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Updated application of a photo-identification based assessment model to southern right whales in South African waters to include data up to 2018

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SUMMARY

The assessment of southern right whales in South African waters is updated to include data from 2018. After three preceding years of very low sightings of females with calves, 2018 saw these numbers increasing to reach a record level of 426. This pattern of results is best explained by variation with time in the probability that a resting female rests again the following year, where this probability increased substantially after 2008, but seems to have fallen back to earlier levels from 2017. Another surprising feature of the data is one extremely high and three extremely low estimates of the probability of sighting a female with calf after 2013. The low estimates do not seem compatible with near unchanged survey conduct for the years concerned, so that a penalty term is added to the assessment to force these to be closer to earlier values. The resultant population trajectory suggests that an annual increase rate of 6.1% from 1979 to 2008 which dropped to 3.9% for the following decade, with the current abundance (including calves) totalling 5838 whales.

INTRODUCTION

The results of Brandão *et al.* (2018) of a photo-id based assessment of southern right whales in South African waters using the three-mature-stages (ovulating - also termed “receptive”, calving and resting) model is updated to include a further year’s data.

However, the probabilities of observing females with calves are estimated to be unusually low between 2015 and 2017, and especially for 2016 for which a probability that is normally in the region of 75% drops to only about 20%. Since nothing in the conduct of the surveys in those years was particularly different and suggestive of a high number of missed sightings, and also because the estimated probability of observing pairs in 2014 is unusually very close to 1, the results of two further model runs are reported in which a penalty is applied to these probabilities over the 2014-2018 period in the negative log likelihood function to attempt to constrain the surprisingly low and high probabilities estimated for most of these years. The penalties applied are:

1. $P_y^A \sim N\left(0.744, 0.072^2\right)$ for the 2014 to 2018 period. These values are the mean and the standard deviation for the estimated probabilities for the period 1982 to 2013 when no penalty is applied.
2. $P_y^A \sim N\left(0.744, 0.02^2\right)$ for the 2014 to 2018 period. In this case the standard deviation of the penalty term was arbitrarily set lower still to attempt to further restrict the variation in the estimates of the probabilities of observing a female whale with its calf.

RESULTS

- Figure 1 plots the unique number of females with calves observed annually. Note the appreciable drop below the earlier general trend over the 2015 to 2017 period, with a record number observed in 2018.
- There is minimal change in the estimated probabilities that a calf is catalogued (Figure 2 – top panel) and in the probabilities of observing a female whale with its calf on aerial surveys (Figure 2 – bottom panel) with the additional year's data. This is true for both the time varying and the time invariant models.
- Allowing for time varying probabilities that a resting whale will rest in the following year (β), the additional data results in higher estimates of the probabilities for the period 2014 to 2016 before dropping thereafter to similar values to those earlier years (Figure 3). For the time invariant model, the estimate of this probability increases from the 0.201 estimated previously to 0.224 (Figure 3).
- Figure 4 shows the expected number of mature female southern right whales that are in the calving, receptive or resting stages for the time varying model. With an additional year's data higher numbers of resting females and lower numbers of receptive females are estimated than previously for the period from 2014. Lower numbers of females are estimated to be calving for the 2016 to 2017 than previously. The model estimates a drop in the number of resting females with a corresponding increase in the number of calving females for 2018 when compared to 2017.
- The additional year's data has minimal impact on the estimate of the number of parous females (Figure 5) and of the total population (including males and calves and assuming a 50:50 sex ratio) (Figure 6).
- There is minimal change in the estimated probabilities that a calf is catalogued (Figure 7 – top panel) when penalties are applied to P_y^A over 2014 to 2018. The drop in the probabilities of observing a female whale with its calf on aerial surveys (Figure 7 – bottom panel) in the last three years of the series is reduced as stricter penalties are applied. However the high probability estimated for 2014 is scarcely affected by these penalties.
- The extent by which time varying probabilities that a resting whale will rest in the following year (β) increase for the period 2014 to 2016 is increased further still as stricter penalties are applied, before dropping to similar values to those for earlier years for 2017 and 2018 (Figure 8).
- Figure 9 shows the expected number of mature female southern right whales that are in the calving, receptive or resting stages for the time varying model with penalties applied to P_y^A for the period from 2014 to 2018.
- Figure 10 shows estimates of the total population (including males and calves and assuming a 50:50 sex ratio) for the time varying model with penalties applied P_y^A for the period from 2014 to 2018.

DISCUSSION

It seems clear that the drop in the number of females with calves observed on the surveys after 2014 is a reflection of an increased probability of resting (β), so that the model with time varying β should be preferred.

