Estimates of harvest for deer, duck and quail from 1985 to 2015

Combining mail and telephone survey results

Game Management Authority

Acknowledgements

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Estimates of harvest for deer, duck, and quail from 1985 to 2015: Combining mail and telephone survey results

Ben G. Fanson and John D. Turnbull

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Front cover photo: Marshes near Kerang - opening morning (GMA Image Library)

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Summary

To estimate harvest rates for deer, duck and quail, the Game Management Authority (GMA) and its predecessors have conducted annual surveys of hunters since 1985 for ducks, 1991 for quail and 1996 for deer. Before 2009, these surveys were conducted at the end of the hunting seasons (June/July) and involved randomly selecting licensed hunters and mailing them a survey to complete. Due to methodological limitations of mail surveys in general (e.g. low response rates, recall bias, rounding of harvest estimates), a new methodology was adopted in which a series of telephone surveys was conducted. The telephone method was thought to provide a less-biased estimate and to be more precise.

From 2009 until 2013, GMA conducted both mail and telephone surveys, allowing for direct comparison of the two methods. Since 2013, only telephone surveys have been conducted. Here we compare the total harvest estimates derived from both survey methods for the five years when both were used and estimate the bias between them. We then adjusted previous mail harvest estimates by this correction factor to allow comparison of harvest estimates across all years, regardless of survey method.

For deer, no statistically significant bias was detected with an estimated ratio (telephone:mail) of 1.17 (95% CI:0.99–1.38). The precision of the estimated ratio (as assessed by the coefficient of variation, %CV) was greater for telephone surveys than for mail surveys (%CV 10.6 vs. 15.5, respectively).

For ducks, there was a significant bias (ratio = 0.85, 95% CI: 0.76, 0.96), resulting in mail estimates being 18% higher than telephone estimates. We suspect that this bias is present in the mail survey due to limitations noted above. Again, the telephone survey for most years was a more precise estimate than the mail estimate (%CV 8.1 vs. 9.6).

For quail, the mail estimates were also higher, by 28% (ratio = 0.78, 95% CI: 0.64, 0.94). In alignment with the other game types, the telephone survey estimates were more precise than mail estimates (%CV 12.9 vs. 17).

Overall, there is evidence that, at least for duck and quail, there is a bias between the telephone and mail survey methods. We suggest here that this bias is most likely present in the mail survey. Furthermore, the telephone survey consistently produced more precise estimates than the corresponding mail survey. Finally, we provide corrected harvest estimates for all mail survey estimates to allow for better comparability between years.

1. Introduction

Game hunting is a popular activity in Victoria involving tens of thousands of hunters harvesting hundreds of thousands of game animals every year. Hunting is also of significant economic importance in the state of Victoria (Morison et al. 2014). Consequently, it is important to effectively manage game hunting. A key component for the effective management of game species is the monitoring of harvest numbers. One method of obtaining estimates of total harvest of game species is the use of hunter surveys following the hunting season. The Game Management Authority (GMA) and its predecessors in Victoria implemented such a survey program to collect data on hunting activities (e.g. hunting location, number of days spent hunting, number of animals harvested). Prior to 2009, surveys were conducted solely by mailing questionnaires to randomly selected hunters. The use of mail questionnaires provided an economical and widespread method of collecting of information from the hunting community. However, after some concern about potential in bias due to low response rates and recall biases (e.g. Sen 1971, Wright 1978), a telephone-based survey was implemented in 2009 in which hunters are called throughout the hunting season, leading to near 100% response rates as well as mitigating potential recall bias. Both the mail and telephone surveys were conducted in parallel until 2013, at which point the GMA switched solely to the telephone survey.

Though surveys have been conducted since 1985, the focus of the surveys has varied through the years. Initially, since game licences did not initially distinguish between different game types, the surveys focused on estimating the number of hunters for each game type, with a secondary focus on total harvest estimates only for waterfowl. In 1991, the survey changed to include deer and quail hunting information, such as total seasonal harvest. However, annual reports were produced solely for duck harvests until 1995 in which annual reports summarised harvest estimates for all game types, except introduced gamebirds (NRE 1995). From 1995, total harvest estimates for all game types (except introduced game birds) have been provided in annual reports.

In Victoria, eight species of waterfowl can be hunted: Australian Shelduck (*Tadorna tadornoides*), Australasian Shoveler (*Anas rhynchotis*), Pacific Black Duck (*Anas superciliosa*), Chestnut Teal (*Anas castanea*), Grey Teal (*Anas gracilis*), Australian Wood Duck (*Chenonetta jubata*), Hardhead (*Aythya australis*), and Pink-eared Duck (*Malacorhynchus, membranaceus*). The hunting season is roughly mid-March to early June and the bag limits have varied over the years in response to environmental conditions and changing population abundances.

Similar to waterfowl, quail season is roughly April to late June. The Stubble Quail (*Coturnix pectoralis*) is the only species of native quail that can be hunted. Bag limits have remained steady over the last ~20 years at 20 birds per day.

Given that populations of introduced game birds can only be found on game bird farms, they have not been the subject of the surveys.

Currently, six species of deer can be hunted in Victoria: Hog Deer, Red Deer, Sambar, Fallow Deer, Chital and Rusa. Prior to 2002, only Sambar, Hog Deer,and Red Deer were allowed to be hunted, with hunting of Hog Deer and Red Deer limited to April and June, respectively. Sambar could be hunted throughout the year. Since 2002, Fallow Deer can be hunted year-round. In 2009, Chital and Rusa were added to the list of game species and could be hunted any time. Since late 2012, Red Deer can be hunted year-round. The only bag limit is for Hog Deer, and this is limited to one male and one female per season.

This study has several objectives. First, we report the temporal pattern in total harvest estimates for each game species from both mail and telephone surveys until 2015. Second, as GMA has switched to telephone surveys for future years, we compare mail and telephone surveys from 2009 to 2013 to determine any bias in mail estimates between the survey methods and present total harvest estimates for all years, corrected for any mail survey bias. This allows harvest estimates to be compared across all years.

2. Methods

Two main survey methods, mail and telephone, have been used to estimate game harvests between 1985 and 2015. The mail survey was initiated in 1985 and ceased in 2013. Initially, the mail questionnaire was distributed to 10,000 licencees in 1985 (Norman and Wingham 1985), followed by only 400 in 1987 (Loyn and Timms 1988), but eventually levelled out at 1,000 licencees in later years. The questionnaires were mailed out at the end of the hunting season in July and asked about the previous financial year's hunting activities. The survey questions varied over the years, but all included questions about which game species were hunted, total animals harvested for the different game species, and a hunter's effort, as well as general questions about educational and management policies.

The telephone surveys were initiated in 2009. Unlike the mail surveys, telephone surveys were conducted throughout the hunting season, though the number of surveys conducted varied with the game type and across years. For example, in 2009, surveys were conducted every two months over the year for deer, four times during the duck season, and three times during the quail season (Gormley and Turnbull 2009). For 2015, deer survey effort remained the same as 2009, but there were seven duck surveys and four quail surveys (Moloney and Turnbull 2015a,b). For each survey, between 200 and 300 randomly selected licensed hunters were interviewed by phone. The respondents were asked if they hunted, how many animals were harvested and for details about their hunting effort, among other questions (e.g. hunting method, location of hunting).

The information from these surveys had been summarised in annual reports dating back to 1985 (e.g. (Norman and Wingham 1985, Loyn and Timms 1988, NRE 1995, Gormley and Turnbull 2009, Moloney and Turnbull 2015b). To estimate total harvest from the surveys, several key pieces of information are necessary. First, the total number of licensed hunters for each game type (deer, duck, and quail) are required. Next, the proportion of those licensed hunters that actually hunted is needed for each game type. This proportion was estimated by calculating the proportion of respondents that hunted. Finally, the average harvest rate per active hunter during the survey period is needed for each game type.

The estimate of the mean harvest per hunter was obtained from the mean harvest of those respondents that hunted. Then the total number of active hunters was multiplied by the mean harvest per active hunter to get an estimate of the total harvest for that survey period. For the mail survey, there was only one survey period and that represented the annual total harvest. For the telephone survey, the annual total harvest was estimated by adding up all the individual survey estimates (see Appendix 2 for more details and equations).

For the telephone surveys, all the above information was available in the annual reports for all game types. However, for the mail surveys, annual reports differed in the information provided, with most annual reports not reporting standard errors of estimates. Consequently, missing information was recalculated when possible. A database of mail survey results from 1996 to 2013 was used to recalculate all estimates for that time period. Prior to 1995, annual reports only reported duck results and hence no information on quail and deer is available. See Appendix 1 for a fuller description of the methodology used. Table A1.1 shows the summary of data completeness.

To test for differences between the survey methods, annual harvest estimates were compared between the methods by calculating the ratio of telephone estimate to mail estimate for each year of overlap. Thus, a ratio less than one indicates that the mail survey estimate was higher. We then averaged the ratios from each year to obtain an estimate of the difference between the surveys (see Appendix 2 for more details and equations).

3. Results

The data used to generate the figures are provided in Appendix 3, with the exception of the species-specific estimates, due to the length of those tables.

Deer

Summary of deer surveys (1996–2015)

In Figure 1, the annual harvest estimates of all deer are presented. Harvest estimates have steadily increased since the early 2000s. Between 2009 and 2013, mail and telephone estimates overlap fairly well, with their 95% confidence intervals (95% CI) overlapping for every year.

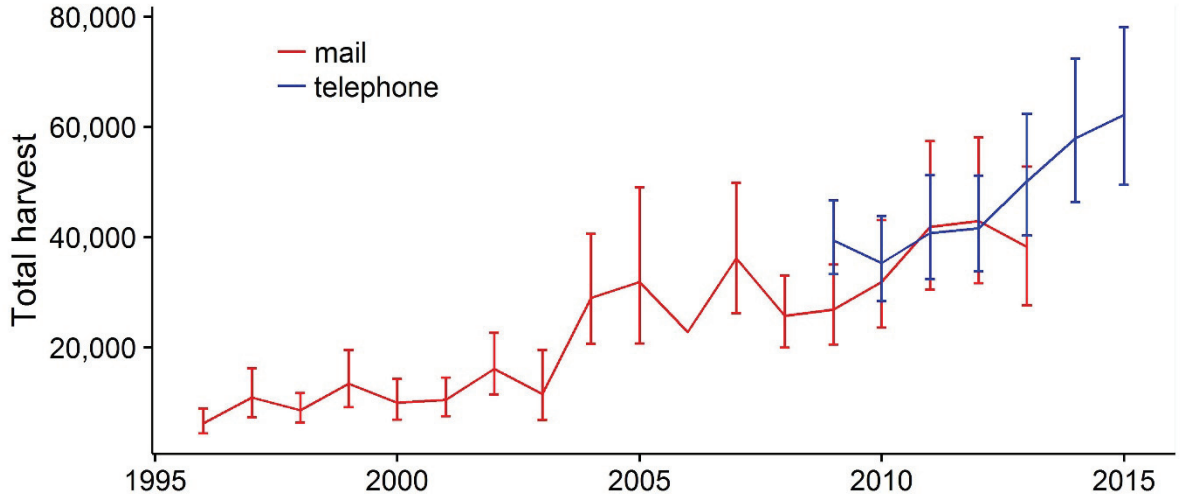

Figure 1: Annual estimates of total harvest for all deer species combined. Colour of line indicates survey method. Error bars are 95% confidence intervals. Note – the missing error bar in 2006 is due to lack of error estimates presented in the 2006 report (See Appendix 1 for more information).

