Addressing uncertainty in braided river bird counts

Jennifer A. Brown and Timothy J. Robinson

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Addressing uncertainty in braided river bird counts

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ABSTRACT

When estimating a true population parameter from survey data, there is always some level of uncertainty as a result of imperfect detection, imperfect observation, spatial and temporal variation, and sampling error. In this report, we discuss the sources of uncertainty in New Zealand braided river bird counts. We use Monte Carlo simulations to illustrate the effect of different survey designs on uncertainty in counts for two species of bird: wrybill (*Anarhynchus frontalis*) and black-fronted tern (*Sterna albostriata*). The simulations were based on observed counts from previous river surveys. In general, larger annual changes can be detected with less uncertainty than smaller changes. Additional survey effort, e.g. replicate counts within a year, replicate sections within a river or replicate surveys over sequential years, will reduce uncertainty.

Keywords: survey design, Monte Carlo simulation, variance

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1. Introduction

Management decisions in conservation biology are often based on an observed change in status of an ecological system. This change will have been measured in some way, usually by assessing data collected from field-based surveys. There is considerable literature on how to conduct field surveys and on sampling (e.g. Thompson et al. 1998; Borchers et al. 2002; Thompson 2002; Thompson 2004). However, even with a perfectly designed survey, there will always be a degree of uncertainty in how well the survey results reflect the true population. Survey uncertainty is inevitable in conservation biology because environmental systems are variable, complex in multiple underlying population processes, and exceedingly hard to measure with high accuracy. This is especially true for mobile animals, inconspicuous plants, and elusive and rare species (Thompson 2004: 1).

In this report, we discuss how to estimate uncertainty associated with counts from New Zealand braided river bird surveys. The study was motivated by a request to assess uncertainty in past surveys of Canterbury rivers for two species: wrybill (*Anarhynchus frontalis*) and black-fronted tern (*Sterna albostriata*). These two species were selected because they represent a range from cryptic and primarily solitary species (wrybill) to conspicuous and flocking species (black-fronted tern). In addition, both birds are nationally threatened species of conservation concern (black-fronted tern is classified as 'Nationally Endangered', wrybill as 'Nationally Vulnerable'; Hitchmough et al. 2007).

Although we focus on these two bird species in this report, the general concept of survey uncertainty can be applied to any situation. The purpose of this report is to explain sources of survey uncertainty and illustrate how to assess this, rather than to provide specific recommendations on surveys of wrybill and black-fronted tern—something that is best done with a full consideration of the species' biology.

Four main factors contribute to survey uncertainty from counts of observed braided river birds:

1. **Imperfect detection**—For birds on braided river beds, there are a number of reasons why it is not possible to detect all birds in the population at any one time. The main reasons are:
    - Hidden birds—birds are hidden by rocks, dips in slopes, vegetation and other landscape features
    - Adverse weather—poor weather conditions make birds less visible
    - Diurnal behaviour patterns—birds may be more or less detectable at different times of the day
    - Group density—large groups of birds are more easily seen than small groups or solitary birds

2. **Imperfect observation**—The ability to detect birds varies between observers, and the ability of each observer may also change through time; for example, it can decline as a result of fatigue as the day progresses, and improve as a result of increasing experience over a longer time frame.
3. **Spatial and temporal variation**—When birds are mobile between seasons (migrating between distant places) and within seasons (moving around a particular area, and onto and off adjacent lands and waters), the proportion of the total population available to be counted varies. This spatial and temporal variation reflects the change in the number of birds that could be counted given perfect detection and observation, and with no change in the total bird population.
4. **Statistical sampling error**—As only a fraction of a braided river is surveyed at any one time and surveys can only occur in discrete sections of time, any count of birds is only a 'sample' both spatially and temporally, rather than a total count of the population. When this count is used in some way (such as to derive an index) to infer some biological state in the total bird population (e.g. the population is increasing or decreasing), the estimated uncertainty needs to include some measure to account for the fact that not all of the river was surveyed and surveys were not done at all points in (infinite) time. Instead, only a fraction of the river was surveyed in only a fraction of time, and there is no information on what bird counts would be in other parts of the river or at other times (a day later or an hour earlier, for example). However, with appropriate statistical survey design, counts for the parts of the river and the sections of time that were not surveyed can be 'inferred' from the survey results on hand. This uncertainty associated with counting only a fraction of the total population is referred to as statistical sampling error.

Given these different sources of uncertainty, any reported bird count or derived index used to make inference about the total population needs to include some statement about how well it measures the total population. This is usually given as a confidence interval (Thompson 2002).

In this report, we illustrate how uncertainty in bird counts can affect estimated changes in bird population sizes, and describe a computer simulation method we used to illustrate the level of uncertainty associated with different survey designs.

2. Methods

We used Monte Carlo simulations to illustrate uncertainty in estimating population trends from counts of wrybills and black-fronted terns. Data from counts of the two species in Canterbury braided river beds were supplied by Andrew Grant, Canterbury Conservancy, Department of Conservation. The data were collected during the following surveys, in which both species were counted:

- Occasional annual counts from the Tekapo River, October–November, from 1991 to 1998 (5 years surveyed)
- Occasional annual counts from the Ahuriri River, sections 1-3 and sections 4–7, October–November, from 1991 to 1998 (5 years surveyed)
- Near-annual counts from the Ashburton River/Hakatere, October–November, from 1981 to 1999 (total of 13 years surveyed over this 19-year period)
- Daily repeat counts (3 days) in the Ahuriri River, sections 4–5, in 1995
- Daily repeat counts (3 days) in the lower Ohau River in 1995
- Daily repeat counts (3 days) in the upper Ohau River in 1995
- Repeat counts within a day (5 hours) in the lower Ohau River in 1993
- Daily repeat counts (2–7 days) over multiple sections (ten sections) of the Ahuriri River in 1982 and 1983