The resultant low probability estimated for sighting a female with a calf in 2016 (Figure 2) is, however, a concern. This follows from the overall low number of sightings that year (Figure 1), but there is no reason from the manner in which the survey was conducted that year to have expected this. Consequently, penalties were imposed for those probabilities for the period 2014 to 2018, and those do lead to an increase in this probability value (Figure 7), but result in a lower current abundance (Figure 10). The contributions to the penalised negative log-likelihood shown in Table 1 indicate that all of the adult re-sightings histories, the calf re-sighting histories, and the penalty on β variation prefer the P_y^A estimates as they were before addition of these further penalties, with the adult histories being the most influential in that respect.

Interestingly introduction of these further penalties does not reduce the very high P_y^A sighting probability estimated for 2014 (see Figure 7), which suggests virtually every female with a calf was seen in that year compared to the norm of about 75%. The 2014 survey encountered very poor weather conditions, necessitating frequent restarts and hence more repeated sightings of female-calf pairs than is the norm (43% of the female-calf pairs photographed during the entire survey were duplicates, compared to an average of 17% for other years). It could be that this different conduct of the survey also led to this very high value of P_{2014}^A with hardly any pairs being missed.

Which penalty for P_y^A is the most defensible? Given that 0.072 is the standard deviation of earlier annual probabilities for such sightings, that does seem the most appropriate choice for specifying what is in effect a prior. However, it remains surprising that this results in increasing P_{2016}^A from 0.17 to only 0.37, compared to the lowest value earlier of 0.59.

Accepting the associated model, on that basis, as the best currently available, Table 2 indicates that the annual increase rate of 6.1% from 1979 to 2008 fell to 3.9% for the following decade, with the total population at present being 5838 whales. It is believed that poor feeding conditions may have led to the increase in resting probabilities since 2008 (Figure 8) causing this reduction in the increase rate. Although there is no direct evidence available to support this hypothesis, van den Berg *et al*. (2019) indicates a clear link between the annual number of female-calf pairs on the South African coast and the Southern Ocean climate and productivity. Fortunately, however, it seems that this situation has very recently returned to normal.

REFERENCES

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van den Berg, G., Vermeulen, E., Hui, C., Findlay, K., Von der Heyden, S., Midlgey, G. 2019. Linking climate and ocean productivity to the prevalence of southern right whales (*Eubalaena australis*) in South African waters. IWC document SC/68a/SH/12.

ACKNOWLEDGEMENTS

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Table 1. Contributions to the penalised negative log-likelihood function by its various components.

	No penalty	Penalty (σ =0.07)	Penalty (σ =0.02)
Adult histories	2183	2188	2216
Calf histories	510.0	515.4	521.1
Beta random effects	24.30	29.68	32.75
Penalty beginning of series (1979 – 1981)	0.102	0.104	0.106
Penalty end of series (2014 – 2018)		23.69	83.96

Table 2. Estimated total number of the whole population (including males and calves, under the assumption of a 50:50 sex ratio at birth) in 2018 (in 2017 in the case of the previous analyses) and the estimated percentage annual rates of increase for the periods pre-2009 and post-2008 for the various models reported in this paper. The percentage annual rates of increase were computed as $100\left[\left(N_{final}/N_{initial}\right)^{1/period}-1\right]$.

Model	% rate of increase for period 1979 to 2008	% rate of increase for period 2009 to 2018	Total population estimate for 2018
Time invariant (previous)	6.95	6.34†	7656†
Time varying (previous)	6.39	4.36†	6116†
Time invariant	6.75	6.23	7862
Time varying	6.47	4.72	6648
Time varying (penalty = 0.07)	6.11	3.91	5838
Time varying (penalty = 0.02)	5.86	3.56	5445

† These values refer to 2017 instead of 2018.

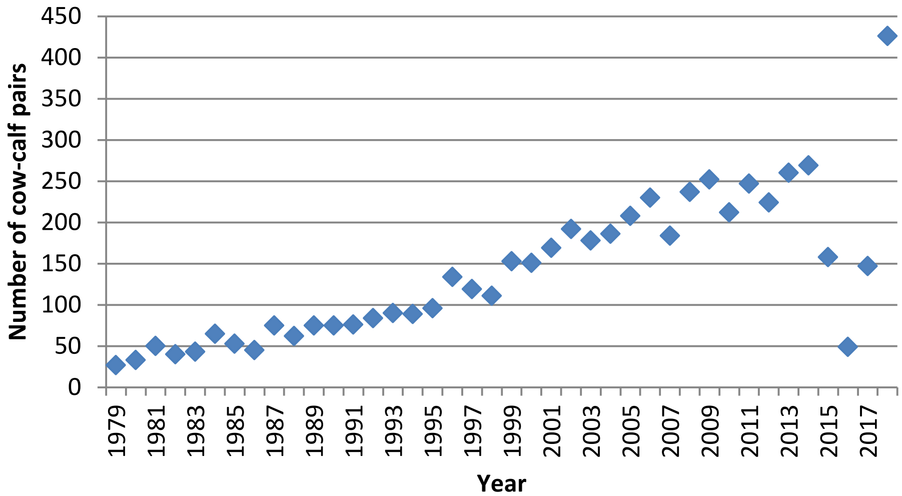


Figure 1. Number of adult female-calf pairs sighted during the annual southern right whale surveys off South Africa.

