Are there fewer North Atlantic right whales than we think?

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The right whale report card includes several estimators of the abundance of North Atlantic right whales (NARW), but only one includes estimates of survival. In order to review survival estimates, we ran multiple mark-recapture models on photo-identification data from 1990 to 2017. Models run included a classical Jolly-Seber (JS) model, Schwartz-Arnason variants of JS models in the *openCR* library of R, and Cormack-Jolly-Seber (CJS) models in *marked*. Initially we ran models from 1990 to 2017. All models were fit in a likelihood framework and showed the same general pattern of abundance increasing until 2010/2011 and declining thereafter. Annual survival showed a decline in later years, so we then re-ran the models for 2000-2017. Model selection on this truncated time series invariably selected best-fit models with survival and probability of capture varying by time. All models concluded with abundance estimates around 10% less than those of Pace et al 2017. Annual estimates of calf production from JS models were similar to actual calving. For a CJS model that included sex as a covariate, best-fit models included sex differences in survival and probability of capture. Finally, we fit this form of CJS model in a Bayesian framework. Males' survival declined from a mean estimate of 0.994 in 2008 to 0.960 in 2016, and females from 0.988 to 0.929 over the same period, a six-fold increase in annual mortality. We generated a time series of abundance from this CJS model using a Horvitz-Thompson estimator. For the start of 2017, this estimated 392 whales: 152 females, 223 males, and 17 whales of unknown sex. Whether this model is biased low requires further investigation, but all models indicate that there may be fewer NARWs than current estimates suggest.