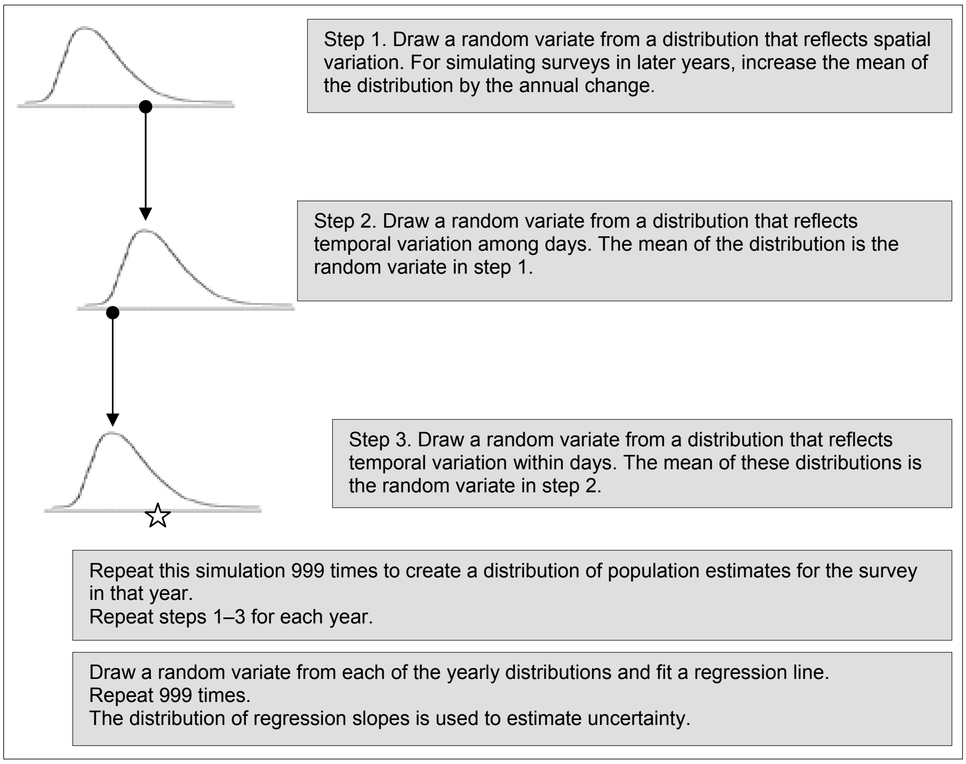
Monte Carlo simulations were written in R (R version 2.5.1, The R Foundation for Statistical Computing, 2007). This R code is available from the authors. Suitable distributions of counts were chosen from observed distributions of the provided data. Distribution parameter values were estimated from the data.

The Monte Carlo simulations used the following steps (Fig. 1):

1. Step 1—Uncertainty as a result of spatial variation in bird counts along a river was estimated by drawing a random variate from a distribution that reflected the variation among spring counts from the ten Ahuriri River sections.
2. Step 2—Uncertainty as a result of temporal variation between days in bird counts for a given section of river was estimated by drawing a random variate from a distribution that reflected the variation between counts on repeat days. The mean of this distribution was the random variate drawn in step 1.
3. Step 3—Uncertainty as a result of temporal variation within days in bird counts for a given section of river was estimated by drawing a random variate from a distribution that reflected the variation between counts in repeat surveys within the same day from the lower Ohau data. The mean of this distribution was the random variate drawn in step 2.

The other sources of uncertainty (imperfect detection and observation) were implicitly included because the estimates of spatial and temporal variation were derived from the provided bird count data.

The Monte Carlo bird count index was the random variate from step 3. This simulation method can readily accommodate designs that include surveys of multiple sections of river, repeat days, and repeat surveys within days. For surveys with repeat counts within a day, the index was taken as the average of the random variates. For example, to simulate a design that included surveys of



Step 1. Draw a random variate from a distribution that reflects spatial variation. For simulating surveys in later years, increase the mean of the distribution by the annual change.

Step 2. Draw a random variate from a distribution that reflects temporal variation among days. The mean of the distribution is the random variate in step 1.

Step 3. Draw a random variate from a distribution that reflects temporal variation within days. The mean of these distributions is the random variate in step 2.

Repeat this simulation 999 times to create a distribution of population estimates for the survey in that year.
Repeat steps 1–3 for each year.

Draw a random variate from each of the yearly distributions and fit a regression line.
Repeat 999 times.
The distribution of regression slopes is used to estimate uncertainty.

Figure 1. Summary of Monte Carlo method used to create a distribution of 1000 estimates for trend using different survey designs.

multiple sections, step 1 would be repeated for each section; to simulate a design that included surveys on repeat days, step 2 would be repeated for each day; and to simulate a survey that included four repeat counts on 1 day, four random variates would be drawn in step 3. The average of these would be the index.

This Monte Carlo simulation was repeated 999 times for each survey design and for each bird species, creating a distribution of 1000 values of each count index that mimicked variation in realistic bird counts.

The distributions generated by this process were then ‘grown-on’ each year by the annual change—e.g. 5% increase in counts—for up to 10 years to create a synthetic population of bird count indices changing over time for each species. This was done by returning to step 1 and increasing the parameter for the mean and any other related parameter of the distribution by 5%.