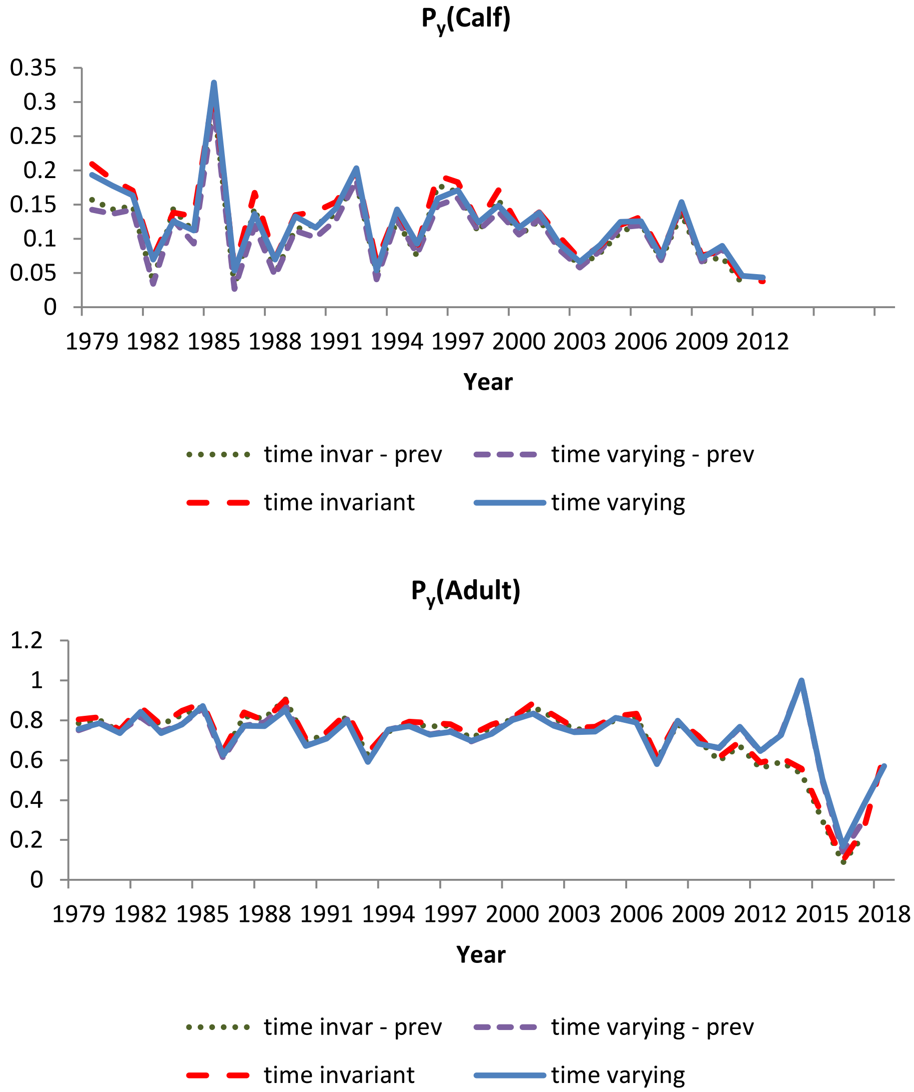


Figure 2. Estimated probabilities that a calf is catalogued (top) and of observing a female whale with its calf (bottom) on aerial surveys under the time invariant model and the time varying model. For comparison, the previous (Brandão *et al.*, 2018) estimated probabilities for the time invariant and (β) time varying models are also shown.

