Estimation of differential vulnerability and fall age ratios of American black ducks (REVISED)

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1 Distribution of Banding Data

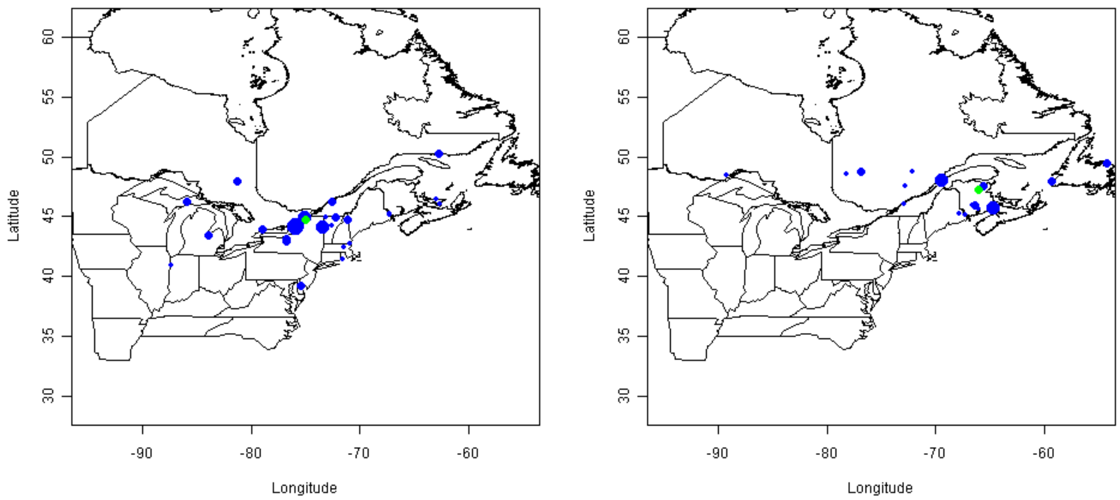
Before I get into the estimation of vulnerability and age ratios, I wanted to try and take a stab at the question, of how representative are the banding data of the black duck population. While I don't think I was actually able to fully answer this question, I was able to address the distribution of black duck bandings over time. To do this, I queried the banding data and selected all preseason banding's of all age-sex black ducks coded at normal wild, control, spotlighted, or blood drawn, banded in the AF, MF, and Canadian Provinces, from 1960–2008. For all unique stations that banded at least 25 black ducks in a given year, I calculated the mean banding latitude and longitude of the station weighted by the total number of black ducks banded at the station each year. What results from this is a mean latitude and longitude of all stations that banded at least 25 black ducks annually over the period of 1960–2008. Ideally, if the distribution of bandings has remained stable over time the relative location of the mean lat/long should be in the same place. Thus, plotting each year and looking where the mean banding location fell each year, and its change over time is a good indication of where the bulk of the banding's are coming from.

Overall, there has been a shift in the distribution of black duck banding's (Figure 1(a)). On average, the mean lat/long of banding stations has migrated to the northeast. This really is not all that surprising, and could have occurred for two reasons: 1.) known changes in the abundance of black ducks over time (i.e., west-east decline in black duck abundance), or 2.) There has been some reduction or expansion in black duck banding effort in the west or east, respectively.

2 Differential Vulnerability Estimation

The estimation of differential or relative vulnerability (V) was done in several stages to address a number of questions. For these analyses, I have assumed that V is temporally variable, even though it may be difficult to justify the basis for this biologically. Some initial questions that I felt needed to be addressed were;

1. Is it necessary to estimate V for each age-sex class?
2. How variable are V estimates across age, sex, and recovery regions?
3. Does it matter how estimates are calculated? In other words, a certain portion of the banded population is harvested in Canada prior to the opening of US hunting seasons.



(a) 1960 (b) 2008

Figure 1: Distribution of black banding's (blue), and mean banding location (green) from 2 selected years. Blue dot size indicates relative numbers of black ducks banded at a given station.

> Thus, the banded sample able to be recovered in the US is some fraction of the total preseason bandings (i.e., conditional harvest). Does failing to account for this have a measurable effect on the estimates?

2.1 Data

Data used in these analyses are similar to those described above. I included only black ducks banded preseason (1 July–30 September) as AHY, L, or HY, of all sexes that were coded as normal wild (300), control band (304), blood drawn (318), or spotlighted (370). To ensure the largest sample size possible, all black ducks banded in AF, MF, or all of Canada were used. The recovery sample was subset using the identical criteria, with additional constraints that birds must have been shot, or found dead anywhere in the US or Canada, and then reported to the BBL by the finder during the first season after banding. Indirect recoveries currently were not included in the analysis, however, they could be with additional work. The impact of these additional recoveries could be measurable if the estimates of recovery rates for adults males increased or decreased substantially. Lesser impact would be observed if the additional recoveries only impacted recovery rates of adult females, or serve to shrink the error around the current estimates for males and females. Recoveries of US banded black ducks recovered in Canada were excluded to simplify the analysis, since there were very few.

2.2 Analyses

Differential vulnerability could be estimated a number of different ways and is generally expressed as the ratio of juveniles to adults, usually based on recovery or harvest rates. However, this can be generalized to express the vulnerability of any age-sex cohort relative to another age-sex cohort, although adult males are typically used as the standard for comparison. Using recovery rates as the parameter, vulnerability were calculated as,

$$V_{t,j} = \frac{f_{t,j}}{f_{t,am}}, \tag{1}$$

where t was time, and j were the remaining age-sex cohorts. Using harvest rates is probably more appropriate, since they more closely represent information regarding the true kill of different ages and sexes. However, the challenges of estimating these parameters should be obvious. So, by using recovery rates we inherently are required to assume that the band reporting rate does not differ among the age-sex cohorts. In addition, we must account for known changes in reporting rates among the different band types that have been distributed over the course of black duck banding. For simplicity of modeling, Equation 1 was rearranged, such that recovery rates of all other age-sex cohorts were expressed as a function of adult male recovery rates and a vulnerability parameter V (Equation 2).

$$f_{i,j} = f_{i,am} * V_{i,j} \tag{2}$$

While this provides the basis for estimation, we are interested in whether estimates of vulnerability vary over some spatial unit. These analyses were limited to gross spatial scales (i.e., US or Canada). Intuitively, given that a bird was banded in Canada, it could be recovered in Canada, the US, or not at all during the first hunting season after banding. The same is also true of black ducks banded in the US (see data section regarding recoveries of US bandings). Some thought must be given to the mathematical representation of the harvest process. Consider that the entire hunting season covers a span of almost 5 months. The hunting season in Canada opens prior to the US hunting season, by several weeks, and the US hunting season extends beyond the close of the Canadian hunting season by several weeks, due to regulatory season closure, or functional season closure resulting from freezeup. The band recovery process could be modeled in 2 ways. The first method suggests that the early opening doesn't mean much and recoveries in the US and Canada are modeled to occur in a simultaneous fashion, in other words, one single long hunting season. On the other hand, this early opening is important and recoveries are modeled as occurring in a sequential or conditional fashion, that is, a bird must survive the Canadian harvest in order to be harvested in the US. Technically, all recoveries must be recovered in Canada prior to any recoveries occurring in the US (this is the assumption in modeling).

Assuming simultaneous recoveries in the US and Canada, recovery and vulnerability rates were modeled as;

$$m_{t,j} \sim Multinomial(f_{t,j}^{b,r} * V_{t,j}^{b,r}, R_{t,j}^{b}) \tag{3}$$

Thus, recoveries in region r in year t, of cohort j are a multinomial with probability $f_{t,j} * V_{t,j}$, given the number banded in time t, of cohort j from banding region b, where the banding and recovery region is the US or Canada. Thus you end up with vulnerability estimates for each age-sex cohort, year, and each combination of banding and recovery region (e.g., young males banded in Canada and recovered in the US in 1972).

Assuming sequential seasons in the US and Canada, recovery and vulnerability rates were modeled as;

$$m_{t,j}^{CA} \sim Bin(f_{t,j}^{b,r} * V_{t,j}^{b,r}, R_{t,j})$$

$$m_{t,j}^{US} \sim Bin(f_{t,j}^{b,r} * V_{t,j}^{b,r}, R_{t,j} - m_{t,j}^{CA}) \tag{4}$$

$$m_{t,j}^{US} \sim Bin(f_{t,j}^{b,r} * V_{t,j}^{b,r}, R_{t,j}^{US})$$

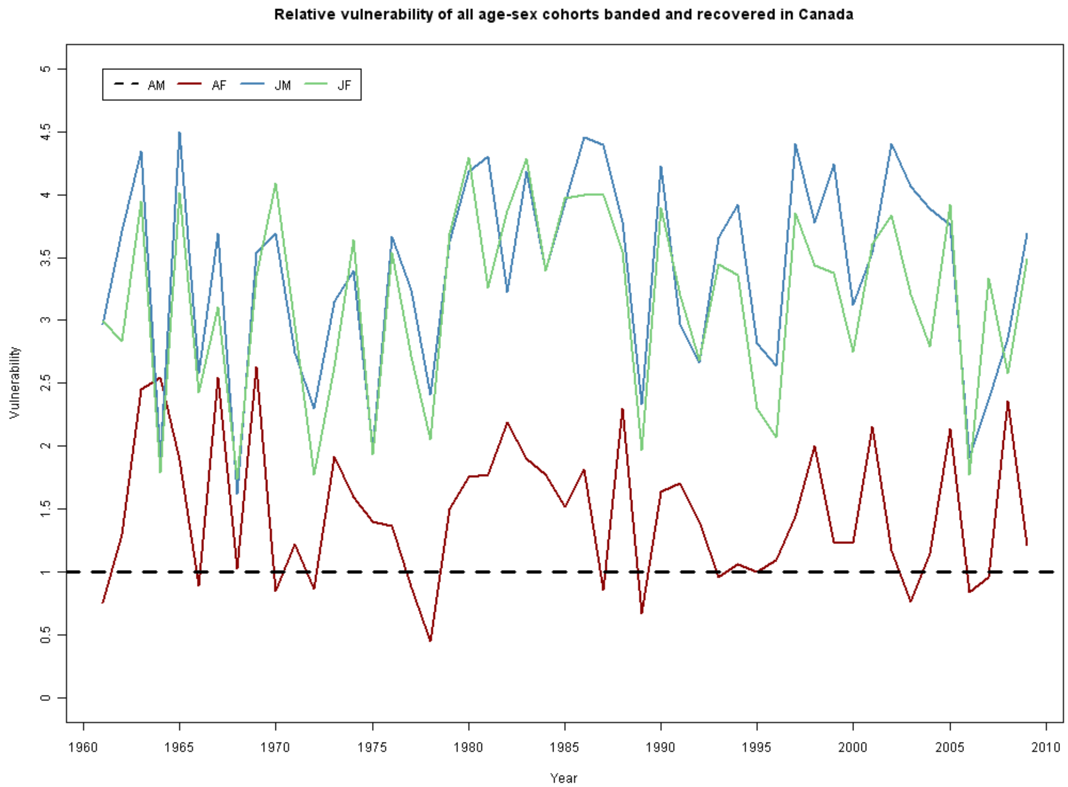
The difference between Equation 3, and Equation 4 is that the recoveries in the US are based on the total bandings versus the number of birds that remain in the population after harvest in Canada. Given the long 49-year banding history (1960–2008) of black ducks, and changes in band types by the BBL, pooling data across band types could potentially be problematic, if different band types are reported at different rates. As such, recoveries of different band types were modeled independently, but vulnerability was assumed not to differ among band types.