To simulate bird surveys, each synthetic bird count population produced using the process just described was sampled. A random count was selected in each year of the survey and a regression line fitted. The slope of the line is a measure of the population trend. The slope was then converted to a more interpretable quantity: percent annual change in the mean. This re-sampling of the synthetic population was repeated 999 times, creating 1000 estimates of trend for each survey design and each species. Because the true trend in the synthetic population is known (as it was defined in the simulation), measures of uncertainty could be calculated. The median (50th percentile) and other quantiles of the estimates of trend were compared with the true trend to assess how well each survey design measured trend, given the likely uncertainty in bird counts. The other measure calculated was how often a decline (or increase), regardless of size, was detected, given a true decline (or increase). See Fig. 1 for an outline of the Monte Carlo method.

Six survey design scenarios were used:

1. Scenario a—annual surveys for 10 years, with one section visited once only during 1 day
2. Scenario b—annual surveys for 10 years, with four sections visited three times a day for 3 days
3. Scenario c—surveys in years 1, 5 and 9, with one section visited once only during 1 day
4. Scenario d—surveys in years 1, 3 and 10, with one section visited once only during 1 day
5. Scenario e—surveys in years 1 and 10, with one section visited once only during 1 day
6. Scenario f—surveys in years 1 and 10, with one section visited once a day, for 3 days

We simulated trends of 2%, 5% and 10% increases and decreases per annum.

For Scenarios e and f, where there were only two annual surveys (years 1 and 10), additional variation for the detected annual trend had to be artificially created, as the (statistical) error from fitting a regression line between two points (where it always fits perfectly) would not be comparable with the error from fitting a regression line between three or more points (where there will usually be some error). The extra variation was computed using the structural variance component of the least squares estimate of the regression line.

3. Results

The parameters used in the Monte Carlo simulations were:

1. Step 1—Uncertainty as a result of spatial variation in bird counts along a river was estimated by drawing a random variate from a negative binomial distribution with $\mu = 10$, $k = 2$ for wrybill and $\mu = 90$, $k = 1.3$ for black-fronted tern.
2. Step 2—Uncertainty as a result of temporal variation between days in bird counts for a given section of river was estimated by drawing a random variate from a Poisson distribution for wrybill and a negative binomial distribution with $k = 15$ for black-fronted tern. The distribution's mean for both was the random variate drawn in Step 1.
3. Step 3—Uncertainty as a result of temporal variation within days in bird counts for a given section of river was estimated by drawing a random variate from a Poisson distribution for wrybill and a negative binomial distribution with $k = 20$ for black-fronted tern. The distribution's mean for both was the random variate drawn in Step 2.

Summary statistics for the two species from each survey are provided in Appendix 1.

The results of the analyses are presented as a series of box plots (Fig. 2 for wrybill and Fig. 3 for black-fronted tern). More complete data are presented as tables in Appendix 2. The box plots (Figs 2 & 3) display information for the range of likely estimated trends (both declines and increases) obtained from the simulations for the three different annual changes (2%, 5% and 10%) for the two bird species (wrybill and black-fronted tern).

3.1 INTERPRETATION OF RESULTS

Consider Fig. 2A (wrybill—simulated 2% annual decline) and assume there is a real decline in wrybill population size of 2% per year for 10 years. The first box plot equates to Scenario a, where the river was surveyed by visiting once a year, in one section on 1 day. The 'box' of the box plot describes where the middle 50% of the (simulated) estimated annual changes lies. Therefore, it can be seen that using this survey design, there is a 50% chance that the annual change estimated would be somewhere between –8.2% and +4.6%. In other words, there is a 50% chance that, with such a survey design and with a real 2% annual decline, the trend estimated from the survey results would be even less than –8.2%, or even greater than 4.6%. However, the box is not centred on zero, so there is more chance that a decline will be reported. In fact, for this scenario, approximately 57% of the estimated trends from the simulations were negative (see Appendix 2). The 'whiskers' on the box plot extend out to the observation within 1.5 times the interquartile range (IQR). The IQR is simply the width of the box. The box plot is a well-used method of displaying spread of a large number of observations (1000 in this application).