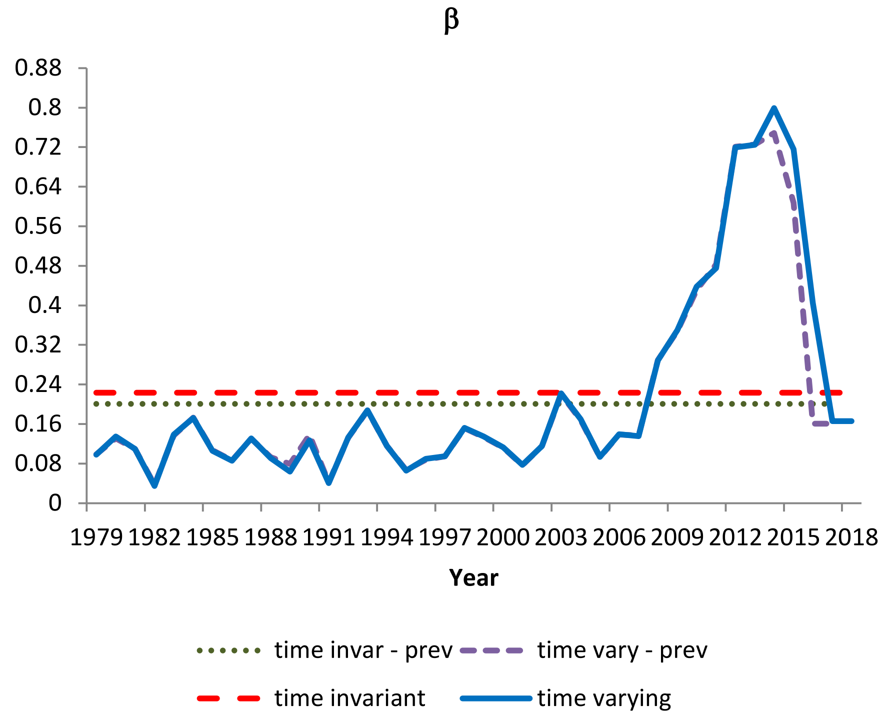


Figure 3. Time varying and time invariant estimates of the probabilities (β) that a resting whale will rest in the following year. For comparison, the previous (Brandão *et al.*, 2018) estimated probabilities are also shown.