Comparison of mail and telephone surveys (2009-2013)

To compare the survey methods, we calculated the ratio of telephone to mail estimates for each year of overlap (Figure 2). Of these five years, only one year, 2009, did not have its 95% CI overlapping with 1 [ratio = 1.47 (95% CI: 1.09, 2.08)], indicating that the telephone harvest estimate was significantly higher (47% higher) than the mail estimate.

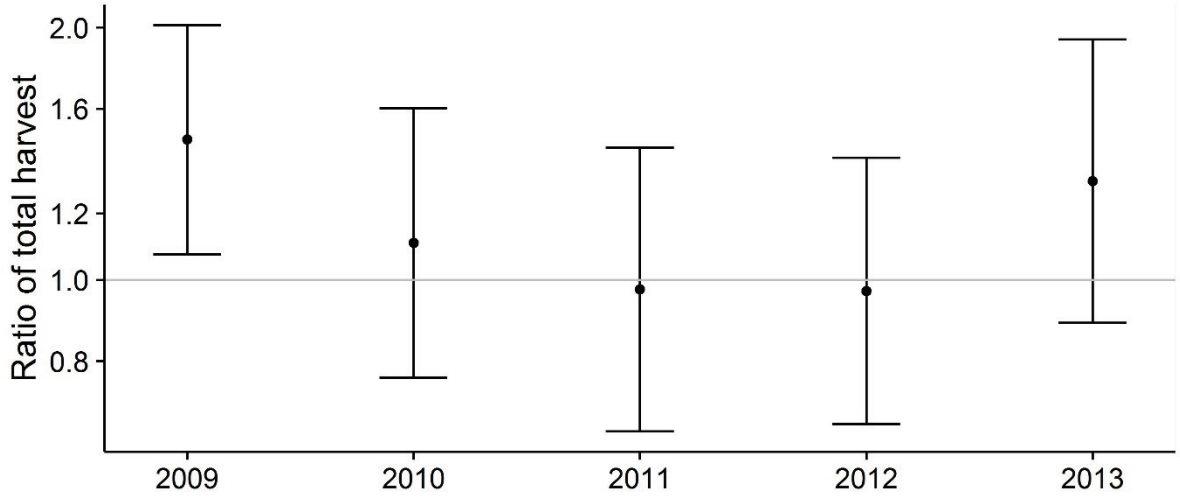

Figure 2: The ratio (telephone survey to mail survey) of estimates of total harvest for all deer species combined for each year. A ratio of <1 indicates the mail survey produced a higher estimate. The grey line indicates equal estimates and hence no bias. Error bars are 95% CI. Note – y-axis is log-scaled.

Besides difference in mean harvest estimates, we also compared the coefficient of variation (%CV) between the survey methods. %CV is a measure of precision of the estimate. As seen in Figure 3, the telephone survey had consistently lower %CV than the mail estimate, with lower %CVs indicating a more precise estimate.

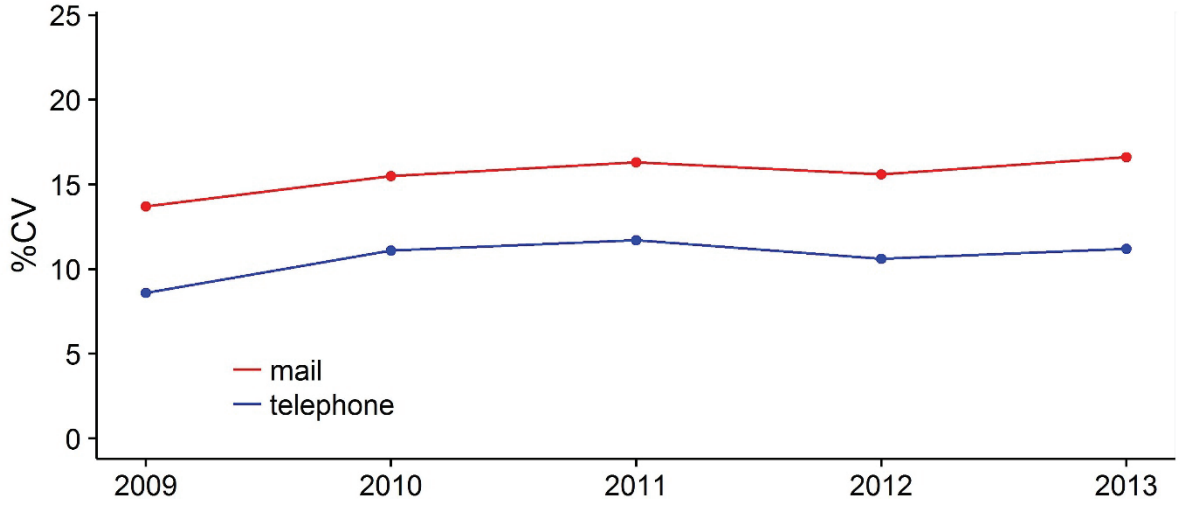

Figure 3: Comparison of %CVs between telephone and mail. Lower %CVs indicate more precise estimates.

Adjusted total estimates

To calculate a general correction factor between mail and telephone surveys, we calculated the average ratio of the five years: ratio = 1.17 (95% CI: 0.99, 1.38). Thus, on average, the telephone survey estimates were 17% higher than the mail survey estimates, but since the 95% CI overlaps with one, there was insufficient evidence statistically to support the conclusion that there is a bias in the estimate.

A couple of points need to be mentioned at this stage. First, by bias, we mean that for a given true total harvest, the mail survey's estimate will be consistently shifted from the telephone's estimate. This does imply that the telephone's estimate is a non-biased component of the true harvest total. It may be that the telephone is a better measure of the true harvest total. However, as noted in the introduction, the telephone survey is likely to be a better estimate as it eliminates potential sources of bias (e.g. having high response rates).

Second, the lack of statistical support for deer does not mean that there is no bias, just that the bias is not large enough to be detected given the amount of variation in the surveys. The estimated ratio can be viewed as our best guess of the actual ratio. Therefore, we proceed by providing mail estimates adjusted for the estimated ratio.

Figure 4 shows the effect of applying the 1.17 correction to mail estimates. Because of the uncertainty in the ratio, the 95% CI are larger for the mail-corrected estimates as they incorporate both the ratio uncertainty and the uncertainty in the original mail estimate. Figure 5 shows the temporal pattern in deer harvest using mail-corrected values.

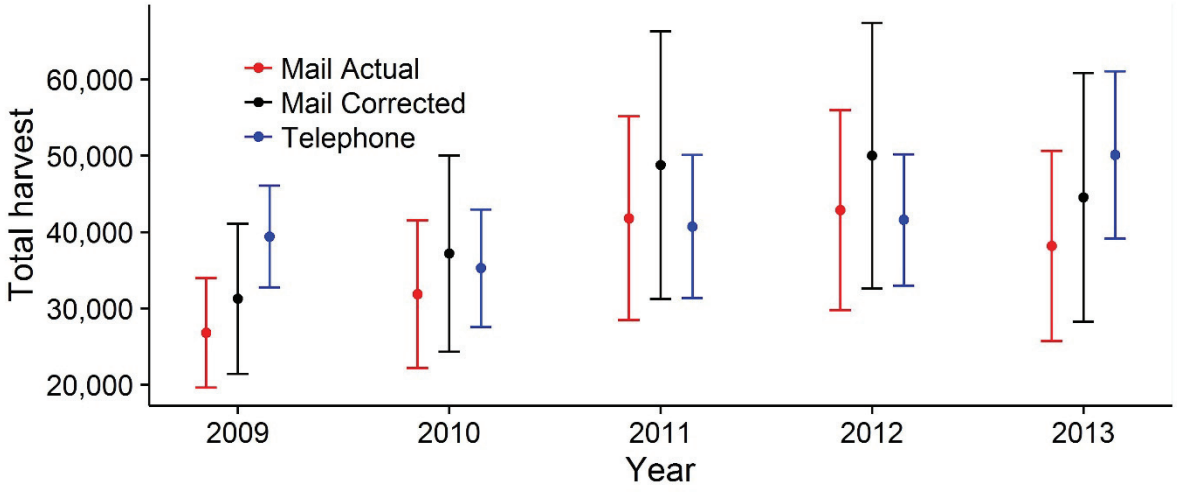

Figure 4: Comparison of annual estimates of deer harvest for each survey method and for the corrected estimate. 'Mail corrected' is the mail estimate corrected for bias. 'Mail Actual' is the actual estimate from the mail survey. 'Telephone' is the actual telephone survey estimate.

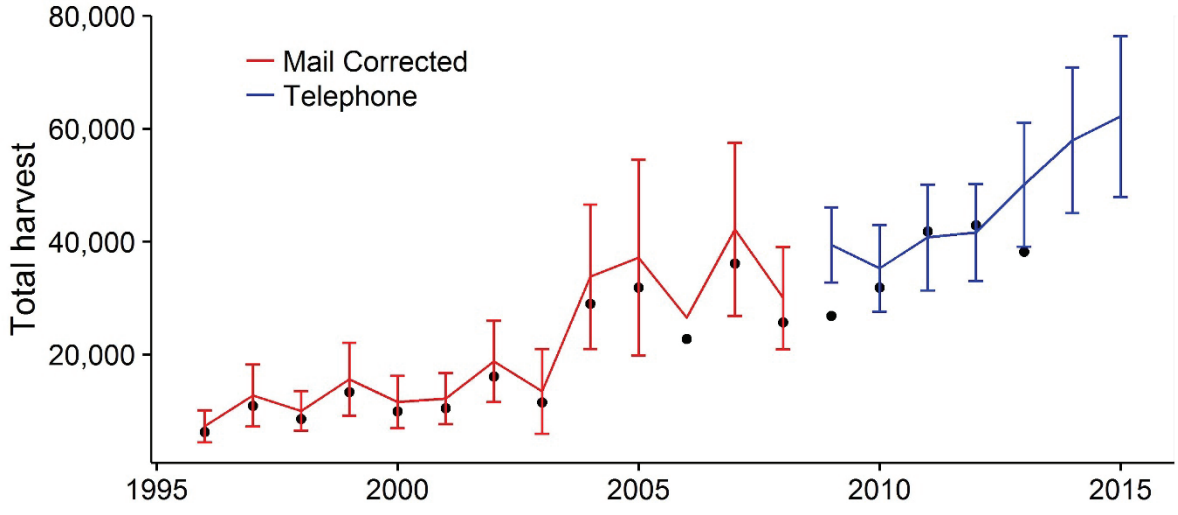

Figure 5: Temporal pattern in annual harvest estimates using corrected mail estimates. Mail estimates before 2009 have been adjusted by the correction factor. Black points show the original mail survey harvest estimates. Note – the missing error bar in 2006 is due to lack of error estimates presented in the 2006 report (See Appendix 1 for more information).