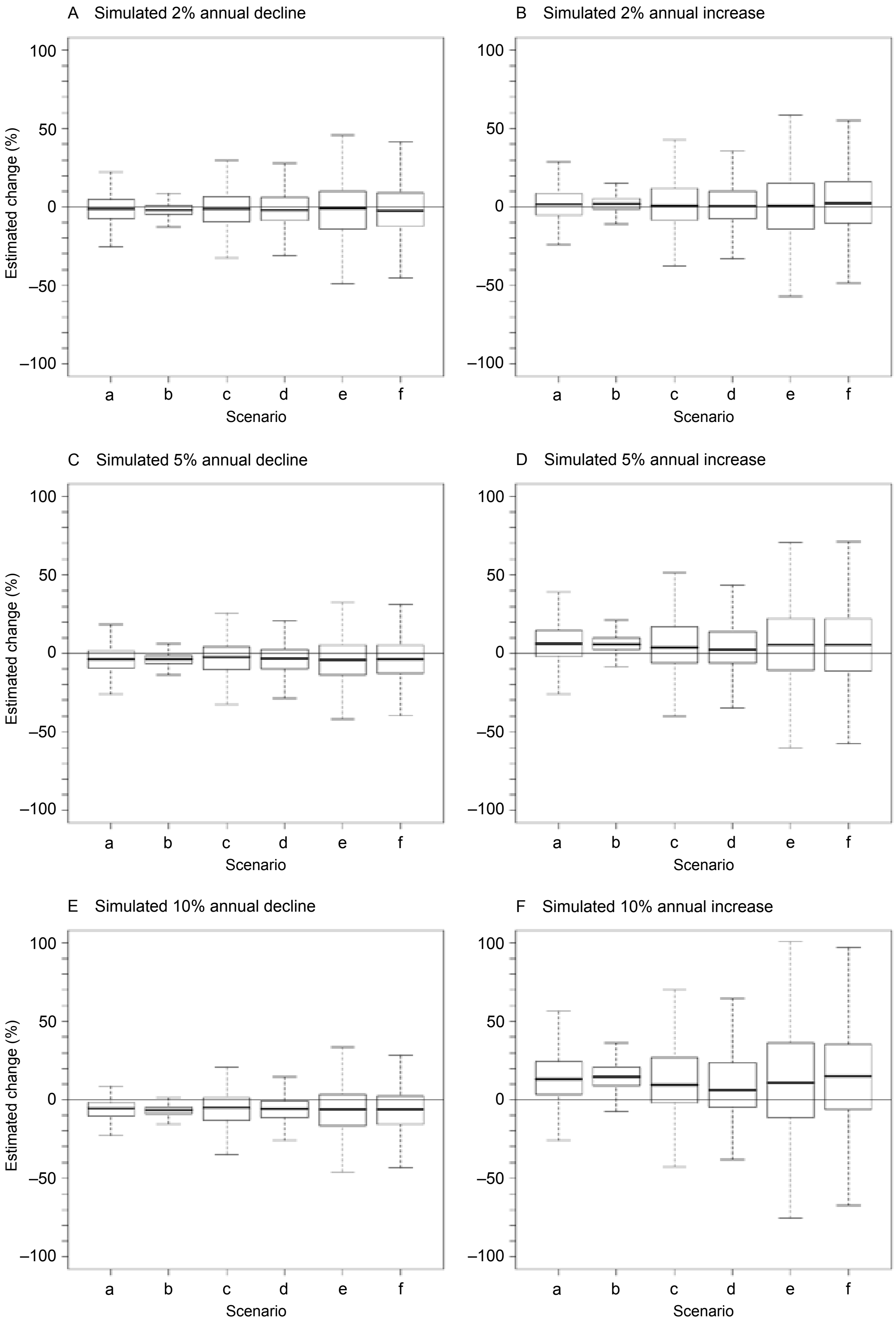


Figure 2. Distribution of estimated trends from Monte Carlo simulations for wrybill (*Anarhynchus frontalis*). The *y*-axis is the estimated change (%) in the population per year, with a reference line for 0 (no change). The six graphs display results for simulated changes in the bird population of 2%, 5% and 10% per year (both declines and increases). See text for the description of scenario and survey designs. For each survey design, 1000 estimates of change per year were produced. The box plot shows the distribution of these 1000 estimates. A perfect survey design would have all 1000 estimates equalling the simulated change.