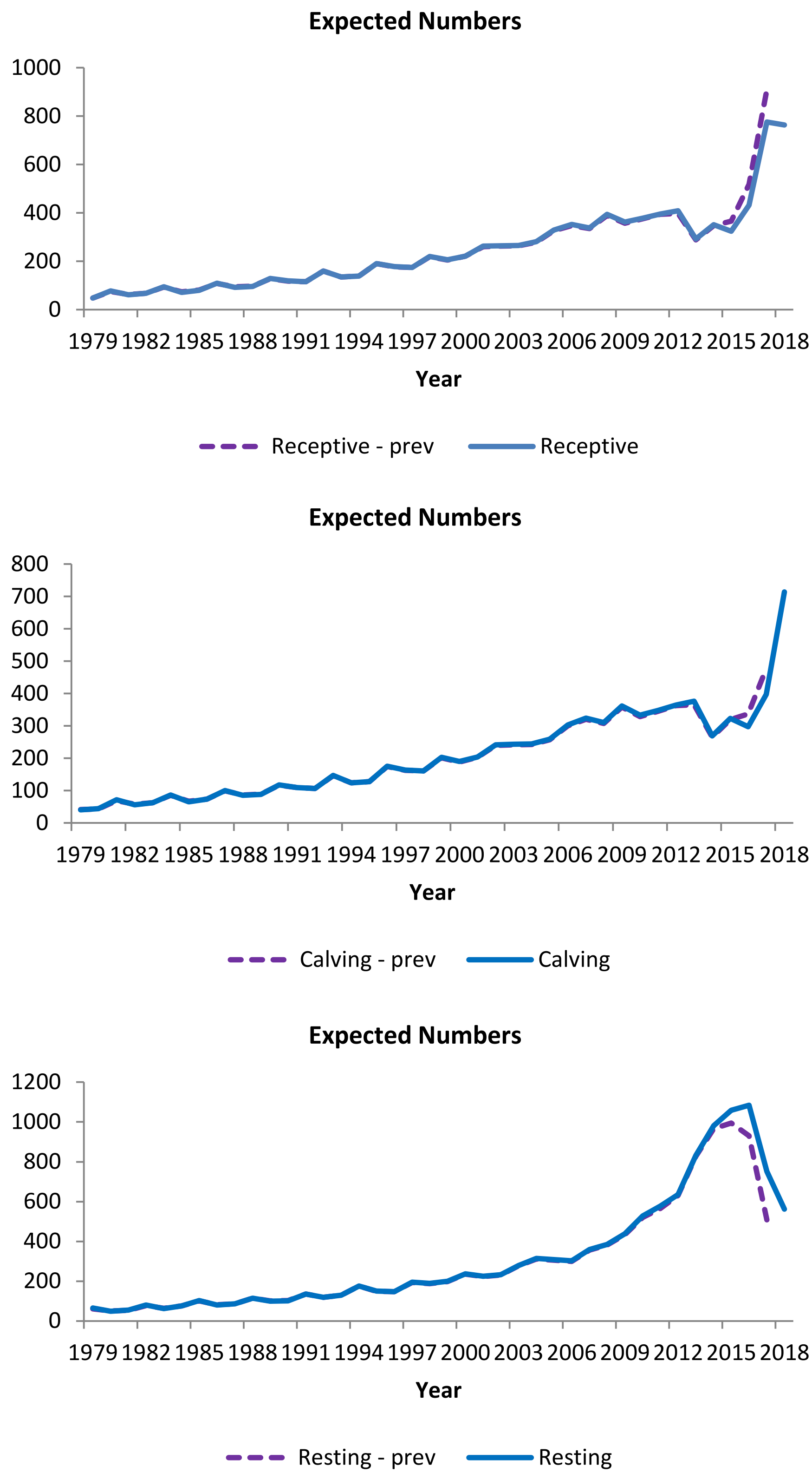


Figure 4. Expected numbers of mature female southern right whales that are in the receptive (top), calving (middle), or resting (bottom) stages under the time varying model. For comparison, the previous (Brandão *et al.*, 2018) estimated expected numbers are also shown.

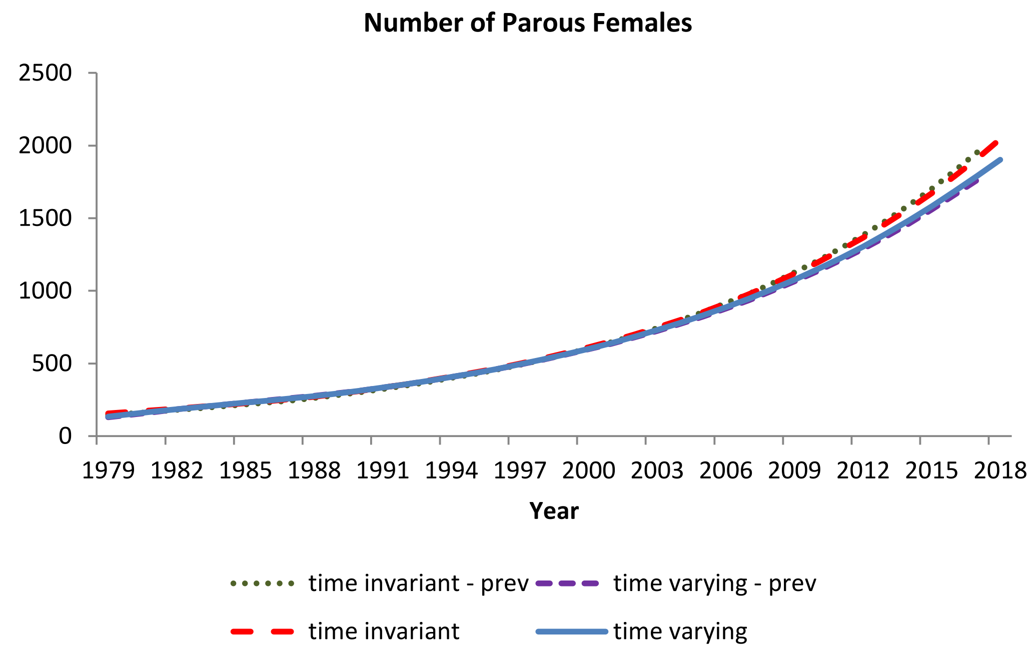


Figure 5. Estimated total number of females having reached the age at first parturition for the time invariant and the time varying models. For comparison, the previous (Brandão *et al.*, 2018) estimated numbers for the time invariant and the time varying models are also shown.