Summary of surveys for each deer species (1996–2015)

Since Sambar is the most hunted deer species, the total deer harvest pattern strongly reflects the Sambar harvest pattern (Figure 6D). Hog and Red Deer have large uncertainties around their estimates, precluding the estimation of a correction factor.

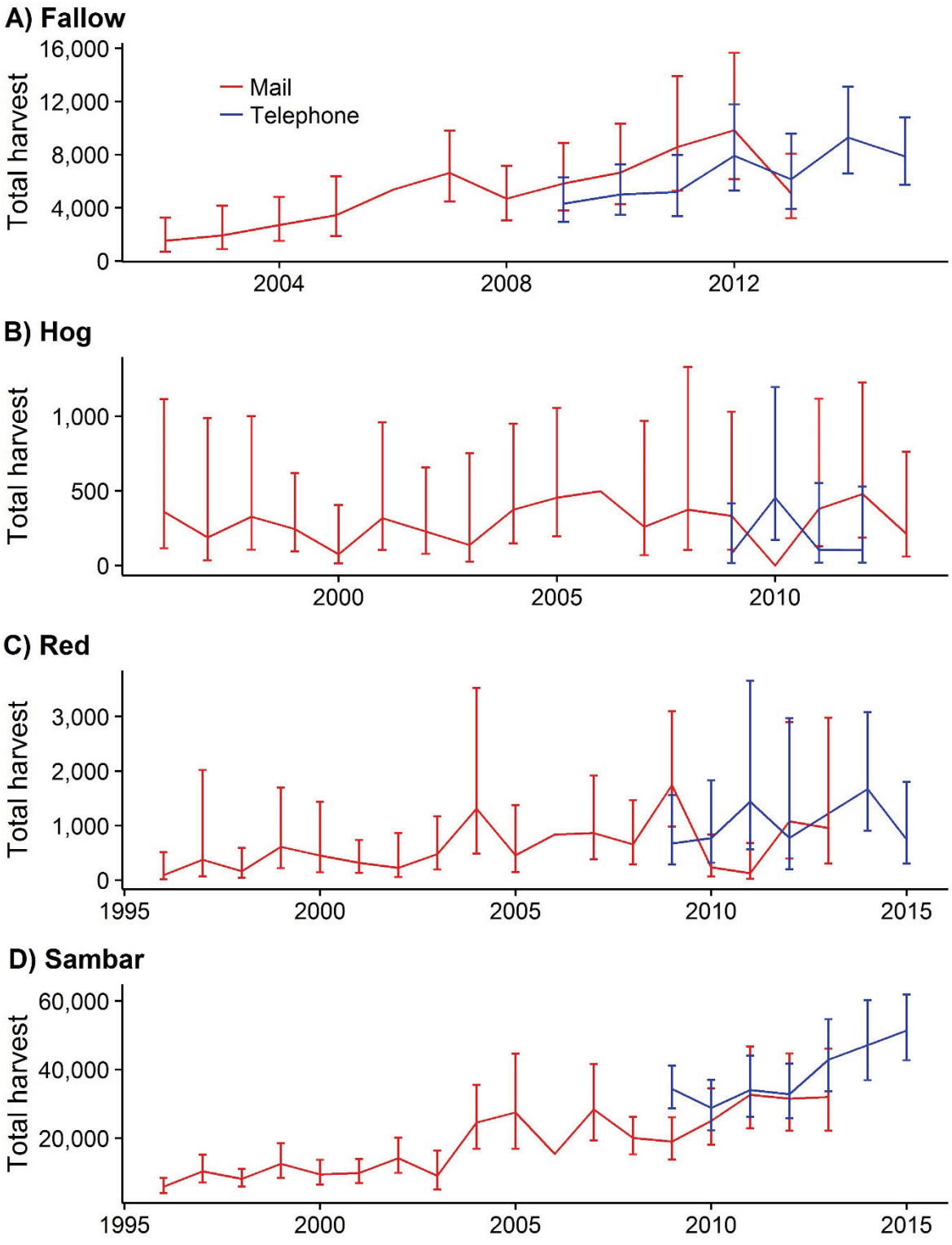

Figure 6: Harvest estimates for Fallow, Hog, Red, and Sambar Deer. Error bars are 95% confidence intervals. There are no wild Chital or Rusa populations in Victoria.

Duck

Summary of duck surveys (1985–2015)

In Figure 7, the annual harvest estimates of all ducks are presented. Harvest estimates drop off from 1985 to 1990, but then remain steady. Overall, mail estimates were higher than telephone estimate for the last three years, but very similar for the first two years.

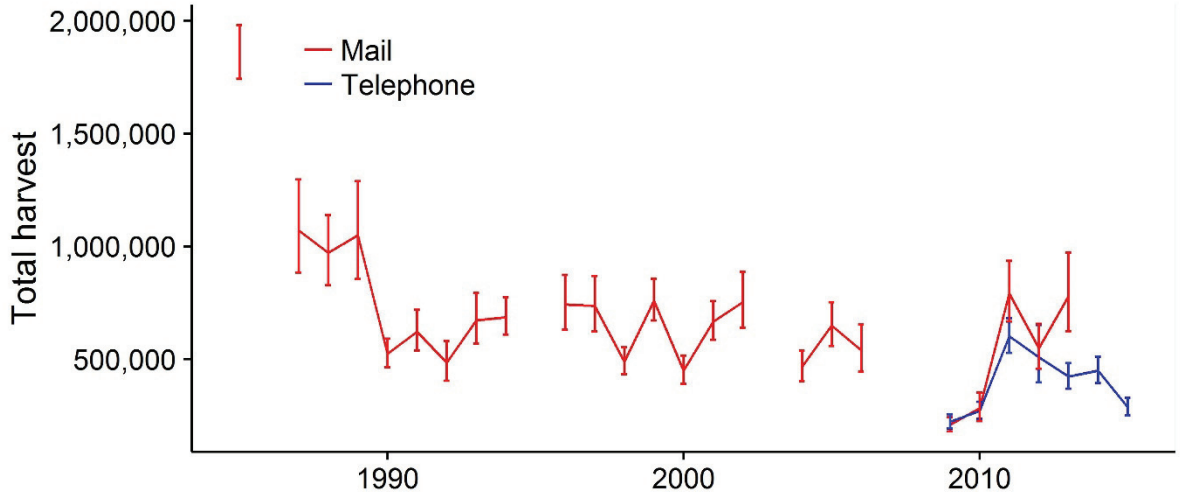

Figure 7: Annual total duck harvest estimates for each survey method. Different coloured lines indicate survey method. Error bars are 95% confidence intervals. Breaks in lines indicate closed duck seasons (1986, 1995, 2003, 2007, and 2008).

Comparison of mail and telephone surveys between 2009 and 2013

We calculated the ratio of telephone to mail estimates for each year of overlap (Figure 8). In two of these five years, 95% confidence intervals (CI) did not overlap with one [2011: ratio=0.76 (95% CI: 0.62, 0.95); 2013: ratio=0.54 (95% CI: 0.42, 0.72)], indicating that the mail harvest estimates were significantly higher than the telephone estimates (32% higher in 2011 and 85% higher in 2013).

We also compared the %CV between the survey methods. Except for 2012, the telephone survey had consistently lower %CV than the mail estimate (Figure 9).

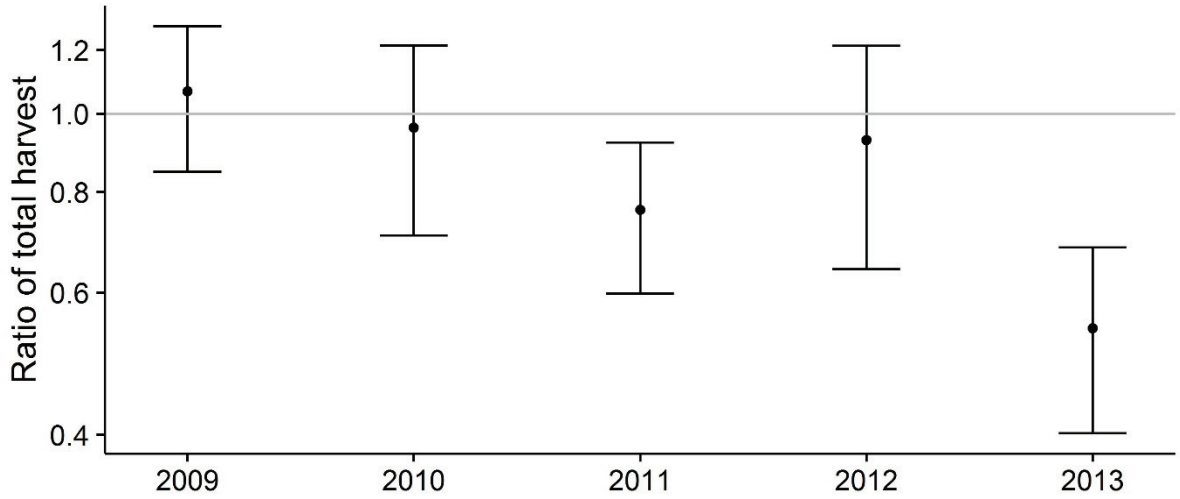

Figure 8: Estimates of the ratio of telephone to mail for each year for ducks. Less than 1 indicates mail survey have higher estimates. The grey line indicates equal estimates and hence no bias. Error bars are 95% CI. Note – y-axis is log-scaled.