While these models seem relatively straight forward there needs to be some discussion regarding recovery rates, specifically adult males recovered in the US. Currently, adult males banded in Canada and recovered in the US were constrained to have the same recovery rate as adult males banded and recovered in the US. Initially, this made sense given both groups were subject to the same set of regulations, which are considered to be the primary determinant of recovery rates. However, this assumption may not be reasonable if the vulnerability of the groups is different, the hypothesis being that Canadian banded ducks are educated once they cross the border, and less susceptible to harvest than naive US banded black ducks that have not been exposed to hunting yet. The implications of this are that the recovery and vulnerability rates of Canadian banded black ducks recovered in the US could be different than US banded black ducks recovered in the US. This does have some implications for the use of these bands in modeling age ratios. This constraint continues to make sense under the unconditional (i.e, simultaneous) recovery model, but might not be appropriate for the conditional (i.e., sequential) model. For the moment, results are only presented for the unconditional model. One easy solution would be to exclude US banded black ducks from the analysis entirely.

2.3 Results

The unconditional model was fit using WinBUGS to permit estimation of variance. Cohort specific estimates of vulnerability from black ducks recovered in Canada conform to expectations (Figure 2.3). Estimates for juvenile males and females are almost identical, and quite a bit higher than those of adult females. A little surprising, was that estimates for adult females, were greater than adult males, which were fixed at 1.0. However, I attribute this to the inability of hunters to be able to select for males while hunting. Estimates of vulnerability of black ducks recovered in the US follow a similar pattern. Juveniles tend to mirror each other, and adult females having less vulnerability (Figure 2.3). However, interestingly there are a number of years where the vulnerability of juveniles is less than that of adult males. At the moment, I not sure why, but may result from sampling variation in the band-recovery data.

Based on a brief discussion with Pat; I overlaid the cohort specific estimates of vulnerability and 95% credible intervals with naive estimates of vulnerability (i.e., "By hand calculation"). To simplify the analysis, I pooled bandings and recoveries over the 3 band types in naive calculations. In general, results suggest problems with the banding and recovery data from 1961–1966. Estimates of V during this period in both the US and Canada



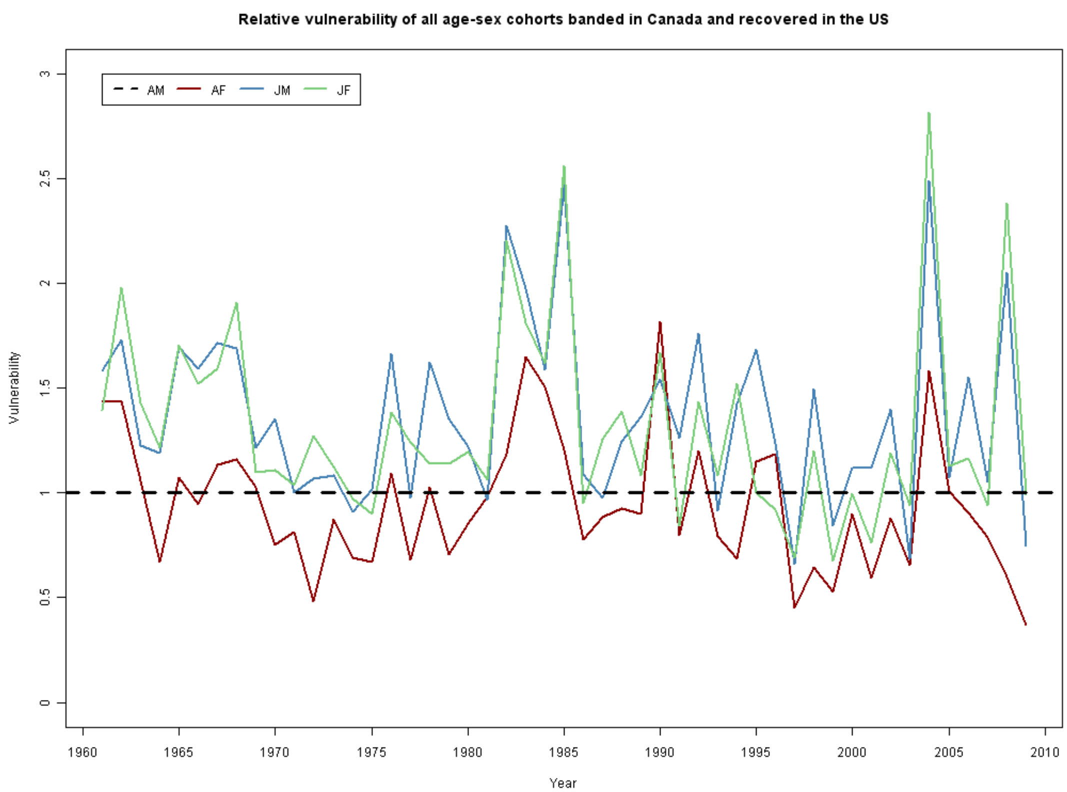


Figure 2: Cohort specific estimates of vulnerability from black ducks recovered in Canada (upper), and in the US (lower).

are off the chart. Bayesian estimates during this same period are more “normal” (Bayesian shirnkage occuring?). Otherwise, results of the 2 methods for the Canadian recoveries track each other very well (Figure 3). I will point out that there are several years where the naive estimates spike, and the spike is present acorss all age-sex cohorts. This would seem to indicate that there may have been very few recoveries of adult males in those years (i.e., sampling variaion in recovery rate of adult males.). Comparison of the 2 methods based on US recoveries is a different story. Naive vulnerabilty estimates in most years exceed the 95% bayesian credible intervals for juveniles. At the moment I am at a loss to explain these results. However, the implications are quite clear. If vulnerability is being over-estimated, and are being used to correct raw age ratios from wing receipts, then resulting corrected age ratios will be biased low, or underestimated. These results bear further investigation to determine if the observed patterns are not resulting from issues of pooling US and Canada-ian banding that were recovered in the US. Hence, the earlier hypothesis of educated black ducks.

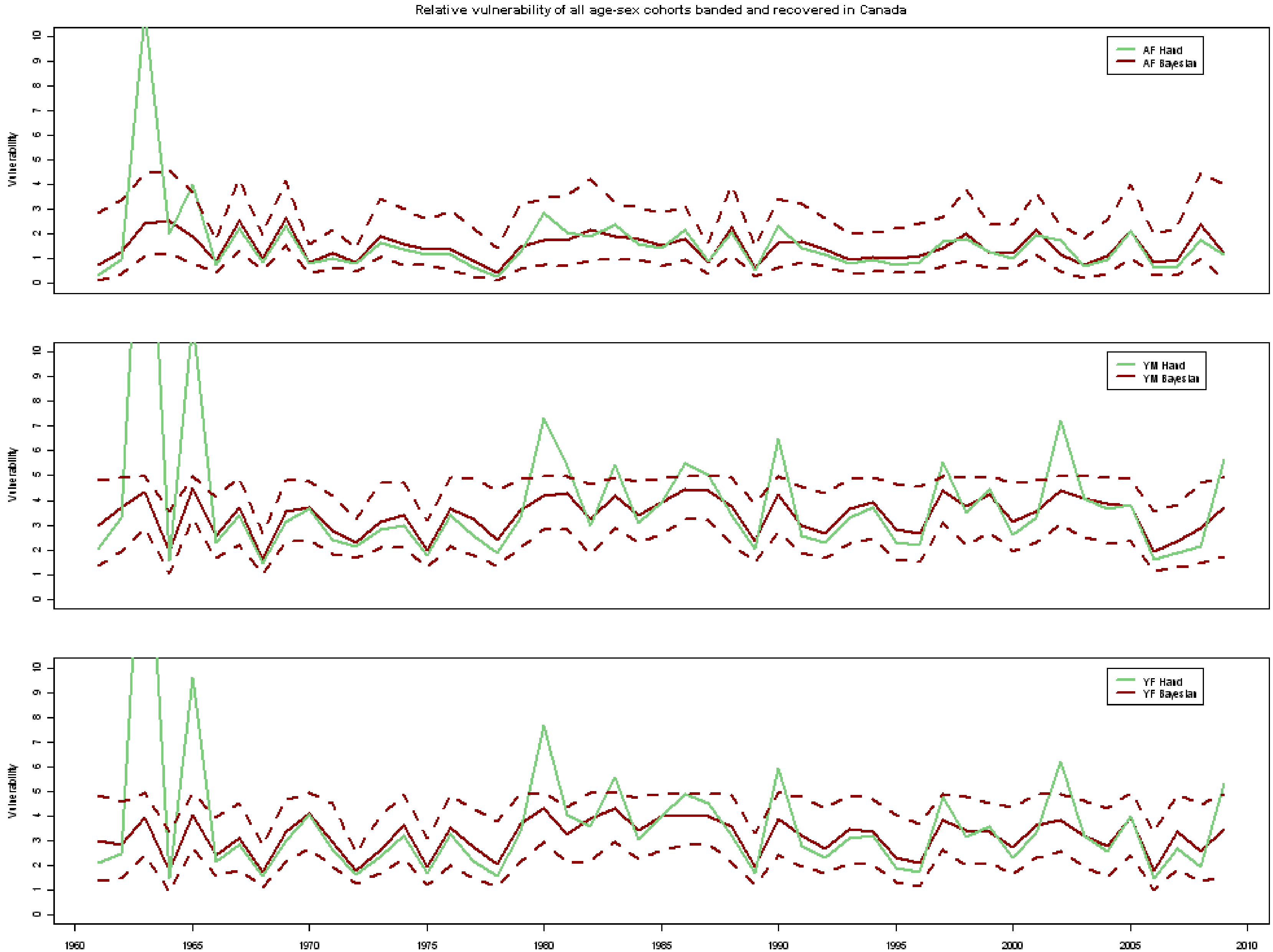


Figure 3: A comparison of vulnerability estimates of Canadian recovered black ducks, from Bayesian estimation, and naive by-hand calculations