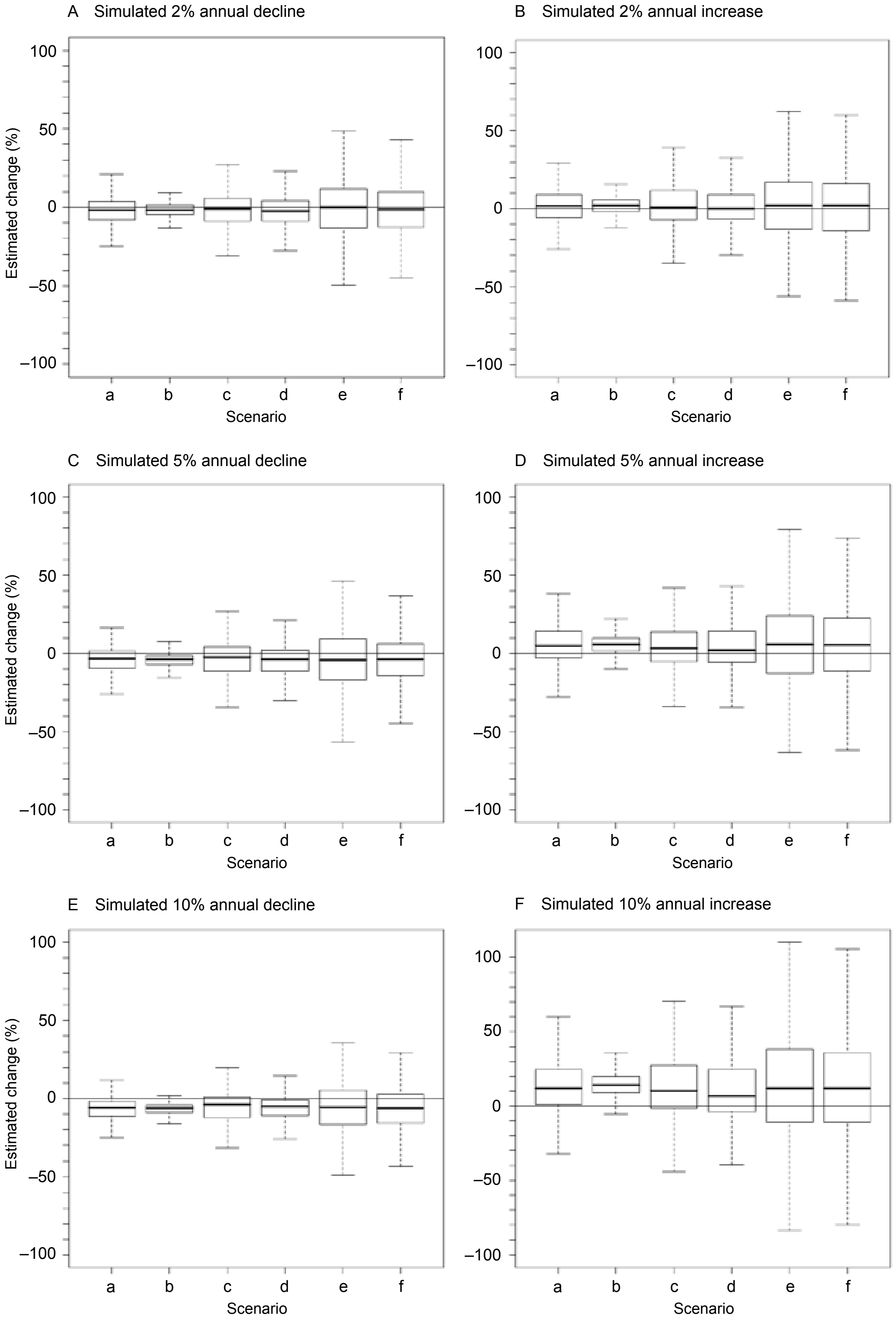


Figure 3. Distribution of estimated trends from Monte Carlo simulations for black-fronted tern (*Sterna albostriata*). The *y*-axis is the estimated change (%) in the population per year, with a reference line for 0 (no change). The six graphs display results for simulated changes in the bird population of 2%, 5% and 10% per year (both declines and increases). See text for the description of scenario and survey designs. For each survey design, 1000 estimates of change per year were produced. The box plot shows the distribution of these 1000 estimates. A perfect survey design would have all 1000 estimates equalling the simulated change.

3.2 OUTCOMES OF SURVEY SCENARIOS

Box plots can be used to compare how well the estimated population trends reflected the real trends using the different survey scenarios (Scenarios a–f), with narrow boxes indicating less uncertainty. For example, where wrybills had a simulated 2% decline (Fig. 2A), it is clear that Scenario b—annual surveys on four sections of the river for 3 days—gave a far narrower box than the other scenarios. The uncertainty associated with the trend estimated from the survey data was lower in this scenario, with a 50% chance that the estimated trend would be between –4.8% and +0.7%. Under the same conditions for black-fronted terns (simulated 2% decline and Scenario b), there was a 50% chance that the estimated trend would be between –4.7% and +1.1% (Fig. 3A).

Overall, for both species and for any level of change, Scenario b consistently resulted in the least uncertainty, while Scenario e—surveys in years 1 and 10 on one section of the river visited once only on 1 day—resulted in the most uncertainty. Scenario b had the most survey effort and least uncertainty and Scenario e had the least effort and most uncertainty, so clearly more survey effort resulted in less uncertainty.

Even differences in survey effort smaller than the difference between Scenarios b and e had an effect on the level of uncertainty. This can be seen by comparing the results of the simulations for Scenarios a and b. Both scenarios involved annual visits for 10 years, but Scenario a had one section visited on 1 day, while Scenario b had four sections visited three times a day for 3 days. The additional survey effort in Scenario b resulted in less uncertainty. For wrybills with a simulated 2% decline, there was a 50% chance that the estimated trend would be between –8.2% and +4.6% with Scenario a, whereas this interval narrowed to –4.8% and +0.7% with the extra survey effort in Scenario b. For black-fronted terns with a simulated 2% decline, there was a 50% chance that the estimated trend would be between –7.9% and +3.8% with Scenario a; this interval narrowed to –4.7% and +1.1% with the extra survey effort in Scenario b.

Reducing the frequency of surveys (e.g. from annual surveys for 10 years to three surveys over 10 years) increased uncertainty. This can be seen by comparing Scenario a and Scenario c, which both had the same survey design (visit one section once only on 1 day) but different frequencies among years (one survey every year for 10 years (Scenario a) compared with three surveys over 10 years (Scenario c)). For wrybills with a simulated 2% decline, there was a 50% chance that the estimated trend would be between –8.2% and +4.6% with Scenario a, whereas the interval was increased to between –10.3% and +6.2% with Scenario c. Similarly, for black-fronted terns with a simulated 2% decline, the Scenario a interval was between –7.9% and +3.8%, while the Scenario c interval was between –8.9% and +5.8%.

What is striking about this comparison of survey effort is that a reduction in the yearly frequency (Scenario a compared with Scenario c) had far less of an effect on uncertainty than a reduction in the within-year survey effort (Scenario a compared with Scenario b). This is partly a result of how change in population size was defined. Here, we used the commonly understood measure of change as the average difference between year 1 and year 10 (estimated by fitting a least squares linear regression line), which meant that having additional information on population sizes in intermediate years was not as important as having information from the early and later years in that 10-year period. If, however, change were defined in a more complex way, e.g. a description of the shape of a non-linear trend, then information from intermediate years would be more important, as it would allow measurement of curvature in the trend. Examples of non-linear trends are where the population increases and then decreases, or where the population initially decreases rapidly and then at a slower rate.

To illustrate further the effect of differences in the frequency of surveys among years, compare Scenario c and Scenario d. These two scenarios both had three surveys over 10 years with the same effort on each survey (one section visited once only on 1 day), but Scenario c had the three visits evenly spacing among years, while Scenario d had two visits in the early years, followed by a gap of 5 years before a final survey in year 10. Scenario d generally had less uncertainty than Scenario c, because more effort was concentrated where there was greatest model variation, i.e. at the beginning or end of the trend line. However, once again, if change were defined in a more complex way, the optimal spacing of three surveys over 10 years would depend on what description of the shape of a non-linear trend was required. If measurement of curvature in the trend was important, then surveys in the middle of the 10-year period would be important. In contrast, if only simple measures of change (e.g. linear trends) were required, then survey effort should be allocated to where there is greatest model variation, i.e. at the beginning or end of the time period.

