Supporting Information

APPENDIX S1 – THE SIMULATION STUDY

METHODS

Using data obtained from the trial and main simulated surveys (detection function parameters provide in Table S1), an estimate of abundance, $\hat{N}$ was calculated using Equations 2 and 3, either by assuming underlying heterogeneity (i.e., group membership) was known (e.g., an observable covariate such as sex) or unknown (e.g., an unobservable covariate):

$$\hat{N}_3 = \frac{A}{A_c}\sum_{i=1}^{n} E_b\left[\frac{1}{\hat{P}(g_i)}\right] \qquad \textbf{Eq. 3}$$

where A is the area of the survey region (=3,000 x 4,300 m^2), A_c is the area of the covered region (= k*w^2, where k is the number of sample points in the main survey and w = 125), and $\hat{P}(g_i)$ is the estimated probability of detecting the ith animal captured in the main survey, given it is in group g. If the group covariate is unknown, then the detection function is assumed to depend only on distance, and no other covariates.

Percentage bias (*%bias*) and root-mean square error (*RMSE*) were calculated as follows:

$$\%bias = \frac{\bar{N} - N}{N}$$

$$RMSE = \sqrt{\sum_{i=1}^{B} \frac{(\hat{N}^{[i]} - N)^2}{B}}$$

where N is the true abundance, $\hat{N}^{[i]}$ is the estimated abundance of the *i*th simulation, $\bar{N}$ is the mean of these estimated abundances, and B is the total number of simulations (999).

In the first simulation, trial survey effort was fixed (360 trap nights) and the number of trials conducted per individual, and the number of individuals was varied. In the second simulation, trial survey effort was varied by increasing the number of individuals in the trials survey.

RESULTS

For a fixed amount of trial survey effort (360 trap nights), when average detectability was high and underlying individual heterogeneity was accounted for, the method used to select trial distances had little impact on either bias or RMSE of population estimates using both estimators (Fig. S1A & 1B). Percentage bias of $\hat{N}_2$ was lowest when the “adaptive” method was used to select trial distances and 18 trials were conducted on each individual (*c.* 4%, Fig. S1A). With decreasing average probability of detection of individuals, the “adaptive” method of selecting trial distances typically resulted in less bias and lower RMSE for both estimators (Fig. S1C, S1D, S1E & S1F). Percentage bias and RMSE for both estimators decreased until at least 10 trials were conducted per individual, after which results changed little if more trials were conducted per individual. With decreasing average probability of detection, more trials were required per individual. When underlying individual heterogeneity was accounted for, $\hat{N}$ was always less biased than $\hat{N}_a$. Bias in $\hat{N}_a$ can be very large in some circumstances, and in general, $\hat{N}$ should be the preferred estimator. The combination of low average detection probability and high between individual variation in scenario 3 caused some estimated detection probabilities to be underestimated and thus abundance estimates were an order of magnitude larger than expected (i.e., in *c.* 1% of the 999 simulations). This severely biased the mean estimated abundance and hence the RMSE. Consequently, RMSE is not shown in Fig. S1E & S1F. The median abundance estimates of both estimators in scenario 3 performed satisfactorily and hence suggests the TPT method can still be used in these situations where the probability of detection is extremely low (Potts 2011). If someone ever obtained such an abundance estimate that was severely overestimated, it would be easy to spot in practice (i.e. abundance estimates would be an order of magnitude larger than expected), and it is recommended that more survey data be collected.

When underlying individual heterogeneity in detection probability was ignored, the “adaptive” method used to select trial distances typically had lower bias and RMSE of population estimates compared to the “uniform” method (Fig. S2). With decreasing average probability of detection, more trials were required per individual. When heterogeneity was ignored (i.e., the incorrect model for detectability was used), $\hat{N}_a$ was less biased than when the correct model was fitted (as in Fig. S1). The reason the bias in $\hat{N}_a$ was relatively small when underlying heterogeneity was ignored, compared to when underlying heterogeneity was accounted for, was because the negative bias in estimating abundance of the medium-detectability group was approximately equal to the positive bias of the high-detectability group. When underlying heterogeneity was accounted for, $\hat{N}_a$ was extremely positively biased. This finding was surprising, and warrants further investigation to explore whether this result can be generalized or was specific to the scenario in question.

As expected, percentage bias and RMSE decreased with increasing total survey effort in the second simulation, regardless of whether underlying group heterogeneity was accounted for (Fig. S3A & S3B) or not (Fig. S3C & S3D).