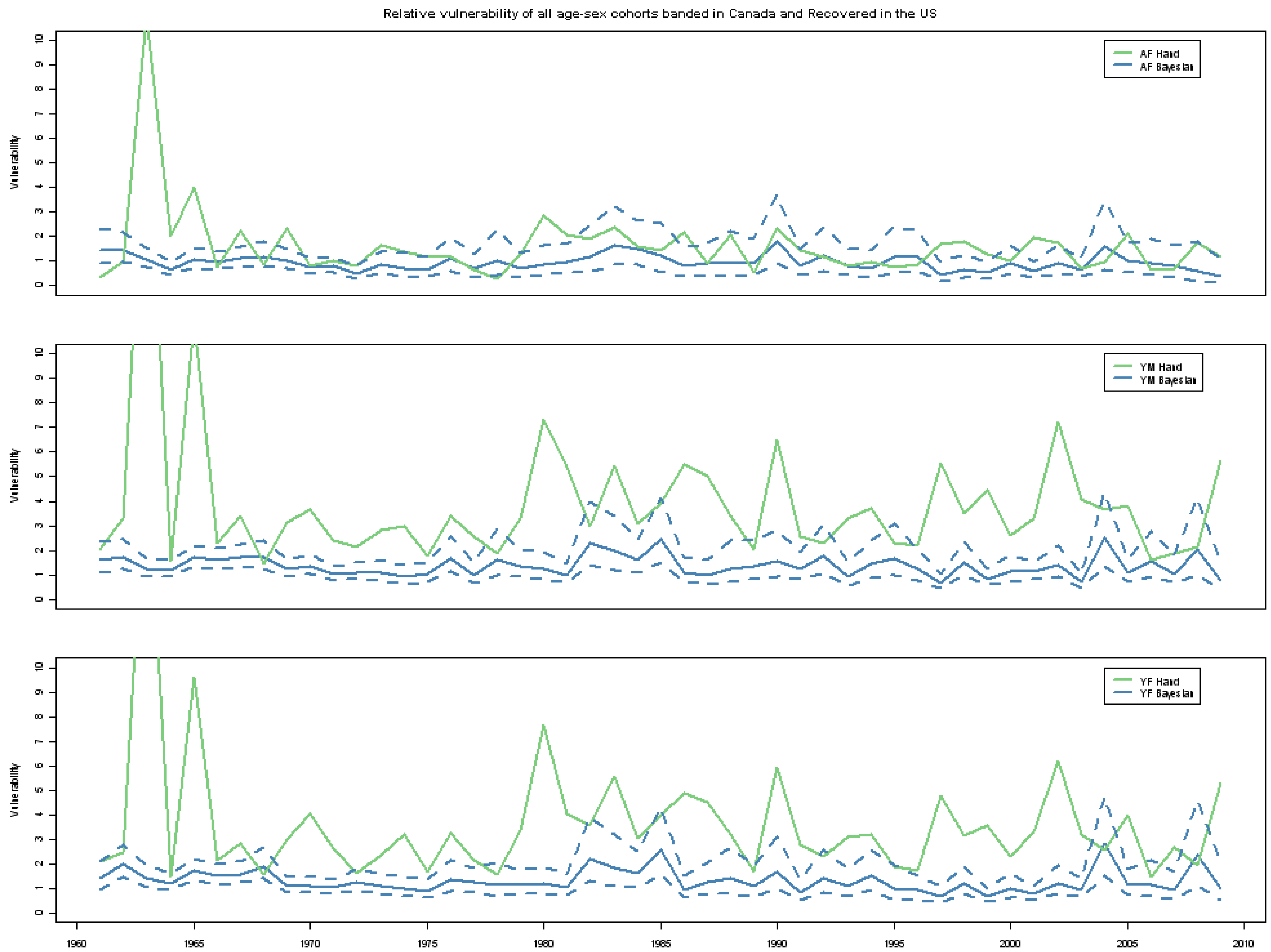


Figure 4: A comparison of vulnerability estimates of US recovered black ducks, from Bayesian estimation, and naive by-hand calculations

3 Estimating preseason age ratios

Estimating fall age ratios for black ducks has been particularly challenging. Using wing data collected from harvest surveys, in conjunction with banding data has been problematic for two reasons. First, general methods provide an estimate but no measure of uncertainty. Second, depending on whether Canadian or US data (wings and band-recovery) are used results in slightly different estimates, with different long-term trends. Further, there is a US banded component to the population, that is generally ignored as being small, yet, its likely that these wings are encountered part of the US wing collection survey, and thus, influence the estimate of age ratios. If possible, these data should be considered in an analysis, if these birds are considered to be part of the same population.

Currently, black ducks are managed as a single population which implies one population wide measure of recruitment. Thus, we need a model that reconciles the information contained in Canadian and US data. Zimmerman et al. (In prep.) developed a Bayesian model framework to integrate banding and harvest survey data to estimate population fall age ratios. This model framework has several advantages in that its flexible, in that it can account for changes in band types, and different hypotheses regarding the variability in vulnerability. Second, the framework provides an estimate of uncertainty around fall age ratios, and finally, we can impose a biological model that stipulates that the age ratio must be the same irregardless of the data used, assuming that the data are derived from a single population. This last point in particularly interesting in that we are able use the information contained in both the US and Canadian surveys to address age ratios, rather than analyzing the data from each survey independently and trying to reconcile estimates post-hoc when they don't agree.

Several analyses were done to address a number of questions surrounding age ratios.

1. Do estimates of age ratios, and their precision change depending on whether vulnerability is specified as constant or temporally variable?

2. What effect does inclusion or exclusion of US banding and recovery data have on the estimate of age ratios?

3. Do estimates change when estimating age ratios using data derived from males or females only?

4. Is there potential to address density dependent mechanisms within the model framework, by modeling recruitment as a function of population size?

3.1 Methods

3.1.1 Data

The banding and recovery data for these analyses were similar those used in the analysis of vulnerability. Only black ducks banded preseason (1 July–30 September) as AHY, L, or HY, of all sexes that were coded as normal wild (300), control band (304), or spotlighted (370) were included. To ensure the largest sample size possible, all black ducks banded in AF, MF, or all of Canada were used. Recovery data had additional constraints that birds must have been shot of found dead during the hunting season, and reported to the BBL/BBO by the finder. Only wing data from the US and Canadian PCS where age and sex were identifiable were included. Analyses were limited to the period between 1969 and 2008. A beginning date of 1969 corresponds to the first year in which the PCS was conducted in both the US and Canada. It is conceivable that the model could be extended to include US wing data from 1961–1968, but adds more coding complexity. However, it should be noted that age and sex identification of black duck wings during this period is missing or questionable, as wing measurement standards had yet to be established (P. Padding, K. Richkus, personal communication). Analyses of male based age ratios and female based age ratios were limited to their respective sex data.

3.1.2 Model

The integrated model framework developed by Zimmerman et al. (In prep.) can be best described as a band-recovery model, and a recruitment model which share a common parameter, differential vulnerability. The band recovery model uses only direct recoveries of birds banded in the US or Canada, and recovered in the US only or the US and Canada, respectively. Under a conditional formulation band-recoveries of Canadian banded black ducks are modeled as

$$m^{CA}_{yr,type} \sim Bin(f^{CA}_{yr,type}, R^{CA}_{yr,type})$$

$$m^{US}_{yr,type} \sim Bin(f^{US}_{yr,type}, R^{CA}_{yr,type} - m^{CA}_{yr,type})$$

and US recoveries of US banded black ducks area modeled as

$$m^{US}_{yr,type} \sim Bin(f^{US}_{yr,type}, R^{US}_{yr,type})$$

Under an unconditional formulation band-recoveries of Canadian banded black ducks are modeled as

$$m^{Country}_{yr,type} \sim Multinomial(f^{Country}_{yr,type}, R^{CA}_{yr,type}).$$

Estimation of US banding and recoveries remains unchanged. Since, recovery rates by definition include reporting rates, we must account for different band types used, since it has been demonstrated that band type has had an influence on reporting rates and thus recovery rates. Over the course of black duck banding (1969–2008) three band types were used; AVISE, ZIP, and Toll Free. AVISE bands spanned from 1969–2007, ZIP bands were used from 1993–2007, and Toll Free bands were first implemented in 1996, and their use continues presently. However, use of AVISE bands after transitioning to ZIP bands and use of ZIP bands after transition to Toll Free bands declined fairly rapidly. The dataset for AVISE and Zip bands was truncated to the time series spanning 1969–2001, and 1993–1999 for AVISE, and ZIP bands, respectively. These data represent years with sufficient banding and recoveries to permit estimation of recovery rates.

Rather than estimate year, age, band type, and country specific recovery rates, which would amount 480 parameters, we can reduce this through the use of offsets. Thus, from 1969 to 2001 we estimate country specific recovery rates of adults banded with AVISE bands. Recovery rates of adults banded with ZIP or Toll Free bands during this period was the product of the AVISE recovery rate, and an offset parameter for each additional band type. After 2001, the only band type in use were Toll Free bands from which recovery rates are estimated independently (i.e., no offsets). This limits the number of parameters specific to recovery rates for estimation to 46. Using the offset also makes more sense biologically, since recovery rates of AIVSE and ZIP bands can't be moving in different directions. In other words, the recovery rates of different band types are forced to move in parallel with one another in years where multiple types were used. Recovery rates of juveniles are estimated in a similar fashion, using an offset to adult recovery rates. In this case, the offset represents the differential vulnerability between adults and juveniles.

$$m_{t,type}^{CA} \sim Bin(f_{t,type}^{CA} V_t^{CA}, R_{t,type}^{CA})$$

$$m_{t,type}^{US} \sim Bin(f_{t,type}^{US} V_t^{US}, R_{t,type}^{CA} - m_{t,type}^{CA})$$

$$m_{t,type}^{US} \sim Bin(f_{t,type}^{US} V_t^{US}, R_{t,type}^{US})$$

Vulnerability (V), was always defined to be country specific, but may have been further constrained to be constant or temporally variable.

The basis for the recruitment model are the wing receipts derived from the parts collection surveys. If the wing receipts are a representative sample of the proportion of young in the population then the proportion of young of a particular sex class (r) in the sample can be modeled as,

$$W_{Young,t}^{c} \sim Bin(r_t^c, W_{Total,t}^{c})$$

where t is time and c is the country specific PCS. The true proportion of young in the population (R) is

$$\frac{V_t^c R_t}{V_t^c R_t + (1 - R_t)}$$

Using WinBUGS, and equating the proportion of young in the sample with the proportion of young in the population, allow the estimation of R, the true proportion of young in the population.

$$r_t^c = \frac{V_t^c R_t}{V_t^c R_t + (1 - R_t)}$$

Finally, if we know the proportion of young in the population then the fall population age ratio (A) is found by

$$A_t = \frac{R_t}{(1 - R_t)}.$$

For this analysis, I considered 6 potential models. Four models result from different combinations of the harvest process (conditional or unconditional), and vulnerability specification (annual or constant). The 2 additional models considered use the conditional model with annually specified vulnerability to explore the implications of the removal of US bandings on age ratio estimates, and fitting a model where age ratios are a linear function of population size.

