



Methods for Estimating Trend in Binary and Count Response Variables from Complex Survey Designs

Natural Resource Report NPS/KLMN/NRR—2018/1641



**ON THIS PAGE**

A patch of green moss (*Acrospongia*) is exposed in the rocky intertidal zone of Prince William Sound, AK
Mandy Lindeberg, NOAA.

ON THE COVER

A mottled star (*Evasterias troschelii*), clings to a rocky outcropping during a low tide in Aialik Bay, Kenai Fjords National Park.

Jim Pfeiffeneberger, NPS.

Methods for Estimating Trend in Binary and Count Response Variables from Complex Survey Designs

Natural Resource Report NPS/KLMN/NRR—2018/1641

Leigh Ann H. Starcevich¹, Trent McDonald¹, Alice Chung-MacCoubrey², Andrea Heard³, Jonathan C. B. Nesmith³, Heather Coletti⁴, and Tom Philippi⁵

¹ Western EcoSystems Technology, Inc. 415 W. 17th St, Suite 200 Cheyenne, Wyoming 82001.

² National Park Service Inventory & Monitoring Program, Klamath Network, 1250 Siskiyou Blvd, Ashland, OR 97520.

³ National Park Service Inventory & Monitoring Program, Sierra Nevada Network, 47050 Generals Highway, Three Rivers, CA, 93271.

⁴ National Park Service Inventory & Monitoring Program, Southwest Alaska Network, 4175 Geist Rd., Fairbanks, AK 99709

⁵ National Park Service Inventory & Monitoring Division, c/o Cabrillo National Monument, 1800 Cabrillo Memorial Dr., San Diego, CA 92106

May 2018

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate comprehensive information and analysis about natural resources and related topics concerning lands managed by the National Park Service. The series supports the advancement of science, informed decision-making, and the achievement of the National Park Service mission. The series also provides a forum for presenting more lengthy results that may not be accepted by publications with page limitations.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

This report received formal, high-level peer review. Peer review was conducted by highly qualified individuals with subject area technical expertise and was overseen by a peer review manager.

Views, statements, findings, conclusions, recommendations, and data in this report do not necessarily reflect views and policies of the National Park Service, U.S. Department of the Interior. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Government.

This report is available in digital format from the [Klamath Network website](#) and the [Natural Resource Publications Management website](#). If you have difficulty accessing information in this publication, particularly if using assistive technology, please email irma@nps.gov.

Please cite this publication as:

Starcevich, L. A. H., T. McDonald, A. Chung-MacCoubrey, A. Heard, J. C. B. Nesmith, H. Coletti, and T. Philippi. 2018. Methods for estimating trend in binary and count response variables from complex survey designs. Natural Resource Report NPS/KLMN/NRR—2018/1641. National Park Service, Fort Collins, Colorado.

Contents

	Page
Figures.....	v
Tables.....	vii
Supplements.....	vii
Abstract.....	viii
Acknowledgments.....	x
List of Acronyms	x
Introduction.....	1
Methods.....	4
Pilot Data	4
Binary data.....	4
Count data.....	5
Trend analysis approaches.....	5
Trend analysis of Pilot Data	8
Simulation	8
Application of pilot data.....	9
Evaluating Trend Estimation Performance.....	11
Results.....	12
Relative bias of trend coefficient.....	12
Binary data.....	12
Count data.....	15
Trend confidence interval coverage	17
Binary data.....	17
Count data.....	17
Test size	20
Binary data.....	20
Count data.....	22

Contents (continued)

	Page
Test power	22
Variance components estimation.....	22
Binary data.....	22
Count data.....	23
Discussion	24
Binary data.....	24
Count data.....	25
Conclusions.....	27
References.....	31

Figures

Page

Figure 1. The sampling frame for rocky intertidal monitoring in the NPS Southwest Alaskan I&M Network Katmai (KATM) and Kenai Fjords (KEFJ) National Parks.	4
Figure 2. Plots of (a) the proportion of quadrats with positive <i>Acrosiphonia</i> detections and (b) the counts of sea stars (<i>Dermasterias imbricata</i>) by Site and Year at KATM and KEFJ between 2008 and 2015.	5
Figure 3. Plots of (a) the proportion of quadrats with positive <i>Acrosiphonia</i> detections and (b) the counts of sea stars (<i>Dermasterias imbricata</i>) by Site and mean site gradient at KATM and KEFJ between 2008 and 2015.	10
Figure 4. Mean relative bias (as a proportion) of the trend regression coefficient for the binary outcome across all simulation scenarios for (a) trend over 12 years with no subpopulation trend, (b) trend over 12 years with a subpopulation trend, (c) trend over 24 years with no subpopulation trend, and (d) trend over 24 years with a subpopulation trend for the unweighted linear mixed model (PO), simple linear regression for design-based estimates (SLRDB), weighted linear regression for design-based estimates (WLRDB), and probability-weighted iterative generalized least squares approaches A-only, A, and AI.	13
Figure 5. Mean relative bias (as a proportion) of the trend regression coefficient for the count outcome across all simulation scenarios for (a) trend over 12 years with no subpopulation trend, (b) trend over 12 years with a subpopulation trend, (c) trend over 24 years with no subpopulation trend, and (d) trend over 24 years with a subpopulation trend for the unweighted linear mixed model (PO), simple linear regression for design-based estimates (SLRDB), weighted linear regression for design-based estimates (WLRDB), and probability-weighted iterative generalized least squares approaches A-only, A, and AI.	16
Figure 6. Mean confidence interval coverage (as a proportion) of the trend regression coefficient for the binary outcome across all simulation scenarios for (a) trend over 12 years with no subpopulation trend, (b) trend over 12 years with a subpopulation trend, (c) trend over 24 years with no subpopulation trend, and (d) trend over 24 years with a subpopulation trend for the unweighted linear mixed model (PO), simple linear regression for design-based estimates (SLRDB), weighted linear regression for design-based estimates (WLRDB), and probability-weighted iterative generalized least squares approaches A-only, A, and AI.	18

Figures (continued)

Page

Figure 7. Mean confidence interval coverage (as a proportion) of the trend regression coefficient for the count outcome across all simulation scenarios for (a) trend over 12 years with no subpopulation trend, (b) trend over 12 years with a subpopulation trend, (c) trend over 24 years with no subpopulation trend, and (d) trend over 24 years with a subpopulation trend for the unweighted linear mixed model (PO), simple linear regression for design-based estimates (SLRDB), weighted linear regression for design-based estimates (WLRDB), and probability-weighted iterative generalized least squares approaches A-only, A, and AI. 19

Figure 8. Simulation test size of the Wald z-test across all simulation scenarios for which no trend was simulated for (a) the binary outcome over 12 years, (b) the binary outcome over 24 years, (c) the count outcome over 12 years, and (d) the count outcome over 24 years for the unweighted linear mixed model (PO), simple linear regression for design-based estimates (SLRDB), weighted linear regression for design-based estimates (WLRDB), and probability-weighted iterative generalized least squares approaches A-only, A, and AI..... 21

Figure 9. Flowchart of recommended trend analysis approaches for binary data collected from complex sample designs. Analytical approaches include PO, WLRDB, SLRDB, and PWIGLS..... 28

Figure 10. Flowchart of recommended trend analysis approaches for count data collected from complex sample designs. Analytical approaches include PO, WLRDB, SLRDB, and PWIGLS..... 29

Tables

	Page
Table 1. Response variables: simulation inputs and levels.	8
Table 2. Survey designs: simulation inputs and levels.....	9

Supplements

	Page
Supplement A: R code for Trend Approaches	35
Supplement B: Simulation Results for the Binary Outcome	45
Supplement C: Simulation Results for the Count Outcome	79
Supplement D: Case Studies	114

Abstract

The National Park Service (NPS) Inventory and Monitoring (I&M) Program assesses the status and trends in condition of park natural resources as part of their mission to protect and preserve these national assets “for the enjoyment of future generations” (Fancy et al. 2009). Probabilistic sampling designs are used so that inference may be made to broader populations or geographic areas such as the park or network. Spatially-balanced sampling approaches, such as Generalized Random Tessellation Stratified (GRTS, Stevens and Olsen 2003, 2004), provide a probabilistic sampling approach that allocates sampling effort more evenly across large areas of interest. Complex survey designs are often incorporated to address practical sampling issues such as estimation of indicators within subpopulations (strata or domains of interest), limited sampling resources, and gradients relative to covariates that impact sampling effort (e.g. elevation). Design elements such as stratification, unequal probability sampling, and temporal revisit designs may be incorporated to address these issues but may also complicate trend estimation and detection. Ignoring the fact that design weights differ among sampling units when design complexity is used can lead to biased estimates of trend and unreliable trend tests.

The purpose of this project is to assess three trend analysis techniques with the goal of obtaining unbiased and precise trend estimation and powerful trend testing for binary and count data collected in natural resource monitoring with complex GRTS sampling designs and revisit designs. Ideally, the preferred trend analysis approach can be performed with standard statistical tools such as the R statistical software environment. We evaluated three analytical trend approaches on simulated data representing a wide range of design scenarios using data from the NPS Southwest Alaskan Network (SWAN) rocky intertidal monitoring program. The three trend analysis approaches included a generalized linear mixed model (GLMM) that does not incorporate design weights and represents a naïve analysis under complex sampling, simple and weighted linear regressions on transformed design-based estimates of annual status (SLRDB and WLRDB, respectively), and a probability-weighted iterative generalized least squares approach (PWIGLS). We assessed performance of these three approaches by evaluating relative bias and confidence interval coverage of the trend estimators and statistical power and size of the trend test. We summarized recommendations for analysis under a range of simulation scenarios using a decision flowchart and illustrated the application of our results using the “TrendNPS” R-package developed for this project using SWAN case study data.

We found that the GLMM corollary of the unweighted linear mixed model proposed by Piepho and Ogutu (2002) often yielded unbiased estimates of trend and nominal confidence interval coverage. For the range of trend magnitudes, sample sizes, and monitoring periods explored in this research, the naïve GLMM approach, which does not incorporate design weights, performed very well in many cases, even for some scenarios with complex sampling and revisit designs. However, in some select cases, the PWIGLS approach yielded superior trend inference with unbiased estimates of trend and nominal (“appropriate”) confidence interval coverage.



USGS Biological technician, John Paszalek, samples the rocky intertidal during a low tide in Kenai Fjords National Park. Photo credit: J. Pfeifferberger, NPS.

Acknowledgments

This project was largely funded by the NPS Inventory and Monitoring Division, whose leadership encouraged and supported networks to solve challenges together. Seven I&M networks collaborated to obtain and/or provide funding for this project, including Sierra Nevada, Mojave Desert, National Capitol Region, Pacific Island, Sonoran Desert, Southern Colorado Plateau, and Upper Columbia Basin Networks. Project work was accomplished through a contract (P14PX03482) and partnership between WEST, Inc. and I&M staff. We are grateful for the contributions and support of colleagues, without whom this work would not have been possible, including Penny Latham, Kelly Kozar, and Nita Tallent. We also would like to thank Brian Gray (USGS), Ryan Monello (PACN), Linda Mutch (SIEN), Sonya Daw (KLMN/GRYN/ROMN), and Jason Ransom (NCCN) for their helpful reviews.

List of Acronyms

GLS	generalized least squares
GRTS	generalized random tessellation stratification
I&M	Inventory & Monitoring
IGLS	iterative generalized least squares
NPS	National Park Service
PO model	Piepho and Ogutu trend model
PWIGLS	probability-weighted iterative least squares approach
REML	restricted maximum likelihood estimation
SWAN	Southwest Alaska Network
SLRDB	simple linear regression of design-based estimates
WLRDB	weighted linear regression of design-based estimates

Introduction

The National Park Service (NPS) manages a long-term ecological program, known as Vital Signs Monitoring, to evaluate status and trends in the condition of natural resources in parks. A total of 32 Inventory and Monitoring (I&M) networks containing over 270 parks were formed based on geography and shared natural resource characteristics (Fancy et al. 2009). Probabilistic sampling forms the statistical basis for status and trend inference in many monitoring programs. Generalized Random Tessellation Stratified (GRTS) sampling, a type of spatially-balanced probabilistic sampling, has been used in the membership design of many networks to obtain sampling locations for long-term monitoring. GRTS sampling easily incorporates sampling complexity (e.g., stratification or unequal probability sampling) or panel-based revisit designs (Urquhart and Kincaid 1999). A panel is a group of sites that are always visited on the same sampling occasion but not necessarily on every sampling occasion. Survey design complexity such as panel designs or complex membership designs are useful in dealing with statistical issues related to sample allocation, temporal replication, and/or logistical efficiency, but they also introduce analytical challenges to trend estimation and detection, such as low trend test power and biased estimates of trend (Bart and Beyer 2012, Reynolds 2012, Urquhart and Kincaid 1999). If a trend test has inflated test size, then the probability that a false trend is detected is higher than the Type-I error rate (α) initially assumed. This propensity toward detecting a false trend of a magnitude that indicates ecological significance may erroneously trigger an unnecessary mitigation effort. If a trend test has low power, an ecologically significant trend may be missed. Either error may be costly in terms of time and effort (field work, laboratory processing, data entry and analysis, unnecessary restoration efforts or mitigation, etc.). The purpose of this project is to examine potential trend analysis techniques for binary and count data that can provide unbiased and precise trend estimation and powerful trend testing for natural resource monitoring data (such as NPS I&M data) collected from complex GRTS sampling designs and panel designs. Ideally, these analytical approaches can be executed using standard statistical software, such as the R statistical software (2016) environment.

Spatially-balanced sampling approaches are useful because they are suitable when sample sizes are small relative to the extent of the sampling frame, they can easily incorporate design complexity, and they can be used with discrete (e.g., lakes), linear (e.g., streams), or areal (e.g., polygons) sampling frames (Stevens and Olsen 2003, 2004). Several spatially balanced designs are available (see Robertson et al. 2013), but the most commonly used approach by NPS I&M networks is the GRTS approach (e.g., Heard et al. 2012, Irvine et al. 2016, McKinney et al. 2012). Analysis tools to obtain design-based estimates of status (the condition of a resource at a point in time, often represented by a summary statistic like a mean or proportion) from GRTS designs are available in the `spsurvey` package (Kincaid and Olsen 2015) in the R statistical program (2016). Many I&M networks have also employed temporal revisit designs to increase the number of unique sites in the total sample across years while maintaining some site-level replication over time. However, when not all sites in the sample are visited every year, additional weighting is required for unbiased inference.

For monitoring programs that employ both GRTS sampling and a panel revisit design, the typical procedure is to select the GRTS sample of a size large enough to accommodate the panel design and

then impose the revisit design on the selected sites. For the above [1-0,1-3] revisit design and an annual sample size of 20 sites with an annual panel of 10 sites, we would draw a GRTS sample of 50 sites and then allocate the first 10 sites in the list to the annual [1-0] panel and each subsequent, consecutive set of 10 sites (i.e., sites 11-20, 21-30, 31-40, 41-50) to each of the four alternating panels. By using consecutive sets of sites from the GRTS order in each panel, we obtain spatially-balanced subsamples of the population in each panel.

In general, estimation of a parameter that is static relative to time or other covariates is conducted with design-based analysis (Gitzen and Millspaugh 2012). In design-based inference, randomization employed during probabilistic sampling provides the basis for inference (Lohr 2009). The inclusion probability, defined as the probability that sampling unit i is selected, is denoted as π_i . When an equiprobable sampling design is used, all sampling units in the population of interest have the same probability of selection and the design is not considered to be complex. Sampling designs incorporating complexity such as stratification or unequal probability sampling result in sampling units with different inclusion probabilities. Accounting for the different inclusion probabilities is necessary for unbiased design-based inference.

Statistical inference of dynamic systems is generally obtained through model-based inference (Gitzen and Millspaugh 2012). In this inferential setting, the outcome of interest is assumed to be a random variable following some probabilistic distribution and that distribution dictates how variability is estimated. The selection mechanism is inconsequential if the inclusion probability is not related to the outcome of interest (Schreuder et al. 2001). However, design complexity often violates this assumption as stratification and unequal probability sampling are often based on design variables that are directly related to the outcome of interest. When subpopulations are surveyed disproportionately to their population distribution and exhibit different trends in the outcome of interest, trend modeling that ignores the design complexity may result in biased estimates of trend (Asparouhov 2006). In this case, a model-assisted approach that combines elements of both design-based and model-based inference is needed for unbiased trend inference.

Trend modeling literature has addressed aspects of the issues introduced by complexity in both the membership design and the revisit design, but the analytical challenges when both occur have not been resolved. Complexity introduced by temporal revisit designs (Urquhart et al. 1993, Urquhart and Kincaid 1999) results in “unbalanced” data because data exist for each site for only a subset of sampling occasions. The trend model of Piepho and Ogutu (2002) exhibited nominal (i.e. reflected the appropriate Type-I error rate) test size for unbalanced data, but the performance of this approach is unknown for sampling design complexity. Nonparametric trend detection methods such as the Regional Kendall Tau (Helsel and Frans 2006) require balanced data, so trend analysis for data collected from a panel design must be reduced to only the subset of sites visited every year. Modeling approaches that incorporate design weights, such as the probability-weighted iterative generalized least squares (PWIGLS) approach (Pfeffermann et al. 1998, Skinner and Holmes 2003), generally incorporate very simple variance structures and large numbers of secondary units (years) within each primary unit (sites). However, for ecological monitoring, these secondary unit sample sizes reported in the literature can greatly exceed the monitoring period lengths that are needed for

effective management of natural resources. A potential solution explored in this research is to model the trend in log- or logit-transformed annual design-based estimates of the parameter of interest, similar to the approach of Brus and deGruijter (2011), where the logit function is defined as $\log[p/(1 - p)]$ for the probability, p , that the binary outcome is 1. Furthermore, none of these approaches have been assessed for discrete outcomes such as binary and count data.

In this project, we compare three general approaches for model-based trend analysis and assess the impact of ignoring design complexity under a range of survey design scenarios that included sampling design complexity, revisit designs, annual sample sizes, annual sampling effort, and monitoring periods. Our goal is to identify the statistical method(s) that provide unbiased estimates of trend for data collected using complex spatial and temporal sampling designs and that can be implemented with widely used statistical software such as R (2016). The first phase of this work (Starcevich et al. 2018) focused on continuous outcomes of interest. Here we extend the methodology explored in the first phase to examine the performance of these methods and trend models with binary and count data.

Methods

Pilot Data

We obtained pilot data for our simulations from the NPS Southwest Alaskan Network I&M program (SWAN), which monitors rocky intertidal indicators such as *Acrosiphonia* (Arctic sea moss, green sea rope, and northern green rope) presence and *Dermasterias imbricata* (leather sea star) counts (Alaska Ocean Observing System 2016). These data are collected from a GRTS sample stratified by two parks, Katmai National Monument (KATM) and Kenai Fjords National Park (KEFJ). The sampling frames consisted of 56,499 sites in KATM and 370,650 sites in KEFJ (Figure 1). Five sites from each park were selected with equal probability and visited annually between 2008 and 2015, with the exception of KATM, which was not visited in 2011. Outcomes of interest included a binary indicator of species presence and a count of sea stars. A measurement of site gradient (in degrees) was also collected and may be used as a model covariate. We describe the pilot data and how the initial trend analysis was used to inform the simulation to examine three trend analysis approaches.

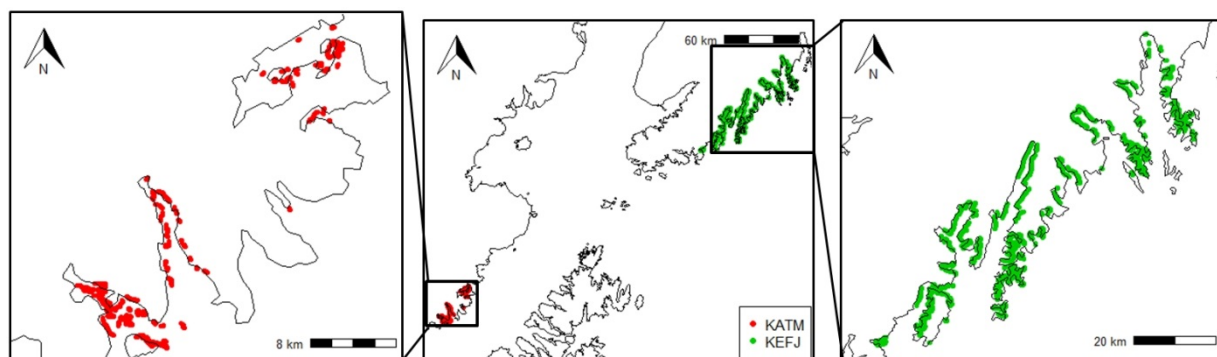


Figure 1. The sampling frame for rocky intertidal monitoring in the NPS Southwest Alaskan I&M Network Katmai (KATM) and Kenai Fjords (KEFJ) National Parks.

Binary data

The binary data in this project were obtained from presence/absence data used to measure cover of rocky intertidal indicators. Response designs differed in 2006 and 2007 from the response design used in subsequent years (Heather Coletti, pers. comm.), so we focused on data collected in 2008 and after. Each site contained a transect with 12 systematically placed 1/4 sq. m. quadrats at two tidal elevations (0.5 m and 1.5 m). Each quadrat contained 25 points for which presence/absence of a species was recorded.

For the SWAN rocky intertidal cover data, the binary outcome was measured at each of 25 points within a quadrat within an elevation band within a site. Because only 5 sites are visited per park, the pseudoreplication of $25 \times 12 \times 2 = 600$ points per site was more than an order of magnitude larger than the independent replication of the survey. Trial modeling of data at the point-within-quadrat-within-site level resulted in convergence errors and null estimates of variance components due to the lack of true replication. Therefore, the data structure was simplified for this analysis. For a given year, any detection within the 25 points in a given quadrat resulted in an indicator of presence at the quadrat

level, and each site had 12 quadrat-level assessments of presence/absence (Figure 2a) at each of two tidal elevations. Therefore, the combined assessment of binary outcomes results in a binomial outcome for each site and elevation class. Modeling quadrat-level presence within a site converged for the full set of variance components; however variance components estimates may be underestimated for binary outcomes (Breslow 2004).

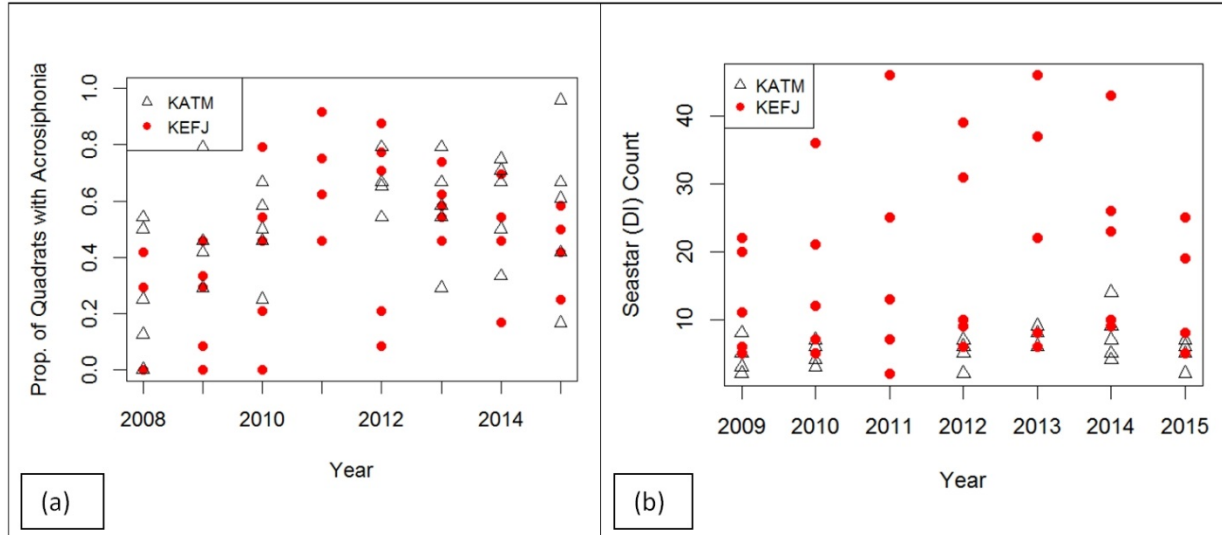


Figure 2. Plots of (a) the proportion of quadrats with positive *Acrosiphonia* detections and (b) the counts of sea stars (*Dermasterias imbricata*) by Site and Year at KATM and KEFJ between 2008 and 2015.

Count data

Count data for this research were obtained from annual counts of sea stars (*D. imbricata*) at the randomly selected sites. Transect lengths varied between 2006 and 2008 after which 50m transects were used exclusively, so we restricted the pilot data to 2009 to 2015. Sea stars were counted along 50 m by 4 m swaths placed with the lower edge at mean lower low water (MLLW, the average height of the lowest tide) along transects at each randomly selected site within sheltered rocky shorelines (Alaska Ocean Observing System 2016). Sea stars were counted visually without moving rocks, so sea star counts are likely to underrepresent the true number of sea stars.

SWAN count data for all sea star species were subject to zero inflation and small counts. Because this project addressed standard Poisson count data, issues of zero inflation were not a primary focus. The count data that were least subject to zero inflation and overdispersion were selected as the basis for the simulation, but a Poisson random variable with mean 5 was added to observed counts to mitigate the effects of zero inflation for the purposes of this simulation study (Figure 2b). Subsequent results for the trend analysis reflect this adjustment to the pilot data, which more accurately reflects a Poisson count outcome.

Trend analysis approaches

The earlier phase of this trend research (Starceovich et al. 2018) addressed trend methods for continuous data and used linear models for trend analysis. In this earlier phase, we examined three

general approaches including a linear mixed model that does not incorporate design weights and represents a naïve analysis under complex sampling (Piepho and Ogutu 2002), a simple linear regression on design-based estimates of annual status similar to methods used by Brus and Gruijter (2011), and probability-weighted iterative generalized least squares (PWIGLS) (Pfeffermann et al. 1998, Asparouhov 2006). In the naïve approach (PO), the sampling design and revisit design are ignored and design weighting is not incorporated into the trend analysis. The second approach uses design-based estimates of status for each year and then models trend with a simple linear regression of the logit- or log-transformed design-based estimates (SLRDB) or weighted linear regression of those transformed estimates (WLRDB) with weights obtained from the inverse of the neighborhood variance estimator for each annual status estimate. This approach accounts for design weighting with design-based estimation prior to the model-based trend analysis. The third approach applies probability-weighted iterative generalized least squares approach (PWIGLS) to account for design weighting. The PWIGLS approach incorporates one of 6 scaling approaches (A-only, A, AI, B, BI, and C) to account for potential bias due to large design weights (see Starcevich et al. 2018 for more information). Samples were obtained from simulation scenarios defined by combinations of monitoring periods (12 and 24 years), sampling designs (equiprobable, stratified and unequal probability GRTS samples), revisit designs ([1-0], [1-0, 1-3], and [1-3]), annual sample sizes (20, 35, and 50 sites), and annual trends (0%, 1%, and 4% per year with subpopulation trends of 0% or 4%).

In this second phase of research, we extend these trend methods to the discrete data case. In the discrete data case, the unweighted PO approach and the PWIGLS approach incorporate a generalized linear mixed model (GLMM) for binary or count data but the random effects structure is defined as by Piepho and Ogutu (2002). Note that the PO and PWIGLS approaches have the same names in the both phases of research but refer to linear mixed models in the first phase and GLMMs in the second phase.

The fixed effects and random effects structure of the Piepho and Ogutu (2002) model is incorporated in the GLMM analysis for discrete data to obtain a naïve trend analysis approach that does not include design weights (akin to the PO approach in the first continuous case). Let i reference the site ($i = 1, \dots, s$), j reference the year ($j = 1, \dots, t$), and k reference the measurements taken at site i during year j ($k = 1, \dots, n_{ij}$). Therefore, we analyze the binary outcomes as a binomial random variable with parameters n_{ij} and probability $p_{ij} = E(y_{ij})$. The GLMM based on the Piepho and Ogutu (2002) variance structure (hereafter the “PO model”) is defined as follows:

$$\eta_{ijk} = \gamma_0 + x_j\gamma_1 + b_j + a_i + x_jt_i,$$

where $g[E(y_{ij})] = g[p_{ij}] = \eta_{ij}$ is the linear predictor for the i^{th} site in the j^{th} year such that:

$g(\cdot)$ is the link function;

x_j = year variable representing the j^{th} year;

γ_0 and γ_1 = fixed intercept and slope of linear trend in time;

b_j = random effect of the j^{th} year, iid $N(0, \sigma_b^2)$;

a_i = random intercept of the i^{th} site; and

t_i = random slope of the i^{th} site, $\begin{pmatrix} a_i \\ t_i \end{pmatrix} \sim N\left(\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{bmatrix} \sigma_a^2 & \sigma_{at} \\ \sigma_{at} & \sigma_t^2 \end{bmatrix}\right)$.

For GLMMs in this study, the measurement-level residual error term is defined by the assumed underlying distribution. A Bernoulli distribution with a logit link function was applied for binary data, and a Poisson distribution with a logarithmic link function was assumed for count data. The PO model in R (2016) is applied with the `glmer` function in the `lme4` package (Bates et al. 2015) and applies a Laplace approximation (Wolfinger 1993, Raudenbush et al. 2000). This Laplace approximation method is appropriate for mixed model analysis when the outcome is not overdispersed and when more than one random effect is included in the model (Bolker et al. 2008). For estimation of a GLMM with the Laplace approximation, the linked outcomes of interest are estimated with a second-order Taylor series expansion. The likelihood of the linearized data, rather than the data directly, is assumed to be distributed approximately normally and predictions of the linked outcome are iteratively updated from mixed model equations until convergence.

For binary outcomes, direct weighting of the random effects design matrix was used as in Phase I of this research. However, preliminary analysis indicated poor convergence when this approach was used for count data. Therefore, the approximate normal distribution of predictions from the Laplace approximation is used for trend inference for count data. We obtain initial predictions from the PO model. The predictions from this model represent the results of the final iteration from the Laplace approximation in the unweighted case. The predictions and Pearson residuals from the initial GLMM are then used to generate the Taylor series predictions of the log-linked count outcomes. These real-valued outcomes are distributed with the same fixed effects and random effects structure as the initial binary or count variable but now with an additional residual error term (Wolfinger 1993). Therefore, we can make valid trend inference directly from the predictions of the log-linked count outcome by applying the Laplace approximation and using the trend analysis methods developed for continuous outcomes in the first phase of this research (Starcevich et al. 2018). Note that, for the binary outcome, modeling the trend in predictions from the Laplace approximation resulted in small standard errors and poor confidence interval coverage. Therefore, direct weighting of the GLMM random effects matrix is used for binary outcomes, and weighting of real-valued predictions from the Laplace approximation is used for count outcomes in this research.

In Phase I of this work, the linearization variance estimator (Skinner et al. 1989) was used with the PWIGLS method for trend testing and confidence intervals construction. Preliminary analyses indicated that the linearization variance of the PWIGLS trend estimate was smaller than the variance from the GLMM Laplace approximation, causing confidence interval coverage with the linearization variance to be inferior. The poorer performance of the linearization variance is likely a result of having already applied a Taylor series approximation to the data in the Laplace approximation, making further linearization less accurate and unnecessary. Therefore, for confidence interval

construction and trend testing, we use the estimate of the trend standard error obtained directly from the model output for both the binary and count outcomes. R code for all trend approaches is provided in Supplement A.

Trend analysis of Pilot Data

An initial trend analysis (Table 1) was conducted with the PO model. A fixed intercept effect for the Park strata was incorporated to provide the basis for a stratification simulation. The intercepts in the trend analysis represented baseline status estimates of each indicator across both parks on the link scale (i.e. logit scale for binary data and log scale for count data). Note that the baseline status for the outcome on the link scale at KATM is obtained by adding the park intercept to the main intercept and the KEFJ intercept is obtained by subtracting the park intercept from the main intercept.

Table 1. Response variables: simulation inputs and levels.

Outcome	Intercept (SE)	Trend (SE)	p-value from two-sided trend test	Park Intercept (SE)	Site-to-site Variance	Site-level Slope Variance	Year-to-year Variance	Over-dispersion Variance
<i>Acrosiphonia</i> presence	-0.7244 (0.3735)	0.1872 (0.0882)	0.0339	0.2672 (0.1311)	0.3069	0.0162	0.2378	–
<i>D. imbricata</i> counts	2.0135 (0.2111)	0.0561 (0.0391)	0.1513	0.4644 (0.1525)	0.2330	0.0001	0.0227	0.0624

A chi-square goodness-of-fit test was used to determine if the outcomes of interest were overdispersed (i.e. exhibited more variation than would be expected given their distributional assumptions). The adjusted count data demonstrated possible extra-Poisson variation ($\chi^2 = 74.26$, $df = 57$, $p = 0.0619$). Therefore, a random effect for overdispersion was added to the GLMM of the adjusted count data (Lee and Nelder 2000). Note that this overdispersion is not incorporated into the simulated outcome so that a standard Poisson count outcome is simulated. The results of the trend analyses will be incorporated into the simulation study of three trend analysis approaches.

Simulation

We applied each trend analysis approach to the set of simulation scenarios (Table 1) using Monte Carlo simulations of populations based on the SWAN pilot data. We identified a range of survey scenarios (i.e., types and levels of sampling design complexity and sampling effort per year) that are common within the NPS I&M program. We investigated sampling designs involving three levels of sampling complexity (GRTS sampling designs) and temporal complexity (panel revisit designs) (Table 2). We examined three levels of annual sample effort, ranging from 20 to 50 total sites per year, and monitoring periods of 12 and 24 years (i.e., periods encompassing at least three sampling cycles for alternating panel designs). We simulated populations with three levels of annual trend and two levels of subpopulation trends. For each combination of GRTS sample design, sample size, temporal revisit design, monitoring period, and trend magnitude, we simulated populations with binary or count outcomes based on baseline status and variance composition from the pilot data, selected the appropriate sample, and applied all trend approaches. If the PO model did not converge,

the random slope variance component was omitted for the PO and PWIGLS approaches for that iteration.

Table 2. Survey designs: simulation inputs and levels

Simulation input	Levels
GRTS sampling designs	Equiprobable, stratified, and unequal probability sampling
Annual sample sizes	20, 35, and 50 sites
Revisit designs	[1-0], [1-0,1-3], and [1-3]
Monitoring periods	12 and 24 years
Annual trends	0%, 1% (24 years), and 2% (12 years)
Subpopulation trends	0%, 4%

Application of pilot data

The results of the trend analyses of SWAN binary and count pilot data were used to inform the simulation of trends for a range of survey design complexity. Using the existing frame, which included stratification, was problematic for the simulation because the parks are not spatially contiguous. Therefore, simulating an unequal probability sample from the SWAN sampling frame would also require accommodating the stratification. Therefore, data from both parks were used to estimate park-level baseline status and for variance component estimation, but we focused on KEFJ as the target population for the simulation. In this way, the impacts of stratification and unequal probability sampling could be isolated in the simulation.

The sampling frame provided by SWAN consists of 427,149 sites across the two parks. This large sampling frame is inefficient for simulation because GRTS sampling is time-consuming for large frames. Therefore, we drew a GRTS master sample of 1000 points from the KEFJ sampling frame, and the master sample served as the simulation sampling frame to reduce the overall computational cost. This simulated sampling frame provided a single contiguous spatial area to use for simulations and provided the basis for defining two strata and three unequal probability sampling classes.

To develop separate simulations for stratification and unequal probability sampling, we modeled the relationships between the mean gradient at a site and quadrat-level presence of *Acrosiphonia* for binary data (Figure 3a) and *D. imbricata* counts (Figure 3b) at KATM and KEFJ. The mean gradient at each site in the KEFJ sampling frame was scaled to represent the total gradient range across both KATM and KEFJ for the purposes of simulation. Sites were stratified into groups falling below (“Low”) or above (“High”) 20 degrees gradient. Mimicking the original SWAN frame, the relative proportions of the strata resulted in 77% of the sites in the Low gradient stratum and 23% in the High gradient stratum. Three gradient classes for unequal probability sampling were obtained by dividing the sites into the following three classes: (1) falling below the 17.5 degree gradient, (2) between 17.5 and 20 degrees, and (3) above 20 degrees with 49%, 28%, and 23% of the sites in each class, respectively. These three classes provide a mechanism to simulate unequal probability sampling and sampling classes disproportionately to their occurrence in the population to examine how design weights can impact trend analysis. Therefore, the Low gradient stratum is comprised of gradient

classes 1 and 2, and the High gradient stratum corresponds to gradient class 3. For complex sampling designs scenarios in this research, only 15% of the High gradient/gradient class 3 sites are sampled to examine the impact of undersampling a subpopulation that exhibits an extreme trend.

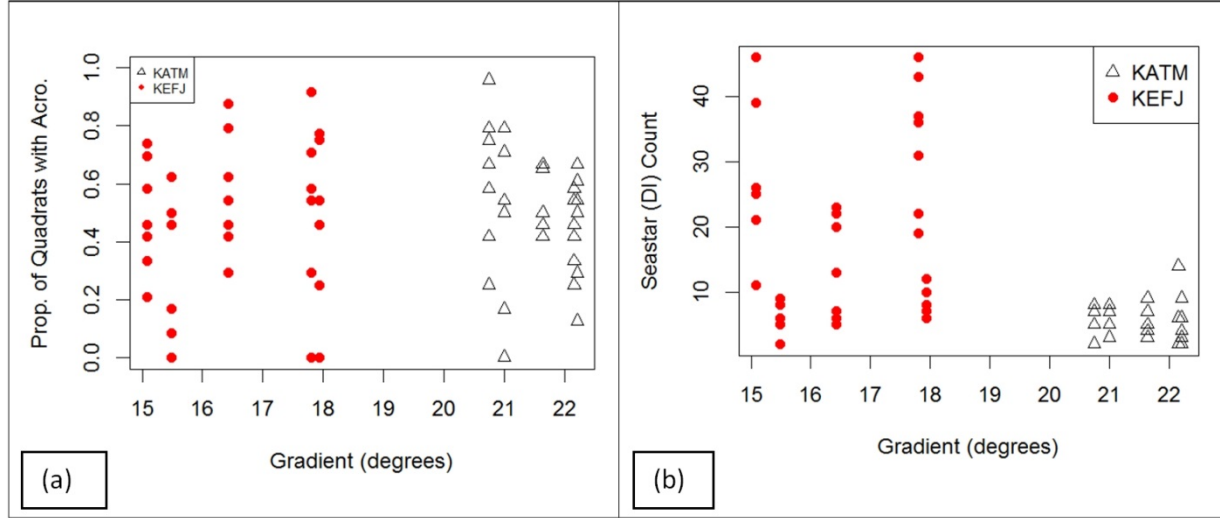


Figure 3. Plots of (a) the proportion of quadrats with positive *Acrosiphonia* detections and (b) the counts of sea stars (*Dermasterias imbricata*) by Site and mean site gradient at KATM and KEFJ between 2008 and 2015.

For binary data, we simulated 25 measurements of presence per site so that site-level cover is accurately estimated and does not confound simulation inference by using a small number of detections at a site. Recall that the logit function is defined as $\log[p/(1 - p)]$, where p is the probability that the binary outcome is 1. Define the odds ratio as the value $p/(1 - p)$. Because the link function for binary data employs the logit link, a convenient interpretation is obtained by modeling the trend of the odds ratio. Positive trends were simulated on the scale of the odds ratio. For count data, site-level counts were simulated without overdispersion to simulate a standard Poisson count outcome, and trends were generated on the log scale. Positive trends were simulated on the scale of the logged site-level count.

We simulated data collected under three revisit designs [1-0], [1-0,1-3], and [1-3]. These revisit designs represent, respectively, a single panel of sites visited every year, an annual panel of sites combined with four panels visited on an alternating schedule, and a set of four panels visiting on an alternating schedule with no annual panel. We simulated samples of 20, 35, and 50 sites each year. Therefore, these annual sample sizes represent the size of each panel in the [1-0] design and each of the four panels in the [1-3] design. The annual panel [1-0,1-3] always contained 10 sites, so the alternating panels always included annual samples of 10, 15, and 40 sites to correspond to the annual total sample sizes of 20, 35, and 50 sites. Under stratified sampling, the annual panel contained 1 or 2 sites in the High elevation stratum and 8 or 9 sites in the Low elevation stratum to reflect the undersampling.

We imposed annual trends of 2% over 12 years and 1% over 24 years on pilot data, each resulting in net increases of 27% over the respective time periods. Trends of 0% were simulated to assess trend test size. For some simulation scenarios, we generated higher trends of 4% over 12 and 24 years at the High gradient stratum or gradient class 3 to assess the impact of an extreme trend at an undersampled subpopulation. We drew GRTS samples from each simulated population and allocated sites to panels sequentially down the list according to the revisit design to maintain spatial balance of samples.

Evaluating Trend Estimation Performance

We assessed the relative bias of the coefficient of trend for responses on the link scale, the 90%-confidence interval coverage (proportion of confidence intervals containing the true trend coefficient), trend test size (proportion of iterations for which a trend was detected when no trend was present), and trend test power (proportion of iterations for which a trend was accurately detected). For each simulation scenario (defined as a combination of sampling design, monitoring period length, temporal revisit design, and trend magnitude), we applied all trend analysis approaches to 500 simulated populations and summarized results across these iterations. We computed relative bias of the trend coefficient estimator as the proportional difference of the mean of the trend coefficient estimates compared to the true trend coefficient, or $\left(\frac{\hat{\gamma}_1 - \gamma_1}{\gamma_1}\right)$. We considered a trend estimate to be nontrivially biased if the true trend coefficient was overestimated or underestimated by 5% or more. For a Type I error rate of 0.10, confidence interval coverage of the trend estimate for a given simulation scenario was calculated as the proportion of times that the 90%-confidence interval contained the true trend regression parameter value. Test size was computed as the proportion of times that the null hypothesis of no trend was rejected in error and a false trend was detected. Given a Type I error rate of 0.10, a trend test with size of roughly 0.10 is desirable and referred to as having “nominal” test size. When evaluating the trend test size results, a trend test with test size near 0.10 was most desirable but we considered test size up to 0.13 to represent an acceptable trend test. We chose the value of 0.13 so that tests of trend with test size close to the desired value of 0.10 would not be classified as undesirable. Test power, the proportion of times that the null hypothesis was correctly rejected when a non-zero trend was simulated, was considered adequate in this research for power of at least 80%.

Results

For the PWIGLS approach, the results for methods A and B are nearly identical when rounded to the second decimal place and, similarly, the results for methods AI and BI are nearly equivalent. For brevity, only the results from the A-only, A, and AI, and C PWIGLS approaches are reported in the report tables. Complete simulation results are provided in Supplements B and C for binary and count data, respectively. Note that relative bias and confidence interval coverage are discussed as percentages but reported as proportions in the figures.

Relative bias of trend coefficient

Binary data

For most simulation scenarios, the trend regression coefficient was underestimated, and the relative bias across all trend approaches ranged from -33% to 159% (Figure 4). The most accurate approach across all simulation scenarios was the PO approach which ranged from -19% to 16% relative bias. However, there were several simulation scenarios for which no unbiased estimate of trend was obtained from any trend method (Supplement B, Table B.1).

The SLRDB and WLRDB approaches overestimated the true trend regression parameter for nearly every simulation scenario with the exception of some cases of equiprobable and unequal probability sampling for revisit designs incorporating larger samples of unique sites. The trend estimate from the SLRDB approach was least biased across all approaches when a [1-3] revisit design was used in the following scenarios: unequal probability sampling over a 12-year monitoring period (range: -4% to -1%); equiprobable sampling over a 12-year monitoring period with a 4% subpopulation trend and at least 35 sites visited annually (range: -4% to -3%); and unequal probability sampling over a 24-year monitoring period with a 4% subpopulation trend (range: 4% to 7%). For the remaining cases, either the PO or PWIGLS approach demonstrated smaller relative bias.

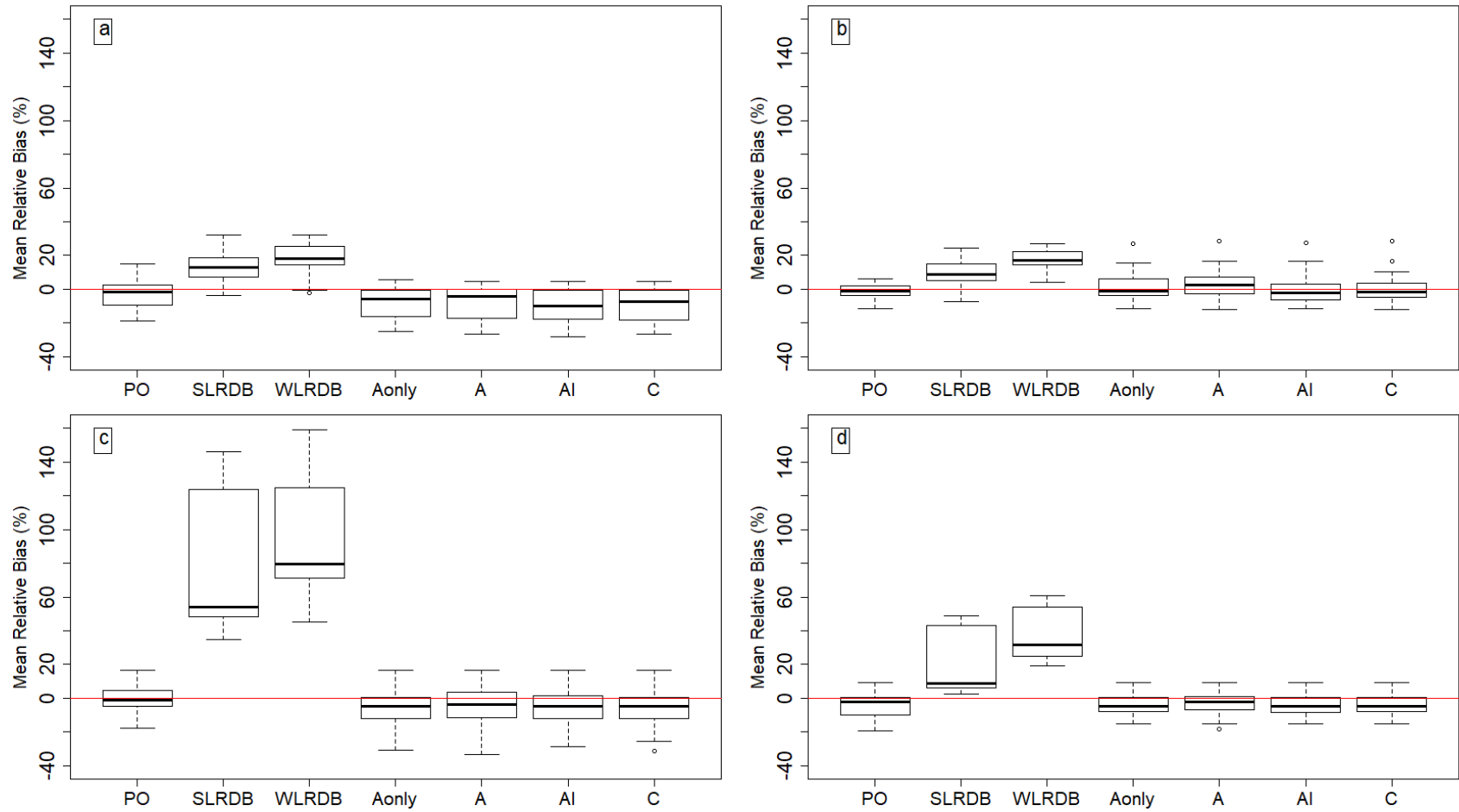


Figure 4. Mean relative bias (as a proportion) of the trend regression coefficient for the binary outcome across all simulation scenarios for (a) trend over 12 years with no subpopulation trend, (b) trend over 12 years with a subpopulation trend, (c) trend over 24 years with no subpopulation trend, and (d) trend over 24 years with a subpopulation trend for the unweighted linear mixed model (PO), simple linear regression for design-based estimates (SLRDB), weighted linear regression for design-based estimates (WLRDB), and probability-weighted iterative generalized least squares approaches A-only, A, and AI.

For a 12-year monitoring period, equiprobable sampling design, and 2% annual trend, the PO method (which would be appropriate for this sampling design with no complexity) yielded estimates of the trend regression coefficient of -8% to 6%. Underestimation was severe for the [1-0] revisit design when stratification was used (-19% to -16%), but the relative bias ranged from -4% to 6% for the [1-0,1-3] and [1-3] revisit designs. The relative bias from estimates of trend using the PWIGLS approach was similar to the PO results when the A and B scaling methods were used. For unequal probability sampling, the PO method was biased (-14% to 15%). The PWIGLS approach was generally unbiased for a [1-0] revisit design but the SLRDB approach provided less biased estimates of trend in most cases for the [1-0,1-3] and [1-3] revisit designs.

When a subpopulation trend was present over the 12-year monitoring period (Figure 4b), estimates of the trend regression coefficient from the SLRDB approach were least biased for equiprobable sampling and the [1-0] and [1-3] revisit designs. PWIGLS with the A-only, A, B, or C scaling methods was the least biased approach for the [1-0,1-3] revisit design and equiprobable sampling. When stratification was used, the PO and PWIGLS approaches with A-only, A, or B scaling were unbiased in all cases. The PO approach was least biased for unequal probability sampling (range: -9% to 1%).

For a 24-year monitoring period, no subpopulation trend, and equiprobable sampling (Figures 4c and 4d), the PO and PWIGLS methods were generally unbiased; the few exceptions observed may simply reflect simulation variability. When stratified random sampling was used with a [1-0] revisit design, no approach provided unbiased estimates of the trend regression coefficient. The PO approach and the PWIGLS approach with the A or B scaling method yielded unbiased estimates of trend for a [1-0,1-3] revisit design, but both methods only produced unbiased estimates for the [1-3] revisit design when a sample of 50 sites was surveyed annually. Estimates of trend from unequal probability sampling were generally quite biased except for samples of at least 35 sites per year with a [1-0] revisit design with the PO approach and a sample of 50 sites annually with the [1-3] revisit design and the PWIGLS approach. When a subpopulation trend was present over the 24-year monitoring period, the PO approach and the A and B scaling methods of the PWIGLS approach were generally unbiased for equiprobable and stratified sampling. For unequal probability sampling, the PWIGLS approach provided generally unbiased estimates of trend for the [1-0] revisit design. The SLRDB approach yielded the least biased trend estimates for the [1-0,1-3] and [1-3] revisit designs but trend was still overestimated in some cases (range: 3% to 10%).



USGS biological technician, John Paszalek, samples the rocky intertidal during a low tide in Kenai Fjords National Park. Photo credit: K. Chritz, NPS.

Count data

The PO and PWIGLS approaches were much more accurate for the analysis of trends in simulated sea star counts (Figure 5). The PO regression coefficient for 12-year trend in the mean count outcome (Figure 5a) was unbiased for all but the smallest sample sizes when equiprobable and stratified GRTS sampling were used, but underestimated trend by -16% to -11% when a subpopulation trend was present and unequal probability sampling was used (Figure 5b). For a 24-year monitoring period (Figures 5c and 5d), similar results for the PO approach were found. Exceptions included underestimation for equiprobable sampling with the [1-0,1-3] revisit design and unequal probability sampling with the [1-0] revisit design and more extreme underestimation when unequal probability sampling was used when a subpopulation trend was present (Supplement C, Table C.1).

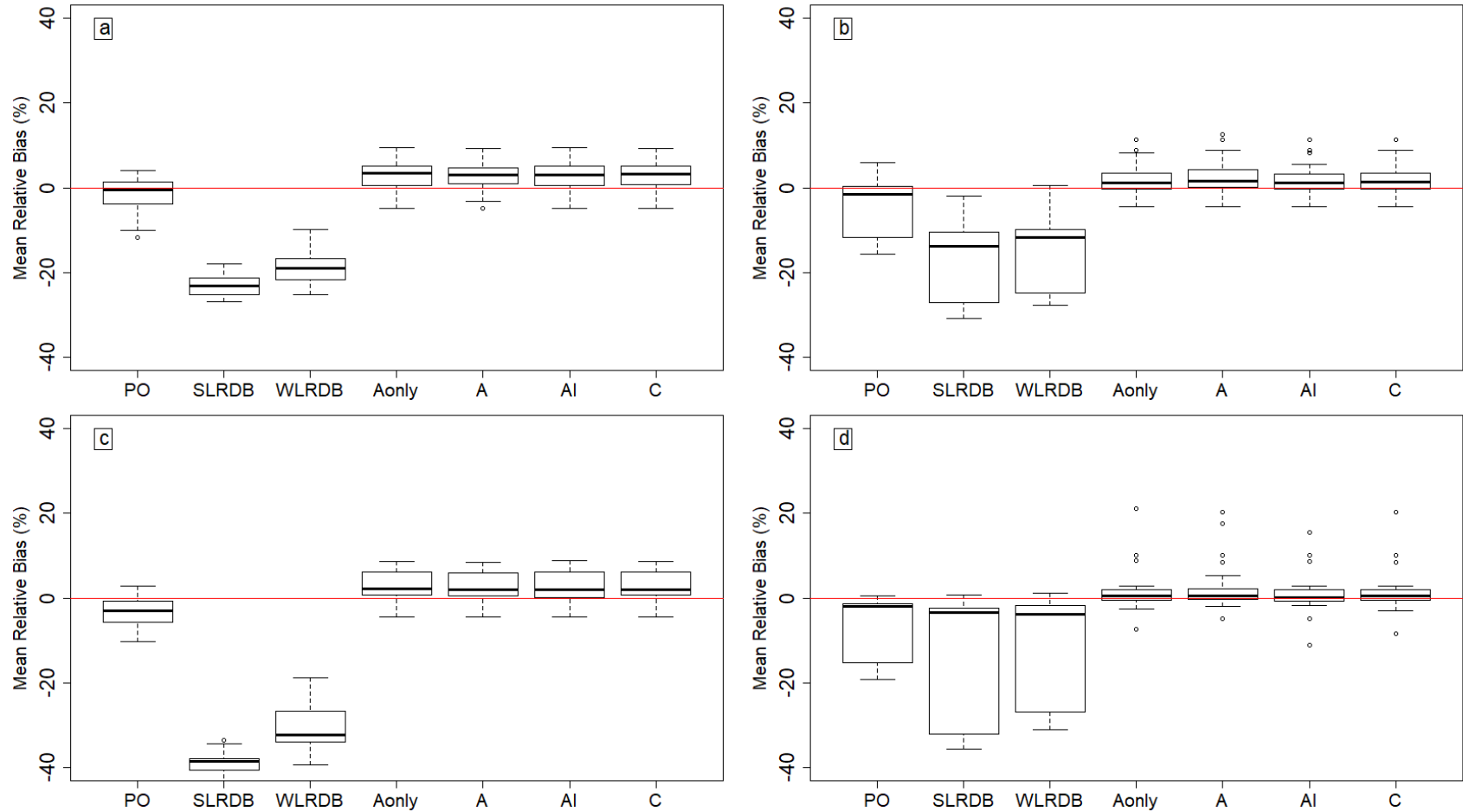


Figure 5. Mean relative bias (as a proportion) of the trend regression coefficient for the count outcome across all simulation scenarios for (a) trend over 12 years with no subpopulation trend, (b) trend over 12 years with a subpopulation trend, (c) trend over 24 years with no subpopulation trend, and (d) trend over 24 years with a subpopulation trend for the unweighted linear mixed model (PO), simple linear regression for design-based estimates (SLRDB), weighted linear regression for design-based estimates (WLRDB), and probability-weighted iterative generalized least squares approaches A-only, A, and AI.

The PWIGLS trend approach performed well for most simulation scenarios, yielding unbiased estimates of the trend regression coefficient for nearly every scenario incorporating a [1-0] revisit design. The most extreme bias in the PWIGLS approach occurred when the [1-3] revisit design was used with an unequal probability sample, overestimating trend by up to 8% for a 12-year trend and up to 21% for a 24-year trend. The SLRDB trend method provided unbiased estimates of trend when a subpopulation trend was present and equiprobable or unequal probability sampling was used. This method was the only trend approach that consistently produced unbiased estimates of trend when a subpopulation trend occurred but was sampled with unequal probability.

Trend confidence interval coverage

Binary data

Overall, confidence interval coverage increased as a function of monitoring period length for both the PO and PWIGLS approaches (Supplement B, Table B.2), but worsened as a function of time for the SLRDB and WLRDB approaches (Figure 6). For the 12-year monitoring period, 90%-confidence interval coverage with the PO approach ranged from 83% to 89% across all simulation scenarios and improved to 85% to 92% for a 24-year monitoring period. Confidence interval coverage of the trend coefficient with the PWIGLS approach was equal to that of the PO approach for equiprobable sampling. For stratified GRTS sampling, the A and B scaling methods of the PWIGLS approach yielded nominal confidence interval coverage for all monitoring periods and revisit designs. For unequal probability sampling over 12 years, confidence interval coverage was closest to nominal for the PO approach and a [1-0] revisit design (range: 84% to 89%) and for the SLRDB approach and [1-0,1-3] and [1-3] revisit designs (range: 82% to 90%). For unequal probability sampling over 24 years, the PO approach yielded nominal confidence interval coverage for all revisit designs and sample sizes.

Count data

Overall, the PO approach provided the most cases of nominal (i.e. 90%) confidence interval coverage (Figure 7). Across all simulation scenarios (Supplement C, Table C.2), confidence interval coverage for the PO approach ranged from 81% to 91% for a 12-year trend and from 79% to 94% for a 24-year trend. However, confidence interval coverage decreased for unequal probability sampling when a subpopulation trend was present due to underestimation by the unweighted PO trend estimates. The SLRDB approach yielded nominal confidence interval coverage for annual samples of at least 35 sites when a subpopulation trend was present and equiprobable or unequal probability sampling was used with the [1-0,1-3] or [1-3] revisit designs (range: 87% to 90%). The PWIGLS approach resulted in nearly nominal confidence interval coverage ranging from 78% to 88% when the [1-0] revisit design was used over 12 years, but only provided nominal confidence interval coverage for small sample sizes when the monitoring period extended to 24 years. Nominal confidence interval coverage was not achieved for any scenario involving unequal probability sampling over 12 years and was only attained for a 24-year monitoring period when 20 sites were visited annually with a [1-0] revisit design. Confidence interval coverage dropped as sample size increased for many scenarios.