We recommend that the adaptive method be used to select trial distances. The preliminary detection function may be updated throughout the data collection period to ensure trials are being set at distances that provide the most information about the underlying detection function. For the detection function scenarios we investigated, approximately 20 trials per individual proved satisfactory, after which additional survey effort should be invested in radio-collaring more individuals, rather than conducting more trials on the same individuals.

See Potts (2011) for a more detailed assessment of these results.

Table S1. Input parameters for the three detection function scenarios, where α_g is the intercept term for an individual in group *g* (g = 1, 2, or 3 for individuals in the "high", "medium" and "low" groups, respectively), β is the coefficient (slope) parameter for the explanatory variable distance *r*, and b_{ig} is a random effect due to individual *i* in group *g*.

Scenario	**Average detectability**	**Group**	α_g	β	b_{ig}
1	High	1	2	-0.15	N(0,0.1)
2	High	1	2	-0.15	N(0,0.1)
	Medium	2	1	-0.15	N(0,0.1)
3	High	1	2	-0.15	N(0,0.1)
	Low	3	-0.3	-0.15	N(0,0.3)

Fig. S1. Plots of percentage bias estimates (left axis, solid line) and RMSE (right axis, dashed line) for both $\hat{N}$ (left column, plots A, C, and E) and $\hat{N}_2$ (right column, plots B, D, and F) when the allocation of total trial survey effort (360 trap nights) changes for detection function scenarios 1 (plots A and B), 2 (plots C and D) and 3 (plots E and F), when underlying heterogeneity in detection probability was accounted for. RMSE for scenario 3 (plots E and F) is not plotted, see text for explanation.

Fig. S2. Plots of percentage bias estimates (left axis, solid line) and RMSE (right axis, dashed line) for both $\hat{N}$ (left column, plots A and C) and $\hat{N}_2$ (right column, plots B and D) when the allocation of total trial survey effort (360 trap nights) changes for detection function scenarios 2 (plots A and B) and 3 (plots C and D), when underlying heterogeneity in detection probability was ignored.

Fig. S3. Plots of percentage bias estimates (left axis, solid line) and RMSE (right axis, dashed line) for both $\hat{N}$ (left column, plots A and C) and $\hat{N}_2$ (right column, plots B and D) when the total trial survey effort changes for detection function scenario 2 (medium detectability) when underlying heterogeneity is accommodated (plots A and B) and ignored (plots C and D).

Fig. S1.

