Guidelines for Designing Short-Term Bird Monitoring Projects[1]

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Introduction

The Coordinated Bird Monitoring Program (Bart and Ralph, this volume) program is helping biologists around the country design short-term monitoring projects for birds. We have found that addressing a series of questions (*table 1*), in a systematic way, helps insure that projects are well planned. The process is being used by several States and organizations in the U.S. Here I describe it in general terms with examples.

Overview of the Process

Guidelines for preparing each component of the project description (*table 1*) are described below. The identified elements are intended as suggestions only. Real examples, as indicated later in this report, usually differ in content and sequence.

Table 1— *Outline used to describe short-term bird monitoring projects.*

Outline
A. Description of the management issue
B. Survey Objectives
1. Biological population
2. Information needed
3. Quantitative objectives
C. Methods
1. Brief description
2. Statistical population
3. Sampling plan
4. Training and field methods
5. Sample size requirements
6. Analytic methods
7. Data management
8. Reports
D. Roles and Responsibilities

A. Description of the Management Issue

Describe the management issue to be addressed or, preferably, the management decision that the monitoring will help managers make. Examples include what treatment to apply, what land to purchase, what direct intervention method to use, and whether to grant a species increased or decreased protection. Explain the spatial and administrative level at which the project is being organized and why this is the right level. The section should end with a clear, albeit qualitative, description of the product needed to address the management issue. If this section is clear, and especially if only one or a few management decisions are the focus of the work, then the rest of the survey description is relatively easy to complete. If the management issue is not clear, then all the rest of the sections are much harder to write.

B. Objectives

1. Biological population

Describe the birds to be studied, e.g., migrating shorebirds, breeding waterfowl, etc. Specify which individuals are included (e.g., all birds, only breeders, only residents?).

2. Information needed

Provide a more detailed description of the information to be obtained in the project's survey. Species, cohorts, times of year, and habitats of greatest interest should be identified, as should auxiliary information such as level of disturbance, evidence of breeding, and habitat relationships. This section should include identification of the parameters to be estimated, expressed in quantitative terms, e.g., density of pairs, trend in abundance, or habitat relationships expressed as regression coefficients. We have found that often one of three products is needed: a regional model, a site-specific model, and project evaluation. These products are described in the next section.

3. Quantitative objectives

Specify the accuracy target, expressed as power or as precision (SEs, CIs, CVs) for each parameter, and discuss how it was chosen. This is frequently a difficult section to write, especially in the early phase of a project, and the target may change as work progresses. Having an accuracy target is important, however, because it provides the basis for calculating sample sizes and, in some projects, for choice of field methods.

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C. Methods

1. Brief description

Provide one or two sentences giving an overview of the methods. This helps readers put the next few sections in context.

2. Statistical population

Identify the population unit and the statistical population. Population units are usually either individuals (birds in our case), capture devices exposed for a given amount of time (e.g., a "mist net-hour"), or, most common of all, a location for a specified period (e.g., as in a 3-minute point count or a 30-minute area search). The statistical population is the set of population units about which we wish to make inferences (the population of interest), or from which we sample (the sampled population); these two should be distinguished if they are different. For example, in a point count project, the spatial dimension of the statistical population might be all forested locations in a National Wildlife Refuge, and the temporal dimension might be mornings without high winds or heavy rain. The population of interest would probably be all possible location-times in the population, and the spatial dimension in the sampled population might be locations along roads and trails.

3. Sampling plan

Define the sampling plan using standard survey sampling terminology, as in the following example. "Two-stage sampling will be employed, with stage one preceded by stratification by habitat. Three strata (probably woodlands, fields, other) will be delineated. Primary units will be locations (i.e., the set of possible survey times at a location), and secondary units will be survey times (at a given location). We anticipate that primary and secondary units will both be selected systematically." Assistance from a statistician familiar with survey sampling may be needed in this phase.

4. Training and field methods

Provide a detailed description of training and field methods. Try to foresee practical problems, how they can be addressed, and how seriously the sampling plan or data collection might be compromised by the problems.

5. Sample size requirements

Use formulas for sample size estimation and allocation of effort, with multi-stage designs, to estimate the sample size needed to achieve the accuracy target for each parameter. Needed sample sizes will differ between parameters (e.g., number of pairs of a species) so the final design will usually be a compromise between costs and meeting most of the accuracy targets.