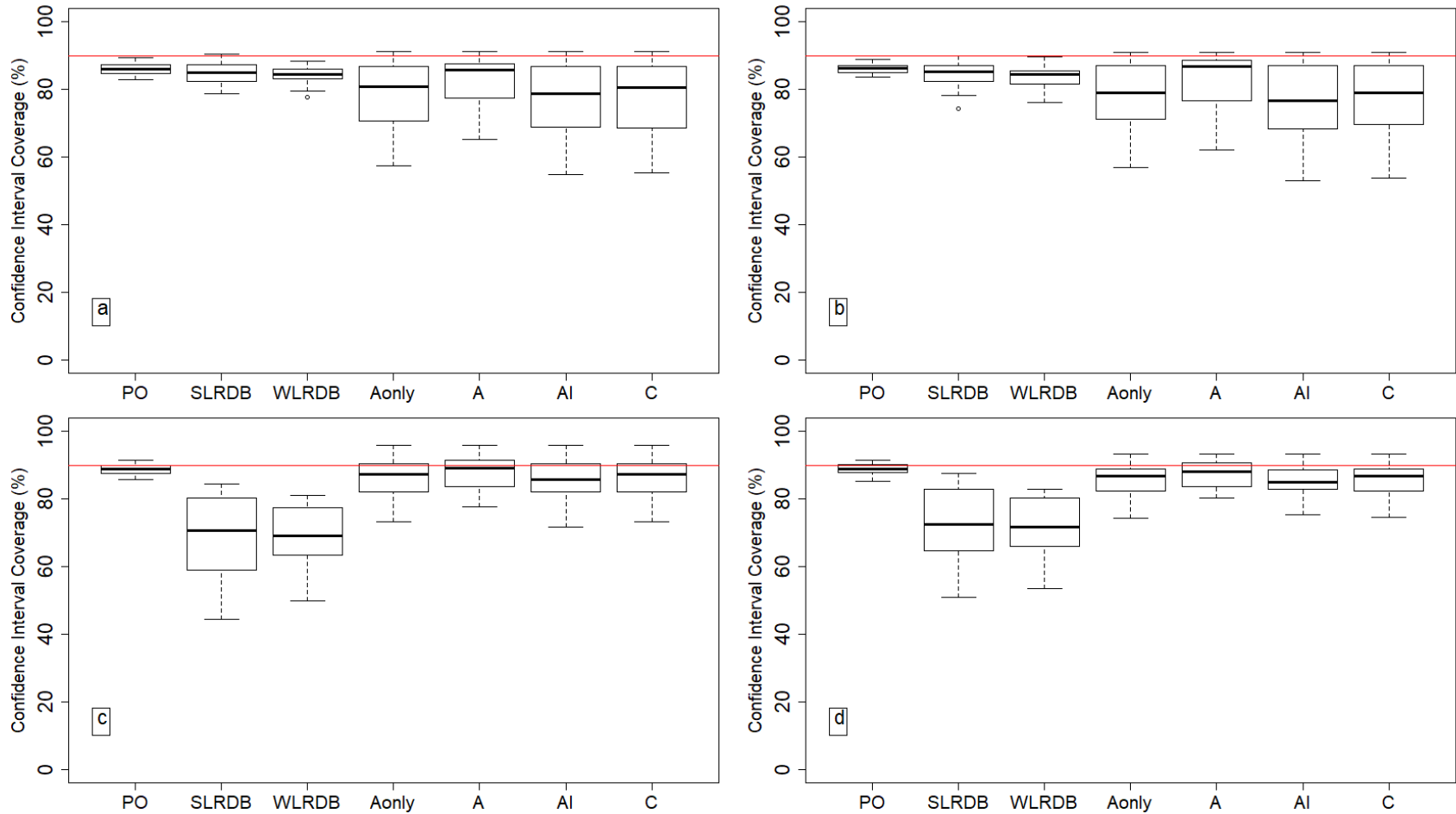


Figure 6. Mean confidence interval coverage (as a proportion) of the trend regression coefficient for the binary outcome across all simulation scenarios for (a) trend over 12 years with no subpopulation trend, (b) trend over 12 years with a subpopulation trend, (c) trend over 24 years with no subpopulation trend, and (d) trend over 24 years with a subpopulation trend for the unweighted linear mixed model (PO), simple linear regression for design-based estimates (SLRDB), weighted linear regression for design-based estimates (WLRDB), and probability-weighted iterative generalized least squares approaches A-only, A, and AI.

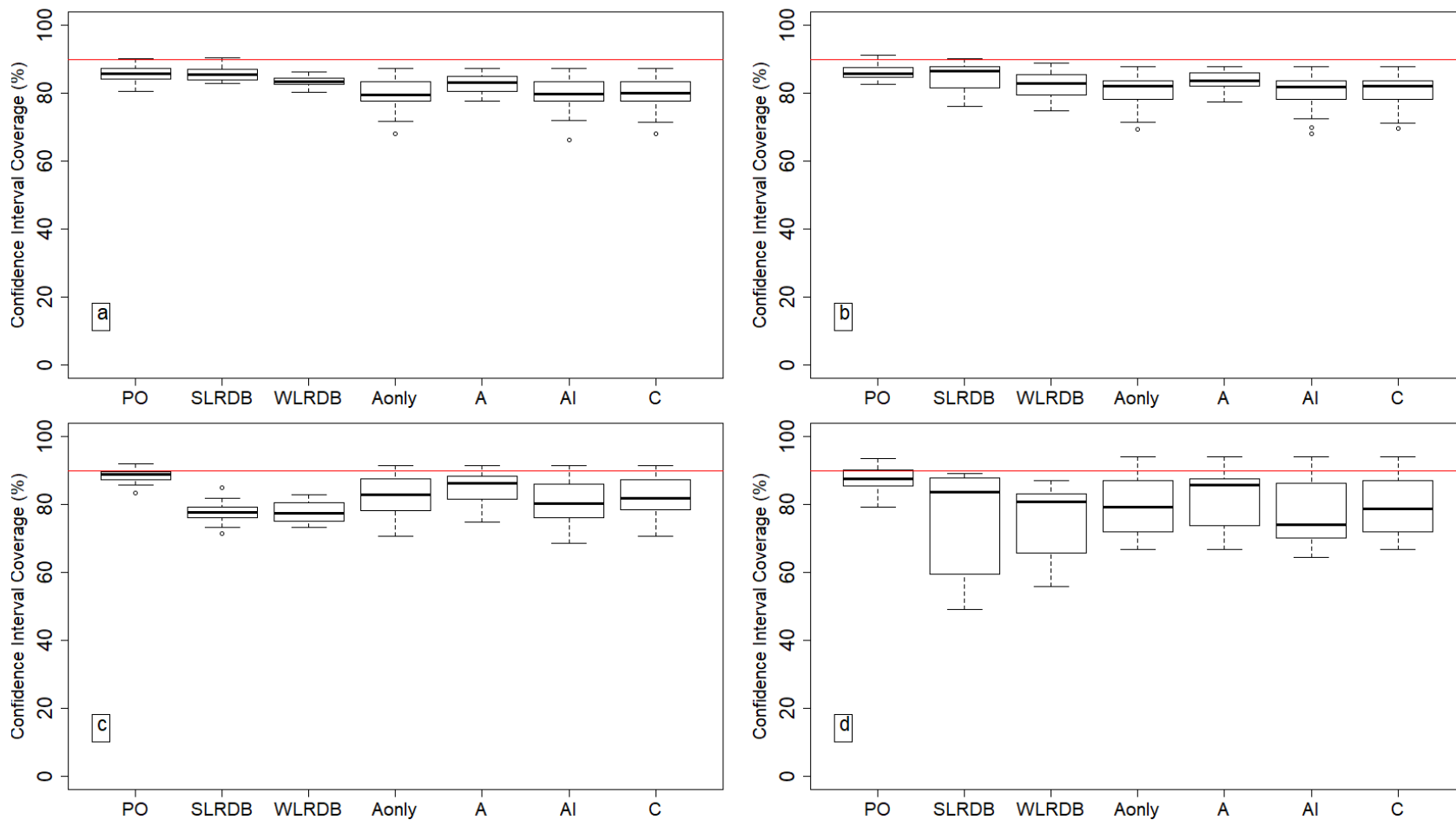


Figure 7. Mean confidence interval coverage (as a proportion) of the trend regression coefficient for the count outcome across all simulation scenarios for (a) trend over 12 years with no subpopulation trend, (b) trend over 12 years with a subpopulation trend, (c) trend over 24 years with no subpopulation trend, and (d) trend over 24 years with a subpopulation trend for the unweighted linear mixed model (PO), simple linear regression for design-based estimates (SLRDB), weighted linear regression for design-based estimates (WLRDB), and probability-weighted iterative generalized least squares approaches A-only, A, and AI.

Test size

The test size, calculated as the proportion of times that a trend was erroneously detected in a given simulation scenario, was computed for two trend tests: a test based on a Wald z-test (Bolker et al. 2008) and a chi-square test of the trend coefficient (Skinner et al. 1989). Trend test size is compared to 0.10, the predetermined Type I error rate. The test size of the Wald z-test was consistently equal to or less than the test size from the chi-squared trend test (Supplement B, Tables B.3 and B.4; Supplement C, Tables C.3 and C.4). Since most trend tests indicated inflated test size as compared to a Type I error rate of 0.10, we omit discussion of the chi-square test and restrict our discussion to the size of the Wald z-test.

Binary data

For trend testing of the two-sided hypothesis of no trend, the PO approach yielded nominal or nearly-nominal test size over both monitoring period lengths with the test size improving as a function of time. For a 12-year monitoring period, test size for the PO and PWIGLS A and B methods ranged from 0.12 to 0.17 (Figure 8a). The PWIGLS A and B methods exhibited nominal test size in most cases of stratified sampling. For unequal probability sampling, the trend test based on the PO approach performed best for the [1-0] revisit design and the SLRDB was preferred for the [1-0,1-3] and [1-3] revisit designs, although test size was high for both (range: 0.12 to 0.14). For a 24-year monitoring period (Figure 8b), the A and B scaling methods of PWIGLS also produced nominal tests for equiprobable and stratified sampling (Supplement B, Table B.3). Overall, the SLRDB and WLRDB approaches yielded inflated test size for a 24-year monitoring period.

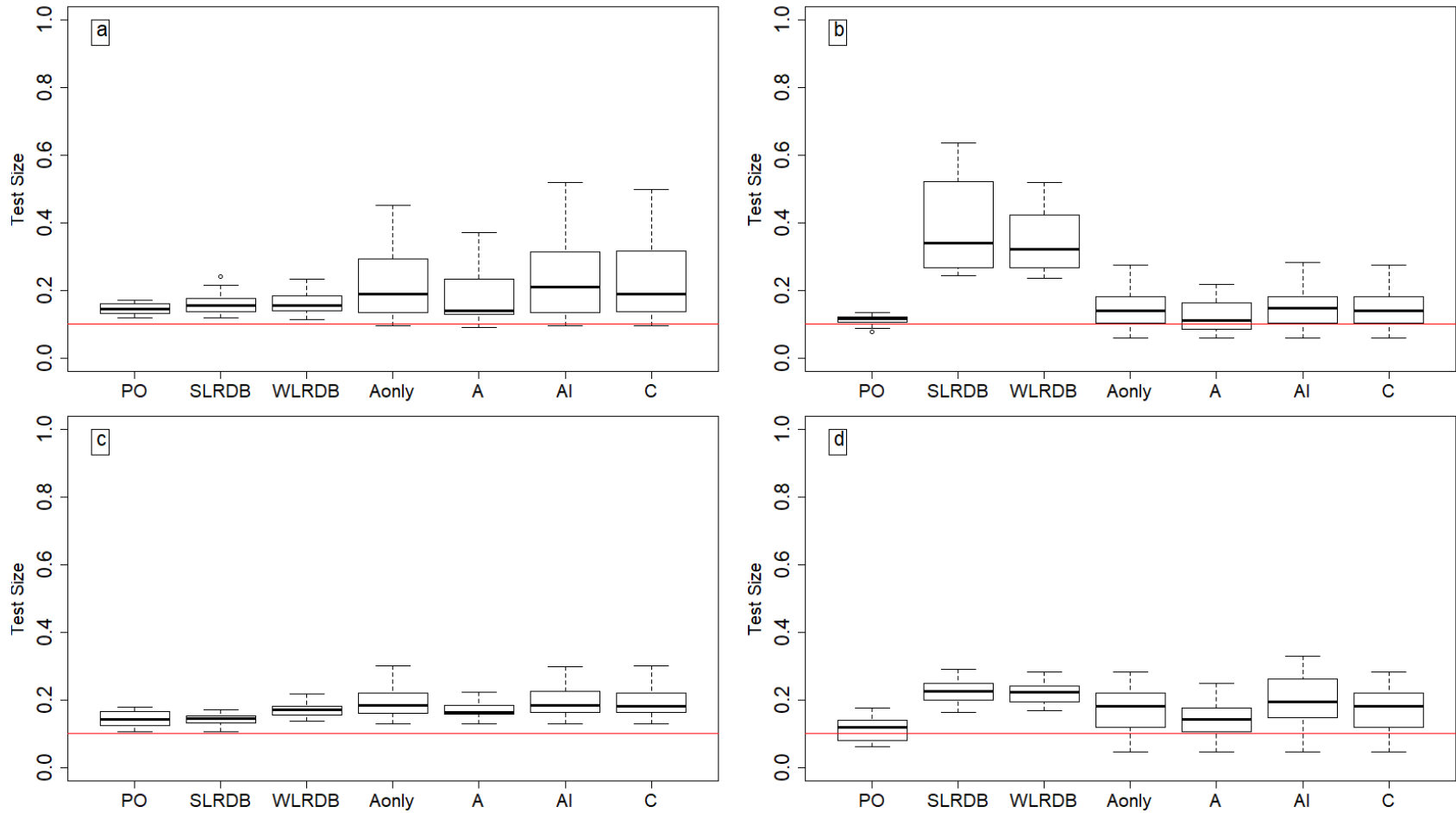


Figure 8. Simulation test size of the Wald z-test across all simulation scenarios for which no trend was simulated for (a) the binary outcome over 12 years, (b) the binary outcome over 24 years, (c) the count outcome over 12 years, and (d) the count outcome over 24 years for the unweighted linear mixed model (PO), simple linear regression for design-based estimates (SLRDB), weighted linear regression for design-based estimates (WLRDB), and probability-weighted iterative generalized least squares approaches A-only, A, and AI.

Count data

Trend test size from the PO approach ranged between 0.06 and 0.18 for all simulation scenarios (Figures 8c and 8d). Test size was lowest for the PO approach when stratified GRTS sampling was used (range: 0.06 to 0.13). When equiprobable or unequal probability sampling was used over a 12-year monitoring period, the SLRDB approach provided the most nominal test size (range: 0.11 to 0.16). However, test size was uniformly inflated for the SLRDB and WLRDB approaches when the monitoring period length was 24 years. Trend test size for a 24-year trend using the A and B methods of the PWIGLS approach achieved nominal levels when the [1-3] revisit design was used with equiprobable or stratified random sampling (Supplement C, Table C.3), and these results indicated an improvement in test size over time. However, test size was more variable among all methods for the longer monitoring period.

Test power

Test power was assessed only for scenarios exhibiting nominal test size since inflated test size results in overly optimistic power estimates. Power to detect trends in the log-odds ratio of the binary probability at the $\alpha = 0.10$ level was uniformly low (9% to 36%) across all simulation scenarios with nominal test size (Supplement B, Table B.5). Power did not always increase with sample sizes of sites or years. Power tended to decrease as a function of sample size when test size increased as a function of sample size. Power to detect trends with the chi-squared trend test was poor compared to that of the z-test and is not discussed further (Supplement B, Table B.6).

Power to detect a trend in the count outcome mean was highest for Wald z-tests of nominal size with the PO approach when stratified GRTS sampling was used and a subpopulation trend was present. In these cases, power ranged from 72% to 82% for a 12-year trend and 97% to 100% for a 24-year trend (Supplement C, Table C.5). PWIGLS tests with nominal test size exhibited slightly higher power than the PO approach when the [1-3] revisit design was used with stratified GRTS sampling, but power was similar otherwise. The greatest impacts on the power to detect trend in count means were the monitoring length and the magnitude of the trend. Power to detect trend with the PO model for 24-year annual trends of 1% achieved power of 54% to 77%, and 24-year trends exhibiting an additional subpopulation trend of 4% annually were detected with power of 91% to 100%. Power increased monotonically with the number of sites and number of years in most cases; the few exceptions reflected slight differences in test size but may have also reflected simulation variation. Similarly to the binary case, power to detect trends in count means with the chi-squared trend test did not perform as well as the z-test and is not discussed further (Supplement C, Table C.6).

Variance components estimation

Because variance components other than residual error are not estimated in the SLRDB and WLRDB approaches and residual error is not specifically part of the GLMMs for binary and count data, the bias of variance components was only calculated for the PO and PWIGLS methods.

Binary data

The variance components estimates for the binary outcome were best estimated with the PO approach. For the equiprobable and unequal probability sampling designs, the relative bias of estimates from the PO approach of site-to-site variance component (σ_a^2) ranged from -8% to 1%

(Supplement B, Table B.7) and random site-level slope (σ_t^2) ranged from -6% to 2% (Supplement B, Table B.8). Relative bias for estimates of the year-to-year variance component (σ_b^2) with equiprobable and unequal probability sampling designs ranged from -16% to -8% for 12-year surveys but this bias to -9% to -3% as the monitoring period increased to 24 years. (Supplement B, Table C.9). For stratified random sampling, relative bias of the year-to-year variance component (σ_b^2) ranged from -43% to -37% for 12-year monitoring periods and from -36% to -31% for 24-year monitoring periods. Relative bias could occur in either direction for the site-to-site variance component (range: -20% to 20%) and random site-level slope (range: -14% to 8%). Variance components estimates from the PWIGLS approach were radically inflated; the least-based estimate of any variance component overestimated the true variance by over 720 times (Supplement B, Tables B7 through B9).

Count data

Variance component estimation was similar for estimation of trend in counts. Estimates of the site-to-site variance component (σ_a^2) from the PO approach were generally unbiased when the total sample size of unique sites across all panels exceeded 35 sites and improved as a function of sample size (range: -17% to 1%; Supplement C, Table C.7). Estimates of random site-level slope (σ_t^2) from the PO model were biased for all 12-year trend scenarios and least biased for the 24-year monitoring period when stratified random sampling was used (range: -19% to 8%; Supplement C, Table C.8). Year-to-year variation (σ_b^2) was almost always underestimated with the PO approach (range: -34% to -2%; Supplement C, Table C.9) with the exception of a 24-year monitoring period during which no sampling or revisit design complexity was used. Relative biases of σ_b^2 and σ_t^2 generally did not improve as a function of sample size and monitoring period. Variance components estimated with the PWIGLS approaches were dramatically overestimated for all simulation scenarios; the least-based estimate of any variance component overestimated the true variance by over 570 times (Supplement C, Tables C7 through C9).

Discussion

Overall, the PO model, which does not incorporate design weights, performed very well, even for some scenarios with sampling complexity and revisit design. The PWIGLS approach performed well in select simulation scenarios, even in some cases with no design complexity. For some simulation scenarios of binary data, no trend analysis approach provided both accurate trend estimation and nominal confidence interval coverage. This may be a result of the large year-to-year variation exhibited by the binary outcome. Analysis methods yielded more precise and accurate estimation for the count outcome, which demonstrated a smaller proportion of year-to-year variation. We discuss the results below.

Binary data

In general, the PO approach provided the best inference for trend estimation and confidence interval coverage, but the PWIGLS approach provided equally acceptable confidence interval coverage for some cases in which equiprobable and stratified GRTS sampling were used. However, the PWIGLS approach exhibited poor confidence interval coverage for all unequal probability sampling scenarios. For most scenarios with no design complexity, the PWIGLS estimate of the trend was more accurate than the PO approach, even though the PO approach is theoretically appropriate for the case of no design complexity. Other cases in which PWIGLS provides better inference for binary outcomes than the PO approach included stratified GRTS sampling and when equiprobable sampling was used with a [1-3] revisit design over a 12-year monitoring period in the absence of a subpopulation trend.

Trend detection for the binary outcome demonstrated substantial bias and inconsistent results in many cases and low power for all scenarios exhibiting nominal test size. This poor performance may be due to the large proportion of year-to-year variation in the binary outcome of interest. For example, in the second year of sampling, roughly 47% of the total variance is contributed by the year-to-year variation component, i.e. $(\sigma_b^2)/(\sigma_a^2 + \sigma_b^2 + \sigma_{bt}^2) = 0.47$. In contrast, the year-to-year variation of the count outcome comprised about 9% of the total variance in the second year of sampling. The levels of proportional year-to-year variation examined in the initial phase of this work (Starceovich et al. 2018) for continuous outcomes examined variables with 0.3% and 5% proportional year-to-year variation. This small difference greatly impacted the performance of the PWIGLS approach for continuous outcomes and may explain the improved performance of the count outcome compared to the binary outcome in the current study.

Unbiased estimation of the trend in the binary outcome was obtained for specific revisit designs with the PO and PWIGLS approaches. The revisit design was more influential on estimator performance for the 12-year time period than for a 24-year monitoring period, but the impact of the revisit design may be more a function of the total number of unique sites than the revisit design itself. In several simulation scenarios including the [1-0] revisit design for stratified sampling and the unequal probability sampling design, no unbiased estimates were obtained.

Overall for the binary outcome, PO and PWIGLS confidence interval coverage improved as the monitoring period increased but worsened as a function of time for the SLRDB and WLRDB approaches, possibly suggesting competing biases in the estimator due to the reduced sample size of

year-level estimates. The increasingly-poor confidence interval coverage is likely due to positive bias in the trend coefficient estimate, possibly caused by logarithm-transformation bias (Newman 1993), which increased as a function of monitoring period length, particularly for stratified GRTS sampling.

For trend testing, the PO approach yielded the most nominal tests of trend overall. However, the A and B methods of the PWIGLS approach performed well for equiprobable and stratified GRTS sampling in most cases. The SLRDB approach provided nominal tests of trend when equiprobable and unequal probability sampling was used with either a [1-0,1-3] design and at least 35 sites per year or a [1-3] revisit design was used for any sample size (i.e. designs incorporating at least 80 unique sites). The SLRDB approach yielded biased trend estimates for non-zero trend, but its nominal test size indicated that trend estimation with the SLRDB approach is accurate and precise for similar populations not exhibiting trend.

Count data

The performance of the trend estimation approaches on count data indicated that the PO approach provided most accurate estimates of trend when the [1-3] revisit design was used with equiprobable sampling, when stratification was used for all revisit designs, and when unequal probability sampling was used with the [1-0,1-3] and [1-3] revisit designs. The PWIGLS approach, particularly with the A and B scaling methods, was found to provide more accurate estimates of trend when the [1-0] and [1-0,1-3] revisit designs were used with equiprobable sampling and in most cases of unequal probability sampling with the [1-0] revisit design. The exception occurred when unequal probability sampling was used over 24 years and a more extreme trend was present in an undersampled subpopulation. In this case, the SLRDB approach provided the most accurate trend estimation.

The PO approach provided nominal confidence interval coverage and nominal trend tests in most cases, but exceptions occurred when equiprobable and unequal probability sampling were used over a 12-year monitoring period and when unequal probability sampling was used over 24 years when an extreme trend in an undersampled subpopulation occurred. In these cases, the SLRDB approach provided the most nominal confidence interval coverage and test size. However, in many cases the confidence interval coverage decreased as a function of monitoring period length, suggesting that some biases may be left unadjusted. Given the relative accuracy of the trend estimates for the PO and PWIGLS approaches in most simulation scenarios, underestimation of the trend coefficient standard error should be examined further. Underestimation of both the trend coefficient and its standard error may be occurring in the SLRDB and WLRDB approaches. Trend standard error estimates that are too small inflate test size and test power, so these issues impact every aspect of trend inference.

The variance components estimates from the PWIGLS methods greatly overestimated the true parameter values for all variance components, likely because the step-B approach of Pfeiffermann et al. (1998) was not used. As also found by Asparouhov (2006), estimates of variance components, which are useful for power analysis of trend tests, should be obtained from the unweighted model (PO). Future examination of the performance of the SLRDB and WLRDB estimators may incorporate variance components assessment tools as outlined by Gray and Burlew (2007).

The PWIGLS approach for GLMMs in this research based tests of trend on the normal approximation. The high test size exhibited in most simulation scenarios for the PO and PWIGLS approaches with binary or count data indicates that the normal approximation may not provide an adequate basis for trend testing, even for designs that do not incorporate weights in the sampling design. Examination of other distributions, such as the t -distribution, may improve test size and confidence interval coverage.

Conclusions

For the range of trend magnitudes, sample sizes, and monitoring periods explored in this research, the PO model, which does not incorporate design weights, performed very well, even for some scenarios with sampling complexity and revisit design. The PWIGLS approach also performed well for some simulation scenarios, which includes some scenarios using a [1-0] revisit design with equiprobable sampling (i.e. no design complexity). The PWIGLS approach often performed best for binary data with equiprobable and unequal probability sampling and for count data with the [1-0] and [1-3] revisit designs.

In some binary data cases, no trend approach provided both accurate trend estimation and nominal confidence interval coverage, likely because the binary outcome from the pilot data exhibited a large proportion of year-to-year variation (47%) compared to the count outcome (9%). Variance composition impacted the power to detect trend, which ranged from 9% to 36% for trend tests of nominal size for binary outcomes compared to power of 24% to 100% for simulated count outcomes. We observed the impact of variance composition relative to the year-to-year variance component in the first phase of this trend research for continuous outcomes. In that research, relatively high year-to-year variation negatively impacted the PWIGLS approach, so similar effects in the extension of the PWIGLS approach to binary and count data may be expected. Trend analysis for these data may be improved by including additional predictors in the trend model.

The results of the simulation are summarized in the following flowcharts for binary and count data (Figures 9 and 10, respectively). In assessing the best approach, we considered both accuracy and precision as well as the simplicity of the approach. In cases where both the unweighted and one or more weighted approaches performed equally well, we recommend the unweighted approach. Our results demonstrated that the unweighted PO approach is appropriate for many scenarios involving complex designs. For the binary outcome, several simulation scenarios did not result in unbiased estimates of trend with nominal confidence interval coverage. In some cases, unbiased estimation was obtained with one trend approach but nominal confidence interval coverage was better obtained with another trend approach. These cases are identified with the appropriate confidence interval coverage approach in parentheses. In these cases, we recommend examining estimates and confidence intervals from both approaches and assessing the impact each has on trend inference. Case studies for binary and count data are presented in Supplement D to demonstrate how these methods and the flowchart are used.

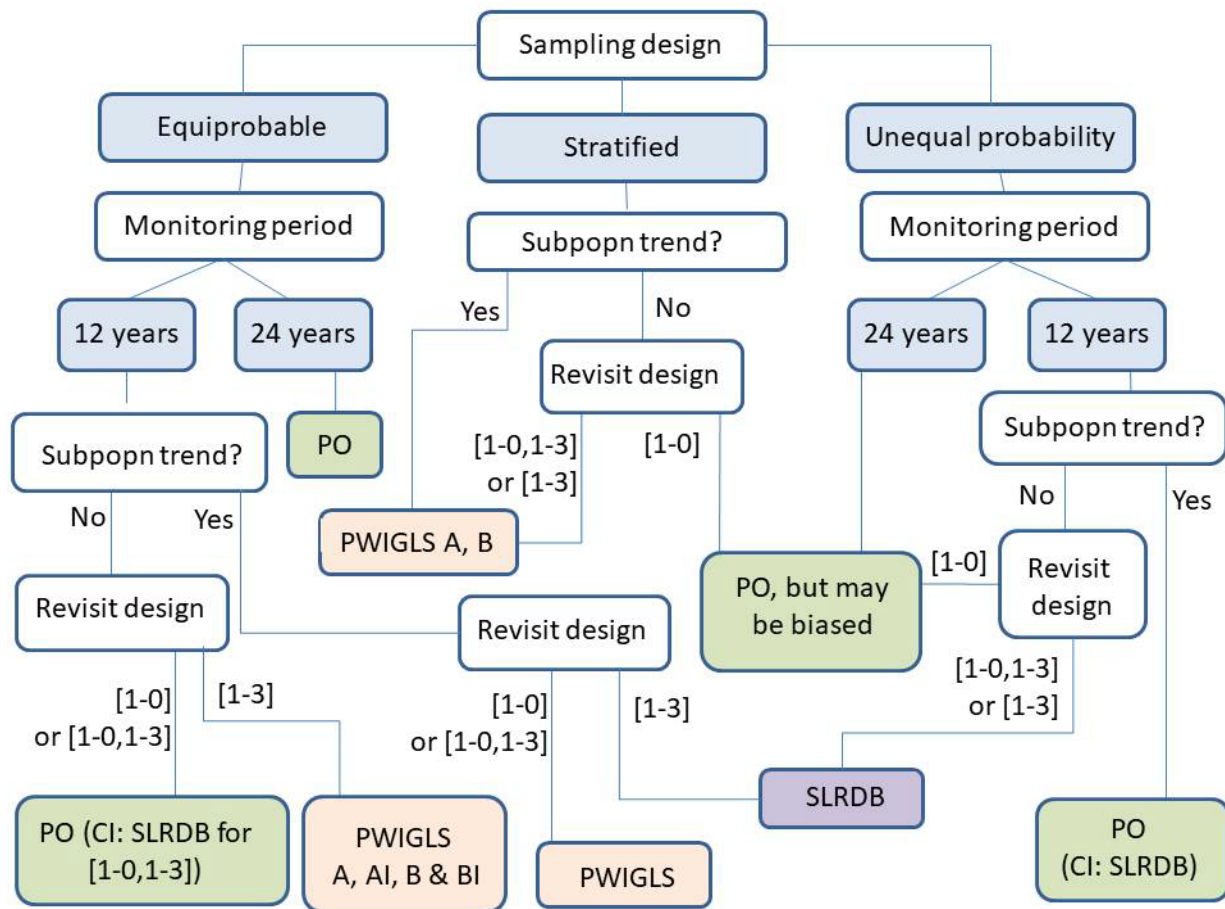


Figure 9. Flowchart of recommended trend analysis approaches for binary data collected from complex sample designs. Analytical approaches include PO, WLRDB, SLRDB, and PWIGLS.

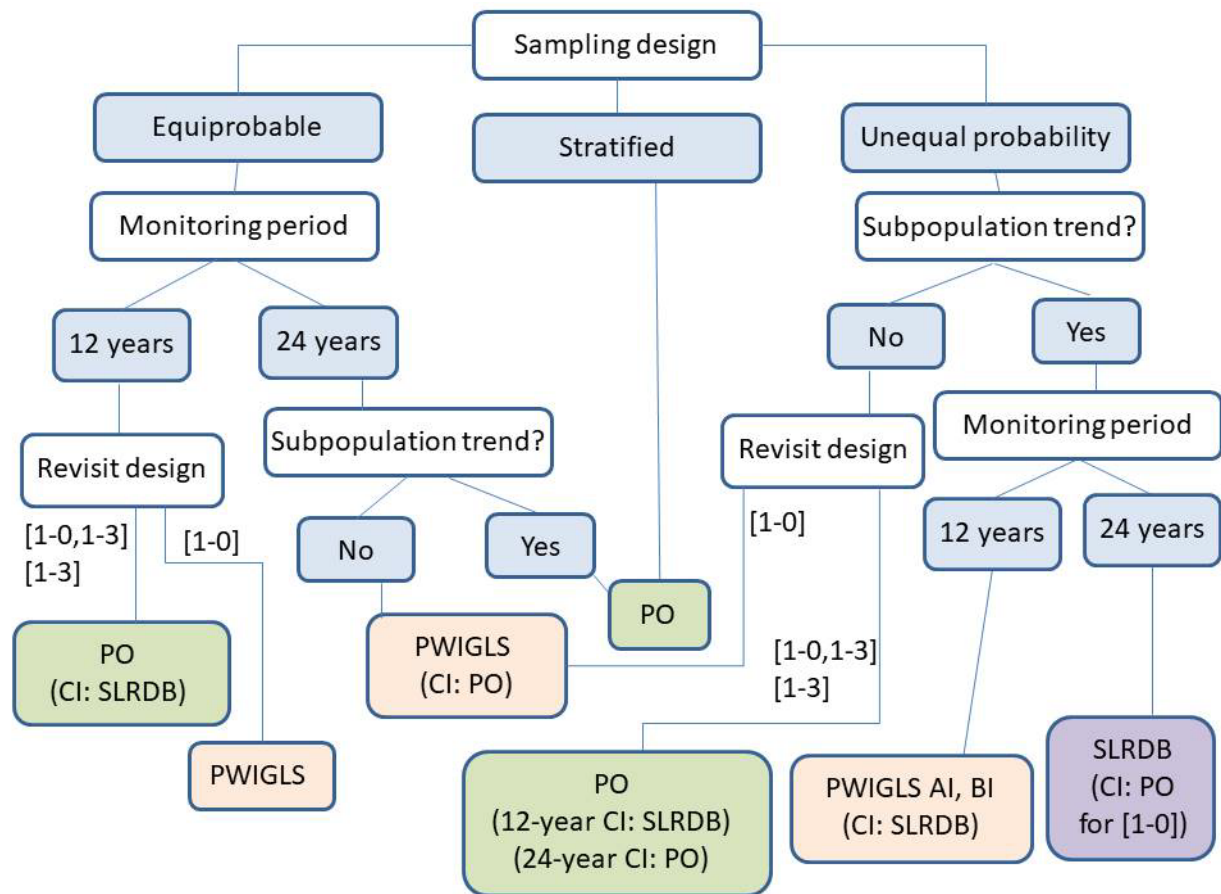


Figure 10. Flowchart of recommended trend analysis approaches for count data collected from complex sample designs. Analytical approaches include PO, WLRDB, SLRDB, and PWIGLS.

Future research on trend analysis of binary and count outcomes from complex survey designs should include a rigorous assessment of the impact of variance components and further examination of the direct weighting of the GLMM random effects design matrix versus applying the Laplace approximation. Marginalized GLMMs (Heagerty and Zeger 2000) or generalized estimating equations (Liang and Zeger 1986) may prove to be more successful approaches for trend estimation with complex survey data. Additionally, confidence interval coverage deterioration over time warrants further review and may be an effect of logarithm-transformation bias (Newman 1993). Inflated test size and confidence interval undercoverage may suggest that a *t*-distribution with Satterthwaite (1946) degrees of freedom may provide a better basis for trend testing than the normal approximation used in the `glmer` R function in the `lme4` package (Bates et al. 2015). Several special cases were not considered in this research, including overdispersion, imperfect detection, and different allocations of sampling effort across strata/categories. These common issues in ecological data would benefit from further study to determine which trend analysis methods are appropriate in these cases. In addition, examining the trend approach for a single binary outcome per site, rather than a set of binary subsamples within a site, would be useful for natural resource managers who are monitoring prevalence indicators.

Some recommendations represented in the flow charts (Figure 9 and 10) included different trend approaches for estimation versus confidence interval coverage. For example, for nearly all of the 12-year trend estimates in mean counts, nominal confidence interval coverage was obtained with the SLRDB approach. However, this approach often greatly underestimated the true trend regression coefficient. Similarly for 24-year trends in counts, the PO approach nearly always provided nominal confidence interval coverage but sometimes other trend methods, such as PWIGLS and SLRDB, yielded the more accurate estimates of the trend regression coefficient. We draw attention to these cases to encourage analysts to compare the estimates and confidence intervals for the two recommended approaches may provide useful information on trend inference and an indicator of the impact of each estimation approach.

The methods and examples provided here demonstrate that conducting a trend analysis of discrete data from complex survey designs is a complicated process. Software programs such as MLWin and HLM may provide similar tools with automated diagnostic plots. Issues such as independent, correlation, overparameterization, and overdispersion must be considered during the analysis process, which requires statistical experience. We provide these tools as a template for estimation but encourage discussion and consultation with experienced analysts.

In summary, the extension of the methods used in the first phase of this trend research (Starcevich et al. 2018) is promising for binary and count outcomes. We demonstrated that, under many scenarios defined by sampling design, revisit design, monitoring period length, and trend magnitude, unbiased estimates of trend with nominal confidence interval coverage can provide reliable trend inference and the basis for trend tests with nominal size. We encourage analysts to use these results when planning a monitoring program of binary and count indicators to weigh the costs of design decisions so that the monitoring program may result in successful trend estimation.

References

- Alaska Ocean Observing System. 2016. Gulf of Alaska Data Integration Portal. Available at: <http://portal.aaos.org/gulf-of-alaska.php#metadata/53c052b6-8874-46d1-b40a-acc615a3879a/project/files>.
- Asparouhov, T. 2006. General multi-level modeling with sampling weights. *Communications in Statistics – Theory and Methods* 35:439-460.
- Bart, J., and H. L. Beyer. 2012. Analysis options for estimating status and trends in long-term monitoring. Pages 253–278 in R. A. Gitzen, J. J. Millspaugh, A. B. Cooper, and D. S. Light (eds.). *Design and analysis of long-term ecological monitoring studies*. Cambridge University Press, UK.
- Bates, D., M. Maechler, B. Bolker, and S. Walker. 2015. Fitting linear mixed-effects models using lme4. *Journal of Statistical Software* 67(1):1-48. [oi:10.18637/jss.v067.i01](https://doi.org/10.18637/jss.v067.i01).
- Bolker, B. M., M. E. Brooks, C. J. Clark, S. W. Geange, J. R. Poulson, M. Henry, H. Stevens, and J.-S. S. White. 2008. Generalized linear mixed models: a practical guide for ecology and evolution. *Trends in Ecology and Evolution* 24(3):127-135.
- Breslow, N. E. 2004. Whither PQL? Pages 1–22 in D. Y. Lin and P. J. Heagerty (eds.). *Proceedings of the Second Seattle Symposium in Biostatistics: Analysis of Correlated Data*. Springer.
- Brus, D. J., and J. J. de Gruijter. 2011. Design-based generalized least squares estimation of status and trend of soil properties from monitoring data. *Geoderma* 164:172–180.
- Fancy, S. G., J. E. Gross, and S. L. Carter. 2009. Monitoring the condition of natural resources in US national parks. *Environmental Monitoring and Assessment* 151:161–174.
- Gitzen, R. A., and J. J. Millspaugh. 2012. Ecological monitoring: the heart of the matter. Pages 3–22 in R. A. Gitzen, J. J. Millspaugh, A. B. Cooper, and D. S. Light (eds.). *Design and analysis of long-term ecological monitoring studies*. Cambridge University Press, UK.
- Heard, A. M., L. A. H. Starcevic, J. O. Sickman, M. Goldin Rose, and D. W. Schweizer. 2012. Sierra Nevada Network lake monitoring protocol. Natural Resource Report NPS/SIEN/NRR—2012/551. National Park Service, Fort Collins, Colorado.
- Gray, B. R., and M. M. Burlew. 2007. Estimating trend precision and power to detect trends across grouped count data. *Ecology* 88(9):2364–2372.
- Heagerty, P. J., and S. L. Zeger. 2000. Marginalized multilevel models and likelihood inference (with comments and a rejoinder by the authors). *Statistical Science* 15(1):1–26.

- Helsel, D. R., and L. M. Frans. 2006. The Regional Kendall test for trend. *Environmental Science and Technology* 40(13):4066–4073.
- Irvine, I. C., T. Sagar, L. Lee, C. A. Brigham, J. Tiszler, L. A. Starcevich, D. Rodriguez, T. Handley, and S. Ostermann-Kelm. 2016. Invasive plant monitoring protocol for the Mediterranean Coast Network—Santa Monica Mountains National Recreation Area and Channel Islands National Park: Narrative, version 1.0. Natural Resource Report NPS/MEDN/NRR—2016/1171. National Park Service, Fort Collins, Colorado.
- Kincaid, T. M. and A. R. Olsen. 2015. *spsurvey: Spatial Survey Design and Analysis*. R package version 3.1. Available at: <http://www.epa.gov/nheerl/arm/>.
- Lee, Y., and J. A. Nelder. 2000. Two ways of modelling overdispersion in non-normal data. *Journal of the Royal Statistical Society, series C.* 49(4): 91–598.
- Liang, K. Y., and S. L. Zeger. 1986. Longitudinal data analysis using generalized linear models. *Biometrika* 73(1):13–22.
- Lohr, S. L. 2010. Sampling: design and analysis, 2nd edition. Brooks/Cole, Boston, Massachusetts.
- McDonald, T. L. 2003. Review of environmental monitoring methods: Survey design. *Environmental Monitoring and Assessment* 85:277–292.
- McKinney, S. T., T. Rodhouse, L. Chow, A. Chung-MacCoubrey, G. Dicus, L. Garrett, K. Irvine, S. Mohren, D. Odion, D. Sarr, and L. A. Starcevich. 2012. Monitoring white pine (*Pinus albicaulis*, *P. balfouriana*, *P. flexilis*) community dynamics in the Pacific West Region - Klamath, Sierra Nevada, and Upper Columbia Basin Networks: Narrative version 1.0. Natural Resource Report NPS/PWR/ NRR—2012/532. National Park Service, Fort Collins, Colorado.
- Newman, M. C. 1993. Regression analysis of log-transformed data: statistical bias and its correction. *Environmental Toxicology and Chemistry* 12:1129–1133.
- Pfeffermann, D., C. J. Skinner, D. J. Holmes, H. Goldstein, and J. Rasbash. 1998. Weighting for unequal selection probabilities in multilevel models. *Journal of the Royal Statistical Society, Series B* 60(1):23-40.
- Piepho, H. P., and J. O. Ogutu. 2002. A simple mixed model for trend analysis in wildlife populations. *Journal of Agricultural, Biological, and Environmental Statistics* 7(3):350–360.
- Pinheiro, J. C., and D. M. Bates. 2000. Mixed-Effects Models in S and S-PLUS. Springer, New York.

- Pinheiro J., D. Bates, S. DebRoy, D. Sarkar, and R Core Team. 2016. nlme: Linear and Nonlinear Mixed Effects Models_. R package version 3.1-128. Available at: <http://CRAN.R-project.org/package=nlme>.
- R Core Team. 2016. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available at: <https://www.R-project.org/>.
- Raudenbush, S. W., M-L Yang, and M. Yosef. 2000. Maximum likelihood for generalized linear models with nested random effects via a high-order, multivariate Laplace approximation. *Journal of Computational and Graphical Statistics* 9(1):141–157.
- Reynolds, J. 2012. An overview of statistical considerations in long-term monitoring. Pages 23–53 in R. A. Gitzen, J. J. Millspaugh, A. B. Cooper, and D. S. Light (eds.). Design and analysis of long-term ecological monitoring studies. Cambridge University Press, UK.
- Robertson, B. L., J. A. Brown, T. McDonald, and P. Jaksons. 2013. BAS: Balanced acceptance sampling of natural resources. *Biometrics* 69:776–784.
- Satterthwaite, F. E. 1946. An approximate distribution of estimates of variance components. *Biometrics* 2:110–114.
- Schreuder, H. T., T. G. Gregoire, and J. P. Weyer. 2001. *Environmental Monitoring and Assessment* 66:281–291.
- Skinner, C. J., and D. J. Holmes. 2003. Random effects models for longitudinal survey data. Ch. 14 in R. L. Chambers and C. J. Skinner (eds.). Analysis of survey data. Wiley, New York.
- Skinner, C. J., D. Holt, and T. M. F. Smith. 1989. Analysis of Complex Surveys. Wiley, New York.
- Starcevich, L. A., T. McDonald, A. Chung-MacCoubrey, A. Heard, J. Nesmith, and T. Philippi. 2018. Methods for estimating trend in continuous response variables from complex survey designs. Natural Resource Report NPS/NRSS/IMD/NRR—2018/1584. National Park Service, Fort Collins, Colorado.
- Starcevich, L. A., and J. Mitchell. 2017. TrendNPS: NPS Trend Analyses for Complex Survey Designs. R package version 0.0.3.
- Stevens, D. L., and A. R. Olsen. 2003. Variance estimation for spatially balanced samples of environmental resources. *Environmetrics* 14:594–610.
- Stevens, D. L., and A. R. Olsen. 2004. Spatially balanced sampling of natural resources. *Journal of the American Statistical Association* 99(465):262–278.

- Urquhart, N. S., and T. M. Kincaid. 1999. Designs for detecting trend from repeated surveys of ecological resources. *Journal of Agricultural, Biological, and Environmental Statistics* 4(4):404–414.
- Urquhart, N. S., W. S. Overton, and D. S. Birkes. 1993. Comparing sampling designs for monitoring ecological status and trends: Impact of temporal patterns. V. Barnett and K. F. Turkman (eds.). *Statistics for the Environment*. John Wiley and Sons Ltd.
- Wolfinger, R. 1993. Laplace's approximation for nonlinear mixed models. *Biometrika* 80(4):791–795.
- Zuur, A. F., E. N. Ieno, and G. M. Smith. 2007. *Analysing ecological dData*. Springer, New York, New York.
- Zuur, A. F., E. N. Ieno, N. J. Walker, A. A. Saveliev, and G. M. Smith. 2009. *Mixed effects models and extensions in ecology with R*. Springer, New York.

Supplement A: R code for Trend Approaches

```
TrendNPS_Binary<-
function(alpha,dat,method,slope=TRUE,type=NA,stratum=NA,Y,lat=NA,long=NA,stag
e1wt=NA,stage2wt=NA,str1prop=NA,nbhd=TRUE) {

# dat = data set for trend analysis of a binary outcome of interest
# dat must contain fields for Site, WYear (scalar year value), and Year (year factor)
# other covariate fields in dat may be used in the trend model, but WYear must be used
# to estimate trend

# Calculates a trend model specified by method:
# 'PO' = Piepho and Ogutu (2002) unreplicated linear mixed model
# 'SLRDB' = Simple linear regression of design-based estimates
# 'WLRDB' = Weighted linear regression of design-based estimates using the inverse of
#           the variance of the estimate as the weight
# 'PWIGLS' = probability-weighted iterative generalized least squares
#            (Pfeffermann et al. 1998, Asparouhov 2002)
# PWIGLS requires the input, type =
# 'Aonly' = probability weighting but no scaling at either stage
# 'A' = scales panel weights with the mean site-level design weight
# 'AI' = scales panel weights with the mean site-level design weight,
#        but removes site-level scaling
# 'B' = scales panel weights with the effective mean site-level design weight
# 'BI' = scales panel weights with the effective mean site-level design weight,
#        but removes site-level scaling
# 'C' = scales only at the year level with the inverse of the mean annual weight

# Inputs needed for SLRDB and WLRDB methods
# stratum = column name of stratification variable in dat
# stratum is used directly in the SLRDB and WLRDB approaches
# The stratification variable must be included in the fixed effect input for
# methods PO and PWIGLS.
# Y = character; column name of the binary outcome of interest for design-based
# estimates
# lat = column name of the latitude
# long = column name of the longitude

# Inputs needed for PWIGLS method
# stage1wt = weight from the sampling design, adjusted for frame and/or nonresponse
# error, if needed
# stage2wt = panel weight from temporal revisit design

# str1prop = proportion of the population represented by stratum 1 in a two-level
# stratification variable. str1 will be the stratum listed first when stratum
# levels are ordered alphabetically.

# requires package lme4, lmerTest, spsurvey

# Calculate sample sizes
Sites = sort(unique(dat$Site))
ma = length(Sites)
Years = as.character(sort(unique(dat$Year)))
WYears = sort(unique(dat$WYear))
mb = length(WYears)

# Assign stratum
if(!is.na(stratum)) dat$Stratum <- dat[,stratum]
```

```
#####
# METHOD P0: Piepho & Ogutu (2002) linear mixed model
# Unreplicated model - one observation per Year and Site
#####
if(method %in% c("P0", "PWIGLS")) {
  if(is.na(stratum)) {
    if(slope) fit<-glmer(Y ~ WYear + (1|Year) +(1+WYear|Site),
family=binomial(link=logit), data=dat,
control=glmerControl(optimizer="bobyqa",optCtrl=list(maxfun=2e6)))
    if(!slope) fit<-glmer(Y ~ WYear + (1|Year) +(1|Site),
family=binomial(link=logit), data=dat,
control=glmerControl(optimizer="bobyqa",optCtrl=list(maxfun=2e6)))
  }
  if(!is.na(stratum)) {
    if(slope) fit<-glmer(Y ~ WYear * Stratum + (1|Year)
+(1+WYear|Site),family=binomial(link=logit), data=dat,
control=glmerControl(optimizer="bobyqa",optCtrl=list(maxfun=2e6)))
    if(!slope) fit<-glmer(Y ~ WYear * Stratum + (1|Year)
+(1|Site),family=binomial(link=logit), data=dat,
control=glmerControl(optimizer="bobyqa",optCtrl=list(maxfun=2e6)))
  }

  if(method=="PWIGLS") {
    fit_P0 = fit
    rm(fit)
  }

  if(method=="P0") {
    if(!slope) {
      sig2a<- VarCorr(fit)$Site          # var(ai)
      sig2t<- sigat<- 0
    }
    if(slope) {
      sig2a<- VarCorr(fit)$Site[1,1]      # var(ai)
      sig2t<- VarCorr(fit)$Site[2,2]      # var(ti)
      sigat<- VarCorr(fit)$Site[1,2]      # cov(ai, ti)
    }
    sig2b<- VarCorr(fit)$Year
    if(is.na(stratum)) {                  # No stratification
      mu<- summary(fit)$coef[1,1]
      trend<- summary(fit)$coef[2,1]
      SETrend<- summary(fit)$coef[2,2]
    }
    if(!is.na(stratum)) {                # Stratification with two levels
      mu<- summary(fit)$coef[1,1]
      c.vec = matrix(c(0,1,0,1-str1prop),1,4)
      trend = c.vec %*% fixef(fit)
      SETrend<- sqrt(c.vec%*% as.matrix(vcov(fit))%*%t(c.vec))
    }
  }

}
# End P0
}
# End P0 or PWIGLS
```

```
#####
# Methods SLRDB and WLRDB: Simple linear regression on annual design-based estimates
# SLRDB: unweighted
# WLRDB: weighted by inverse of variance of each annual estimate
#####

if(method %in% c("SLRDB", "WLRDB")) {
  MeanEsts=data.frame(matrix(NA,mb,3))
  MeanEsts[,1] <- Years

# Calculate annual design-based status estimates of the mean
  for (g in 1:mb) {
    dat.g<-dat[dat$WYear==WYears[g],]
    if(is.na(stratum)) {
      ests <-cont.analysis(
        sites=data.frame(siteID=dat.g$Site, rep(TRUE,nrow(dat.g))),
        subpop= data.frame(siteID=dat.g$Site, Popn1=rep(1, nrow(dat.g))),
        design= data.frame(siteID=dat.g$Site,
          wgt= dat.g$wgt, xcoord = dat.g[,long], ycoord = dat.g[,lat]),
        data.cont= data.frame(siteID=dat.g$Site, Y=dat.g[,Y]), conf=90,
        vartype=ifelse(nbhd,"Local","SRS"))
      MeanEsts[g,2:3] <-ests$Pct[ests$Pct$Statistic=="Mean",6:7]
    }
    if(!is.na(stratum)) {
      ests <-cont.analysis(
        sites=data.frame(siteID=dat.g$Site, rep(TRUE,nrow(dat.g))),
        subpop= data.frame(siteID=dat.g$Site, Popn1=rep(1, nrow(dat.g))),
        design= data.frame(siteID=dat.g$Site,
          wgt= dat.g$wgt, xcoord = dat.g[,long], ycoord = dat.g[,lat],
          stratum=dat.g[,stratum]),
        data.cont= data.frame(siteID=dat.g$Site, Y=dat.g[,Y]), conf=90,
        vartype=ifelse(nbhd,"Local","SRS"))
      MeanEsts[g,2:3] <-ests$Pct[ests$Pct$Statistic=="Mean",6:7]
    }
  }
  MeanEsts[,3] <- as.numeric(MeanEsts[,3])
  names(MeanEsts) <- c("Year", "Est.Mean", "SE")
  MeanEsts$WYear = WYears
# calculate trend in logged mean over time
  if(method=="SLRDB") fit<-lm(logit(Est.Mean) ~ WYear, data=MeanEsts)
  if(method=="WLRDB") fit<-lm(logit(Est.Mean) ~ WYear, weights=1/(SE^2),
    data=MeanEsts)

  mu <- coef(fit)[1] # mu
  trend<- coef(fit)[2] # slope
  SETrend<-sqrt(vcov(fit)[2,2]) # SE
  sig2a<- sig2t<- sigat<- sig2b<- 0
  sig2e<- (summary(fit)$sigma)^2
} # End SLRDB/WLRDB
```

```
#####
# PWIGLS methods
#####

if(method == "PWIGLS") {
  if(!type %in% c("Aonly", "A", "AI", "B", "BI", "C")) return("PWIGLS scaling type
  not recognized.")

  fit<-
  PWIGLS_Binary(Z=getME(fit_P0, "Z"), dat=dat, stage1wt=stage1wt, stage2wt=stage2wt
  , type=type, stratum=stratum, slope=slope, P0.fitted=predict(fit_P0, type="respons
  e"), P0.resid=resid(fit_P0, type="response"))
  mu<- fixef(fit)[1] # intercept
  if(slope) {
    sig2a<- VarCorr(fit)$Site[1,1] # var(ai)
    sig2t<- VarCorr(fit)$Site[2,2] # var(ti)
    sigat<- VarCorr(fit)$Site[1,2] # cov(ai, ti)
    sig2b<- VarCorr(fit)$Year[1] # var(bj)
    sig2e<- attr(VarCorr(fit), "sc")^2 # var(eij)
  }
  if(!slope) {
    sig2a<- VarCorr(fit)$Site[1] # var(ai)
    sig2t<- sigat<- 0
    sig2b<- VarCorr(fit)$Year[1] # var(bj)
    sig2e<- attr(VarCorr(fit), "sc")^2 # var(eij)
  }

  if(is.na(stratum)) { # No strata
    trend<- fixef(fit)[2] # slope
    eta<- summary(fit)$coef[2,3] # Use P0 df
    # Linearization variance -- Pfeffermann 1988
    SETrend <- SEbeta<- sqrt(vcov(fit_P0)[2,2])
  } # END No strata

  if(!is.na(stratum)) { # Stratification with two levels
    trend1<- fixef(fit)[2] # slope of stratum 1
    trend2<- fixef(fit)[4] # slope of stratum 2 - slope
    of stratum 1
    trend=trend1 + (1-str1prop)*trend2 # population estimate of
    trend
    Cont = matrix(c(0,1,0, str1prop),1,4)
    SETrend<-as.numeric(sqrt(Cont%*%vcov(fit)%*%t(Cont))) } # END
  Stratification with two levels
  } # End PWIGLS

  ans.model = data.frame(mu, trend, SETrend, sig2a, sig2t, sigat, sig2b)
  names(ans.model)=c('mu', 'trend', 'SETrend', 'sig2a', 'sig2t', 'sigat', 'sig2b')
  rownames(ans.model) = NULL

  # z test
  ans.trendtest = data.frame(trend = ans.model[2], SE = ans.model[3],
  z.stat=ans.model[2]/ans.model[3],
  pvalue=2*pnorm(as.numeric(abs(ans.model[2]/ans.model[3])), lower.tail =FALSE))
  names(ans.trendtest)[3] = 'z-stat'
}
```

```

# CI on trend:
CI = data.frame(ans.model[2],ans.model[2]-qnorm(1-
(alpha/2))*ans.model[3],ans.model[2]+qnorm(1-(alpha/2))*ans.model[3])
ans.trendCI = exp(CI)-1
names(ans.trendCI) = c("Annual Pct Change", "CI low", "CI high")

if(!method %in% c("SLRDB", "WLRDB")) return(list(ModelEstimates = ans.model,
TrendTest = ans.trendtest, TrendCI = ans.trendCI))
if(method %in% c("SLRDB", "WLRDB")) return(list(ModelEstimates = ans.model,
TrendTest = ans.trendtest, TrendCI = ans.trendCI, DBests =
data.frame(MeanEsts, Resid = resid(fit))))
}

#####

PWIGLS_Binary<-function(Z, dat, stage1wt, stage2wt,
type=type, stratum=stratum, slope=slope, P0.fitted, P0.resid) {

# Calculate probability-weighted estimated of GLMM by Laplace approximation
# Calls PWIGLS_ALL
# las 5.2.17

#dat$Stratum = as.factor(dat$Stratum)

# Laplace Approximation for Linearization Var
# Calc nu, on link scale
dat$LogY = log(P0.fitted) + (1/P0.fitted)* P0.resid

if(is.na(stratum)) {
# Using PWIGLS binary predictions
fit_P0_Laplace = lmer(LogY ~ WYear + (1|Year) +(1+WYear|Site), data = dat)

Z_PO_L = getME(fit_P0_Laplace, "Z")
fit_PWIGLS_Laplace =
PWIGLS_ALL(Z=Z_PO_L, dat=dat, stage1wt=stage1wt, stage2wt=stage2wt, type=type, str
atum=NA, slope=slope)
} # End !StRS

if(!is.na(stratum)) {

# Using PWIGLS binary predictions
fit_P0_Laplace = lmer(LogY ~ WYear*Stratum + (1|Year) +(1+WYear|Site), data
= dat)
Z_PO_L = getME(fit_P0_Laplace, "Z")
fit_PWIGLS_Laplace =
PWIGLS_ALL(Z=Z_PO_L, dat=dat, stage1wt=stage1wt, stage2wt=stage2wt, type=type, str
atum="Stratum", slope=slope)
} # End StRS
return(fit_PWIGLS_Laplace)
}

```

```
#####
TrendNPS_Count<-
function(alpha,dat,method,slope=TRUE,type=NA,stratum=NA,Y,lat=NA,long=NA,stag
e1wt=NA,stage2wt=NA,str1prop=NA,nbhd=TRUE) {

# dat = data set for trend analysis of a count outcome of interest
# dat must contain fields for Site, WYear (scalar year value), and Year (year factor)
# other covariate fields in dat may be used in the trend model, but WYear must be
#   used to estimate trend

# Calculates a trend model specified by method:
# 'PO' = Piepho and Ogutu (2002) unreplicated linear mixed model
# 'SLRDB' = Simple linear regression of design-based estimates
# 'WLRDB' = Weighted linear regression of design-based estimates using the inverse
# of the variance of the estimate as the weight
# 'PWIGLS' = probability-weighted iterative GLS (Pfeffermann et al. 1998,
#   Asparouhov 2002)
#   PWIGLS requires the input, type =
#   'Aonly' = probability weighting but no scaling at either stage
#   'A' = scales panel weights with the mean site-level design weight
#   'AI' = scales panel weights with the mean site-level design weight,
#         but removes site-level scaling
#   'B' = scales panel weights with the effective mean site-level design weight
#   'BI' = scales panel weights with the effective mean site-level design weight,
#         but removes site-level scaling
#   'C' = scales only at the year level with the inverse of the average annual weight

# Inputs needed for SLRDB and WLRDB methods
# stratum = column name of stratification variable in dat
#   stratum is used directly in the SLRDB and WLRDB approaches
#   Stratification variable must be included in the fe input for methods PO and
#   PWIGLS
# Y = character; column name of the count outcome of interest for design-based
#   estimates
# lat = column name of the latitude
# long = column name of the longitude

# Inputs needed for PWIGLS method
# stage1wt = weight from the design, adjusted for frame and/or nonresponse
#   error, if needed
# stage2wt = panel weight from temporal revisit design

# str1prop = proportion of the population represented by stratum 1 in a two-level
#   stratification variable
#   str1 will be the stratum listed first when stratum levels are ordered
#   alphabetically.

# requires package lme4, lmerTest, spsurvey

# Calculate sample sizes
Sites = sort(unique(dat$Site))
ma = length(Sites)
Years = as.character(sort(unique(dat$Year)))
WYears = sort(unique(dat$WYear))
mb = length(WYears)

# Assign stratum
if(!is.na(stratum)) dat$Stratum <- as.factor(dat[,stratum])
dat$Y <- dat[,Y]
```

```
#####
# METHOD P0: Piepho & Ogutu (2002) linear mixed model
# Unreplicated model - one observation per Year and Site
#####

if(method %in% c("P0", "PWIGLS")) {
  if(is.na(stratum)) {
    if(slope) fit<-glmer(Y ~ WYear + (1|Year) +(1+WYear|Site),
family=poisson, data=dat,
control=glmerControl(optimizer="bobyqa",optCtrl=list(maxfun=2e6)))
    if(!slope) fit<-glmer(Y ~ WYear + (1|Year) +(1|Site),
family=poisson, data=dat,
control=glmerControl(optimizer="bobyqa",optCtrl=list(maxfun=2e6)))
  }
  if(!is.na(stratum)) {
    if(slope) fit<-glmer(Y ~ WYear * Stratum + (1|Year)
+(1+WYear|Site),family=poisson, data=dat,
control=glmerControl(optimizer="bobyqa",optCtrl=list(maxfun=2e6)))
    if(!slope) fit<-glmer(Y ~ WYear * Stratum + (1|Year)
+(1|Site),family=poisson, data=dat,
control=glmerControl(optimizer="bobyqa",optCtrl=list(maxfun=2e6)))
  }
}

if(method=="PWIGLS") {
  fit_P0 = fit
  rm(fit)
}

if(method=="P0") {
  if(!slope) {
    sig2a<- VarCorr(fit)$Site          # var(ai)
    sig2t<- sigat<- 0
  }
  if(slope) {
    sig2a<- VarCorr(fit)$Site[1,1]      # var(ai)
    sig2t<- VarCorr(fit)$Site[2,2]      # var(ti)
    sigat<- VarCorr(fit)$Site[1,2]      # cov(ai, ti)
  }
  sig2b<- VarCorr(fit)$Year
  if(is.na(stratum)) {                  # No stratification
    mu<- summary(fit)$coef[1,1]
    trend<- summary(fit)$coef[2,1]
    SETrend<- summary(fit)$coef[2,2]
  }
  if(!is.na(stratum)) {                # Stratification with two levels
    mu<- summary(fit)$coef[1,1]
    c.vec = matrix(c(0,1,0,1-str1prop),1,4)
    trend = c.vec %*% fixef(fit)
    SETrend<- sqrt(c.vec%*% as.matrix(vcov(fit))%*%t(c.vec))
  }
}

} # End P0
} # End P0 or PWIGLS
```

```
#####
# SLRDB and WLRDB: Simple linear regression on annual design-based estimates
# SLRDB: unweighted
# WLRDB: weighted by inverse of variance of each annual estimate
#####

if(method %in% c("SLRDB", "WLRDB")) {
  MeanEsts=data.frame(matrix(NA,mb,3))
  MeanEsts[,1] <- Years

# Calculate annual design-based status estimates of the mean
  for (g in 1:mb) {
    dat.g<-dat[dat$WYear==WYears[g],]
    if(is.na(stratum)) {
      ests <-cont.analysis(
        sites=data.frame(siteID=dat.g$Site, rep(TRUE,nrow(dat.g))),
        subpop= data.frame(siteID=dat.g$Site, Popn1=rep(1, nrow(dat.g))),
        design= data.frame(siteID=dat.g$Site,
          wgt= dat.g$wgt, xcoord = dat.g[,long], ycoord = dat.g[,lat]),
        data.cont= data.frame(siteID=dat.g$Site, Y=dat.g[,Y]), conf=90,
        vartype=ifelse(nbhd,"Local","SRS"))
      MeanEsts[g,2:3] <-ests$Pct[ests$Pct$Statistic=="Mean",6:7]
    }
    if(!is.na(stratum)) {
      ests <-cont.analysis(
        sites=data.frame(siteID=dat.g$Site, rep(TRUE,nrow(dat.g))),
        subpop= data.frame(siteID=dat.g$Site, Popn1=rep(1, nrow(dat.g))),
        design= data.frame(siteID=dat.g$Site,
          wgt= dat.g$wgt, xcoord = dat.g[,long], ycoord = dat.g[,lat],
          stratum=dat.g[,stratum]),
        data.cont= data.frame(siteID=dat.g$Site, Y=dat.g[,Y]), conf=90,
        vartype=ifelse(nbhd,"Local","SRS"))
      MeanEsts[g,2:3] <-ests$Pct[ests$Pct$Statistic=="Mean",6:7]
    }
  }
  MeanEsts[,3] <- as.numeric(MeanEsts[,3])
  names(MeanEsts) <- c("Year", "Est.Mean", "SE")
  MeanEsts$WYear = WYears
# calculate trend in logged mean over time
  if(method=="SLRDB") fit<-lm(log(Est.Mean) ~ WYear, data=MeanEsts)
  if(method=="WLRDB") fit<-lm(log(Est.Mean) ~ WYear, weights=1/(SE^2),
    data=MeanEsts)

  mu <- coef(fit)[1] # mu
  trend<- coef(fit)[2] # slope
  SEtrend<-sqrt(vcov(fit)[2,2]) # SE
  sig2a<- sig2t<- sigat<- sig2b<- 0
  sig2e<- (summary(fit)$sigma)^2
} # End SLRDB/WLRDB
```

```
#####
# PWIGLS methods
#####

if(method == "PWIGLS") {
  if(!type %in% c("Aonly", "A", "AI", "B", "BI", "C")) return("PWIGLS scaling type
  not recognized.")

  fit<-
  PWIGLS_Count(Z=getME(fit_P0, "Z"), dat=dat, stage1wt=stage1wt, stage2wt=stage2wt,
  type=type, stratum=stratum, slope=slope, P0.fitted=predict(fit_P0, type="response
  "), P0.resid=resid(fit_P0, type="response"))
  mu<- fixef(fit)[1] # intercept
  if(slope) {
    sig2a<- VarCorr(fit)$Site[1,1] # var(ai)
    sig2t<- VarCorr(fit)$Site[2,2] # var(ti)
    sigat<- VarCorr(fit)$Site[1,2] # cov(ai, ti)
    sig2b<- VarCorr(fit)$Year[1] # var(bj)
    sig2e<- attr(VarCorr(fit), "sc")^2 # var(eij)
  }
  if(!slope) {
    sig2a<- VarCorr(fit)$Site[1] # var(ai)
    sig2t<- sigat<- 0
    sig2b<- VarCorr(fit)$Year[1] # var(bj)
    sig2e<- attr(VarCorr(fit), "sc")^2 # var(eij)
  }

  if(is.na(stratum)) { # No strata
    trend<- fixef(fit)[2] # slope
    eta<- summary(fit)$coef[2,3] # Use P0 df
    # Linearization variance -- Pfeffermann 1988
    SETrend <- SEbeta<- sqrt(vcov(fit_P0)[2,2])
  } # END No strata

  if(!is.na(stratum)) { # Stratification with two levels
    trend1<- fixef(fit)[2] # slope of stratum 1
    trend2<- fixef(fit)[4] # slope of stratum 2 - slope
    of stratum 1
    trend=trend1 + (1-str1prop)*trend2 # population estimate of
    trend
    Cont = matrix(c(0,1,0, str1prop),1,4)
    SETrend<-as.numeric(sqrt(Cont%*%vcov(fit)%*%t(Cont))) } # END
  Stratification with two levels
  } # End PWIGLS

  ans.model = data.frame(mu, trend, SETrend, sig2a, sig2t, sigat, sig2b)
  names(ans.model)=c('mu', 'trend', 'SETrend', 'sig2a', 'sig2t', 'sigat', 'sig2b')
  rownames(ans.model) = NULL

  # z test
  ans.trendtest = data.frame(trend = ans.model[2], SE = ans.model[3],
  z.stat=ans.model[2]/ans.model[3],
  pvalue=2*pnorm(as.numeric(abs(ans.model[2]/ans.model[3])), lower.tail =FALSE))
  names(ans.trendtest)[3] = 'z-stat'
}
```

```

# CI on trend:
CI = data.frame(ans.model[2], ans.model[2]-qnorm(1-
(alpha/2))*ans.model[3], ans.model[2]+qnorm(1-(alpha/2))*ans.model[3])
ans.trendCI = exp(CI)-1
names(ans.trendCI) = c("Annual Pct Change", "CI low", "CI high")

if(!method %in% c("SLRDB", "WLRDB")) return(list(ModelEstimates = ans.model,
TrendTest = ans.trendtest, TrendCI = ans.trendCI))
if(method %in% c("SLRDB", "WLRDB")) return(list(ModelEstimates = ans.model,
TrendTest = ans.trendtest, TrendCI = ans.trendCI, DBests =
data.frame(MeanEsts, Resid = resid(fit))))

}

#####
PWIGLS_Count<-function(Z, dat, stage1wt, stage2wt,
type=type, stratum=stratum, slope=slope, P0.fitted, P0.resid) {

# Calculate probability-weighted estimated of GLMM by Laplace approximation
# Calls PWIGLS_ALL
# las 5.2.17

#dat$Stratum = as.factor(dat$Stratum)

# Laplace Approximation for Linearization Var
# Calc nu, on link scale
dat$LogY = log(P0.fitted) + (1/P0.fitted)* P0.resid

if(is.na(stratum)) {
# Using PWIGLS Poisson predictions
fit_P0_Laplace = lmer(LogY ~ WYear + (1|Year) +(1+WYear|Site), data = dat)

Z_PO_L = getME(fit_P0_Laplace, "Z")
fit_PWIGLS_Laplace =
PWIGLS_ALL(Z=Z_PO_L, dat=dat, stage1wt=stage1wt, stage2wt=stage2wt, type=type, str
atum=NA, slope=slope)
} # End !StRS

if(!is.na(stratum)) {

# Using PWIGLS Poisson predictions
fit_P0_Laplace = lmer(LogY ~ WYear*Stratum + (1|Year) +(1+WYear|Site), data
= dat)

Z_PO_L = getME(fit_P0_Laplace, "Z")
fit_PWIGLS_Laplace =
PWIGLS_ALL(Z=Z_PO_L, dat=dat, stage1wt=stage1wt, stage2wt=stage2wt, type=type, str
atum="Stratum", slope=slope)
} # End StRS

return(fit_PWIGLS_Laplace)
}

```

Supplement B: Simulation Results for the Binary Outcome

Table B1. Percent Relative Bias of the Binary Trend Slope Estimate. Note the relative bias values > 5% or < -5% (also shaded).