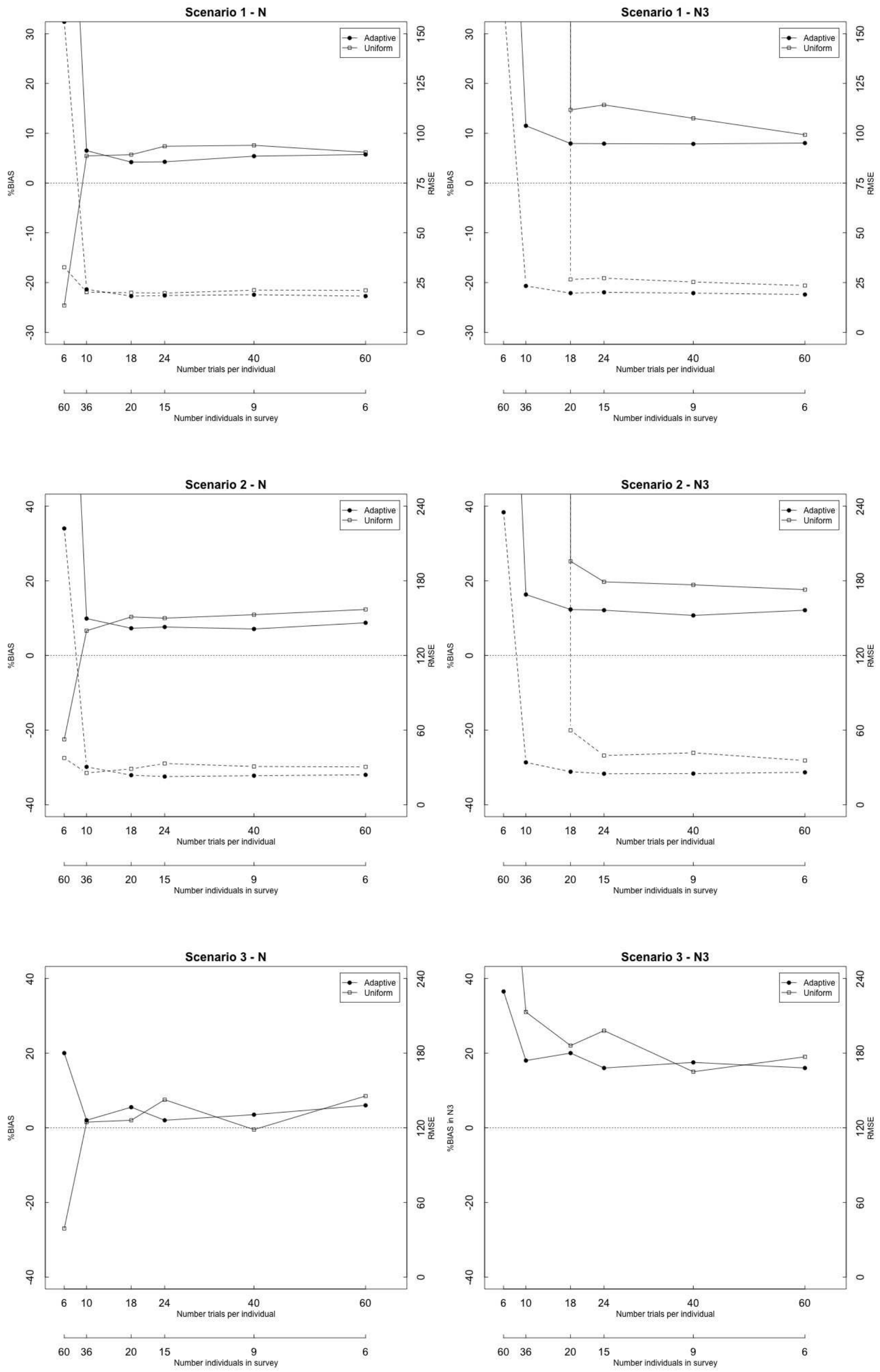
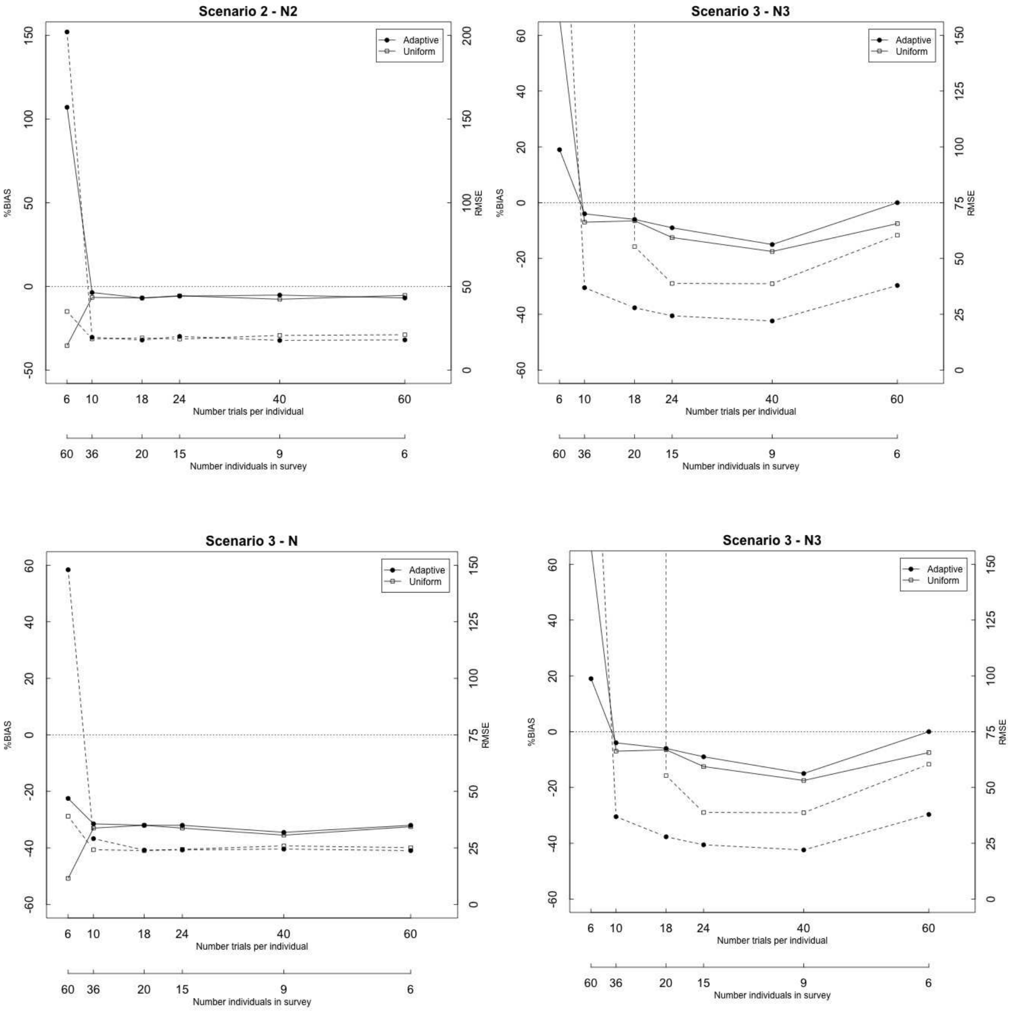
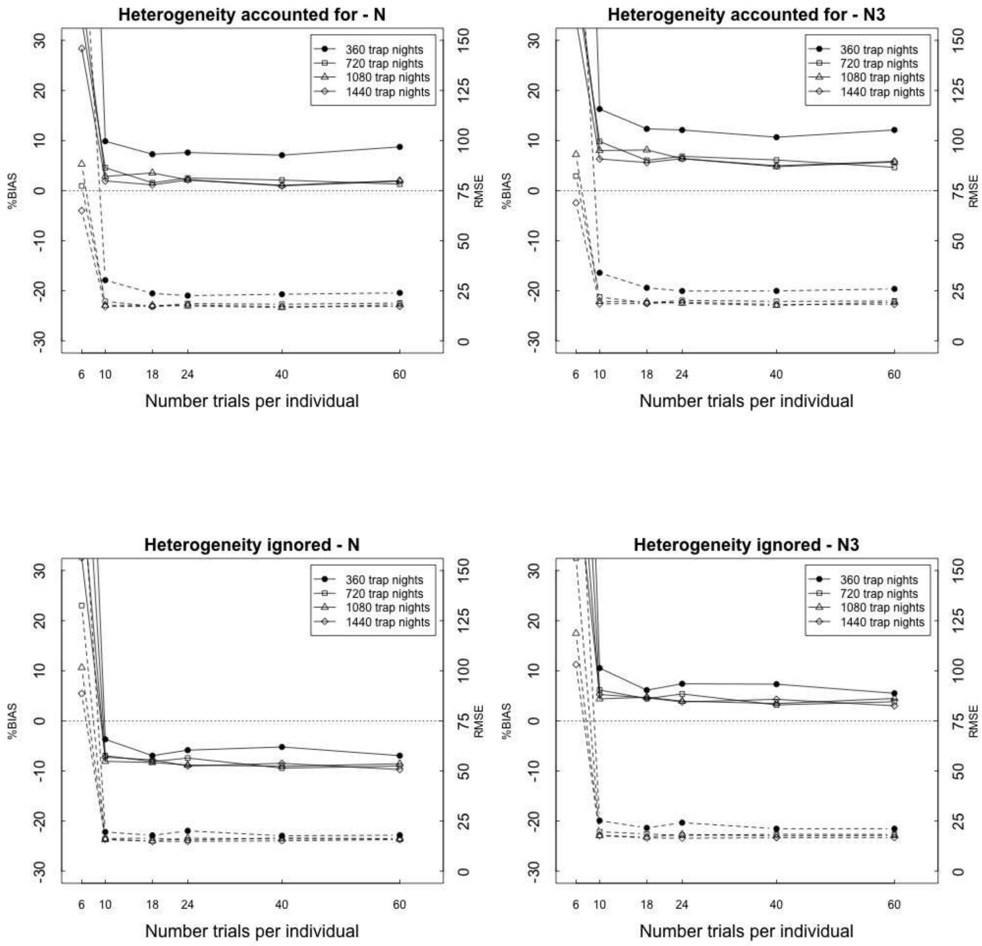

Scenario 1 - N
Scenario 1 - N3
Scenario 2 - N
Scenario 2 - N3
Scenario 3 - N
Scenario 3 - N3
Adaptive
Uniform
%BIAS
%BIAS in N3
RMSE
Number trials per individual
Number individuals in survey

Fig. S2.



Scenario 2 - N2
Scenario 3 - N3
Scenario 3 - N
Scenario 3 - N3
Adaptive
Uniform
%BIAS
RMSE
Number trials per individual
Number individuals in survey

Fig. S3.


Heterogeneity accounted for - N
Heterogeneity accounted for - N3
Heterogeneity ignored - N
Heterogeneity ignored - N3
360 trap nights
720 trap nights
1080 trap nights
1440 trap nights
%BIAS
RMSE
Number trials per individual