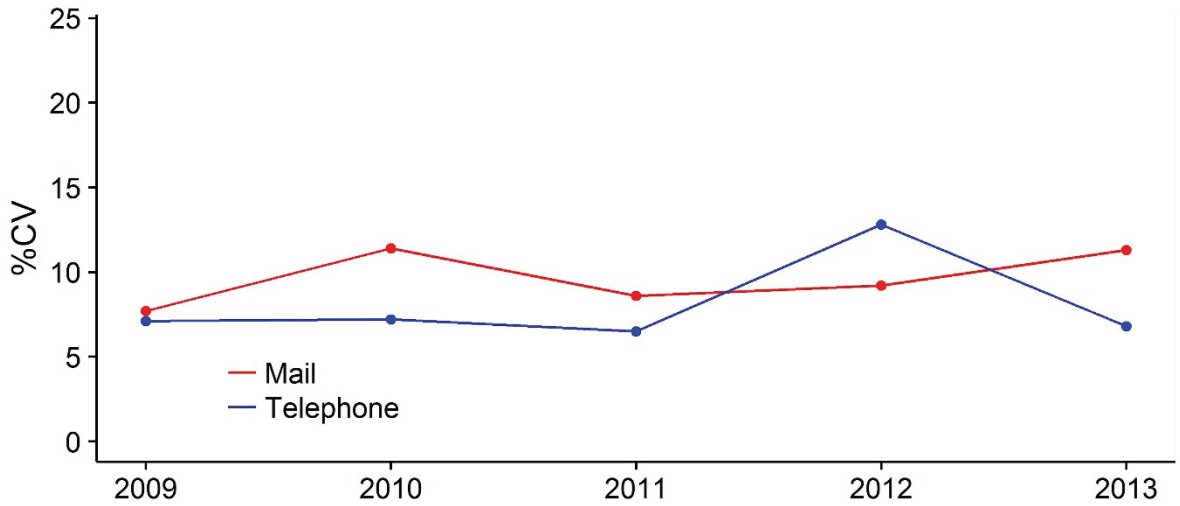

Figure 9: Comparison of %CVs between telephone and mail for ducks. Note: %CV is a measure of the precision, with lower %CVs indicating a more precise estimate.

Adjusted total estimates

The average ratio of the five years was 0.85 (95% CI: 0.76, 0.96). Thus, on average, the mail survey estimates were 18% higher than the telephone survey estimates. As the 95% CI did not overlap with one, there is strong statistical support that survey methods differ in their mean estimates, indicating a bias between the methods.

Figure 10 shows the effect of applying the 0.85 correction to mail estimates. Because of the uncertainty in the ratio, the 95% CI are larger for the mail-corrected estimates as they incorporate both the ratio uncertainty and the uncertainty in the original mail estimate. It can be seen that 2013 had very different estimates between the methods and even the corrected estimate 95% CI did not overlap with the telephone mean estimate, suggesting that this year may be behaving differently. Figure 11 shows the temporal pattern in duck harvest using mail-corrected values.

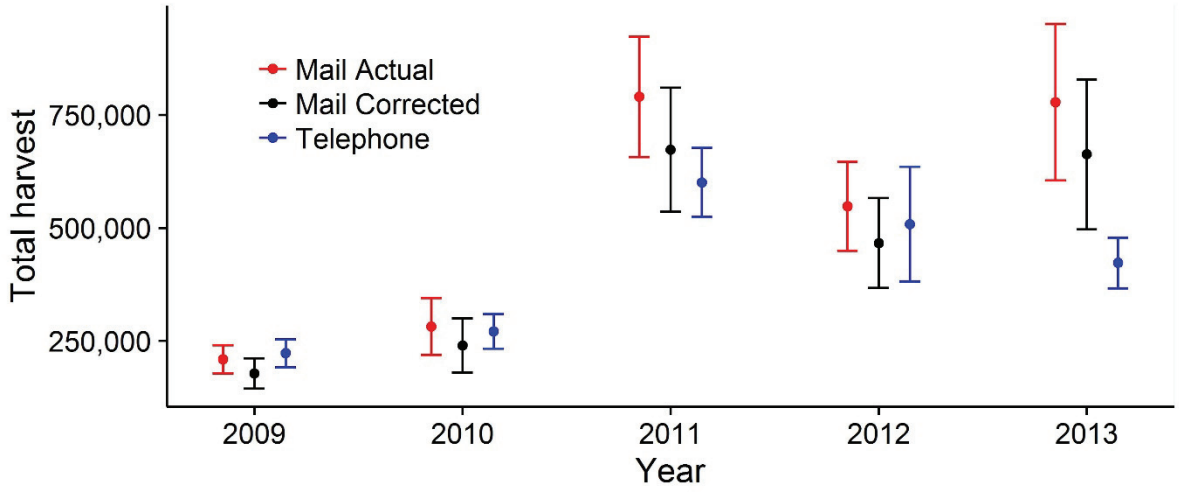

Figure 10: Comparison of annual duck harvest estimates for each survey method and for the corrected estimate. Corrected survey is the mail estimate corrected for any bias.

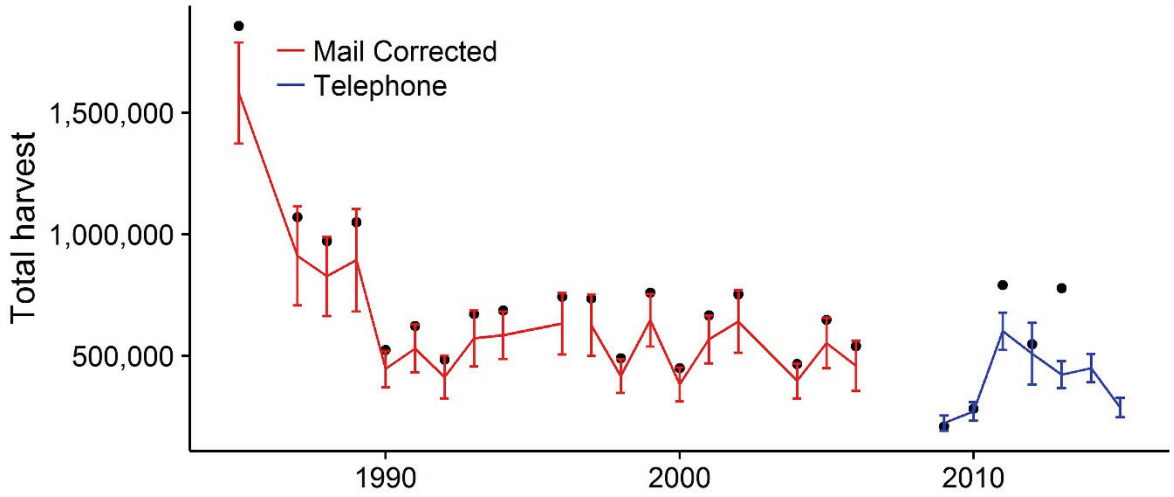

Figure 11: Temporal pattern in annual duck harvest estimates using corrected mail estimates. Corrected mail has been adjusted by the correction factor. Black points show the original mail survey harvest estimates.

Summary of surveys for each duck species (1996–2015)

Figure 12 shows the temporal patterns for each species. Mail survey data after 2011 lack species information. Consequently, only temporal patterns are presented and no correction analysis is conducted.

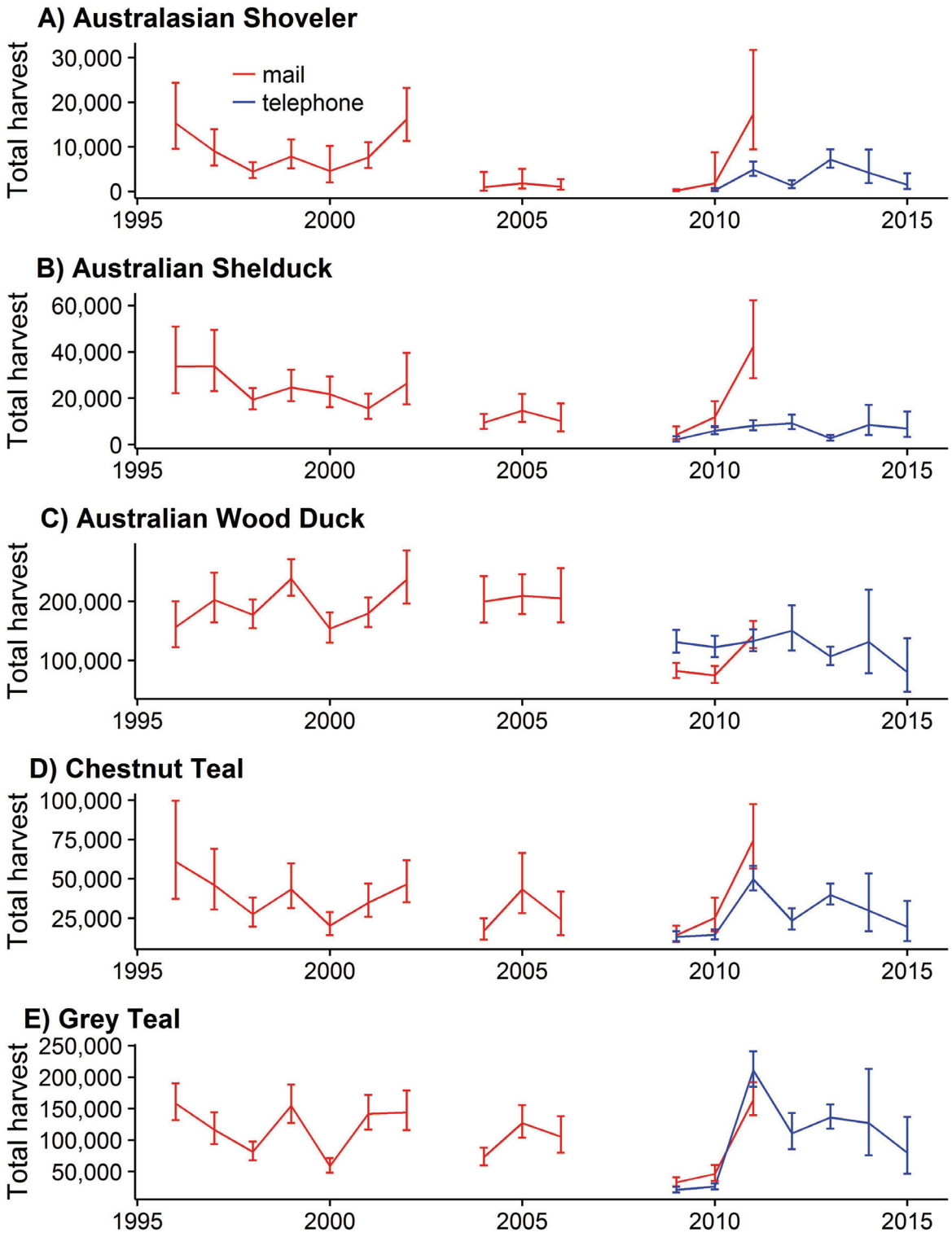

Figure 12: Harvest estimates for each duck species.
Different coloured lines indicate survey method (red – mail, blue – telephone). Error bars are 95% confidence intervals.
Note: there are no species-specific estimates after 2011 for mail surveys as data was not present in database.