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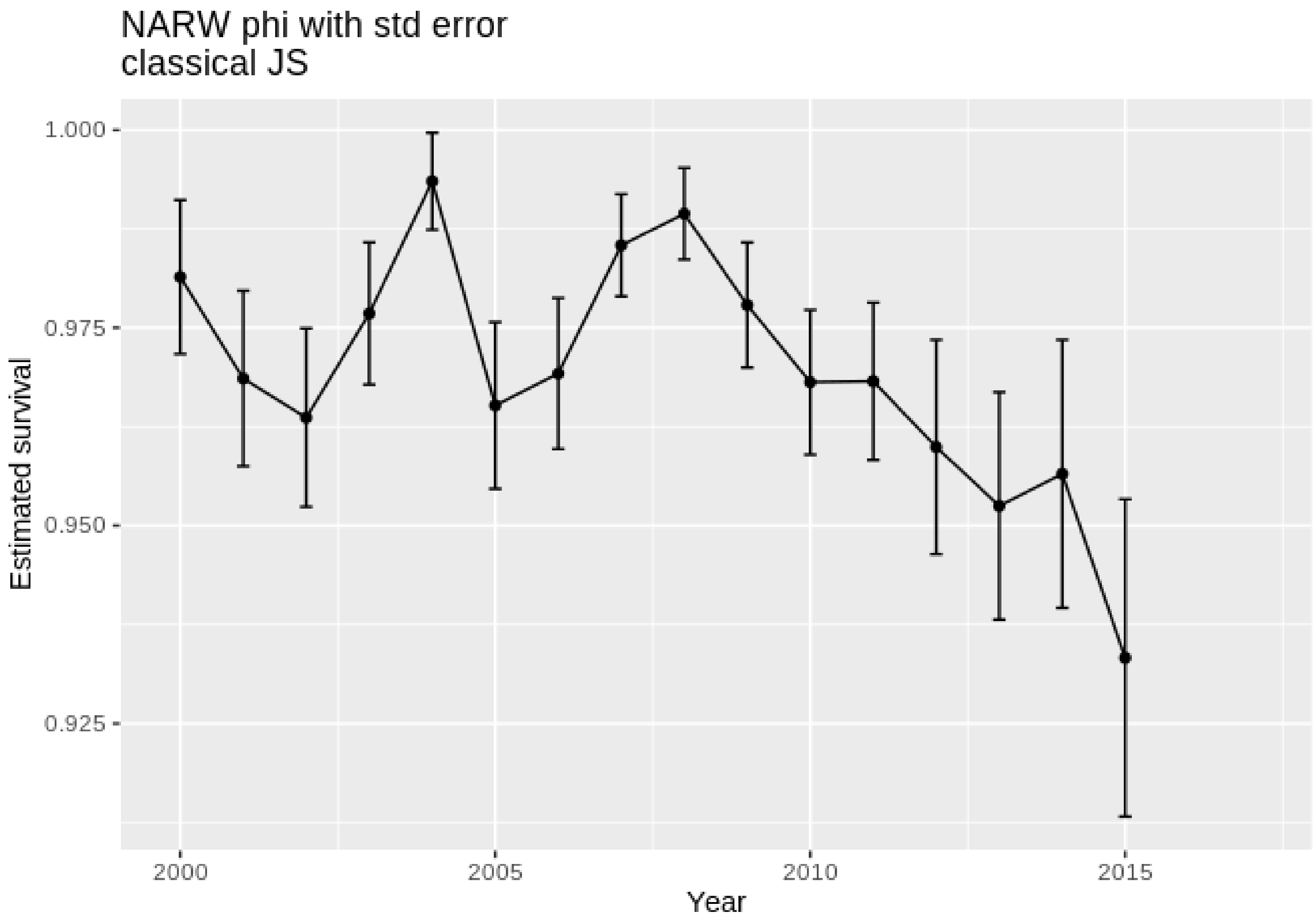