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	SLRDB	WLRDB	Aonly	A	AI	B	BI	C
12	0.02	0	SRS	1	20	2.90	11.73	13.86	2.85	2.85	2.85	2.85	2.85	2.85
12	0.02	0	SRS	1	35	4.64	13.90	17.93	4.15	4.15	4.15	4.15	4.15	4.15
12	0.02	0	SRS	1	50	-7.85	3.01	4.64	-8.30	-8.30	-8.30	-8.30	-8.30	-8.30
12	0.02	0	SRS	2	20	-2.04	10.26	25.10	-13.26	-2.83	-16.42	-2.83	-16.42	-15.96
12	0.02	0	SRS	2	35	-2.15	8.63	16.29	-9.06	-4.20	-15.67	-4.20	-15.67	-12.78
12	0.02	0	SRS	2	50	-4.33	6.25	18.23	-15.66	-6.88	-27.28	-6.88	-27.28	-24.22
12	0.02	0	SRS	3	20	-0.20	9.10	17.84	-0.58	-0.87	-0.33	-0.87	-0.33	-0.87
12	0.02	0	SRS	3	35	3.85	13.04	23.34	3.12	1.73	2.28	1.73	2.28	1.73
12	0.02	0	SRS	3	50	6.27	14.86	23.79	5.66	2.90	2.64	2.90	2.64	2.90
12	0.02	0	StRS	1	20	-18.77	12.84	6.49	-18.19	-18.19	-18.19	-18.19	-18.19	-18.19
12	0.02	0	StRS	1	35	-16.92	14.72	14.84	-17.82	-17.82	-17.82	-17.82	-17.82	-17.82
12	0.02	0	StRS	1	50	-15.91	15.81	16.96	-16.43	-16.43	-16.43	-16.43	-16.43	-16.43
12	0.02	0	StRS	2	20	2.44	30.20	26.35	-3.71	0.00	-4.60	0.00	-4.60	-3.93
12	0.02	0	StRS	2	35	1.74	28.77	32.35	-4.59	-0.49	-9.95	-0.49	-9.95	-7.13
12	0.02	0	StRS	2	50	-3.53	24.35	22.65	-12.13	-5.36	-17.83	-5.36	-17.83	-20.08
12	0.02	0	StRS	3	20	5.83	32.16	28.52	4.11	3.69	4.68	3.69	4.68	3.69
12	0.02	0	StRS	3	35	-0.09	26.88	27.03	-1.87	-3.65	-3.21	-3.65	-3.21	-3.65
12	0.02	0	StRS	3	50	0.82	27.63	25.41	-0.47	-5.52	-4.09	-5.52	-4.09	-5.52
12	0.02	0	Unequal	1	20	14.82	20.40	30.64	4.57	4.57	4.57	4.57	4.57	4.57
12	0.02	0	Unequal	1	35	-1.56	7.66	19.27	-5.62	-5.62	-5.62	-5.62	-5.62	-5.62
12	0.02	0	Unequal	1	50	6.21	16.80	27.49	-0.65	-0.65	-0.65	-0.65	-0.65	-0.65
12	0.02	0	Unequal	2	20	-10.24	-2.71	5.76	-16.30	-18.03	-16.23	-18.03	-16.23	-18.16
12	0.02	0	Unequal	2	35	0.73	12.87	21.85	-3.32	-0.09	-11.40	-0.09	-11.40	-5.75
12	0.02	0	Unequal	2	50	-8.25	2.30	16.01	-18.54	-18.36	-27.99	-18.36	-27.99	-23.04

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	SLRDB	WLRDB	Aonly	A	AI	B	BI	C
12	0.02	0	Unequal	3	20	-11.35	-2.57	-2.04	-22.59	-23.27	-22.06	-23.27	-22.06	-23.27
12	0.02	0	Unequal	3	35	-13.73	-3.65	-0.63	-24.91	-26.80	-27.55	-26.80	-27.55	-26.80
12	0.02	0	Unequal	3	50	-11.45	-0.84	9.18	-22.06	-23.17	-21.40	-23.17	-21.40	-23.17
12	0.02	0.04	SRS	1	20	-1.56	1.27	12.85	-1.68	-1.68	-1.68	-1.68	-1.68	-1.68
12	0.02	0.04	SRS	1	35	-2.76	-0.19	13.10	-3.20	-3.20	-3.20	-3.20	-3.20	-3.20
12	0.02	0.04	SRS	1	50	-9.13	-5.92	5.81	-9.52	-9.52	-9.52	-9.52	-9.52	-9.52
12	0.02	0.04	SRS	2	20	4.68	8.57	15.42	-4.08	3.84	-6.76	3.84	-6.76	-3.89
12	0.02	0.04	SRS	2	35	6.22	7.73	16.23	1.67	4.92	-7.59	4.92	-7.59	-0.56
12	0.02	0.04	SRS	2	50	6.33	7.49	16.86	-1.68	4.16	-5.62	4.16	-5.62	-3.98
12	0.02	0.04	SRS	3	20	-11.36	-7.26	3.92	-11.55	-12.04	-11.40	-12.04	-11.40	-12.04
12	0.02	0.04	SRS	3	35	-7.70	-3.83	7.37	-7.90	-9.07	-8.91	-9.07	-8.91	-9.07
12	0.02	0.04	SRS	3	50	-7.18	-3.36	9.76	-7.90	-9.17	-9.77	-9.17	-9.77	-9.17
12	0.02	0.04	StRS	1	20	2.76	18.63	18.48	2.34	2.34	2.34	2.34	2.34	2.34
12	0.02	0.04	StRS	1	35	-1.28	14.18	14.96	-2.35	-2.35	-2.35	-2.35	-2.35	-2.35
12	0.02	0.04	StRS	1	50	1.17	17.11	16.93	0.54	0.54	0.54	0.54	0.54	0.54
12	0.02	0.04	StRS	2	20	4.38	24.53	24.91	-4.22	2.26	-6.36	2.26	-6.36	-4.72
12	0.02	0.04	StRS	2	35	3.35	22.26	26.63	-3.88	0.77	-8.19	0.77	-8.19	-5.79
12	0.02	0.04	StRS	2	50	4.55	20.44	23.01	-1.11	2.36	-4.30	2.36	-4.30	-6.96
12	0.02	0.04	StRS	3	20	0.52	15.78	15.59	-1.03	-1.63	-0.96	-1.63	-0.96	-1.63
12	0.02	0.04	StRS	3	35	-1.24	14.06	14.15	-3.20	-4.86	-3.98	-4.86	-3.98	-4.86
12	0.02	0.04	StRS	3	50	0.96	16.38	18.84	-0.56	-3.68	-2.94	-3.68	-2.94	-3.68
12	0.02	0.04	Unequal	1	20	0.82	13.96	24.70	7.66	7.66	7.66	7.66	7.66	7.66
12	0.02	0.04	Unequal	1	35	-8.50	3.24	16.49	0.21	0.21	0.21	0.21	0.21	0.21
12	0.02	0.04	Unequal	1	50	-4.91	9.09	22.39	6.84	6.84	6.84	6.84	6.84	6.84
12	0.02	0.04	Unequal	2	20	-0.52	12.66	23.73	6.25	12.52	3.27	12.52	3.27	6.90
12	0.02	0.04	Unequal	2	35	-2.93	6.58	21.78	6.01	7.39	2.28	7.39	2.28	4.49
12	0.02	0.04	Unequal	2	50	-2.17	7.79	17.14	7.45	13.77	4.60	13.77	4.60	2.47

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	SLRDB	WLRDB	Aonly	A	AI	B	BI	C
12	0.02	0.04	Unequal	3	20	-4.94	7.30	21.95	10.63	10.46	11.32	10.46	11.32	10.46
12	0.02	0.04	Unequal	3	35	-2.04	8.61	22.56	15.68	16.77	16.42	16.77	16.42	16.77
12	0.02	0.04	Unequal	3	50	1.28	13.18	26.78	26.83	28.40	27.37	28.40	27.37	28.40
24	0.01	0	SRS	1	20	-14.05	42.78	69.45	-13.97	-13.97	-13.97	-13.97	-13.97	-13.97
24	0.01	0	SRS	1	35	-3.03	48.43	79.42	-3.03	-3.03	-3.03	-3.03	-3.03	-3.03
24	0.01	0	SRS	1	50	-3.56	48.01	74.49	-3.53	-3.53	-3.53	-3.53	-3.53	-3.53
24	0.01	0	SRS	2	20	-2.05	53.50	88.69	-6.46	-1.97	-6.95	-1.97	-6.95	-6.59
24	0.01	0	SRS	2	35	4.03	60.37	96.45	-4.43	4.03	-2.94	4.03	-2.94	-4.70
24	0.01	0	SRS	2	50	10.55	57.81	94.04	2.47	10.54	7.27	10.54	7.27	2.49
24	0.01	0	SRS	3	20	4.01	54.64	68.55	3.88	3.94	3.95	3.94	3.95	3.94
24	0.01	0	SRS	3	35	2.46	52.40	72.54	2.50	2.45	2.55	2.45	2.55	2.45
24	0.01	0	SRS	3	50	-1.15	51.25	70.79	-1.17	-1.17	-1.14	-1.17	-1.14	-1.17
24	0.01	0	StRS	1	20	9.66	138.69	156.52	9.90	9.90	9.90	9.90	9.90	9.90
24	0.01	0	StRS	1	35	16.48	146.16	159.14	16.79	16.79	16.79	16.79	16.79	16.79
24	0.01	0	StRS	1	50	8.94	139.47	153.84	9.33	9.33	9.33	9.33	9.33	9.33
24	0.01	0	StRS	2	20	3.10	125.20	129.35	-3.55	2.83	0.76	2.83	0.76	-3.41
24	0.01	0	StRS	2	35	2.38	130.61	135.23	-7.57	1.65	-7.00	1.65	-7.00	-7.51
24	0.01	0	StRS	2	50	-4.48	131.28	137.64	-11.35	-4.64	-11.09	-4.64	-11.09	-11.43
24	0.01	0	StRS	3	20	-17.61	118.89	118.14	-18.37	-18.63	-18.56	-18.63	-18.56	-18.63
24	0.01	0	StRS	3	35	-11.92	122.71	120.11	-12.65	-12.79	-12.71	-12.79	-12.71	-12.79
24	0.01	0	StRS	3	50	-4.10	130.35	136.78	-4.66	-4.64	-4.66	-4.64	-4.66	-4.64
24	0.01	0	Unequal	1	20	12.88	58.32	85.03	13.18	13.18	13.18	13.18	13.18	13.18
24	0.01	0	Unequal	1	35	3.73	50.10	72.12	-5.29	-5.29	-5.29	-5.29	-5.29	-5.29
24	0.01	0	Unequal	1	50	-3.31	47.53	73.08	-9.20	-9.20	-9.20	-9.20	-9.20	-9.20
24	0.01	0	Unequal	2	20	-13.84	36.79	45.39	-18.10	-18.24	-16.20	-18.24	-16.20	-18.17
24	0.01	0	Unequal	2	35	-12.20	45.02	56.55	-25.55	-25.04	-23.89	-25.04	-23.89	-25.51
24	0.01	0	Unequal	2	50	-15.04	34.93	50.02	-30.82	-33.22	-28.89	-33.22	-28.89	-31.26

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	SLRDB	WLRDB	Aonly	A	AI	B	BI	C
24	0.01	0	Unequal	3	20	-5.10	42.43	59.94	-14.47	-14.49	-14.47	-14.49	-14.47	-14.49
24	0.01	0	Unequal	3	35	5.35	49.30	71.93	-11.04	-10.82	-10.97	-10.82	-10.97	-10.82
24	0.01	0	Unequal	3	50	9.00	53.85	72.33	-3.57	-3.49	-3.57	-3.49	-3.57	-3.49
24	0.01	0.04	SRS	1	20	0.54	8.49	25.80	0.53	0.53	0.53	0.53	0.53	0.53
24	0.01	0.04	SRS	1	35	9.18	11.28	30.40	9.18	9.18	9.18	9.18	9.18	9.18
24	0.01	0.04	SRS	1	50	5.25	8.23	25.46	5.27	5.27	5.27	5.27	5.27	5.27
24	0.01	0.04	SRS	2	20	-2.03	3.78	19.36	-5.12	-1.99	-7.23	-1.99	-7.23	-5.11
24	0.01	0.04	SRS	2	35	0.35	6.22	22.91	-5.70	0.38	-4.90	0.38	-4.90	-5.27
24	0.01	0.04	SRS	2	50	2.26	5.16	21.91	-3.77	2.23	-2.18	2.23	-2.18	-3.66
24	0.01	0.04	SRS	3	20	2.22	6.28	27.33	2.28	2.28	2.23	2.28	2.23	2.28
24	0.01	0.04	SRS	3	35	1.01	4.58	23.82	0.98	0.99	0.99	0.99	0.99	0.99
24	0.01	0.04	SRS	3	50	0.63	4.17	22.04	0.63	0.61	0.63	0.61	0.63	0.61
24	0.01	0.04	StRS	1	20	3.52	48.68	60.04	3.23	3.23	3.23	3.23	3.23	3.23
24	0.01	0.04	StRS	1	35	-9.08	41.76	52.68	-9.75	-9.75	-9.75	-9.75	-9.75	-9.75
24	0.01	0.04	StRS	1	50	-3.91	45.87	56.79	-4.33	-4.33	-4.33	-4.33	-4.33	-4.33
24	0.01	0.04	StRS	2	20	-3.28	42.74	54.49	-7.87	-4.95	-4.86	-4.95	-4.86	-7.87
24	0.01	0.04	StRS	2	35	0.01	47.37	60.65	-8.99	-2.04	-8.58	-2.04	-8.58	-8.99
24	0.01	0.04	StRS	2	50	-1.54	45.10	57.81	-8.30	-2.79	-7.38	-2.79	-7.38	-8.30
24	0.01	0.04	StRS	3	20	-6.10	43.05	53.50	-7.88	-7.93	-7.77	-7.93	-7.77	-7.93
24	0.01	0.04	StRS	3	35	-2.71	45.71	58.04	-4.59	-4.62	-4.62	-4.62	-4.62	-4.62
24	0.01	0.04	StRS	3	50	-0.21	46.77	58.52	-1.74	-1.73	-1.74	-1.73	-1.74	-1.73
24	0.01	0.04	Unequal	1	20	-1.19	12.65	37.02	3.91	3.91	3.91	3.91	3.91	3.91
24	0.01	0.04	Unequal	1	35	-12.86	12.83	35.44	-0.59	-0.59	-0.59	-0.59	-0.59	-0.59
24	0.01	0.04	Unequal	1	50	-10.87	8.36	31.89	-5.69	-5.69	-5.69	-5.69	-5.69	-5.69
24	0.01	0.04	Unequal	2	20	-9.43	8.27	32.04	-3.77	-4.17	-4.80	-4.17	-4.80	-3.78
24	0.01	0.04	Unequal	2	35	-19.47	2.74	24.39	-13.97	-18.31	-13.72	-18.31	-13.72	-13.90
24	0.01	0.04	Unequal	2	50	-10.81	9.53	32.27	-6.97	-12.83	-8.62	-12.83	-8.62	-7.06

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	SLRDB	WLRDB	Aonly	A	AI	B	BI	C
24	0.01	0.04	Unequal	3	20	-17.20	4.34	24.47	-11.91	-11.84	-11.67	-11.84	-11.67	-11.84
24	0.01	0.04	Unequal	3	35	-13.86	6.97	29.95	-12.62	-12.82	-12.92	-12.82	-12.92	-12.82
24	0.01	0.04	Unequal	3	50	-13.77	7.17	28.28	-15.10	-14.96	-15.09	-14.96	-15.09	-14.96

Table B2. Confidence Interval Coverage of the Binary Trend Slope Estimate ($\alpha = 0.10$). Note confidence interval coverage values < 0.87 (also shaded).

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	SLRDB	WLRDB	Aonly	A	AI	B	BI	C
12	0.02	0	SRS	1-0	20	0.87	0.82	0.81	0.87	0.87	0.87	0.87	0.87	0.87
12	0.02	0	SRS	1-0	35	0.87	0.84	0.84	0.86	0.86	0.86	0.86	0.86	0.86
12	0.02	0	SRS	1-0	50	0.84	0.84	0.86	0.84	0.84	0.84	0.84	0.84	0.84
12	0.02	0	SRS	1-0	20	0.84	0.84	0.83	0.71	0.84	0.65	0.84	0.65	0.69
12	0.02	0	SRS	1-0	35	0.83	0.85	0.86	0.65	0.83	0.58	0.83	0.58	0.62
12	0.02	0	SRS	1-0	50	0.85	0.87	0.86	0.63	0.85	0.60	0.85	0.60	0.57
12	0.02	0	SRS	1-0,1-3	20	0.87	0.90	0.87	0.87	0.87	0.87	0.87	0.87	0.87
12	0.02	0	SRS	1-0,1-3	35	0.86	0.90	0.88	0.86	0.86	0.86	0.86	0.86	0.86
12	0.02	0	SRS	1-0,1-3	50	0.88	0.90	0.88	0.88	0.88	0.88	0.88	0.88	0.88
12	0.02	0	StRS	1-0,1-3	20	0.88	0.79	0.81	0.90	0.90	0.90	0.90	0.90	0.90
12	0.02	0	StRS	1-0,1-3	35	0.89	0.82	0.85	0.91	0.91	0.91	0.91	0.91	0.91
12	0.02	0	StRS	1-0,1-3	50	0.85	0.80	0.83	0.88	0.88	0.88	0.88	0.88	0.88
12	0.02	0	StRS	1-3	20	0.89	0.79	0.78	0.81	0.91	0.71	0.91	0.71	0.81
12	0.02	0	StRS	1-3	35	0.88	0.83	0.84	0.74	0.90	0.70	0.90	0.70	0.72
12	0.02	0	StRS	1-3	50	0.86	0.85	0.88	0.71	0.89	0.69	0.89	0.69	0.68
12	0.02	0	StRS	1-3	20	0.85	0.86	0.82	0.86	0.86	0.86	0.86	0.86	0.86
12	0.02	0	StRS	1-3	35	0.86	0.87	0.84	0.87	0.87	0.87	0.87	0.87	0.87
12	0.02	0	StRS	1-3	50	0.85	0.86	0.85	0.86	0.87	0.86	0.87	0.86	0.87

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	SLRDB	WLRDB	Aonly	A	AI	B	BI	C
12	0.02	0	Unequal	1-0	20	0.89	0.81	0.80	0.81	0.81	0.81	0.81	0.81	0.81
12	0.02	0	Unequal	1-0	35	0.85	0.83	0.84	0.79	0.79	0.79	0.79	0.79	0.79
12	0.02	0	Unequal	1-0	50	0.86	0.84	0.83	0.75	0.75	0.75	0.75	0.75	0.75
12	0.02	0	Unequal	1-0	20	0.86	0.82	0.78	0.66	0.73	0.61	0.73	0.61	0.64
12	0.02	0	Unequal	1-0	35	0.86	0.87	0.88	0.65	0.74	0.57	0.74	0.57	0.62
12	0.02	0	Unequal	1-0	50	0.86	0.89	0.87	0.57	0.65	0.55	0.65	0.55	0.55
12	0.02	0	Unequal	1-0,1-3	20	0.83	0.87	0.84	0.77	0.76	0.77	0.76	0.77	0.76
12	0.02	0	Unequal	1-0,1-3	35	0.85	0.87	0.85	0.73	0.71	0.70	0.71	0.70	0.71
12	0.02	0	Unequal	1-0,1-3	50	0.84	0.87	0.85	0.69	0.65	0.69	0.65	0.69	0.65
12	0.02	0.04	SRS	1-0,1-3	20	0.87	0.82	0.80	0.87	0.87	0.87	0.87	0.87	0.87
12	0.02	0.04	SRS	1-0,1-3	35	0.87	0.85	0.85	0.86	0.86	0.86	0.86	0.86	0.86
12	0.02	0.04	SRS	1-0,1-3	50	0.87	0.87	0.85	0.87	0.87	0.87	0.87	0.87	0.87
12	0.02	0.04	SRS	1-3	20	0.88	0.85	0.83	0.70	0.88	0.67	0.88	0.67	0.70
12	0.02	0.04	SRS	1-3	35	0.87	0.89	0.85	0.67	0.87	0.63	0.87	0.63	0.65
12	0.02	0.04	SRS	1-3	50	0.86	0.88	0.86	0.67	0.86	0.59	0.86	0.59	0.62
12	0.02	0.04	SRS	1-3	20	0.85	0.86	0.86	0.85	0.85	0.85	0.85	0.85	0.85
12	0.02	0.04	SRS	1-3	35	0.87	0.89	0.87	0.87	0.87	0.87	0.87	0.87	0.87
12	0.02	0.04	SRS	1-3	50	0.85	0.87	0.87	0.85	0.85	0.85	0.85	0.85	0.85
12	0.02	0.04	StRS	1-0	20	0.85	0.74	0.77	0.88	0.88	0.88	0.88	0.88	0.88
12	0.02	0.04	StRS	1-0	35	0.88	0.80	0.83	0.90	0.90	0.90	0.90	0.90	0.90
12	0.02	0.04	StRS	1-0	50	0.89	0.85	0.84	0.91	0.91	0.91	0.91	0.91	0.91
12	0.02	0.04	StRS	1-0	20	0.87	0.78	0.77	0.80	0.89	0.75	0.89	0.75	0.80
12	0.02	0.04	StRS	1-0	35	0.87	0.82	0.82	0.77	0.90	0.73	0.90	0.73	0.75
12	0.02	0.04	StRS	1-0	50	0.85	0.84	0.85	0.72	0.87	0.70	0.87	0.70	0.70
12	0.02	0.04	StRS	1-0,1-3	20	0.87	0.87	0.86	0.90	0.90	0.90	0.90	0.90	0.90
12	0.02	0.04	StRS	1-0,1-3	35	0.87	0.88	0.88	0.89	0.89	0.89	0.89	0.89	0.89
12	0.02	0.04	StRS	1-0,1-3	50	0.89	0.90	0.90	0.89	0.90	0.89	0.90	0.89	0.90

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	SLRDB	WLRDB	Aonly	A	AI	B	BI	C
12	0.02	0.04	Unequal	1-0,1-3	20	0.86	0.78	0.76	0.79	0.79	0.79	0.79	0.79	0.79
12	0.02	0.04	Unequal	1-0,1-3	35	0.86	0.82	0.80	0.76	0.76	0.76	0.76	0.76	0.76
12	0.02	0.04	Unequal	1-0,1-3	50	0.85	0.84	0.80	0.75	0.75	0.75	0.75	0.75	0.75
12	0.02	0.04	Unequal	1-3	20	0.86	0.82	0.82	0.67	0.77	0.64	0.77	0.64	0.66
12	0.02	0.04	Unequal	1-3	35	0.85	0.85	0.82	0.62	0.72	0.57	0.72	0.57	0.62
12	0.02	0.04	Unequal	1-3	50	0.84	0.88	0.85	0.57	0.62	0.53	0.62	0.53	0.54
12	0.02	0.04	Unequal	1-3	20	0.84	0.85	0.82	0.77	0.76	0.77	0.76	0.77	0.76
12	0.02	0.04	Unequal	1-3	35	0.84	0.87	0.85	0.72	0.72	0.71	0.72	0.71	0.72
12	0.02	0.04	Unequal	1-3	50	0.84	0.86	0.84	0.67	0.65	0.66	0.65	0.66	0.65
24	0.01	0	SRS	1-0	20	0.89	0.59	0.64	0.89	0.89	0.89	0.89	0.89	0.89
24	0.01	0	SRS	1-0	35	0.89	0.71	0.69	0.89	0.89	0.89	0.89	0.89	0.89
24	0.01	0	SRS	1-0	50	0.91	0.76	0.73	0.91	0.91	0.91	0.91	0.91	0.91
24	0.01	0	SRS	1-0	20	0.90	0.69	0.69	0.88	0.90	0.86	0.90	0.86	0.88
24	0.01	0	SRS	1-0	35	0.87	0.80	0.76	0.78	0.87	0.77	0.87	0.77	0.78
24	0.01	0	SRS	1-0	50	0.89	0.83	0.79	0.81	0.89	0.82	0.89	0.82	0.81
24	0.01	0	SRS	1-0,1-3	20	0.87	0.80	0.76	0.87	0.87	0.87	0.87	0.87	0.87
24	0.01	0	SRS	1-0,1-3	35	0.91	0.83	0.80	0.91	0.91	0.91	0.91	0.91	0.91
24	0.01	0	SRS	1-0,1-3	50	0.86	0.82	0.80	0.86	0.86	0.86	0.86	0.86	0.86
24	0.01	0	StRS	1-0,1-3	20	0.86	0.44	0.50	0.90	0.90	0.90	0.90	0.90	0.90
24	0.01	0	StRS	1-0,1-3	35	0.88	0.46	0.58	0.92	0.92	0.92	0.92	0.92	0.92
24	0.01	0	StRS	1-0,1-3	50	0.91	0.53	0.61	0.96	0.96	0.96	0.96	0.96	0.96
24	0.01	0	StRS	1-3	20	0.89	0.51	0.55	0.90	0.92	0.86	0.92	0.86	0.90
24	0.01	0	StRS	1-3	35	0.90	0.55	0.61	0.89	0.92	0.87	0.92	0.87	0.89
24	0.01	0	StRS	1-3	50	0.89	0.57	0.63	0.86	0.92	0.84	0.92	0.84	0.86
24	0.01	0	StRS	1-3	20	0.89	0.65	0.66	0.92	0.91	0.92	0.91	0.92	0.91
24	0.01	0	StRS	1-3	35	0.90	0.64	0.71	0.93	0.93	0.93	0.93	0.93	0.93
24	0.01	0	StRS	1-3	50	0.90	0.60	0.66	0.93	0.92	0.92	0.92	0.92	0.92

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	SLRDB	WLRDB	Aonly	A	AI	B	BI	C
24	0.01	0	Unequal	1-0	20	0.87	0.58	0.57	0.82	0.82	0.82	0.82	0.82	0.82
24	0.01	0	Unequal	1-0	35	0.89	0.64	0.68	0.83	0.83	0.83	0.83	0.83	0.83
24	0.01	0	Unequal	1-0	50	0.90	0.73	0.73	0.84	0.84	0.84	0.84	0.84	0.84
24	0.01	0	Unequal	1-0	20	0.87	0.74	0.68	0.82	0.84	0.79	0.84	0.79	0.82
24	0.01	0	Unequal	1-0	35	0.88	0.76	0.75	0.74	0.78	0.72	0.78	0.72	0.73
24	0.01	0	Unequal	1-0	50	0.87	0.80	0.80	0.73	0.80	0.74	0.80	0.74	0.73
24	0.01	0	Unequal	1-0,1-3	20	0.92	0.84	0.80	0.85	0.85	0.85	0.85	0.85	0.85
24	0.01	0	Unequal	1-0,1-3	35	0.89	0.84	0.81	0.80	0.80	0.80	0.80	0.80	0.80
24	0.01	0	Unequal	1-0,1-3	50	0.88	0.84	0.80	0.79	0.79	0.79	0.79	0.79	0.79
24	0.01	0.04	SRS	1-0,1-3	20	0.87	0.59	0.63	0.87	0.87	0.87	0.87	0.87	0.87
24	0.01	0.04	SRS	1-0,1-3	35	0.88	0.69	0.72	0.88	0.88	0.88	0.88	0.88	0.88
24	0.01	0.04	SRS	1-0,1-3	50	0.90	0.77	0.81	0.90	0.90	0.90	0.90	0.90	0.90
24	0.01	0.04	SRS	1-3	20	0.90	0.72	0.70	0.86	0.90	0.84	0.90	0.84	0.86
24	0.01	0.04	SRS	1-3	35	0.89	0.80	0.77	0.82	0.89	0.83	0.89	0.83	0.82
24	0.01	0.04	SRS	1-3	50	0.88	0.86	0.83	0.80	0.88	0.81	0.88	0.81	0.80
24	0.01	0.04	SRS	1-3	20	0.91	0.85	0.83	0.91	0.91	0.91	0.91	0.91	0.91
24	0.01	0.04	SRS	1-3	35	0.88	0.83	0.80	0.88	0.88	0.88	0.88	0.88	0.88
24	0.01	0.04	SRS	1-3	50	0.89	0.87	0.82	0.89	0.89	0.89	0.89	0.89	0.89
24	0.01	0.04	StRS	1-0	20	0.85	0.51	0.54	0.88	0.88	0.88	0.88	0.88	0.88
24	0.01	0.04	StRS	1-0	35	0.91	0.59	0.62	0.93	0.93	0.93	0.93	0.93	0.93
24	0.01	0.04	StRS	1-0	50	0.88	0.62	0.67	0.92	0.92	0.92	0.92	0.92	0.92
24	0.01	0.04	StRS	1-0	20	0.90	0.55	0.54	0.89	0.93	0.86	0.93	0.86	0.89
24	0.01	0.04	StRS	1-0	35	0.90	0.61	0.61	0.89	0.92	0.85	0.92	0.85	0.89
24	0.01	0.04	StRS	1-0	50	0.88	0.68	0.68	0.83	0.91	0.83	0.91	0.83	0.83
24	0.01	0.04	StRS	1-0,1-3	20	0.85	0.73	0.70	0.89	0.89	0.89	0.89	0.89	0.89
24	0.01	0.04	StRS	1-0,1-3	35	0.88	0.73	0.73	0.91	0.91	0.91	0.91	0.91	0.91
24	0.01	0.04	StRS	1-0,1-3	50	0.86	0.71	0.72	0.89	0.89	0.89	0.89	0.89	0.89

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	SLRDB	WLRDB	Aonly	A	AI	B	BI	C
24	0.01	0.04	Unequal	1-0,1-3	20	0.90	0.60	0.59	0.83	0.83	0.83	0.83	0.83	0.83
24	0.01	0.04	Unequal	1-0,1-3	35	0.87	0.67	0.65	0.83	0.83	0.83	0.83	0.83	0.83
24	0.01	0.04	Unequal	1-0,1-3	50	0.90	0.75	0.74	0.84	0.84	0.84	0.84	0.84	0.84
24	0.01	0.04	Unequal	1-3	20	0.91	0.70	0.67	0.82	0.85	0.80	0.85	0.80	0.82
24	0.01	0.04	Unequal	1-3	35	0.88	0.82	0.80	0.79	0.83	0.77	0.83	0.77	0.79
24	0.01	0.04	Unequal	1-3	50	0.90	0.86	0.80	0.74	0.81	0.75	0.81	0.75	0.75
24	0.01	0.04	Unequal	1-3	20	0.89	0.82	0.75	0.83	0.83	0.83	0.83	0.83	0.83
24	0.01	0.04	Unequal	1-3	35	0.89	0.87	0.81	0.82	0.82	0.82	0.82	0.82	0.82
24	0.01	0.04	Unequal	1-3	50	0.88	0.88	0.82	0.80	0.80	0.80	0.80	0.80	0.80

Table B3. Trend Test Size of the z-test for the Binary Trend Slope Estimate. Note values > 0.13 (also shaded).

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	SLRDB	WLRDB	Aonly	A	AI	B	BI	C
12	0	0	SRS	1-0	20	0.14	0.12	0.19	0.12	0.12	0.12	0.12	0.12	0.12
12	0	0	SRS	1-0	35	0.15	0.11	0.16	0.16	0.16	0.16	0.16	0.16	0.16
12	0	0	SRS	1-0	50	0.15	0.11	0.17	0.14	0.14	0.14	0.14	0.14	0.14
12	0	0	SRS	1-0	20	0.13	0.11	0.15	0.37	0.13	0.39	0.13	0.39	0.38
12	0	0	SRS	1-0	35	0.14	0.10	0.15	0.47	0.14	0.48	0.14	0.48	0.44
12	0	0	SRS	1-0	50	0.14	0.11	0.15	0.52	0.14	0.54	0.14	0.54	0.51
12	0	0	SRS	1-0,1-3	20	0.16	0.12	0.18	0.15	0.15	0.16	0.15	0.16	0.15
12	0	0	SRS	1-0,1-3	35	0.17	0.12	0.17	0.18	0.17	0.17	0.17	0.17	0.17
12	0	0	SRS	1-0,1-3	50	0.17	0.13	0.18	0.16	0.17	0.16	0.17	0.16	0.17
12	0	0	StRS	1-0,1-3	20	0.15	0.28	0.25	0.12	0.12	0.12	0.12	0.12	0.12
12	0	0	StRS	1-0,1-3	35	0.13	0.22	0.21	0.12	0.12	0.12	0.12	0.12	0.12
12	0	0	StRS	1-0,1-3	50	0.12	0.18	0.18	0.11	0.11	0.11	0.11	0.11	0.11
12	0	0	StRS	1-3	20	0.12	0.20	0.23	0.18	0.10	0.24	0.10	0.24	0.18

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	SLRDB	WLRDB	Aonly	A	AI	B	BI	C
12	0	0	StRS	1-3	35	0.13	0.19	0.18	0.25	0.12	0.28	0.12	0.28	0.27
12	0	0	StRS	1-3	50	0.14	0.16	0.16	0.29	0.11	0.32	0.11	0.32	0.30
12	0	0	StRS	1-3	20	0.12	0.14	0.16	0.09	0.09	0.09	0.09	0.09	0.09
12	0	0	StRS	1-3	35	0.15	0.15	0.15	0.13	0.13	0.12	0.13	0.12	0.13
12	0	0	StRS	1-3	50	0.14	0.13	0.14	0.12	0.12	0.12	0.12	0.12	0.12
12	0	0	Unequal	1-0	20	0.15	0.12	0.18	0.25	0.25	0.25	0.25	0.25	0.25
12	0	0	Unequal	1-0	35	0.15	0.13	0.16	0.31	0.31	0.31	0.31	0.31	0.31
12	0	0	Unequal	1-0	50	0.16	0.13	0.17	0.42	0.42	0.42	0.42	0.42	0.42
12	0	0	Unequal	1-0	20	0.17	0.14	0.19	0.44	0.28	0.44	0.28	0.44	0.44
12	0	0	Unequal	1-0	35	0.17	0.13	0.18	0.54	0.32	0.56	0.32	0.56	0.54
12	0	0	Unequal	1-0	50	0.15	0.13	0.18	0.59	0.39	0.60	0.39	0.60	0.59
12	0	0	Unequal	1-0,1-3	20	0.18	0.14	0.21	0.28	0.27	0.26	0.27	0.26	0.27
12	0	0	Unequal	1-0,1-3	35	0.16	0.13	0.18	0.30	0.30	0.31	0.30	0.31	0.30
12	0	0	Unequal	1-0,1-3	50	0.17	0.12	0.20	0.37	0.39	0.38	0.39	0.38	0.39
24	0	0	SRS	1-0	20	0.13	0.12	0.18	0.12	0.12	0.12	0.12	0.12	0.12
24	0	0	SRS	1-0	35	0.13	0.12	0.17	0.12	0.12	0.12	0.12	0.12	0.12
24	0	0	SRS	1-0	50	0.13	0.12	0.18	0.13	0.13	0.13	0.13	0.13	0.13
24	0	0	SRS	1-0	20	0.15	0.14	0.20	0.40	0.15	0.39	0.15	0.39	0.40
24	0	0	SRS	1-0	35	0.14	0.13	0.18	0.49	0.13	0.49	0.13	0.49	0.48
24	0	0	SRS	1-0	50	0.14	0.13	0.19	0.52	0.15	0.51	0.15	0.51	0.53
24	0	0	SRS	1-0,1-3	20	0.11	0.11	0.17	0.13	0.13	0.12	0.13	0.12	0.13
24	0	0	SRS	1-0,1-3	35	0.13	0.11	0.18	0.12	0.13	0.13	0.13	0.13	0.13
24	0	0	SRS	1-0,1-3	50	0.12	0.11	0.16	0.12	0.12	0.12	0.12	0.12	0.12
24	0	0	StRS	1-0,1-3	20	0.13	0.63	0.55	0.09	0.09	0.09	0.09	0.09	0.09
24	0	0	StRS	1-0,1-3	35	0.09	0.60	0.48	0.07	0.07	0.07	0.07	0.07	0.07
24	0	0	StRS	1-0,1-3	50	0.09	0.64	0.52	0.07	0.07	0.07	0.07	0.07	0.07
24	0	0	StRS	1-3	20	0.13	0.56	0.46	0.12	0.09	0.16	0.09	0.16	0.12

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	Aonly	A	AI	B	BI	C
24	0	0	SRS	1-0,1-3	50	0.12	0.12	0.12	0.12	0.12	0.12	0.12
24	0	0	StRS	1-0,1-3	20	0.12	0.22	0.22	0.22	0.22	0.22	0.22
24	0	0	StRS	1-0,1-3	35	0.11	0.21	0.21	0.21	0.21	0.21	0.21
24	0	0	StRS	1-0,1-3	50	0.11	0.18	0.18	0.18	0.18	0.18	0.18
24	0	0	StRS	1-3	20	0.11	0.20	0.18	0.23	0.18	0.23	0.20
24	0	0	StRS	1-3	35	0.12	0.20	0.19	0.23	0.19	0.23	0.20
24	0	0	StRS	1-3	50	0.12	0.22	0.19	0.24	0.19	0.24	0.22
24	0	0	StRS	1-3	20	0.09	0.16	0.16	0.17	0.16	0.17	0.16
24	0	0	StRS	1-3	35	0.11	0.16	0.16	0.16	0.16	0.16	0.16
24	0	0	StRS	1-3	50	0.08	0.17	0.17	0.17	0.17	0.17	0.17
24	0	0	Unequal	1-0	20	0.12	0.18	0.18	0.18	0.18	0.18	0.18
24	0	0	Unequal	1-0	35	0.12	0.16	0.16	0.16	0.16	0.16	0.16
24	0	0	Unequal	1-0	50	0.12	0.19	0.19	0.19	0.19	0.19	0.19
24	0	0	Unequal	1-0	20	0.12	0.20	0.17	0.23	0.17	0.23	0.19
24	0	0	Unequal	1-0	35	0.12	0.22	0.17	0.22	0.17	0.22	0.22
24	0	0	Unequal	1-0	50	0.13	0.28	0.22	0.28	0.22	0.28	0.28
24	0	0	Unequal	1-0,1-3	20	0.11	0.18	0.18	0.18	0.18	0.18	0.18
24	0	0	Unequal	1-0,1-3	35	0.10	0.16	0.16	0.16	0.16	0.16	0.16
24	0	0	Unequal	1-0,1-3	50	0.12	0.21	0.22	0.21	0.22	0.21	0.22

Table B5. Trend Test Power of the z-test for the Binary Trend Slope Estimate (for trend tests of size 0.13 or less). Note power values < 0.80 (also shaded).

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	SLRDB	WLRDB	Aonly	A	AI	B	BI	C
12	0.02	0	SRS	1-0	20	–	0.24	–	0.16	0.16	0.16	0.16	0.16	0.16
12	0.02	0	SRS	1-0	35	–	0.18	–	–	–	–	–	–	–
12	0.02	0	SRS	1-0	50	–	0.20	–	–	–	–	–	–	–
12	0.02	0	SRS	1-0	20	–	0.20	–	–	0.18	–	0.18	–	–
12	0.02	0	SRS	1-0	35	–	0.17	–	–	–	–	–	–	–
12	0.02	0	SRS	1-0	50	–	0.19	–	–	–	–	–	–	–
12	0.02	0	SRS	1-0,1-3	20	–	0.16	–	–	–	–	–	–	–
12	0.02	0	SRS	1-0,1-3	35	–	0.16	–	–	–	–	–	–	–
12	0.02	0	SRS	1-0,1-3	50	–	0.18	–	–	–	–	–	–	–
12	0.02	0	StRS	1-0,1-3	20	–	–	–	0.11	0.11	0.11	0.11	0.11	0.11
12	0.02	0	StRS	1-0,1-3	35	–	–	–	0.12	0.12	0.12	0.12	0.12	0.12
12	0.02	0	StRS	1-0,1-3	50	0.17	–	–	0.15	0.15	0.15	0.15	0.15	0.15
12	0.02	0	StRS	1-3	20	0.19	–	–	–	0.16	–	0.16	–	–
12	0.02	0	StRS	1-3	35	0.20	–	–	–	0.17	–	0.17	–	–
12	0.02	0	StRS	1-3	50	–	–	–	–	0.16	–	0.16	–	–
12	0.02	0	StRS	1-3	20	0.18	–	–	0.17	0.17	0.17	0.17	0.17	0.17
12	0.02	0	StRS	1-3	35	–	–	–	0.17	0.17	0.17	0.17	0.17	0.17
12	0.02	0	StRS	1-3	50	–	–	–	0.17	0.17	0.17	0.17	0.17	0.17
12	0.02	0	Unequal	1-0	20	–	0.22	–	–	–	–	–	–	–
12	0.02	0	Unequal	1-0	35	–	0.22	–	–	–	–	–	–	–
12	0.02	0	Unequal	1-0	50	–	0.21	–	–	–	–	–	–	–
12	0.02	0	Unequal	1-0	20	–	–	–	–	–	–	–	–	–
12	0.02	0	Unequal	1-0	35	–	0.17	–	–	–	–	–	–	–
12	0.02	0	Unequal	1-0	50	–	–	–	–	–	–	–	–	–
12	0.02	0	Unequal	1-0,1-3	20	–	–	–	–	–	–	–	–	–

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	SLRDB	WLRDB	Aonly	A	AI	B	BI	C
12	0.02	0	Unequal	1-0,1-3	35	–	0.15	–	–	–	–	–	–	–
12	0.02	0	Unequal	1-0,1-3	50	–	0.16	–	–	–	–	–	–	–
12	0.02	0.04	SRS	1-0,1-3	20	–	0.27	–	0.18	0.18	0.18	0.18	0.18	0.18
12	0.02	0.04	SRS	1-0,1-3	35	–	0.24	–	0.18	0.18	0.18	0.18	0.18	0.18
12	0.02	0.04	SRS	1-0,1-3	50	0.21	0.24	–	0.21	0.21	0.21	0.21	0.21	0.21
12	0.02	0.04	SRS	1-3	20	–	–	–	–	–	–	–	–	–
12	0.02	0.04	SRS	1-3	35	–	0.23	–	–	0.23	–	0.23	–	–
12	0.02	0.04	SRS	1-3	50	–	–	–	–	–	–	–	–	–
12	0.02	0.04	SRS	1-3	20	0.20	0.18	–	–	0.20	0.20	0.20	0.20	0.20
12	0.02	0.04	SRS	1-3	35	0.23	0.20	–	0.23	0.23	0.23	0.23	0.23	0.23
12	0.02	0.04	SRS	1-3	50	0.23	0.21	–	0.23	0.23	0.24	0.23	0.24	0.23
12	0.02	0.04	StRS	1-0	20	0.21	–	–	0.18	0.18	0.18	0.18	0.18	0.18
12	0.02	0.04	StRS	1-0	35	0.22	–	–	0.19	0.19	0.19	0.19	0.19	0.19
12	0.02	0.04	StRS	1-0	50	0.22	–	–	0.19	0.19	0.19	0.19	0.19	0.19
12	0.02	0.04	StRS	1-0	20	0.21	–	–	0.30	0.19	–	0.19	–	0.31
12	0.02	0.04	StRS	1-0	35	0.22	–	–	0.37	0.19	0.39	0.19	0.39	0.37
12	0.02	0.04	StRS	1-0	50	0.26	–	–	–	0.23	–	0.23	–	–
12	0.02	0.04	StRS	1-0,1-3	20	0.23	–	–	0.20	0.20	0.20	0.20	0.20	0.20
12	0.02	0.04	StRS	1-0,1-3	35	0.24	–	–	0.20	0.20	0.20	0.20	0.20	0.20
12	0.02	0.04	StRS	1-0,1-3	50	0.25	–	–	0.23	0.23	0.23	0.23	0.23	0.23
12	0.02	0.04	Unequal	1-0,1-3	20	–	0.30	–	–	–	–	–	–	–
12	0.02	0.04	Unequal	1-0,1-3	35	0.22	0.28	–	–	–	–	–	–	–
12	0.02	0.04	Unequal	1-0,1-3	50	–	0.28	–	–	–	–	–	–	–
12	0.02	0.04	Unequal	1-3	20	–	0.28	–	–	–	–	–	–	–
12	0.02	0.04	Unequal	1-3	35	–	0.24	–	–	–	–	–	–	–
12	0.02	0.04	Unequal	1-3	50	–	0.23	–	–	–	–	–	–	–
12	0.02	0.04	Unequal	1-3	20	–	0.21	–	–	–	–	–	–	–

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	SLRDB	WLRDB	Aonly	A	AI	B	BI	C
12	0.02	0.04	Unequal	1-3	35	–	0.22	–	–	–	–	–	–	–
12	0.02	0.04	Unequal	1-3	50	–	0.23	–	–	–	–	–	–	–
24	0.01	0	SRS	1-0	20	–	0.48	–	0.16	0.16	0.16	0.16	0.16	0.16
24	0.01	0	SRS	1-0	35	–	0.45	–	0.11	0.11	0.11	0.11	0.11	0.11
24	0.01	0	SRS	1-0	50	0.13	0.41	–	0.13	0.13	0.13	0.13	0.13	0.13
24	0.01	0	SRS	1-0	20	–	–	–	–	–	–	–	–	–
24	0.01	0	SRS	1-0	35	–	0.39	–	–	0.15	–	0.15	–	–
24	0.01	0	SRS	1-0	50	–	–	–	–	–	–	–	–	–
24	0.01	0	SRS	1-0,1-3	20	0.16	0.36	–	–	0.16	0.16	0.16	0.16	0.16
24	0.01	0	SRS	1-0,1-3	35	0.15	0.37	–	0.15	0.15	0.15	0.15	0.15	0.15
24	0.01	0	SRS	1-0,1-3	50	0.19	0.38	–	0.19	0.19	0.19	0.19	0.19	0.19
24	0.01	0	StRS	1-0,1-3	20	0.16	–	–	0.12	0.12	0.12	0.12	0.12	0.12
24	0.01	0	StRS	1-0,1-3	35	0.14	–	–	0.11	0.11	0.11	0.11	0.11	0.11
24	0.01	0	StRS	1-0,1-3	50	0.12	–	–	0.09	0.09	0.09	0.09	0.09	0.09
24	0.01	0	StRS	1-3	20	0.15	–	–	0.15	0.11	–	0.11	–	0.15
24	0.01	0	StRS	1-3	35	0.14	–	–	0.15	0.11	0.18	0.11	0.18	0.15
24	0.01	0	StRS	1-3	50	0.16	–	–	–	0.12	–	0.12	–	–
24	0.01	0	StRS	1-3	20	0.14	–	–	0.11	0.11	0.11	0.11	0.11	0.11
24	0.01	0	StRS	1-3	35	0.15	–	–	0.11	0.11	0.11	0.11	0.11	0.11
24	0.01	0	StRS	1-3	50	0.18	–	–	0.16	0.16	0.16	0.16	0.16	0.16
24	0.01	0	Unequal	1-0	20	–	0.50	–	–	–	–	–	–	–
24	0.01	0	Unequal	1-0	35	0.15	0.45	–	–	–	–	–	–	–
24	0.01	0	Unequal	1-0	50	–	0.40	–	–	–	–	–	–	–
24	0.01	0	Unequal	1-0	20	–	0.37	–	–	–	–	–	–	–
24	0.01	0	Unequal	1-0	35	–	0.37	–	–	–	–	–	–	–
24	0.01	0	Unequal	1-0	50	–	0.37	–	–	–	–	–	–	–
24	0.01	0	Unequal	1-0,1-3	20	–	0.33	–	–	–	–	–	–	–

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	SLRDB	WLRDB	Aonly	A	AI	B	BI	C
24	0.01	0	Unequal	1-0,1-3	35	–	0.32	–	–	–	–	–	–	–
24	0.01	0	Unequal	1-0,1-3	50	–	0.36	–	–	–	–	–	–	–
24	0.01	0.04	SRS	1-0,1-3	20	–	0.54	–	0.19	0.19	0.19	0.19	0.19	0.19
24	0.01	0.04	SRS	1-0,1-3	35	–	0.57	–	0.23	0.23	0.23	0.23	0.23	0.23
24	0.01	0.04	SRS	1-0,1-3	50	0.22	0.53	–	0.22	0.22	0.22	0.22	0.22	0.22
24	0.01	0.04	SRS	1-3	20	–	–	–	–	–	–	–	–	–
24	0.01	0.04	SRS	1-3	35	–	0.53	–	–	0.29	–	0.29	–	–
24	0.01	0.04	SRS	1-3	50	–	–	–	–	–	–	–	–	–
24	0.01	0.04	SRS	1-3	20	0.26	0.45	–	–	0.26	0.26	0.26	0.26	0.26
24	0.01	0.04	SRS	1-3	35	0.30	0.48	–	0.30	0.30	0.30	0.30	0.30	0.30
24	0.01	0.04	SRS	1-3	50	0.32	0.47	–	0.32	0.32	0.32	0.32	0.32	0.32
24	0.01	0.04	StRS	1-0	20	0.22	–	–	0.17	0.17	0.17	0.17	0.17	0.17
24	0.01	0.04	StRS	1-0	35	0.18	–	–	0.16	0.16	0.16	0.16	0.16	0.16
24	0.01	0.04	StRS	1-0	50	0.22	–	–	0.18	0.18	0.18	0.18	0.18	0.18
24	0.01	0.04	StRS	1-0	20	0.21	–	–	0.21	0.18	–	0.18	–	0.21
24	0.01	0.04	StRS	1-0	35	0.26	–	–	0.27	0.21	0.30	0.21	0.30	0.27
24	0.01	0.04	StRS	1-0	50	0.30	–	–	–	0.25	–	0.25	–	–
24	0.01	0.04	StRS	1-0,1-3	20	0.25	–	–	0.20	0.20	0.20	0.20	0.20	0.20
24	0.01	0.04	StRS	1-0,1-3	35	0.30	–	–	0.26	0.26	0.26	0.26	0.26	0.26
24	0.01	0.04	StRS	1-0,1-3	50	0.36	–	–	0.32	0.32	0.32	0.32	0.32	0.32
24	0.01	0.04	Unequal	1-0,1-3	20	–	0.59	–	–	–	–	–	–	–
24	0.01	0.04	Unequal	1-0,1-3	35	0.20	0.57	–	–	–	–	–	–	–
24	0.01	0.04	Unequal	1-0,1-3	50	–	0.54	–	–	–	–	–	–	–
24	0.01	0.04	Unequal	1-3	20	–	0.51	–	–	–	–	–	–	–
24	0.01	0.04	Unequal	1-3	35	–	0.49	–	–	–	–	–	–	–
24	0.01	0.04	Unequal	1-3	50	–	0.53	–	–	–	–	–	–	–
24	0.01	0.04	Unequal	1-3	20	–	0.44	–	–	–	–	–	–	–

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	SLRDB	WLRDB	Aonly	A	AI	B	BI	C
24	0.01	0.04	Unequal	1-3	35	–	0.49	–	–	–	–	–	–	–
24	0.01	0.04	Unequal	1-3	50	–	0.52	–	–	–	–	–	–	–

Table B6. Trend Test Power of the χ^2 -test for the Binary Trend Slope Estimate (for trend tests of size 0.13 or less). Note power values < 0.80 (also shaded).