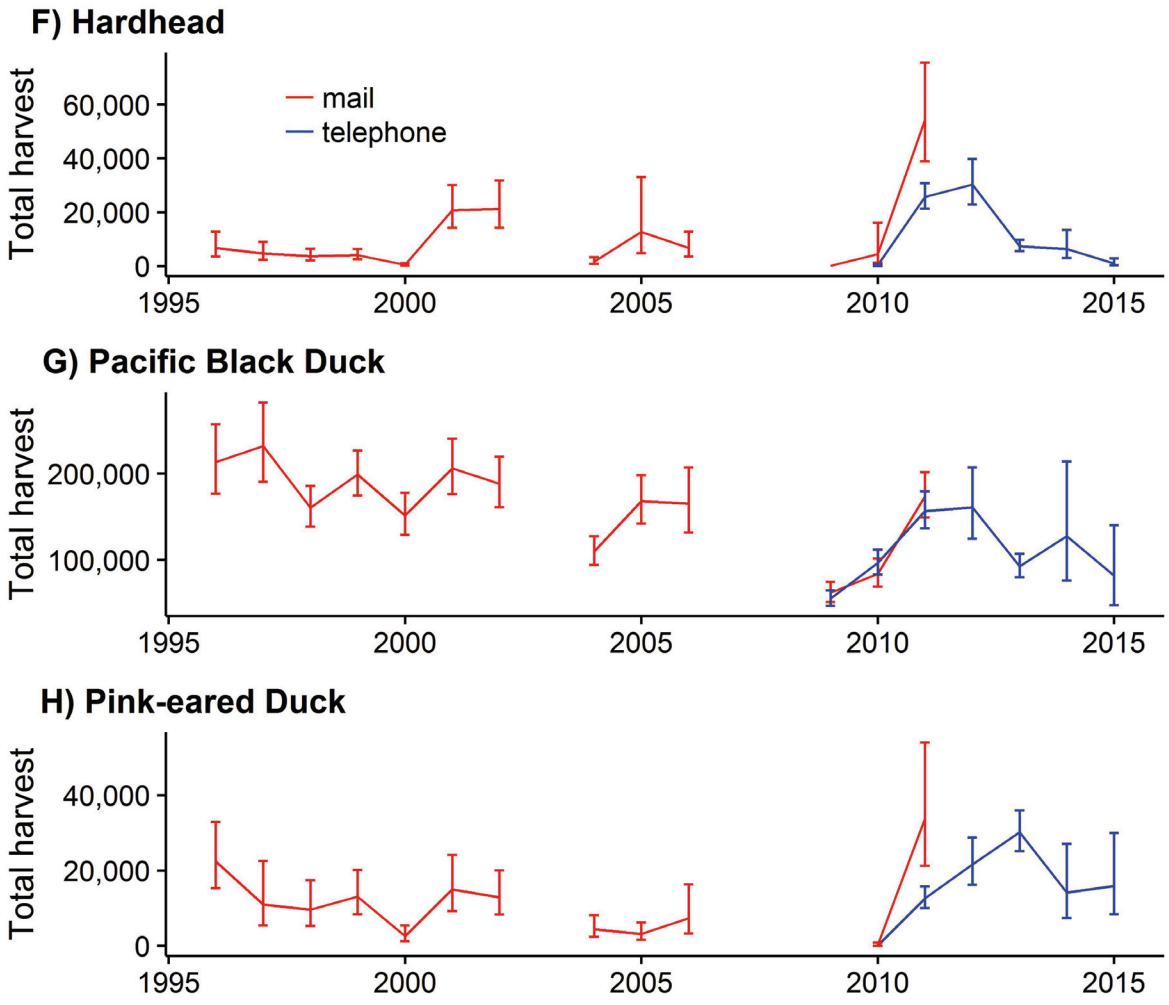

Figure 12 (continued): Harvest estimates for each duck species.
Different coloured lines indicate survey method (red – mail, blue – telephone). Error bars are 95% confidence intervals.
Note: there are no species-specific estimates after 2011 for mail surveys as data was not present in database.

Quail

Summary of quail surveys (1996–2015)

In Figure 13, the annual harvest estimates of Stubble Quail are shown. Distinct peaks in quail harvest are apparent in 2001–2002, 2004–2005 and 2011. Overall, mail estimates were generally higher than telephone estimates.

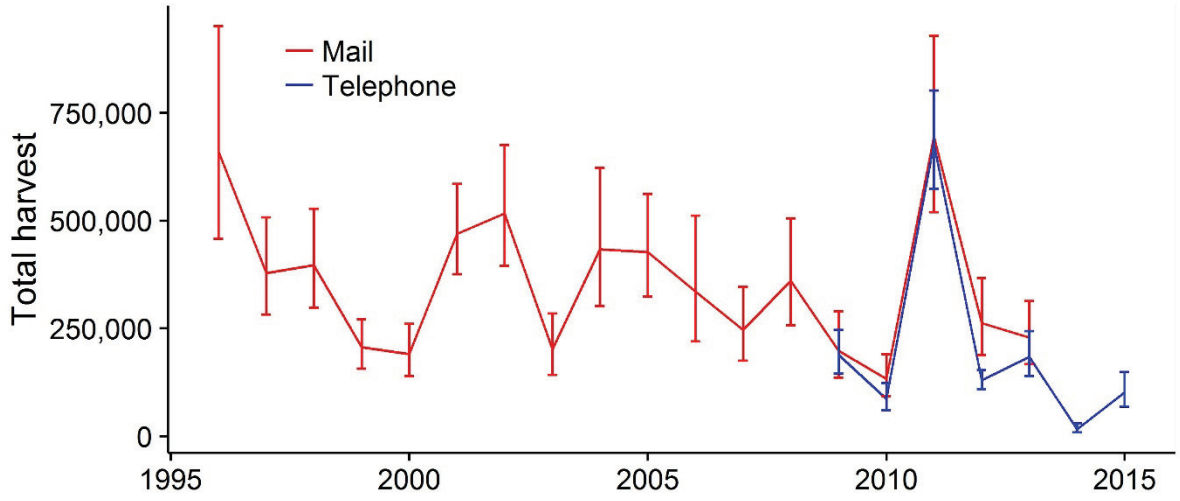

Figure 13: Total harvest estimates of harvest of Stubble Quail for each survey method. Different coloured lines indicate survey method. Error bars are 95% confidence intervals.

Comparison of mail and telephone surveys between 2009 and 2013

The ratio of telephone to mail estimates for each year of overlap are shown in Figure 14. Of these five years, one year did not have its 95% confidence interval (CI) overlapping with 1 [2012: ratio=0.49 (95% CI: 0.34, 0.72)], indicating that the mail harvest estimates were significantly higher than the telephone estimates (104% higher in 2012).

Similar to deer, the telephone survey had consistently lower %CV than the mail estimate (Figure 15).

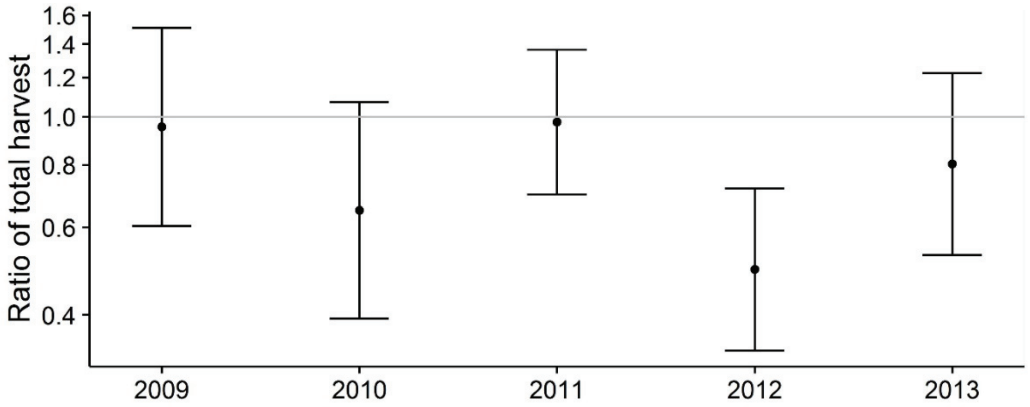

Figure 14: Annual estimates of the ratio of total harvest of Stubble Quail obtained by the two survey methods (telephone: mail). Values <1 indicate that the mail survey provided a higher estimate. The grey line indicates equal estimates and hence no bias. Error bars are 95% confidence intervals. Note – Y-axis is log-scaled.

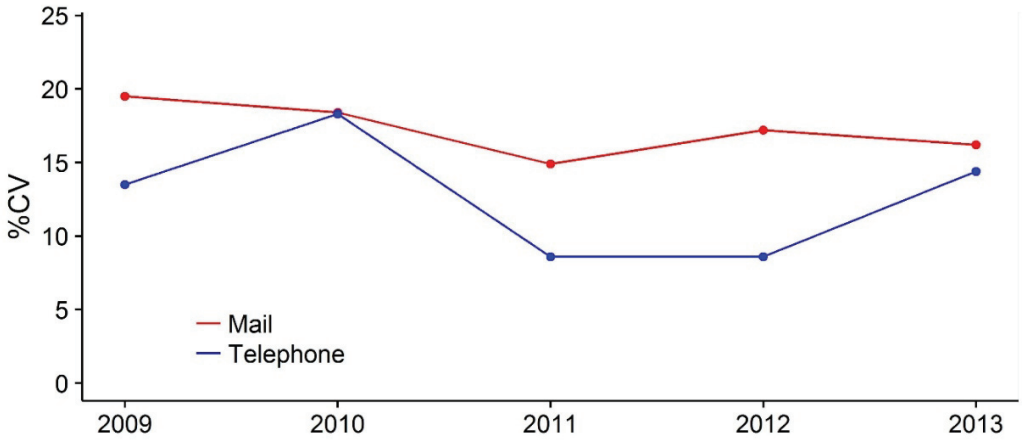

Figure 15: Comparison of %CVs between telephone and mail survey methods for Stubble Quail.
Note: %CV is a measure of the precision, with lower %CVs indicating a more precise estimate.

Adjusted total estimates

The average ratio of the five years was 0.78 (95% CI: 0.64, 0.94). Thus, on average, the mail survey estimates were 28% higher than the telephone survey estimates. As the 95% CI did not overlap with one, there is strong statistical support that survey methods differ in their mean estimates, indicating a bias between the methods.

Figure 16 shows the effect of applying the 0.78 correction to mail estimates. Figure 17 shows the temporal pattern in Stubble Quail harvest using mail-corrected values.