6. Analytic methods

Describe the methods to be used identifying any possibly problematic issues and how they are being addressed – to the extent possible – in the project design. Extremely detailed accounts are not needed, but demonstrate that careful thought has been given to where the analyses may lead and insuring, insofar as possible, that the data collection will support the most useful analyses.

7. Data management

Describe how the data will be organized; how they will be entered, stored, and retrieved; and whether data will be contributed to regional, national, or continental repositories (and if not, why not).

8. Reports

Describe when reports will be prepared and what they will contain.

D. Roles and Responsibilities

Describe who will have responsibility for detailed design, field work, data management, analysis, and communication. Also describe who will support the project and how (e.g., contracts, in-house support).

Kinds of Information Needed

Short-term monitoring or assessment projects are sometimes undertaken to characterize the birds of an area using simple field and analytic methods. More commonly, however, these projects are undertaken to produce what can be termed regional models, site-based models, or project evaluations (*table 2*). This section describes each product and provides guidelines for producing them.

All three products involve one or more independent (predictor) variables and a dependent (response) variable. In most applications, predictor variables will be habitat descriptors, such as cover type or elevation for regional models or more specific habitat descriptors (e.g., stand density, understory condition, forb cover) for site-based analyses. In project evaluations, the independent variable may be as simple as presence/absence of a habitat implementation project, but can also include habitat characteristics that are a result of the project (e.g., tree densities after revegetation).

The response variable is typically a measure of bird abundance during a specified time of year or a fitness

Table 2— *Summary of typical products of short-term Coordinated Bird Monitoring projects.*

Regional model	Description	A model that expresses the parameter[1] of interest (e.g., focal species abundance) as a function of independent variables (e.g., habitat type) whose values are known throughout a region
	Uses	Understand large-scale patterns in abundance Estimate statewide population Identify low- and high-quality areas throughout the region
	Methods	Maps showing distribution of the focal habitat are obtained Regionwide bird surveys in the habitat, perhaps using stratification to insure samples are obtained from a variety of conditions Independent variables suspected to be correlated with bird abundance (or other dependent variables) are obtained (usually from GIS layers) throughout the region Models are developed using standard regression methods
Site-based model	Description	Similar to the regional model but includes independent variables known only for the surveyed areas (e.g., understory type, tree density, burn history, etc.).
	Uses	Better understand determinants of habitat quality by including specific habitat variables not measurable statewide Estimate effects of proposed projects (e.g., habitat conversion, protection, or restoration)
	Methods	Same methods as for the regional model In addition, stand-specific variables are collected by field work, examination of aerial photos, or other sources
Project evaluation	Description	Estimated value of the parameter[1] (e.g., focal species abundance), within a habitat implementation project area, measured before, during, and after the project.
	Uses	Help evaluate habitat implementation projects, and perhaps revise project plans Document effects of the project on birds
	Methods	Surveys on the project area before, during and after the project

[1]The parameter of interest may be bird abundance during any period of the year or a fitness indicator such as productivity or nutritional status.

indicator, such as productivity or nutritional status. Focal species may include a single species, species of special concern (e.g., habitat obligates) in the area, or all species present. The response variable must often be defined as the total abundance of all focal species to obtain sufficient sample size to achieve the accuracy target.

Regional Models

Regional models express the parameter of interest as a function of independent (usually habitat) variables whose values are known throughout a region. The model is applied to the entire region or, more typically, to all of a regional habitat type (e.g., aspen or Mojave lowland riparian). The model may predict the abundance of a group of focal species, or it may be species-specific. The results of these analyses provide an estimate of regionwide species abundance, help managers understand large-scale patterns in abundance, and identify high- and low-quality habitats throughout the region. The models are constructed by obtaining field data from a substantial sample of randomly-selected sites (usually using stratified sampling). Broadly defined habitat variables are then identified that are thought to be correlated with bird populations and which are available in regionwide Geographic Information Systems (GIS) layers.

Site-based Models

Site-specific models also express the bird population parameters as a function of independent (usually habitat) variables. But, in addition to variables whose values are known throughout the region, site-based models may also include variables that were measured for each surveyed site and that are not available regionwide. These variables are usually habitat measurements that are obtained in the field or from detailed vegetation maps, aerial photos, or other supporting data. Results from these models usually make better predictions of bird population parameters

Table 3— *Estimation of sample size to detect a stated change.*

Step 1: Select power and Z_β

Power (1- β)	β	Z_β
0.6	0.4	0.25
0.8	0.2	0.84
0.9	0.1	1.28

Step 2: select the significance level and $Z_{\alpha/2}$ (assuming a two-tailed test and large sample size.)