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	SLRDB	WLRDB	Aonly	A	AI	B	BI	C
12	0.02	0	SRS	1-0	20	0.17	–	–	0.16	0.16	0.16	0.16	0.16	0.16
12	0.02	0	SRS	1-0	35	–	–	–	–	–	–	–	–	–
12	0.02	0	SRS	1-0	50	–	–	–	–	–	–	–	–	–
12	0.02	0	SRS	1-0	20	–	–	–	–	–	–	–	–	–
12	0.02	0	SRS	1-0	35	–	–	–	–	–	–	–	–	–
12	0.02	0	SRS	1-0	50	–	–	–	–	–	–	–	–	–
12	0.02	0	SRS	1-0,1-3	20	–	–	–	–	–	–	–	–	–
12	0.02	0	SRS	1-0,1-3	35	–	–	–	–	–	–	–	–	–
12	0.02	0	SRS	1-0,1-3	50	–	–	–	–	–	–	–	–	–
12	0.02	0	StRS	1-0,1-3	20	0.14	–	–	–	–	–	–	–	–
12	0.02	0	StRS	1-0,1-3	35	0.14	–	–	–	–	–	–	–	–
12	0.02	0	StRS	1-0,1-3	50	0.17	–	–	–	–	–	–	–	–
12	0.02	0	StRS	1-3	20	0.19	–	–	–	–	–	–	–	–
12	0.02	0	StRS	1-3	35	0.20	–	–	–	–	–	–	–	–
12	0.02	0	StRS	1-3	50	–	–	–	–	–	–	–	–	–
12	0.02	0	StRS	1-3	20	–	–	–	–	–	–	–	–	–
12	0.02	0	StRS	1-3	35	–	–	–	–	–	–	–	–	–
12	0.02	0	StRS	1-3	50	–	–	–	–	–	–	–	–	–
12	0.02	0	Unequal	1-0	20	–	–	–	–	–	–	–	–	–

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	SLRDB	WLRDB	Aonly	A	AI	B	BI	C
12	0.02	0.04	Unequal	1-0,1-3	35	–	–	–	–	–	–	–	–	–
12	0.02	0.04	Unequal	1-0,1-3	50	–	–	–	–	–	–	–	–	–
12	0.02	0.04	Unequal	1-3	20	–	–	–	–	–	–	–	–	–
12	0.02	0.04	Unequal	1-3	35	–	–	–	–	–	–	–	–	–
12	0.02	0.04	Unequal	1-3	50	–	–	–	–	–	–	–	–	–
12	0.02	0.04	Unequal	1-3	20	–	–	–	–	–	–	–	–	–
12	0.02	0.04	Unequal	1-3	35	–	–	–	–	–	–	–	–	–
12	0.02	0.04	Unequal	1-3	50	–	–	–	–	–	–	–	–	–
24	0.01	0	SRS	1-0	20	0.16	–	–	0.16	0.16	0.16	0.16	0.16	0.16
24	0.01	0	SRS	1-0	35	0.11	–	–	0.11	0.11	0.11	0.11	0.11	0.11
24	0.01	0	SRS	1-0	50	0.13	–	–	0.13	0.13	0.13	0.13	0.13	0.13
24	0.01	0	SRS	1-0	20	0.12	–	–	–	0.12	–	0.12	–	–
24	0.01	0	SRS	1-0	35	0.15	–	–	–	0.15	–	0.15	–	–
24	0.01	0	SRS	1-0	50	0.18	–	–	–	0.18	–	0.18	–	–
24	0.01	0	SRS	1-0,1-3	20	0.16	–	–	0.16	0.16	0.16	0.16	0.16	0.16
24	0.01	0	SRS	1-0,1-3	35	–	–	–	–	–	–	–	–	–
24	0.01	0	SRS	1-0,1-3	50	0.19	–	–	0.19	0.19	0.19	0.19	0.19	0.19
24	0.01	0	StRS	1-0,1-3	20	0.16	–	–	–	–	–	–	–	–
24	0.01	0	StRS	1-0,1-3	35	0.14	–	–	–	–	–	–	–	–
24	0.01	0	StRS	1-0,1-3	50	0.12	–	–	–	–	–	–	–	–
24	0.01	0	StRS	1-3	20	0.15	–	–	–	–	–	–	–	–
24	0.01	0	StRS	1-3	35	0.14	–	–	–	–	–	–	–	–
24	0.01	0	StRS	1-3	50	0.16	–	–	–	–	–	–	–	–
24	0.01	0	StRS	1-3	20	0.14	–	–	–	–	–	–	–	–
24	0.01	0	StRS	1-3	35	0.15	–	–	–	–	–	–	–	–
24	0.01	0	StRS	1-3	50	0.18	–	–	–	–	–	–	–	–
24	0.01	0	Unequal	1-0	20	0.16	–	–	–	–	–	–	–	–

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	SLRDB	WLRDB	Aonly	A	AI	B	BI	C
24	0.01	0	Unequal	1-0	35	0.15	–	–	–	–	–	–	–	–
24	0.01	0	Unequal	1-0	50	0.15	–	–	–	–	–	–	–	–
24	0.01	0	Unequal	1-0	20	0.16	–	–	–	–	–	–	–	–
24	0.01	0	Unequal	1-0	35	0.16	–	–	–	–	–	–	–	–
24	0.01	0	Unequal	1-0	50	–	–	–	–	–	–	–	–	–
24	0.01	0	Unequal	1-0,1-3	20	0.13	–	–	–	–	–	–	–	–
24	0.01	0	Unequal	1-0,1-3	35	0.18	–	–	–	–	–	–	–	–
24	0.01	0	Unequal	1-0,1-3	50	0.19	–	–	–	–	–	–	–	–
24	0.01	0.04	SRS	1-0,1-3	20	0.18	–	–	0.19	0.19	0.19	0.19	0.19	0.19
24	0.01	0.04	SRS	1-0,1-3	35	0.23	–	–	0.23	0.23	0.23	0.23	0.23	0.23
24	0.01	0.04	SRS	1-0,1-3	50	0.22	–	–	0.22	0.22	0.22	0.22	0.22	0.22
24	0.01	0.04	SRS	1-3	20	0.23	–	–	–	0.22	–	0.22	–	–
24	0.01	0.04	SRS	1-3	35	0.29	–	–	–	0.29	–	0.29	–	–
24	0.01	0.04	SRS	1-3	50	0.30	–	–	–	0.30	–	0.30	–	–
24	0.01	0.04	SRS	1-3	20	0.26	–	–	0.26	0.26	0.26	0.26	0.26	0.26
24	0.01	0.04	SRS	1-3	35	–	–	–	–	–	–	–	–	–
24	0.01	0.04	SRS	1-3	50	0.32	–	–	0.32	0.32	0.32	0.32	0.32	0.32
24	0.01	0.04	StRS	1-0	20	0.22	–	–	–	–	–	–	–	–
24	0.01	0.04	StRS	1-0	35	0.18	–	–	–	–	–	–	–	–
24	0.01	0.04	StRS	1-0	50	0.22	–	–	–	–	–	–	–	–
24	0.01	0.04	StRS	1-0	20	0.21	–	–	–	–	–	–	–	–
24	0.01	0.04	StRS	1-0	35	0.26	–	–	–	–	–	–	–	–
24	0.01	0.04	StRS	1-0	50	0.30	–	–	–	–	–	–	–	–
24	0.01	0.04	StRS	1-0,1-3	20	0.25	–	–	–	–	–	–	–	–
24	0.01	0.04	StRS	1-0,1-3	35	0.30	–	–	–	–	–	–	–	–
24	0.01	0.04	StRS	1-0,1-3	50	0.36	–	–	–	–	–	–	–	–
24	0.01	0.04	Unequal	1-0,1-3	20	0.17	–	–	–	–	–	–	–	–

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	SLRDB	WLRDB	Aonly	A	AI	B	BI	C
24	0.01	0.04	Unequal	1-0,1-3	35	0.20	–	–	–	–	–	–	–	–
24	0.01	0.04	Unequal	1-0,1-3	50	0.18	–	–	–	–	–	–	–	–
24	0.01	0.04	Unequal	1-3	20	0.21	–	–	–	–	–	–	–	–
24	0.01	0.04	Unequal	1-3	35	0.20	–	–	–	–	–	–	–	–
24	0.01	0.04	Unequal	1-3	50	–	–	–	–	–	–	–	–	–
24	0.01	0.04	Unequal	1-3	20	0.23	–	–	–	–	–	–	–	–
24	0.01	0.04	Unequal	1-3	35	0.24	–	–	–	–	–	–	–	–
24	0.01	0.04	Unequal	1-3	50	0.27	–	–	–	–	–	–	–	–

Table B7. Percent Relative Bias of the Binary Site-to-Site Variance Estimate. Note the relative bias values > 5% or < -5% (also shaded).

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	Aonly	A	AI	B	BI	C
12	0.02	0	SRS	1-0	20	-8.18	1688039.37	1688039.37	1688039.37	1688039.37	1688039.37	1688039.37
12	0.02	0	SRS	1-0	35	-2.26	963829.64	963829.64	963829.64	963829.64	963829.64	963829.64
12	0.02	0	SRS	1-0	50	1.08	702315.43	702315.43	702315.43	702315.43	702315.43	702315.43
12	0.02	0	SRS	1-0	20	-0.62	645086.60	580571.99	1095784.87	580571.99	1095784.87	558603.99
12	0.02	0	SRS	1-0	35	-1.66	338183.85	244188.04	496047.10	244188.04	496047.10	263276.35
12	0.02	0	SRS	1-0	50	-0.38	204068.10	136743.31	289602.57	136743.31	289602.57	122285.74
12	0.02	0	SRS	1-0,1-3	20	-2.73	429200.38	407240.67	1780927.48	407240.67	1780927.48	407240.67
12	0.02	0	SRS	1-0,1-3	35	-1.91	239502.24	184347.68	824059.75	184347.68	824059.75	184347.68
12	0.02	0	SRS	1-0,1-3	50	-0.92	165437.84	112142.49	393294.32	112142.49	393294.32	112142.49
12	0.02	0	StRS	1-0,1-3	20	-20.30	1497653.66	1497653.66	1497653.66	1497653.66	1497653.66	1497653.66
12	0.02	0	StRS	1-0,1-3	35	-7.23	927273.46	927273.46	927273.46	927273.46	927273.46	927273.46
12	0.02	0	StRS	1-0,1-3	50	-6.79	663355.43	663355.43	663355.43	663355.43	663355.43	663355.43
12	0.02	0	StRS	1-3	20	1.11	681023.87	651051.46	1088276.03	651051.46	1088276.03	672959.63
12	0.02	0	StRS	1-3	35	8.20	448361.91	397936.90	946750.51	397936.90	946750.51	387963.79

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	Aonly	A	AI	B	BI	C
12	0.02	0	StRS	1-3	50	11.06	318547.66	259676.61	715462.41	259676.61	715462.41	247820.88
12	0.02	0	StRS	1-3	20	20.00	508102.48	494031.93	2046798.71	494031.93	2046798.71	494031.93
12	0.02	0	StRS	1-3	35	17.22	280554.10	238640.00	1002593.90	238640.00	1002593.90	238640.00
12	0.02	0	StRS	1-3	50	18.85	203943.66	134583.37	614652.42	134583.37	614652.42	134583.37
12	0.02	0	Unequal	1-0	20	-7.59	1542298.13	1542298.13	1542298.13	1542298.13	1542298.13	1542298.13
12	0.02	0	Unequal	1-0	35	-0.30	903429.85	903429.85	903429.85	903429.85	903429.85	903429.85
12	0.02	0	Unequal	1-0	50	-1.94	627260.24	627260.24	627260.24	627260.24	627260.24	627260.24
12	0.02	0	Unequal	1-0	20	-2.18	603260.10	530941.83	1127093.99	530941.83	1127093.99	515061.88
12	0.02	0	Unequal	1-0	35	-1.17	299680.35	227346.19	447213.44	227346.19	447213.44	257726.29
12	0.02	0	Unequal	1-0	50	-1.10	172551.66	91846.33	221439.47	91846.33	221439.47	127115.62
12	0.02	0	Unequal	1-0,1-3	20	-0.85	375041.03	338844.00	1580713.10	338844.00	1580713.10	338844.00
12	0.02	0	Unequal	1-0,1-3	35	-1.96	219919.83	178683.25	693094.77	178683.25	693094.77	178683.25
12	0.02	0	Unequal	1-0,1-3	50	-0.71	144194.59	72377.75	557438.95	72377.75	557438.95	72377.75
12	0.02	0.04	SRS	1-0,1-3	20	-5.68	1732446.30	1732446.30	1732446.30	1732446.30	1732446.30	1732446.30
12	0.02	0.04	SRS	1-0,1-3	35	-2.05	977583.99	977583.99	977583.99	977583.99	977583.99	977583.99
12	0.02	0.04	SRS	1-0,1-3	50	-1.93	673271.91	673271.91	673271.91	673271.91	673271.91	673271.91
12	0.02	0.04	SRS	1-3	20	-4.39	598943.53	543359.05	982345.20	543359.05	982345.20	532608.51
12	0.02	0.04	SRS	1-3	35	-2.14	336282.79	242102.49	450885.16	242102.49	450885.16	271686.85
12	0.02	0.04	SRS	1-3	50	-1.83	198671.29	146855.27	260363.66	146855.27	260363.66	124430.53
12	0.02	0.04	SRS	1-3	20	-0.95	448978.21	416097.82	1829548.78	416097.82	1829548.78	416097.82
12	0.02	0.04	SRS	1-3	35	-2.60	248523.62	192617.42	827458.14	192617.42	827458.14	192617.42
12	0.02	0.04	SRS	1-3	50	-2.57	160531.27	122150.27	400045.82	122150.27	400045.82	122150.27
12	0.02	0.04	StRS	1-0	20	-17.01	1520847.23	1520847.23	1520847.23	1520847.23	1520847.23	1520847.23
12	0.02	0.04	StRS	1-0	35	-5.92	948189.93	948189.93	948189.93	948189.93	948189.93	948189.93
12	0.02	0.04	StRS	1-0	50	-4.16	684747.42	684747.42	684747.42	684747.42	684747.42	684747.42
12	0.02	0.04	StRS	1-0	20	1.65	726037.11	680225.35	1061757.09	680225.35	1061757.09	721866.19
12	0.02	0.04	StRS	1-0	35	7.16	448880.19	392766.13	957932.59	392766.13	957932.59	394799.03

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	Aonly	A	AI	B	BI	C
12	0.02	0.04	StRS	1-0	50	10.07	318917.17	274742.89	725362.54	274742.89	725362.54	238060.20
12	0.02	0.04	StRS	1-0,1-3	20	17.69	511076.86	485329.24	2017890.27	485329.24	2017890.27	485329.24
12	0.02	0.04	StRS	1-0,1-3	35	14.58	275806.56	229587.36	1014074.72	229587.36	1014074.72	229587.36
12	0.02	0.04	StRS	1-0,1-3	50	17.95	204054.02	140952.02	626398.46	140952.02	626398.46	140952.02
12	0.02	0.04	Unequal	1-0,1-3	20	-7.28	1515184.12	1515184.12	1515184.12	1515184.12	1515184.12	1515184.12
12	0.02	0.04	Unequal	1-0,1-3	35	-0.79	921656.02	921656.02	921656.02	921656.02	921656.02	921656.02
12	0.02	0.04	Unequal	1-0,1-3	50	0.18	651127.11	651127.11	651127.11	651127.11	651127.11	651127.11
12	0.02	0.04	Unequal	1-3	20	-0.63	597886.27	527891.12	1130993.38	527891.12	1130993.38	523280.16
12	0.02	0.04	Unequal	1-3	35	-1.59	304184.99	237459.58	452927.47	237459.58	452927.47	262676.36
12	0.02	0.04	Unequal	1-3	50	-2.01	173267.68	96655.54	242144.11	96655.54	242144.11	119632.38
12	0.02	0.04	Unequal	1-3	20	-1.98	370229.02	341179.10	1562461.19	341179.10	1562461.19	341179.10
12	0.02	0.04	Unequal	1-3	35	-1.50	222113.16	178940.53	697106.51	178940.53	697106.51	178940.53
12	0.02	0.04	Unequal	1-3	50	-0.81	146057.46	72050.58	532046.88	72050.58	532046.88	72050.58
24	0.01	0	SRS	1-0	20	-5.66	1737109.89	1737109.89	1737109.89	1737109.89	1737109.89	1737109.89
24	0.01	0	SRS	1-0	35	-0.28	1055918.43	1055918.43	1055918.43	1055918.43	1055918.43	1055918.43
24	0.01	0	SRS	1-0	50	-2.13	723885.25	723885.25	723885.25	723885.25	723885.25	723885.25
24	0.01	0	SRS	1-0	20	-0.86	753546.79	735960.64	2171374.14	735960.64	2171374.14	754862.27
24	0.01	0	SRS	1-0	35	-1.06	341730.15	334429.31	1185638.12	334429.31	1185638.12	343363.86
24	0.01	0	SRS	1-0	50	-0.06	221690.81	217003.49	808938.54	217003.49	808938.54	221633.48
24	0.01	0	SRS	1-0,1-3	20	-5.46	455597.68	456372.16	1811499.79	456372.16	1811499.79	456372.16
24	0.01	0	SRS	1-0,1-3	35	-0.61	263445.52	263949.38	1053067.97	263949.38	1053067.97	263949.38
24	0.01	0	SRS	1-0,1-3	50	0.49	185780.31	185520.51	744815.36	185520.51	744815.36	185520.51
24	0.01	0	StRS	1-0,1-3	20	-10.13	1628691.52	1628691.52	1628691.52	1628691.52	1628691.52	1628691.52
24	0.01	0	StRS	1-0,1-3	35	-4.85	991968.93	991968.93	991968.93	991968.93	991968.93	991968.93
24	0.01	0	StRS	1-0,1-3	50	-7.81	683653.84	683653.84	683653.84	683653.84	683653.84	683653.84
24	0.01	0	StRS	1-3	20	-0.24	779163.16	759795.84	2101980.68	759795.84	2101980.68	778229.36
24	0.01	0	StRS	1-3	35	0.88	435744.85	426801.27	1222117.40	426801.27	1222117.40	436250.61

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	Aonly	A	AI	B	BI	C
24	0.01	0	StRS	1-3	50	4.28	311108.97	305643.75	890394.04	305643.75	890394.04	310594.00
24	0.01	0	StRS	1-3	20	3.69	481246.22	487192.03	1932969.01	487192.03	1932969.01	487192.03
24	0.01	0	StRS	1-3	35	6.53	274196.33	276041.24	1097421.57	276041.24	1097421.57	276041.24
24	0.01	0	StRS	1-3	50	9.76	200116.26	199760.22	800762.74	199760.22	800762.74	199760.22
24	0.01	0	Unequal	1-0	20	-1.89	1713332.81	1713332.81	1713332.81	1713332.81	1713332.81	1713332.81
24	0.01	0	Unequal	1-0	35	0.34	1000052.82	1000052.82	1000052.82	1000052.82	1000052.82	1000052.82
24	0.01	0	Unequal	1-0	50	-2.33	681461.93	681461.93	681461.93	681461.93	681461.93	681461.93
24	0.01	0	Unequal	1-0	20	0.31	707147.78	686047.56	2052077.65	686047.56	2052077.65	706509.30
24	0.01	0	Unequal	1-0	35	-0.03	316506.36	308408.80	1086704.06	308408.80	1086704.06	316625.61
24	0.01	0	Unequal	1-0	50	-0.26	203423.29	199057.10	737038.37	199057.10	737038.37	201966.87
24	0.01	0	Unequal	1-0,1-3	20	-2.89	419504.61	422202.00	1674494.29	422202.00	1674494.29	422202.00
24	0.01	0	Unequal	1-0,1-3	35	-0.47	238756.80	240563.46	957529.43	240563.46	957529.43	240563.46
24	0.01	0	Unequal	1-0,1-3	50	-1.77	165962.08	165644.87	664149.06	165644.87	664149.06	165644.87
24	0.01	0.04	SRS	1-0,1-3	20	-2.81	1796650.94	1796650.94	1796650.94	1796650.94	1796650.94	1796650.94
24	0.01	0.04	SRS	1-0,1-3	35	0.99	1069365.34	1069365.34	1069365.34	1069365.34	1069365.34	1069365.34
24	0.01	0.04	SRS	1-0,1-3	50	-2.02	727627.71	727627.71	727627.71	727627.71	727627.71	727627.71
24	0.01	0.04	SRS	1-3	20	-3.39	740503.65	719695.28	2129660.29	719695.28	2129660.29	741566.20
24	0.01	0.04	SRS	1-3	35	-0.78	341995.68	335202.95	1185450.82	335202.95	1185450.82	344075.38
24	0.01	0.04	SRS	1-3	50	-0.68	221208.25	215924.36	803630.17	215924.36	803630.17	218723.49
24	0.01	0.04	SRS	1-3	20	-3.42	455089.94	459622.06	1823365.84	459622.06	1823365.84	459622.06
24	0.01	0.04	SRS	1-3	35	-1.45	261220.44	262729.26	1047694.53	262729.26	1047694.53	262729.26
24	0.01	0.04	SRS	1-3	50	0.11	185422.82	182866.74	741993.86	182866.74	741993.86	182866.74
24	0.01	0.04	StRS	1-0	20	-10.18	1620496.12	1620496.12	1620496.12	1620496.12	1620496.12	1620496.12
24	0.01	0.04	StRS	1-0	35	-6.59	971662.91	971662.91	971662.91	971662.91	971662.91	971662.91
24	0.01	0.04	StRS	1-0	50	-4.60	702295.85	702295.85	702295.85	702295.85	702295.85	702295.85
24	0.01	0.04	StRS	1-0	20	-0.33	782682.05	761582.54	2117674.72	761582.54	2117674.72	782682.26
24	0.01	0.04	StRS	1-0	35	1.42	433330.53	425472.69	1211768.54	425472.69	1211768.54	433328.21

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	Aonly	A	AI	B	BI	C
24	0.01	0.04	StRS	1-0	50	3.12	306300.62	301673.63	883385.69	301673.63	883385.69	306301.28
24	0.01	0.04	StRS	1-0,1-3	20	1.24	484447.80	487483.92	1923422.73	487483.92	1923422.73	487483.92
24	0.01	0.04	StRS	1-0,1-3	35	5.80	273847.17	274723.23	1099181.88	274723.23	1099181.88	274723.23
24	0.01	0.04	StRS	1-0,1-3	50	8.86	198654.48	197737.24	794913.87	197737.24	794913.87	197737.24
24	0.01	0.04	Unequal	1-0,1-3	20	-3.23	1690147.43	1690147.43	1690147.43	1690147.43	1690147.43	1690147.43
24	0.01	0.04	Unequal	1-0,1-3	35	0.02	990789.77	990789.77	990789.77	990789.77	990789.77	990789.77
24	0.01	0.04	Unequal	1-0,1-3	50	-1.23	693107.54	693107.54	693107.54	693107.54	693107.54	693107.54
24	0.01	0.04	Unequal	1-3	20	-0.36	710118.41	686044.44	2029967.24	686044.44	2029967.24	711487.93
24	0.01	0.04	Unequal	1-3	35	-1.00	313006.68	305190.91	1075398.25	305190.91	1075398.25	313776.48
24	0.01	0.04	Unequal	1-3	50	-0.34	203402.08	198638.61	739446.33	198638.61	739446.33	201505.02
24	0.01	0.04	Unequal	1-3	20	-4.74	411762.86	415979.59	1664004.36	415979.59	1664004.36	415979.59
24	0.01	0.04	Unequal	1-3	35	-0.57	237309.92	239587.72	952841.76	239587.72	952841.76	239587.72
24	0.01	0.04	Unequal	1-3	50	-0.07	168035.20	167340.04	673627.89	167340.04	673627.89	167340.04

Table B8. Percent Relative Bias of the Binary Site-Level Slope Variance Estimate. Note the relative bias values > 5% or < -5% (also shaded).

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	Aonly	A	AI	B	BI	C
12	0.02	0	SRS	1-0	20	-3.68	1786492.79	1786492.79	1786492.79	1786492.79	1786492.79	1786492.79
12	0.02	0	SRS	1-0	35	-1.54	1014426.16	1014426.16	1014426.16	1014426.16	1014426.16	1014426.16
12	0.02	0	SRS	1-0	50	1.56	730676.22	730676.22	730676.22	730676.22	730676.22	730676.22
12	0.02	0	SRS	1-0	20	-0.45	686340.47	653117.27	1639641.99	653117.27	1639641.99	639007.95
12	0.02	0	SRS	1-0	35	-1.01	338293.55	285998.01	807058.93	285998.01	807058.93	295493.12
12	0.02	0	SRS	1-0	50	-0.16	211279.44	171666.78	520533.22	171666.78	520533.22	164279.78
12	0.02	0	SRS	1-0,1-3	20	-1.55	446208.47	436558.53	1812275.03	436558.53	1812275.03	436558.53
12	0.02	0	SRS	1-0,1-3	35	-1.53	251027.46	219613.52	918960.70	219613.52	918960.70	219613.52
12	0.02	0	SRS	1-0,1-3	50	-0.76	173956.32	143658.30	539954.36	143658.30	539954.36	143658.30

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	Aonly	A	AI	B	BI	C
12	0.02	0	StRS	1-0,1-3	20	-13.41	1580809.82	1580809.82	1580809.82	1580809.82	1580809.82	1580809.82
12	0.02	0	StRS	1-0,1-3	35	-4.83	981175.52	981175.52	981175.52	981175.52	981175.52	981175.52
12	0.02	0	StRS	1-0,1-3	50	-5.40	686746.99	686746.99	686746.99	686746.99	686746.99	686746.99
12	0.02	0	StRS	1-3	20	-1.61	711302.89	700019.79	1580428.77	700019.79	1580428.77	705311.81
12	0.02	0	StRS	1-3	35	3.20	434755.09	409374.50	1139504.55	409374.50	1139504.55	401319.26
12	0.02	0	StRS	1-3	50	5.30	306386.22	274823.09	840325.43	274823.09	840325.43	266243.77
12	0.02	0	StRS	1-3	20	6.58	475333.54	470059.26	1891137.46	470059.26	1891137.46	470059.26
12	0.02	0	StRS	1-3	35	6.45	268298.23	245553.06	1004333.12	245553.06	1004333.12	245553.06
12	0.02	0	StRS	1-3	50	6.61	189955.33	153309.72	650184.97	153309.72	650184.97	153309.72
12	0.02	0	Unequal	1-0	20	-5.52	1642709.99	1642709.99	1642709.99	1642709.99	1642709.99	1642709.99
12	0.02	0	Unequal	1-0	35	-2.24	953117.42	953117.42	953117.42	953117.42	953117.42	953117.42
12	0.02	0	Unequal	1-0	50	-0.88	677216.90	677216.90	677216.90	677216.90	677216.90	677216.90
12	0.02	0	Unequal	1-0	20	-1.32	647298.99	610305.77	1597697.54	610305.77	1597697.54	597200.88
12	0.02	0	Unequal	1-0	35	-0.46	311540.51	271340.69	750126.58	271340.69	750126.58	286659.15
12	0.02	0	Unequal	1-0	50	-0.33	189171.63	141424.67	458822.28	141424.67	458822.28	162376.00
12	0.02	0	Unequal	1-0,1-3	20	-0.23	407455.00	386018.01	1665104.40	386018.01	1665104.40	386018.01
12	0.02	0	Unequal	1-0,1-3	35	-0.79	235273.79	211919.40	830613.47	211919.40	830613.47	211919.40
12	0.02	0	Unequal	1-0,1-3	50	0.52	159730.92	117338.16	626936.02	117338.16	626936.02	117338.16
12	0.02	0.04	SRS	1-0,1-3	20	-1.78	1830734.25	1830734.25	1830734.25	1830734.25	1830734.25	1830734.25
12	0.02	0.04	SRS	1-0,1-3	35	-0.06	1036875.41	1036875.41	1036875.41	1036875.41	1036875.41	1036875.41
12	0.02	0.04	SRS	1-0,1-3	50	1.66	728305.73	728305.73	728305.73	728305.73	728305.73	728305.73
12	0.02	0.04	SRS	1-3	20	-0.94	674273.67	643945.68	1582932.24	643945.68	1582932.24	637439.23
12	0.02	0.04	SRS	1-3	35	1.54	345971.02	294767.26	804684.87	294767.26	804684.87	308795.85
12	0.02	0.04	SRS	1-3	50	0.10	210731.48	180070.95	513139.91	180070.95	513139.91	167833.72
12	0.02	0.04	SRS	1-3	20	0.51	462316.79	447306.80	1863214.15	447306.80	1863214.15	447306.80
12	0.02	0.04	SRS	1-3	35	-0.52	258862.43	227546.93	938728.40	227546.93	938728.40	227546.93
12	0.02	0.04	SRS	1-3	50	-0.11	174456.55	151748.17	559532.14	151748.17	559532.14	151748.17

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	Aonly	A	AI	B	BI	C
12	0.02	0.04	StRS	1-0	20	-13.58	1579770.90	1579770.90	1579770.90	1579770.90	1579770.90	1579770.90
12	0.02	0.04	StRS	1-0	35	-5.28	979366.44	979366.44	979366.44	979366.44	979366.44	979366.44
12	0.02	0.04	StRS	1-0	50	-3.59	701725.62	701725.62	701725.62	701725.62	701725.62	701725.62
12	0.02	0.04	StRS	1-0	20	-0.97	734769.31	718467.38	1571468.80	718467.38	1571468.80	735775.37
12	0.02	0.04	StRS	1-0	35	1.69	431615.86	404832.59	1139007.23	404832.59	1139007.23	401707.89
12	0.02	0.04	StRS	1-0	50	2.92	301434.25	278644.98	831581.37	278644.98	831581.37	256719.05
12	0.02	0.04	StRS	1-0,1-3	20	7.84	485624.18	475234.75	1915209.89	475234.75	1915209.89	475234.75
12	0.02	0.04	StRS	1-0,1-3	35	5.50	266860.52	242366.17	1014852.46	242366.17	1014852.46	242366.17
12	0.02	0.04	StRS	1-0,1-3	50	8.27	194622.23	159978.65	669767.45	159978.65	669767.45	159978.65
12	0.02	0.04	Unequal	1-0,1-3	20	-3.14	1701709.24	1701709.24	1701709.24	1701709.24	1701709.24	1701709.24
12	0.02	0.04	Unequal	1-0,1-3	35	1.23	996997.73	996997.73	996997.73	996997.73	996997.73	996997.73
12	0.02	0.04	Unequal	1-0,1-3	50	0.94	693773.47	693773.47	693773.47	693773.47	693773.47	693773.47
12	0.02	0.04	Unequal	1-3	20	0.20	650745.96	612196.95	1615109.15	612196.95	1615109.15	606133.51
12	0.02	0.04	Unequal	1-3	35	1.20	321652.29	282511.45	774335.63	282511.45	774335.63	296587.09
12	0.02	0.04	Unequal	1-3	50	0.08	193134.24	146530.22	481459.89	146530.22	481459.89	162334.67
12	0.02	0.04	Unequal	1-3	20	-1.20	406948.37	391149.48	1657068.82	391149.48	1657068.82	391149.48
12	0.02	0.04	Unequal	1-3	35	-0.34	238531.35	213154.39	841851.83	213154.39	841851.83	213154.39
12	0.02	0.04	Unequal	1-3	50	1.00	162758.25	118804.58	619201.49	118804.58	619201.49	118804.58
24	0.01	0	SRS	1-0	20	-6.27	1733166.34	1733166.34	1733166.34	1733166.34	1733166.34	1733166.34
24	0.01	0	SRS	1-0	35	-1.34	1044727.97	1044727.97	1044727.97	1044727.97	1044727.97	1044727.97
24	0.01	0	SRS	1-0	50	-1.51	729342.61	729342.61	729342.61	729342.61	729342.61	729342.61
24	0.01	0	SRS	1-0	20	-1.29	719866.24	732167.76	2315336.33	732167.76	2315336.33	720341.17
24	0.01	0	SRS	1-0	35	-0.57	329950.32	335669.12	1202782.35	335669.12	1202782.35	330598.47
24	0.01	0	SRS	1-0	50	0.18	215631.44	218002.53	814556.33	218002.53	814556.33	215650.48
24	0.01	0	SRS	1-0,1-3	20	-3.14	457448.25	457568.26	1824674.73	457568.26	1824674.73	457568.26
24	0.01	0	SRS	1-0,1-3	35	-0.40	263839.72	264147.20	1055706.66	264147.20	1055706.66	264147.20
24	0.01	0	SRS	1-0,1-3	50	0.00	185088.25	184939.48	741163.55	184939.48	741163.55	184939.48

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	Aonly	A	AI	B	BI	C
24	0.01	0	StRS	1-0,1-3	20	-12.26	1591920.30	1591920.30	1591920.30	1591920.30	1591920.30	1591920.30
24	0.01	0	StRS	1-0,1-3	35	-5.58	988474.52	988474.52	988474.52	988474.52	988474.52	988474.52
24	0.01	0	StRS	1-0,1-3	50	-6.28	692489.22	692489.22	692489.22	692489.22	692489.22	692489.22
24	0.01	0	StRS	1-3	20	-3.67	737663.26	745825.59	2269061.57	745825.59	2269061.57	736844.19
24	0.01	0	StRS	1-3	35	-3.23	409722.58	414861.52	1308093.24	414861.52	1308093.24	409950.16
24	0.01	0	StRS	1-3	50	-1.03	288676.53	292258.03	935111.35	292258.03	935111.35	288399.74
24	0.01	0	StRS	1-3	20	-3.40	448248.74	450350.64	1796027.86	450350.64	1796027.86	450350.64
24	0.01	0	StRS	1-3	35	-1.39	258708.52	259556.07	1035792.19	259556.07	1035792.19	259556.07
24	0.01	0	StRS	1-3	50	-0.31	183843.69	183718.49	735674.55	183718.49	735674.55	183718.49
24	0.01	0	Unequal	1-0	20	-2.99	1746305.37	1746305.37	1746305.37	1746305.37	1746305.37	1746305.37
24	0.01	0	Unequal	1-0	35	-1.52	1013590.65	1013590.65	1013590.65	1013590.65	1013590.65	1013590.65
24	0.01	0	Unequal	1-0	50	-3.03	702669.59	702669.59	702669.59	702669.59	702669.59	702669.59
24	0.01	0	Unequal	1-0	20	0.70	707036.07	716282.77	2310875.10	716282.77	2310875.10	706855.56
24	0.01	0	Unequal	1-0	35	-0.96	316407.36	320565.23	1152263.43	320565.23	1152263.43	316419.56
24	0.01	0	Unequal	1-0	50	-0.62	207145.98	209040.52	779897.47	209040.52	779897.47	206454.25
24	0.01	0	Unequal	1-0,1-3	20	-1.50	444506.00	445608.56	1776512.94	445608.56	1776512.94	445608.56
24	0.01	0	Unequal	1-0,1-3	35	-0.67	252431.11	253302.40	1011530.07	253302.40	1011530.07	253302.40
24	0.01	0	Unequal	1-0,1-3	50	-0.55	177508.32	177355.05	710333.50	177355.05	710333.50	177355.05
24	0.01	0.04	SRS	1-0,1-3	20	-2.19	1810480.09	1810480.09	1810480.09	1810480.09	1810480.09	1810480.09
24	0.01	0.04	SRS	1-0,1-3	35	2.04	1080506.67	1080506.67	1080506.67	1080506.67	1080506.67	1080506.67
24	0.01	0.04	SRS	1-0,1-3	50	-0.07	741197.70	741197.70	741197.70	741197.70	741197.70	741197.70
24	0.01	0.04	SRS	1-3	20	-0.65	725082.78	737586.76	2359306.85	737586.76	2359306.85	725600.30
24	0.01	0.04	SRS	1-3	35	-0.50	329549.36	335593.07	1202483.36	335593.07	1202483.36	330414.32
24	0.01	0.04	SRS	1-3	50	0.62	216848.87	219189.64	816692.08	219189.64	816692.08	215908.40
24	0.01	0.04	SRS	1-3	20	-0.15	466414.00	468314.96	1866945.64	468314.96	1866945.64	468314.96
24	0.01	0.04	SRS	1-3	35	0.75	266726.45	267486.83	1068638.66	267486.83	1068638.66	267486.83
24	0.01	0.04	SRS	1-3	50	1.33	187698.48	186626.21	751095.41	186626.21	751095.41	186626.21

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	Aonly	A	AI	B	BI	C
24	0.01	0.04	StRS	1-0	20	-12.18	1585580.03	1585580.03	1585580.03	1585580.03	1585580.03	1585580.03
24	0.01	0.04	StRS	1-0	35	-7.92	961720.64	961720.64	961720.64	961720.64	961720.64	961720.64
24	0.01	0.04	StRS	1-0	50	-5.16	698380.13	698380.13	698380.13	698380.13	698380.13	698380.13
24	0.01	0.04	StRS	1-0	20	-4.61	732820.04	740861.18	2264813.31	740861.18	2264813.31	732819.74
24	0.01	0.04	StRS	1-0	35	-1.54	414495.99	419476.03	1323879.07	419476.03	1323879.07	414494.88
24	0.01	0.04	StRS	1-0	50	-2.66	283662.84	287232.82	922398.77	287232.82	922398.77	283663.05
24	0.01	0.04	StRS	1-0,1-3	20	-4.73	448923.91	450020.52	1788658.80	450020.52	1788658.80	450020.52
24	0.01	0.04	StRS	1-0,1-3	35	-1.25	259819.63	260165.40	1040958.10	260165.40	1040958.10	260165.40
24	0.01	0.04	StRS	1-0,1-3	50	-0.18	184268.56	183993.25	737373.03	183993.25	737373.03	183993.25
24	0.01	0.04	Unequal	1-0,1-3	20	-3.23	1734664.19	1734664.19	1734664.19	1734664.19	1734664.19	1734664.19
24	0.01	0.04	Unequal	1-0,1-3	35	0.66	1033978.66	1033978.66	1033978.66	1033978.66	1033978.66	1033978.66
24	0.01	0.04	Unequal	1-0,1-3	50	0.58	730440.02	730440.02	730440.02	730440.02	730440.02	730440.02
24	0.01	0.04	Unequal	1-3	20	-0.39	708789.97	717303.75	2294102.41	717303.75	2294102.41	709016.66
24	0.01	0.04	Unequal	1-3	35	1.17	326585.79	330444.27	1190527.00	330444.27	1190527.00	326811.46
24	0.01	0.04	Unequal	1-3	50	1.05	210666.03	212814.69	795843.04	212814.69	795843.04	209964.90
24	0.01	0.04	Unequal	1-3	20	-1.40	448469.07	450099.06	1800641.27	450099.06	1800641.27	450099.06
24	0.01	0.04	Unequal	1-3	35	0.68	256423.24	257519.95	1028013.60	257519.95	1028013.60	257519.95
24	0.01	0.04	Unequal	1-3	50	1.43	181233.29	180894.47	725769.67	180894.47	725769.67	180894.47

Table B9. Percent Relative Bias of the Binary Year-to-Year Variance Estimate. Note the relative bias values > 5% or < -5% (also shaded).

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	Aonly	A	AI	B	BI	C
12	0.02	0	SRS	1-0	20	-8.25	1699389.75	1699389.75	1699389.75	1699389.75	1699389.75	1699389.75
12	0.02	0	SRS	1-0	35	-9.21	958430.54	958430.54	958430.54	958430.54	958430.54	958430.54
12	0.02	0	SRS	1-0	50	-9.60	667671.33	667671.33	667671.33	667671.33	667671.33	667671.33
12	0.02	0	SRS	1-0	20	-12.76	895981.22	642562.09	927025.36	642562.09	927025.36	362117.49

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	Aonly	A	AI	B	BI	C
12	0.02	0	SRS	1-0	35	-12.31	509351.03	292063.06	534953.88	292063.06	534953.88	166318.25
12	0.02	0	SRS	1-0	50	-13.47	383267.98	187015.80	401395.34	187015.80	401395.34	117904.81
12	0.02	0	SRS	1-0,1-3	20	-15.47	1565673.71	390908.64	1566592.93	390908.64	1566592.93	390908.64
12	0.02	0	SRS	1-0,1-3	35	-15.45	893518.90	221775.77	890666.74	221775.77	890666.74	221775.77
12	0.02	0	SRS	1-0,1-3	50	-15.83	621398.60	154527.66	614848.24	154527.66	614848.24	154527.66
12	0.02	0	StRS	1-0,1-3	20	-38.96	1169507.13	1169507.13	1169507.13	1169507.13	1169507.13	1169507.13
12	0.02	0	StRS	1-0,1-3	35	-38.81	667389.82	667389.82	667389.82	667389.82	667389.82	667389.82
12	0.02	0	StRS	1-0,1-3	50	-41.48	448558.01	448558.01	448558.01	448558.01	448558.01	448558.01
12	0.02	0	StRS	1-3	20	-38.23	672953.13	507120.71	700854.57	507120.71	700854.57	287293.78
12	0.02	0	StRS	1-3	35	-38.21	368622.56	274446.93	378129.64	274446.93	378129.64	151283.31
12	0.02	0	StRS	1-3	50	-40.20	247178.74	180723.26	252346.84	180723.26	252346.84	100198.54
12	0.02	0	StRS	1-3	20	-41.49	1083662.80	271257.66	1083745.72	271257.66	1083745.72	271257.66
12	0.02	0	StRS	1-3	35	-40.11	627890.30	156506.40	627049.08	156506.40	627049.08	156506.40
12	0.02	0	StRS	1-3	50	-42.10	427613.56	106686.34	426574.19	106686.34	426574.19	106686.34
12	0.02	0	Unequal	1-0	20	-13.97	1369536.30	1369536.30	1369536.30	1369536.30	1369536.30	1369536.30
12	0.02	0	Unequal	1-0	35	-14.99	793874.49	793874.49	793874.49	793874.49	793874.49	793874.49
12	0.02	0	Unequal	1-0	50	-15.24	553585.33	553585.33	553585.33	553585.33	553585.33	553585.33
12	0.02	0	Unequal	1-0	20	-14.22	744700.85	565808.13	766948.53	565808.13	766948.53	301378.75
12	0.02	0	Unequal	1-0	35	-15.35	410428.59	253062.67	433356.98	253062.67	433356.98	132445.46
12	0.02	0	Unequal	1-0	50	-15.58	318030.77	165630.49	332421.45	165630.49	332421.45	94820.13
12	0.02	0	Unequal	1-0,1-3	20	-15.29	1422065.32	354874.42	1421294.83	354874.42	1421294.83	354874.42
12	0.02	0	Unequal	1-0,1-3	35	-14.77	821623.05	204841.17	818065.66	204841.17	818065.66	204841.17
12	0.02	0	Unequal	1-0,1-3	50	-15.14	571551.49	141032.77	572281.77	141032.77	572281.77	141032.77
12	0.02	0.04	SRS	1-0,1-3	20	-12.89	1613362.47	1613362.47	1613362.47	1613362.47	1613362.47	1613362.47
12	0.02	0.04	SRS	1-0,1-3	35	-13.03	918255.17	918255.17	918255.17	918255.17	918255.17	918255.17
12	0.02	0.04	SRS	1-0,1-3	50	-13.70	636848.46	636848.46	636848.46	636848.46	636848.46	636848.46
12	0.02	0.04	SRS	1-3	20	-13.93	889265.37	631700.10	922840.57	631700.10	922840.57	358513.19

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	Aonly	A	AI	B	BI	C
12	0.02	0.04	SRS	1-3	35	-15.90	490369.54	280320.13	520014.89	280320.13	520014.89	159828.60
12	0.02	0.04	SRS	1-3	50	-15.98	375757.82	181702.37	391151.20	181702.37	391151.20	113718.12
12	0.02	0.04	SRS	1-3	20	-15.90	1557757.75	388797.82	1558559.25	388797.82	1558559.25	388797.82
12	0.02	0.04	SRS	1-3	35	-15.53	893535.14	221724.90	889989.20	221724.90	889989.20	221724.90
12	0.02	0.04	SRS	1-3	50	-14.90	627551.84	156394.07	621585.89	156394.07	621585.89	156394.07
12	0.02	0.04	StRS	1-0	20	-37.50	1194279.58	1194279.58	1194279.58	1194279.58	1194279.58	1194279.58
12	0.02	0.04	StRS	1-0	35	-37.26	682375.80	682375.80	682375.80	682375.80	682375.80	682375.80
12	0.02	0.04	StRS	1-0	50	-40.33	456714.09	456714.09	456714.09	456714.09	456714.09	456714.09
12	0.02	0.04	StRS	1-0	20	-42.96	617692.48	467240.23	650127.72	467240.23	650127.72	264193.34
12	0.02	0.04	StRS	1-0	35	-41.58	351578.39	259273.65	358339.06	259273.65	358339.06	144258.85
12	0.02	0.04	StRS	1-0	50	-42.75	235936.53	173226.39	239522.44	173226.39	239522.44	96732.96
12	0.02	0.04	StRS	1-0,1-3	20	-40.79	1096432.08	273934.39	1096983.50	273934.39	1096983.50	273934.39
12	0.02	0.04	StRS	1-0,1-3	35	-40.85	622459.39	154898.32	622061.87	154898.32	622061.87	154898.32
12	0.02	0.04	StRS	1-0,1-3	50	-41.53	432637.13	107880.49	430223.80	107880.49	430223.80	107880.49
12	0.02	0.04	Unequal	1-0,1-3	20	-11.73	1435819.79	1435819.79	1435819.79	1435819.79	1435819.79	1435819.79
12	0.02	0.04	Unequal	1-0,1-3	35	-12.89	803822.59	803822.59	803822.59	803822.59	803822.59	803822.59
12	0.02	0.04	Unequal	1-0,1-3	50	-14.33	559866.05	559866.05	559866.05	559866.05	559866.05	559866.05
12	0.02	0.04	Unequal	1-3	20	-13.30	745910.81	575177.24	770196.96	575177.24	770196.96	301668.07
12	0.02	0.04	Unequal	1-3	35	-15.11	411889.40	256460.58	436475.90	256460.58	436475.90	133171.13
12	0.02	0.04	Unequal	1-3	50	-14.68	317723.67	172520.99	334677.22	172520.99	334677.22	96259.70
12	0.02	0.04	Unequal	1-3	20	-15.93	1419138.52	354437.05	1421082.19	354437.05	1421082.19	354437.05
12	0.02	0.04	Unequal	1-3	35	-15.39	835321.19	208214.09	830182.41	208214.09	830182.41	208214.09
12	0.02	0.04	Unequal	1-3	50	-14.99	593827.36	146486.00	593859.36	146486.00	593859.36	146486.00
24	0.01	0	SRS	1-0	20	-5.13	1757639.58	1757639.58	1757639.58	1757639.58	1757639.58	1757639.58
24	0.01	0	SRS	1-0	35	-5.07	1005209.07	1005209.07	1005209.07	1005209.07	1005209.07	1005209.07
24	0.01	0	SRS	1-0	50	-6.15	695580.34	695580.34	695580.34	695580.34	695580.34	695580.34
24	0.01	0	SRS	1-0	20	-2.91	1009998.36	719613.39	1016370.35	719613.39	1016370.35	403866.33

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	Aonly	A	AI	B	BI	C
24	0.01	0	SRS	1-0	35	-4.24	587737.18	322514.93	588005.34	322514.93	588005.34	186959.12
24	0.01	0	SRS	1-0	50	-3.56	446699.98	210127.81	444973.93	210127.81	444973.93	131295.41
24	0.01	0	SRS	1-0,1-3	20	-8.75	1691600.27	422817.47	1691311.64	422817.47	1691311.64	422817.47
24	0.01	0	SRS	1-0,1-3	35	-8.78	966263.03	241452.49	966182.62	241452.49	966182.62	241452.49
24	0.01	0	SRS	1-0,1-3	50	-9.29	672325.09	168004.24	672396.75	168004.24	672396.75	168004.24
24	0.01	0	StRS	1-0,1-3	20	-31.73	1300581.74	1300581.74	1300581.74	1300581.74	1300581.74	1300581.74
24	0.01	0	StRS	1-0,1-3	35	-31.33	746575.49	746575.49	746575.49	746575.49	746575.49	746575.49
24	0.01	0	StRS	1-0,1-3	50	-33.90	505674.55	505674.55	505674.55	505674.55	505674.55	505674.55
24	0.01	0	StRS	1-3	20	-32.66	731066.31	550731.67	737572.35	550731.67	737572.35	310993.03
24	0.01	0	StRS	1-3	35	-32.43	411245.84	300451.30	413882.75	300451.30	413882.75	167293.68
24	0.01	0	StRS	1-3	50	-34.23	278330.95	200536.79	280235.95	200536.79	280235.95	111282.27
24	0.01	0	StRS	1-3	20	-31.27	1296422.87	324151.06	1296410.72	324151.06	1296410.72	324151.06
24	0.01	0	StRS	1-3	35	-31.62	734542.35	183544.90	734404.19	183544.90	734404.19	183544.90
24	0.01	0	StRS	1-3	50	-33.19	504883.15	126123.35	504865.18	126123.35	504865.18	126123.35
24	0.01	0	Unequal	1-0	20	-4.24	1486675.61	1486675.61	1486675.61	1486675.61	1486675.61	1486675.61
24	0.01	0	Unequal	1-0	35	-4.04	859084.25	859084.25	859084.25	859084.25	859084.25	859084.25
24	0.01	0	Unequal	1-0	50	-4.63	601189.39	601189.39	601189.39	601189.39	601189.39	601189.39
24	0.01	0	Unequal	1-0	20	-5.12	825703.99	597437.70	831599.27	597437.70	831599.27	330215.59
24	0.01	0	Unequal	1-0	35	-5.87	481118.40	267677.26	483269.84	267677.26	483269.84	152993.45
24	0.01	0	Unequal	1-0	50	-6.82	363127.04	173466.76	364462.59	173466.76	364462.59	106734.09
24	0.01	0	Unequal	1-0,1-3	20	-4.35	1523463.98	380813.50	1523745.48	380813.50	1523745.48	380813.50
24	0.01	0	Unequal	1-0,1-3	35	-6.27	852651.95	213059.69	852297.47	213059.69	852297.47	213059.69
24	0.01	0	Unequal	1-0,1-3	50	-6.59	595902.10	148862.55	595908.31	148862.55	595908.31	148862.55
24	0.01	0.04	SRS	1-0,1-3	20	-4.33	1772819.26	1772819.26	1772819.26	1772819.26	1772819.26	1772819.26
24	0.01	0.04	SRS	1-0,1-3	35	-4.50	1011294.43	1011294.43	1011294.43	1011294.43	1011294.43	1011294.43
24	0.01	0.04	SRS	1-0,1-3	50	-5.34	701654.12	701654.12	701654.12	701654.12	701654.12	701654.12
24	0.01	0.04	SRS	1-3	20	-4.96	989276.58	704476.36	996628.32	704476.36	996628.32	395659.41

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	Aonly	A	AI	B	BI	C
24	0.01	0.04	SRS	1-3	35	-6.74	575843.43	314171.53	574854.58	314171.53	574854.58	182933.44
24	0.01	0.04	SRS	1-3	50	-5.91	436084.38	205004.61	434843.54	205004.61	434843.54	128267.75
24	0.01	0.04	SRS	1-3	20	-7.57	1712849.00	428031.40	1712044.12	428031.40	1712044.12	428031.40
24	0.01	0.04	SRS	1-3	35	-8.57	968535.27	242056.67	968437.92	242056.67	968437.92	242056.67
24	0.01	0.04	SRS	1-3	50	-8.56	677746.91	169301.58	677739.50	169301.58	677739.50	169301.58
24	0.01	0.04	StRS	1-0	20	-31.14	1313758.11	1313758.11	1313758.11	1313758.11	1313758.11	1313758.11
24	0.01	0.04	StRS	1-0	35	-30.75	752580.65	752580.65	752580.65	752580.65	752580.65	752580.65
24	0.01	0.04	StRS	1-0	50	-33.38	509338.80	509338.80	509338.80	509338.80	509338.80	509338.80
24	0.01	0.04	StRS	1-0	20	-33.73	719533.26	542502.88	726202.74	542502.88	726202.74	306124.33
24	0.01	0.04	StRS	1-0	35	-33.04	409004.73	297358.77	411561.48	297358.77	411561.48	166392.51
24	0.01	0.04	StRS	1-0	50	-35.00	276314.78	198191.88	278013.74	198191.88	278013.74	110462.30
24	0.01	0.04	StRS	1-0,1-3	20	-33.73	1251901.50	312878.88	1250740.69	312878.88	1250740.69	312878.88
24	0.01	0.04	StRS	1-0,1-3	35	-32.64	724801.24	181058.76	724599.11	181058.76	724599.11	181058.76
24	0.01	0.04	StRS	1-0,1-3	50	-35.71	486561.86	121555.32	486551.06	121555.32	486551.06	121555.32
24	0.01	0.04	Unequal	1-0,1-3	20	-2.71	1514817.59	1514817.59	1514817.59	1514817.59	1514817.59	1514817.59
24	0.01	0.04	Unequal	1-0,1-3	35	-4.14	857342.81	857342.81	857342.81	857342.81	857342.81	857342.81
24	0.01	0.04	Unequal	1-0,1-3	50	-4.28	601086.13	601086.13	601086.13	601086.13	601086.13	601086.13
24	0.01	0.04	Unequal	1-3	20	-5.65	825585.68	595230.61	832474.38	595230.61	832474.38	330104.59
24	0.01	0.04	Unequal	1-3	35	-6.35	479336.11	267578.51	481634.77	267578.51	481634.77	152429.64
24	0.01	0.04	Unequal	1-3	50	-7.57	360479.46	173479.51	362572.54	173479.51	362572.54	106097.08
24	0.01	0.04	Unequal	1-3	20	-7.00	1475547.52	368832.07	1476553.65	368832.07	1476553.65	368832.07
24	0.01	0.04	Unequal	1-3	35	-7.97	842110.43	210502.79	842275.08	210502.79	842275.08	210502.79
24	0.01	0.04	Unequal	1-3	50	-8.07	592471.45	148029.57	592489.82	148029.57	592489.82	148029.57

Supplement C: Simulation Results for the Count Outcome

Table C1. Percent Relative Bias of the Count Trend Slope Estimate. Note the relative bias values > 5% or < -5% (also shaded).