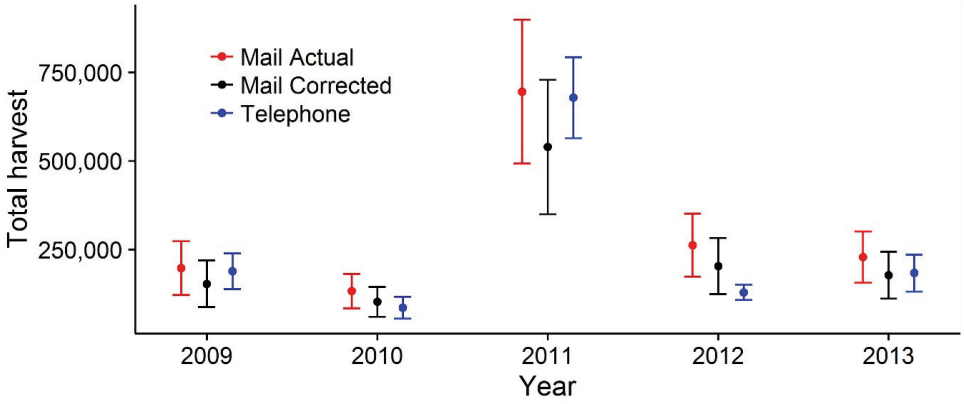

Figure 16: Comparison of estimates of the total harvest of Stubble Quail for each survey method and the corrected estimates. Different colour lines indicate the survey method. Corrected survey is the mail estimate corrected for any bias.

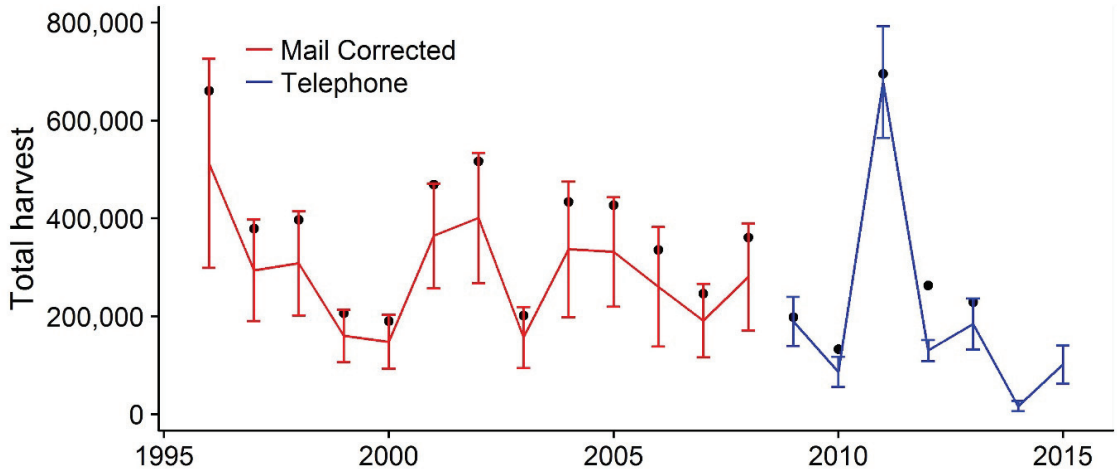

Figure 17: Temporal pattern in annual harvest estimates using corrected mail estimates. Corrected mail has been adjusted by the correction factor. Black points show the original harvest mail survey estimates.

Long-term trends using corrected harvest estimates

Finally, a general additive model (GAM) was fitted to mail-corrected estimates and telephone survey estimates (see Appendix 4 for more details on the model). All GAMs found a significant temporal trend (Table A4.1; Figure 18). Deer harvest has increased over time, while duck and Stubble Quail harvests have declined.

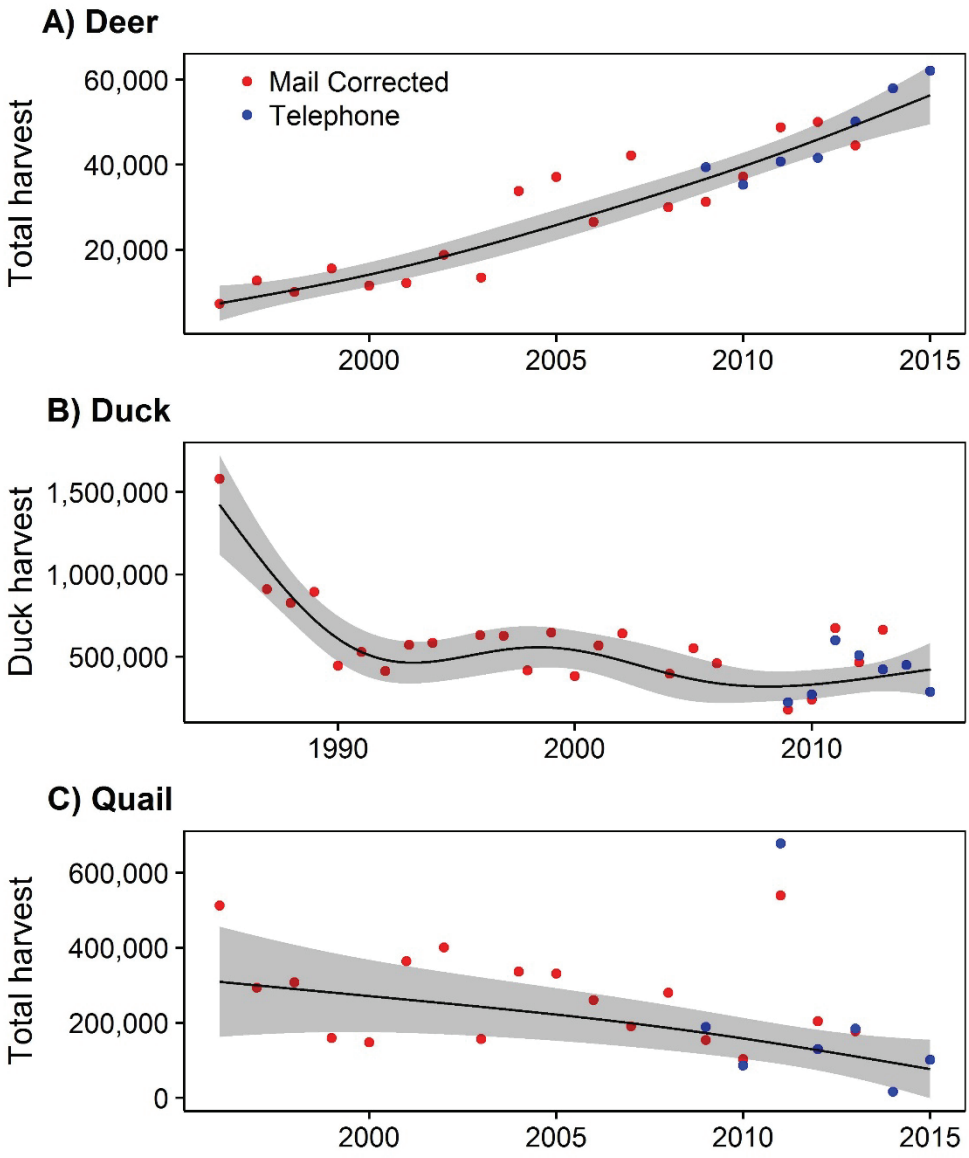

Figure 18: Temporal patterns predicted by a GAM for each game type.
Corrected mail has been adjusted by the correction factor. The curve shows the fitted spline, with a 95% confidence band.

4. Discussion

In 2009, the Department of Sustainability and Environment (DSE) in Victoria implemented a telephone survey to help ameliorate sampling issues with the mail surveys of hunter activity that had been conducted since 1985. In particular, the DSE was concerned about the accuracy of harvest estimates derived from the mail surveys. Inaccuracy may be caused by recall bias, rounding of harvest estimates, and non-response biases (Gormley and Turnbull 2009). Results from both the mail and telephone surveys have been maintained by the Game Management Authority. The analyses presented here found some bias between mail and telephone surveys, although the strength of the bias depended on the game type.

Deer results

The difference in estimates of total harvest between survey methods was 17%, with the telephone survey giving a higher estimate. It may not be surprising that there was not statistical support (as assessed through 95% CI) for a strong bias in the deer harvest estimates. We would expect that recall bias would be smaller for deer hunters as they harvest fewer deer and each successful hunt would be memorable. Similarly, rounding of harvest is again less likely for deer as only a few deer are harvested per year (approximately two deer per hunter per year, (Moloney and Turnbull 2015b)). Furthermore, Kilpatrick et al. (2005) found no difference in harvest rates between responders and non-responders (i.e. those that did not respond to the first survey) using the follow-up survey methodology.

However, given that the lower end of the 95% CI was near one and the mean estimate was 17%, a moderate bias may exist, but we did not have the statistical power to detect it. Consequently, we still applied the correction factor as this represented the best estimate of any potential bias. We would expect that if a bias does exist, it is more likely to be present in the mail survey method as noted. In agreement, telephone surveys have been found to produce no bias in mule deer (*Odocoileus hemionus*) and elk (*Cervus elaphus*) compared to check stations (Steinert et al. 1994, Unsworth et al. 2002).

Besides a bias, it was also important to look at the precision of the estimate. A consistent pattern was found that the telephone survey had lower %CVs, indicating that the telephone survey is a more precise method. A higher recall error is likely to be a major source of the additional variation in the mail survey. With the telephone method, surveys are conducted at regular intervals, mitigating recall error intervals and occur closer to the hunting event. With the mail survey, hunters are more likely to round harvest estimates, forget about hunting trips and inaccurately delineate between current and previous seasons. These issues can lead to increased variation in harvest estimates.

Duck results

Unlike deer, there was a statistically significant difference between duck estimates, with the mail survey having higher estimates (18% on average). We suspect that the difference is due mainly to a bias in the mail survey, due to the reasons discussed above. In particular, hunter estimates of harvest seem to be problematic. Wright (1978) reported that waterfowl harvests from hunter surveys were more than twice that observed at check stations, and there was little difference between harvest rates between responders (i.e. those that filled out the survey) and non-responders, suggesting little bias due to non-response. Similarly, Filion (1975) did not find a significant difference between harvest rates between responders and non-responders. The potential for over-estimating harvest rates in mail surveys is in accordance with the results here. Finally, %CVs were consistently lower for the telephone method, similar to the deer results.

Quail results

Quail estimates showed the largest differences between the surveys. Overall, mail estimates were 28% higher than the telephone estimates. Every year the mail estimates provided higher estimates than the telephone estimates, ranging from 5% to 104%. Again, we assumed that the telephone was a better estimate of the true harvest given the potential bias with mail surveys (as noted above). Correcting for the possible bias in the mail survey resulted in confidence intervals that always included the telephone survey mean estimate and majority of the telephone 95% confidence interval. A potential concern with the correction is that 2011 was over-corrected as the adjusted estimate is substantially lower than telephone survey 95% confidence interval. Without more data, it is not clear if the correction factor may not be appropriate for high harvest years in general or if 2011 was a unique year. Finally, %CVs were consistently lower for the telephone method, concurring with the other game types.