3.3 OUTCOMES OF DIFFERENT LEVELS OF ANNUAL CHANGE AND SPECIES DIFFERENCES

The box plots show how differing annual changes (both declines and increases) and different sizes of the annual changes affect uncertainty in estimates for the two bird species. Clearly, uncertainty is lower where there are larger annual changes. For example, using Scenario a (annual surveys for 10 years, with one section visited once only on 1 day), when a 10% annual decline for wrybills was simulated, a decline in the population size was almost always detected (84% of the Monte Carlo simulations; Fig. 2E); in contrast, when a 2% annual decline was simulated, only 57% of the Monte Carlo simulations detected a decline (Fig. 2A). Similarly, when a 10% annual decline was simulated for black-fronted terns, a decline in the population size was detected in 84% of the Monte Carlo simulations (Fig 3), whereas when a 2% annual decline was simulated, a decline was detected in only 58% of the Monte Carlo simulations (Fig. 3A).

There was little difference in the ability to detect a decline or an increase (for the same size absolute change). There was a general trend that declining populations had less uncertainty in estimated change than increasing populations, but this observation was not consistent over all the simulations.

Interestingly, the two species produced comparable levels of uncertainty for the different survey designs and simulated amounts of change, despite being simulated from different distributions. The main difference in the simulations was that a negative binomial distribution was used for black-fronted terns, compared with the Poisson distribution for wrybills. The negative binomial distribution is often used to characterise the spatial pattern of populations with flocking or clustering tendency (White & Bennetts 1996). The overall predominance of the size of the uncertainty (i.e. wide box plots) swamped any subtle differences between these distribution models.

4. Conclusions

Interpretation of the box plots suggests that these survey results are uninformative and could even be misleading. For example, given a 2% annual decline in wrybills, there is a 25% chance that the reported trend would be greater than +4.6%, and only a 57% chance that the reported trend would, in fact, be negative. Reporting that a population is increasing when, in fact, it is decreasing can have serious management consequences. However, interpretations such as these must be viewed in context. There is always uncertainty with any survey that does not involve a full census. Further, for environmental surveys, where populations are transitory and changing through time and in geographic space, there can be a large amount of stochastic variation in population size.

One way to reduce uncertainty is to have clear survey objectives. A survey objective such as 'estimate population size' is usually too simplistic. Instead, survey objectives should have a spatial and temporal context, e.g. the average population size measured over 2 months that occupied a length of river bed that was so many metres wide, between two geographic points. This at least restricts the survey to a spatial and temporal reference.

Survey uncertainty can be reduced by using common survey protocols in terms of observer training, the route observers walk, their speed, and whether single or multiple observers are used. If possible, surveys should be standardised by time of day, level of effort, weather, and day or week within the season. This will facilitate direct comparison among surveys.

While we did not conduct these simulations to provide recommendations on optimal survey design or on how much total effort should be allocated to surveys, some general trends are obvious. Uncertainty will decrease with additional survey effort, but the marginal gains in reduction of uncertainty depend on where that extra effort is allocated. The allocation of effort within annual surveys to repeat visits to the river within days, among days and to replicate river sections needs to be optimised in terms of both reduction of uncertainty and survey cost. There was not sufficient variation in the datasets used in this study to allow detailed exploration of alternative within-year survey designs. Our personal experience of forest bird surveys suggests that multiple efforts among days is preferable to multiple efforts within days, and that spatial replication (e.g. multiple survey transects) is very important if uncertainty is to be reduced. However, we do not know how well these findings for forest bird surveys would apply to surveys of braided river birds. The question of how best to design a survey for braided river birds needs to be addressed, but to do so will require either access to suitable data for simulation or a dedicated field study. If further research were to be conducted, alternative survey methods (beyond just counting numbers of birds) could also be considered. Examples of other approaches include mark recapture studies, territory mapping and population modelling (Richad Maloney, DOC, pers. comm.).

The simulations show how uncertainty can be reduced by surveying in multiple years through a 10-year period. If surveys were conducted at less than annual frequency, then the desirable spacing between survey years would depend on whether change was to be reported as a simple change (e.g. a 2% decline over 10 years), or in a more complex way (i.e. describing a non-linear trend). If a simple measure only was required (e.g. to report overall change in numbers over a particular period), then for non-annual surveys, effort should be concentrated at the beginning and end of the time-period. However, if a more complex measure was required, then surveys should be spaced more evenly. In the absence of a common definition on how to report trend, and to allow for changes in reporting requirements, the most sensible approach would be to conduct annual surveys, to ensure that any reporting framework could be accommodated.

5. Acknowledgements

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6. References

Borchers, D.L.; Buckland, S.T.; Zucchini, W. 2002: Estimating animal abundance. Springer-Verlag, London. 314 p.

Hitchmough, R.; Bull, L.; Cromarty, P. (Comps) 2007: New Zealand Threat Classification System lists—2005. Department of Conservation, Wellington. 194 p.

Thompson, S.K. 2002: Sampling. 2nd Edition. Wiley, New York. 343 p.

Thompson, W.L. (Ed.) 2004: Sampling rare and elusive species: concepts, designs and techniques for estimating population parameters. Island Press, Washington, DC.

Thompson, W.L.; White, G.C.; Gowan, C. 1998: Monitoring vertebrate populations. Academic Press, London. 365 p.

White, G.C.; Bennetts, R.E. 1996: Analysis of frequency count data using the negative binomial distribution. *Ecology* 77: 2549–2557.