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	SLRDB	WLRDB	Aonly	A	AI	B	BI	C
12	0.02	0	SRS	1	20	-10.10	-26.13	-22.37	-3.20	-3.20	-3.20	-3.20	-3.20	-3.20
12	0.02	0	SRS	1	35	-9.28	-23.55	-21.37	-0.84	-0.84	-0.84	-0.84	-0.84	-0.84
12	0.02	0	SRS	1	50	-3.81	-23.99	-21.59	-0.92	-0.92	-0.92	-0.92	-0.92	-0.92
12	0.02	0	SRS	2	20	-3.95	-23.62	-20.38	0.30	1.71	0.83	1.71	0.83	0.46
12	0.02	0	SRS	2	35	-3.69	-26.27	-23.20	2.53	1.11	2.37	1.11	2.37	2.54
12	0.02	0	SRS	2	50	-2.53	-26.21	-24.49	1.51	2.80	0.15	2.80	0.15	1.17
12	0.02	0	SRS	3	20	-0.57	-23.13	-16.34	4.19	4.64	4.45	4.64	4.45	4.64
12	0.02	0	SRS	3	35	-0.51	-22.65	-18.07	5.01	4.93	4.95	4.93	4.95	4.93
12	0.02	0	SRS	3	50	3.65	-19.44	-15.89	9.39	9.34	9.46	9.34	9.46	9.34
12	0.02	0	StRS	1	20	1.75	-18.04	-16.64	4.05	4.05	4.05	4.05	4.05	4.05
12	0.02	0	StRS	1	35	3.97	-19.20	-17.85	5.40	5.40	5.40	5.40	5.40	5.40
12	0.02	0	StRS	1	50	3.17	-20.50	-18.78	4.36	4.36	4.36	4.36	4.36	4.36
12	0.02	0	StRS	2	20	0.10	-22.17	-19.01	3.36	3.11	3.38	3.11	3.38	3.23
12	0.02	0	StRS	2	35	0.38	-22.78	-19.22	3.95	3.94	4.17	3.94	4.17	4.03
12	0.02	0	StRS	2	50	0.76	-21.56	-20.34	4.43	3.81	2.97	3.81	2.97	4.41
12	0.02	0	StRS	3	20	-1.20	-24.87	-16.73	1.81	1.68	1.77	1.68	1.77	1.68
12	0.02	0	StRS	3	35	-2.36	-25.41	-18.94	0.81	0.81	0.83	0.81	0.83	0.81
12	0.02	0	StRS	3	50	-1.44	-25.86	-21.77	1.73	1.72	1.66	1.72	1.66	1.72
12	0.02	0	Unequal	1	20	-8.75	-23.40	-20.68	-1.10	-1.10	-1.10	-1.10	-1.10	-1.10
12	0.02	0	Unequal	1	35	-11.78	-27.01	-25.32	-4.88	-4.88	-4.88	-4.88	-4.88	-4.88
12	0.02	0	Unequal	1	50	-4.42	-25.66	-25.05	-1.01	-1.01	-1.01	-1.01	-1.01	-1.01
12	0.02	0	Unequal	2	20	-0.17	-21.13	-15.96	5.31	4.58	5.64	4.58	5.64	5.31
12	0.02	0	Unequal	2	35	-2.29	-25.26	-22.65	2.13	1.85	1.31	1.85	1.31	1.67
12	0.02	0	Unequal	2	50	-0.24	-22.65	-18.81	6.50	5.93	6.30	5.93	6.30	6.24

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	SLRDB	WLRDB	Aonly	A	AI	B	BI	C
12	0.02	0	Unequal	3	20	2.45	-18.71	-9.85	6.74	6.55	6.72	6.55	6.72	6.55
12	0.02	0	Unequal	3	35	1.88	-21.81	-12.60	5.81	5.24	5.87	5.24	5.87	5.24
12	0.02	0	Unequal	3	50	3.36	-18.80	-13.88	7.59	8.23	7.85	8.23	7.85	8.23
12	0.02	0.04	SRS	1	20	-6.63	-14.52	-14.59	-3.65	-3.65	-3.65	-3.65	-3.65	-3.65
12	0.02	0.04	SRS	1	35	-7.00	-14.72	-14.15	-4.40	-4.40	-4.40	-4.40	-4.40	-4.40
12	0.02	0.04	SRS	1	50	-4.31	-13.91	-12.66	-2.81	-2.81	-2.81	-2.81	-2.81	-2.81
12	0.02	0.04	SRS	2	20	-2.54	-12.53	-10.68	1.18	0.09	0.75	0.09	0.75	0.86
12	0.02	0.04	SRS	2	35	1.31	-9.27	-8.88	2.58	3.97	2.38	3.97	2.38	2.19
12	0.02	0.04	SRS	2	50	2.04	-8.84	-6.44	5.54	4.81	4.73	4.81	4.73	5.48
12	0.02	0.04	SRS	3	20	5.99	-2.03	0.60	8.90	8.81	8.91	8.81	8.91	8.81
12	0.02	0.04	SRS	3	35	3.12	-7.24	-5.92	5.57	5.55	5.52	5.55	5.52	5.55
12	0.02	0.04	SRS	3	50	0.28	-9.46	-8.09	2.62	2.67	2.85	2.67	2.85	2.67
12	0.02	0.04	StRS	1	20	0.43	-27.31	-25.36	2.38	2.38	2.38	2.38	2.38	2.38
12	0.02	0.04	StRS	1	35	0.70	-28.66	-26.40	1.54	1.54	1.54	1.54	1.54	1.54
12	0.02	0.04	StRS	1	50	-0.26	-30.03	-27.87	0.13	0.13	0.13	0.13	0.13	0.13
12	0.02	0.04	StRS	2	20	-1.65	-27.06	-24.48	0.71	0.39	0.94	0.39	0.94	0.66
12	0.02	0.04	StRS	2	35	-0.71	-27.16	-24.39	1.12	1.28	1.25	1.28	1.25	1.31
12	0.02	0.04	StRS	2	50	-0.25	-30.66	-27.73	1.09	1.57	1.21	1.57	1.21	1.26
12	0.02	0.04	StRS	3	20	-0.78	-30.93	-26.04	1.10	1.04	1.11	1.04	1.11	1.04
12	0.02	0.04	StRS	3	35	-0.59	-30.24	-27.28	1.22	1.28	1.24	1.28	1.24	1.28
12	0.02	0.04	StRS	3	50	0.50	-29.22	-26.42	2.42	2.39	2.58	2.39	2.58	2.39
12	0.02	0.04	Unequal	1	20	-12.25	-9.58	-8.30	-0.66	-0.66	-0.66	-0.66	-0.66	-0.66
12	0.02	0.04	Unequal	1	35	-13.70	-10.37	-11.32	3.44	3.44	3.44	3.44	3.44	3.44
12	0.02	0.04	Unequal	1	50	-10.79	-10.79	-10.63	11.36	11.36	11.36	11.36	11.36	11.36
12	0.02	0.04	Unequal	2	20	-12.74	-12.26	-11.33	-3.33	-1.94	-3.40	-1.94	-3.40	-3.29
12	0.02	0.04	Unequal	2	35	-12.50	-12.08	-10.48	-2.30	3.89	-3.50	3.89	-3.50	-2.35
12	0.02	0.04	Unequal	2	50	-11.40	-11.47	-9.42	3.32	12.51	2.61	12.51	2.61	3.41

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	SLRDB	WLRDB	Aonly	A	AI	B	BI	C
12	0.02	0.04	Unequal	3	20	-15.04	-13.89	-10.15	-3.62	-3.69	-3.77	-3.69	-3.77	-3.69
12	0.02	0.04	Unequal	3	35	-14.24	-13.72	-11.81	4.57	4.44	4.14	4.44	4.14	4.44
12	0.02	0.04	Unequal	3	50	-15.73	-16.29	-14.11	8.13	8.15	8.27	8.15	8.27	8.15
24	0.01	0	SRS	1	20	0.10	-37.74	-33.18	2.43	2.43	2.43	2.43	2.43	2.43
24	0.01	0	SRS	1	35	-3.77	-38.20	-33.80	1.67	1.67	1.67	1.67	1.67	1.67
24	0.01	0	SRS	1	50	-5.30	-39.51	-35.55	0.20	0.20	0.20	0.20	0.20	0.20
24	0.01	0	SRS	2	20	-10.23	-42.42	-32.09	-1.07	-1.19	-2.96	-1.19	-2.96	-0.99
24	0.01	0	SRS	2	35	-6.13	-41.50	-32.32	2.09	2.02	1.28	2.02	1.28	2.00
24	0.01	0	SRS	2	50	-5.60	-43.01	-36.66	1.72	1.50	2.01	1.50	2.01	1.69
24	0.01	0	SRS	3	20	-9.32	-38.10	-26.48	1.52	1.53	1.53	1.53	1.53	1.53
24	0.01	0	SRS	3	35	-3.49	-40.62	-32.28	3.86	3.79	3.82	3.79	3.82	3.79
24	0.01	0	SRS	3	50	-2.99	-40.64	-32.40	4.64	4.64	4.69	4.64	4.69	4.64
24	0.01	0	StRS	1	20	-1.97	-36.77	-31.82	1.15	1.15	1.15	1.15	1.15	1.15
24	0.01	0	StRS	1	35	-1.73	-40.14	-34.25	0.49	0.49	0.49	0.49	0.49	0.49
24	0.01	0	StRS	1	50	-0.61	-39.19	-34.13	0.09	0.09	0.09	0.09	0.09	0.09
24	0.01	0	StRS	2	20	-5.98	-38.17	-29.42	1.07	0.58	-2.07	0.58	-2.07	1.74
24	0.01	0	StRS	2	35	-1.92	-38.98	-32.61	2.46	2.31	3.44	2.31	3.44	1.75
24	0.01	0	StRS	2	50	-0.96	-39.54	-33.26	3.86	2.88	2.88	2.88	2.88	4.28
24	0.01	0	StRS	3	20	-0.04	-34.46	-23.27	6.73	6.62	6.74	6.62	6.74	6.62
24	0.01	0	StRS	3	35	2.83	-34.90	-25.13	8.34	8.45	8.39	8.45	8.39	8.45
24	0.01	0	StRS	3	50	2.05	-34.87	-26.58	7.96	7.87	8.27	7.87	8.27	7.87
24	0.01	0	Unequal	1	20	-5.18	-41.22	-34.63	-3.21	-3.21	-3.21	-3.21	-3.21	-3.21
24	0.01	0	Unequal	1	35	-7.89	-42.78	-38.04	-3.45	-3.45	-3.45	-3.45	-3.45	-3.45
24	0.01	0	Unequal	1	50	-9.97	-44.21	-39.38	-4.53	-4.53	-4.53	-4.53	-4.53	-4.53
24	0.01	0	Unequal	2	20	-6.59	-38.30	-26.96	1.99	1.62	-0.31	1.62	-0.31	1.93
24	0.01	0	Unequal	2	35	0.61	-35.28	-24.95	8.71	8.50	8.88	8.50	8.88	8.57
24	0.01	0	Unequal	2	50	0.66	-38.10	-28.50	7.40	6.04	7.37	6.04	7.37	7.48

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	SLRDB	WLRDB	Aonly	A	AI	B	BI	C
24	0.01	0	Unequal	3	20	-4.46	-33.56	-18.82	5.70	5.73	5.91	5.73	5.91	5.73
24	0.01	0	Unequal	3	35	-0.74	-38.08	-25.74	6.69	6.65	6.51	6.65	6.51	6.65
24	0.01	0	Unequal	3	50	-0.99	-38.53	-28.83	7.24	7.26	7.00	7.26	7.00	7.26
24	0.01	0.04	SRS	1	20	-1.04	-1.68	-1.63	0.14	0.14	0.14	0.14	0.14	0.14
24	0.01	0.04	SRS	1	35	-1.46	-3.77	-3.79	-1.12	-1.12	-1.12	-1.12	-1.12	-1.12
24	0.01	0.04	SRS	1	50	-1.94	-4.16	-4.28	-0.60	-0.60	-0.60	-0.60	-0.60	-0.60
24	0.01	0.04	SRS	2	20	-1.56	-3.50	-3.15	-1.52	-1.08	-1.55	-1.08	-1.55	-1.92
24	0.01	0.04	SRS	2	35	-1.12	-1.71	-0.13	-0.49	-0.43	-0.71	-0.43	-0.71	-0.55
24	0.01	0.04	SRS	2	50	-1.74	-1.84	0.03	-0.41	-0.24	-0.76	-0.24	-0.76	-0.52
24	0.01	0.04	SRS	3	20	-2.32	-3.34	-2.35	-1.74	-1.80	-1.69	-1.80	-1.69	-1.80
24	0.01	0.04	SRS	3	35	-1.24	-1.95	-0.73	0.20	0.21	0.20	0.21	0.20	0.21
24	0.01	0.04	SRS	3	50	-2.07	-3.02	-1.65	-0.34	-0.36	-0.34	-0.36	-0.34	-0.36
24	0.01	0.04	StRS	1	20	-1.83	-32.82	-29.76	1.98	1.98	1.98	1.98	1.98	1.98
24	0.01	0.04	StRS	1	35	-1.64	-32.74	-29.63	2.38	2.38	2.38	2.38	2.38	2.38
24	0.01	0.04	StRS	1	50	-0.64	-33.97	-30.19	1.92	1.92	1.92	1.92	1.92	1.92
24	0.01	0.04	StRS	2	20	-2.40	-28.47	-22.47	0.76	-0.03	0.78	-0.03	0.78	0.78
24	0.01	0.04	StRS	2	35	-0.15	-31.73	-26.35	1.11	1.40	-0.29	1.40	-0.29	1.41
24	0.01	0.04	StRS	2	50	0.53	-35.65	-31.02	1.47	1.87	0.14	1.87	0.14	1.23
24	0.01	0.04	StRS	3	20	-2.84	-35.72	-27.75	0.15	0.17	0.14	0.17	0.14	0.17
24	0.01	0.04	StRS	3	35	-1.61	-35.72	-28.69	0.77	0.82	0.77	0.82	0.77	0.82
24	0.01	0.04	StRS	3	50	-0.63	-34.54	-29.19	1.89	1.86	1.96	1.86	1.96	1.86
24	0.01	0.04	Unequal	1	20	-16.76	-2.46	-4.51	0.55	0.55	0.55	0.55	0.55	0.55
24	0.01	0.04	Unequal	1	35	-13.62	0.24	-1.33	2.86	2.86	2.86	2.86	2.86	2.86
24	0.01	0.04	Unequal	1	50	-13.85	0.82	1.25	10.09	10.09	10.09	10.09	10.09	10.09
24	0.01	0.04	Unequal	2	20	-18.75	-4.92	-7.37	-7.34	-4.80	-11.14	-4.80	-11.14	-8.42
24	0.01	0.04	Unequal	2	35	-18.57	-2.94	-2.83	-2.69	5.24	-4.83	5.24	-4.83	-3.04
24	0.01	0.04	Unequal	2	50	-17.91	-3.48	-2.72	2.81	17.58	1.10	17.58	1.10	2.80

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	SLRDB	WLRDB	Aonly	A	AI	B	BI	C
24	0.01	0.04	Unequal	3	20	-19.18	-2.46	-4.33	-1.52	-1.90	-1.69	-1.90	-1.69	-1.90
24	0.01	0.04	Unequal	3	35	-18.29	-2.99	-1.86	8.93	8.41	8.61	8.41	8.61	8.41
24	0.01	0.04	Unequal	3	50	-18.38	-2.77	-1.70	21.19	20.26	15.62	20.26	15.62	20.26

Table C2. Confidence Interval Coverage of the Count Trend Slope Estimate ($\alpha = 0.10$). Note confidence interval coverage values < 0.87 (also shaded).

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	SLRDB	WLRDB	Aonly	A	AI	B	BI	C
12	0.02	0	SRS	1-0	20	0.85	0.84	0.81	0.85	0.85	0.85	0.85	0.85	0.85
12	0.02	0	SRS	1-0	35	0.86	0.84	0.84	0.87	0.87	0.87	0.87	0.87	0.87
12	0.02	0	SRS	1-0	50	0.84	0.84	0.83	0.84	0.84	0.84	0.84	0.84	0.84
12	0.02	0	SRS	1-0	20	0.88	0.88	0.84	0.81	0.87	0.80	0.87	0.80	0.81
12	0.02	0	SRS	1-0	35	0.86	0.88	0.85	0.77	0.86	0.77	0.86	0.77	0.77
12	0.02	0	SRS	1-0	50	0.85	0.86	0.84	0.73	0.84	0.73	0.84	0.73	0.73
12	0.02	0	SRS	1-0,1-3	20	0.83	0.87	0.83	0.80	0.80	0.80	0.80	0.80	0.80
12	0.02	0	SRS	1-0,1-3	35	0.81	0.86	0.83	0.78	0.78	0.78	0.78	0.78	0.78
12	0.02	0	SRS	1-0,1-3	50	0.82	0.86	0.85	0.79	0.79	0.79	0.79	0.79	0.79
12	0.02	0	StRS	1-0,1-3	20	0.88	0.83	0.82	0.84	0.84	0.84	0.84	0.84	0.84
12	0.02	0	StRS	1-0,1-3	35	0.90	0.84	0.82	0.87	0.87	0.87	0.87	0.87	0.87
12	0.02	0	StRS	1-0,1-3	50	0.89	0.85	0.83	0.87	0.87	0.87	0.87	0.87	0.87
12	0.02	0	StRS	1-3	20	0.89	0.87	0.84	0.78	0.84	0.78	0.84	0.78	0.78
12	0.02	0	StRS	1-3	35	0.87	0.85	0.84	0.72	0.83	0.72	0.83	0.72	0.72
12	0.02	0	StRS	1-3	50	0.88	0.84	0.83	0.68	0.85	0.66	0.85	0.66	0.68
12	0.02	0	StRS	1-3	20	0.87	0.87	0.82	0.84	0.84	0.84	0.84	0.84	0.84
12	0.02	0	StRS	1-3	35	0.86	0.83	0.81	0.83	0.83	0.83	0.83	0.83	0.83
12	0.02	0	StRS	1-3	50	0.86	0.84	0.84	0.83	0.83	0.83	0.83	0.83	0.83

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	SLRDB	WLRDB	Aonly	A	AI	B	BI	C
12	0.02	0	Unequal	1-0	20	0.83	0.84	0.80	0.82	0.82	0.82	0.82	0.82	0.82
12	0.02	0	Unequal	1-0	35	0.84	0.83	0.83	0.80	0.80	0.80	0.80	0.80	0.80
12	0.02	0	Unequal	1-0	50	0.86	0.85	0.86	0.82	0.82	0.82	0.82	0.82	0.82
12	0.02	0	Unequal	1-0	20	0.87	0.89	0.83	0.79	0.85	0.78	0.85	0.78	0.79
12	0.02	0	Unequal	1-0	35	0.86	0.90	0.85	0.75	0.82	0.74	0.82	0.74	0.75
12	0.02	0	Unequal	1-0	50	0.86	0.88	0.86	0.73	0.81	0.73	0.81	0.73	0.73
12	0.02	0	Unequal	1-0,1-3	20	0.84	0.88	0.84	0.79	0.79	0.79	0.79	0.79	0.79
12	0.02	0	Unequal	1-0,1-3	35	0.82	0.86	0.83	0.78	0.78	0.78	0.78	0.78	0.78
12	0.02	0	Unequal	1-0,1-3	50	0.86	0.89	0.86	0.78	0.78	0.78	0.78	0.78	0.78
12	0.02	0.04	SRS	1-0,1-3	20	0.85	0.84	0.81	0.86	0.86	0.86	0.86	0.86	0.86
12	0.02	0.04	SRS	1-0,1-3	35	0.86	0.87	0.85	0.88	0.88	0.88	0.88	0.88	0.88
12	0.02	0.04	SRS	1-0,1-3	50	0.87	0.87	0.85	0.87	0.87	0.87	0.87	0.87	0.87
12	0.02	0.04	SRS	1-3	20	0.87	0.87	0.83	0.80	0.86	0.79	0.86	0.79	0.80
12	0.02	0.04	SRS	1-3	35	0.88	0.90	0.88	0.76	0.85	0.76	0.85	0.76	0.76
12	0.02	0.04	SRS	1-3	50	0.87	0.90	0.86	0.76	0.87	0.74	0.87	0.74	0.76
12	0.02	0.04	SRS	1-3	20	0.86	0.90	0.89	0.84	0.84	0.83	0.84	0.83	0.84
12	0.02	0.04	SRS	1-3	35	0.84	0.88	0.86	0.83	0.83	0.83	0.83	0.83	0.83
12	0.02	0.04	SRS	1-3	50	0.85	0.88	0.86	0.83	0.83	0.83	0.83	0.83	0.83
12	0.02	0.04	StRS	1-0	20	0.91	0.79	0.76	0.88	0.88	0.88	0.88	0.88	0.88
12	0.02	0.04	StRS	1-0	35	0.88	0.77	0.76	0.86	0.86	0.86	0.86	0.86	0.86
12	0.02	0.04	StRS	1-0	50	0.89	0.76	0.75	0.85	0.85	0.85	0.85	0.85	0.85
12	0.02	0.04	StRS	1-0	20	0.90	0.84	0.80	0.79	0.86	0.80	0.86	0.80	0.79
12	0.02	0.04	StRS	1-0	35	0.89	0.81	0.78	0.75	0.85	0.75	0.85	0.75	0.75
12	0.02	0.04	StRS	1-0	50	0.89	0.80	0.80	0.72	0.86	0.68	0.86	0.68	0.72
12	0.02	0.04	StRS	1-0,1-3	20	0.87	0.83	0.79	0.84	0.83	0.84	0.83	0.84	0.83
12	0.02	0.04	StRS	1-0,1-3	35	0.85	0.78	0.76	0.82	0.82	0.82	0.82	0.82	0.82
12	0.02	0.04	StRS	1-0,1-3	50	0.85	0.81	0.78	0.81	0.81	0.81	0.81	0.81	0.81

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	SLRDB	WLRDB	Aonly	A	AI	B	BI	C
12	0.02	0.04	Unequal	1-0,1-3	20	0.86	0.85	0.82	0.84	0.84	0.84	0.84	0.84	0.84
12	0.02	0.04	Unequal	1-0,1-3	35	0.87	0.86	0.82	0.84	0.84	0.84	0.84	0.84	0.84
12	0.02	0.04	Unequal	1-0,1-3	50	0.85	0.85	0.84	0.78	0.78	0.78	0.78	0.78	0.78
12	0.02	0.04	Unequal	1-3	20	0.85	0.87	0.83	0.79	0.82	0.79	0.82	0.79	0.78
12	0.02	0.04	Unequal	1-3	35	0.83	0.87	0.83	0.71	0.77	0.73	0.77	0.73	0.71
12	0.02	0.04	Unequal	1-3	50	0.85	0.90	0.86	0.69	0.79	0.70	0.79	0.70	0.70
12	0.02	0.04	Unequal	1-3	20	0.85	0.89	0.85	0.83	0.83	0.82	0.83	0.82	0.83
12	0.02	0.04	Unequal	1-3	35	0.85	0.88	0.86	0.79	0.79	0.78	0.79	0.78	0.79
12	0.02	0.04	Unequal	1-3	50	0.84	0.87	0.85	0.80	0.80	0.80	0.80	0.80	0.80
24	0.01	0	SRS	1-0	20	0.87	0.78	0.75	0.89	0.89	0.89	0.89	0.89	0.89
24	0.01	0	SRS	1-0	35	0.87	0.77	0.75	0.84	0.84	0.84	0.84	0.84	0.84
24	0.01	0	SRS	1-0	50	0.88	0.76	0.76	0.85	0.85	0.85	0.85	0.85	0.85
24	0.01	0	SRS	1-0	20	0.87	0.77	0.79	0.83	0.89	0.77	0.89	0.77	0.82
24	0.01	0	SRS	1-0	35	0.90	0.80	0.81	0.81	0.90	0.79	0.90	0.79	0.81
24	0.01	0	SRS	1-0	50	0.87	0.77	0.77	0.78	0.89	0.78	0.89	0.78	0.78
24	0.01	0	SRS	1-0,1-3	20	0.89	0.82	0.83	0.88	0.88	0.88	0.88	0.88	0.88
24	0.01	0	SRS	1-0,1-3	35	0.89	0.81	0.83	0.88	0.88	0.87	0.88	0.87	0.88
24	0.01	0	SRS	1-0,1-3	50	0.89	0.78	0.80	0.88	0.88	0.84	0.88	0.84	0.88
24	0.01	0	StRS	1-0,1-3	20	0.90	0.74	0.73	0.91	0.91	0.91	0.91	0.91	0.91
24	0.01	0	StRS	1-0,1-3	35	0.92	0.71	0.74	0.75	0.75	0.75	0.75	0.75	0.75
24	0.01	0	StRS	1-0,1-3	50	0.90	0.74	0.73	0.78	0.78	0.78	0.78	0.78	0.78
24	0.01	0	StRS	1-3	20	0.90	0.76	0.75	0.81	0.88	0.69	0.88	0.69	0.80
24	0.01	0	StRS	1-3	35	0.91	0.75	0.76	0.78	0.86	0.69	0.86	0.69	0.79
24	0.01	0	StRS	1-3	50	0.91	0.73	0.76	0.74	0.88	0.69	0.88	0.69	0.73
24	0.01	0	StRS	1-3	20	0.89	0.82	0.80	0.87	0.87	0.87	0.87	0.87	0.87
24	0.01	0	StRS	1-3	35	0.92	0.78	0.81	0.89	0.89	0.89	0.89	0.89	0.89
24	0.01	0	StRS	1-3	50	0.89	0.78	0.80	0.86	0.86	0.82	0.86	0.82	0.86

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	SLRDB	WLRDB	Aonly	A	AI	B	BI	C
24	0.01	0	Unequal	1-0	20	0.90	0.76	0.74	0.90	0.90	0.90	0.90	0.90	0.90
24	0.01	0	Unequal	1-0	35	0.89	0.74	0.76	0.80	0.80	0.80	0.80	0.80	0.80
24	0.01	0	Unequal	1-0	50	0.90	0.76	0.75	0.80	0.80	0.80	0.80	0.80	0.80
24	0.01	0	Unequal	1-0	20	0.83	0.78	0.77	0.78	0.81	0.72	0.81	0.72	0.77
24	0.01	0	Unequal	1-0	35	0.86	0.79	0.79	0.71	0.82	0.71	0.82	0.71	0.71
24	0.01	0	Unequal	1-0	50	0.87	0.79	0.80	0.71	0.81	0.71	0.81	0.71	0.71
24	0.01	0	Unequal	1-0,1-3	20	0.88	0.85	0.82	0.84	0.83	0.83	0.83	0.83	0.83
24	0.01	0	Unequal	1-0,1-3	35	0.89	0.82	0.81	0.84	0.83	0.81	0.83	0.81	0.83
24	0.01	0	Unequal	1-0,1-3	50	0.87	0.78	0.82	0.80	0.80	0.77	0.80	0.77	0.80
24	0.01	0.04	SRS	1-0,1-3	20	0.93	0.82	0.78	0.94	0.94	0.94	0.94	0.94	0.94
24	0.01	0.04	SRS	1-0,1-3	35	0.91	0.84	0.82	0.74	0.74	0.74	0.74	0.74	0.74
24	0.01	0.04	SRS	1-0,1-3	50	0.94	0.87	0.85	0.70	0.70	0.70	0.70	0.70	0.70
24	0.01	0.04	SRS	1-3	20	0.90	0.86	0.82	0.83	0.89	0.73	0.89	0.73	0.81
24	0.01	0.04	SRS	1-3	35	0.88	0.88	0.85	0.79	0.87	0.72	0.87	0.72	0.79
24	0.01	0.04	SRS	1-3	50	0.89	0.89	0.87	0.77	0.86	0.77	0.86	0.77	0.78
24	0.01	0.04	SRS	1-3	20	0.85	0.87	0.83	0.86	0.84	0.86	0.84	0.86	0.84
24	0.01	0.04	SRS	1-3	35	0.87	0.89	0.85	0.87	0.87	0.87	0.87	0.87	0.87
24	0.01	0.04	SRS	1-3	50	0.88	0.88	0.86	0.87	0.87	0.85	0.87	0.85	0.87
24	0.01	0.04	StRS	1-0	20	0.87	0.57	0.61	0.91	0.91	0.91	0.91	0.91	0.91
24	0.01	0.04	StRS	1-0	35	0.86	0.52	0.56	0.71	0.71	0.71	0.71	0.71	0.71
24	0.01	0.04	StRS	1-0	50	0.89	0.53	0.58	0.67	0.67	0.67	0.67	0.67	0.67
24	0.01	0.04	StRS	1-0	20	0.88	0.65	0.70	0.81	0.87	0.74	0.87	0.74	0.81
24	0.01	0.04	StRS	1-0	35	0.89	0.56	0.61	0.76	0.87	0.69	0.87	0.69	0.76
24	0.01	0.04	StRS	1-0	50	0.90	0.49	0.56	0.72	0.87	0.64	0.87	0.64	0.72
24	0.01	0.04	StRS	1-0,1-3	20	0.92	0.62	0.69	0.90	0.89	0.90	0.89	0.90	0.89
24	0.01	0.04	StRS	1-0,1-3	35	0.91	0.55	0.62	0.90	0.90	0.90	0.90	0.90	0.90
24	0.01	0.04	StRS	1-0,1-3	50	0.91	0.54	0.63	0.90	0.90	0.88	0.90	0.88	0.90

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	SLRDB	WLRDB	Aonly	A	AI	B	BI	C
24	0.01	0.04	Unequal	1-0,1-3	20	0.87	0.73	0.73	0.88	0.88	0.88	0.88	0.88	0.88
24	0.01	0.04	Unequal	1-0,1-3	35	0.86	0.81	0.80	0.69	0.69	0.69	0.69	0.69	0.69
24	0.01	0.04	Unequal	1-0,1-3	50	0.87	0.84	0.82	0.67	0.67	0.67	0.67	0.67	0.67
24	0.01	0.04	Unequal	1-3	20	0.80	0.83	0.80	0.77	0.83	0.67	0.83	0.67	0.76
24	0.01	0.04	Unequal	1-3	35	0.82	0.88	0.83	0.78	0.85	0.75	0.85	0.75	0.77
24	0.01	0.04	Unequal	1-3	50	0.79	0.87	0.83	0.72	0.74	0.70	0.74	0.70	0.72
24	0.01	0.04	Unequal	1-3	20	0.81	0.89	0.81	0.83	0.82	0.83	0.82	0.83	0.82
24	0.01	0.04	Unequal	1-3	35	0.81	0.89	0.86	0.82	0.82	0.81	0.82	0.81	0.82
24	0.01	0.04	Unequal	1-3	50	0.80	0.88	0.83	0.72	0.72	0.71	0.72	0.71	0.72

Table C3. Trend Test Size of the z-test for the Count Trend Slope Estimate. Note values > 0.13 (also shaded).

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	SLRDB	WLRDB	Aonly	A	AI	B	BI	C
12	0	0	SRS	1-0	20	0.14	0.14	0.18	0.13	0.13	0.13	0.13	0.13	0.13
12	0	0	SRS	1-0	35	0.17	0.17	0.18	0.16	0.16	0.16	0.16	0.16	0.16
12	0	0	SRS	1-0	50	0.16	0.16	0.17	0.16	0.16	0.16	0.16	0.16	0.16
12	0	0	SRS	1-0	20	0.14	0.12	0.18	0.19	0.16	0.19	0.16	0.19	0.19
12	0	0	SRS	1-0	35	0.17	0.16	0.17	0.26	0.18	0.27	0.18	0.27	0.26
12	0	0	SRS	1-0	50	0.17	0.15	0.16	0.29	0.18	0.29	0.18	0.29	0.29
12	0	0	SRS	1-0,1-3	20	0.15	0.13	0.16	0.17	0.17	0.17	0.17	0.17	0.17
12	0	0	SRS	1-0,1-3	35	0.16	0.13	0.16	0.18	0.18	0.18	0.18	0.18	0.18
12	0	0	SRS	1-0,1-3	50	0.14	0.11	0.14	0.17	0.18	0.17	0.18	0.17	0.18
12	0	0	StRS	1-0,1-3	20	0.12	0.16	0.17	0.14	0.14	0.14	0.14	0.14	0.14
12	0	0	StRS	1-0,1-3	35	0.11	0.17	0.18	0.14	0.14	0.14	0.14	0.14	0.14
12	0	0	StRS	1-0,1-3	50	0.11	0.17	0.18	0.15	0.15	0.15	0.15	0.15	0.15
12	0	0	StRS	1-3	20	0.13	0.12	0.16	0.22	0.16	0.22	0.16	0.22	0.22

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	SLRDB	WLRDB	Aonly	A	AI	B	BI	C
12	0	0	StRS	1-3	35	0.11	0.15	0.15	0.22	0.13	0.23	0.13	0.23	0.22
12	0	0	StRS	1-3	50	0.11	0.14	0.14	0.25	0.14	0.30	0.14	0.30	0.25
12	0	0	StRS	1-3	20	0.13	0.11	0.14	0.17	0.16	0.17	0.16	0.17	0.16
12	0	0	StRS	1-3	35	0.12	0.15	0.16	0.16	0.16	0.16	0.16	0.16	0.16
12	0	0	StRS	1-3	50	0.12	0.14	0.15	0.16	0.16	0.16	0.16	0.16	0.16
12	0	0	Unequal	1-0	20	0.14	0.14	0.18	0.16	0.16	0.16	0.16	0.16	0.16
12	0	0	Unequal	1-0	35	0.17	0.15	0.22	0.20	0.20	0.20	0.20	0.20	0.20
12	0	0	Unequal	1-0	50	0.16	0.15	0.22	0.19	0.19	0.19	0.19	0.19	0.19
12	0	0	Unequal	1-0	20	0.18	0.13	0.16	0.23	0.19	0.26	0.19	0.26	0.23
12	0	0	Unequal	1-0	35	0.16	0.15	0.19	0.29	0.22	0.27	0.22	0.27	0.29
12	0	0	Unequal	1-0	50	0.17	0.15	0.19	0.30	0.22	0.30	0.22	0.30	0.30
12	0	0	Unequal	1-0,1-3	20	0.14	0.11	0.14	0.18	0.18	0.18	0.18	0.18	0.18
12	0	0	Unequal	1-0,1-3	35	0.15	0.14	0.17	0.19	0.19	0.19	0.19	0.19	0.19
12	0	0	Unequal	1-0,1-3	50	0.18	0.14	0.16	0.21	0.21	0.22	0.21	0.22	0.21
24	0	0	SRS	1-0,1-3	20	0.14	0.24	0.27	0.12	0.12	0.12	0.12	0.12	0.12
24	0	0	SRS	1-0,1-3	35	0.15	0.25	0.25	0.17	0.17	0.17	0.17	0.17	0.17
24	0	0	SRS	1-0,1-3	50	0.13	0.25	0.24	0.19	0.19	0.19	0.19	0.19	0.19
24	0	0	SRS	1-3	20	0.18	0.21	0.21	0.20	0.15	0.28	0.15	0.28	0.21
24	0	0	SRS	1-3	35	0.14	0.23	0.24	0.21	0.14	0.23	0.14	0.23	0.22
24	0	0	SRS	1-3	50	0.13	0.24	0.23	0.27	0.15	0.28	0.15	0.28	0.27
24	0	0	SRS	1-3	20	0.12	0.18	0.17	0.10	0.10	0.10	0.10	0.10	0.10
24	0	0	SRS	1-3	35	0.10	0.20	0.17	0.11	0.11	0.11	0.11	0.11	0.11
24	0	0	SRS	1-3	50	0.12	0.20	0.21	0.12	0.12	0.18	0.12	0.18	0.12
24	0	0	StRS	1-0	20	0.07	0.25	0.24	0.05	0.05	0.05	0.05	0.05	0.05
24	0	0	StRS	1-0	35	0.08	0.29	0.25	0.21	0.21	0.21	0.21	0.21	0.21
24	0	0	StRS	1-0	50	0.06	0.28	0.26	0.25	0.25	0.25	0.25	0.25	0.25

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	SLRDB	WLRDB	Aonly	A	AI	B	BI	C
24	0	0	StRS	1-0	20	0.09	0.24	0.23	0.18	0.13	0.28	0.13	0.28	0.18
24	0	0	StRS	1-0	35	0.06	0.25	0.21	0.21	0.10	0.27	0.10	0.27	0.21
24	0	0	StRS	1-0	50	0.07	0.24	0.23	0.25	0.10	0.33	0.10	0.33	0.25
24	0	0	StRS	1-0,1-3	20	0.07	0.19	0.19	0.09	0.09	0.09	0.09	0.09	0.09
24	0	0	StRS	1-0,1-3	35	0.07	0.22	0.20	0.10	0.10	0.10	0.10	0.10	0.10
24	0	0	StRS	1-0,1-3	50	0.08	0.22	0.19	0.10	0.10	0.16	0.10	0.16	0.10
24	0	0	Unequal	1-0,1-3	20	0.14	0.26	0.28	0.14	0.14	0.14	0.14	0.14	0.14
24	0	0	Unequal	1-0,1-3	35	0.17	0.25	0.23	0.23	0.23	0.23	0.23	0.23	0.23
24	0	0	Unequal	1-0,1-3	50	0.15	0.27	0.26	0.25	0.25	0.25	0.25	0.25	0.25
24	0	0	Unequal	1-3	20	0.17	0.19	0.22	0.21	0.18	0.27	0.18	0.27	0.22
24	0	0	Unequal	1-3	35	0.14	0.21	0.19	0.25	0.18	0.25	0.18	0.25	0.25
24	0	0	Unequal	1-3	50	0.14	0.20	0.21	0.28	0.21	0.29	0.21	0.29	0.28
24	0	0	Unequal	1-3	20	0.13	0.18	0.20	0.16	0.16	0.16	0.16	0.16	0.16
24	0	0	Unequal	1-3	35	0.11	0.16	0.17	0.13	0.13	0.16	0.13	0.16	0.13
24	0	0	Unequal	1-3	50	0.11	0.18	0.18	0.15	0.16	0.17	0.16	0.17	0.16

Table C4. Trend Test Size of the χ^2 -test for the Count Trend Slope Estimate. Note values > 0.13 (also shaded).

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	Aonly	A	AI	B	BI	C
12	0	0	SRS	1-0	20	0.14	0.13	0.13	0.13	0.13	0.13	0.13
12	0	0	SRS	1-0	35	0.17	0.16	0.16	0.16	0.16	0.16	0.16
12	0	0	SRS	1-0	50	0.16	0.16	0.16	0.16	0.16	0.16	0.16
12	0	0	SRS	1-0	20	0.14	0.19	0.16	0.19	0.16	0.19	0.19
12	0	0	SRS	1-0	35	0.17	0.26	0.18	0.27	0.18	0.27	0.26
12	0	0	SRS	1-0	50	0.17	0.29	0.18	0.29	0.18	0.29	0.29

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	Aonly	A	AI	B	BI	C
12	0	0	SRS	1-0,1-3	20	0.15	0.17	0.17	0.17	0.17	0.17	0.17
12	0	0	SRS	1-0,1-3	35	0.16	0.18	0.18	0.18	0.18	0.18	0.18
12	0	0	SRS	1-0,1-3	50	0.14	0.17	0.18	0.17	0.18	0.17	0.18
12	0	0	StRS	1-0,1-3	20	0.12	0.14	0.14	0.14	0.14	0.14	0.14
12	0	0	StRS	1-0,1-3	35	0.11	0.14	0.14	0.14	0.14	0.14	0.14
12	0	0	StRS	1-0,1-3	50	0.11	0.15	0.15	0.15	0.15	0.15	0.15
12	0	0	StRS	1-3	20	0.13	0.22	0.16	0.22	0.16	0.22	0.22
12	0	0	StRS	1-3	35	0.11	0.22	0.13	0.23	0.13	0.23	0.22
12	0	0	StRS	1-3	50	0.11	0.25	0.14	0.30	0.14	0.30	0.25
12	0	0	StRS	1-3	20	0.13	0.17	0.16	0.17	0.16	0.17	0.16
12	0	0	StRS	1-3	35	0.12	0.16	0.16	0.16	0.16	0.16	0.16
12	0	0	StRS	1-3	50	0.12	0.16	0.16	0.16	0.16	0.16	0.16
12	0	0	Unequal	1-0	20	0.14	0.16	0.16	0.16	0.16	0.16	0.16
12	0	0	Unequal	1-0	35	0.17	0.20	0.20	0.20	0.20	0.20	0.20
12	0	0	Unequal	1-0	50	0.16	0.19	0.19	0.19	0.19	0.19	0.19
12	0	0	Unequal	1-0	20	0.18	0.23	0.19	0.26	0.19	0.26	0.23
12	0	0	Unequal	1-0	35	0.16	0.29	0.22	0.27	0.22	0.27	0.29
12	0	0	Unequal	1-0	50	0.17	0.30	0.22	0.30	0.22	0.30	0.30
12	0	0	Unequal	1-0,1-3	20	0.14	0.18	0.18	0.18	0.18	0.18	0.18
12	0	0	Unequal	1-0,1-3	35	0.15	0.19	0.19	0.19	0.19	0.19	0.19
12	0	0	Unequal	1-0,1-3	50	0.18	0.21	0.21	0.22	0.21	0.22	0.21
24	0	0	SRS	1-0,1-3	20	0.14	0.12	0.12	0.12	0.12	0.12	0.12
24	0	0	SRS	1-0,1-3	35	0.15	0.17	0.17	0.17	0.17	0.17	0.17
24	0	0	SRS	1-0,1-3	50	0.13	0.19	0.19	0.19	0.19	0.19	0.19
24	0	0	SRS	1-3	20	0.18	0.20	0.15	0.28	0.15	0.28	0.21
24	0	0	SRS	1-3	35	0.14	0.21	0.14	0.23	0.14	0.23	0.22
24	0	0	SRS	1-3	50	0.13	0.27	0.15	0.28	0.15	0.28	0.27

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	Aonly	A	AI	B	BI	C
24	0	0	SRS	1-3	20	0.12	0.10	0.10	0.10	0.10	0.10	0.10
24	0	0	SRS	1-3	35	0.10	0.11	0.11	0.11	0.11	0.11	0.11
24	0	0	SRS	1-3	50	0.12	0.12	0.12	0.18	0.12	0.18	0.12
24	0	0	StRS	1-0	20	0.07	0.05	0.05	0.05	0.05	0.05	0.05
24	0	0	StRS	1-0	35	0.08	0.21	0.21	0.21	0.21	0.21	0.21
24	0	0	StRS	1-0	50	0.06	0.25	0.25	0.25	0.25	0.25	0.25
24	0	0	StRS	1-0	20	0.09	0.18	0.13	0.28	0.13	0.28	0.18
24	0	0	StRS	1-0	35	0.06	0.21	0.10	0.27	0.10	0.27	0.21
24	0	0	StRS	1-0	50	0.07	0.25	0.10	0.33	0.10	0.33	0.25
24	0	0	StRS	1-0,1-3	20	0.07	0.09	0.09	0.09	0.09	0.09	0.09
24	0	0	StRS	1-0,1-3	35	0.07	0.10	0.10	0.10	0.10	0.10	0.10
24	0	0	StRS	1-0,1-3	50	0.08	0.10	0.10	0.16	0.10	0.16	0.10
24	0	0	Unequal	1-0,1-3	20	0.14	0.14	0.14	0.14	0.14	0.14	0.14
24	0	0	Unequal	1-0,1-3	35	0.17	0.23	0.23	0.23	0.23	0.23	0.23
24	0	0	Unequal	1-0,1-3	50	0.15	0.25	0.25	0.25	0.25	0.25	0.25
24	0	0	Unequal	1-3	20	0.17	0.21	0.18	0.27	0.18	0.27	0.22
24	0	0	Unequal	1-3	35	0.14	0.25	0.18	0.25	0.18	0.25	0.25
24	0	0	Unequal	1-3	50	0.14	0.28	0.21	0.29	0.21	0.29	0.28
24	0	0	Unequal	1-3	20	0.13	0.16	0.16	0.16	0.16	0.16	0.16
24	0	0	Unequal	1-3	35	0.11	0.13	0.13	0.16	0.13	0.16	0.13
24	0	0	Unequal	1-3	50	0.11	0.15	0.16	0.17	0.16	0.17	0.16

Table C5. Trend Test Power of the z-test for the Count Trend Slope Estimate (for trend tests of size 0.13 or less). Note power values < 0.80 (also shaded).

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	SLRDB	WLRDB	Aonly	A	AI	B	BI	C
12	0	0	SRS	1-0	20	–	–	–	0.39	0.39	0.39	0.39	0.39	0.39
12	0	0	SRS	1-0	35	–	–	–	–	–	–	–	–	–
12	0	0	SRS	1-0	50	–	–	–	–	–	–	–	–	–
12	0	0	SRS	1-0	20	–	0.27	–	–	–	–	–	–	–
12	0	0	SRS	1-0	35	–	–	–	–	–	–	–	–	–
12	0	0	SRS	1-0	50	–	–	–	–	–	–	–	–	–
12	0	0	SRS	1-0,1-3	20	–	0.25	–	–	–	–	–	–	–
12	0	0	SRS	1-0,1-3	35	–	–	–	–	–	–	–	–	–
12	0	0	SRS	1-0,1-3	50	–	0.35	–	–	–	–	–	–	–
12	0	0	StRS	1-0,1-3	20	0.46	–	–	–	–	–	–	–	–
12	0	0	StRS	1-0,1-3	35	0.52	–	–	–	–	–	–	–	–
12	0	0	StRS	1-0,1-3	50	0.55	–	–	–	–	–	–	–	–
12	0	0	StRS	1-3	20	0.50	0.34	–	–	–	–	–	–	–
12	0	0	StRS	1-3	35	0.49	–	–	–	–	–	–	–	–
12	0	0	StRS	1-3	50	0.53	–	–	–	–	–	–	–	–
12	0	0	StRS	1-3	20	0.46	0.28	–	–	–	–	–	–	–
12	0	0	StRS	1-3	35	0.52	–	–	–	–	–	–	–	–
12	0	0	StRS	1-3	50	0.54	–	–	–	–	–	–	–	–
12	0	0	Unequal	1-0	20	–	–	–	–	–	–	–	–	–
12	0	0	Unequal	1-0	35	–	–	–	–	–	–	–	–	–
12	0	0	Unequal	1-0	50	–	–	–	–	–	–	–	–	–
12	0	0	Unequal	1-0	20	–	0.27	–	–	–	–	–	–	–
12	0	0	Unequal	1-0	35	–	–	–	–	–	–	–	–	–
12	0	0	Unequal	1-0	50	–	–	–	–	–	–	–	–	–
12	0	0	Unequal	1-0,1-3	20	–	0.24	–	–	–	–	–	–	–

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	SLRDB	WLRDB	Aonly	A	AI	B	BI	C
24	0	0.04	Unequal	1-3	35	0.91	–	–	0.99	0.99	–	0.99	–	0.99
24	0	0.04	Unequal	1-3	50	0.94	–	–	–	–	–	–	–	–

Table C6. Trend Test Power of the χ^2 -test for the Count Trend Slope Estimate (for trend tests of size 0.13 or less). Note power values < 0.80 (also shaded).

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	Aonly	A	AI	B	BI	C
12	0.02	0	SRS	1-0	20	–	0.39	0.39	0.39	0.39	0.39	0.39
12	0.02	0	SRS	1-0	35	–	–	–	–	–	–	–
12	0.02	0	SRS	1-0	50	–	–	–	–	–	–	–
12	0.02	0	SRS	1-0	20	–	–	–	–	–	–	–
12	0.02	0	SRS	1-0	35	–	–	–	–	–	–	–
12	0.02	0	SRS	1-0	50	–	–	–	–	–	–	–
12	0.02	0	SRS	1-0,1-3	20	–	–	–	–	–	–	–
12	0.02	0	SRS	1-0,1-3	35	–	–	–	–	–	–	–
12	0.02	0	SRS	1-0,1-3	50	–	–	–	–	–	–	–
12	0.02	0	StRS	1-0,1-3	20	0.46	–	–	–	–	–	–
12	0.02	0	StRS	1-0,1-3	35	0.52	–	–	–	–	–	–
12	0.02	0	StRS	1-0,1-3	50	0.55	–	–	–	–	–	–
12	0.02	0	StRS	1-3	20	0.50	–	–	–	–	–	–
12	0.02	0	StRS	1-3	35	0.49	–	–	–	–	–	–
12	0.02	0	StRS	1-3	50	0.53	–	–	–	–	–	–
12	0.02	0	StRS	1-3	20	0.46	–	–	–	–	–	–
12	0.02	0	StRS	1-3	35	0.52	–	–	–	–	–	–
12	0.02	0	StRS	1-3	50	0.54	–	–	–	–	–	–
12	0.02	0	Unequal	1-0	20	–	–	–	–	–	–	–

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	Aonly	A	AI	B	BI	C
12	0.02	0	Unequal	1-0	35	–	–	–	–	–	–	–
12	0.02	0	Unequal	1-0	50	–	–	–	–	–	–	–
12	0.02	0	Unequal	1-0	20	–	–	–	–	–	–	–
12	0.02	0	Unequal	1-0	35	–	–	–	–	–	–	–
12	0.02	0	Unequal	1-0	50	–	–	–	–	–	–	–
12	0.02	0	Unequal	1-0,1-3	20	–	–	–	–	–	–	–
12	0.02	0	Unequal	1-0,1-3	35	–	–	–	–	–	–	–
12	0.02	0	Unequal	1-0,1-3	50	–	–	–	–	–	–	–
12	0.02	0.04	SRS	1-0,1-3	20	–	0.60	0.60	0.60	0.60	0.60	0.60
12	0.02	0.04	SRS	1-0,1-3	35	–	–	–	–	–	–	–
12	0.02	0.04	SRS	1-0,1-3	50	–	–	–	–	–	–	–
12	0.02	0.04	SRS	1-3	20	–	–	–	–	–	–	–
12	0.02	0.04	SRS	1-3	35	–	–	–	–	–	–	–
12	0.02	0.04	SRS	1-3	50	–	–	–	–	–	–	–
12	0.02	0.04	SRS	1-3	20	0.69	0.69	0.70	0.70	0.70	0.70	0.70
12	0.02	0.04	SRS	1-3	35	0.70	0.72	0.72	0.72	0.72	0.72	0.72
12	0.02	0.04	SRS	1-3	50	0.70	0.73	0.72	–	0.72	–	0.72
12	0.02	0.04	StRS	1-0	20	0.74	0.79	0.79	0.79	0.79	0.79	0.79
12	0.02	0.04	StRS	1-0	35	0.79	–	–	–	–	–	–
12	0.02	0.04	StRS	1-0	50	0.77	–	–	–	–	–	–
12	0.02	0.04	StRS	1-0	20	0.72	–	0.76	–	0.76	–	–
12	0.02	0.04	StRS	1-0	35	0.76	–	0.81	–	0.81	–	–
12	0.02	0.04	StRS	1-0	50	0.79	–	0.83	–	0.83	–	–
12	0.02	0.04	StRS	1-0,1-3	20	0.72	0.77	0.77	0.77	0.77	0.77	0.77
12	0.02	0.04	StRS	1-0,1-3	35	0.80	0.83	0.83	0.83	0.83	0.83	0.83
12	0.02	0.04	StRS	1-0,1-3	50	0.82	0.85	0.85	–	0.85	–	0.85
12	0.02	0.04	Unequal	1-0,1-3	20	–	–	–	–	–	–	–

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	Aonly	A	AI	B	BI	C
12	0.02	0.04	Unequal	1-0,1-3	35	–	–	–	–	–	–	–
12	0.02	0.04	Unequal	1-0,1-3	50	–	–	–	–	–	–	–
12	0.02	0.04	Unequal	1-3	20	–	–	–	–	–	–	–
12	0.02	0.04	Unequal	1-3	35	–	–	–	–	–	–	–
12	0.02	0.04	Unequal	1-3	50	–	–	–	–	–	–	–
12	0.02	0.04	Unequal	1-3	20	–	–	–	–	–	–	–
12	0.02	0.04	Unequal	1-3	35	0.62	–	0.74	–	0.74	–	0.74
12	0.02	0.04	Unequal	1-3	50	0.61	–	–	–	–	–	–
24	0.01	0	SRS	1-0	20	–	0.50	0.50	0.50	0.50	0.50	0.50
24	0.01	0	SRS	1-0	35	–	–	–	–	–	–	–
24	0.01	0	SRS	1-0	50	–	–	–	–	–	–	–
24	0.01	0	SRS	1-0	20	–	–	–	–	–	–	–
24	0.01	0	SRS	1-0	35	–	–	–	–	–	–	–
24	0.01	0	SRS	1-0	50	–	–	–	–	–	–	–
24	0.01	0	SRS	1-0,1-3	20	0.54	0.62	0.62	0.62	0.62	0.62	0.62
24	0.01	0	SRS	1-0,1-3	35	0.60	0.67	0.67	0.69	0.67	0.69	0.67
24	0.01	0	SRS	1-0,1-3	50	0.62	0.70	0.70	–	0.70	–	0.70
24	0.01	0	StRS	1-0,1-3	20	0.60	0.61	0.61	0.61	0.61	0.61	0.61
24	0.01	0	StRS	1-0,1-3	35	0.67	–	–	–	–	–	–
24	0.01	0	StRS	1-0,1-3	50	0.72	–	–	–	–	–	–
24	0.01	0	StRS	1-3	20	0.62	–	0.73	–	0.73	–	–
24	0.01	0	StRS	1-3	35	0.66	–	0.75	–	0.75	–	–
24	0.01	0	StRS	1-3	50	0.73	–	0.79	–	0.79	–	–
24	0.01	0	StRS	1-3	20	0.70	0.77	0.77	0.77	0.77	0.77	0.77
24	0.01	0	StRS	1-3	35	0.77	0.83	0.83	0.83	0.83	0.83	0.83
24	0.01	0	StRS	1-3	50	0.77	0.82	0.83	–	0.83	–	0.83
24	0.01	0	Unequal	1-0	20	–	–	–	–	–	–	–

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	Aonly	A	AI	B	BI	C
24	0.01	0	Unequal	1-0	35	–	–	–	–	–	–	–
24	0.01	0	Unequal	1-0	50	–	–	–	–	–	–	–
24	0.01	0	Unequal	1-0	20	–	–	–	–	–	–	–
24	0.01	0	Unequal	1-0	35	–	–	–	–	–	–	–
24	0.01	0	Unequal	1-0	50	–	–	–	–	–	–	–
24	0.01	0	Unequal	1-0,1-3	20	–	–	–	–	–	–	–
24	0.01	0	Unequal	1-0,1-3	35	0.66	–	0.73	–	0.73	–	0.73
24	0.01	0	Unequal	1-0,1-3	50	0.69	–	–	–	–	–	–
24	0.01	0.04	SRS	1-0,1-3	20	–	0.85	0.85	0.85	0.85	0.85	0.85
24	0.01	0.04	SRS	1-0,1-3	35	–	–	–	–	–	–	–
24	0.01	0.04	SRS	1-0,1-3	50	–	–	–	–	–	–	–
24	0.01	0.04	SRS	1-3	20	–	–	–	–	–	–	–
24	0.01	0.04	SRS	1-3	35	–	–	–	–	–	–	–
24	0.01	0.04	SRS	1-3	50	–	–	–	–	–	–	–
24	0.01	0.04	SRS	1-3	20	0.95	0.95	0.95	0.95	0.95	0.95	0.95
24	0.01	0.04	SRS	1-3	35	0.97	0.97	0.97	0.97	0.97	0.97	0.97
24	0.01	0.04	SRS	1-3	50	0.99	0.99	0.99		0.99		0.99
24	0.01	0.04	StRS	1-0	20	0.97	0.98	0.98	0.98	0.98	0.98	0.98
24	0.01	0.04	StRS	1-0	35	0.99	–	–	–	–	–	–
24	0.01	0.04	StRS	1-0	50	0.99	–	–	–	–	–	–
24	0.01	0.04	StRS	1-0	20	0.99	–	0.98	–	0.98	–	–
24	0.01	0.04	StRS	1-0	35	0.99	–	1.00	–	1.00	–	–
24	0.01	0.04	StRS	1-0	50	1.00	–	1.00	–	1.00	–	–
24	0.01	0.04	StRS	1-0,1-3	20	1.00	1.00	1.00	1.00	1.00	1.00	1.00
24	0.01	0.04	StRS	1-0,1-3	35	1.00	1.00	1.00	1.00	1.00	1.00	1.00
24	0.01	0.04	StRS	1-0,1-3	50	1.00	1.00	1.00	–	1.00	–	1.00
24	0.01	0.04	Unequal	1-0,1-3	20	–	–	–	–	–	–	–

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	Aonly	A	AI	B	BI	C
24	0.01	0.04	Unequal	1-0,1-3	35	–	–	–	–	–	–	–
24	0.01	0.04	Unequal	1-0,1-3	50	–	–	–	–	–	–	–
24	0.01	0.04	Unequal	1-3	20	–	–	–	–	–	–	–
24	0.01	0.04	Unequal	1-3	35	–	–	–	–	–	–	–
24	0.01	0.04	Unequal	1-3	50	–	–	–	–	–	–	–
24	0.01	0.04	Unequal	1-3	20	–	–	–	–	–	–	–
24	0.01	0.04	Unequal	1-3	35	0.91	–	0.99	–	0.99	–	0.99
24	0.01	0.04	Unequal	1-3	50	0.94	–	–	–	–	–	–

Table C7. Percent Relative Bias of the Count Site-to-Site Variance Estimate. Note the relative bias values > 5% or < -5% (also shaded).

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	Aonly	A	AI	B	BI	C
12	0.02	0	SRS	1-0	20	-8.23	1892033.12	1892033.12	1892033.12	1892033.12	1892033.12	1892033.12
12	0.02	0	SRS	1-0	35	-10.63	1066478.19	1066478.19	1066478.19	1066478.19	1066478.19	1066478.19
12	0.02	0	SRS	1-0	50	-3.38	733338.16	733338.16	733338.16	733338.16	733338.16	733338.16
12	0.02	0	SRS	1-0	20	-2.22	797637.82	785768.89	2340778.10	785768.89	2340778.10	792093.95
12	0.02	0	SRS	1-0	35	0.85	373159.48	370904.62	1221513.12	370904.62	1221513.12	372222.68
12	0.02	0	SRS	1-0	50	0.65	234051.24	235772.86	754806.38	235772.86	754806.38	239453.43
12	0.02	0	SRS	1-0,1-3	20	1.25	517557.10	522624.34	2073846.65	522624.34	2073846.65	522624.34
12	0.02	0	SRS	1-0,1-3	35	1.71	300235.37	293231.45	1191193.95	293231.45	1191193.95	293231.45
12	0.02	0	SRS	1-0,1-3	50	1.43	206886.18	203919.07	827563.66	203919.07	827563.66	203919.07
12	0.02	0	StRS	1-0,1-3	20	-10.71	1657352.34	1657352.34	1657352.34	1657352.34	1657352.34	1657352.34
12	0.02	0	StRS	1-0,1-3	35	-5.28	999271.55	999271.55	999271.55	999271.55	999271.55	999271.55
12	0.02	0	StRS	1-0,1-3	50	-2.02	734509.66	734509.66	734509.66	734509.66	734509.66	734509.66
12	0.02	0	StRS	1-3	20	-3.69	770492.33	766613.66	2284839.87	766613.66	2284839.87	769501.91
12	0.02	0	StRS	1-3	35	-0.39	439280.66	436067.91	1351753.84	436067.91	1351753.84	436416.03

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	Aonly	A	AI	B	BI	C
12	0.02	0	StRS	1-3	50	-0.05	305771.29	306056.78	196598.96	306056.78	196598.96	305071.66
12	0.02	0	StRS	1-3	20	0.23	479565.81	475751.46	1928618.81	475751.46	1928618.81	475751.46
12	0.02	0	StRS	1-3	35	0.26	275733.25	275722.07	1100836.02	275722.07	1100836.02	275722.07
12	0.02	0	StRS	1-3	50	1.32	195453.12	195092.41	779968.39	195092.41	779968.39	195092.41
12	0.02	0	Unequal	1-0	20	-10.00	1794123.46	1794123.46	1794123.46	1794123.46	1794123.46	1794123.46
12	0.02	0	Unequal	1-0	35	-9.26	1026543.86	1026543.86	1026543.86	1026543.86	1026543.86	1026543.86
12	0.02	0	Unequal	1-0	50	-1.58	736606.79	736606.79	736606.79	736606.79	736606.79	736606.79
12	0.02	0	Unequal	1-0	20	-0.35	739745.32	734160.72	2111380.19	734160.72	2111380.19	729106.20
12	0.02	0	Unequal	1-0	35	0.81	330003.21	326112.52	754757.78	326112.52	754757.78	329594.89
12	0.02	0	Unequal	1-0	50	1.00	211784.78	210907.32	766559.25	210907.32	766559.25	214253.48
12	0.02	0	Unequal	1-0,1-3	20	2.12	471350.34	464373.84	1880839.99	464373.84	1880839.99	464373.84
12	0.02	0	Unequal	1-0,1-3	35	2.44	269402.47	263712.12	1076947.27	263712.12	1076947.27	263712.12
12	0.02	0	Unequal	1-0,1-3	50	1.16	183238.07	183174.78	734561.14	183174.78	734561.14	183174.78
12	0.02	0.04	SRS	1-0,1-3	20	-9.39	1858645.86	1858645.86	1858645.86	1858645.86	1858645.86	1858645.86
12	0.02	0.04	SRS	1-0,1-3	35	-9.21	1053729.72	1053729.72	1053729.72	1053729.72	1053729.72	1053729.72
12	0.02	0.04	SRS	1-0,1-3	50	-4.05	741762.82	741762.82	741762.82	741762.82	741762.82	741762.82
12	0.02	0.04	SRS	1-3	20	-2.10	796378.29	788641.34	2323919.16	788641.34	2323919.16	791728.68
12	0.02	0.04	SRS	1-3	35	0.73	373862.29	368313.28	1229193.83	368313.28	1229193.83	367091.87
12	0.02	0.04	SRS	1-3	50	0.77	235044.86	240346.25	676583.40	240346.25	676583.40	241722.39
12	0.02	0.04	SRS	1-3	20	-1.08	524689.50	521821.76	2078262.67	521821.76	2078262.67	521821.76
12	0.02	0.04	SRS	1-3	35	0.20	301278.88	295732.45	1190288.15	295732.45	1190288.15	295732.45
12	0.02	0.04	SRS	1-3	50	-0.24	203974.02	202479.60	806332.95	202479.60	806332.95	202479.60
12	0.02	0.04	StRS	1-0	20	-12.98	1660736.99	1660736.99	1660736.99	1660736.99	1660736.99	1660736.99
12	0.02	0.04	StRS	1-0	35	-4.71	1017304.76	1017304.76	1017304.76	1017304.76	1017304.76	1017304.76
12	0.02	0.04	StRS	1-0	50	-2.17	729306.73	729306.73	729306.73	729306.73	729306.73	729306.73
12	0.02	0.04	StRS	1-0	20	-3.27	777805.11	776859.84	2328693.48	776859.84	2328693.48	773453.03

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	Aonly	A	AI	B	BI	C
12	0.02	0.04	StRS	1-0	35	-2.71	430169.87	428914.72	1330326.58	428914.72	1330326.58	426556.82
12	0.02	0.04	StRS	1-0	50	0.11	309465.51	308265.01	230149.77	308265.01	230149.77	308849.92
12	0.02	0.04	StRS	1-0,1-3	20	-0.22	489563.69	487107.92	1966593.90	487107.92	1966593.90	487107.92
12	0.02	0.04	StRS	1-0,1-3	35	0.91	281467.99	280423.49	1122128.90	280423.49	1122128.90	280423.49
12	0.02	0.04	StRS	1-0,1-3	50	0.01	196964.28	195467.20	779148.36	195467.20	779148.36	195467.20
12	0.02	0.04	Unequal	1-0,1-3	20	-8.24	1766725.48	1766725.48	1766725.48	1766725.48	1766725.48	1766725.48
12	0.02	0.04	Unequal	1-0,1-3	35	-8.54	1022706.62	1022706.62	1022706.62	1022706.62	1022706.62	1022706.62
12	0.02	0.04	Unequal	1-0,1-3	50	-3.59	722980.41	722980.41	722980.41	722980.41	722980.41	722980.41
12	0.02	0.04	Unequal	1-3	20	-3.11	728820.95	721966.31	2094809.04	721966.31	2094809.04	719833.03
12	0.02	0.04	Unequal	1-3	35	-0.34	330765.77	325795.35	717901.48	325795.35	717901.48	330129.66
12	0.02	0.04	Unequal	1-3	50	1.24	216064.40	216172.12	777282.56	216172.12	777282.56	218183.32
12	0.02	0.04	Unequal	1-3	20	-0.72	468191.10	462108.46	1851679.08	462108.46	1851679.08	462108.46
12	0.02	0.04	Unequal	1-3	35	-0.27	262829.37	261113.25	1041896.60	261113.25	1041896.60	261113.25
12	0.02	0.04	Unequal	1-3	50	-0.88	181526.30	182430.59	724996.42	182430.59	724996.42	182430.59
24	0.01	0	SRS	1-0	20	-2.55	1037272.15	1037272.15	1037272.15	1037272.15	1037272.15	1037272.15
24	0.01	0	SRS	1-0	35	-6.49	837543.37	837543.37	837543.37	837543.37	837543.37	837543.37
24	0.01	0	SRS	1-0	50	-7.47	575619.71	575619.71	575619.71	575619.71	575619.71	575619.71
24	0.01	0	SRS	1-0	20	-7.21	765248.84	751088.29	982594.41	751088.29	982594.41	738086.54
24	0.01	0	SRS	1-0	35	-3.08	353588.59	350040.43	1109238.50	350040.43	1109238.50	347064.89
24	0.01	0	SRS	1-0	50	-0.89	231131.69	228848.17	782385.48	228848.17	782385.48	226765.40
24	0.01	0	SRS	1-0,1-3	20	-10.11	482395.58	471465.80	1920121.17	471465.80	1920121.17	471465.80
24	0.01	0	SRS	1-0,1-3	35	-1.36	278933.03	275414.77	1036867.91	275414.77	1036867.91	275414.77
24	0.01	0	SRS	1-0,1-3	50	-0.71	197093.93	195997.05	601791.76	195997.05	601791.76	195997.05
24	0.01	0	StRS	1-0,1-3	20	-11.75	675503.92	675503.92	675503.92	675503.92	675503.92	675503.92
24	0.01	0	StRS	1-0,1-3	35	-5.68	403475.10	403475.10	403475.10	403475.10	403475.10	403475.10
24	0.01	0	StRS	1-0,1-3	50	-3.40	196726.93	196726.93	196726.93	196726.93	196726.93	196726.93

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	Aonly	A	AI	B	BI	C
24	0.01	0	StRS	1-3	20	-10.72	708765.90	696041.09	704004.24	696041.09	704004.24	678026.42
24	0.01	0	StRS	1-3	35	-1.73	410390.23	401424.21	394560.37	401424.21	394560.37	404011.03
24	0.01	0	StRS	1-3	50	-0.67	296234.29	288932.37	379065.49	288932.37	379065.49	287367.57
24	0.01	0	StRS	1-3	20	-5.64	467478.91	447768.89	1863963.70	447768.89	1863963.70	447768.89
24	0.01	0	StRS	1-3	35	-0.96	273453.06	270593.09	1096756.57	270593.09	1096756.57	270593.09
24	0.01	0	StRS	1-3	50	-3.64	188738.21	185821.54	614149.53	185821.54	614149.53	185821.54
24	0.01	0	Unequal	1-0	20	-3.93	856923.32	856923.32	856923.32	856923.32	856923.32	856923.32
24	0.01	0	Unequal	1-0	35	-5.73	587713.97	587713.97	587713.97	587713.97	587713.97	587713.97
24	0.01	0	Unequal	1-0	50	-7.44	480625.91	480625.91	480625.91	480625.91	480625.91	480625.91
24	0.01	0	Unequal	1-0	20	-9.44	688811.72	685280.00	1032614.07	685280.00	1032614.07	675058.12
24	0.01	0	Unequal	1-0	35	-3.07	331163.45	326848.35	1095347.55	326848.35	1095347.55	326436.62
24	0.01	0	Unequal	1-0	50	-0.10	215378.77	214048.10	749719.31	214048.10	749719.31	214914.37
24	0.01	0	Unequal	1-0,1-3	20	-9.27	445069.19	435645.42	1744014.63	435645.42	1744014.63	435645.42
24	0.01	0	Unequal	1-0,1-3	35	-0.07	262413.14	260024.17	850471.12	260024.17	850471.12	260024.17
24	0.01	0	Unequal	1-0,1-3	50	0.07	183819.39	183154.04	617364.77	183154.04	617364.77	183154.04
24	0.01	0.04	SRS	1-0,1-3	20	-5.08	656603.90	656603.90	656603.90	656603.90	656603.90	656603.90
24	0.01	0.04	SRS	1-0,1-3	35	-4.99	331263.97	331263.97	331263.97	331263.97	331263.97	331263.97
24	0.01	0.04	SRS	1-0,1-3	50	-2.93	185434.27	185434.27	185434.27	185434.27	185434.27	185434.27
24	0.01	0.04	SRS	1-3	20	-7.62	592883.12	573734.06	499510.15	573734.06	499510.15	564875.62
24	0.01	0.04	SRS	1-3	35	-5.15	347621.10	325783.02	697927.29	325783.02	697927.29	317094.07
24	0.01	0.04	SRS	1-3	50	-1.32	211621.03	206960.21	713433.86	206960.21	713433.86	210139.82
24	0.01	0.04	SRS	1-3	20	-9.78	478710.15	442667.74	1870995.79	442667.74	1870995.79	442667.74
24	0.01	0.04	SRS	1-3	35	-2.35	279091.56	273798.42	1096888.86	273798.42	1096888.86	273798.42
24	0.01	0.04	SRS	1-3	50	-1.48	195238.94	194666.11	737477.67	194666.11	737477.67	194666.11
24	0.01	0.04	StRS	1-0	20	-16.57	662079.61	662079.61	662079.61	662079.61	662079.61	662079.61
24	0.01	0.04	StRS	1-0	35	-14.96	388818.03	388818.03	388818.03	388818.03	388818.03	388818.03

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	Aonly	A	AI	B	BI	C
24	0.01	0.04	StRS	1-0	50	-8.83	153500.20	153500.20	153500.20	153500.20	153500.20	153500.20
24	0.01	0.04	StRS	1-0	20	-11.36	695737.55	688940.67	798770.86	688940.67	798770.86	686336.31
24	0.01	0.04	StRS	1-0	35	-2.47	405738.24	400427.04	325358.20	400427.04	325358.20	392029.48
24	0.01	0.04	StRS	1-0	50	-0.48	298347.94	290483.75	359829.91	290483.75	359829.91	288173.06
24	0.01	0.04	StRS	1-0,1-3	20	-4.97	476983.15	454412.87	1904825.55	454412.87	1904825.55	454412.87
24	0.01	0.04	StRS	1-0,1-3	35	-2.79	271327.69	267653.63	1086861.98	267653.63	1086861.98	267653.63
24	0.01	0.04	StRS	1-0,1-3	50	-2.93	192245.55	188835.10	649856.45	188835.10	649856.45	188835.10
24	0.01	0.04	Unequal	1-0,1-3	20	-0.64	695011.13	695011.13	695011.13	695011.13	695011.13	695011.13
24	0.01	0.04	Unequal	1-0,1-3	35	-5.09	273862.44	273862.44	273862.44	273862.44	273862.44	273862.44
24	0.01	0.04	Unequal	1-0,1-3	50	-5.52	168631.42	168631.42	168631.42	168631.42	168631.42	168631.42
24	0.01	0.04	Unequal	1-3	20	-8.05	622322.27	588493.33	435859.61	588493.33	435859.61	587818.34
24	0.01	0.04	Unequal	1-3	35	-7.00	303731.88	291374.80	802788.08	291374.80	802788.08	293907.55
24	0.01	0.04	Unequal	1-3	50	-1.26	208409.75	207967.25	677982.72	207967.25	677982.72	206900.69
24	0.01	0.04	Unequal	1-3	20	-8.96	442291.01	426123.27	1724494.60	426123.27	1724494.60	426123.27
24	0.01	0.04	Unequal	1-3	35	-1.31	253188.63	248424.24	994237.94	248424.24	994237.94	248424.24
24	0.01	0.04	Unequal	1-3	50	-2.27	176182.40	170489.19	534432.96	170489.19	534432.96	170489.19

Table C8. Percent Relative Bias of the Count Site-Level Slope Variance Estimate. Note the relative bias values > 5% or < -5% (also shaded).