3.2 Results (REVISED)

Results are presented for the conditional and unconditional models, as well as a brief comparison to black duck AHM in separate sections to aid discussion.

Table 1: Estimates of vulnerability under the conditional model for the US and Canada when they are assumed to be temporally constant.

	Males		Females	
Recovery Area	Median	95% CI	Median	95% CI
Canada	3.888	3.652–4.137	3.093	2.865–3.345
United States	0.935	0.882–0.990	1.188	1.103–1.281

3.2.1 Conditional Model

Recall that the conditional model represents a sequential timing to the harvest. Model parameters were estimated separately using male and female data. Figure 5 and Figure 6 show recovery rates of adult male and female black ducks recovered in the US and Canada by band type. In general, the patterns observed in the results conform to what is known or expected for black ducks.

Note that the vulnerability estimates for females are not comparable to female vulnerability estimates from the previous section. In this case vulnerability is scaled to adult females, rather than adult males in the previous section. Under the constant vulnerability model, "on average", juvenile males and females are 3 and 4.6 times more vulnerable than adult males and females recovered in Canada, respectively. Yet, generally speaking recoveries in the US suggest that juveniles have about the same vulnerability as adults. One could attribute this to the learning hypotheses stated earlier, but the model does account for US banded and recovered black ducks which should be just as naive as Canadian banded and recovered black ducks, and thus expect vulnerability rates greater than 1.0. It's possible that Canadian recoveries are swamping out any information regarding vulnerability of US banded black ducks.

Annual vulnerability rates are harder to interpret, other than to say that Canadian vulnerability is quite a bit higher and more variable, but this was expected given cursory examination of the data. The greater precision around US vulnerability estimates likely results from higher estimated recovery rates thus, more band recoveries from which to estimate parameters.

Model estimates of fall age ratios are interesting. Figure 13 shows fall population age ratios estimates under constant and annual vulnerability specification for males and females. Surprisingly, the vulnerability doesn't have a big impact on the median estimate of the age ratio. What is impacted is the precision around the estimate; with a constant specification having greater precision. In figure 3.2.1 I've overlaid the age ratio estimates derived from male and female data, under a constant vulnerability specification. Information derived from female data suggest higher age ratios than data derived from males, although the pattern of change is similar. It would appear that both datasets have a slight declining trend over time if one ignores the first few years of data (Yet to be investigated).

3.2.2 Unconditional Model

Recovery rates under the unconditional specification show similar patterns as the conditional specification. Recovery rates of AVISE under the unconditional specification are slightly higher than then the conditional specification. Recovery rates of Toll Free bands are higher over the period of overlap with AVISE bands, but almost identical between the two models

Table 2: Estimates of vulnerability under the unconditional model for the US and Canada when assumed to be temporally constant.

	Males		Females	
Recovery Area	Median	95% CI	Median	95% CI
Canada	3.939	3.728–4.163	3.038	2.844–3.258
United States	0.952	0.905–1.003	1.169	1.096–1.251

when estimated independently (post 2002).

Estimates of vulnerability change very little between the conditional and unconditional model for male data.

Using male data, I graphed age ratio estimates for each model under the 2 assumptions of vulnerability (Figure 15). Well they are identical when vulnerability is constant. Slight differences are observed when vulnerability is specified as being annual, with the unconditional model having slightly higher precision in years with differences.

3.2.3 Other

The final lingering question yet to be addressed was does the removal of US bandings and recoveries affect the fall age ratio estimate? For reference, this analysis and comparison was made using the conditional harvest specification, with constant vulnerability, and male data. Removing US banding and recoveries from the analysis, results in higher fall age ratios. At first this didn't make intuitive sense, but after some thought removing those bandings and recoveries has an effect on recovery and thus vulnerability rates. The estimate of recruitment doesn't change, because we have no way to identify whether a wing in the US PCS was from a US or Canadian derived bird. What results is essentially a scaling of the fall age ratio, because vulnerability was assumed constant under the model. Results under a model with annually varying vulnerability might be different.

My intent was to look for evidence in density dependence, by fitting a linear model on age ratios (proportion of young in fall population, actually).

$$A = \alpha + \beta * pop$$

I was able to get model convergence, but other model validation statistics still suggest problems with the model. Under a cautionary interpretation the coefficient for population size was 0.187 (95% CI 0.133–0.235), which indicate some correlation between age ratios and population size. Although, this in not in a direction that I would have expected. Some problems encountered may be due to the short time series. The model uses the integrated breeding survey estimates as the index to population size which begins in 1990. Earlier analyses by Conroy found that after accounting for black duck population size, there was still a declining trend in the residuals. There are other models that I will run in the near future, but mainly for my own interest.

3.3 Comparison to models used in Black Duck AHM

This formulation is very similar to that used by Mike Conroy in the Black duck Adaptive Harvest Management framework.

$$H^c_{y,t} = \frac{N_{t,y} f^c_{t,y}}{N_{t,y} f^c_{t,y} + N_{t,a} f^c_{t,y}}$$

Dividing through by $f_{t,y}$ yields

$$H = \frac{N_y}{N_y + N_a f_y / f_a}$$

let $A = N_y / N_a$ then

$$A^c_w = \frac{A}{(A + f_{t,a} / f_{t,y})}$$

I will point out that $f_{t,a}/f_{t,y}$ is equivalent to $1/V$. Initial runs through the models used herein and those used in black duck AHM, using the identical dataset show quite different results. I briefly discussed methods and results with Bill Link and the math behind both methods is sound. Without further discussions with Mike its very possible that while the math is correct I have not correctly implemented the model in WinBUGS (Figure 17).

4 Conclusions

I was optimistic that these analysis would show clear differences, and it would be obvious of where to proceed in the future. From these analyses some things are clear, and some things have been muddied. The model imposes by definition that the US and Canadian data infer the same conclusions regarding age ratios of the black duck population. The reasoning for the differences when done by hand appears to result from the sampling variation in the data that is ignored with manual calculations. I would recommend that the methods developed here and by Zimmerman et al. (In prep.) be used as the standard for estimating age ratios for black ducks.

For the most part it doesn't matter which harvest process model is used in calculations. This is partially because the two models chosen are from the same family of models (the binomial is a special case of the multinomial). The more important question is how to represent vulnerability, as this is likely to have the biggest impact on age ratio estimates. Biologically speaking there is good reason to suggest that vulnerability should not change over time, but can the variation in annual estimates be totally explained through sampling variation. More formal model selection techniques may be necessary. In addition, should age ratios be male based or female based, as their are slight differences. Finally, should future work on black ducks, consider the US breeding population of black ducks?

References

Zimmerman, G., W. A. Link, and M. J. Conroy. In prep. Estimating migratory game bird recruitment by integrating age ratio and banding data .

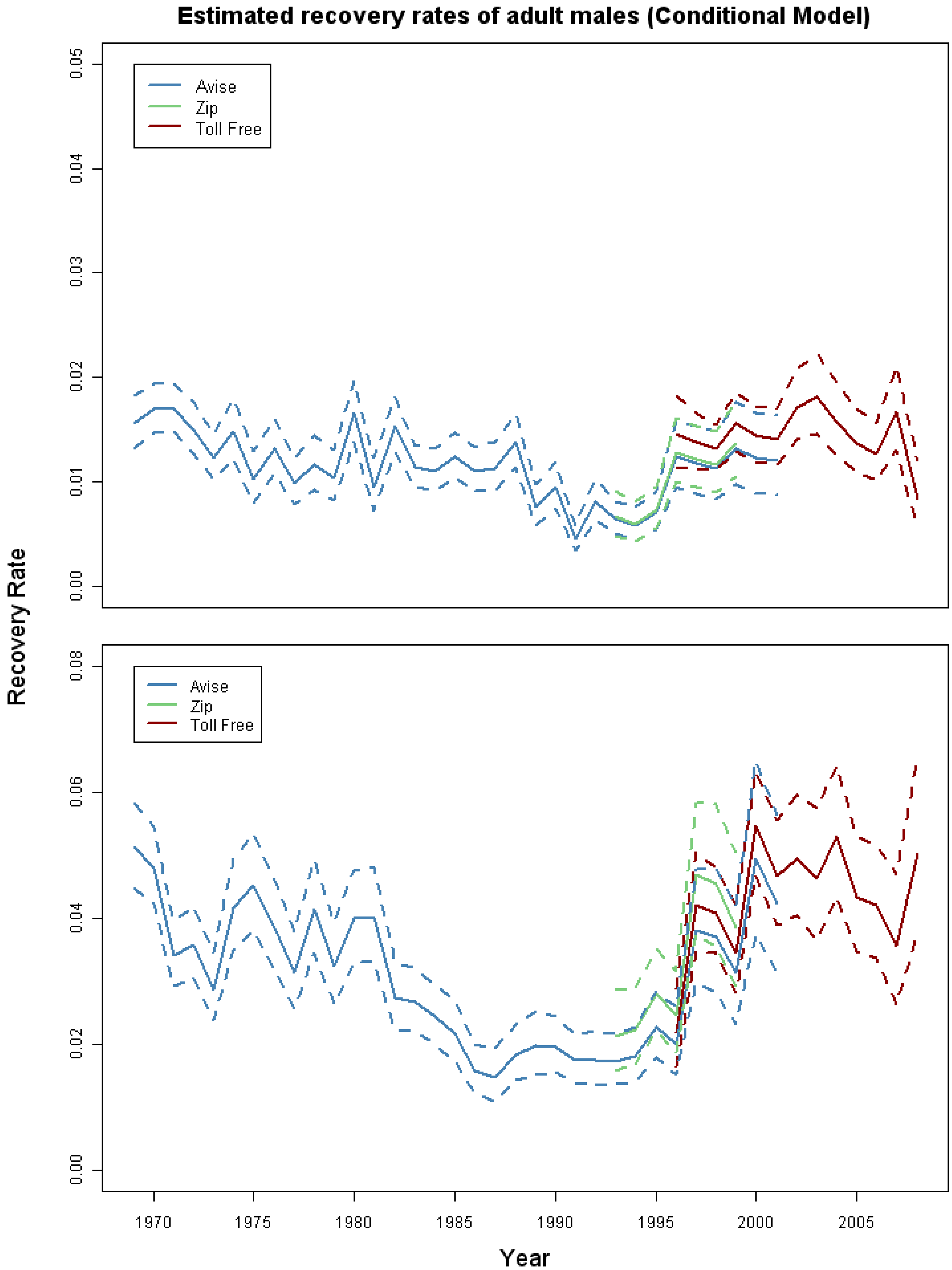


Figure 5: Recovery rates of adult males in Canada (upper), and the US (lower) under a conditional harvest process and a constant vulnerability.