Significance (α)	α	$Z_{\alpha/2}$
0.05	0.025	1.96
0.10	0.05	1.65
0.15	0.075	1.44

Step 3: Read the corresponding value of G

	Power		
Significance	0.6	0.8	0.9
0.05	5.8482	2.5088	0.9248
0.10	3.92	1.3122	0.2738
0.15	2.8322	0.72	0.0512

Step 4. Estimate the CV (see text) and read the sample size.

		R		
G	CV	1.5	2	3
5	0.5	11	5	3
5	1.0	45	20	11
5	1.5	101	45	25
5	2.0	180	80	45
10	0.5	23	10	6
10	1.0	90	40	23
10	1.5	203	90	51
10	2.0	360	160	90
15	0.5	34	15	8
15	1.0	135	60	34
15	1.5	304	135	76
15	2.0	540	240	135

for specific sites, and may reveal more about which habitat variables are correlated with bird population data than the regionwide models can reveal. Site models cannot be extrapolated statistically to the entire region because, by definition, they include variables whose values are not known regionwide. However, basic habitat management guidelines derived from site-based models can be applied throughout the region in which the habitat characteristics used in the model apply. As a hypothetical example, if a site-based model for aspen were to predict a higher abundance of aspen-associated focal species with increased shrub coverage, then this insight could be applied to aspen management throughout the region in which aspen-associated birds were believed to respond to this effect.

Project Evaluations

Project evaluations involve surveys on a habitat implementation project site before, during, and after the project. These surveys help evaluate and perhaps revise the project and they document effects of the project on birds.

Sample Size Needed to Detect a Specified Change

Suppose we wish to detect a ratio change (R) in abundance or some other parameter, R = Y_2/Y_1, where Y_1 and Y_2 are the values at two times, for example, before and after a project. R will be estimated as $r = y_2/y_1$ where y_1 and y_2 are the estimates of Y_1 and Y_2. Estimating the needed sample size requires that we specify the value of R to be detected, the significance level, the power, and the CV(r), which depends on the CVs of y_1 and y_2 and on their correlation. A convenient way to make the calculations is presented in *table 3*. The CV(r) must be estimated from a pilot study (ideally), from other similar studies, or using professional judgment. Tentative values for *R*, the level of significance, and power may then be selected and the required sample size to achieve the stated power may be read from *table 3*. This process may be repeated until a satisfactory compromise is reached between the desire for high power and the resources available for the study. The example, presented in the next section, provides an illustration of calculating the CV and using it to choose the sample size.

A Sample Project Description: Effects of Altering Riparian Habitats on Birds

A description for a short-term assessment project is presented below. It is modified from the Nevada CBM Plan (Ammon et al. 2003). Species lists and other tabular material have been omitted, and the format is slightly different from the description above.

Description of the Management Issue

Riparian habitats are here defined to include rivers, lowland springs and streams, and montane streams. Major rivers include the Truckee, Carson, Walker, Mary's, Reese, Virgin, Muddy, Colorado, White and the entire Humboldt River system. Lowland springs and streams occur mainly in southern Nevada, for example at Meadow Valley Wash, Ash Meadows, and Warm Springs. Montane streams are widely distributed in northern Nevada but in southern Nevada occur mainly on the Spring and Sheep Mountains.

Riparian areas in Nevada are used by a total of 136 bird species, including 66 focal species for this objective. (The original description included the entire list and the list of 66 focal species.) Riparian areas are among the most heavily impacted environments in the state. During the past 150 years, riparian habitats have been converted, rivers have been channelized, and substantial amounts of water have been withdrawn for agricultural or municipal uses. Nevada is one of the fastest-growing regions in the country so the pressure to develop riparian bottomlands, remove ground water, and develop other water projects is likely to increase during the coming decades. Concerns about impacts on riparian areas have led to many riparian restoration efforts. In 2002, Nevada passed a $200 million bond issue for acquisition and preservation of open space and wildlife habitats around the state, and much of this money is intended for the protection of riparian resources.

Numerous lowland riparian habitat implementation projects have been undertaken, or are being considered, in Nevada. For example, restoration is planned or underway on McCarran, Ferretto, and Mustang Ranches on the Truckee River; on River Fork Ranch on the Carson River; on Rosaci Ranch on the Walker River; and on Torrance and Parker Ranches on the Amargosa River. In each of these projects, studies are needed (and in many cases are in progress) of effects on birds of planned or occurring activities.