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	Aonly	A	AI	B	BI	C
12	0.02	0	SRS	1-0	20	62.55	5280878.97	5280878.97	5280878.97	5280878.97	5280878.97	5280878.97
12	0.02	0	SRS	1-0	35	18.96	2392385.83	2392385.83	2392385.83	2392385.83	2392385.83	2392385.83
12	0.02	0	SRS	1-0	50	49.47	1482456.43	1482456.43	1482456.43	1482456.43	1482456.43	1482456.43
12	0.02	0	SRS	1-0	20	133.88	2520006.60	2431660.89	5707938.12	2431660.89	5707938.12	2502647.86
12	0.02	0	SRS	1-0	35	138.43	1118224.02	1100627.84	2759034.13	1100627.84	2759034.13	1119374.73

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	Aonly	A	AI	B	BI	C
12	0.02	0	SRS	1-0	50	140.01	688337.13	693496.26	1752907.29	693496.26	1752907.29	710668.19
12	0.02	0	SRS	1-0,1-3	20	263.97	2496268.09	2518443.46	10092075.46	2518443.46	10092075.46	2518443.46
12	0.02	0	SRS	1-0,1-3	35	191.45	1158308.46	1117199.46	4608767.95	1117199.46	4608767.95	1117199.46
12	0.02	0	SRS	1-0,1-3	50	170.37	774957.79	760382.50	3047485.97	760382.50	3047485.97	760382.50
12	0.02	0	StRS	1-0,1-3	20	26.07	2718664.42	2718664.42	2718664.42	2718664.42	2718664.42	2718664.42
12	0.02	0	StRS	1-0,1-3	35	39.86	1501395.96	1501395.96	1501395.96	1501395.96	1501395.96	1501395.96
12	0.02	0	StRS	1-0,1-3	50	30.80	1022666.31	1022666.31	1022666.31	1022666.31	1022666.31	1022666.31
12	0.02	0	StRS	1-3	20	56.27	1349474.93	1319105.39	3728829.65	1319105.39	3728829.65	1347309.77
12	0.02	0	StRS	1-3	35	50.72	689064.85	674765.72	1955059.26	674765.72	1955059.26	686782.54
12	0.02	0	StRS	1-3	50	48.74	485316.86	483176.66	253191.25	483176.66	253191.25	483336.56
12	0.02	0	StRS	1-3	20	138.33	1115406.13	1098332.20	4476736.39	1098332.20	4476736.39	1098332.20
12	0.02	0	StRS	1-3	35	93.78	483688.24	483033.79	1928690.28	483033.79	1928690.28	483033.79
12	0.02	0	StRS	1-3	50	90.31	332881.07	332608.75	1335616.57	332608.75	1335616.57	332608.75
12	0.02	0	Unequal	1-0	20	53.80	4463978.87	4463978.87	4463978.87	4463978.87	4463978.87	4463978.87
12	0.02	0	Unequal	1-0	35	19.24	2186745.21	2186745.21	2186745.21	2186745.21	2186745.21	2186745.21
12	0.02	0	Unequal	1-0	50	68.30	1518587.39	1518587.39	1518587.39	1518587.39	1518587.39	1518587.39
12	0.02	0	Unequal	1-0	20	176.83	2470242.78	2399212.18	5479924.07	2399212.18	5479924.07	2424863.21
12	0.02	0	Unequal	1-0	35	144.28	899524.88	888090.02	1799562.20	888090.02	1799562.20	910119.06
12	0.02	0	Unequal	1-0	50	131.54	528568.18	530000.63	1539411.73	530000.63	1539411.73	536176.55
12	0.02	0	Unequal	1-0,1-3	20	279.20	1975657.81	1963453.05	7896120.10	1963453.05	7896120.10	1963453.05
12	0.02	0	Unequal	1-0,1-3	35	183.34	886101.25	877216.94	3552598.64	877216.94	3552598.64	877216.94
12	0.02	0	Unequal	1-0,1-3	50	146.01	517910.47	518725.53	2081059.61	518725.53	2081059.61	518725.53
12	0.02	0.04	SRS	1-0,1-3	20	126.38	7112529.81	7112529.81	7112529.81	7112529.81	7112529.81	7112529.81
12	0.02	0.04	SRS	1-0,1-3	35	116.97	3672327.16	3672327.16	3672327.16	3672327.16	3672327.16	3672327.16
12	0.02	0.04	SRS	1-0,1-3	50	204.72	2442398.20	2442398.20	2442398.20	2442398.20	2442398.20	2442398.20
12	0.02	0.04	SRS	1-3	20	273.65	3481489.66	3340556.38	6123411.67	3340556.38	6123411.67	3464262.00

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	Aonly	A	AI	B	BI	C
12	0.02	0.04	SRS	1-3	35	294.56	1479246.94	1438126.38	2945954.06	1438126.38	2945954.06	1451482.84
12	0.02	0.04	SRS	1-3	50	282.37	844588.94	867720.06	1594204.16	867720.06	1594204.16	866922.16
12	0.02	0.04	SRS	1-3	20	333.63	2710859.69	2687090.20	10639746.65	2687090.20	10639746.65	2687090.20
12	0.02	0.04	SRS	1-3	35	298.54	1404693.00	1367609.23	5516724.68	1367609.23	5516724.68	1367609.23
12	0.02	0.04	SRS	1-3	50	270.77	801103.21	790372.25	3175808.08	790372.25	3175808.08	790372.25
12	0.02	0.04	StRS	1-0	20	24.14	2890254.13	2890254.13	2890254.13	2890254.13	2890254.13	2890254.13
12	0.02	0.04	StRS	1-0	35	32.21	1523279.00	1523279.00	1523279.00	1523279.00	1523279.00	1523279.00
12	0.02	0.04	StRS	1-0	50	30.89	1036739.63	1036739.63	1036739.63	1036739.63	1036739.63	1036739.63
12	0.02	0.04	StRS	1-0	20	57.77	1421038.11	1395553.72	3884901.55	1395553.72	3884901.55	1407650.29
12	0.02	0.04	StRS	1-0	35	45.20	691337.41	673505.10	1966527.19	673505.10	1966527.19	685978.68
12	0.02	0.04	StRS	1-0	50	48.63	491621.79	483932.77	316124.07	483932.77	316124.07	490451.61
12	0.02	0.04	StRS	1-0,1-3	20	130.07	1181334.41	1176135.82	4760677.52	1176135.82	4760677.52	1176135.82
12	0.02	0.04	StRS	1-0,1-3	35	103.08	549211.73	546573.48	2187269.24	546573.48	2187269.24	546573.48
12	0.02	0.04	StRS	1-0,1-3	50	85.25	373145.21	368627.46	1472231.93	368627.46	1472231.93	368627.46
12	0.02	0.04	Unequal	1-0,1-3	20	134.78	5356769.18	5356769.18	5356769.18	5356769.18	5356769.18	5356769.18
12	0.02	0.04	Unequal	1-0,1-3	35	83.64	2538514.37	2538514.37	2538514.37	2538514.37	2538514.37	2538514.37
12	0.02	0.04	Unequal	1-0,1-3	50	177.62	1786241.39	1786241.39	1786241.39	1786241.39	1786241.39	1786241.39
12	0.02	0.04	Unequal	1-3	20	239.66	2669269.62	2548498.67	5374641.92	2548498.67	5374641.92	2597544.36
12	0.02	0.04	Unequal	1-3	35	220.14	917757.57	878900.48	1612045.27	878900.48	1612045.27	912436.38
12	0.02	0.04	Unequal	1-3	50	230.58	556802.48	561755.54	1490802.39	561755.54	1490802.39	562092.48
12	0.02	0.04	Unequal	1-3	20	325.25	1891033.20	1846679.29	7385710.84	1846679.29	7385710.84	1846679.29
12	0.02	0.04	Unequal	1-3	35	298.70	913362.67	908867.85	3608946.75	908867.85	3608946.75	908867.85
12	0.02	0.04	Unequal	1-3	50	257.97	567249.29	572739.25	2253055.81	572739.25	2253055.81	572739.25
24	0.01	0	SRS	1-0	20	12.36	1309778.46	1309778.46	1309778.46	1309778.46	1309778.46	1309778.46
24	0.01	0	SRS	1-0	35	-2.11	1001143.94	1001143.94	1001143.94	1001143.94	1001143.94	1001143.94
24	0.01	0	SRS	1-0	50	-4.51	667439.62	667439.62	667439.62	667439.62	667439.62	667439.62

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	Aonly	A	AI	B	BI	C
24	0.01	0	SRS	1-0	20	4.52	997447.12	973450.84	1398713.04	973450.84	1398713.04	965399.47
24	0.01	0	SRS	1-0	35	10.24	439773.52	435525.49	1306388.14	435525.49	1306388.14	430829.07
24	0.01	0	SRS	1-0	50	11.95	281426.71	279880.52	906786.12	279880.52	906786.12	276082.06
24	0.01	0	SRS	1-0,1-3	20	5.83	673441.39	658725.38	2675920.59	658725.38	2675920.59	658725.38
24	0.01	0	SRS	1-0,1-3	35	16.69	359846.48	354098.09	1335286.20	354098.09	1335286.20	354098.09
24	0.01	0	SRS	1-0,1-3	50	13.81	244476.11	243270.52	749864.21	243270.52	749864.21	243270.52
24	0.01	0	StRS	1-0,1-3	20	-7.26	757041.66	757041.66	757041.66	757041.66	757041.66	757041.66
24	0.01	0	StRS	1-0,1-3	35	-3.63	443887.16	443887.16	443887.16	443887.16	443887.16	443887.16
24	0.01	0	StRS	1-0,1-3	50	-0.49	215540.66	215540.66	215540.66	215540.66	215540.66	215540.66
24	0.01	0	StRS	1-3	20	-10.53	793293.79	777965.51	764236.97	777965.51	764236.97	764550.51
24	0.01	0	StRS	1-3	35	3.26	447592.74	437693.04	457418.89	437693.04	457418.89	443158.02
24	0.01	0	StRS	1-3	50	3.86	318284.24	312104.83	418056.89	312104.83	418056.89	311416.58
24	0.01	0	StRS	1-3	20	4.55	546684.21	526467.93	2182252.64	526467.93	2182252.64	526467.93
24	0.01	0	StRS	1-3	35	8.19	307683.52	304803.22	1233972.60	304803.22	1233972.60	304803.22
24	0.01	0	StRS	1-3	50	1.35	204775.91	201654.41	651768.26	201654.41	651768.26	201654.41
24	0.01	0	Unequal	1-0	20	10.77	1049732.37	1049732.37	1049732.37	1049732.37	1049732.37	1049732.37
24	0.01	0	Unequal	1-0	35	-1.21	693463.23	693463.23	693463.23	693463.23	693463.23	693463.23
24	0.01	0	Unequal	1-0	50	-4.72	557759.63	557759.63	557759.63	557759.63	557759.63	557759.63
24	0.01	0	Unequal	1-0	20	0.46	860787.67	852581.92	1351868.95	852581.92	1351868.95	844744.53
24	0.01	0	Unequal	1-0	35	8.94	407909.65	401937.00	1299547.55	401937.00	1299547.55	400909.30
24	0.01	0	Unequal	1-0	50	15.33	262117.42	261218.35	890170.47	261218.35	890170.47	261722.05
24	0.01	0	Unequal	1-0,1-3	20	5.98	586770.73	574549.94	2293274.25	574549.94	2293274.25	574549.94
24	0.01	0	Unequal	1-0,1-3	35	21.76	342073.17	339239.84	1103663.97	339239.84	1103663.97	339239.84
24	0.01	0	Unequal	1-0,1-3	50	16.66	228324.11	227499.89	777878.30	227499.89	777878.30	227499.89
24	0.01	0.04	SRS	1-0,1-3	20	232.57	2206137.14	2206137.14	2206137.14	2206137.14	2206137.14	2206137.14
24	0.01	0.04	SRS	1-0,1-3	35	191.66	1048395.61	1048395.61	1048395.61	1048395.61	1048395.61	1048395.61

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	Aonly	A	AI	B	BI	C
24	0.01	0.04	SRS	1-0,1-3	50	204.96	565226.73	565226.73	565226.73	565226.73	565226.73	565226.73
24	0.01	0.04	SRS	1-3	20	167.06	1806057.40	1710989.67	940553.28	1710989.67	940553.28	1716336.01
24	0.01	0.04	SRS	1-3	35	198.14	1035838.09	968223.76	1570966.45	968223.76	1570966.45	943028.63
24	0.01	0.04	SRS	1-3	50	254.92	644304.56	631539.54	1797940.87	631539.54	1797940.87	638570.14
24	0.01	0.04	SRS	1-3	20	147.74	1425638.50	1316664.72	5510823.61	1316664.72	5510823.61	1316664.72
24	0.01	0.04	SRS	1-3	35	245.73	850846.64	837763.48	3348895.74	837763.48	3348895.74	837763.48
24	0.01	0.04	SRS	1-3	50	249.12	588912.60	588265.69	2219949.93	588265.69	2219949.93	588265.69
24	0.01	0.04	StRS	1-0	20	-18.76	736387.48	736387.48	736387.48	736387.48	736387.48	736387.48
24	0.01	0.04	StRS	1-0	35	-18.95	434172.64	434172.64	434172.64	434172.64	434172.64	434172.64
24	0.01	0.04	StRS	1-0	50	-10.46	168043.78	168043.78	168043.78	168043.78	168043.78	168043.78
24	0.01	0.04	StRS	1-0	20	-13.20	778452.90	773676.71	850223.75	773676.71	850223.75	770544.20
24	0.01	0.04	StRS	1-0	35	1.67	439798.78	436381.51	361586.77	436381.51	361586.77	427674.94
24	0.01	0.04	StRS	1-0	50	5.11	330180.80	323438.73	402822.62	323438.73	402822.62	321438.85
24	0.01	0.04	StRS	1-0,1-3	20	5.76	574467.17	548954.50	2295517.84	548954.50	2295517.84	548954.50
24	0.01	0.04	StRS	1-0,1-3	35	6.35	310624.46	306045.76	1242449.54	306045.76	1242449.54	306045.76
24	0.01	0.04	StRS	1-0,1-3	50	4.53	218981.95	215085.51	730186.33	215085.51	730186.33	215085.51
24	0.01	0.04	Unequal	1-0,1-3	20	185.37	1753942.86	1753942.86	1753942.86	1753942.86	1753942.86	1753942.86
24	0.01	0.04	Unequal	1-0,1-3	35	155.47	718812.62	718812.62	718812.62	718812.62	718812.62	718812.62
24	0.01	0.04	Unequal	1-0,1-3	50	149.24	415664.88	415664.88	415664.88	415664.88	415664.88	415664.88
24	0.01	0.04	Unequal	1-3	20	137.19	1356039.00	1245730.49	611639.27	1245730.49	611639.27	1257873.71
24	0.01	0.04	Unequal	1-3	35	157.42	577071.06	538487.41	1001560.34	538487.41	1001560.34	550982.48
24	0.01	0.04	Unequal	1-3	50	204.93	395269.80	383751.83	915611.63	383751.83	915611.63	392865.25
24	0.01	0.04	Unequal	1-3	20	126.61	800302.97	770174.04	3124285.59	770174.04	3124285.59	770174.04
24	0.01	0.04	Unequal	1-3	35	205.52	457021.85	444689.81	1779498.97	444689.81	1779498.97	444689.81
24	0.01	0.04	Unequal	1-3	50	204.91	299857.97	289612.78	899035.81	289612.78	899035.81	289612.78

Table C9. Percent Relative Bias of the Count Year-to-Year Variance Estimate. Note the relative bias values > 5% or < -5% (also shaded).

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	Aonly	A	AI	B	BI	C
12	0.02	0	SRS	1-0	20	-15.78	1563593.74	1563593.74	1563593.74	1563593.74	1563593.74	1563593.74
12	0.02	0	SRS	1-0	35	-16.94	876693.80	876693.80	876693.80	876693.80	876693.80	876693.80
12	0.02	0	SRS	1-0	50	-15.00	602539.63	602539.63	602539.63	602539.63	602539.63	602539.63
12	0.02	0	SRS	1-0	20	-17.17	879497.02	621940.74	886462.89	621940.74	886462.89	348843.34
12	0.02	0	SRS	1-0	35	-16.49	531995.21	286548.48	497691.63	286548.48	497691.63	168397.27
12	0.02	0	SRS	1-0	50	-17.18	377376.04	180120.02	343756.84	180120.02	343756.84	115368.26
12	0.02	0	SRS	1-0,1-3	20	-22.11	1415249.48	363567.39	1404958.96	363567.39	1404958.96	363567.39
12	0.02	0	SRS	1-0,1-3	35	-19.87	852013.97	203649.38	842953.57	203649.38	842953.57	203649.38
12	0.02	0	SRS	1-0,1-3	50	-20.35	583808.73	143676.69	575787.07	143676.69	575787.07	143676.69
12	0.02	0	StRS	1-0,1-3	20	-23.69	1167220.52	1167220.52	1167220.52	1167220.52	1167220.52	1167220.52
12	0.02	0	StRS	1-0,1-3	35	-21.64	699480.97	699480.97	699480.97	699480.97	699480.97	699480.97
12	0.02	0	StRS	1-0,1-3	50	-23.55	479402.49	479402.49	479402.49	479402.49	479402.49	479402.49
12	0.02	0	StRS	1-3	20	-25.93	634806.44	478818.73	639324.42	478818.73	639324.42	270105.62
12	0.02	0	StRS	1-3	35	-23.93	381341.10	276246.71	383666.94	276246.71	383666.94	152741.84
12	0.02	0	StRS	1-3	50	-26.00	255701.82	184592.54	57034.71	184592.54	57034.71	101721.83
12	0.02	0	StRS	1-3	20	-32.19	1061106.02	263054.84	1070154.92	263054.84	1070154.92	263054.84
12	0.02	0	StRS	1-3	35	-30.38	641636.10	160333.78	639085.07	160333.78	639085.07	160333.78
12	0.02	0	StRS	1-3	50	-33.26	428350.16	106860.45	423719.44	106860.45	423719.44	106860.45
12	0.02	0	Unequal	1-0	20	-17.38	1271412.11	1271412.11	1271412.11	1271412.11	1271412.11	1271412.11
12	0.02	0	Unequal	1-0	35	-12.46	773330.17	773330.17	773330.17	773330.17	773330.17	773330.17
12	0.02	0	Unequal	1-0	50	-13.82	537270.16	537270.16	537270.16	537270.16	537270.16	537270.16
12	0.02	0	Unequal	1-0	20	-15.76	745240.64	533643.48	754670.63	533643.48	754670.63	291411.26
12	0.02	0	Unequal	1-0	35	-18.51	414250.22	228296.92	276992.01	228296.92	276992.01	131456.58
12	0.02	0	Unequal	1-0	50	-16.08	315606.31	153688.45	318001.14	153688.45	318001.14	94480.75
12	0.02	0	Unequal	1-0,1-3	20	-20.54	1263343.58	308798.86	1262677.30	308798.86	1262677.30	308798.86

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	Aonly	A	AI	B	BI	C
12	0.02	0	Unequal	1-0,1-3	35	-21.33	714262.46	174535.26	709792.70	174535.26	709792.70	174535.26
12	0.02	0	Unequal	1-0,1-3	50	-17.83	520000.06	128186.48	519968.81	128186.48	519968.81	128186.48
12	0.02	0.04	SRS	1-0,1-3	20	-14.87	1563390.88	1563390.88	1563390.88	1563390.88	1563390.88	1563390.88
12	0.02	0.04	SRS	1-0,1-3	35	-15.57	889520.95	889520.95	889520.95	889520.95	889520.95	889520.95
12	0.02	0.04	SRS	1-0,1-3	50	-15.60	607321.64	607321.64	607321.64	607321.64	607321.64	607321.64
12	0.02	0.04	SRS	1-3	20	-14.30	908740.02	634514.76	924973.90	634514.76	924973.90	361474.29
12	0.02	0.04	SRS	1-3	35	-15.51	532368.37	284672.82	509906.93	284672.82	509906.93	162296.42
12	0.02	0.04	SRS	1-3	50	-15.26	377734.44	188747.81	313528.55	188747.81	313528.55	117634.91
12	0.02	0.04	SRS	1-3	20	-18.39	1583163.83	388914.56	1547566.81	388914.56	1547566.81	388914.56
12	0.02	0.04	SRS	1-3	35	-19.39	865210.37	210589.66	845640.15	210589.66	845640.15	210589.66
12	0.02	0.04	SRS	1-3	50	-20.57	583145.37	145669.64	567510.34	145669.64	567510.34	145669.64
12	0.02	0.04	StRS	1-0	20	-27.68	1158529.04	1158529.04	1158529.04	1158529.04	1158529.04	1158529.04
12	0.02	0.04	StRS	1-0	35	-27.14	670503.98	670503.98	670503.98	670503.98	670503.98	670503.98
12	0.02	0.04	StRS	1-0	50	-28.01	463785.12	463785.12	463785.12	463785.12	463785.12	463785.12
12	0.02	0.04	StRS	1-0	20	-26.68	664078.02	499923.19	665073.59	499923.19	665073.59	280018.96
12	0.02	0.04	StRS	1-0	35	-25.31	388563.44	281734.64	390075.27	281734.64	390075.27	154523.15
12	0.02	0.04	StRS	1-0	50	-25.87	264605.42	191883.16	64050.40	191883.16	64050.40	105987.79
12	0.02	0.04	StRS	1-0,1-3	20	-34.03	1061808.78	263595.65	1064091.81	263595.65	1064091.81	263595.65
12	0.02	0.04	StRS	1-0,1-3	35	-32.22	639267.80	158595.89	636797.46	158595.89	636797.46	158595.89
12	0.02	0.04	StRS	1-0,1-3	50	-32.91	440887.10	109586.41	431206.07	109586.41	431206.07	109586.41
12	0.02	0.04	Unequal	1-0,1-3	20	-12.26	1372166.90	1372166.90	1372166.90	1372166.90	1372166.90	1372166.90
12	0.02	0.04	Unequal	1-0,1-3	35	-13.38	779879.23	779879.23	779879.23	779879.23	779879.23	779879.23
12	0.02	0.04	Unequal	1-0,1-3	50	-10.13	587631.15	587631.15	587631.15	587631.15	587631.15	587631.15
12	0.02	0.04	Unequal	1-3	20	-23.21	684899.78	484302.43	688344.78	484302.43	688344.78	266798.48
12	0.02	0.04	Unequal	1-3	35	-21.36	403579.65	223904.51	254311.95	223904.51	254311.95	127803.50
12	0.02	0.04	Unequal	1-3	50	-20.79	310277.39	155754.46	310539.85	155754.46	310539.85	92510.12

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	Aonly	A	AI	B	BI	C
12	0.02	0.04	Unequal	1-3	20	-24.38	1226322.44	299303.39	1197672.92	299303.39	1197672.92	299303.39
12	0.02	0.04	Unequal	1-3	35	-20.87	744234.55	185124.27	721574.09	185124.27	721574.09	185124.27
12	0.02	0.04	Unequal	1-3	50	-20.29	540929.34	135830.26	534097.22	135830.26	534097.22	135830.26
24	0.01	0	SRS	1-0	20	-7.04	1605232.05	1605232.05	1605232.05	1605232.05	1605232.05	1605232.05
24	0.01	0	SRS	1-0	35	-6.71	793787.38	793787.38	793787.38	793787.38	793787.38	793787.38
24	0.01	0	SRS	1-0	50	-6.64	542446.67	542446.67	542446.67	542446.67	542446.67	542446.67
24	0.01	0	SRS	1-0	20	-7.12	978218.42	662258.12	427297.42	662258.12	427297.42	366897.66
24	0.01	0	SRS	1-0	35	-8.44	575794.27	303433.29	494161.83	303433.29	494161.83	177716.46
24	0.01	0	SRS	1-0	50	-8.60	441539.05	198635.65	394790.42	198635.65	394790.42	125333.33
24	0.01	0	SRS	1-0,1-3	20	-11.65	1661034.16	401529.20	1646562.02	401529.20	1646562.02	401529.20
24	0.01	0	SRS	1-0,1-3	35	-8.39	961446.22	237199.58	883954.80	237199.58	883954.80	237199.58
24	0.01	0	SRS	1-0,1-3	50	-9.73	668812.08	166896.58	495733.53	166896.58	495733.53	166896.58
24	0.01	0	StRS	1-0,1-3	20	-15.87	1170639.90	1170639.90	1170639.90	1170639.90	1170639.90	1170639.90
24	0.01	0	StRS	1-0,1-3	35	-15.12	334955.30	334955.30	334955.30	334955.30	334955.30	334955.30
24	0.01	0	StRS	1-0,1-3	50	-17.48	146148.99	146148.99	146148.99	146148.99	146148.99	146148.99
24	0.01	0	StRS	1-3	20	-16.94	687255.78	498537.13	214598.46	498537.13	214598.46	274594.97
24	0.01	0	StRS	1-3	35	-16.25	403058.84	281668.34	125374.85	281668.34	125374.85	159829.10
24	0.01	0	StRS	1-3	50	-17.41	288796.25	199331.36	118083.02	199331.36	118083.02	111979.29
24	0.01	0	StRS	1-3	20	-21.37	1227383.96	287731.89	1217383.73	287731.89	1217383.73	287731.89
24	0.01	0	StRS	1-3	35	-20.82	710151.40	175103.08	712729.20	175103.08	712729.20	175103.08
24	0.01	0	StRS	1-3	50	-22.85	485982.38	118804.18	378620.39	118804.18	378620.39	118804.18
24	0.01	0	Unequal	1-0	20	-6.83	1324685.43	1324685.43	1324685.43	1324685.43	1324685.43	1324685.43
24	0.01	0	Unequal	1-0	35	-6.36	503889.20	503889.20	503889.20	503889.20	503889.20	503889.20
24	0.01	0	Unequal	1-0	50	-5.30	396333.13	396333.13	396333.13	396333.13	396333.13	396333.13
24	0.01	0	Unequal	1-0	20	-10.98	758984.64	538030.49	407270.11	538030.49	407270.11	293545.70
24	0.01	0	Unequal	1-0	35	-11.31	452483.68	242270.01	418234.72	242270.01	418234.72	140651.59

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	Aonly	A	AI	B	BI	C
24	0.01	0	Unequal	1-0	50	-11.05	354365.82	162560.15	327171.21	162560.15	327171.21	103792.98
24	0.01	0	Unequal	1-0,1-3	20	-9.95	1399755.78	338449.42	1362778.32	338449.42	1362778.32	338449.42
24	0.01	0	Unequal	1-0,1-3	35	-9.37	800113.88	196648.53	632120.20	196648.53	632120.20	196648.53
24	0.01	0	Unequal	1-0,1-3	50	-11.78	550085.31	136508.13	452948.72	136508.13	452948.72	136508.13
24	0.01	0.04	SRS	1-0,1-3	20	-2.09	1622977.84	1622977.84	1622977.84	1622977.84	1622977.84	1622977.84
24	0.01	0.04	SRS	1-0,1-3	35	-2.25	336949.25	336949.25	336949.25	336949.25	336949.25	336949.25
24	0.01	0.04	SRS	1-0,1-3	50	-3.99	172938.32	172938.32	172938.32	172938.32	172938.32	172938.32
24	0.01	0.04	SRS	1-3	20	-5.47	770877.45	519255.88	229506.38	519255.88	229506.38	286126.45
24	0.01	0.04	SRS	1-3	35	-6.37	561169.32	282282.10	319060.06	282282.10	319060.06	157790.48
24	0.01	0.04	SRS	1-3	50	-6.08	400625.76	186465.41	363190.81	186465.41	363190.81	117837.61
24	0.01	0.04	SRS	1-3	20	-9.98	1629641.93	362816.87	1584948.68	362816.87	1584948.68	362816.87
24	0.01	0.04	SRS	1-3	35	-11.44	937606.00	229446.26	911434.32	229446.26	911434.32	229446.26
24	0.01	0.04	SRS	1-3	50	-10.27	661893.78	165223.61	617064.98	165223.61	617064.98	165223.61
24	0.01	0.04	StRS	1-0	20	-20.52	1196891.27	1196891.27	1196891.27	1196891.27	1196891.27	1196891.27
24	0.01	0.04	StRS	1-0	35	-19.94	337068.37	337068.37	337068.37	337068.37	337068.37	337068.37
24	0.01	0.04	StRS	1-0	50	-21.94	122595.58	122595.58	122595.58	122595.58	122595.58	122595.58
24	0.01	0.04	StRS	1-0	20	-24.06	679084.31	487935.26	226465.67	487935.26	226465.67	281085.67
24	0.01	0.04	StRS	1-0	35	-22.64	393852.49	276332.36	102865.22	276332.36	102865.22	151270.07
24	0.01	0.04	StRS	1-0	50	-25.43	276832.86	190506.34	106760.27	190506.34	106760.27	106388.03
24	0.01	0.04	StRS	1-0,1-3	20	-22.32	1314582.01	304446.86	1309883.67	304446.86	1309883.67	304446.86
24	0.01	0.04	StRS	1-0,1-3	35	-23.26	743298.08	181785.67	746803.48	181785.67	746803.48	181785.67
24	0.01	0.04	StRS	1-0,1-3	50	-26.00	504747.80	123002.29	404248.61	123002.29	404248.61	123002.29
24	0.01	0.04	Unequal	1-0,1-3	20	-6.26	1313752.44	1313752.44	1313752.44	1313752.44	1313752.44	1313752.44
24	0.01	0.04	Unequal	1-0,1-3	35	-6.10	241946.93	241946.93	241946.93	241946.93	241946.93	241946.93
24	0.01	0.04	Unequal	1-0,1-3	50	-6.46	136334.18	136334.18	136334.18	136334.18	136334.18	136334.18
24	0.01	0.04	Unequal	1-3	20	-7.84	711458.46	481269.77	179606.22	481269.77	179606.22	268027.58

Years	Trend (p)	Subpop Trend	Sampling Design	Revisit Design	Sites	PO	Aonly	A	AI	B	BI	C
24	0.01	0.04	Unequal	1-3	35	-8.86	454814.89	245475.22	339211.84	245475.22	339211.84	138828.13
24	0.01	0.04	Unequal	1-3	50	-8.98	377914.82	191594.33	339808.85	191594.33	339808.85	110293.96
24	0.01	0.04	Unequal	1-3	20	-9.64	1452255.86	341637.16	1409113.87	341637.16	1409113.87	341637.16
24	0.01	0.04	Unequal	1-3	35	-11.53	866239.73	211608.48	853719.52	211608.48	853719.52	211608.48
24	0.01	0.04	Unequal	1-3	50	-9.90	684877.18	162812.02	493825.52	162812.02	493825.52	162812.02

Supplement D: Case Studies

Example trend analyses are conducted in R with the TrendNPS package (Starcevich and Mitchell 2017) developed for this research project and with tools available in the spsurvey (Kincaid and Olsen 2015) and lme4 (Bates et al. 2015) packages. To begin the analysis, the TrendNPS should be installed and loaded in R. Installing the TrendNPS package either from a local zipped file or from a binary source file is a straightforward process. When using RStudio as an interface for R, first install the TrendNPS package from a standard R application and then the package will be accessible through RStudio. The installation files should be available on the user's hard drive in a known directory. These files may be downloaded from the following web site:

<https://irma.nps.gov/DataStore/Reference/Profile/2248489>.

To begin installation of TrendNPS, open the R program, ensure that an internet connection is available, and, in the command window at the prompt (indicated by a greater-than symbol: >), type the following and hit Enter to install the dependent packages required by TrendNPS:

```
install.packages( c("lme4", "lmerTest", "spsurvey", "stats"), repos="http://cran.r-project.org")
```

To install from the zipped installation file (TrendNPS_0.0.5.4.zip), open R and select the drop-down menu item Packages>Install package(s) from local zip files... then use the browser window to locate and select the zipped installation file. If any dependent packages are missing, an error messages will print indicating which packages are needed. Install these missing packages and the TrendNPS package. When the TrendNPS package is successfully installed, the message “package ‘TrendNPS’ successfully unpacked and MD5 sums checked” will print to the console.

The remaining instructions will focus on installing directly from a binary source program. Download the TrendNPS installation file TrendNPS_0.0.5.4.tar.gz and store it in an appropriate directory on your computer. Let “..PATH..” represent the directory on the user's computer where the file TrendNPS_1.0.tar.gz is stored. Install TrendNPS by typing the following line and hitting enter:

```
install.packages("../PATH../TrendNPS_0.0.5.4.tar.gz", type="source", repos=NULL)
```

For example, if the installation file is downloaded to the TEMP directory on the C drive, then the path is “C:/TEMP” and the following command would be used to install TrendNPS:

```
install.packages("C:/TEMP/TrendNPS_0.0.5.4.tar.gz", type="source", repos=NULL)
```

If you have already changed your working directory to the location of the installation file, then enter:

```
install.packages("TrendNPS_0.0.5.4.tar.gz", type="source", repos=NULL)
```

Once the package is installed, the user can load the TrendNPS package into the R environment by either typing at the command line:

```
require(TrendNPS)
```

or by navigating on the menu to Packages/Load package... and selecting TrendNPS from the list of installed packages.

Data collected for the SWAN rocky intertidal monitoring program between 2008 and 2013 are analyzed to determine if trends are present. The sampling design for the SWAN rocky intertidal survey employed strata defined by park (KATM and KEFJ) and equal probability sampling within each stratum. Five sites per park were visited each year in a [1-0] revisit design for a total of 10 unique sites. However, note that sites in KATM were not visited in 2011. Design weights did not need adjustment for nonsampling error, but panel weights were adjusted for the missing year at KATM. Refer to the Phase I report case studies for examples on weighting adjustment when sites are inaccessible or determined to not meet the definition of the target population (Starcevich et al. 2018).

We use the SWAN rocky intertidal data to demonstrate the tools presented in this report. Because only 5 sites were surveyed over 8 years for each of two strata, applying the complex trend models proposed here may result in overparameterization. We rely on model convergence to assess trend model overparameterization, but note that analysts will always want to consider parsimonious models and appropriate sample sizes when examining trend.

R code to read the SWAN rocky intertidal data sets, format binary and count data for trend analysis, calculate panel weights, and conduct trend analyses is provided below. CSV files are located in the TrendNPS\extdata subdirectory in the R library.

```
#####  
# Load R packages  
#####  
require(rgdal)  
require(sp)  
require(spsurvey)  
require(lme4)  
require(lmerTest)  
require(TrendNPS)  
require(reshape)  
  
# May also load data from workspace:  
data(Acro_Cover)  
data(Seastar)  
  
#####  
# Read data  
#####  
# Binary data  
Cover_Acro = read.csv("Cover_Acro.csv", header=TRUE)  
# Count data  
Seastar = read.csv("Seastar.csv", header=TRUE)  
  
# Read in polygon shapefile for plotting and update projection  
# "." represents current directory. If shapefiles are not in current  
# directory, either copy them or insert the actual directory in the R  
# library where shapefile is located. Note: use / to separate directories.  
AK <- rgdal::readOGR(paste0(find.package("TrendNPS"),  
"/extdata"), "mv_alaska_1mil_py")
```

```

proj4string(AK) = CRS("+init=epsg:3338")
AK.proj = spTransform(AK, CRS("+proj=utm +zone=5, ellps=WGS84"))

#####
# Format data for analysis
#####

##### BINARY #####

# Design weights for samples of 5 sites per park
Cover_Acro$wgt[Cover_Acro$Park== "KATM"] = 56499/5
Cover_Acro$wgt[Cover_Acro$Park== "KEFJ"] = 370650/5

# Calculate panel weights
table(Seastar$Site, Seastar$Year)
Cover_Acro$PanelWt[Cover_Acro$Park== "KATM"] = 8/7
Cover_Acro$PanelWt[Cover_Acro$Park== "KEFJ"] = 1

# Make Year a factor for modeling
Cover_Acro$Year = as.factor(Cover_Acro$Year)
##### COUNT #####
# Design weights for samples of 5 sites per park
Seastar$wgt[Seastar$Park== "KATM"] = 56499/5
Seastar$wgt[Seastar$Park== "KEFJ"] = 370650/5

# Calculate panel weights
table(Seastar$Site, Seastar$Year)
Seastar$PanelWt[Seastar$Park== "KATM"] = 7/6
Seastar$PanelWt[Seastar$Park== "KEFJ"] = 1

# Make Year a factor for modeling
Seastar$Year = as.factor(Seastar$Year)

```

Case study 1: Binary data

We examine trend in the cover of *Acrosiphonia* between 2009 and 2015 across the two parks. Five sites were selected with GRTS sampling at each park. Within each site, 12 quadrats were randomly located within each of two elevation bands representing mid- and high-elevation in the rocky intertidal zone. Each quadrat was sampled and a presence or absence of *Acrosiphonia* was recorded. Inputs for the simulation were obtained by pooling quadrat-level outcomes across the two elevation bands within each site. For the case study, we also explicitly model the effect of mid- vs. upper-elevation quadrats in the rocky intertidal zone. We also consider a continuous site-level model predictor, gradient, which is the overall slope at a site measured in degrees.

We begin by examining plots of the proportion of quadrats at a site with *Acrosiphonia*. Then the GLMM PO model is used to model trend with the glmer function of the lme4 (Bates et al. 2015) R package. We then assess the model fit with residual diagnostics. Finally, the appropriate trend method is determined using the flowchart for binary data (Figure 9) and trend analysis is conducted.

First, we plot the cover data by park and tidal elevation level by calculating site level proportional cover (proportion of quadrats where *Acrosiphonia* was detected and recorded as $Y = 1$) (Figure 11).

```
# Calc proportional Cover by Site and Year
Cover_Acro_Mean = aggregate(list(PropCover=Cover_Acro$Y),
list(Site=Cover_Acro$Site, Year=Cover_Acro$Year, Park=Cover_Acro$Park,
Elev=Cover_Acro$Elev), mean)
Cover_Acro_Mean$Year = as.numeric(as.character(Cover_Acro_Mean$Year))
pch.code=ifelse(Cover_Acro_Mean$Elev=="Mid" & Cover_Acro_Mean$Park=="KATM", 2,
ifelse(Cover_Acro_Mean$Elev=="Upper" & Cover_Acro_Mean$Park=="KATM", 17,
ifelse(Cover_Acro_Mean$Elev=="Mid" & Cover_Acro_Mean$Park=="KEFJ", 1, 19)))
plot(Cover_Acro_Mean$Year, Cover_Acro_Mean$PropCover, xlab="Year",
ylab="Prop. Acrosiphonia Cover",
col=as.numeric(as.factor(Cover_Acro_Mean$Park)),
pch=pch.code)
legend("topleft", col=c(1, 1, 2, 2), pch=c(2, 17, 1, 19), legend=c("KATM Mid", "KATM
Upper", "KEFJ Mid", "KEFJ Upper"), cex=0.62)
```

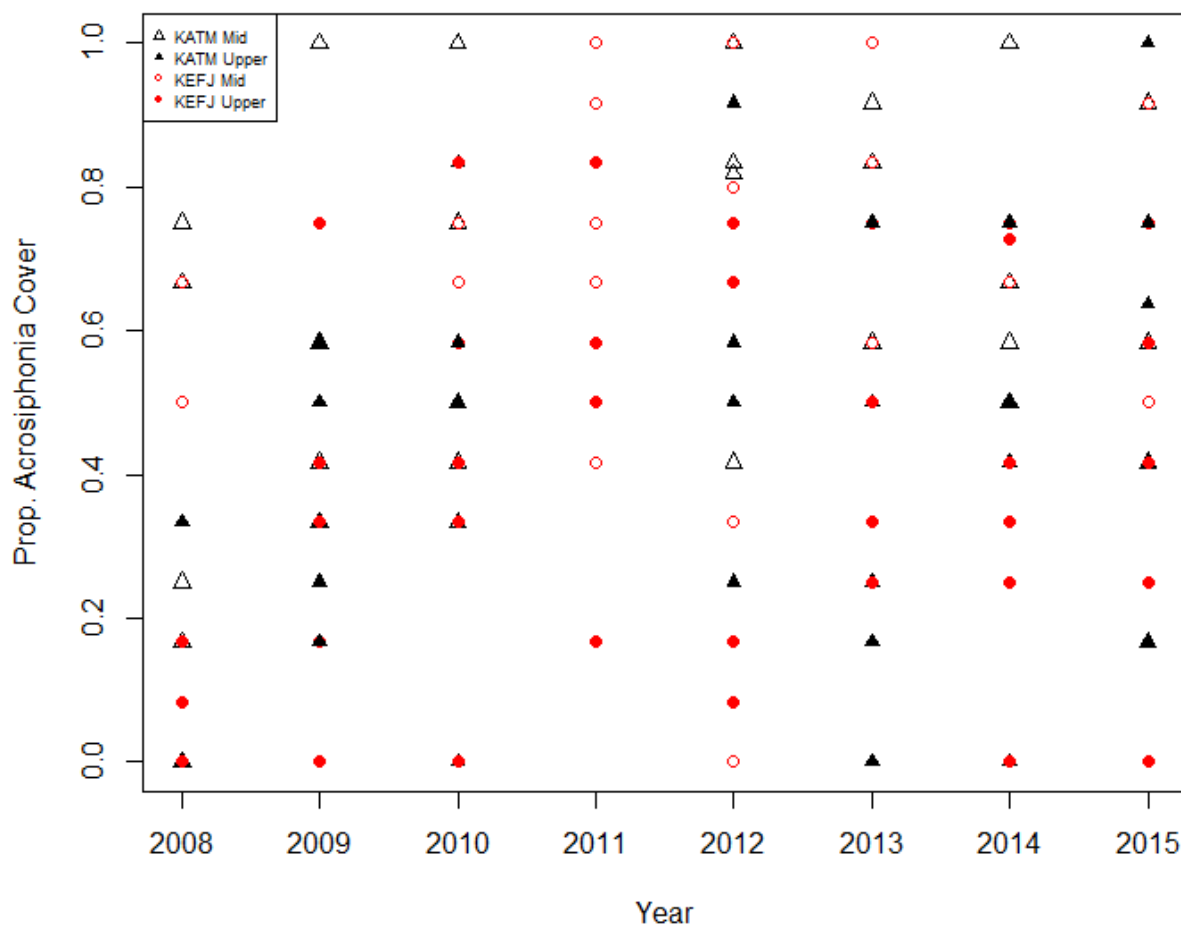


Figure 11. Proportion of quadrats with Acrosiphonia presence by Site, Year, and Park.

Now the GLMM version of the Piepho and Ogutu (2002) trend model will be fit to the data. We start with fixed effects for WYear (an integer value of time starting with 0), Park, their interaction, and the elevation of the quadrat (Elev) as well as a variance components model with terms for year-to-year variation, site-to-site variation, and site-level slope variation.

```
# Fit the P0 model in the lme4 package with the glmer function for
```

```
# generalized linear mixed-effects models. Specify a binomial
# distribution and logit link.
require(lme4)
fit.Acro.1 = glmer(Y ~ WYear*Park + Elev + (1|Year) + (1+WYear|Site) ,
family=binomial(link=logit), data = Cover_Acro)
summary(fit.Acro.1)
```

Random effects:

Groups	Name	Variance	Std.Dev.	Corr
Site	(Intercept)	0.32223	0.5677	
	WYear	0.01577	0.1256	-0.75
Year	(Intercept)	0.27246	0.5220	

Number of obs: 1794, groups: Site, 10; Year, 8

Fixed effects:

	Estimate	Std. Error	z value	Pr(> z)
(Intercept)	0.18679	0.44674	0.418	0.6759
WYear	0.14880	0.10304	1.444	0.1487
ParkKEFJ	-0.90262	0.41419	-2.179	0.0293 *
ElevUpper	-1.00154	0.10449	-9.585	<2e-16 ***
WYear:ParkKEFJ	0.09826	0.09181	1.070	0.2845

We use a chi-square test of binomial overdispersion (Zuur et al. 2009, p. 233), which occurs when the data contain more 0's or 1's than would be expected in a binomial distribution. The function to test for overdispersion for a GLMM is as follows:

```
overdisp_fun = function(model) {
  # From http://glmm.wikidot.com/faq
  ## number of variance parameters in
  ## an n-by-n variance-covariance matrix
  vpars <- function(m) {
    nrow(m)*(nrow(m)+1)/2
  }
  model.df <- sum(sapply(VarCorr(model), vpars))+length(fixef(model))
  rdf <- nrow(model.frame(model))-model.df
  rp <- residuals(model, type="pearson")
  Pearson.chisq <- sum(rp^2)
  prat <- Pearson.chisq/rdf
  pval <- pchisq(Pearson.chisq, df=rdf, lower.tail=FALSE)
  c(chisq=Pearson.chisq, ratio=prat, rdf=rdf, p=pval)
}
```

```
overdisp_fun(fit.Acro.1)
#      chisq      ratio      rdf      p
# 1732.3255640    0.9704905 1785.0000000    0.8103608
```

The p-value for the chi-square goodness-of-fit test comparing the data to a binomial random variable indicated no substantial overdispersion at the 0.10 level (p-value = 0.8361). The initial model contained a fixed effect for park-specific trend (WYear:ParkKEFJ) that was also not significant at the $\alpha = 0.10$ level (p-value = 0.2843), so we simplify the model and assume a single trend across both parks.

```
# Fit the reduced P0 model without the separate park slope term
```

```
fit.Acro.2 = glmer(Y ~ WYear + Park + Elev + (1|Year) + (1+WYear|Site),
family=binomial(link=logit), data = Cover_Acro)
summary(fit.Acro.2)
```

Random effects:

Groups	Name	Variance	Std.Dev.	Corr
Site	(Intercept)	0.34481	0.5872	
	WYear	0.01826	0.1351	-0.77
Year	(Intercept)	0.26908	0.5187	

Number of obs: 1794, groups: Site, 10; Year, 8

Fixed effects:

	Estimate	Std. Error	z value	Pr(> z)
(Intercept)	0.02106	0.42278	0.050	0.9603
WYear	0.19748	0.09363	2.109	0.0349 *
ParkKEFJ	-0.56577	0.27728	-2.040	0.0413 *
ElevUpper	-1.00160	0.10449	-9.585	<2e-16 ***

We see that there is evidence of a significant increasing trend in *Acrosiphonia* cover across the two parks between 2008 and 2015 (p-value = 0.0349). The overall proportional cover of in KEFJ is significantly lower than in KATM as evidenced by the negative effect of -0.56577 (p-value = 0.0413), and quadrats at higher elevations have significantly lower cover (p-value < 0.0001).

We also examine whether any subpopulations exhibit a trend. We recommend that, in practice, potential domains be identified a priori based on ecological knowledge. A significant effect of quadrat elevation on *Acrosiphonia* cover was observed in the initial trend model. We now examine if trends in time differ by quadrat elevation class by adding an interaction between the integer year term (WYear) and the two-level elevation factor (Elev).

```
fit.Acro.3 = glmer(Y ~ WYear * Elev + Park + (1|Year) + (1+WYear|Site) ,
family=binomial(link=logit), data = Cover_Acro)
summary(fit.Acro.3)
overdisp_fun(fit.Acro.3)
AIC(fit.Acro.3) # 2232.996
AIC(fit.Acro.2) # 2233.921
```

Random effects:

Groups	Name	Variance	Std.Dev.	Corr
Site	(Intercept)	0.33041	0.5748	
	WYear	0.01823	0.1350	-0.76
Year	(Intercept)	0.26063	0.5105	

Number of obs: 1794, groups: Site, 10; Year, 8

Fixed effects:

	Estimate	Std. Error	z value	Pr(> z)
(Intercept)	-0.10244	0.42308	-0.242	0.808690
WYear	0.23336	0.09496	2.457	0.013997 *
ElevUpper	-0.71332	0.19648	-3.630	0.000283 ***
ParkKEFJ	-0.57117	0.27610	-2.069	0.038577 *
WYear:ElevUpper	-0.07798	0.04547	-1.715	0.086376 .

The results of the separate-slopes trend model for the elevation factor indicate that the trend in the Upper elevation quadrats may be different from the trend in Lower elevation quadrats (p-value =

0.0864). Note that the interaction term (wYear:ElevUpper) indicates the additional trend relative to the trend in the Lower elevation quadrats. To obtain an estimate of the trend in Upper elevation quadrats, the two trend terms are summed. We apply a linear combination to calculate the Upper elevation trend, standard error, and two-sided test of no trend as follows:

```
contr = c(0,1,0,0,1)
trendUpper = contr%%fixef(fit.Acro.3)
SE_trendUpper = sqrt(contr%%vcov(fit.Acro.3)%%contr)
z.stat=as.numeric(trendUpper/SE_trendUpper)
2*pnorm(abs(z.stat), lower.tail=FALSE) # 0.1042178
```

At the $\alpha = 0.10$ level, we find inconclusive evidence of unequal trends in the two elevation categories. We would want to continue to monitor the two subpopulations closely over time, especially given that the p-value of the trend test is very close to the Type I error rate and p-values of GLMM are approximate (Zuur et al. 2009). Using the flowchart (Figure 9) to determine the appropriate trend analysis procedure, we are directed from the option for stratified sampling to the 12-year option (our closest option). We see from the flowchart for binary trend inference for the [1-0] revisit design that unbiased estimates of trend may not be obtained, indicating that the simulation exercise found no trend approach that provided reasonable bias and confidence interval coverage for this scenario. This result might suggest a modification to the revisit design, such as changing to a [1-0,1-3] or [1-3] design especially since only 5 sites are currently visited per park.

We proceed with the previous fit that does not account for different trends for elevation classes assess the assumptions of the generalized linear mixed model following the guidance of Zuur et al. (2009) and Pinheiro and Bates (2000). The model assessment for a binomial GLM (Zuur et al. 2009) involves plotting the deviance residuals against fitted values, model covariates, and covariates related to time and space. Any patterns that emerge may indicate a violation of the independence assumption or model misspecification. The assumptions of the mixed model structure for within-group errors include independence, identical normal distributions and independent of random effects (Pinheiro and Bates 2000). Assumptions for random effects include normal distribution and independence among groups as defined by sites and years.

Model assessment for the binary GLM requires plotting deviance residuals against covariates. We plot the residuals against fitted values, model covariates, and time (Figure 12) to look for patterns that might indicate a departure from the independence assumption. No patterns are observed in the residual plots by fitted values or year, but the median of the deviance residuals is larger at KATM and at mid-elevation quadrats. We have included the Park in the mean structure of the binomial GLMM, but modeling variance components resulted in convergence problems (not shown). We will explore trend as a function of quadrat elevation after an examination of the random effects assumptions.

```
fit = fit.Acro.2
dat = Cover_Acro
```

```

dat$resid = residuals(fit, type="deviance")
dat$fitted = fitted(fit)

par(mfrow=c(3,2))
# plot deviance resid vs fitted
plot(dat$resid, dat$fitted, cex.axis=1.35,cex.lab=1.5, xlab="Deviance
residuals", ylab="Fitted values", main="(a)")

# plot deviance resid vs model vars
plot(dat$WYear+2008, dat$resid, cex.axis=1.35,cex.lab=1.5, ylab="Deviance
residuals", xlab="Year", main="(b)")
boxplot(dat$resid ~ dat$Park , cex.axis=1.35,cex.lab=1.5, ylab="Deviance
residuals", xlab="Park", main="(c)")
boxplot(dat$resid ~ dat$Elev, cex.axis=1.35,cex.lab=1.5, ylab="Deviance
residuals", xlab="Quadrat Elevation", main="(d)")

# plot deviance resid vs vars not in the model
plot(dat$Gradient, dat$resid, cex.axis=1.35,cex.lab=1.5, ylab="Deviance
residuals", xlab="Site Gradient (degrees)", main="(e)")

```

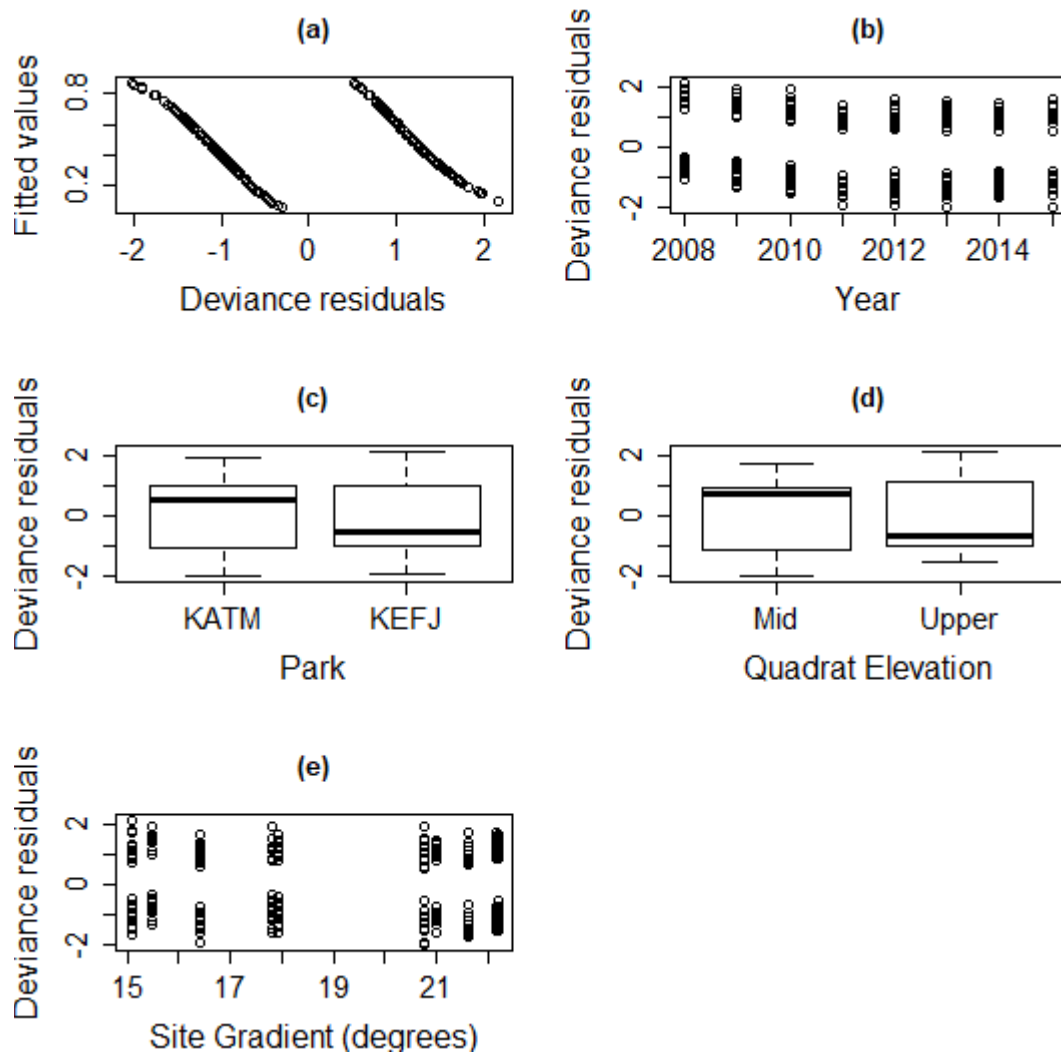


Figure 12. Deviance residuals for (a) fitted values, (b) WYear, (c) Park, (d) Quadrat elevation, and (e) Site Gradient.