Limitation in determining bias causes

Because of the differences in methodologies used, it was not possible to identify precisely how the bias emerges in the harvest estimates. Total harvest estimates are based on knowing the number of licensed hunters, proportion of hunters active, and the average harvest per active hunter (Appendix 2). As the number of hunters is roughly the same between the mail and telephone surveys, differences in the proportion of hunters and the average harvest rate account for differences in total harvest estimates. However, given the current sampling protocol, it is not possible to compare between surveys. The mail survey asked hunters if they hunted at any point during the season and their total harvest for the year. The telephone surveys asked the same questions but only for a limited temporal window (e.g. during opening weekend or during the last two weeks), and new respondents are used for each temporal window of the season. Therefore, for the telephone survey we can estimate the total number of hunters per period, but we cannot estimate the total number of unique hunters for the whole season, as calculated in the mail survey. Consequently, these differences limit our understanding of the causes of variation in the survey estimates.

Despite these limitations, the recalculation of the seasonal harvests using the correction factors provides a more accurate record of historical estimates of game harvests. This will help to improve management, including the use of these data in adaptive harvest modelling.

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Appendix 1: Extracting data from reports and databases

Table A1.1: Available data for deer, duck and quail.

Year	Duck	Quail	Deer	Data source for mail survey	Data source for telephone survey
1985	Complete			Annual Report	
1986	Closed			No Report	
1987	Estimated SD			Annual Report	
1988	Estimated SD			Annual Report	
1989	Estimated SD			Annual Report	
1990	Estimated SD			Annual Report	
1991	Estimated SD	Total Only		Annual Report	
1992	Estimated SD	Total Only		Annual Report	
1993	Complete	Total Only		Annual Report	
1994	Complete	Total Only		Annual Report	
1995	Closed	Complete		Annual Report	
1996	Complete	Complete	Complete	HMS Database	
1997	Complete	Complete	Complete	HMS Database	
1998	Complete	Complete	Complete	HMS Database	
1999	Complete	Complete	Complete	HMS Database	
2000	Complete	Complete	Complete	HMS Database	
2001	Complete	Complete	Complete	HMS Database	
2002	Complete	Complete	Complete	HMS Database	
2003	Closed	Complete	Complete	HMS Database	
2004	Complete	Complete	Complete	HMS Database	
2005	Complete	Complete	Complete	HMS Database	
2006	Complete	Complete	Complete	HMS Database	
2007	Closed	Complete	Complete	HMS Database	
2008	Closed	Complete	Complete	HMS Database	
2009	Complete	Complete	Complete	HMS Database	Annual Report
2010	Complete	Complete	Complete	HMS Database	Annual Report
2011	Complete	Complete	Complete	HMS Database	Annual Report
2012	Complete	Complete	Complete	HMS Database	Annual Report
2013	Complete	Complete	Complete	HMS Database	Annual Report
2014	Complete	Complete	Complete		Annual Report
2015	Complete	Complete	Complete		Annual Report

Note: 'Complete' indicates that number of licensed hunters, proportion hunting, and mean and standard deviation (SD) for harvest rates were available.
'Total only' indicates that the total harvest estimate without a SD was available.
'Estimated SD' indicates that no SD was reported but was estimated from the SDs from previous years (see methods below).
'Closed' indicates that there was no hunting season that year.
HMS = Hunter's mail survey.

Extracting deer data

All telephone survey information for deer was extracted from the annual reports. Both total and species estimates were extracted. No new calculations were performed with these data.

For mail surveys, no annual reports were available prior to 1995. The 1995 annual report had only total harvest with no standard errors. From 1996 to 2013, the HMS database was used to calculate the proportion hunting, annual harvest rate per active hunter, and total harvest using the methodology outlined in Appendix 2.

In 2006, the database had no survey results from deer licences, but the annual report indicated that there were 167 respondents. Furthermore, the database only included one record for deer hunting, but the report indicated there were 145. Therefore, the numbers in the 2006 GMA report were used and not the database records. However, standard errors were absent in the report and hence will be missing for total estimates.

Extracting duck data

All telephone survey information for ducks was extracted from the annual reports. No new calculations were performed with these data.

With the mail survey data, only annual reports existed for data between 1985 and 1996. To obtain estimates for number of duck harvested, each report was examined and the following information was extracted: number of licensed hunters, number of survey respondents, percentage of hunters that hunted, annual harvest rate per active hunter, a measure of variation in harvest rate, and estimate of total harvest. For 1996 to 2013, the HMS database was used to estimate proportion hunting, harvest rate (with standard error), and total harvest across all species (with standard error). Estimates were calculated using the methodology outlined in Appendix 2.

From 1987 to 1992, summary reports of duck harvests did not include an estimate of the standard deviation (SD) for season harvest rate (average harvest per hunter). To get an estimate for SD, a regression line was fitted between SD and mean harvest rates for all years. Overall, the linear model had an R2 = 0.91 and a slope of 1.48 ± 0.097. Given the good fit of this linear model, the SD for each mean harvest rate was predicted with no SD estimate.

For 1992, the number of respondents was not reported in the annual report. To provide an estimate, the average number of respondents from 1987 to 1994 was used.

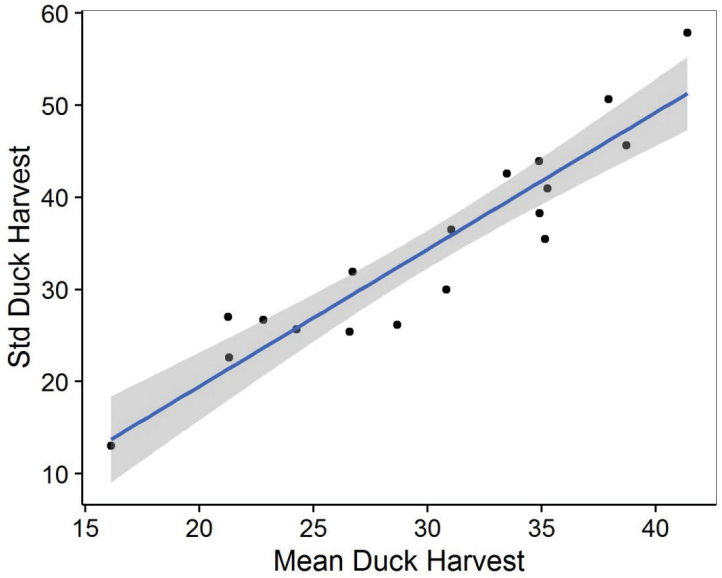

Figure A1.1: Relationship between mean annual duck harvest and standard deviation of duck harvest.
The line is the regression model with 95% confidence band.

Extracting quail data

All telephone survey information for quail was extracted from the annual reports. No new calculations were performed with these data.

For the mail survey, the first quail information was reported in the 1995 annual report, which provided total estimates (no standard errors) back to 1991, but no other usable information. From 1996–2013, the HMS database was used to calculate proportion hunting, season harvest rate (average harvest/hunter) (with standard error), and total harvest estimates (with standard error). Estimates were calculated using the methodology outlined in Appendix 2.

Appendix 2: Estimating total harvest

Methods for estimating total harvest from hunter's follow Gormley and Turnbull (2009) and is outlined below:

Common abbreviations used

SD = standard deviation of the data. Represents the variation in the numbers reported.

SE = standard error of the mean. Represents the variation in the estimated mean.

CV = coefficient of variation. Calculated as: CV = SE ÷ mean. This provides an indication of how much uncertainty is in the estimate relative to the mean.

Estimating total harvest

Note - For the mail survey, there was only one survey period, but for the telephone survey there were multiple surveys for each game type.

For each survey j, we surveyed n_j respondents, of which h_j had hunted. The proportion of respondents who hunted in each period j is given by:

$$p_j = \frac{h_j}{n_j}$$

The total number of hunters for each survey period (H_j) was estimated by multiplying the total number of licence holders (L) by the proportion of respondents who reported having hunted during that survey period (p_j), as found previously:

$$H_j = p_j L$$

The estimated average harvest per hunter (w_j) is the total reported harvest for survey j (y_j) divided by the total number of respondents who hunted (h_j):

$$w_j = \frac{y_j}{h_j}$$

The total harvest for each survey period (W_j) was estimated by multiplying the average harvest per hunter (w_j) by the total number of hunters (H_j):

$$W_j = w_j H_j$$

The estimate of the total harvest was calculated as the sum of the estimated harvest for each survey period:

$$W_{TOT} = W_1 + W_2 + W_3 + W_4 + W_5 + W_6 + W_7 .$$

(for the mail survey, $W_{TOT} = w_1 H_1$ since there is only one survey period)

Standard errors (SEs) for the proportion of respondents who hunted are given by:

$$\mathrm{SE}(\mathrm{p_j}) = \sqrt{\frac{\mathrm{p_j}(1-\mathrm{p_j})}{\mathrm{n_j}}} \quad .$$

Standard errors for the average harvest per hunter are given by:

$$\mathrm{SE}(w_j) = \frac{\mathrm{SD}(w_j)}{\sqrt{h_j}}$$

The standard error for the total estimated harvest per survey period (W_j) was found by determining the coefficient of variation (CV) of p_j and w_j and then adding their sum of squares to find the combined CV (assuming independence).

$$\mathrm{CV}(w_j) = \frac{\mathrm{SE}(w_j)}{w_j}, \text{ and } \mathrm{CV}(p_j) = \frac{\mathrm{SE}(p_j)}{p_j}$$

$$\mathrm{CV}(W_j) = \sqrt{\left(\mathrm{CV}(w_j)\right)^2 + \left(\mathrm{CV}(p_j)\right)^2}$$

$$\mathrm{SE}(W_j) = \mathrm{CV}\left(W_j\right) \times W_j .$$

The standard error of the total harvest was calculated by:

$$\mathrm{SE}(W_{TOT}) = \sqrt{\left(\mathrm{SE}(W_1)\right)^2 + \left(\mathrm{SE}(W_2)\right)^2 + \cdots + \left(\mathrm{SE}(W_7)\right)^2} .$$

Estimating the correction factor for total harvest

For each hunting group and for each year, the bias in the estimate of total harvest was calculated by estimating the ratio of telephone total harvest H_t to mail total harvest H_m:

$$R_{yr} = \frac{H_t}{H_m}$$

To estimate the standard error for $\hat{R}_H$, we used the delta method approximation for ratios (Cox 1990) [assuming independence]:

$$SE\left(R_{yr}\right) = \frac{H_t}{H_m} * \sqrt{\left(\frac{SE(H_m)}{H_m}\right)^2 + \left(\frac{SE(H_t)}{H_t}\right)^2}$$