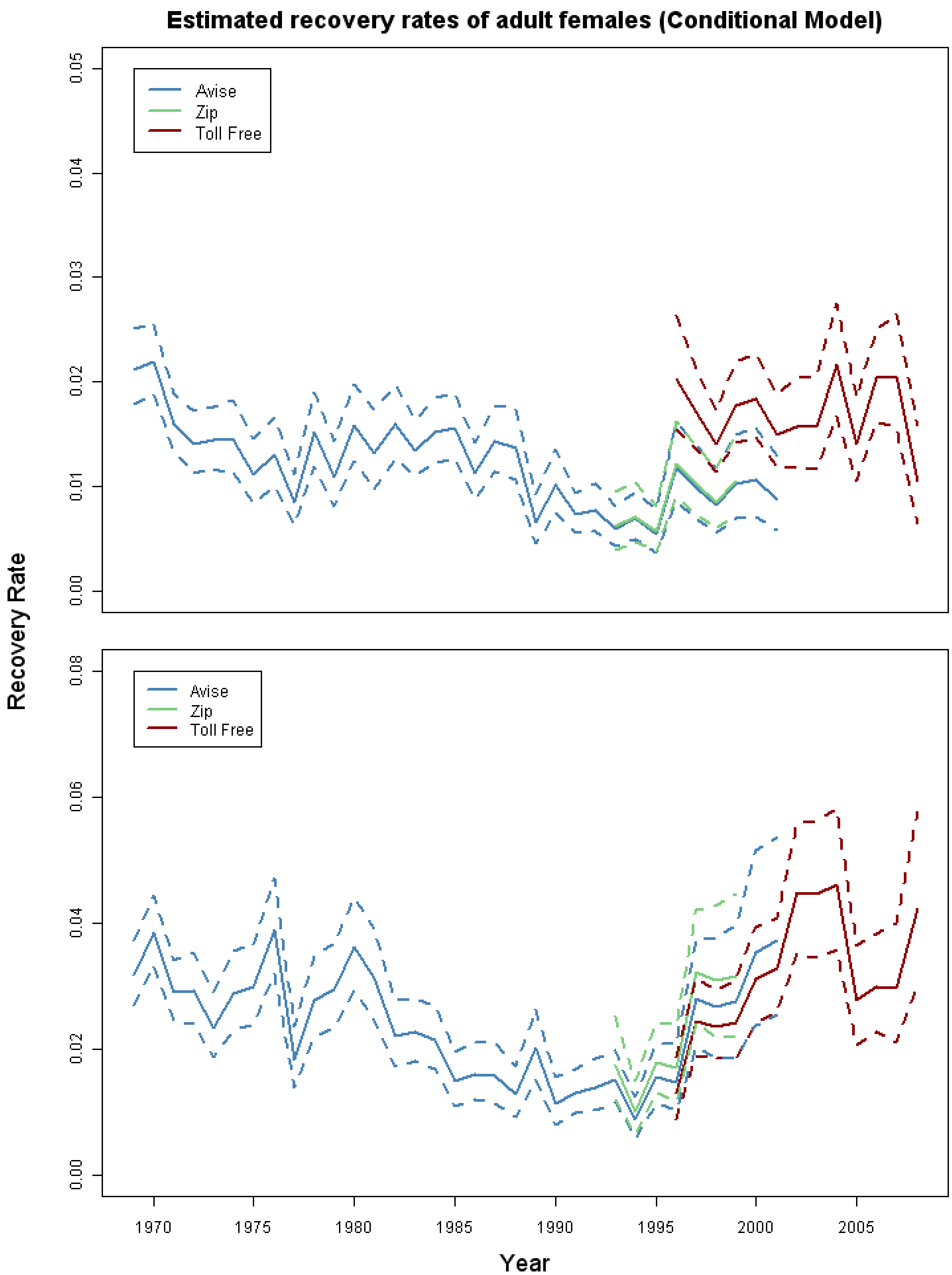


Figure 6: Recovery rates of adult females in Canada (upper), and the US (lower) under a conditional harvest process and a constant vulnerability.

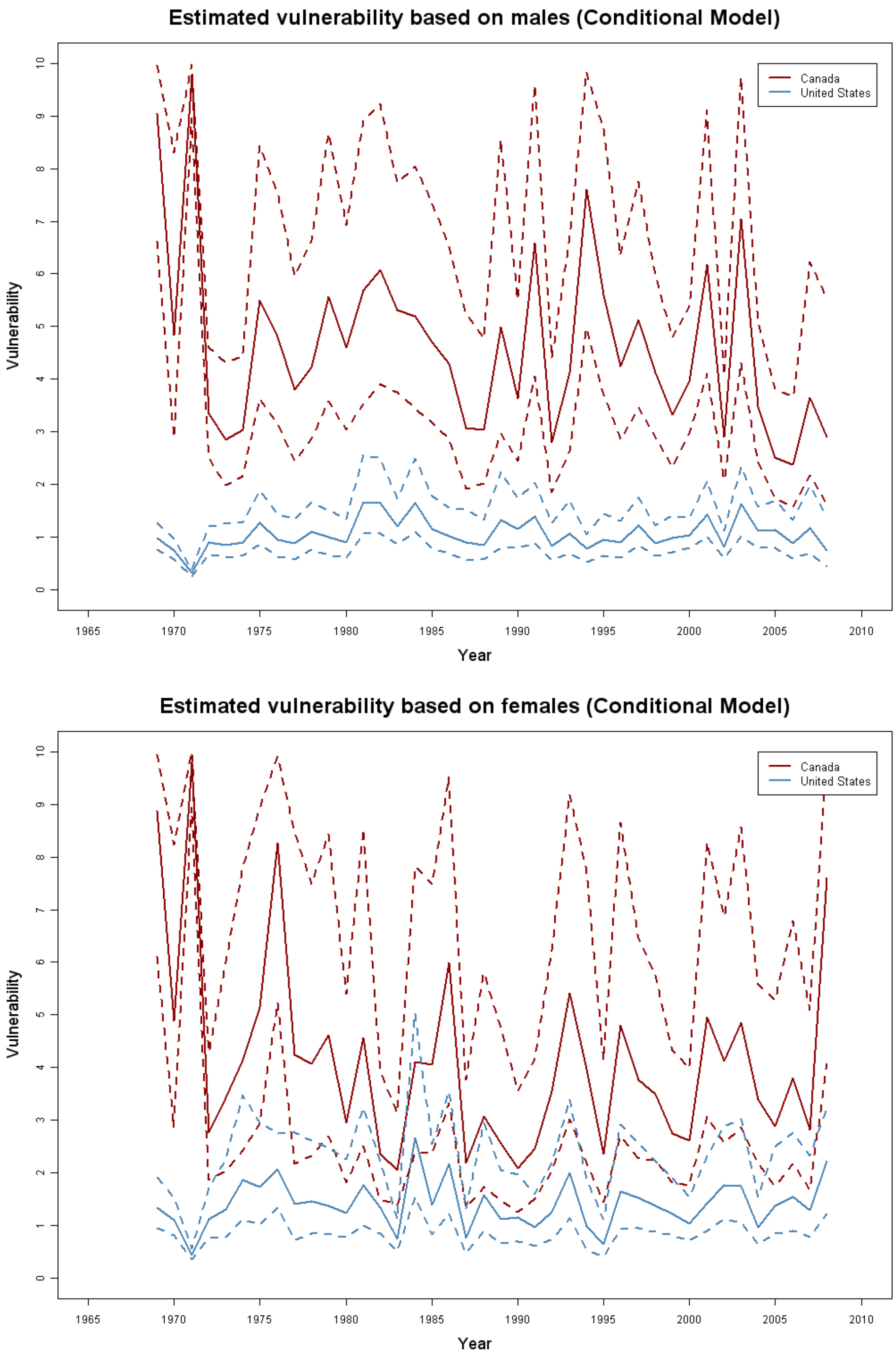


Figure 7: US and Canadian juvenile vulnerability estimates.

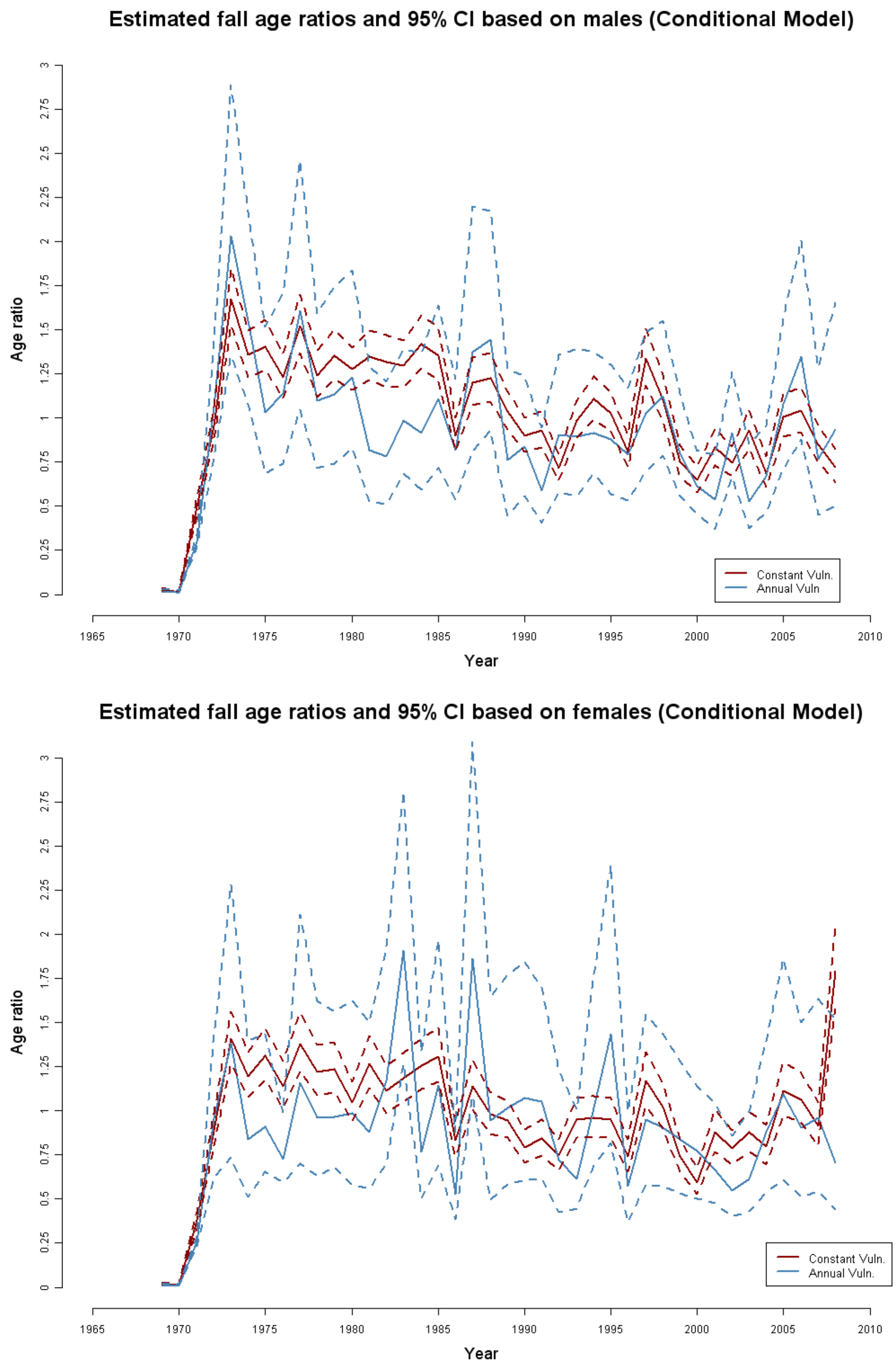


Figure 8: Fall population age ratios of males and females under the assumption of temporally varying vulnerability.