The first assumption of the random effects model portion of the model is assessed by evaluating within-group residuals, where groups in this setting are defined by Year and Site. The independence assumption is examined with partial autocorrelation plots of site-level residuals to determine if any serial correlation remains in trend model residuals (indicated by lag lines extending beyond the blue dashed lines). A function to create a time series of the mean residuals for each site and plot the partial autocorrelation function is provided. Partial autocorrelation plots for each site indicate no substantial serial correlation in trend model residuals based on the plots (Figures 13 and 14), although some evidence is shown for Site AKP_B10_RI_05. The time series is relatively short at 8 years and is available for only 5 sites per park, so nontrivial serial autocorrelation may be as-of-yet undetectable. We proceed assuming no substantial autocorrelation but considering possible underestimation of the trend standard error if autocorrelation is present (Zuur 2007).

```
Residual_ts=function(resids,yr,site) {
# Function to format residuals to examine serial correlation by site
```

```

# requires reshape package
dat=data.frame(res=resids,yr=yr,site=site)
yy=unique(data.frame(yr=dat$yr))
yy=data.frame(yy,ind=1:nrow(yy))
dat=merge(dat,yy)
dat$variable=dat$res
dat_cast=cast(dat,ind~site, mean)
dat_ts=ts(dat_cast,start=c(2008,1),deltat=1/nrow(yy),class= c("mts", "ts",
"matrix"))
return(dat_ts)
}

Cover_ts=Residual_ts(resids=dat$resid,yr=dat$Year,site=dat$Site)
require(reshape)
Cover_ts=Residual_ts(resids=dat$resid,yr=dat$Year,site=dat$Site)
op <- par(mfrow=c(3,2),
oma = c(0,2,1,0) + 0.1,
mar = c(2,1.5,3.5,1) + 0.1)

# KATM sites
for (i in which(grepl("AKP",colnames(Cover_ts)))) {
if(length(Cover_ts[!is.na(Cover_ts[,i]),i])>2) Cover_ts.i =
pacf(Cover_ts[!is.na(Cover_ts[,i]),i], na.action=na.pass, plot=FALSE)
plot(Cover_ts.i, type="h", main=colnames(Cover_ts)[i])
}

# KEFJ sites
op <- par(mfrow=c(3,2),
oma = c(0,2,1,0) + 0.1,
mar = c(2,1.5,3.5,1) + 0.1)
for (i in which(grepl("KEP",colnames(Cover_ts)))) {
if(length(Cover_ts[!is.na(Cover_ts[,i]),i])>2) Cover_ts.i =
pacf(Cover_ts[!is.na(Cover_ts[,i]),i], na.action=na.pass, plot=FALSE)
plot(Cover_ts.i, type="h", main=colnames(Cover_ts)[i])
}

```

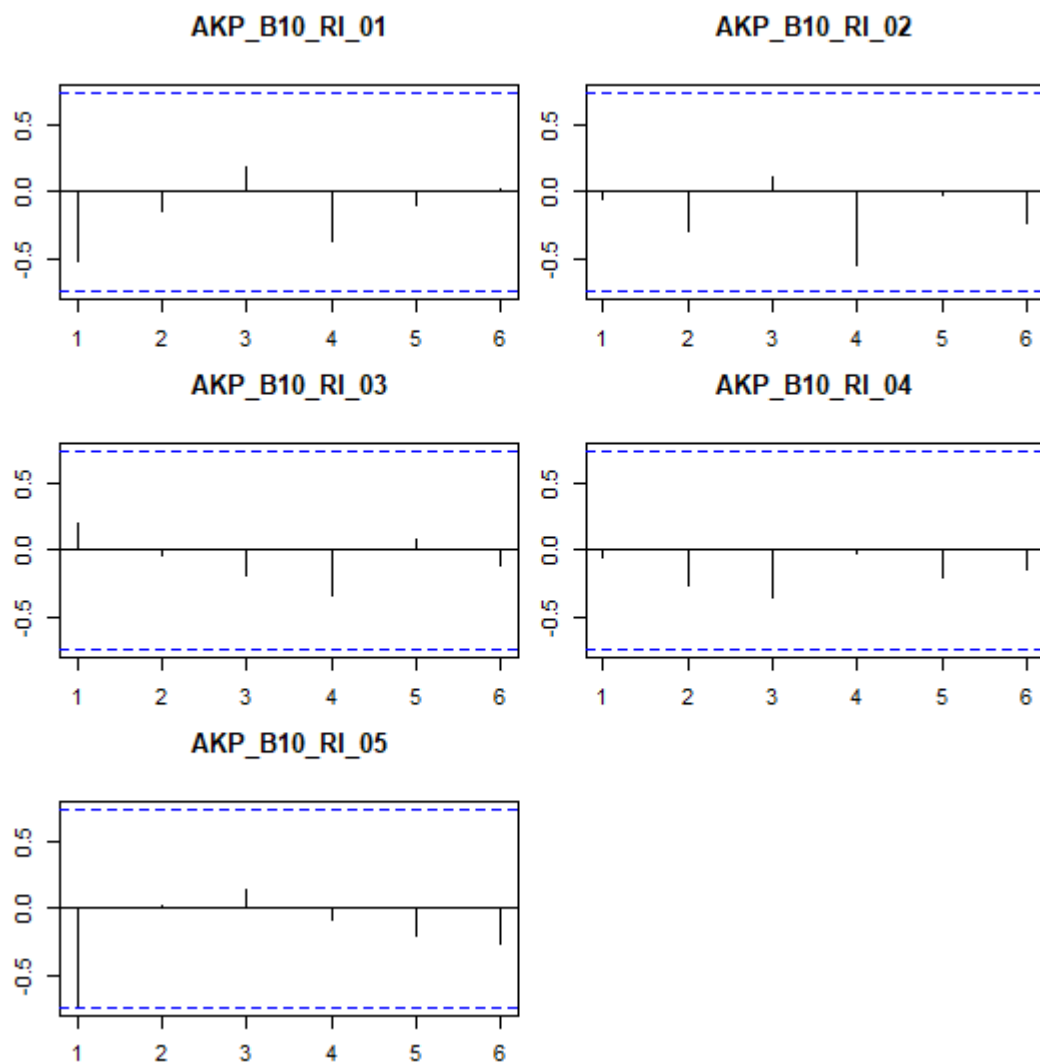


Figure 13. Partial autocorrelation function plots of residuals for sites in KATM.

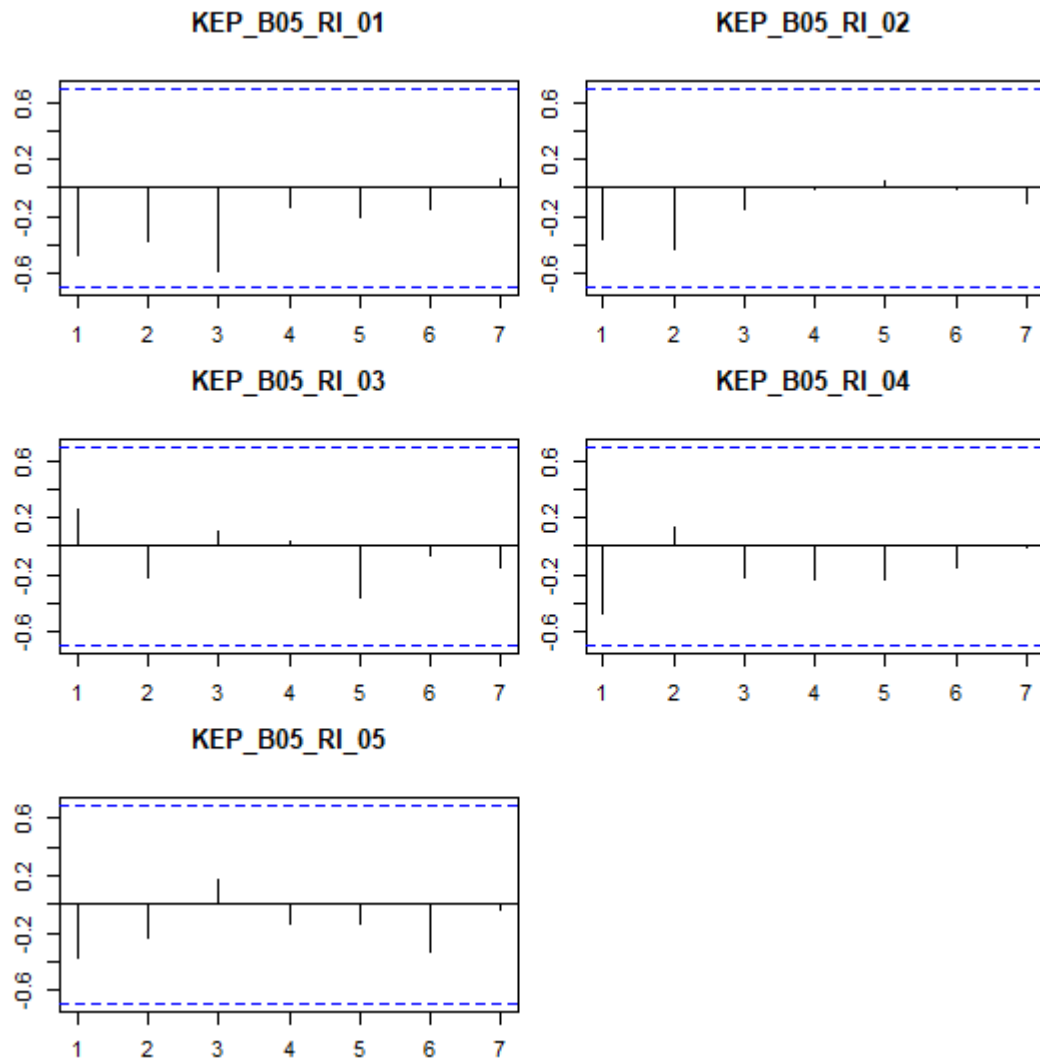


Figure 14. Partial autocorrelation function plots of residuals for sites in KATM.

The equal variance requirement is assessed with a plot of residuals against fitted values across all groups (Figure 15). The curvature in the residuals may indicate a missing model predictor. A quadratic trend was examined but did not improve residual diagnostics, so a latent variable is likely missing. We assume equal variance for the given model because the residuals are generally within the interval $[-2, 2]$ and the spread is roughly equal across all years.

```
require(ggplot2)
ggplot(data=dat, aes(x=wYear, y=resid)) + geom_jitter(aes(colour=Y), width=0.75)
+ stat_smooth(se=FALSE, colour="black") + xlab("Year") + ylab("Residual
(Deviance)")
```

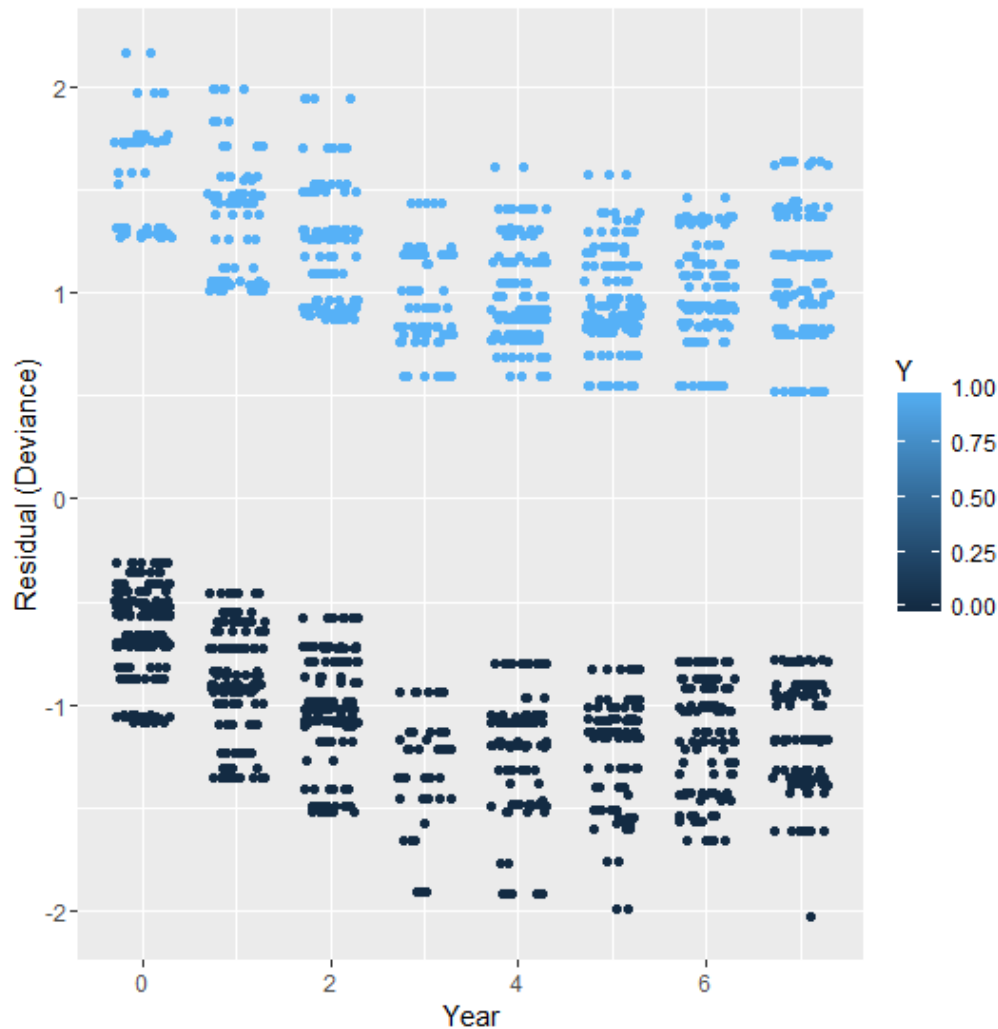


Figure 15. Deviance residuals by Year.

Now we examine the residuals by group, beginning with grouping by Site (Figures 16 and 17) and then by Year (Figures 18 and 19). Some heterogeneity is observed but the residuals are centered on zero overall. The residual plots by year indicate lower residuals for 2008-2010 and higher residuals for 2011-2015. This may indicate larger environmental effects, effects of field crew training, or some other factor that may be identified and included in the model. With only 5 sites per park, including several model predictors in the mean structure may not be possible due to the small sample size.

```
# Examine residuals by Site across Years
plot(fit, Site~ resid(., type = "deviance"), abline = 0) # Figure 16
plot(fit, resid(., type = "deviance") ~ fitted(.) | Site) # Figure 17

# Examine residuals by Site across Years
plot(fit, Year~ resid(., type = "deviance"), abline = 0) # Figure 18
plot(fit, resid(., type = "deviance") ~ fitted(.) | Year) # Figure 19
```

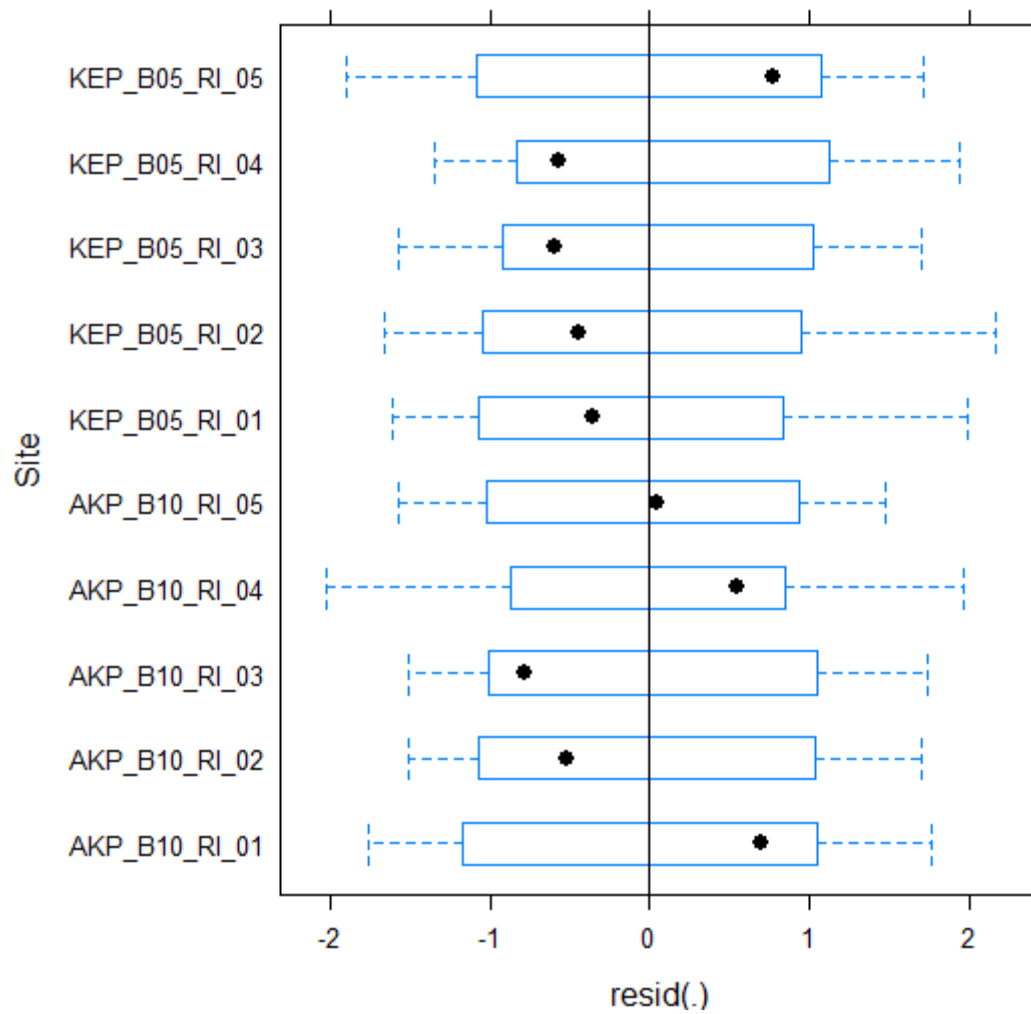


Figure 16. Boxplot of deviance residuals by Site across Years.

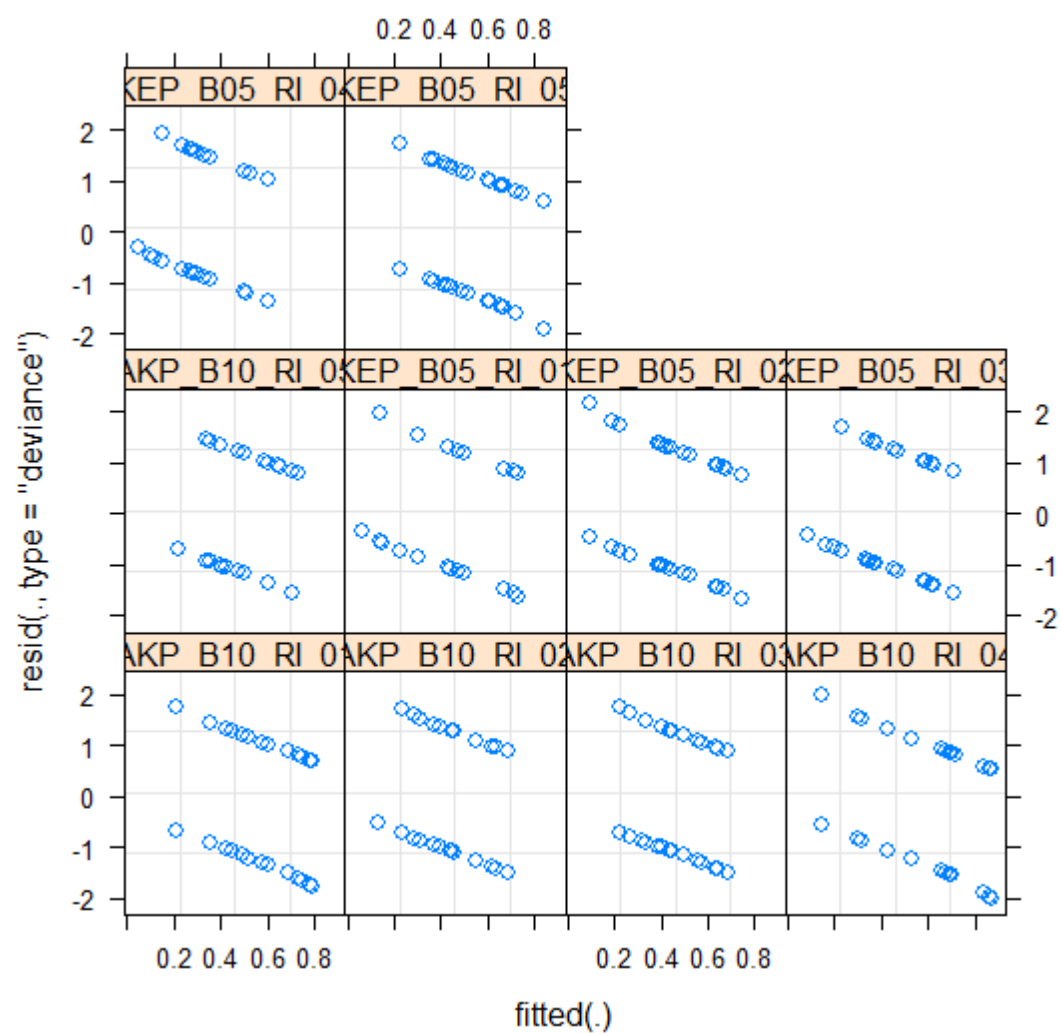


Figure 17. Deviance residuals by Site.

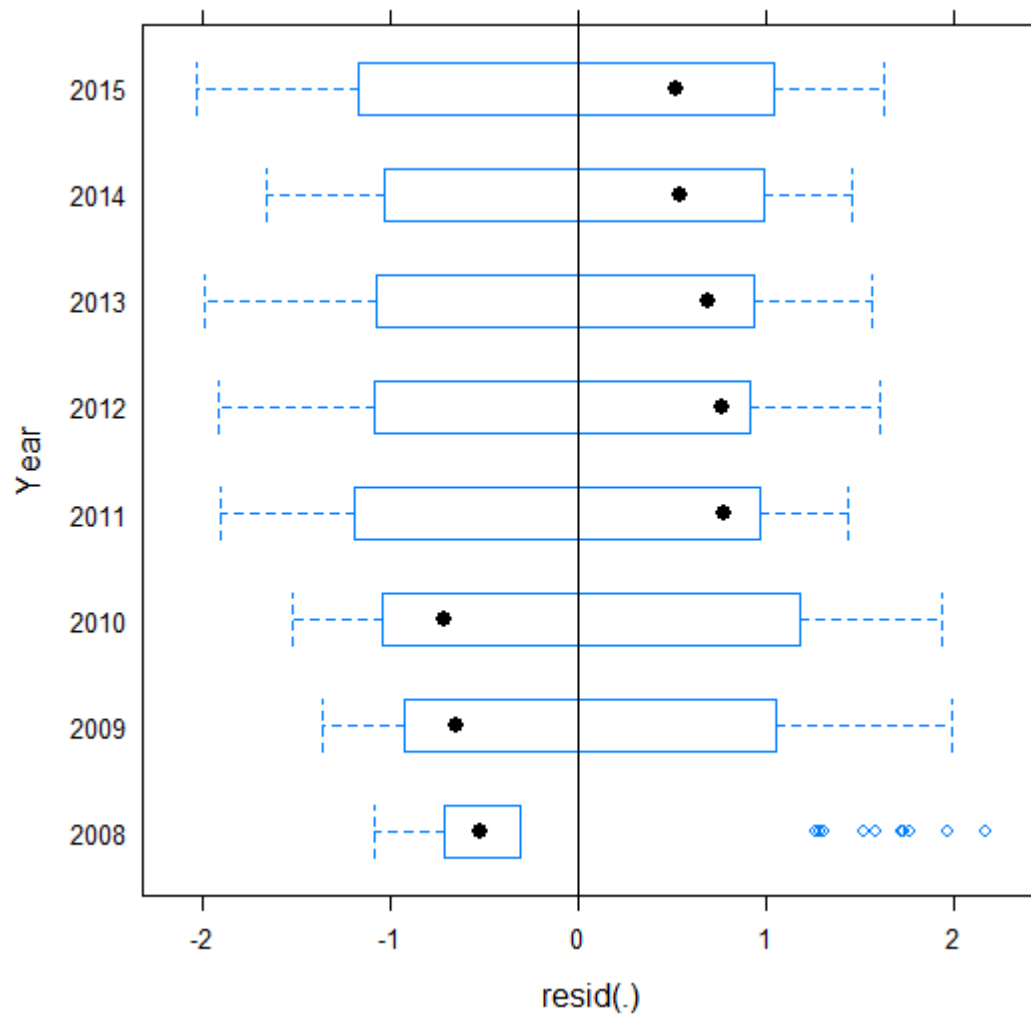


Figure 18. Boxplot of deviance residuals by Year across Sites.

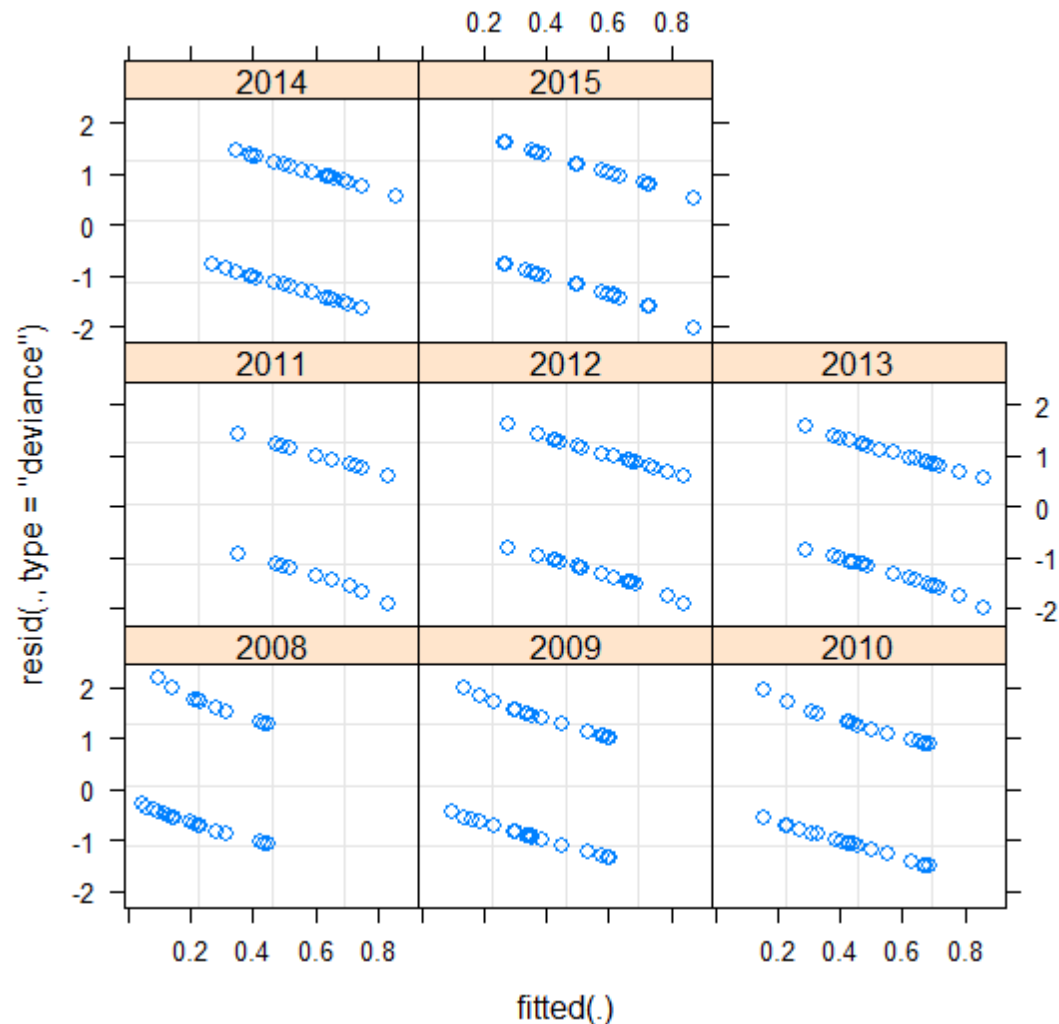


Figure 19. Deviance residuals by Year.

Testing for normality is assessed by reviewing normal distribution quantile-quantile plots of deviance residuals by Site (Figures 20 and 21) and by Year (Figure 22). Note that the residuals are grouped because the outcome takes only two unique values. Quantile-quantile plots show some skewness but are roughly normal for such a small sample size of sites.

```
# Quantile-quantile plots of residuals by site
siteVec <- unique(dat$Site)
length(siteVec) # 8
par(mfrow=c(3,2))
for(w in which(grepl("AKP", siteVec))) {
  qqnorm(dat$resid[dat$Site == siteVec[w]],
    main = paste("Site", siteVec[w]))
  qqline(dat$resid[dat$Site==siteVec[w]])
}
```

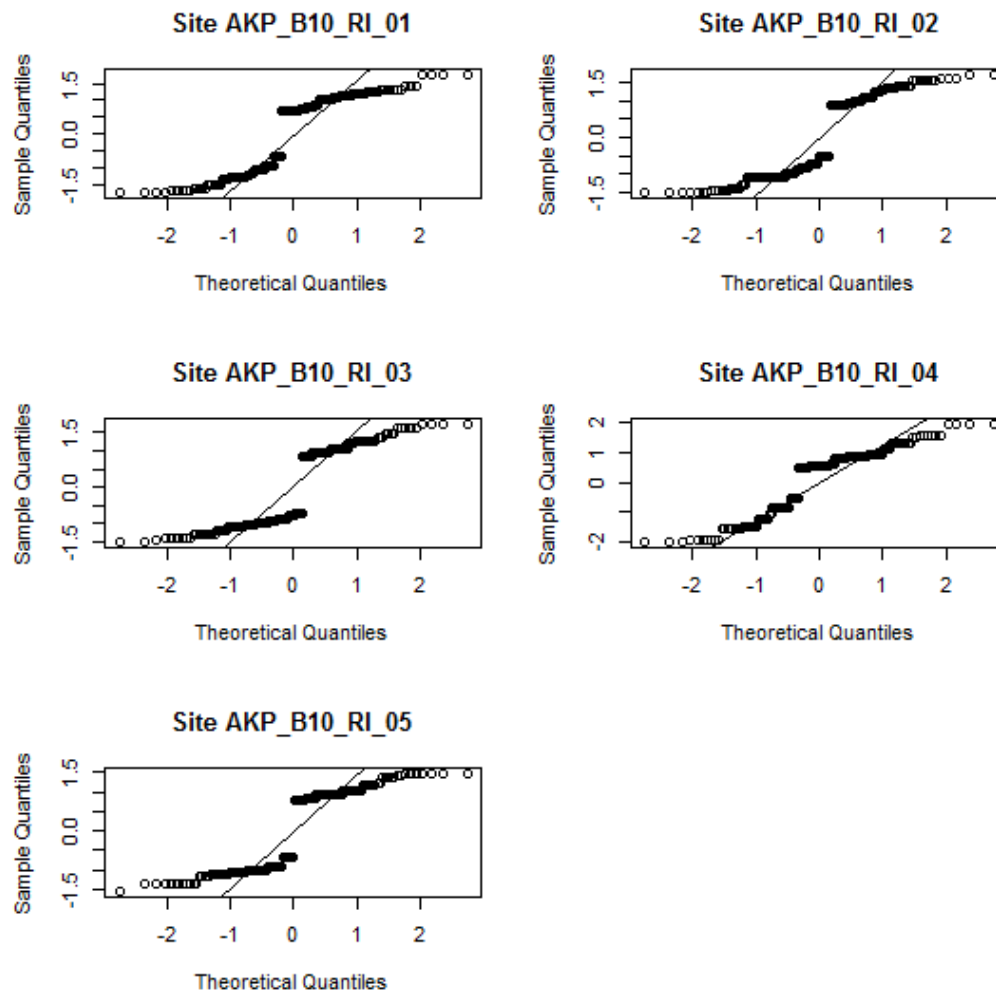


Figure 20. Normal quantile-quantile plots of deviance residuals by Site for KATM.

```
par(mfrow=c(3,2))
for(w in which(grepl("KEP",siteVec))) {
  qqnorm(dat$resid[dat$Site == siteVec[w]],
    main = paste("Site",siteVec[w]))
  qqline(dat$resid[dat$Site==siteVec[w]])
}
```

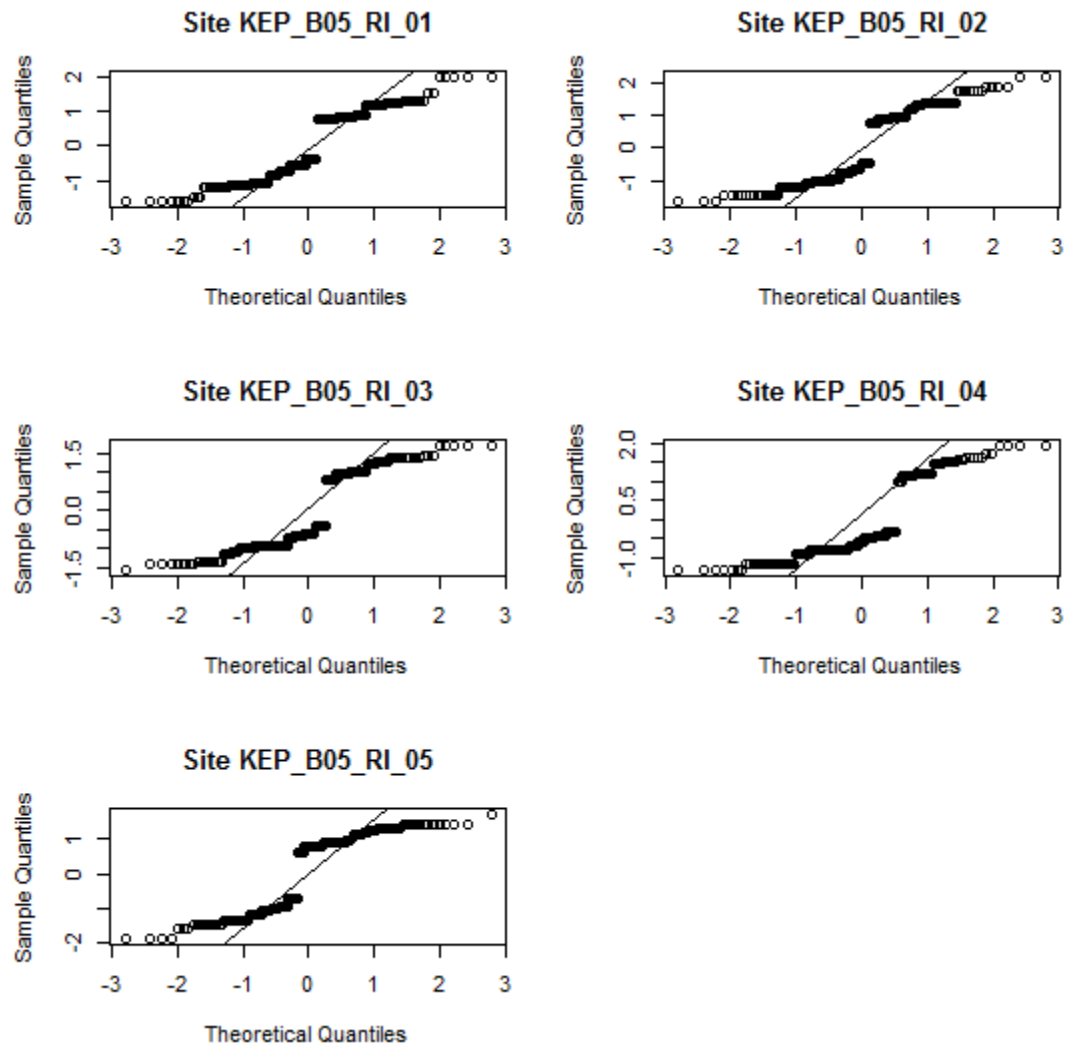


Figure 21. Normal quantile-quantile plots of deviance residuals by Site for KEFJ.

```
# Quantile-quantile plots of residuals by year
Years = sort(unique(dat$WYear))+2008
length(Years)      # 8
par(mfrow=c(4,2))
for(w in 1:8) {
  qqnorm(dat$resid[dat$Year == Years[w]],
        main = Years[w])
  qqline(dat$resid[dat$Year==Years[w]])
}
```

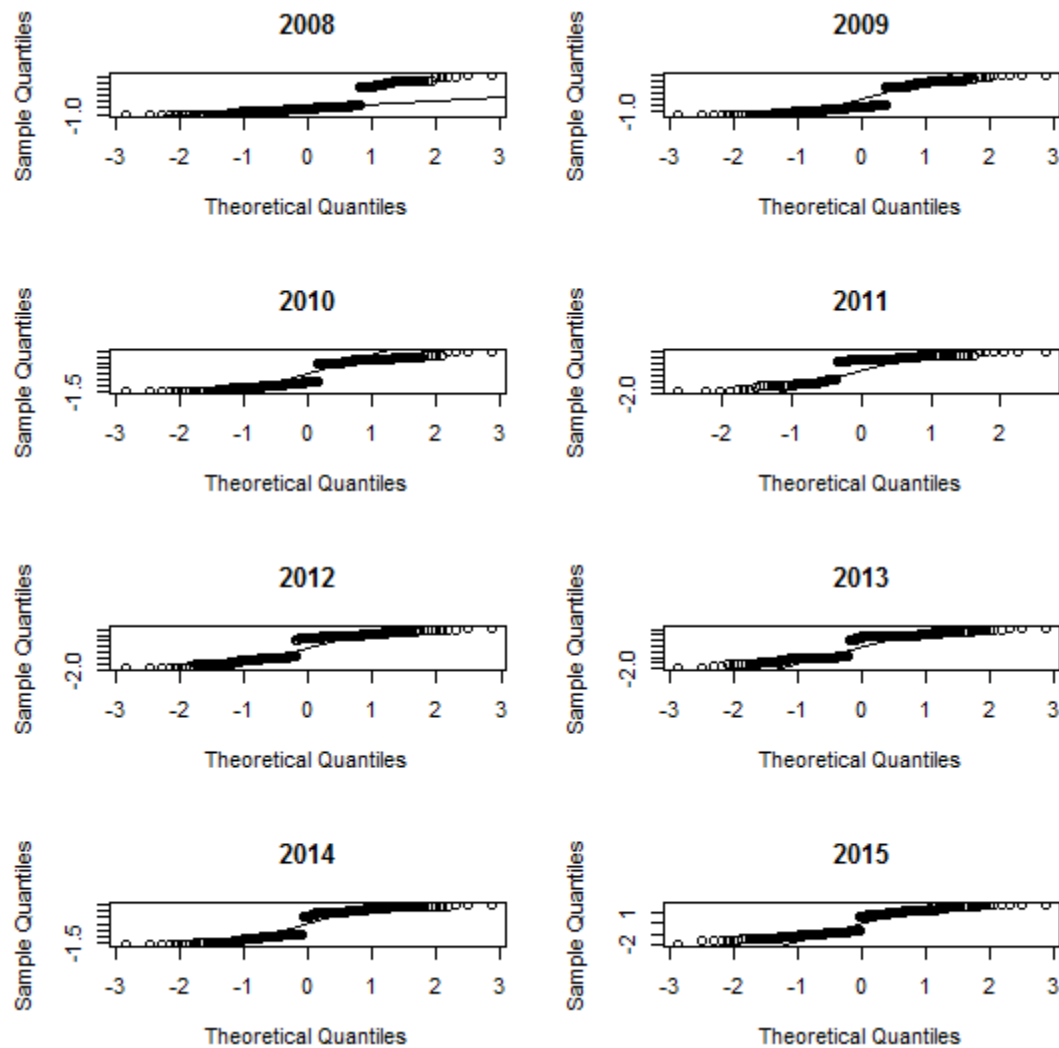


Figure 22. Normal quantile-quantile plots of Deviance residuals by Year.

The independence assumption is addressed by examining possible correlation between the residuals and the site- and year-level random effects. Pearson's correlation tests are conducted to assess any possible linear correlation. As shown by the test results below, evidence of small positive correlations between the residuals and the Site and Year effects are observed but the relationship is not obvious in the plots (Figure 23). This correlation may be an artifact of a relatively-short time series for a small sample of sites caused by larger residuals for sites or years with larger random effects.

```
# Independence assumption -- independence of RE and resids
SiteRE = data.frame(Site=rownames(ranef(fit)$Site), SiteRE=ranef(fit)$Site)
names(SiteRE)[2] = 'SiteRE'
rownames(SiteRE)=NULL
YearRE = data.frame(Year=rownames(ranef(fit)$Year), YearRE=ranef(fit)$Year)
names(YearRE)[2] = 'YearRE'
rownames(YearRE)=NULL

dat = merge(dat, SiteRE)
```

```

dat = merge(dat, YearRE)

cor.test(dat$resid, dat$SiteRE)
# cor = 0.0440, t = 1.8651, df = 1792, p-value = 0.06232
cor.test(dat$resid, dat$SiteRE.WYear)
# cor = -0.0021, t = -0.088746, df = 1792, p-value = 0.9293
cor.test(dat$resid, dat$YearRE)
# cor = 0.0604, t = 2.5596, df = 1792, p-value = 0.01056

par(mfrow=c(2,2))
plot(resid ~ SiteRE, data=dat, main="Site Random Effects", xlab="Site RE",
ylab="Residuals")
abline(0,0,col=2)
plot(resid ~ SiteRE.WYear, data=dat, main="Site Slope Random Effects",
xlab="Site RE", ylab="Residuals")
abline(0,0,col=2)
plot(resid ~ YearRE, data=dat, main="Year Random Effects", xlab="Year RE",
ylab="Residuals")
abline(0,0,col=2)

```

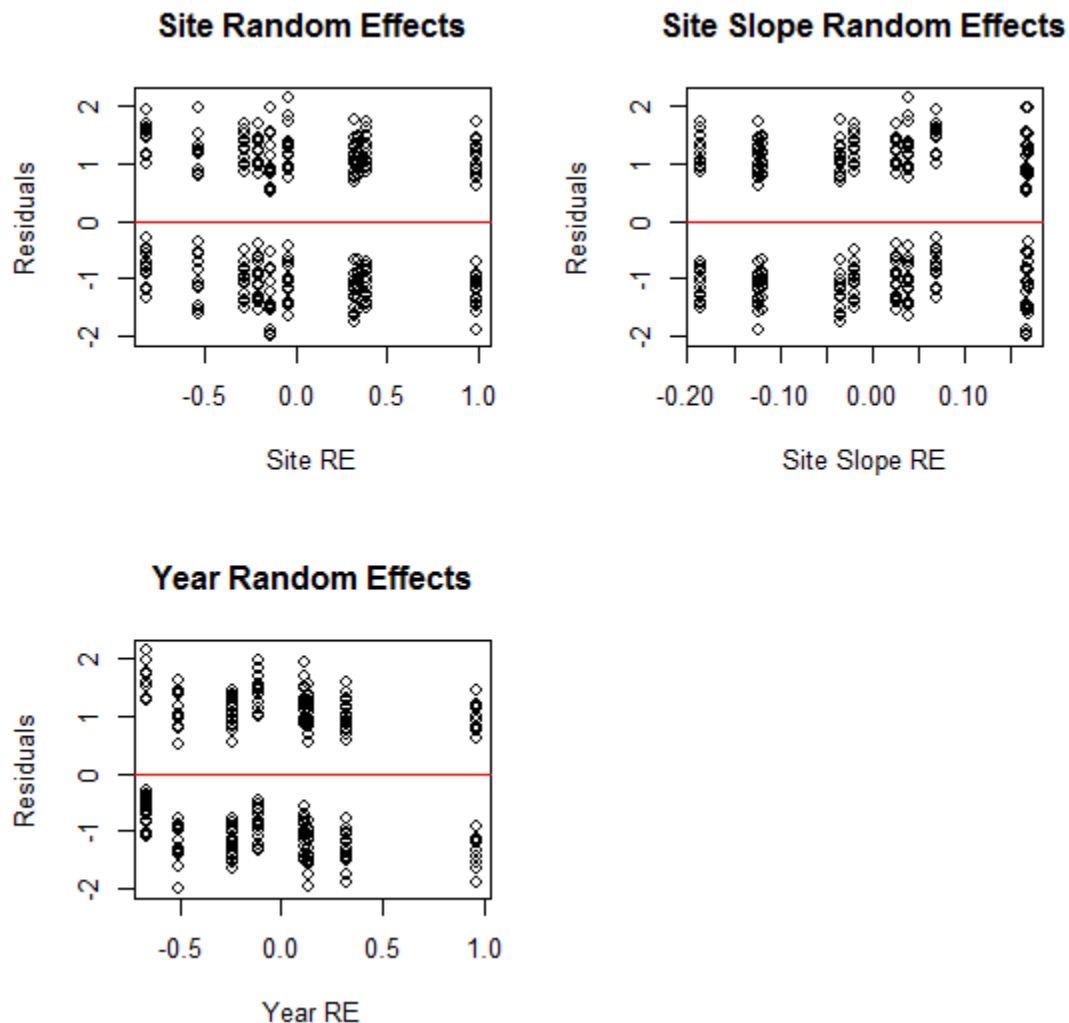


Figure 23. Plots of residuals against Site- and Year-level random effects.

We also checked assumptions on the estimated random effects, also called “best least unbiased estimators,” or BLUPs. These are obtained in the lme4 package with the ranef(fit) function. First, the normality of the BLUPs is assessed with normal quantile-quantile plots for each group (Figure 24) which indicates approximate normality.

```
# Normality of BLUPs
par(mfrow=c(2,2))
qqnorm(ranef(fit)$Site[,1], main = "Random site-intercept effect")
qqline(ranef(fit)$Site[,1])
qqnorm(ranef(fit)$Site[,2], main = "Random site-slope effect")
qqline(ranef(fit)$Site[,2])
qqnorm(ranef(fit)$Year[,1], main = "Random year-intercept effect")
qqline(ranef(fit)$Year[,1])
```

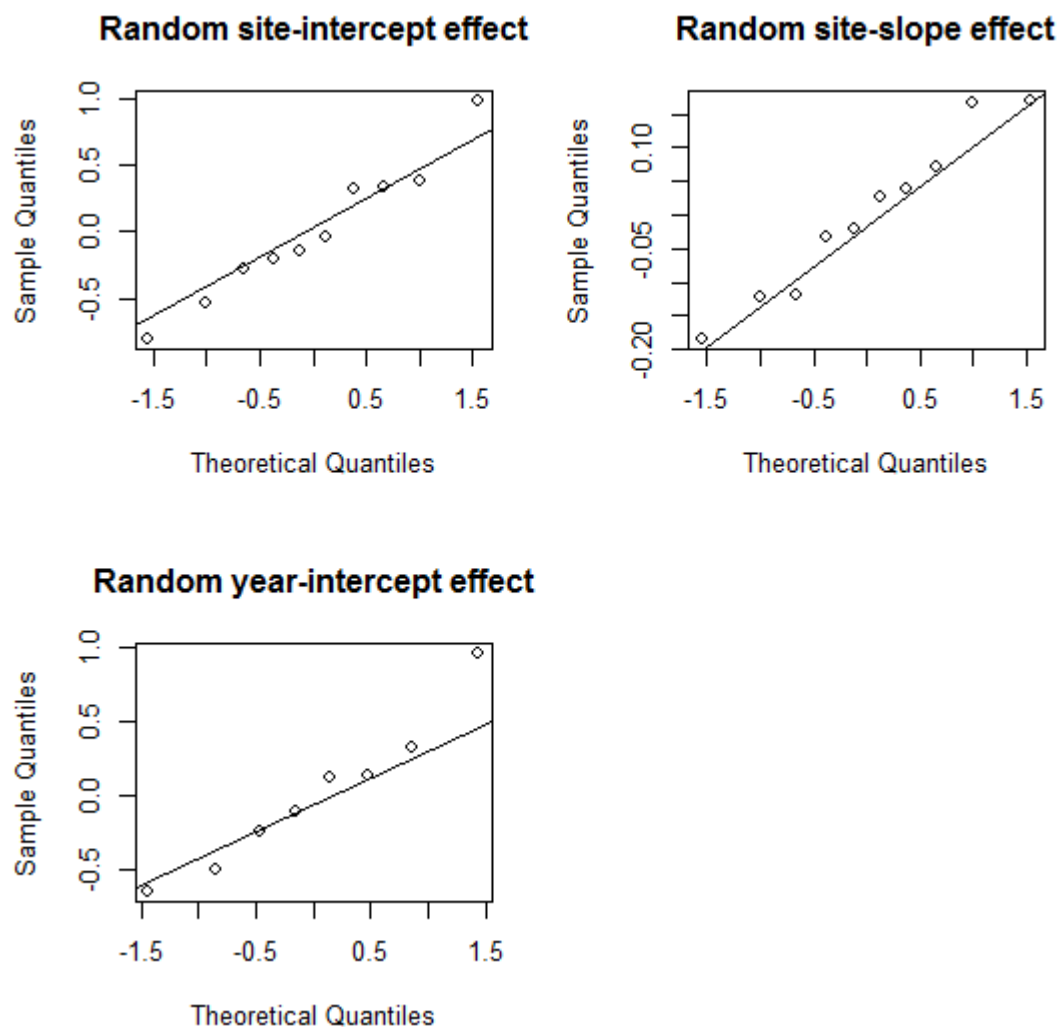


Figure 24. Normal quantile-quantile plots of random effects by group.

Histograms of the site- and year-level random effects were examined to evaluate the assumption that each group of random effects is centered on zero (Figure 25). The histograms indicate that the

random effects are centered on zero, but evaluation of normality is difficult due to the small sample size and is better assessed with the normal quantile-quantile plots (Figure 24).

```
range(ranef(fit)$Site[,1])    # -0.8131616  0.9904301
range(ranef(fit)$Site[,2])    # -0.1859309  0.1705265
range(ranef(fit)$Year[,1])    # -0.6588361  0.9614155
par(mfrow=c(2,2))
hist(ranef(fit)$Site[,1],breaks=seq(-1,1,0.1),xlab="Site RE", main="Random
site-intercept effect")
hist(ranef(fit)$Site[,2],breaks=seq(-.2,.2,0.05),xlab="Site RE", main="Random
site-slope effect")
hist(ranef(fit)$Year[,1],breaks=seq(-1,1,0.1), xlab="Year RE",main="Random
year-intercept effect")
```

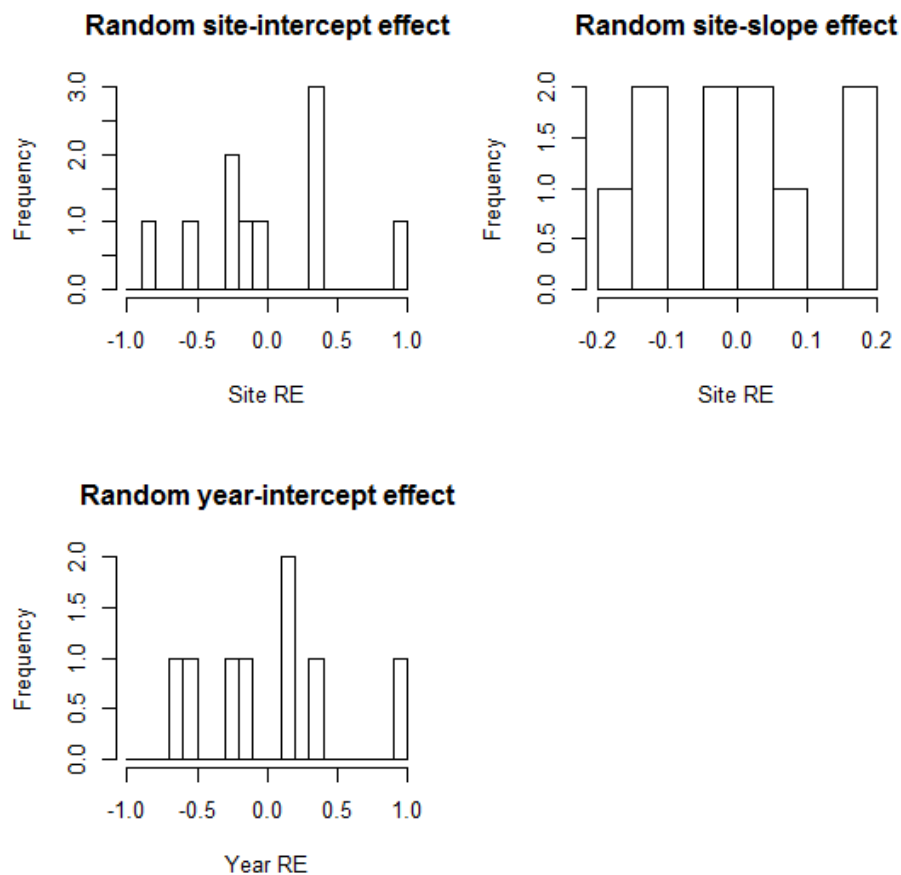


Figure 25. Histograms of random effects by Site and Year.

The assumption that random effects are independent for each group may also be tested. Groups could include fixed effects from the trend model or other random effects. Pinheiro and Bates (2000) suggest testing the independence assumption with different covariance structures, which requires the nlme (Pinheiro et al. 2016) package. More complex variance structures were attempted for this pilot data set, but the sample size was insufficient for more covariance parameters. Please refer to Pinheiro and Bates (2000) for more information on assessing the assumptions of linear mixed models.

Assuming the unweighted PO model, we can also use tools in the TrendNPS (Starcevich and Mitchell 2017) package to calculate the annual trend in *Acrosophonia* cover across quadrat elevation levels on the original scale of the binomial proportion, to calculate confidence intervals, and to conduct a two-sided test of no trend. First we calculate the proportion of the population in each stratum from the sampling frame, and then we use the TrendNPS_Binary function to calculate the PO model for a model containing fixed effects for the year, park, and year-by-park interaction. Finally, the park-level trends are weighted to provide the estimate of population trend. The SWAN sampling frame consisted of 86.773% points in KEFJ and 13.227% in KATM. The TrendNPS R code will use the first stratum in alphabetical order as the default, so we use str1prop = 0.13227 as the Stratum 1 proportion.

```
TrendAcro_PO_StRS = TrendNPS_Binary(alpha=0.1,
dat=Cover_Acro,method="PO",slope=TRUE,type=NA,stratum="Park",Y="Y",
stage1wt="wgt",stage2wt="PanelWt",
str1prop=0.13227)

$ModelEstimates
      mu      trend SEtrend      sig2a      sig2t      sigat      sig2b
1 -0.2992528 0.2219282 0.093413 0.2867147 0.01394016 -0.04732572 0.2411203

$TrendTest
      trend SEtrend z-stat pvalue
1 0.2219282 0.093413 2.375774 0.01751218

$TrendCIofOddsRatio
      Annual Pct Change      CI low      CI high
1      0.2484817 0.07066234 0.4558339
```

The output of the TrendNPS_Binary function includes the model estimates from the trend regression model, a trend test conducted at the specified alpha level of 0.10, and the estimate of the annual percent trend. The trend test indicates a significant non-zero trend (p-value = 0.0175). We estimate a 24.85% annual increase in the proportional cover of *Acrosophonia* and a 90%-confidence interval of (7.07%, 45.58%).

Case study 2: Sea star count data

We examine trend in the cover of *Dermasterias imbricata* (generally referred to subsequently as sea stars) between 2009 and 2015 across the two parks. Note that these counts are summarized at the Site level, so we do not have the additional hierarchy of mid- vs. upper-elevation quadrats for these data. The variance composition of the GLMM PO model is used to model trend with the `glmer` function of the `lme4` (Bates et al. 2015) R package so that the model fit can be assessed with residual diagnostics. Finally, the appropriate trend method is determined using the flowchart for count data (Figure 10) and trend analysis is conducted. First, we plot the sea star count data by park (Figure 26).

```
par(mfrow=c(1,1))
plot(Seastar$WYear+2009, Seastar$Count, xlab="Year", ylab="Seastar Count",
col=as.numeric(as.factor(Seastar$Park)), pch=19)
legend("topleft", col=1:2, pch=19, legend=c("KATM", "KEFJ"))
```

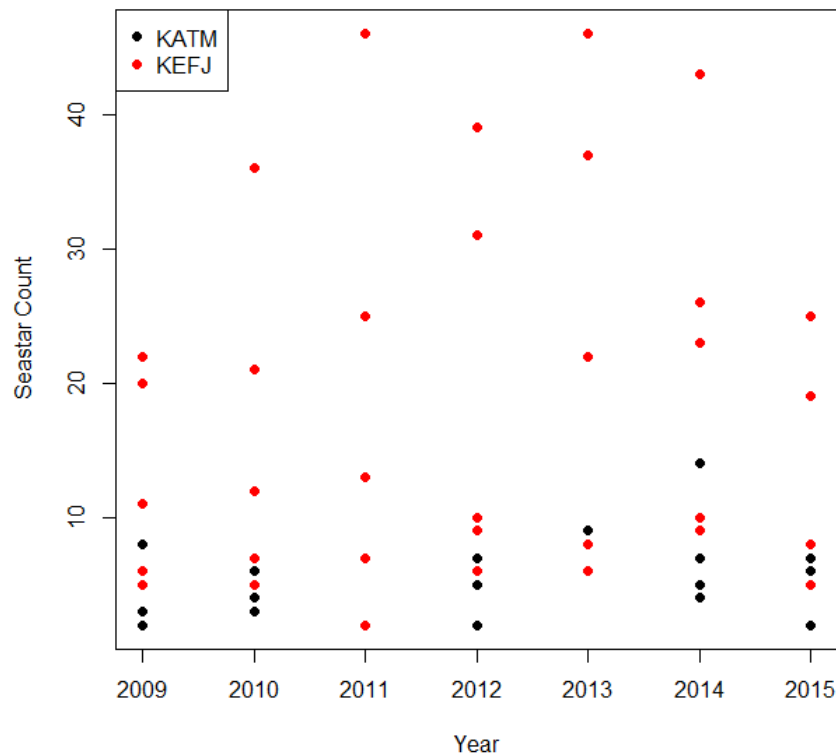


Figure 26. Sea star counts by Site, Year, and Park.

We modeled trend in sea star counts with a Poisson GLMM with variance components for year, site, and site-level slope (Piepho and Ogutu 2002). The initial model of the mean structure included fixed effects for WYear (an integer value of time starting with 0), Park, and their interaction.

```
# Fit the PO model in the lme4 package with the glmer function for
# generalized linear mixed-effects models. Specify a Poisson
# distribution and log link.
require(lme4)
```

```
fit_Seastar_1 = glmer(Count ~ WYear * Park + (1|Year) +(1+WYear|Site),
family = poisson(link=log), data = Seastar,
control=glmerControl(optimizer="bobyqa",optCtrl=list(maxfun=2e5)))
summary(fit_Seastar_1)
overdisp_fun(fit_Seastar_1)
#      chisq      ratio      rdf      p
# 74.26461605  1.30288800 57.00000000  0.06194214
```

The chi-square test of Poisson overdispersion (Zuur et al. 2009, p. 233) indicated that the counts exhibit more variation than would be expected in a Poisson distribution. We add a variable called Overdisp to model this overdispersion (Lee and Nelder 2000). Note that this specific issue of overdispersed counts is not addressed specifically in this research, but it cannot be ignored in practice.

```
Seastar$Overdisp = 1:nrow(Seastar)
fit_Seastar_2 = glmer(Count ~ WYear * Park + (1|Year) +(1+WYear|Site) +
(1|Overdisp), family = poisson(link=log), data = Seastar,
control=glmerControl(optimizer="bobyqa",optCtrl=list(maxfun=2e5)))
summary(fit_Seastar_2)
```

Random effects:

Groups	Name	Variance	Std.Dev.	Corr
Overdisp	(Intercept)	6.107e-02	0.247130	
Site	(Intercept)	2.228e-01	0.472037	
	WYear	6.531e-05	0.008082	-1.00
Year	(Intercept)	2.303e-02	0.151753	

Number of obs: 65, groups: Overdisp, 65; Site, 10; Year, 7

Fixed effects:

	Estimate	Std. Error	z value	Pr(> z)	
(Intercept)	1.44408	0.29411	4.910	9.1e-07	***
WYear	0.08278	0.05255	1.575	0.1152	
ParkKEFJ	1.09483	0.36627	2.989	0.0028	**
WYear:ParkKEFJ	-0.04175	0.05460	-0.765	0.4445	

```
overdisp_fun(fit_Seastar_2)
#      chisq      ratio      rdf      p
# 28.3733557  0.5066671 56.00000000  0.9992277
```

The p-value for the chi-square goodness-of-fit test indicated no substantial overdispersion at the 0.10 level (p-value = 0.9992), so the random effect was effective in modeling the extra variation. The initial model contained a fixed effect for park-specific trend (WYear:ParkKEFJ) that was also not significant at the $\alpha = 0.10$ level (p-value = 0.4445), so we simplify the model and assume a single trend across both parks.

```
# Fit the reduced P0 model without the separate park slope term
fit_Seastar_3 = glmer(Count ~ WYear + Park + (1|Year) +(1+WYear|Site) +
(1|Overdisp), family = poisson(link=log), data = Seastar,
control=glmerControl(optimizer="bobyqa",optCtrl=list(maxfun=2e5)))
summary(fit_Seastar_3)
```

Random effects:

Groups	Name	Variance	Std.Dev.	Corr
--------	------	----------	----------	------

```

Overdisp (Intercept) 0.0624134 0.24983
Site      (Intercept) 0.2329705 0.48267
           WYear      0.0001284 0.01133 -1.00
Year      (Intercept) 0.0227388 0.15079
Number of obs: 65, groups: Overdisp, 65; Site, 10; Year, 7

```

Fixed effects:

```

              Estimate Std. Error z value Pr(>|z|)
(Intercept)  1.54910    0.26067   5.943 2.8e-09 ***
WYear        0.05607    0.03908   1.435 0.15134
ParkKEFJ     0.92882    0.30494   3.046 0.00232 **

```

However, note that the correlation between the random Site intercept and random Site slope was -1.00 in the previous and in the current model (in red). This indicates that the trend model was overspecified. We removed the random slope term as follows:

```

fit_Seastar_4 = glmer(Count ~ WYear + Park + (1|Year) +(1|Site) +
(1|Overdisp), family = poisson(link=log), data = Seastar,
control=glmerControl(optimizer="bobyqa",optCtrl=list(maxfun=2e5)))
summary(fit_Seastar_4)

```

Random effects:

```

Groups   Name      Variance Std.Dev.
Overdisp (Intercept) 0.06310  0.2512
Site     (Intercept) 0.19925  0.4464
Year     (Intercept) 0.02263  0.1504
Number of obs: 65, groups: Overdisp, 65; Site, 10; Year, 7

```

Fixed effects:

```

              Estimate Std. Error z value Pr(>|z|)
(Intercept)  1.54645    0.25721   6.013 1.83e-09 ***
WYear        0.05281    0.03823   1.381 0.16714
ParkKEFJ     0.95599    0.30319   3.153 0.00162 **

```

We found no evidence of a significant increasing trend in sea star counts across the two parks between 2009 and 2015 (p-value = 0.1671). The mean sea star count in KEFJ is significantly higher than in KATM as evidenced by the positive difference of 0.92882 (p-value = 0.0016).