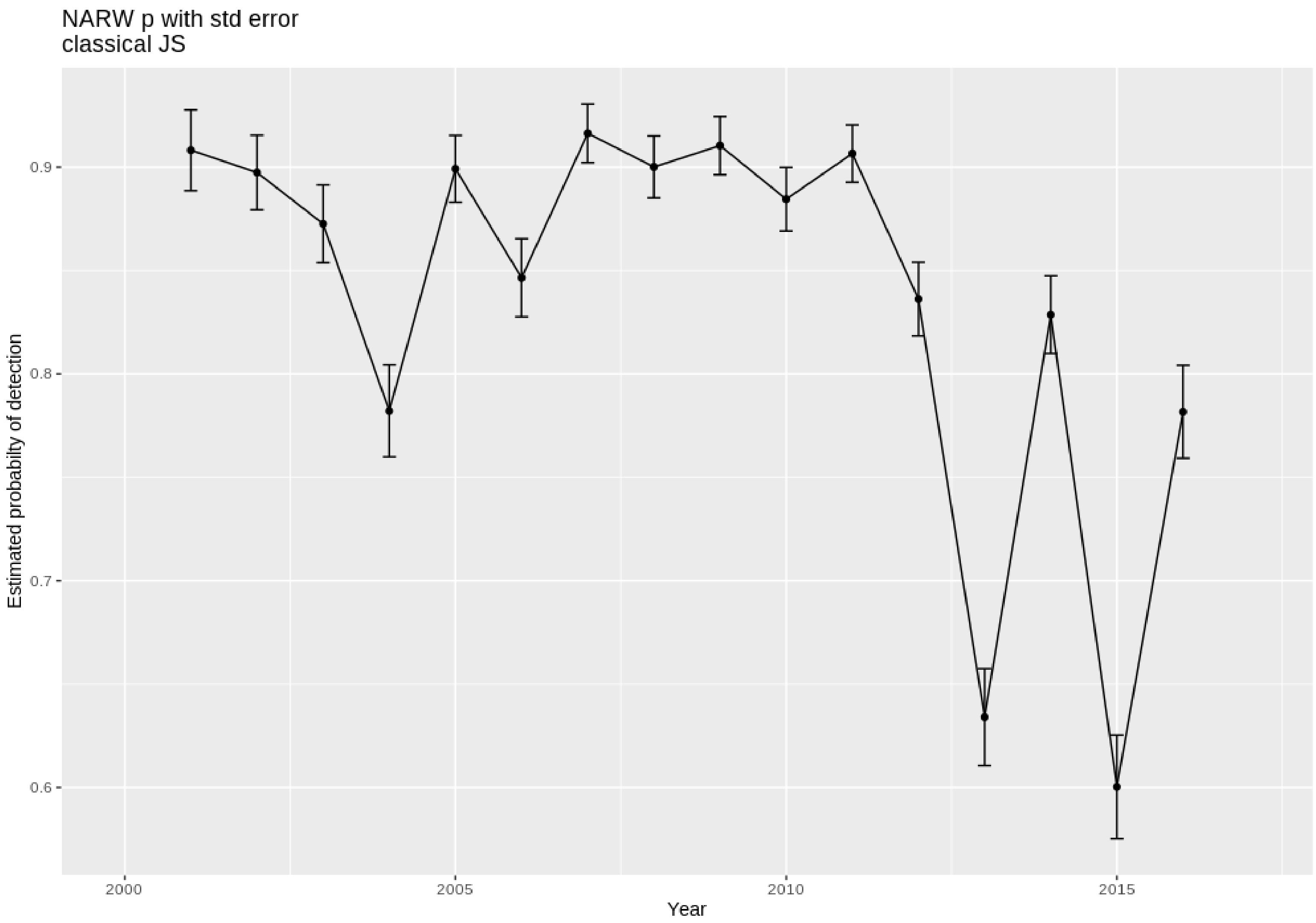
Why we got thinking about this