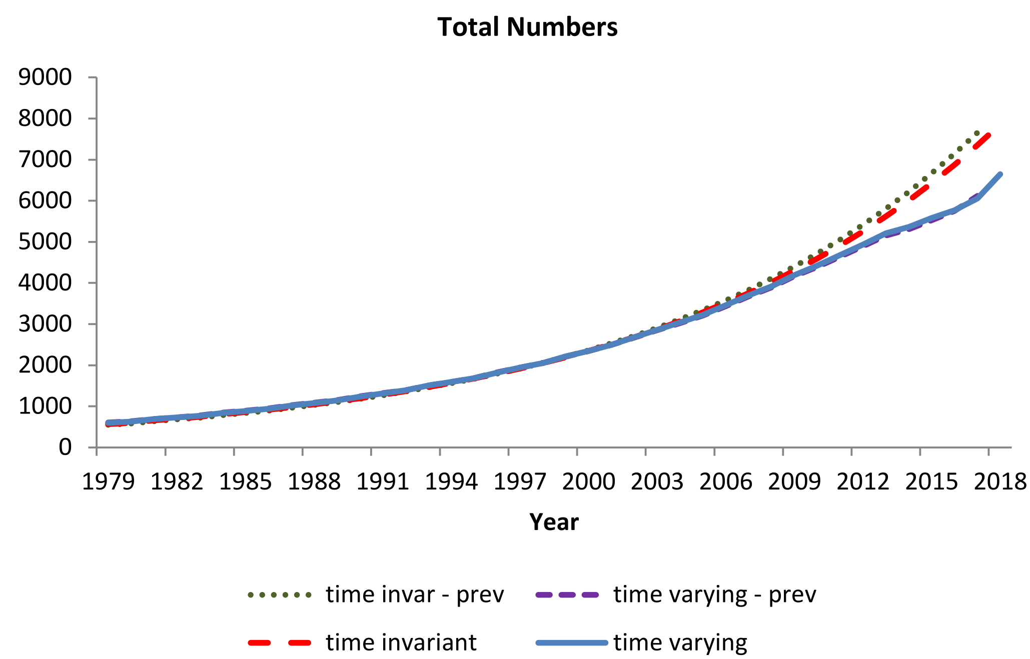
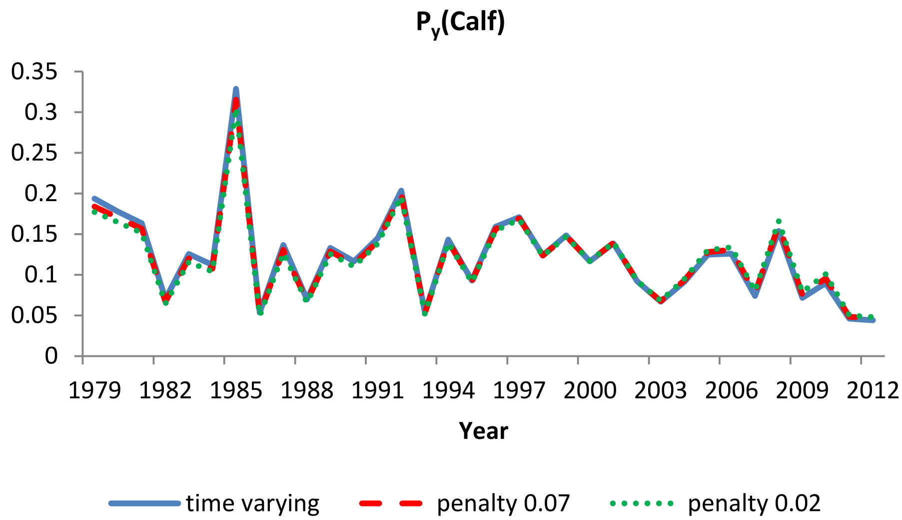


Figure 6. Estimated total number of the whole population (including males and calves, under the assumption of a 50:50 sex ratio at birth) for the time invariant and the time varying models. For comparison, the previous (Brandão *et al.*, 2018) estimated numbers for the time invariant and the time varying models are also shown.



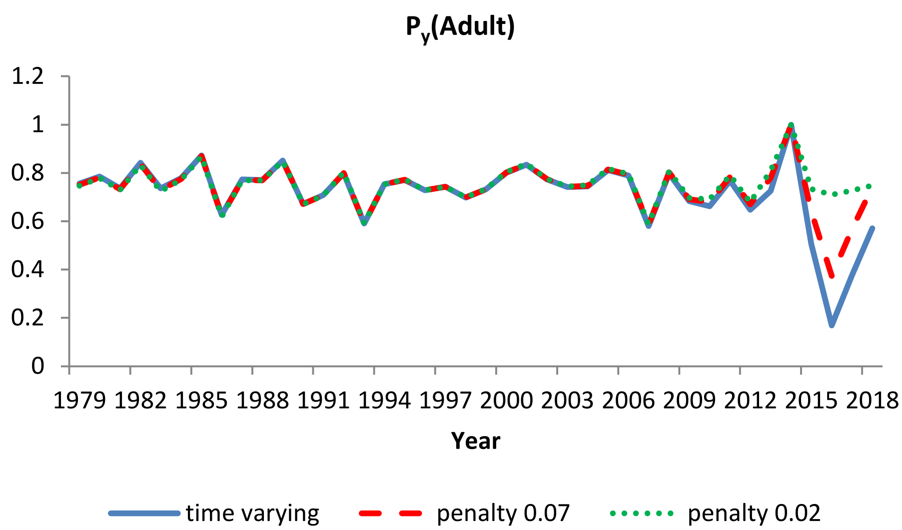


Figure 7. Estimated probabilities that a calf is catalogued (top) and of observing a female whale with its calf (bottom) on aerial surveys under the time varying model with penalties applied to the P_y^A estimates for the 2014 to 2018 period. For comparison, the estimated probabilities with no penalty are also shown.