As in the binary outcome case study, we assessed the assumptions of the generalized linear mixed model following the guidance of Zuur et al (2009) and Pinheiro and Bates (2000). Model assessment for the Poisson GLM included plotting the residuals against fitted values, time, and other model covariates (Figure 27). The plot of logged fitted values against residuals indicated an increasing pattern in residuals, and the deviance residuals plotted against time suggested some curvature. However, the small number of sites visited over a relatively-short monitoring period precluded additional model terms.

```

fit = fit_Seastar_4      # use the linear model with full no random slope
dat = Seastar
dat$resid = residuals(fit, type="deviance")
dat$fitted = fitted(fit)
par(mfrow=c(2,2))
# plot deviance resids vs fitted

```

```

plot(dat$resid, log(dat$fitted), xlab="Deviance residuals", ylab="Fitted
values", main="(a)")

# plot deviance resids vs model vars
plot(dat$WYear+2008, dat$resid, ylab="Deviance residuals", xlab="Year",
main="(b)")
boxplot(dat$resid ~ dat$Park , ylab="Deviance residuals", xlab="Park",
main="(c)")

# plot deviance resids vs vars not in the model
plot(dat$Gradient, dat$resid, ylab="Deviance residuals", xlab="Site Gradient
(degrees)", main="(d)")

```

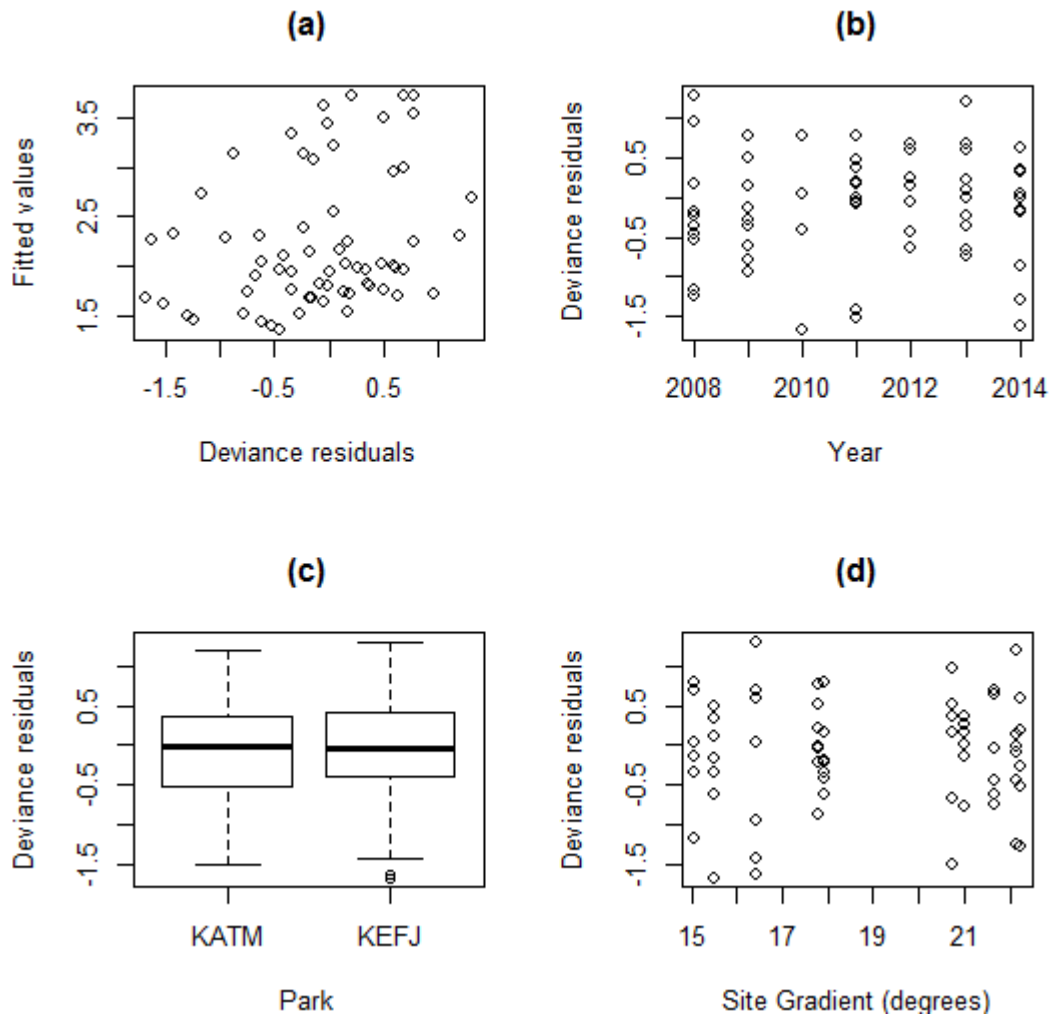


Figure 27. Linear trend model deviance residuals for (a) fitted values, (b) WYear, (c) Park, and (d) Site Gradient.

The first assumption of the random effects portion of the model is assessed by evaluating within-group residuals, where groups in this setting are defined by Year and Site. The independence assumption is examined with partial autocorrelation functions of site-level residuals to determine if any serial correlation remains in trend model residuals. A function to create a time series of the mean

residuals for each site and plot the partial autocorrelation function is provided. Partial autocorrelation plots for each site indicate no substantial serial correlation in trend model residuals (Figures 28 and 29), but nontrivial autocorrelation may not be detectable with only 5 sites surveyed over 8 years.

```
require(reshape)
Seastar_ts=Residual_ts(resids=dat$resid, yr=dat$Year, site=dat$Site)
op <- par(mfrow=c(3,2),
          oma = c(0,2,1,0) + 0.1,
          mar = c(2,1.5,3.5,1) + 0.1)

# KATM sites
for (i in which(grepl("AKP", colnames(Seastar_ts)))) {
  if(length(Seastar_ts[!is.na(Seastar_ts[,i]),i])>2) Seastar_ts.i =
  pacf(Seastar_ts[!is.na(Seastar_ts[,i]),i], na.action=na.pass, plot=FALSE)
  plot(Seastar_ts.i, type="h", main=colnames(Seastar_ts)[i])
}
```

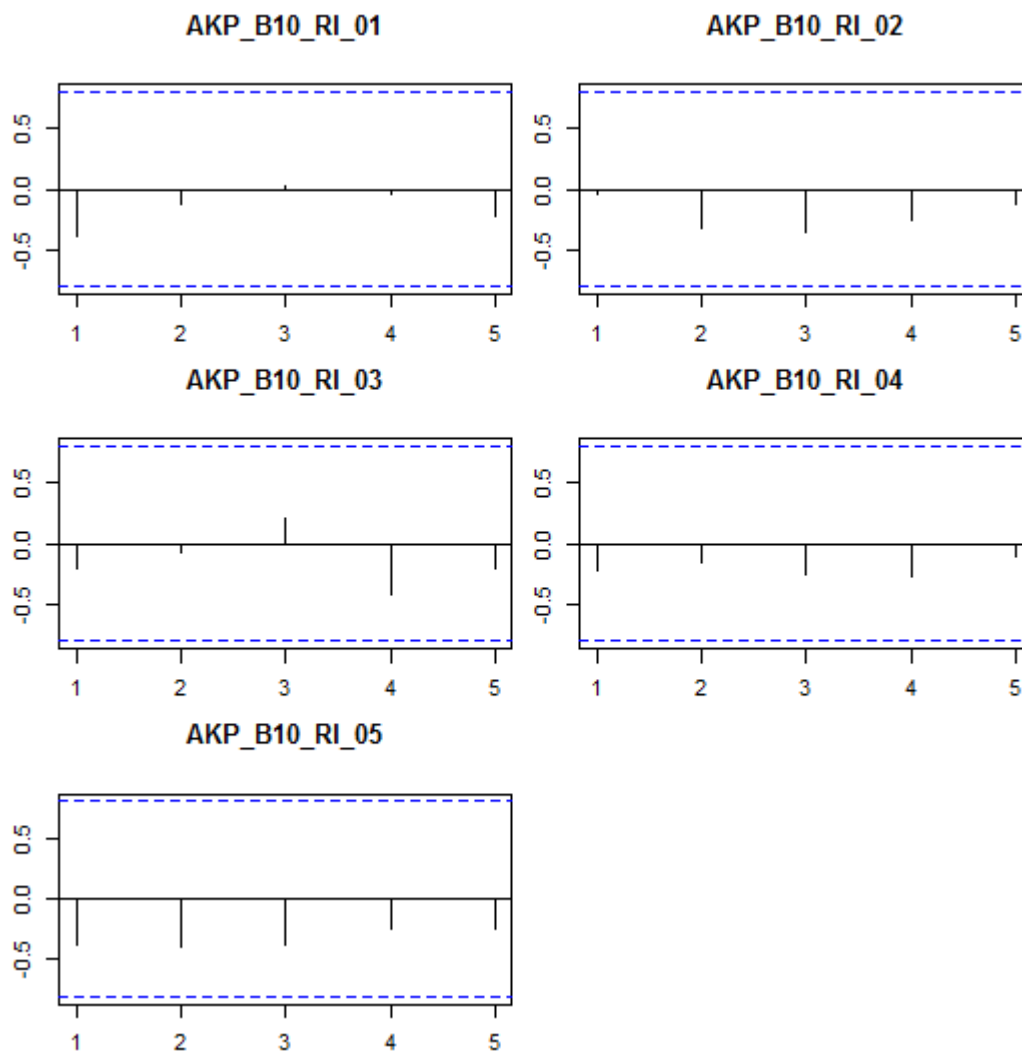


Figure 28. Partial autocorrelation function plots of residuals for sites in KATM.

```

# KEFJ sites
op <- par(mfrow=c(3,2),
          oma = c(0,2,1,0) + 0.1,
          mar = c(2,1.5,3.5,1) + 0.1)
for (i in which(grepl("KEP",colnames(Seastar_ts)))) {
  if(length(Seastar_ts[!is.na(Seastar_ts[,i]),i])>2) Seastar_ts.i =
  pacf(Seastar_ts[!is.na(Seastar_ts[,i]),i], na.action=na.pass, plot=FALSE)
  plot(Seastar_ts.i, type="h", main=colnames(Seastar_ts)[i])
}

```

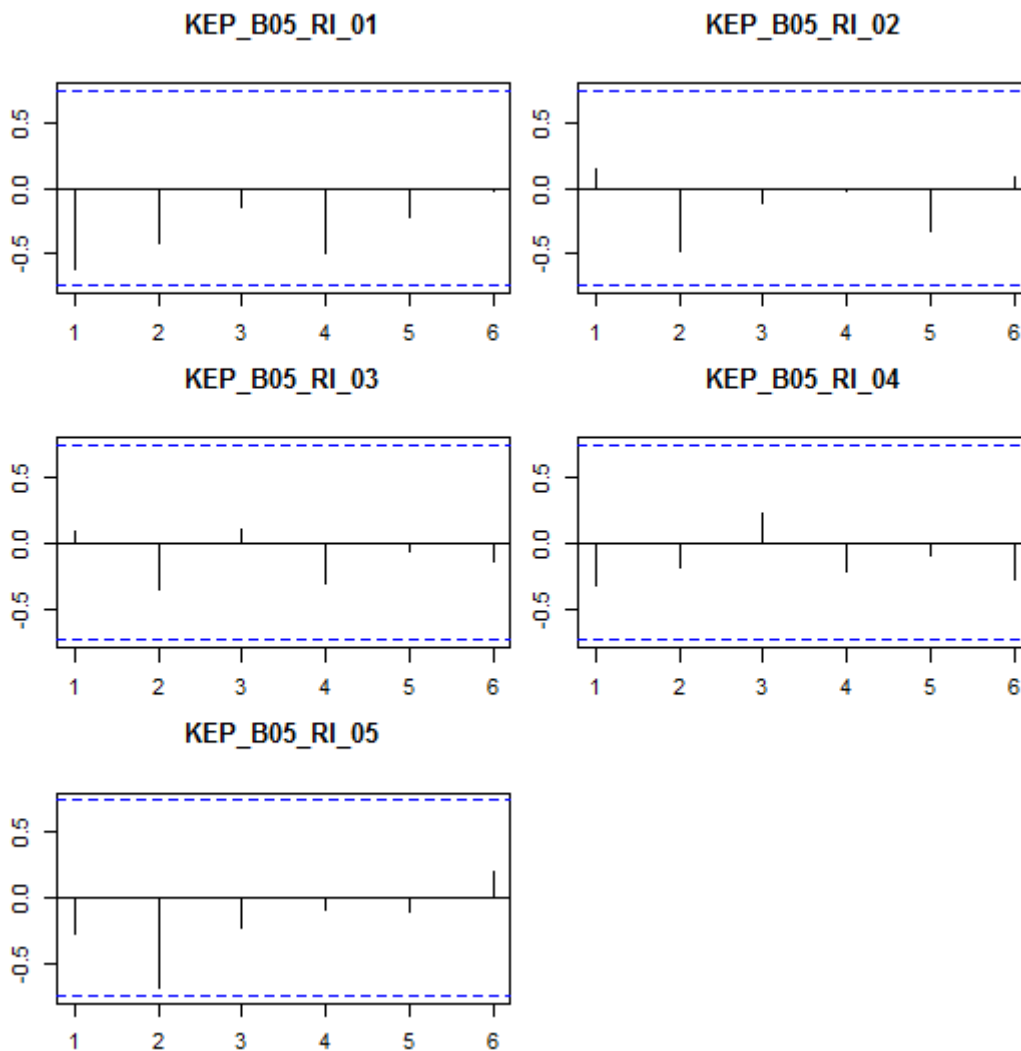


Figure 29. Partial autocorrelation function plots of residuals for sites in KATM.

The equal variance requirement is assessed with a plot of residuals against fitted values across all groups (Figure 30). We see some deviations from a mean of 0, but the magnitude of the residuals is small and variance looks roughly equal across years.

```
require(ggplot2)
```

```
ggplot(data=dat, aes(x=wYear, y=resid)) + geom_jitter(aes(colour= Count),
width=0.75) + stat_smooth(se=FALSE, colour="black") + xlab("Year") +
ylab("Residual (Deviance)")
```

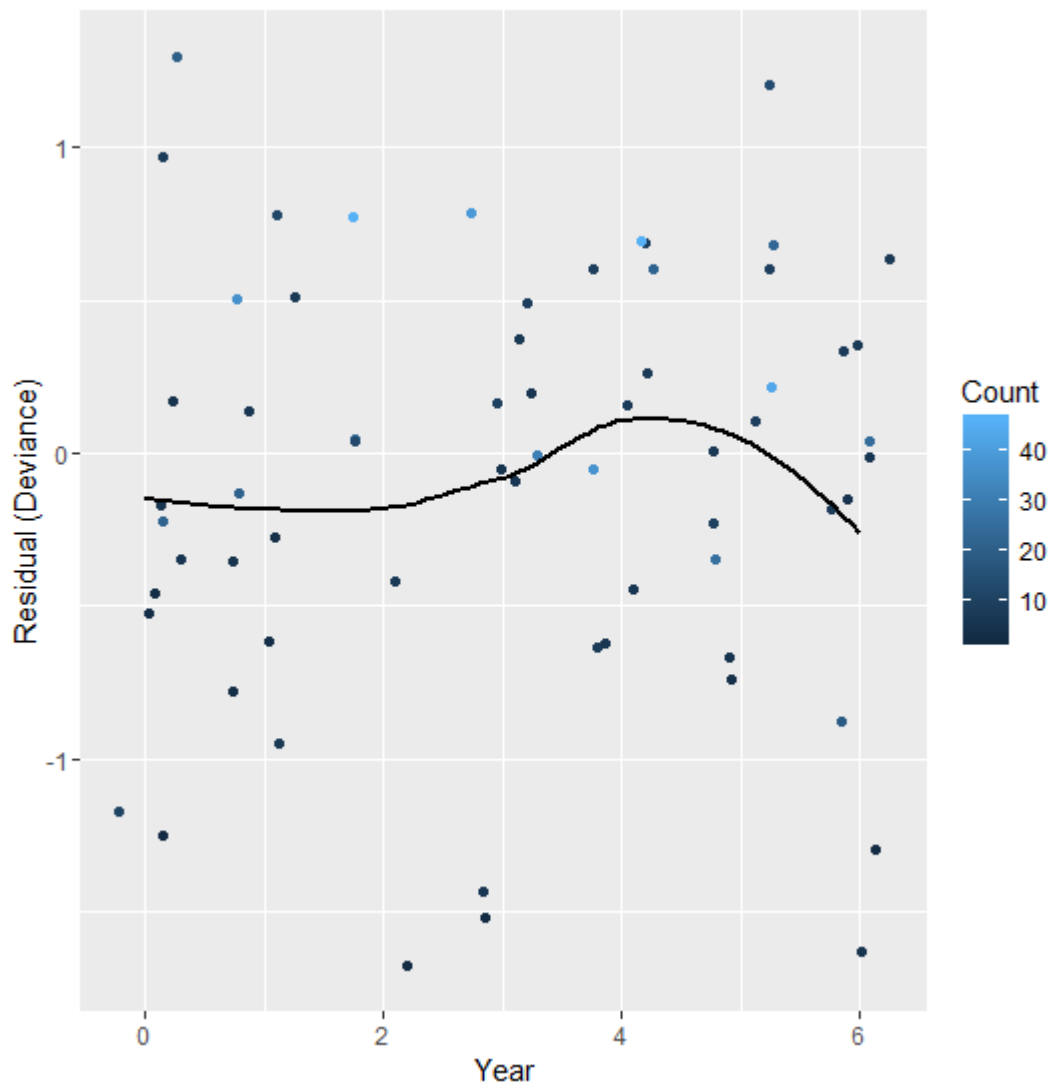


Figure 30. Deviance residuals by Year.

Now we examine the residuals by group, beginning with grouping by Site (Figures 31 and 32) and then by Year (Figures 33 and 34). Some heterogeneity is observed but the residuals are centered on zero overall. The residual plots by year indicate lower residuals for 2008-2009, which may indicate latent environmental effects, effects of field crew training, or some other factor that may be identified and included in the model. With only 5 sites per park, including several model predictors in the mean structure may not be possible due to the small sample size.

```
# Examine residuals by Site across Years
plot(fit, Site~resid(.), abline = 0) # Figure 31
plot(fit, resid(., type = "deviance") ~ fitted(.) | Site) # Figure 32
# Examine residuals by Site across Years
```

```
plot(fit, Year~resid(.), abline = 0) # Figure 33
plot(fit, resid(., type = "deviance") ~ fitted(.) | Year) # Figure 34
```

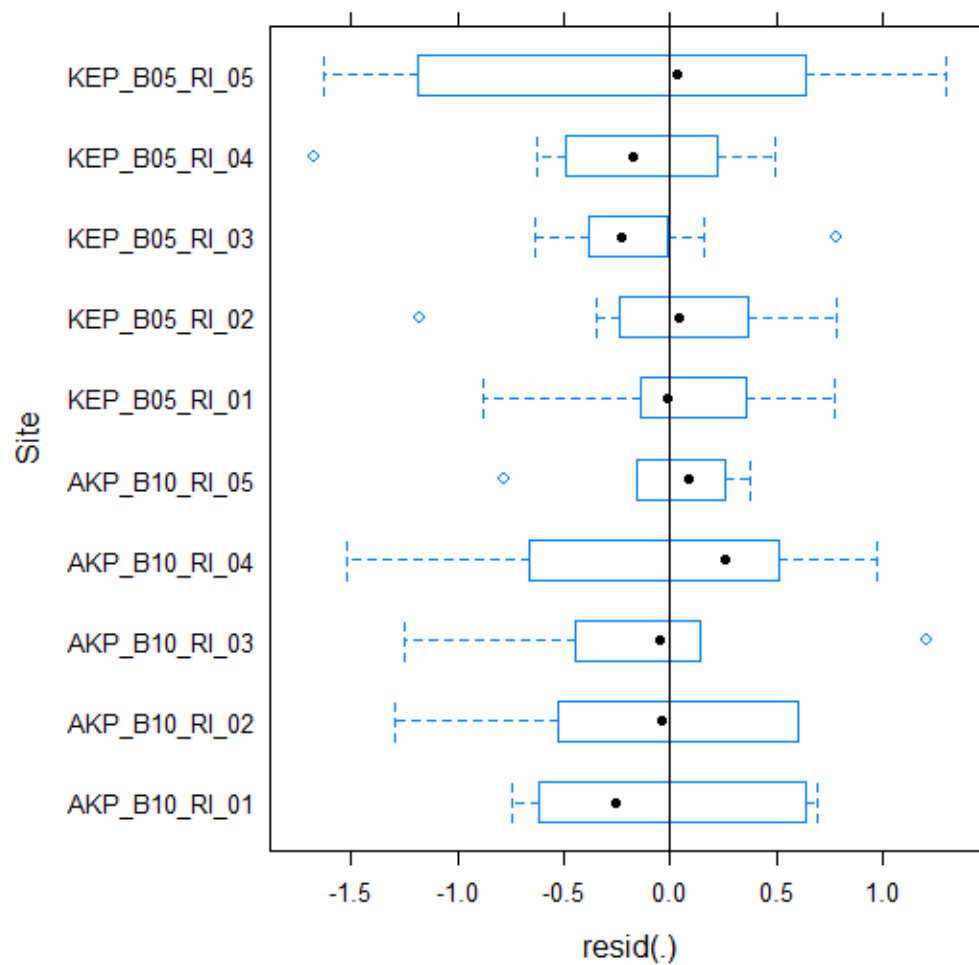


Figure 31. Boxplot of deviance residuals by Site across Years.

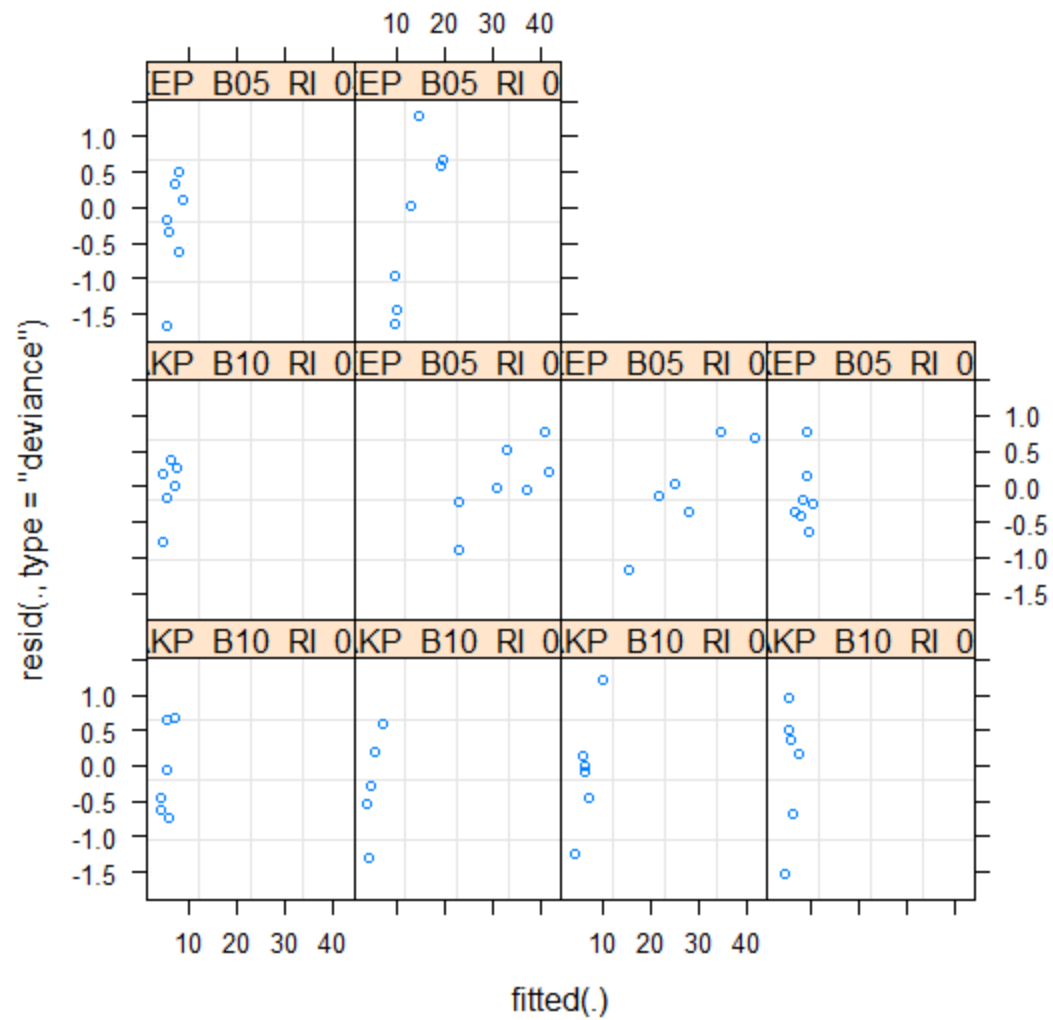


Figure 32. Deviance residuals by Site.

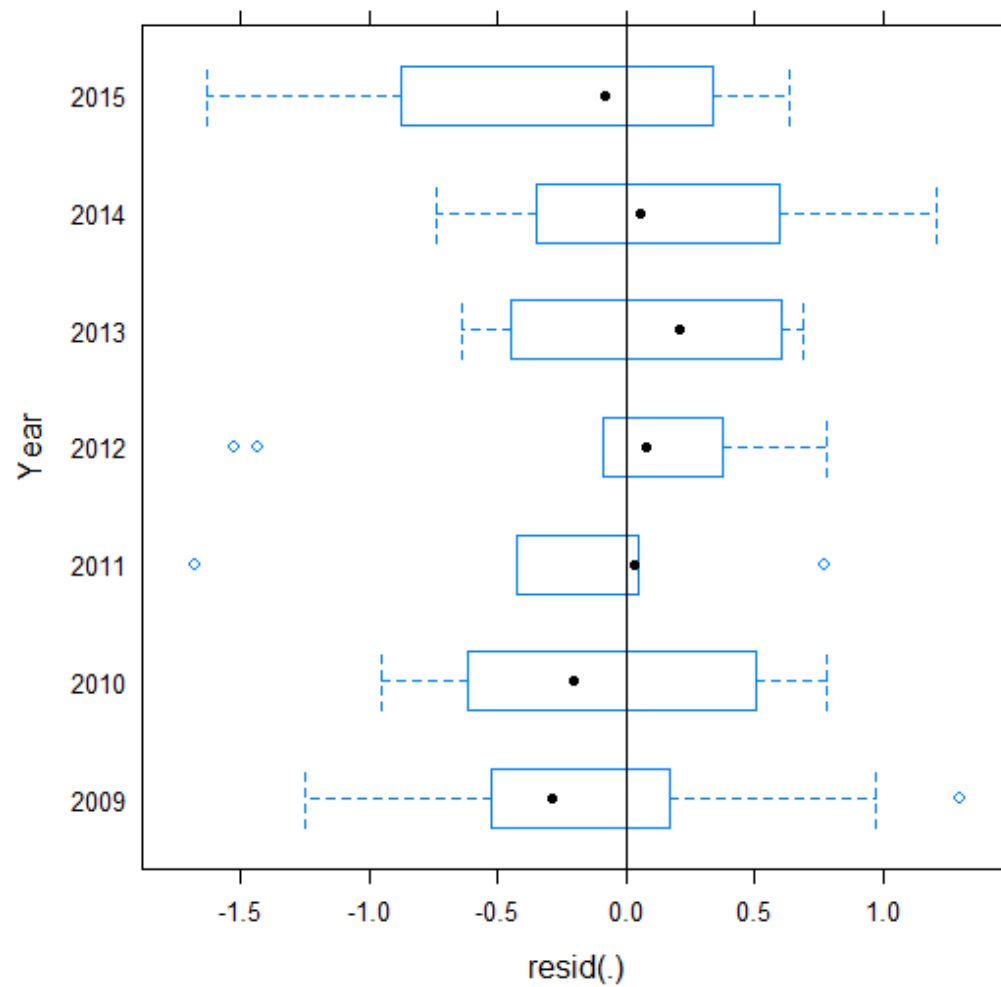


Figure 33. Boxplot of deviance residuals by Year across Sites.

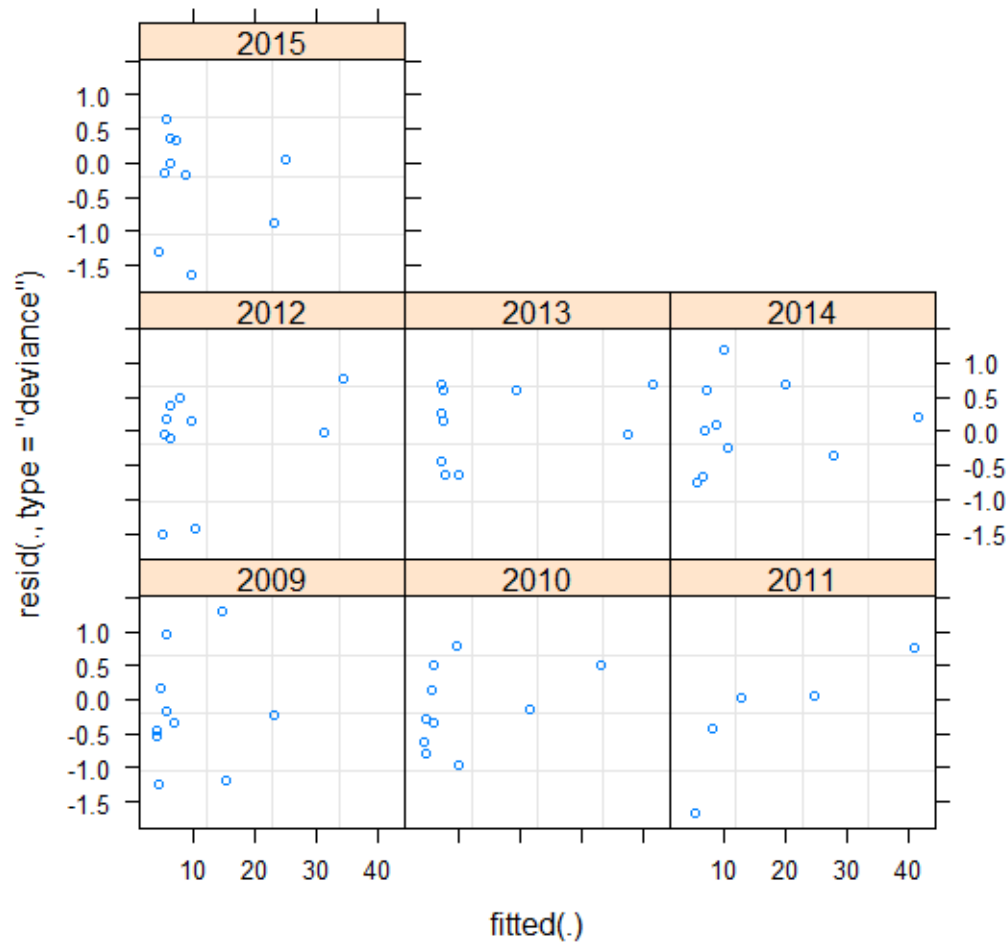


Figure 34. Deviance residuals by Year.

Testing for normality is assessed by reviewing normal distribution quantile-quantile plots of group-level residuals for Site (Figures 35 and 36), which indicate approximate normality for most sites and across all sites (Figure 37), and Year (Figure 38). For sites with residuals that stray from the line indicating quantiles of the standard normal distribution, the outliers are not extreme (outside the interval $[-2, 2]$) but we would consider that other model predictors or groupings might be needed if the departure from normality was exhibited as more years of monitoring data were added to the time series. The plot of residuals by year indicates some low residuals in 2012 that might indicate an unknown effect in that year for those sites.

```
# Quantile-quantile plots of residuals by site
siteVec <- unique(dat$Site)
length(siteVec) # 8
par(mfrow=c(3,2))
for(w in which(grepl("AKP", siteVec))) {
  qqnorm(dat$resid[dat$Site == siteVec[w]],
    main = paste("Site", siteVec[w]))
  qqline(dat$resid[dat$Site==siteVec[w]])
}
```

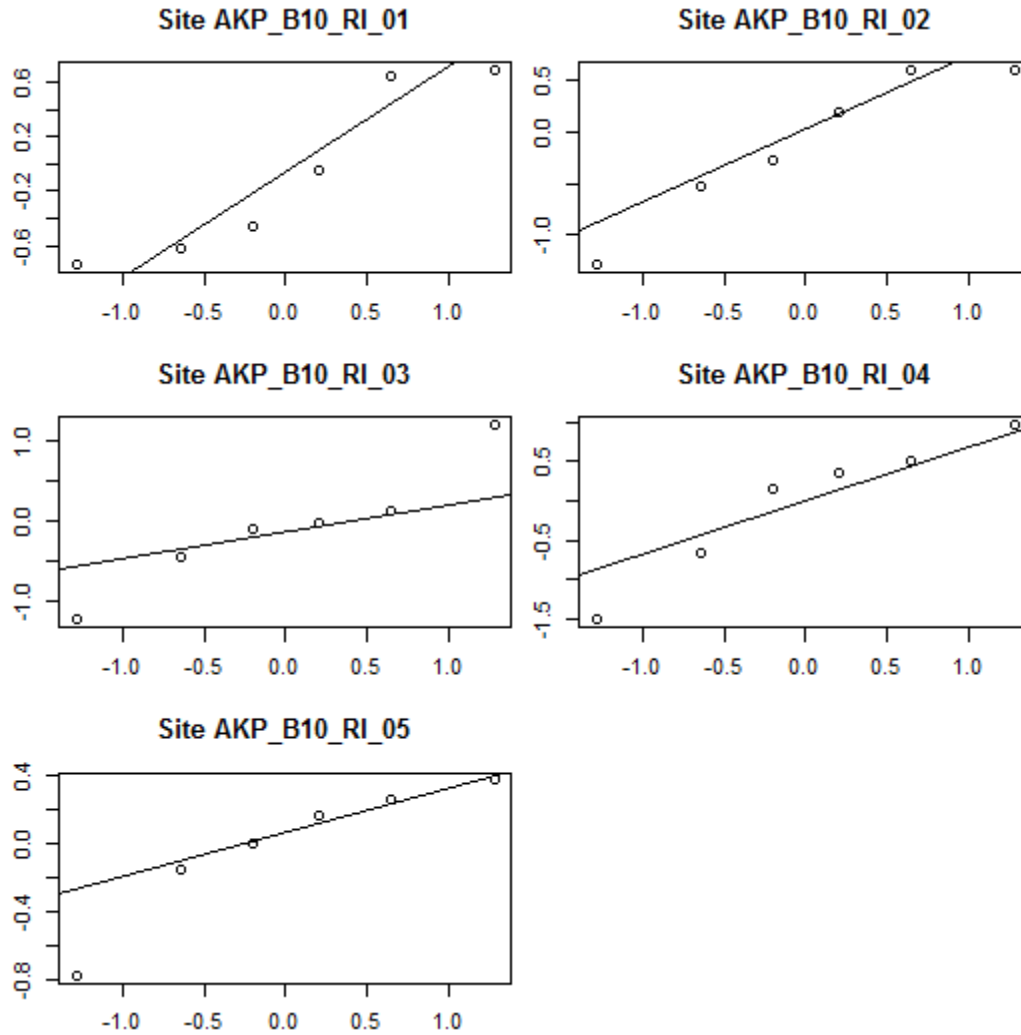


Figure 35. Normal quantile-quantile plots of deviance residuals by Site for KATM.

```
par(mfrow=c(3,2))
for(w in which(grepl("KEP",siteVec))) {
  qqnorm(dat$resid[dat$Site == siteVec[w]],
    main = paste("Site",siteVec[w]))
  qqline(dat$resid[dat$Site==siteVec[w]])
}
```

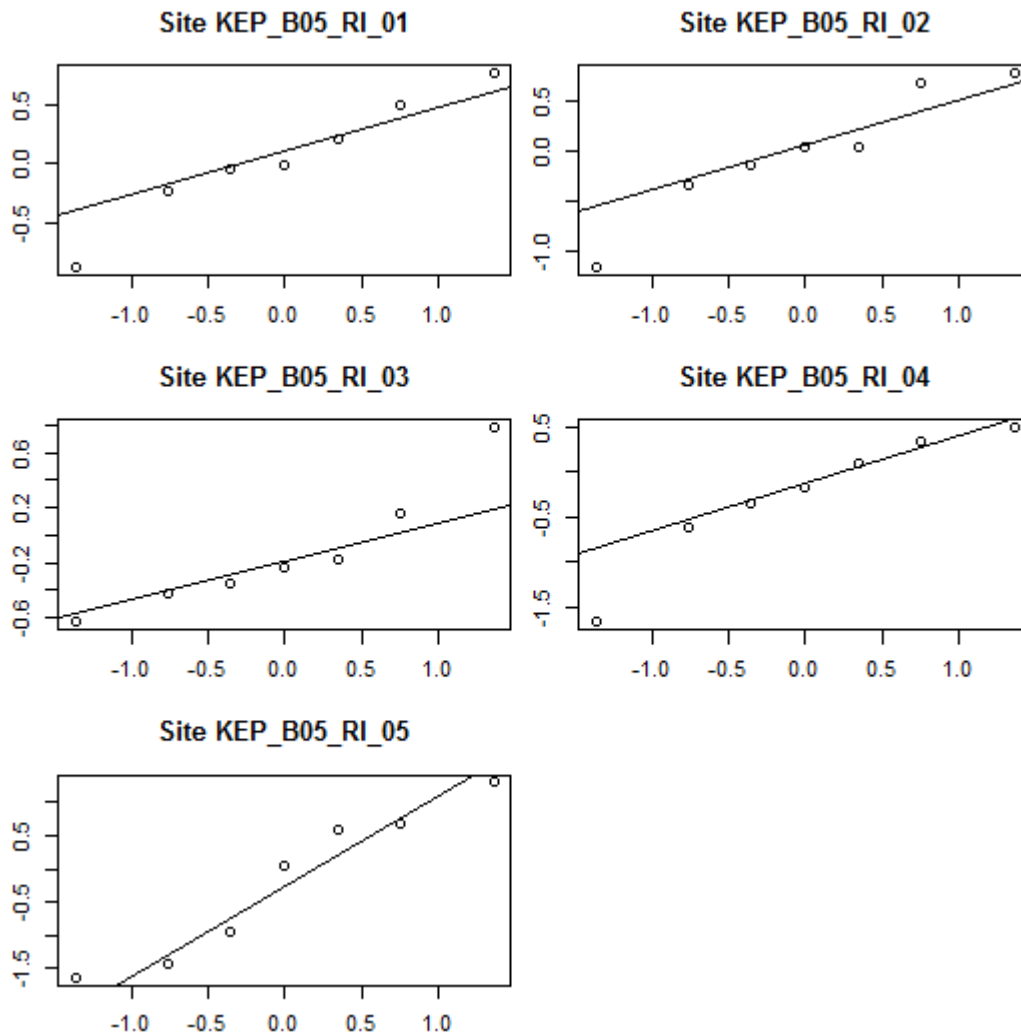


Figure 36. Normal quantile-quantile plots of deviance residuals by Site for KEFJ.

Given that the sample size of sites is relatively small, we lump residuals across sites to assess normality (Figure 37) and note that approximate normality is indicated.

`qqnorm(dat$resid)`

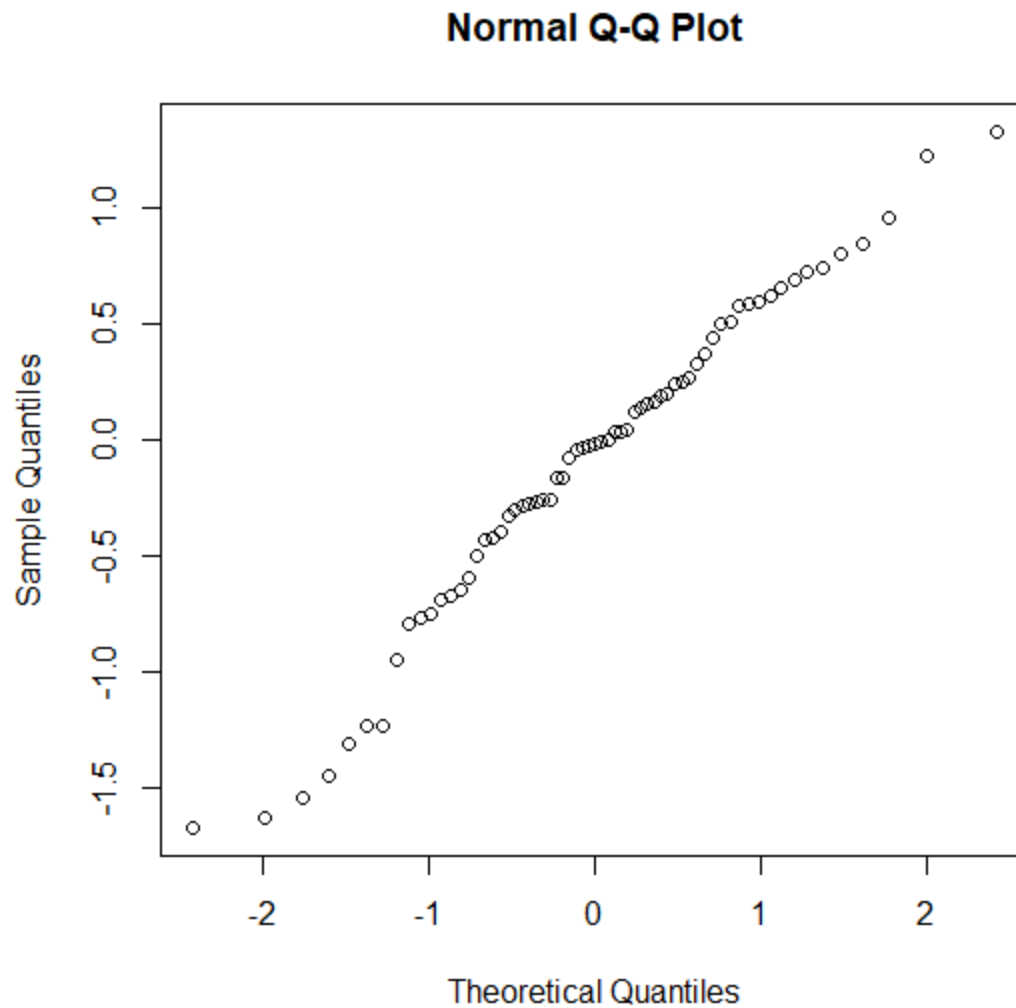


Figure 37. Normal quantile-quantile plots of deviance residuals for all Sites.

```
# Quantile-quantile plots of residuals by year
Years = sort(unique(dat$WYear))+2009
length(Years)      # 8
par(mfrow=c(4,2))
for(w in 1:8) {
  qqnorm(dat$resid[dat$Year == Years[w]],
        main = Years[w])
  qqline(dat$resid[dat$Year==Years[w]])
}
```

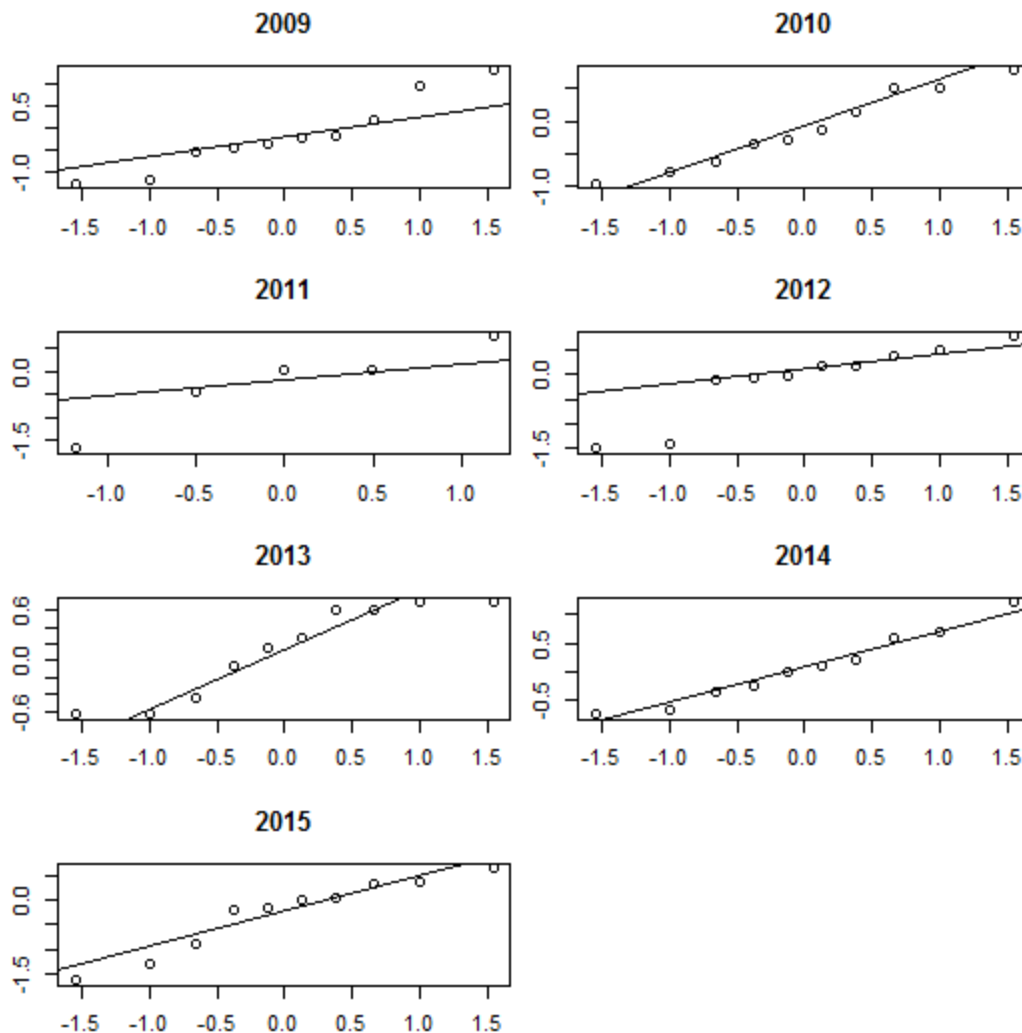


Figure 38. Normal quantile-quantile plots of Deviance residuals by Year.

The independence assumption is addressed by examining possible correlation between the residuals and the site- and year-level random effects. Pearson's correlation tests are conducted to assess any possible linear correlation. As shown by the test results below and in Figure 39, no evidence of correlation between the residuals and either the Site effects or the Year effect is observed.

```
# Independence assumption -- independence of RE and resids
SiteRE = data.frame(Site=rownames(ranef(fit)$Site), SiteRE=ranef(fit)$Site)
names(SiteRE)[2] = 'SiteRE'
rownames(SiteRE)=NULL
YearRE = data.frame(Year=rownames(ranef(fit)$Year), YearRE=ranef(fit)$Year)
names(YearRE)[2] = 'YearRE'
rownames(YearRE)=NULL

dat = merge(dat, SiteRE)
dat = merge(dat, YearRE)

cor.test(dat$resid, dat$YearRE)
# cor = 0.1908, t = 1.5431, df = 63, p-value = 0.1278
```

```

cor.test(dat$resid, dat$SiteRE)
# cor = 0.1165, t = 0.93122, df = 63, p-value = 0.3553
# cor.test(dat$resid, dat$SiteRE.WYear)
# No random slope in this model

par(mfrow=c(2,2))
plot(resid ~ SiteRE, data=dat, main="Site Random Effects", xlab="Site RE",
ylab="Residuals")
abline(0,0,col=2)
# No random slope
#plot(resid ~ SiteRE.WYear, data=dat, main="Site Slope Random Effects",
#xlab="Site RE", ylab="Residuals")
#abline(0,0,col=2)
plot(resid ~ YearRE, data=dat, main="Year Random Effects", xlab="Year RE",
ylab="Residuals")
abline(0,0,col=2)

```

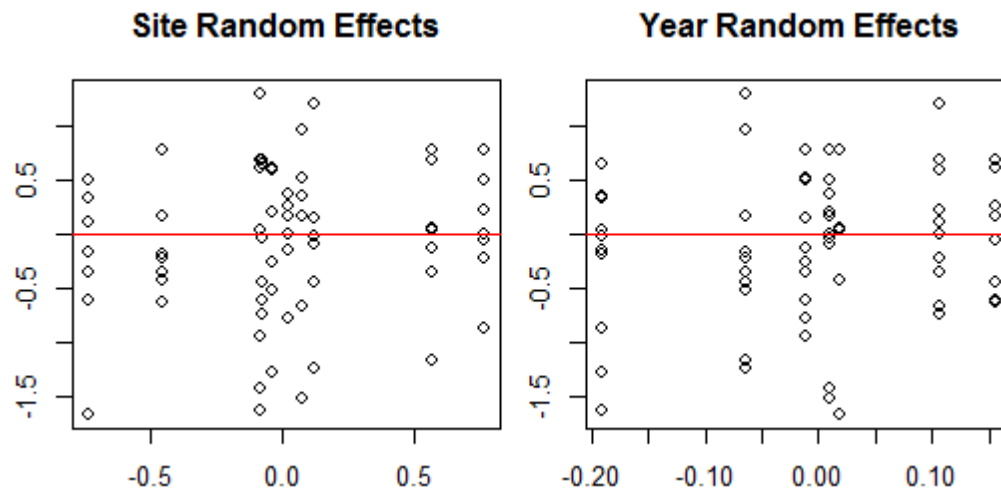


Figure 39. Plots of residuals against Site- and Year-level random effects.

We also checked assumptions on the estimated random effects, also called “best least unbiased estimators,” or BLUPs. These are obtained in the lme4 package with the ranef(fit) function. First, the normality of the BLUPs is assessed with normal quantile-quantile plots for each group (Figure 40) which indicates approximate normality. The random effects that depart from the normal quantile line may indicate missing model predictors or are simply an effect of a small sample size of sites (5 in each park).

```

# Normality of BLUPs
par(mfrow=c(2,2))
qqnorm(ranef(fit)$Site[,1], main = "Random site-intercept effect")
qqline(ranef(fit)$Site[,1])
#qqnorm(ranef(fit)$Site[,2], main = "Random site-slope effect")
#qqline(ranef(fit)$Site[,2])
qqnorm(ranef(fit)$Year[,1], main = "Random year-intercept effect")
qqline(ranef(fit)$Year[,1])

```

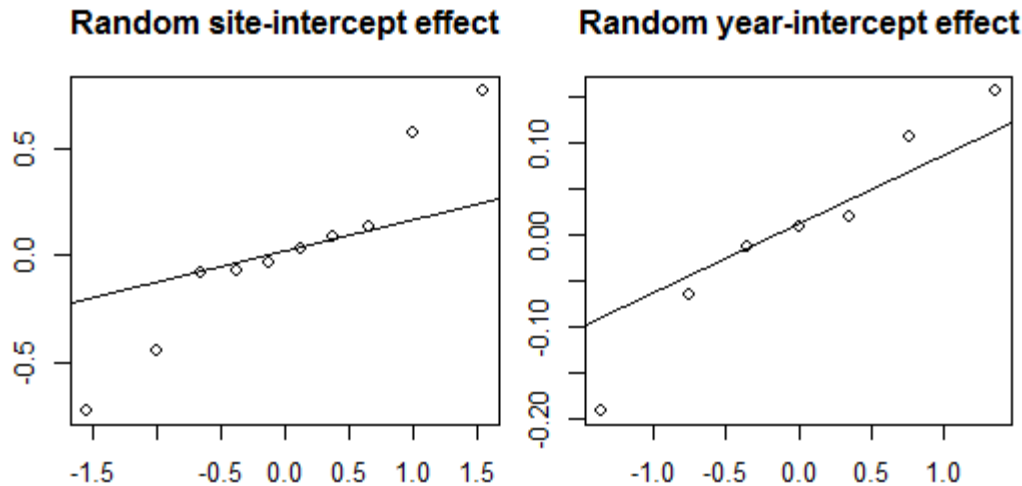


Figure 40. Normal quantile-quantile plots of random effects by group.

Histograms of the site- and year-level random effects were examined to evaluate the assumption that each group of random effects is centered on zero (Figure 41). The histograms indicate that the random effects are centered on zero; assessing normality given the small sample size is easier with normal quantile-quantile plots (Figure 40) than with histograms (Figure 41).

```
range(ranef(fit)$Site[,1])    # -0.7286840  0.7684565
#range(ranef(fit)$Site[,2])# No random slope
range(ranef(fit)$Year[,1])   # -0.1908055  0.1564766
par(mfrow=c(2,2))
hist(ranef(fit)$Site[,1],breaks=seq(-1,1,0.1),xlab="Site RE", main="Random
site-intercept effect")
#hist(ranef(fit)$Site[,2],breaks=seq(-.02,.02,0.005),xlab="Site RE",
#main="Random site-slope effect")
hist(ranef(fit)$Year[,1],breaks=seq(-0.2,0.2,0.01), xlab="Year
RE",main="Random year-intercept effect")
```

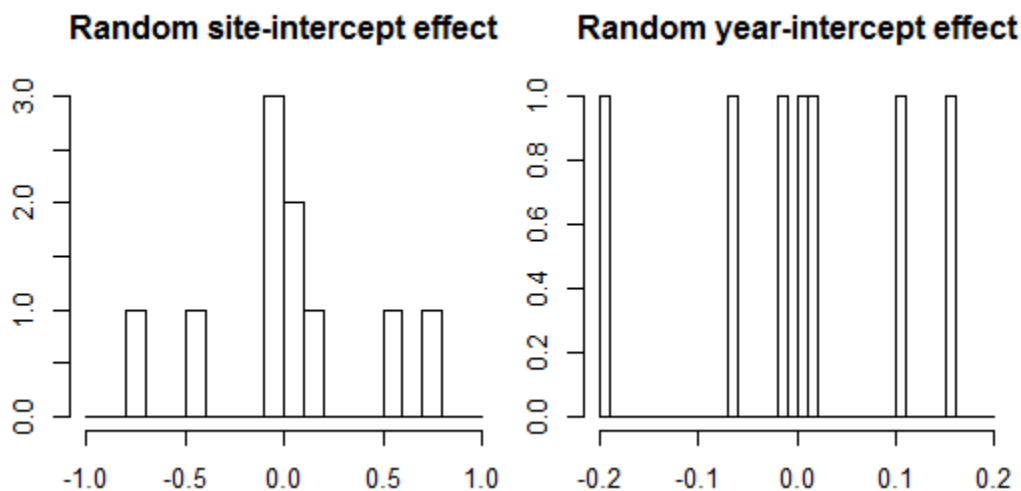


Figure 41. Histograms of random effects by Site and Year.

The assumption that random effects are independent for each group may also be tested. Groups could include fixed effects from the trend model or other random effects. Please refer to Pinheiro and Bates (2000) for more information testing the independence assumption with different covariance structures, which requires the nlme (Pinheiro et al. 2016) package.

After the model assumptions have been evaluated, subpopulations trends are explored. We recommend that, in practice, potential subpopulations be identified a priori based on ecological knowledge. For these data, the only covariate that has not been assessed is mean site gradient. However, this site gradient is associated with Park for these data, so we continue with the analysis considering only the Park and time covariates for the trend model.

Using the flowchart (Figure 10) to determine the appropriate trend analysis procedure, we follow the options for stratified sampling and 12 years (our closest option for a 7-year monitoring period) and are directed to conduct the trend analysis with the PO model with stratification by Park. We will omit the random slope term to avoid trend model overspecification. Because the TrendNPS tools are created for Poisson outcomes that are not subject to overdispersion, we use the PO model obtained previously for inference, fit_Seastar_4.

```
ans.model =
data.frame(fixef(fit)[1], fixef(fit)[2], summary(fit)$coefficients[2,2], VarCorr(
fit)$Site[1], sig2t=0, sigat=0, VarCorr(fit)$Year[1], VarCorr(fit)$Overdisp[1])
names(ans.model)=c('mu', 'trend', 'SEtrend', 'sig2a', 'sig2t', 'sigat', 'sig2b', 'si
g2OverDisp')
rownames(ans.model) = NULL

# Trend test
ans.trendtest = data.frame(trend = ans.model[2], SE = ans.model[3],
z.stat=ans.model[2]/ans.model[3], pvalue=2*pnorm(as.numeric(abs(ans.model[2]/a
ns.model[3])), lower.tail =FALSE))
names(ans.trendtest)[3] = 'z-stat'

# CI on trend:
alpha=0.1
CI = data.frame(ans.model[2], ans.model[2]-qnorm(1-
(alpha/2))*ans.model[3], ans.model[2]+qnorm(1-(alpha/2))*ans.model[3])
ans.trendCI = exp(CI)-1
names(ans.trendCI) = c("Annual Pct Change", "CI low", "CI high")

TrendSeastar_PO_StRS = list(ModelEstimates = ans.model,
TrendTest = ans.trendtest, TrendCI = CI)

TrendSeastar_PO_StRS
$ModelEstimates
      mu      trend      SEtrend      sig2a sig2t sigat      sig2b sig2OverDisp
1.546454 0.05280853 0.03822643 0.1992481    0    0 0.02262625 0.06309556

$TrendTest
      trend      SEtrend      z-stat      pvalue
1 0.05280853 0.03822643 1.381467 0.1671356

$TrendCI
      trend      trend.1      trend.2
```

1 0.05280853 -0.01006835 0.1156854

The output of the TrendNPS_Count function includes the model estimates from the trend regression model, a trend test for the normal approximation, and the estimate of the annual percent trend on the count scale with a 90%-confidence interval. We see that the estimated annual trend in the mean count is 5.28% with a 90%-confidence interval of -1.01% to 11.57%. While no significant trend in the mean count over the monitoring period is indicated in the strict statistical sense, intertidal ecologists may choose to increase annual sampling effort to increase precision in the trend estimate for more robust trend inference and monitoring.

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

NPS 963/145052, May 2018

National Park Service
U.S. Department of the Interior



[Natural Resource Stewardship and Science](#)

1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525