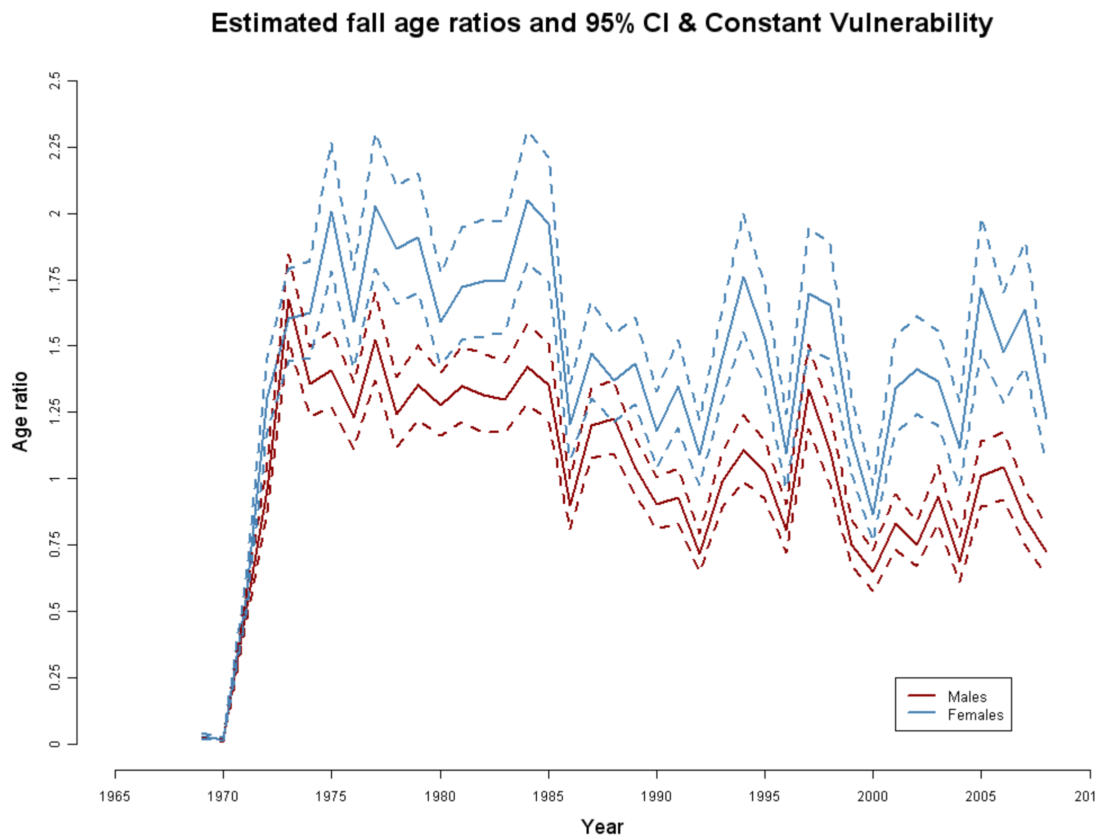


Figure 9: Overlay of age ratios generated from male and female data under a conditional model and constant vulnerability.

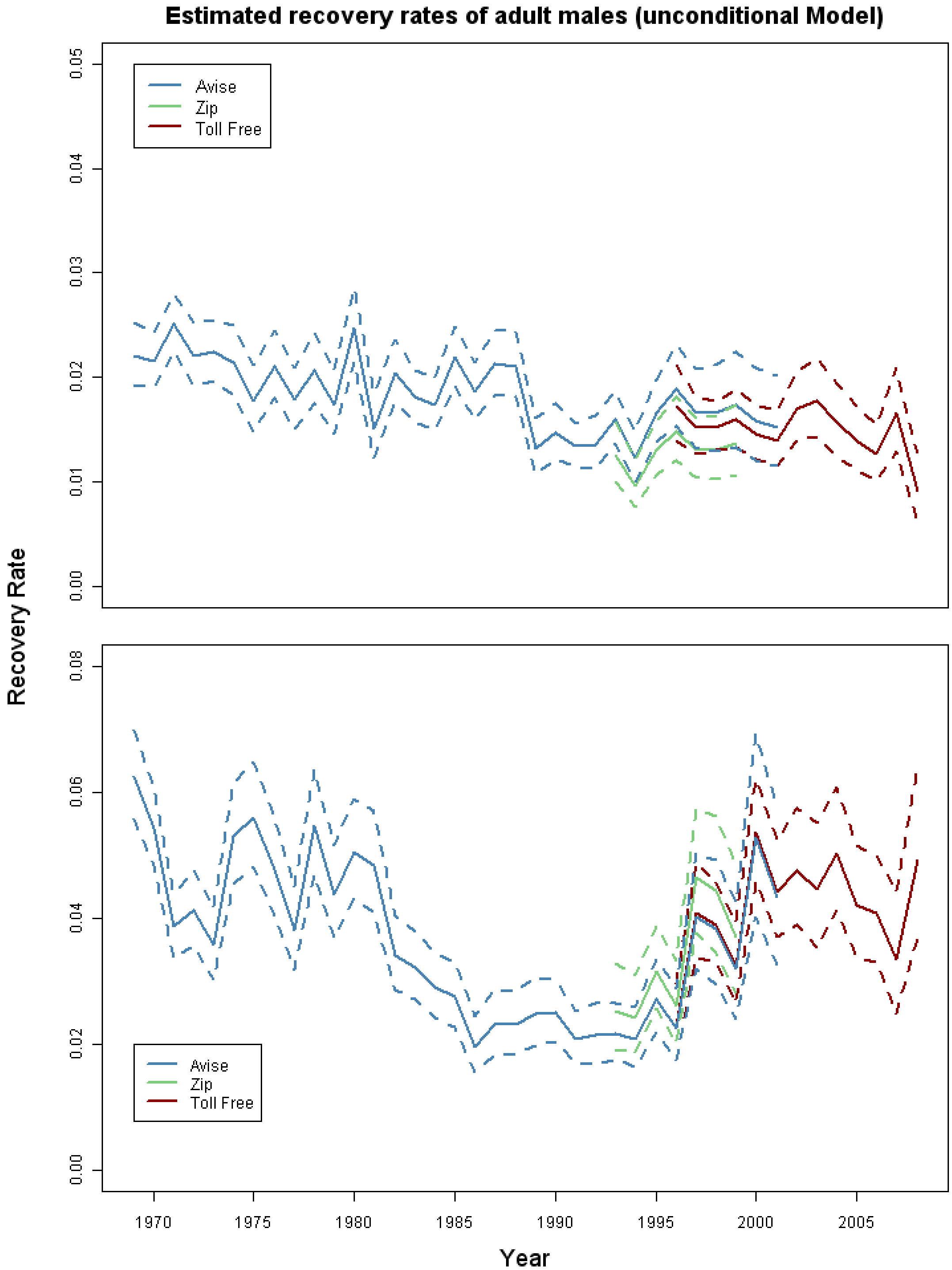


Figure 10: Recovery rates of adult males in Canada (upper), and the US (lower) under an unconditional harvest process and a constant vulnerability.

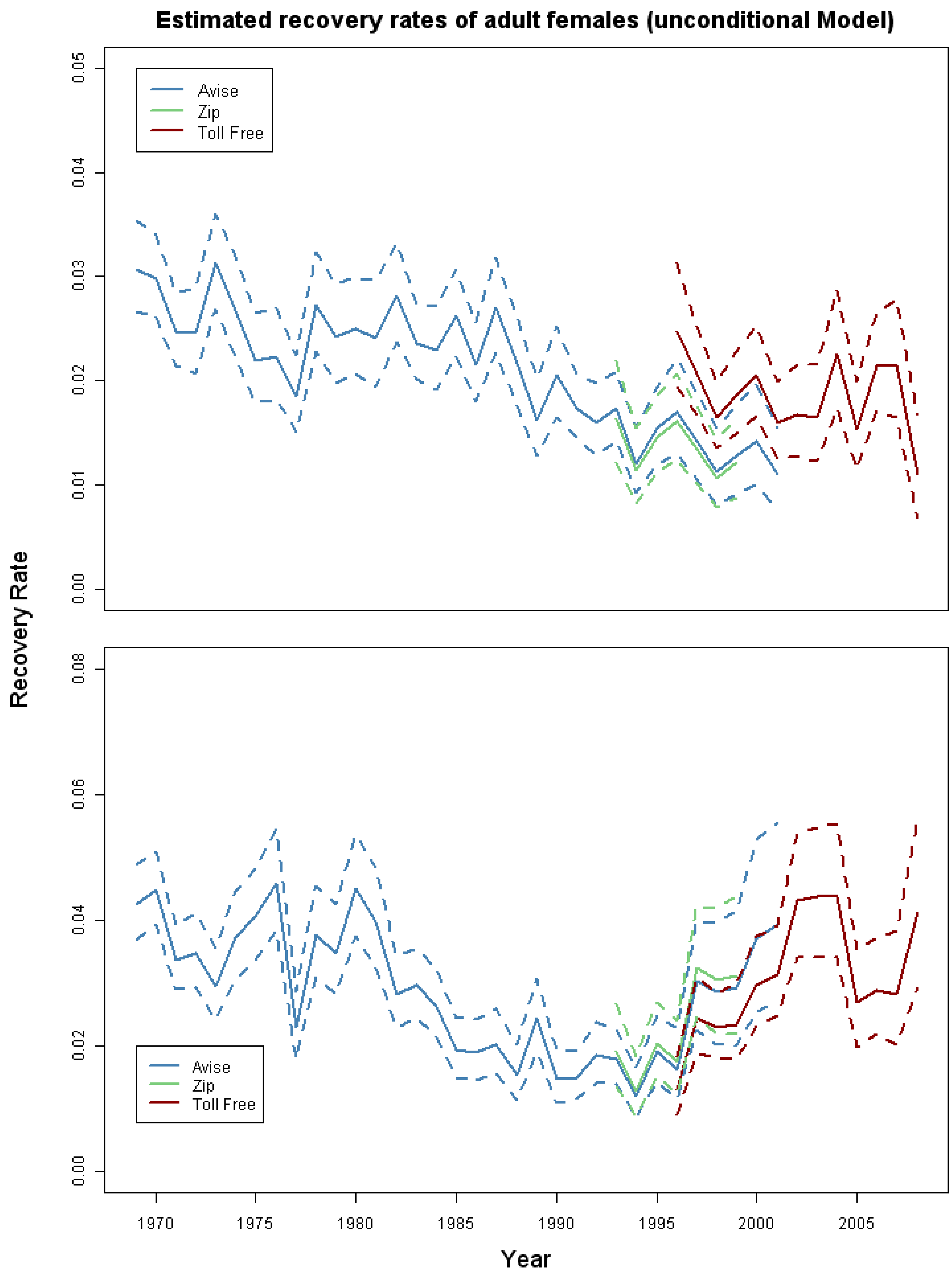


Figure 11: Recovery rates of adult females in Canada (upper), and the US (lower) under an unconditional harvest process and a constant vulnerability.