- **Pace et al paper & model an excellent development**
  - But – only estimator of survival available
  - Survival (and its corollary, mortality) fairly flat over the decline, with substantial uncertainty
    - Somewhat baked into the model?
- **Modelling approach (BaSTA) that estimated longevity assumes constant survival**
  - Because otherwise the model approach won't work
  - Is this legitimate?
    - Needed to test prior to considering publication
- **Is survival constant? Does the 20 year increase 1990-2010 over-ride the effect of the post-2010 decline?**
  - Check using other CMR models
  - Used multiple approaches, some shown here
  - JS, JSSA (~POPAN), CJS
  - Used 1990-2017 & 2000-2017 data to model, latter shown now

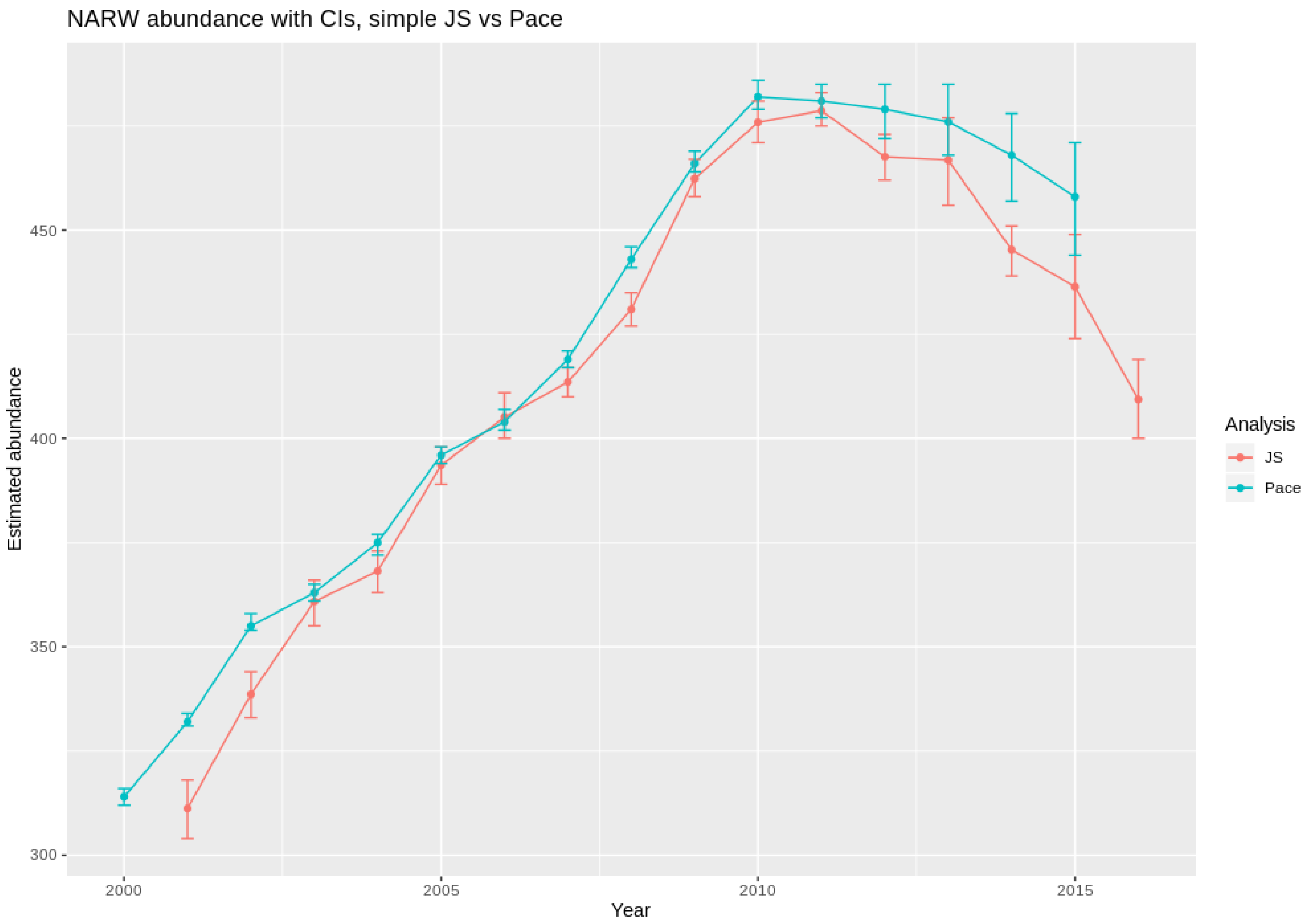
J-S: annual survival 2000 - 2015



J-S: annual likelihood of detection



Abundance 2000 - 2016



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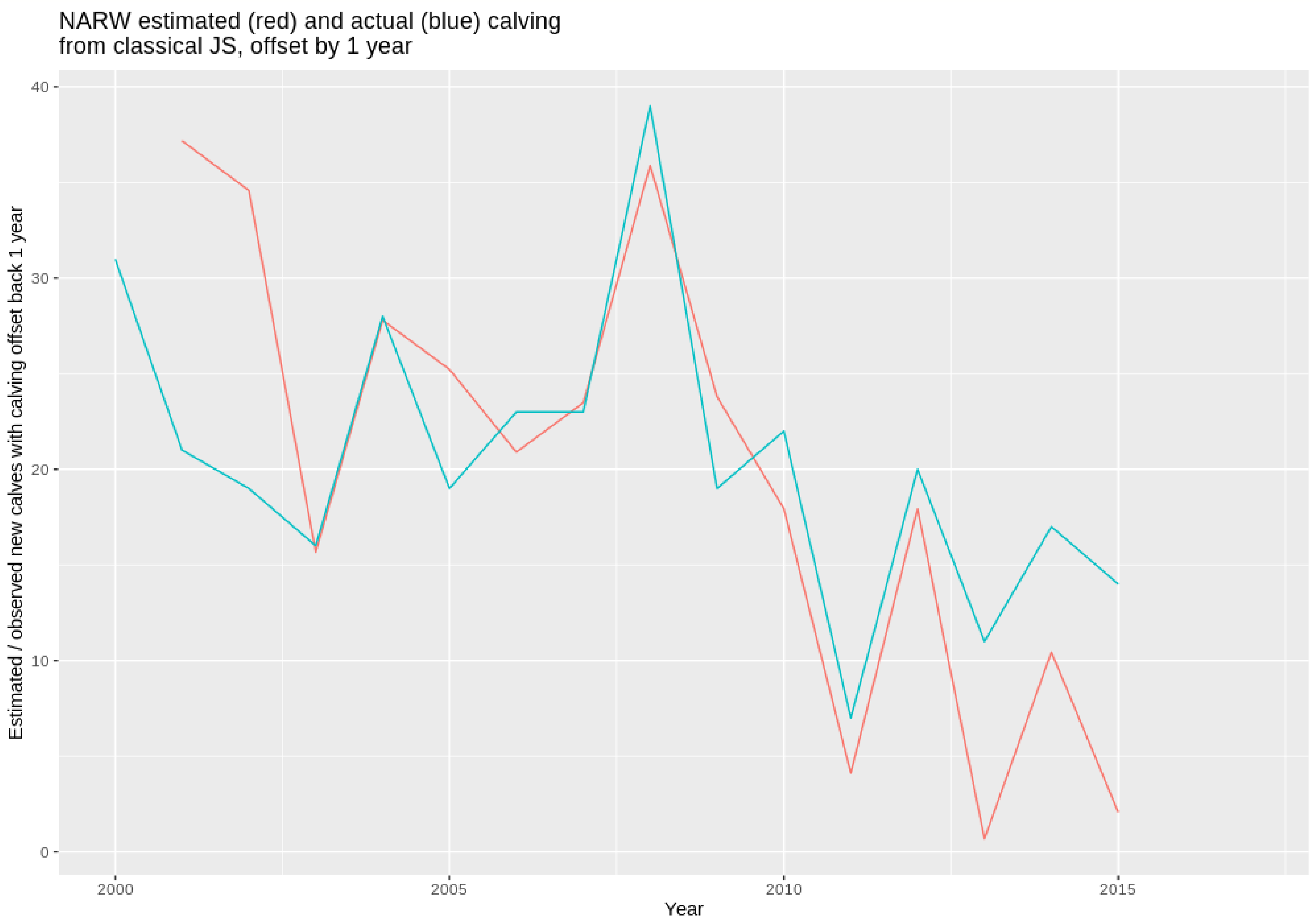
J-S: new entrants