Appendix 1

SUMMARY OF DATASETS USED TO ESTIMATE DISTRIBUTION PARAMETERS FOR WRYBILL (*Anarhynchus frontalis*) AND BLACK-FRONTED TERN (*Sterna albostriata*)

SURVEY	SURVEY TYPE	WRYBILL		BLACK-FRONTED TERN	
		MEAN	SD	MEAN	SD
Tekapo River	5 years	11.20	4.09	161.60	109.70
Ahuriri sections 1-3	5 years	23.60	14.31	181.80	97.94
Ahuriri sections 4-7	5 years	14.20	6.22	144.60	54.32
Ashburton River/Hakatere	13 years	5.08	4.39	30.62	17.42
Ahuriri sections 4-5	3 days	9.67	1.15	104.67	6.81
Lower Ohau	3 days	3.33	2.08	19.67	8.50
Upper Ohau	3 days	0.67	1.15	152.67	41.04
Lower Ohau	5 hours	4.40	1.82	91.00	23.05
Ahuriri	Ten sections	10.15	8.49	90.24	80.51
Ahuriri	2-7 days	10.15	7.49	90.24	39.29

Appendix 2

MONTE CARLO SIMULATION QUANTILES FOR ESTIMATED ANNUAL CHANGE

The following tables show the quantiles of estimated percent annual change for wrybill (*Anarhynchus frontalis*) and black-fronted tern (*Sterna albostriata*) data. For example, for scenario a, when a –2% per annum change was simulated, the lower 0.025 proportion of the 1000 Monte Carlo trend estimates were –22.4% or less, the lower 0.10 proportion of the 1000 Monte Carlo trend estimates were –14.6% or less, etc. The third column (% correct) shows the percentage of the 1000 trend estimates that correctly measured a decreasing (when a negative annual change was simulated) or increasing (when a positive annual change was simulated) trend.

Scenario a

SPECIES	ANNUAL	%	QUANTILES OF ESTIMATED % ANNUAL CHANGE						
	CHANGE	CORRECT	0.025	0.10	0.25	0.5	0.75	0.90	0.975
Wrybill	-10%	84.2%	-23.0%	-15.7%	-10.6%	-5.8%	-1.6%	1.6%	4.7%
	-5%	68.9%	-21.4%	-14.6%	-9.5%	-4.2%	0.9%	5.2%	9.9%
	-2%	56.6%	-22.4%	-14.6%	-8.2%	-1.2%	4.6%	10.5%	17.0%
	2%	57.5%	-20.4%	-11.7%	-4.7%	2.0%	9.1%	16.1%	22.9%
	5%	69.6%	-17.9%	-9.4%	-2.4%	5.6%	14.4%	23.4%	33.5%
	10%	82.0%	-13.7%	-4.1%	3.4%	13.1%	24.3%	36.8%	50.0%
Black-fronted tern	-10%	84.4%	-24.7%	-16.9%	-11.0%	-5.9%	-1.8%	1.3%	5.3%
	-5%	67.1%	-23.1%	-15.0%	-9.4%	-3.4%	1.8%	6.1%	12.4%
	-2%	58.4%	-23.5%	-14.4%	-7.9%	-1.7%	3.8%	10.2%	17.3%
	2%	56.2%	-20.0%	-12.1%	-5.6%	1.7%	9.0%	15.9%	26.0%
	5%	67.5%	-20.2%	-10.1%	-2.8%	5.0%	13.9%	22.5%	36.5%
	10%	77.7%	-19.5%	-8.0%	1.3%	11.8%	24.8%	38.6%	58.4%

Scenario b

SPECIES	ANNUAL	%	QUANTILES OF ESTIMATED % ANNUAL CHANGE						
	CHANGE	CORRECT	0.025	0.10	0.25	0.5	0.75	0.90	0.975
Wrybill	-10%	99.1%	-14.2%	-11.3%	-8.7%	-6.4%	-4.3%	-2.7%	-0.9%
	-5%	86.9%	-11.8%	-8.9%	-6.6%	-3.9%	-1.5%	0.7%	3.5%
	-2%	67.6%	-9.8%	-7.2%	-4.8%	-1.9%	0.7%	3.0%	5.3%
	2%	66.0%	-7.8%	-4.4%	-1.6%	1.9%	5.2%	7.6%	11.0%
	5%	86.6%	-4.9%	-1.2%	2.2%	5.6%	9.7%	13.8%	17.9%
	10%	97.7%	1.8%	6.2%	10.1%	14.9%	20.1%	25.7%	32.7%
Black-fronted tern	-10%	97.5%	-14.5%	-11.5%	-9.1%	-6.4%	-4.2%	-2.5%	0.0%
	-5%	83.0%	-14.6%	-10.3%	-6.9%	-3.8%	-1.1%	1.5%	3.9%
	-2%	65.3%	-10.6%	-7.7%	-4.7%	-1.7%	1.1%	3.8%	7.0%
	2%	65.2%	-8.5%	-4.8%	-1.6%	2.0%	5.6%	9.6%	13.0%
	5%	83.5%	-5.9%	-1.8%	1.7%	5.9%	10.1%	14.1%	18.8%
	10%	97.4%	-0.1%	4.4%	8.9%	13.9%	19.9%	25.3%	33.5%

Scenario c

SPECIES	ANNUAL CHANGE	% CORRECT	QUANTILES OF ESTIMATED % ANNUAL CHANGE						
			0.025	0.10	0.25	0.5	0.75	0.90	0.975
Wrybill	-10%	70.2%	-35.7%	-22.1%	-13.4%	-5.7%	0.2%	4.9%	9.7%
	-5%	61.6%	-35.0%	-20.9%	-11.3%	-2.9%	4.1%	12.0%	20.7%
	-2%	54.9%	-31.8%	-20.8%	-10.3%	-1.4%	6.2%	15.8%	25.5%
	2%	53.1%	-31.2%	-17.1%	-7.2%	1.8%	11.8%	22.9%	38.1%
	5%	60.0%	-30.7%	-16.4%	-6.3%	4.2%	15.8%	30.8%	48.6%
	10%	70.6%	-27.5%	-15.9%	-3.6%	10.7%	28.8%	51.3%	75.6%
Black-fronted tern	-10%	70.0%	-46.7%	-24.3%	-12.1%	-3.8%	0.8%	5.2%	12.9%
	-5%	60.0%	-41.0%	-22.8%	-11.3%	-2.3%	4.2%	10.9%	21.7%
	-2%	55.0%	-37.4%	-19.7%	-8.9%	-0.9%	5.8%	16.2%	32.1%
	2%	52.9%	-36.4%	-18.2%	-7.0%	0.8%	11.5%	27.3%	49.8%
	5%	59.6%	-36.0%	-16.9%	-5.6%	3.2%	13.5%	28.8%	57.3%
	10%	71.4%	-32.1%	-13.1%	-1.5%	10.2%	27.2%	44.6%	81.3%