Adjusting estimates of total harvest

To estimate the correction factor of mail surveys, we first calculated the average ratio $\bar{R}$ for each hunting group (*n* = # of years of overlap):

$$\bar{R} = \frac{R_{2009} + R_{2010} + \cdots + R_{2013}}{n}$$

To calculate the standard error $SE(\bar{R})$, we used the following formula:

$$SE(\bar{R}) = \sqrt{\frac{SE(\hat{R}_{H,2009})^2 + SE(\hat{R}_{H,2010})^2 + \cdots + SE(\hat{R}_{H,2013})^2}{n^2}}$$

Finally, we then calculated the adjusted $H_{mail\ adj}$ for the mail survey data using the following equations:

$$H_{mail\ adj} = H_m * \bar{R}$$

Standard error was calculated again using the delta method:

$$SE\left(H_{mail\ adj}\right) = H_{mail\ adj} * \sqrt{\left(\frac{SE(H_m)}{H_m}\right)^2 + \left(\frac{SE(\bar{R})}{\bar{R}}\right)^2}$$

Confidence intervals for estimates

Confidence intervals were computed on the natural logarithm scale and back-transformed to ensure that lower limits were ≥0. A consequence is that the confidence intervals were asymmetric and cannot be reported as the estimate plus or minus a fixed value. In general, for some estimates denoted as $\hat{X}$, 95% confidence interval limits were calculated using:

upper limit $= \hat{X} \times r$

lower limit $= \hat{X} \div r$, where:

$$r = \exp\left(1.96\sqrt{\ln\left(1 + CV^2\right)}\right)$$

Appendix 3: Tables of estimates used in report figures

Deer Tables

Table A3.1: Data for Figure 1 – Deer estimates.

a: Mail survey results

Year	Total harvest	Lower 95%	Upper 95%
1996	6,223	4,372	8,859
1997	10,900	7,335	16,198
1998	8,574	6,296	11,675
1999	13,362	9,159	19,493
2000	9,918	6,903	14,251
2001	10,455	7,515	14,544
2002	16,099	11,429	22,677
2003	11,533	6,825	19,489
2004	28,959	20,645	40,621
2005	31,841	20,683	49,019
2006	22,745	-	-
2007	36,130	26,186	49,849
2008	25,698	19,985	33,043
2009	26,822	20,543	35,021
2010	31,869	23,580	43,074
2011	41,819	30,453	57,426
2012	42,883	31,649	58,105
2013	38,198	27,631	52,805

b: Telephone survey results

Year	Total harvest	Lower 95%	Upper 95%
2009	39,418	33,299	46,661
2010	35,278	28,382	43,850
2011	40,728	32,381	51,228
2012	41,601	33,839	51,142
2013	50,112	40,279	62,346
2014	57,945	46,382	72,392
2015	62,165	49,458	78,136

Table A3.2: Data for Figure 2 – Deer ratios.

Year	Ratio	Lower 95%	Upper 95%
2009	1.47	1.07	2.01
2010	1.11	0.76	1.6
2011	0.97	0.66	1.44
2012	0.97	0.67	1.4
2013	1.31	0.89	1.94
Total	**1.17**	**0.99**	**1.38**

Table A3.3: Data for Figure 4 – %CV estimates.

Year	Mail %CV	Telephone %CV
2009	13.7	8.6
2010	15.5	11.1
2011	16.3	11.7
2012	15.6	10.6
2013	16.6	11.2

Table A3.4: Data for Figure 5 – Deer adjusted estimates.

Year	Total harvest	Lower 95%	Upper 95%
1996	7,260	4,411	10,110
1997	12,716	7,210	18,222
1998	10,002	6,483	13,521
1999	15,588	9,112	22,064
2000	11,571	6,929	16,212
2001	12,196	7,668	16,725
2002	18,781	11,593	25,969
2003	13,454	5,931	20,977
2004	33,784	20,984	46,583
2005	37,145	19,801	54,490
2006	26,534	-	-
2007	42,149	26,818	57,481
2008	29,979	20,935	39,024
2009	39,418	32,756	46,080
2010	35,278	27,581	42,975
2011	40,728	31,354	50,102
2012	41,601	32,987	50,215
2013	50,112	39,132	61,092
2014	57,945	45,005	70,885
2015	62,165	47,902	76,428

Duck Tables

Table A3.5: Data for Figure 7 – Duck estimates.

a: Mail survey results

Year	Total harvest	Lower 95%	Upper 95%
1985	1,857,225	1,741,627	1,980,495
1986	-	-	-
1987	1,069,759	883,390	1,295,447
1988	970,788	826,986	1,139,595
1989	1,049,136	854,095	1,288,717
1990	523,003	463,469	590,185
1991	621,783	537,952	718,677
1992	484,109	404,210	579,802
1993	671,814	568,765	793,535
1994	686,027	608,588	773,321
1995	-	-	-
1996	741,893	630,447	873,039
1997	735,080	622,483	868,044
1998	488,930	433,068	551,997
1999	758,992	672,187	857,007
2000	448,806	391,025	515,125
2001	665,839	585,312	757,445
2002	752,733	639,155	886,494
2003	-	-	-
2004	464,914	402,415	537,119
2005	648,255	558,924	751,864
2006	538,662	443,875	653,689
2007	-	-	-
2008	-	-	-
2009	208,633	179,576	242,392
2010	281,589	225,364	351,843
2011	790,172	667,641	935,191
2012	547,729	457,549	655,681
2013	778,444	623,664	971,638

b: Telephone survey results

Year	Total harvest	Lower 95%	Upper 95%
2009	222,302	193,360	255,576
2010	270,574	234,857	311,723
2011	600,739	528,557	682,779
2012	508,256	396,054	652,245
2013	422,294	369,821	482,212
2014	449,032	394,157	511,547
2015	286,729	249,645	329,322

Table A3.6: Data for Figure 8 – Duck ratios.

Year	Ratio	Lower 95%	Upper 95%
2009	1.07	0.87	1.31
2010	0.96	0.74	1.25
2011	0.76	0.62	0.94
2012	0.93	0.68	1.26
2013	0.54	0.42	0.7
Total	**0.85**	**0.76**	**0.96**

Table A3.7: Data for Figure 9 – %CV estimates.

Year	Mail %CV	Telephone %CV
2009	7.7	7.1
2010	11.4	7.2
2011	8.6	6.5
2012	9.2	12.8
2013	11.3	6.8

A3.8: Data for Figure 11 – Duck adjusted estimates.

Year	Total harvest	Lower 95%	Upper 95%
1985	1,581,241	1,372,763	1,789,719
1987	910,793	706,993	1,114,593
1988	826,529	663,219	989,838
1989	893,234	682,255	1,104,214
1990	445,285	370,930	519,640
1991	529,386	431,369	627,403
1992	412,171	323,842	500,499
1993	571,983	456,054	687,911
1994	584,084	487,006	681,162
1996	631,648	505,574	757,722
1997	625,847	499,132	752,563
1998	416,275	346,620	485,929
1999	646,206	538,016	754,396
2000	382,113	313,448	450,779
2001	566,895	468,865	664,925
2002	640,877	512,546	769,208
2004	395,828	322,680	468,975
2005	551,925	448,230	655,619
2006	458,616	355,154	562,078
2009	222,302	191,256	253,348
2010	270,574	232,219	308,929
2011	600,739	523,756	677,722
2012	508,256	380,964	635,548
2013	422,294	366,199	478,389
2014	449,032	390,438	507,626
2015	286,729	246,968	326,490

Quail Tables

Table A3.9: Data for Figure 13 – Quail estimates.

a: Mail survey results

Year	Total harvest	Lower 95%	Upper 95%
1996	660,461	458,240	951,921
1997	378,604	282,385	507,609
1998	396,934	298,446	527,923
1999	206,029	156,492	271,248
2000	190,360	138,971	260,751
2001	469,285	376,222	585,368
2002	516,614	394,928	675,795
2003	201,654	142,749	284,864
2004	433,893	302,611	622,128
2005	427,056	324,328	562,322
2006	335,690	220,163	511,837
2007	246,241	175,192	346,103
2008	361,099	257,866	505,659
2009	198,144	135,716	289,288
2010	132,986	93,039	190,084
2011	695,400	520,224	929,563
2012	262,655	187,840	367,267
2013	229,070	167,141	313,944

b: Telephone survey results

Year	Total harvest	Lower 95%	Upper 95%
2009	189,155	145,328	246,198
2010	86,302	60,465	123,180
2011	678,431	573,511	802,545
2012	129,711	109,534	153,605
2013	184,123	139,007	243,882
2014	16,243	8,699	30,330
2015	101,244	68,761	149,074

Table A3.10: Data for Figure 14 – Quail ratios.

Year	Ratio	Lower 95%	Upper 95%
2009	0.96	0.6	1.51
2010	0.65	0.39	1.07
2011	0.98	0.7	1.36
2012	0.49	0.34	0.72
2013	0.8	0.53	1.22
Total	**0.78**	**0.64**	**0.94**

Table A3.11: Data for Figure 15 – %CV estimates.

Year	Mail %CV	Telephone %CV
2009	19.5	13.5
2010	18.4	18.3
2011	14.9	8.6
2012	17.2	8.6
2013	16.2	14.4

A3.12: Data for Figure 17 – Quail adjusted estimates.

Year	Total harvest	Lower 95%	Upper 95%
1996	512,254	298,837	725,670
1997	293,645	190,014	397,276
1998	307,862	201,306	414,417
1999	159,796	105,847	213,746
2000	147,643	92,818	202,469
2001	363,977	256,763	471,191
2002	400,686	267,537	533,835
2003	156,403	94,073	218,732
2004	336,527	197,908	475,147
2005	331,225	219,359	443,090
2006	260,361	138,320	382,403
2007	190,984	115,731	266,237
2008	280,068	170,639	389,497
2009	189,155	139,073	239,237
2010	86,302	55,342	117,262
2011	678,431	564,241	792,621
2012	129,711	107,739	151,683
2013	184,123	132,103	236,143
2014	16,243	5,837	26,649
2015	101,244	61,687	140,801

Appendix 4: Analysis of temporal trends in surveys

To analyse temporal trends in harvest estimates, a general additive model (GAM) was performed using gam() from the mgcv package (Wood 2006). Separate GAMs were performed for each game type. For each model, harvest estimate (corrected for the mail survey) was the response variable and year was included as a thin-plate spline (i.e. s(year)). Estimate errors were added as weights to the model, allowing for more precise estimates to have more statistical weight.

Table A4.1: GAM results for each game type.

Game type	Year EDF	F-value	P-value
Deer	2.3	84.7	<0.001
Duck	4.7	10.7	<0.001
Quail	2.2	8.6	<0.001

EDF is the estimated degree of freedom for the spline and lower EDFs indicate smoother splines.
For instance, EDF around 1 is a linear spline; EDF around 2 is quadratic(-ish).

Notes


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