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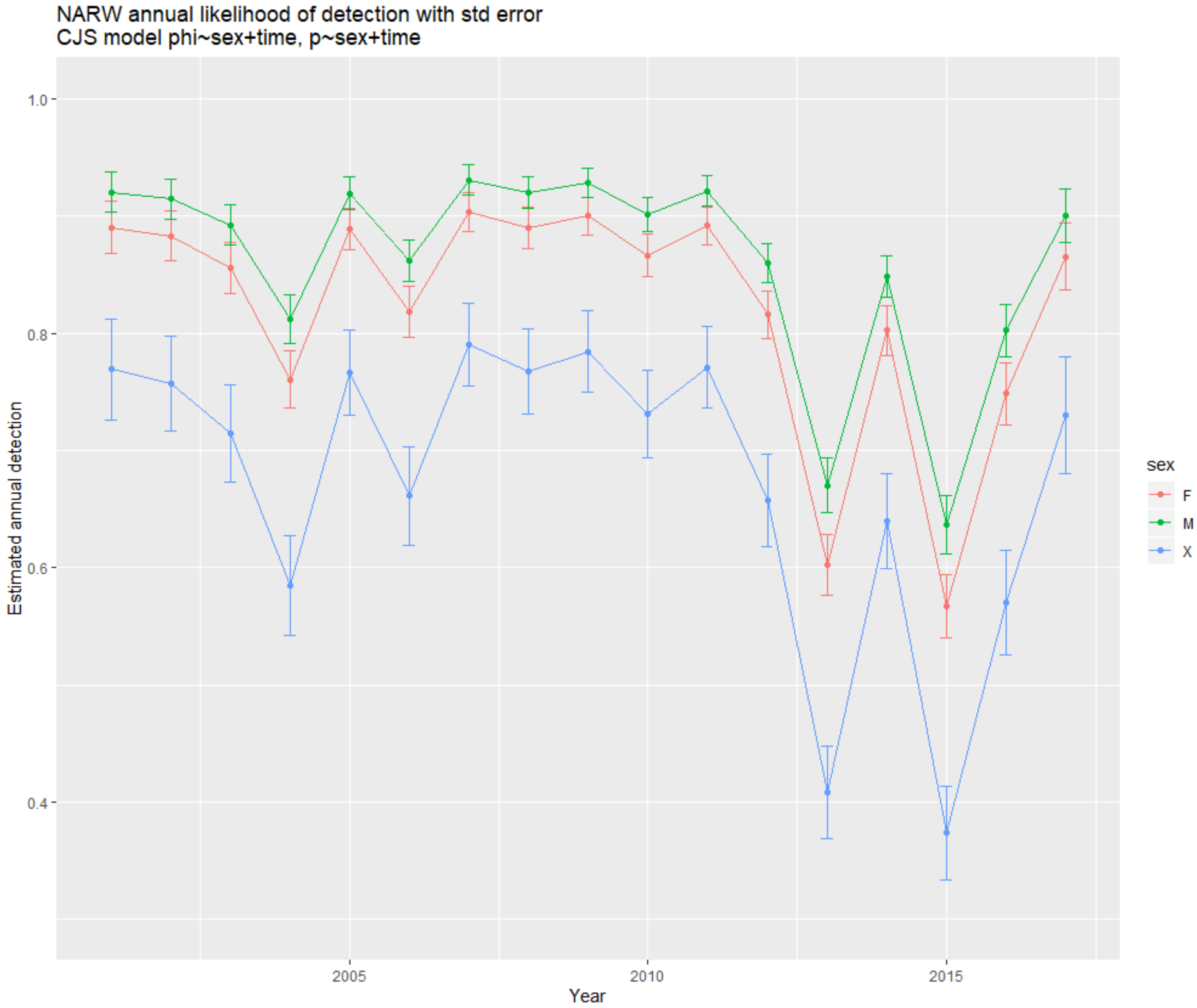
Very simple, classical Jolly-Seber: Results

- **Simplest possible approach**
  - Well, almost
  - Abundance: general pattern very similar to Pace et al model
  - Run using R library *openCR*
- **Differences with Pace et al model**
  - Peaks @479 in 2011, Pace 482 in 2010, 481 in 2011
  - 436 in 2015, Pace 458 in 2015
  - 409 in 2016, Pace 428 at start of 2017
- **These patterns were repeated for other variants of Jolly-Seber models**
  - JSSA (~POPAN) models, for which AIC used to determine the best-fit model
  - Slight differences in abundance, but all less than Pace et al
  - Consistent decline in survival
  - JSSA models allow estimate of # of whales missed by sampling (a consistent concern pre-2017) - trivial