Montane streams of particular interest in Nevada include Mahogany Creek (a proposed Important Bird Area); streams in the Montana Range, where restoration work is planned; streams in the Selenite Range and other ranges in Bureau of Land Management's (BLM) Winnemucca District, where effects on birds of a recent change in grazing management are being evaluated; and streams in the Santa Rosa Range, in the Mountain City area, and the Spring Mountains which support focal species that are otherwise rare in Nevada. Other sites of importance may include Porter Springs in the Seven Troughs Range and streams of the Snowstorm Range that have been studied by Nevada Division of Wildlife (NDOW) and others.

Managers working in riparian areas primarily need two kinds of information: predicted effects of proposed habitat implementation projects on birds, and actual effects of implemented projects. A site-based model is needed to provide the first kind of information; project evaluations are needed to produce the second kind of information.

Survey Objectives

Needed information

Project evaluations should, at a minimum, document breeding abundance of focal species, but focal species abundance throughout the year and measures of fitness, including productivity during the breeding season and foraging success during migration, would also be highly desirable especially in large projects.

A site-based model should predict the abundance of focal species relative to a continuum in habitat conditions influenced by fire, grazing, and restoration treatments. The models should be generated for both breeding and migration, but this draft of the Nevada Plan only discusses abundance during the breeding season. Later revisions will address other needed information. Short-term trends in abundance, as projects are implemented, may also be of interest particularly in large projects.

Quantitative objectives

Species-specific estimates of abundance are desirable but often cannot be obtained with sufficient precision to be useful. As an alternative, we define the primary parameter of interest as the mean number of individuals of all riparian focal species that would be recorded with a large sample.

The desired accuracy of models to predict abundance, should a proposed project be implemented, must be established independently of specific projects. More experience is needed in developing these models for riparian habitats in Nevada, but we believe that a reasonable initial target is that the CV of the predicted abundance for a single project area should be 0.25.

Projects affecting riparian habitat often cause major changes in habitat, and thus bird abundance, so surveys can be designed to detect large, rather than small, changes. As an approximate guideline, it seems reasonable that power to detect a 2- to 3-fold change should be at least 80 percent. The lower precision goal (detecting a 3-fold change) might be appropriate for smaller projects. The higher precision goal might be appropriate for larger projects.

Methods

Bird survey methods

Abundance of landbirds during the breeding season is usually determined using point counts in programs like the Nevada Bird Count, a transect-based point count program.

Sample size requirements

Sample sizes for project evaluations were estimated from data collected in the Nevada Bird Count. We used individual points as the primary sampling unit, assuming that points would be distributed evenly across the project area. The Nevada Bird Count uses two-stage sampling (selection of transects, selection of points within transects) so we calculated means and SDs within transects and then estimated CVs as (mean of the SDs/mean of the means). The number of surveys per year varied from 1 to 3. Our sample included 50 transects surveyed during 2001-2003. There was little variation in CVs with number of surveys, indicating that most variation results from change in place, rather than change in time. The grand CV was 1.36 (*table 4*). If the level of significance is 0.05 and power is 0.8, then G, from *table 3*, is 16 and, using CV = 1.5 to be conservative, the needed sample is 135 if the change is R = 2 and is 76 if the change is R = 3. If surveys are conducted for three years prior to a project and three years after a project, then 25-50 points should be surveyed each year, depending on whether a two-fold or three-fold change is expected. Note, however, that the parameter is number of individuals of all riparian species of special concern. Much larger sample sizes would be needed for species-specific estimates, and the sample size requirement would vary enormously depending on abundance of the focal species in the project area.

Table 4— *CVs ($SD(y_i)/\bar{y}$) for 10-minute point counts in riparian habitat conducted during the Nevada Bird Count[1].*

	Number of surveys			
	1	2	3	All
N transects	28	8	14	50
N points	275	82	139	496
Average SD	1.0	0.5	0.8	0.8
Mean no. birds	0.7	0.4	0.6	0.6
CV(means)	1.37	1.41	1.31	1.36

[1] y_i is the mean number of birds recorded at the i^{th} station; the calculations (see text) exclude two counts >80; the remaining counts were <10 except for two counts of 11 and 21.