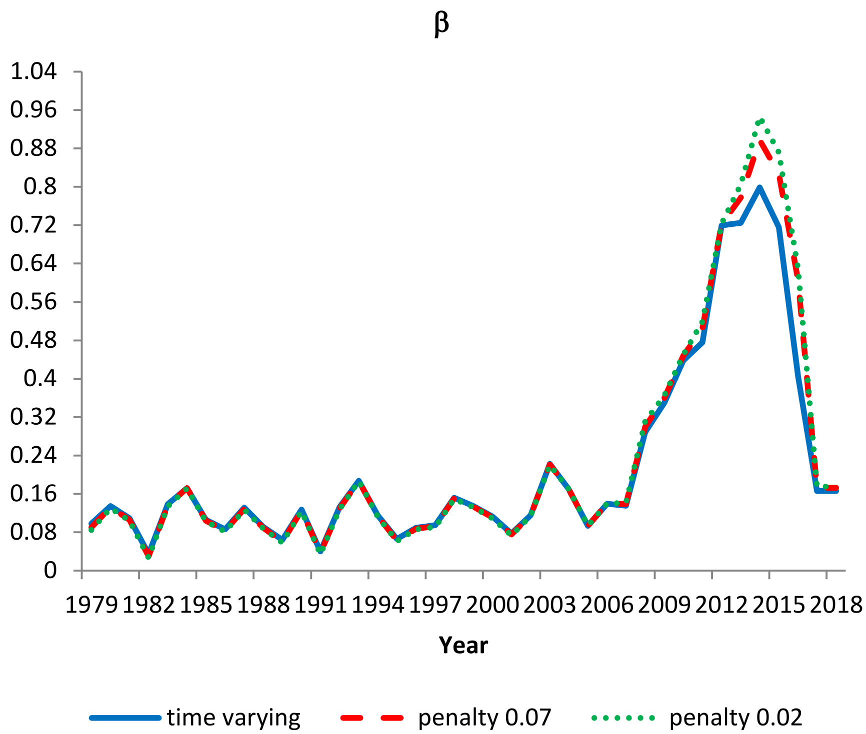


Figure 8. Time varying estimates of the probabilities that a resting whale will rest in the following year with penalties applied to the P_y^A estimates for the 2014 to 2018 period. For comparison, the estimated probabilities with no penalty are also shown.