Scenario d

SPECIES	ANNUAL CHANGE	% CORRECT	QUANTILES OF ESTIMATED % ANNUAL CHANGE						
			0.025	0.10	0.25	0.5	0.75	0.90	0.975
Wrybill	-10%	78.2%	-27.1%	-17.8%	-10.9%	-5.3%	0.0%	4.2%	10.3%
	-5%	65.6%	-24.0%	-15.3%	-9.1%	-2.9%	3.7%	9.8%	17.3%
	-2%	57.4%	-24.7%	-15.4%	-9.0%	-2.1%	4.5%	12.9%	23.2%
	2%	51.9%	-24.6%	-15.3%	-7.3%	1.5%	12.0%	25.6%	41.8%
	5%	57.0%	-21.7%	-13.0%	-5.1%	3.2%	15.3%	28.7%	47.4%
	10%	63.4%	-27.8%	-15.4%	-4.4%	7.8%	25.3%	47.6%	76.0%
Black-fronted tern	-10%	79.1%	-28.7%	-17.6%	-10.9%	-5.0%	-0.8%	3.7%	9.6%
	-5%	67.1%	-32.2%	-18.9%	-11.0%	-3.7%	2.0%	9.1%	23.6%
	-2%	60.3%	-26.9%	-16.8%	-8.7%	-2.5%	4.2%	12.9%	26.5%
	2%	50.0%	-24.3%	-13.3%	-6.6%	0.0%	9.2%	21.2%	44.7%
	5%	55.7%	-23.9%	-12.1%	-5.8%	2.0%	13.9%	28.4%	49.1%
	10%	67.3%	-23.5%	-12.1%	-3.9%	6.9%	24.4%	49.2%	77.1%

Scenario e

SPECIES	ANNUAL	%	QUANTILES OF ESTIMATED % ANNUAL CHANGE						
	CHANGE	CORRECT	0.025	0.10	0.25	0.5	0.75	0.90	0.975
Wrybill	-10%	66.0%	-35.9%	-25.8%	-16.6%	-6.3%	3.5%	12.8%	22.8%
	-5%	61.5%	-33.2%	-22.8%	-12.8%	-3.9%	5.4%	14.0%	21.9%
	-2%	52.0%	-40.1%	-25.4%	-14.0%	-1.0%	10.0%	20.0%	32.5%
	2%	51.7%	-44.1%	-25.6%	-14.0%	0.9%	15.0%	31.1%	47.5%
	5%	58.6%	-43.7%	-26.8%	-10.9%	5.4%	22.3%	39.8%	62.5%
	10%	62.7%	-52.2%	-31.7%	-11.2%	10.8%	36.3%	62.2%	92.7%
Black-fronted tern	-10%	63.7%	-45.1%	-29.5%	-16.4%	-5.2%	5.2%	14.2%	26.0%
	-5%	58.3%	-50.3%	-29.6%	-16.9%	-4.1%	9.3%	19.3%	30.9%
	-2%	50.5%	-42.2%	-24.4%	-13.0%	-0.1%	11.6%	23.2%	35.7%
	2%	53.5%	-40.8%	-25.9%	-13.2%	2.2%	17.0%	32.1%	51.1%
	5%	57.7%	-49.2%	-27.7%	-12.9%	5.8%	24.2%	40.8%	65.0%
	10%	63.5%	-57.3%	-32.7%	-10.7%	12.1%	38.0%	64.1%	95.4%

Scenario f

SPECIES	ANNUAL	%	QUANTILES OF ESTIMATED % ANNUAL CHANGE						
	CHANGE	CORRECT	0.025	0.10	0.25	0.5	0.75	0.90	0.975
Wrybill	-10%	69.0%	-37.2%	-26.0%	-15.9%	-6.1%	2.5%	9.3%	17.1%
	-5%	61.4%	-31.9%	-22.0%	-13.5%	-3.9%	5.5%	13.2%	21.3%
	-2%	56.1%	-36.6%	-24.5%	-12.6%	-2.4%	9.0%	18.7%	31.3%
	2%	56.2%	-35.3%	-22.7%	-10.2%	2.4%	16.4%	28.6%	41.2%
	5%	59.4%	-45.1%	-26.2%	-11.0%	5.4%	22.0%	37.8%	55.8%
	10%	68.9%	-42.3%	-23.8%	-6.1%	15.1%	35.2%	56.6%	85.7%
Black-fronted tern	-10%	66.8%	-40.7%	-28.0%	-15.8%	-6.2%	3.0%	11.4%	19.3%
	-5%	59.6%	-37.1%	-24.4%	-14.1%	-3.8%	6.4%	15.0%	25.6%
	-2%	53.2%	-37.2%	-24.1%	-12.3%	-1.2%	10.1%	20.1%	35.6%
	2%	53.4%	-44.1%	-28.3%	-14.0%	1.9%	16.0%	31.1%	47.4%
	5%	58.7%	-45.4%	-29.3%	-11.0%	5.4%	22.9%	39.2%	62.9%
	10%	64.3%	-49.8%	-31.3%	-10.8%	12.0%	35.9%	60.4%	92.0%

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