, these data suggest that blocking on observer and number of weeks into the breeding season is a worthwhile effort. Blocking on number of hours into the early morning appears less important, although it is probably more important if surveys are conducted beyond 0800.

In practice, researchers often attempt to increase the power of their design by having the largest sample sizes possible. Elevating sample sizes by 17.8 or 30.6% is likely to be impractical, cost prohibitive, or simply impossible. This is especially true with projects that assess the influence of management practices or work with small populations. Therefore, blocking on known effects should be viewed as a valuable tool for field ornithologists.

Acknowledgments.—Funding for this project was provided by the Minnesota Environment and Natural Resources Trust Fund, the Wilkie-Dayton Fund of the Bell Museum of Natural History, and the Minnesota Agricultural Experiment Station. We thank J. Probst and G. DelGiudice for reviewing earlier stages of the manuscript.

Literature Cited

Balph, D. F., and H. C. Romesburg. 1986. The possible impact of observer bias on some avian research. Auk 103:831–833.

Bart, J., and J. D. Schoultz. 1984. Reliability of singing bird surveys: Changes in observer efficiency with avian density. Auk 101:307–318.

Blake, J. G., J. M. Hanowski, G. J. Niemi, and P. T. Collins. 1991. Hourly variation in transect counts of birds. Ornis Fennica 68:139–147.

Hanowski, J. M., and G. J. Niemi. 1995. Experimental design considerations for establishing an off-road, habitat-specific bird monitoring program using point counts. Pages 145–150 *in* Monitoring bird populations by point counts (C. J. Ralph, J. R. Sauer, and S. Droege, Eds.). United States Forest Service General Technical Report PSW-GTR-149.

Hill, G. J. E., A. Barnes, and G. R. Wilson. 1985. Time of day and aerial counts of grey kangaroos. Journal of Wildlife Management 49:843–849.

Kamil, A. C. 1988. Experimental design in ornithology. Current Ornithology 5:313–346.

Kepler, C. B., and J. M. Scott. 1981. Reducing bird count variability by training. Pages 366–371 *in* Estimating numbers of terrestrial birds (C. J. Ralph and J. M. Scott, Eds.). Studies in Avian Biology No. 6.

Merrill, S. B., F. J. Cuthbert, and G. Oehlert. 1998. Residual patches and their contribution to forest bird diversity on northern Minnesota aspen clearcuts. Conservation Biology 12:190–199.

Montgomery, D. C. 1991. Design and analysis of experiments, 3rd ed. John Wiley and Sons, New York.

Oehlert, G. W., and C. Bingham. 1993. MacAnova user's guide. University of Minnesota School of Statistics Technical Report No. 493.

Palmeirim, J. M., and J. E. Rabaça. 1994. A method to analyze and compensate for time-of-day effects on bird counts. Journal of Field Ornithology 65:17–26.

Steidl, R. P., J. P. Hayes, E. Schauber. 1997. Statistical power analysis in wildlife research. Journal of Wildlife Management 61:270–279.

Verner, J., and K. A. Milne. 1990. Analyst and observer variability in density estimates from spot mapping. Auk 92:313–325.

Received 4 May 1998, accepted 21 April 1999.
Associate Editor: J. D. Brawn