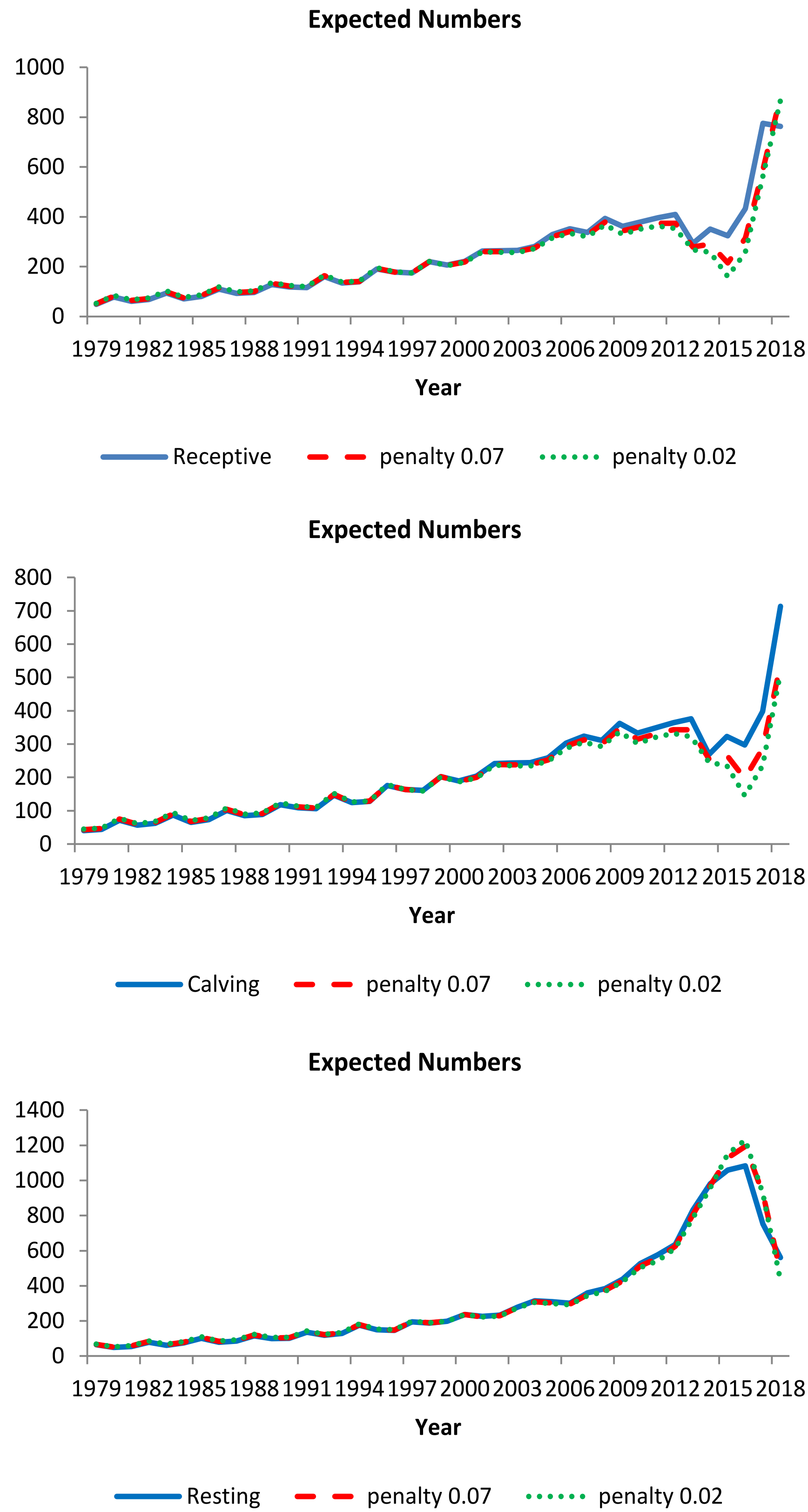


Figure 9. Expected numbers of mature female southern right whales that are in the receptive (top), calving (middle), or resting (bottom) stages under the time varying model with penalties applied to the P_y^A estimates for the 2014 to 2018 period. For comparison, the estimated numbers with no penalty are also shown.

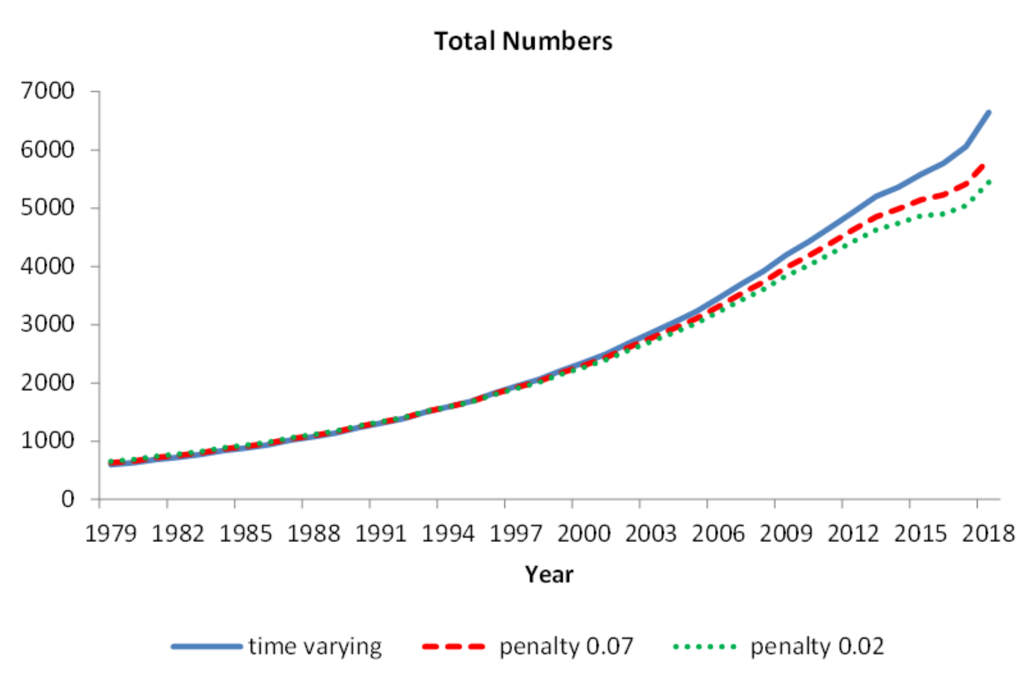


Figure 10. Estimated total number of the whole population (including males and calves, under the assumption of a 50:50 sex ratio at birth) for the time varying models with penalties applied to the P_y^A estimates for the 2014 to 2018 period. For comparison, the estimated total numbers with no penalty are also shown.