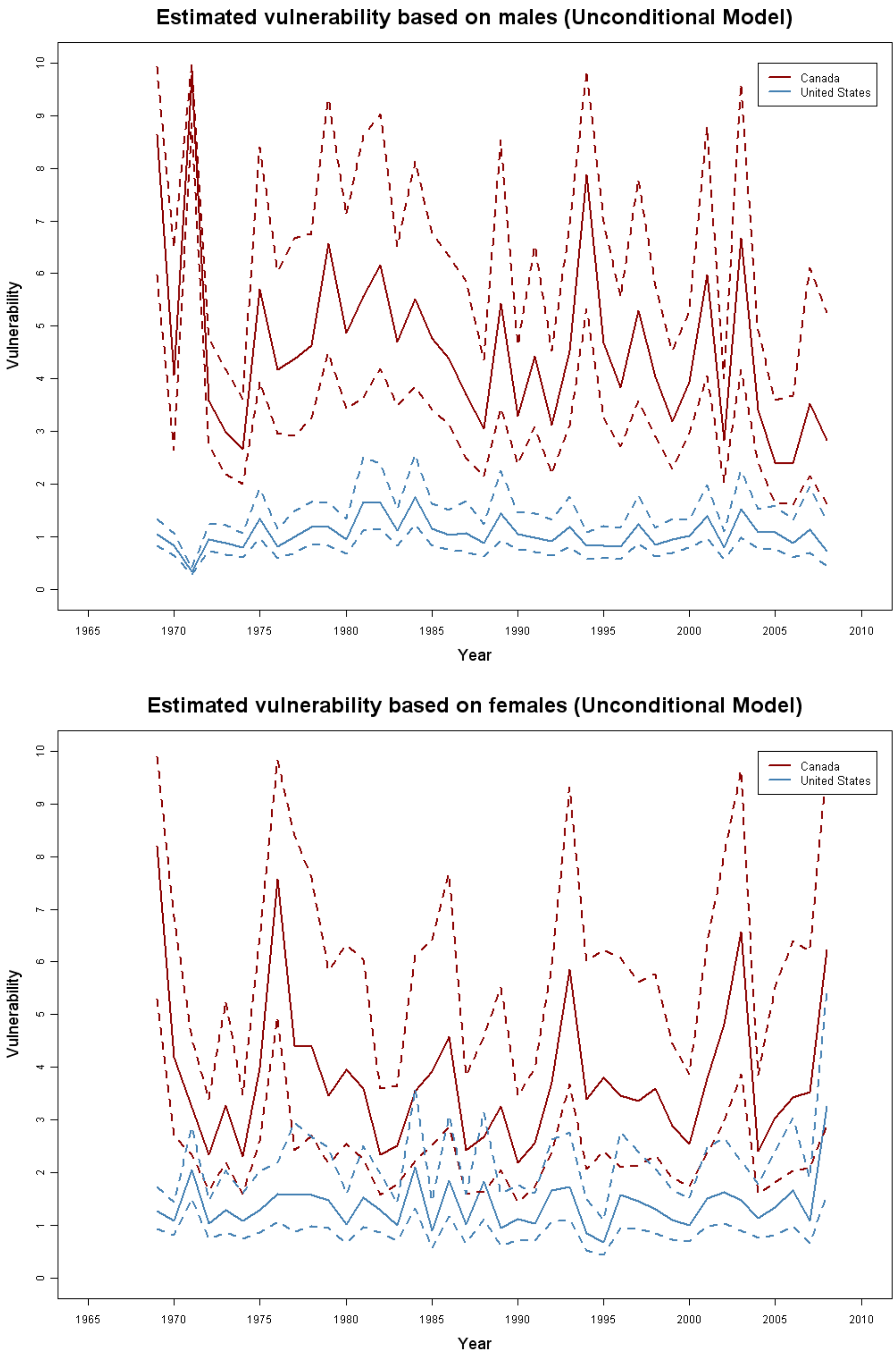


Figure 12: US and Canadian juvenile vulnerability estimates under an unconditional harvest model.

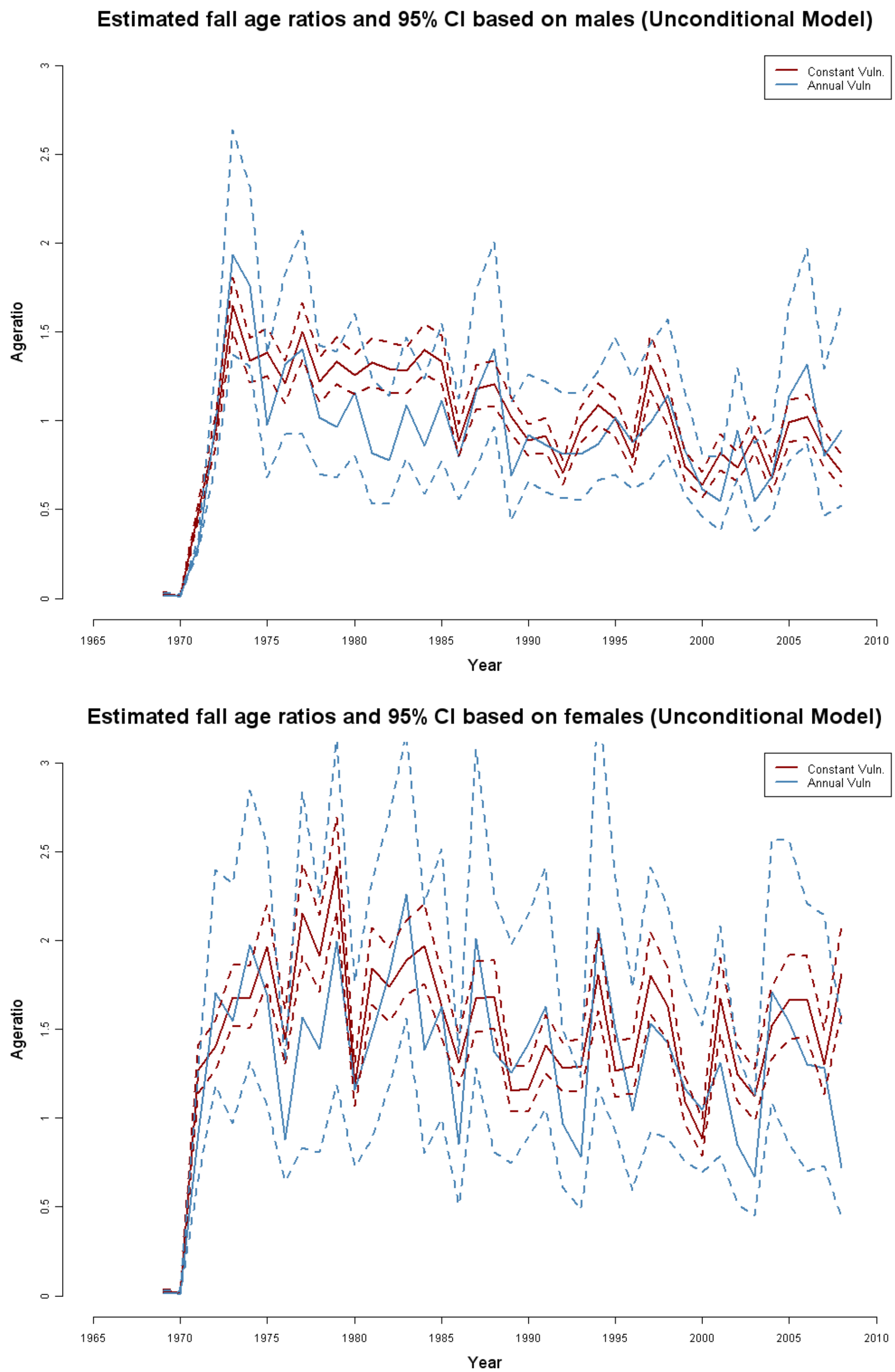


Figure 13: Fall age ratios based on males under assumptions of constant and annually varying vulnerability.