Sample sizes required to construct the site-based model are hard to estimate, in part because the number of different models must be specified. At present, we suspect that separate models will be needed for (a) northern rivers, (b) southern rivers and springs, and (c) montane streams. An initial estimate is that the accuracy target for each of these models (CVs of 0.50) can be met if data are available from 200 points (20 ten-point transects in the Nevada Bird Count). Three counts per season from each point would be useful (and are being collected at some stations) but a single count might suffice. The sample size target is thus 200 points in each of the three regions: northern rivers, southern rivers and springs, and montane streams.

Habitat survey methods

Habitat data already exist for several projects (e.g., the Bureau of Reclamation's lower Colorado River surveys, and Truckee and Carson River surveys) and may be supplemented with data from additional sites to increase our knowledge of habitat associations. This information is essential in developing the predictive model, since the predictions are based on habitat variables (defined broadly). Habitat variables may include predictors such as width of riparian woodland corridor, total woodland cover, cover by exotic shrubs and trees, measures of foliage height diversity, cover by native understory species, cover by floodplain wetlands, and emergent vegetation cover.

Sampling plans

Project evaluation surveys should probably employ one-stage systematic sampling, perhaps preceded by stratification, when project areas are small enough for this to be feasible, and should use multi-stage sampling (e.g., clusters of ten stations as in the Nevada Bird Count) when the strata are too large for this approach. Precision will generally be higher, for a fixed number of stations, with the first approach.

The same general approach will probably work to gather the data for development of the site-based predictive model, although in most cases strata will be large enough that clusters of point count stations will be used. Strata should be delineated to insure that a wide range of habitat types is included. Analysis should acknowledge the stratification and multi-stage nature of the sampling plan.

Finding high-quality sites may be especially difficult. Mary's River may provide the best site for developing the model for northern rivers. Warm Springs may be most useful in developing the model for southern rivers and springs, although better reference sites for Mojave riparian areas may be found outside of Nevada. For montane streams, several exclosure sites could be used as reference sites, for example in Sheldon National Wildlife Refuge, at Mahogany Creek, and several BLM exclosures in Humboldt County. However, other areas may also provide useful information on reference conditions.

Table 5— *Projects that will affect riparian birds in Nevada and information about them.*

Name	Location	Size	Status	Monitoring?
McCarran Ranch	Truckee River	5 river miles	Currently being implemented	Yes
Ferretto Ranch	Truckee River	2 river miles	In planning stage	Yes, but needs to be combined with McCarran for evaluation
Mustang Ranch	Truckee River	5 river miles	In planning stage	Some, but probably not enough for evaluation
River Fork Ranch	Carson River	3 river miles	In planning stage	Some, but probably not enough for evaluation
Rosaci Ranch	Walker River	2 river miles	In planning stage	Yes (enough for evaluation?)
Humboldt County streams	About 40 streams	About 100 stream miles total	Change in grazing management implemented in late 90’s	Yes
Torrance Ranch	Amargosa River	2 river miles	Partially implemented	Some, but long-term uncertain
Parker Ranch	Amargosa River	2 river miles	Partially implemented	None currently
Las Vegas Valley Wash			In planning stage	
Meadow Valley Wash		60 river miles	In planning stage	Some, but no long-term plans
Virgin River		About 25 river miles	likely projects in the future	some, but coordination needed
Muddy River, Warm Springs		about 6 miles of river	in planning stage	some, but no long-term plans
Ash Meadows spring restoration projects	Ash Meadows NWR	several springs	several have been completed	none currently
Corn Creek	Desert Wildlife Range	1 mile of stream	partially completed	some, but not enough for evaluation

Roles and Responsibilities

Project monitoring surveys

Information about existing projects that will affect riparian birds is summarized in *table 5*.

Predictive (site-based) model

Many riparian surveys have been conducted in Nevada. For example, surveys made during the Nevada Bird Count included nine 10-point transects on the middle and lower Truckee River (three visits during each of two breeding seasons); seven 10-point transects along the Carson River (two or four visits during each of two breeding seasons); and 20 or more, 10-point transects located elsewhere in the State surveyed once per season. Other surveys, conducted by NDOW and BLM, covered stretches of the Humboldt River and numerous tributaries of the King, Quinn, Reese, and Humboldt rivers. Habitat information has been recorded in some, but not all, of these surveys, and methods have varied. The next steps in developing predictive models are to consolidate this information, record additional habitat data as needed, and develop draft models. This work will clarify what additional field work, if any, is needed.

Project management

A number of funding partners (Clark County, BLM, U.S. Forest Service, NDOW, and U.S. Geological Survey) are providing support for the Nevada Bird Count, which is providing much of the currently available data. As part of the Nevada Bird Count program, the Great Basin Bird Observatory (GBBO) takes responsibility for data management, analysis and reporting. Coordination with other monitoring efforts is also actively pursued as part of the mission of GBBO's Nevada Bird Count. Information resulting from analyses for this management issue will be made available online, through reports to funding partners, and through peer-reviewed publications.

Conclusions

While each plan will differ in details, the topics above, if all covered clearly and in approximately the order above, provide a logical and complete description of the project's goals, objectives, and methods, including an action plan for implementation. While none of the topics is difficult to cover, finding all of this material for a monitoring project has been rare in the past. Hopefully this situation will change in the next few years.

Literature Cited

Ammon, E., L. Neel, and J. Bart. 2003. **Coordinated bird monitoring in Nevada.** Unpublished report available from Nevada Division of Wildlife, 1100 Valley Road, Reno, Nevada, 89512.

Bart, J., and C. J. Ralph. this volume. **The need for a North American coordinated bird monitoring program.**

Appendix: Derivation of *Table 3*

Let the estimated ratio of population size, y_2/y_1 be r, and let the ratio of actual sizes be R. The value of R under the null hypothesis is 1.0 so we will declare the sample estimate significant if $|r\text{-}1|/\text{SE}(r) < Z_{\alpha/2}$. We initially assume a large sample and α = 0.05 so $Z_{\alpha/2}$ = 1.96. Since R is >1, we assume $r > 1$ and use r-1 in place of $|r\text{-}1|$. For power to be 0.80, we thus want

$$P\left[\frac{r-1}{\text{SE}(r)} > Z_{\alpha/2}\right] = 1-\beta \quad (1)$$

We convert the right side of the inequality to a standard normal,

$$P\left[\frac{r}{\text{SE}(r)} - \frac{1}{\text{SE}(r)} - \frac{\text{R}}{\text{SE}(r)} > Z_{\alpha/2} - \frac{\text{R}}{\text{SE}(r)}\right] = 1-\beta \quad (2)$$

$$P\left[\frac{r-\text{R}}{\text{SE}(r)} > Z_{\alpha/2} - \frac{\text{R}-1}{\text{SE}(r)}\right] = 1-\beta \quad (3)$$

and thus

$$P\left[N(0,1) > Z_{\alpha/2} - \frac{\text{R}-1}{\text{SE}(r)}\right] = 1-\beta\,. \quad (4)$$

By the definition of a standard normal variable, the right side of the inequality must equal $Z_{1\text{-}\beta}$ for power to be 1-β,

$$Z_{\alpha/2} - \frac{\text{R}-1}{\text{SE}(r)} = Z_{1-\beta}\,. \quad (5)$$

Solving for SE(r) yields

$$\text{SE}(r) = \frac{\text{R}-1}{Z_{\alpha/2} - Z_{1-\beta}} \quad (6)$$

or, since $-Z_{1\text{-}\beta} = Z_\beta$,

$$\text{SE}(r) = \frac{\text{R}-1}{Z_{\text{df},\alpha/2} - Z_{1-\beta}} \quad (7)$$

and so

$$\text{V}(r) = \frac{(\text{R}-1)^2}{(Z_{\alpha/2} + Z_\beta)^2}\,. \quad (8)$$

If we assume (a) the sample sizes, n, are equal, (b) the two estimates are independent (which is conservative), and (c) that the CVs, are equal, then variance of r may be expressed as

$$\begin{aligned}\text{V}(r) &= \frac{\text{R}^2}{n}(\text{CV}(y_{1i})^2 + \text{CV}(y_{2i})^2) \\ &= \frac{2\text{R}^2\text{CV}(y_i)^2}{\text{n}}\end{aligned} \quad (9)$$

where the CVs are SD/mean, not SE/mean. Setting expressions (8) and (9) equal to each other and solving for n yields

$$\text{n} = 2(Z_{\alpha/2} + Z_\beta)^2\text{CV}(y_i)^2\left(\frac{\text{R}}{\text{R}-1}\right)^2$$

or, with $\text{G} = 2(Z_{\alpha/2}+Z_\beta)^2$,

$$\text{n} = \text{GCV}(y_i)^2\left(\frac{\text{R}}{\text{R}-1}\right)^2.$$

This is the sample size assuming the SE is known. Snedecor and Cochran recommend multiplying n by (df+3)/(df+1) which in our case equals 1+2/n and increases the sample size by <10 percent if n > 20, which is almost always the case. This correction is therefore ignored in *table 3*.