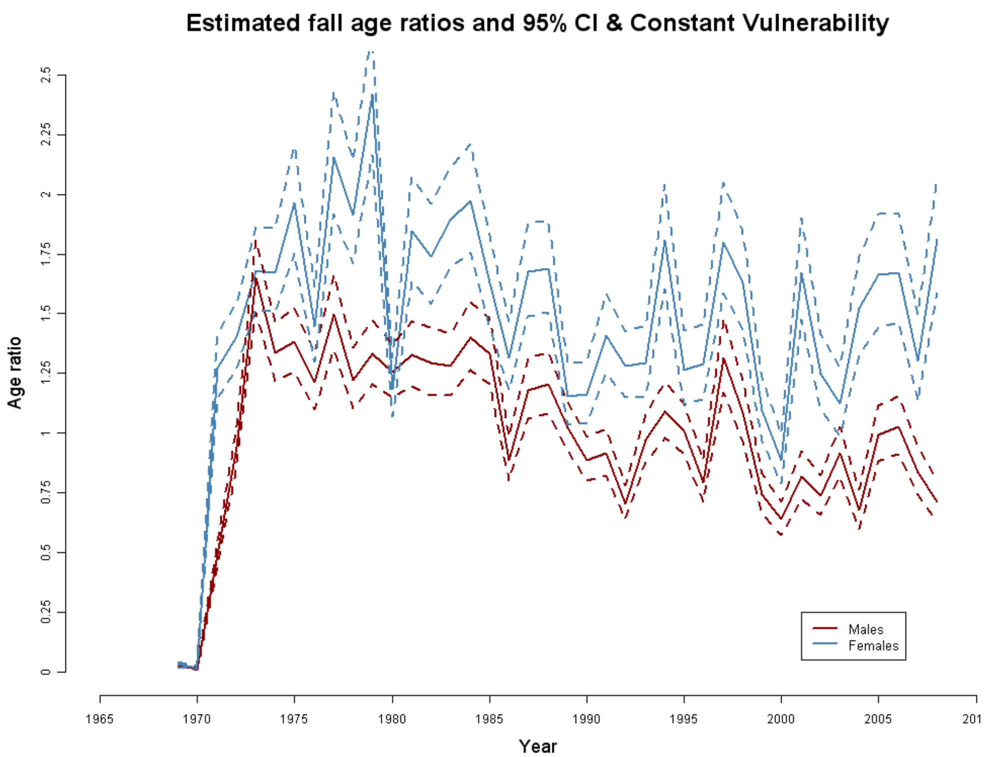
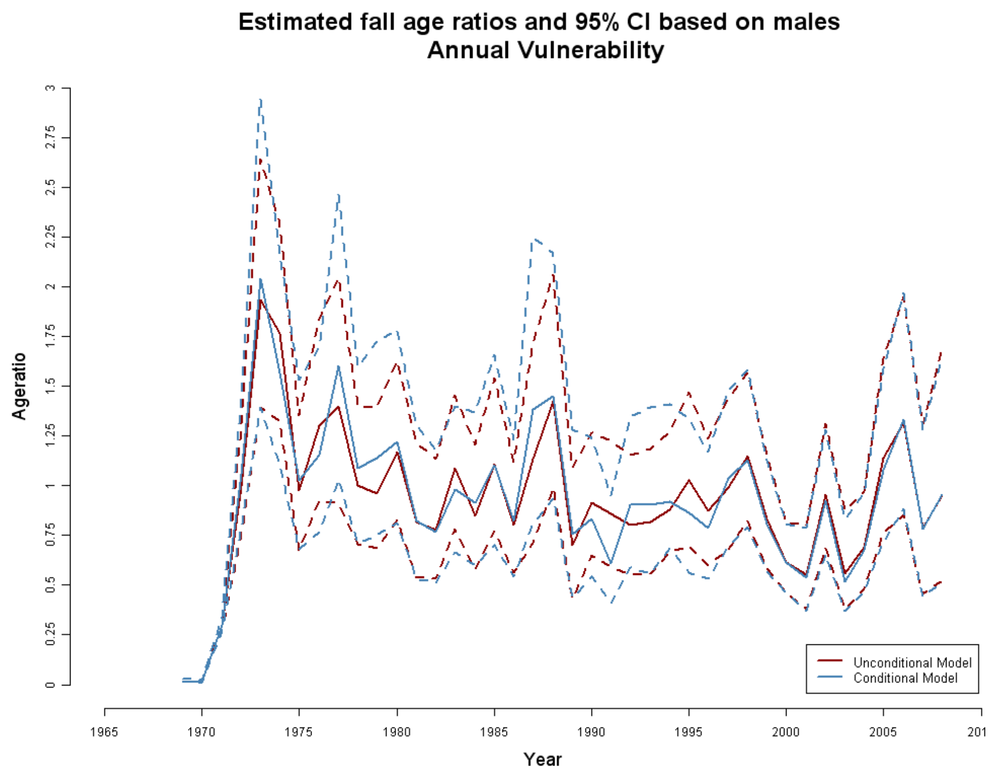


Figure 14: Comparison of age ratios from male and female data using the unconditional model, and constant vulnerability.



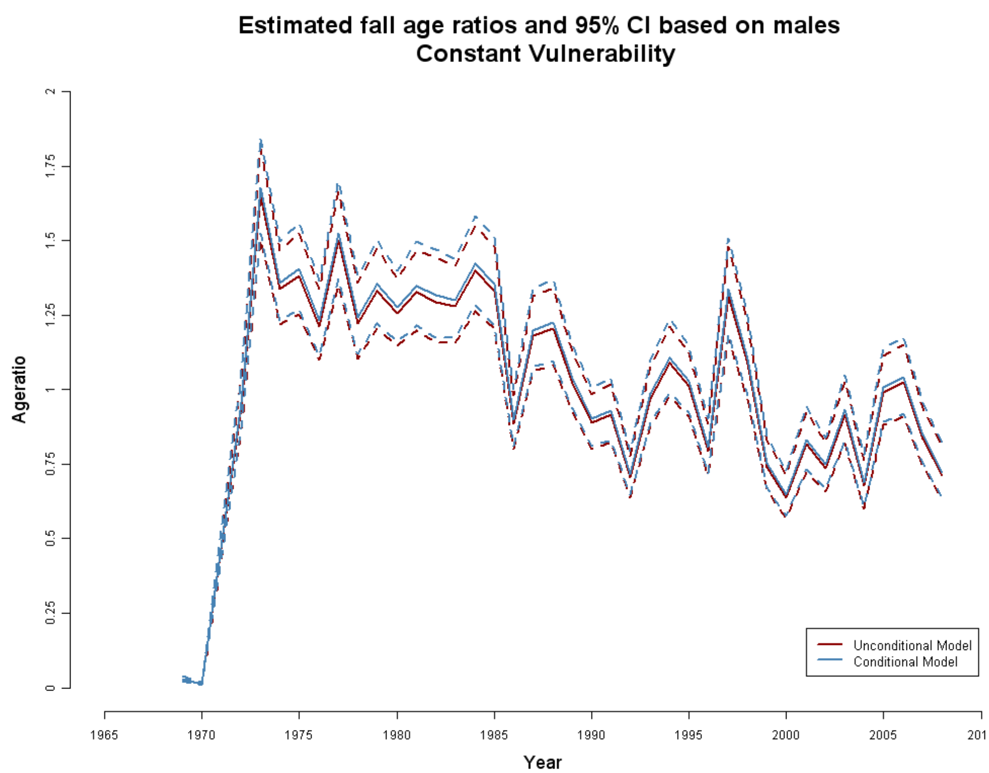


Figure 15: Fall age ratios of males for each harvest model under assumptions of constant and annually varying vulnerability.

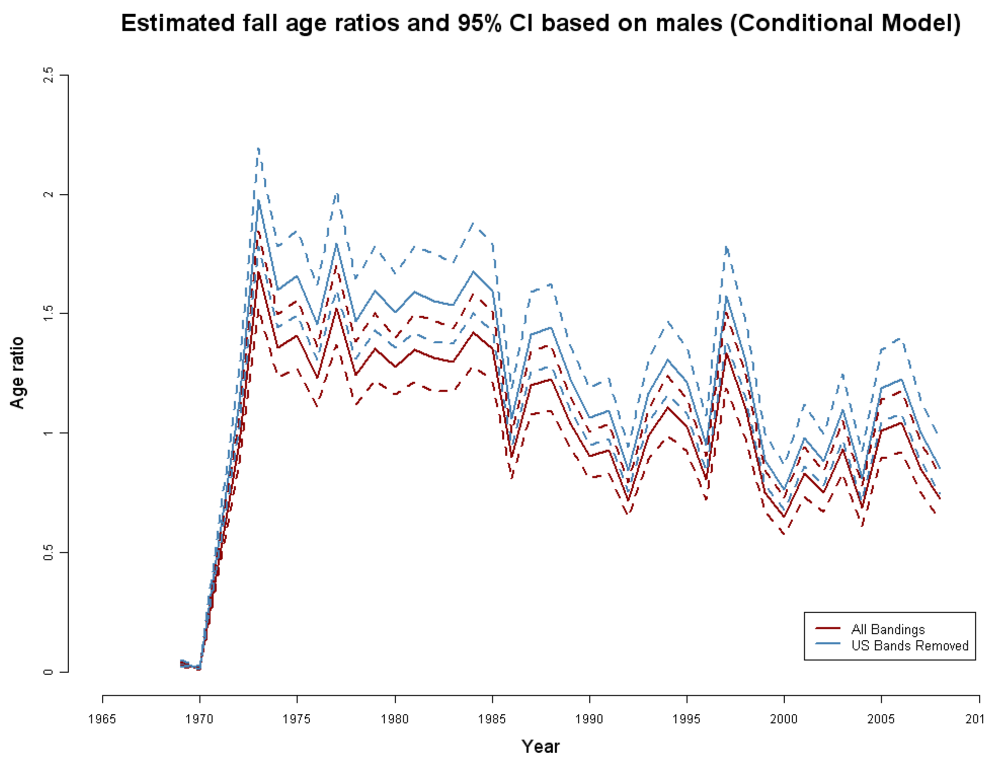


Figure 16: Comparison of fall age ratios of males when US banding and recoveries are removed from the analysis.

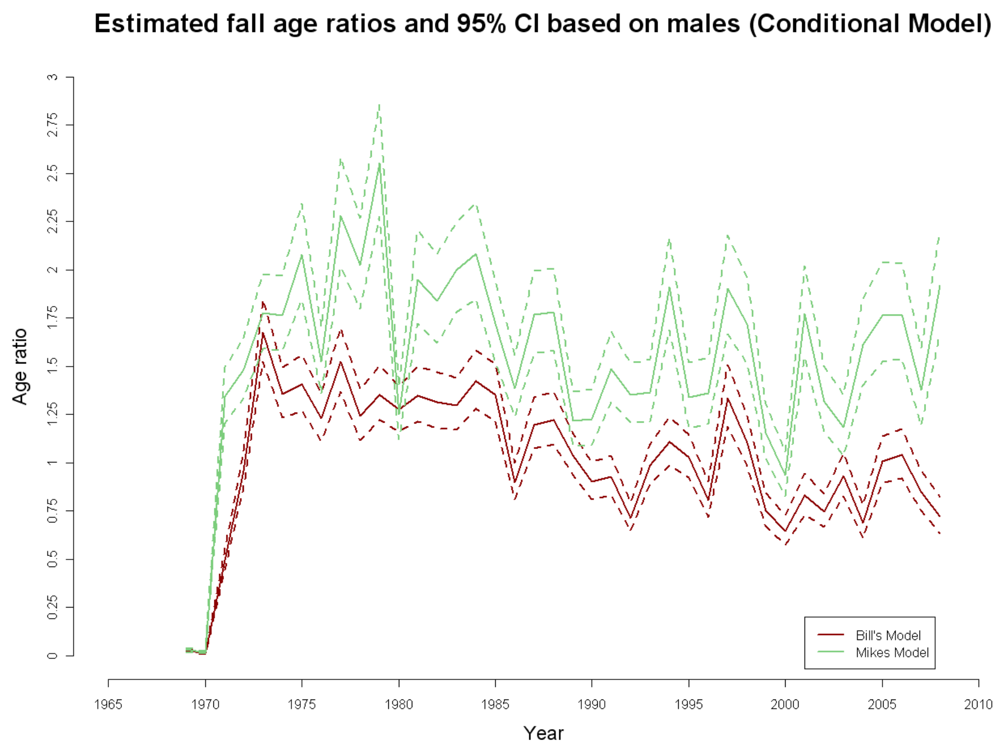


Figure 17: Results of Black duck AHM recruitment models, and the models developed here based on identical datasets.