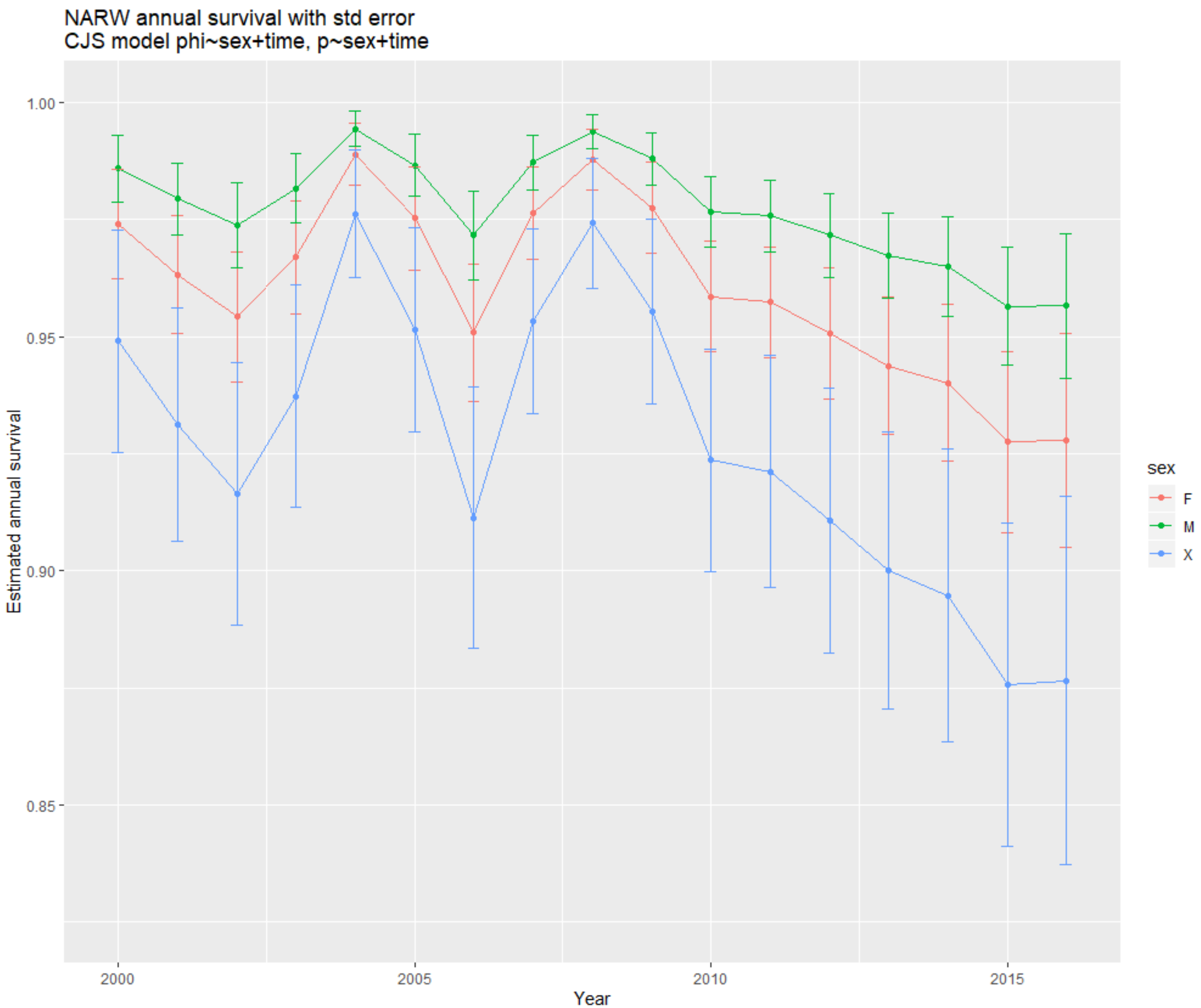
Cormack-Jolly-Seber models
Run in *marked* library

Model	Npar	AIC	Delta AIC
Phi(~sex + time)p(~sex + time)	38	7066	0
Phi(~sex)p(~sex + time)	22	7069	2.233
Phi(~sex + time)p(~sex * time)	70	7070	3.457
Phi(~sex)p(~sex * time)	54	7074	7.765
Phi(~time)p(~sex + time)	36	7088	21.860

CJS annual likelihood of detection



CJS: annual survival



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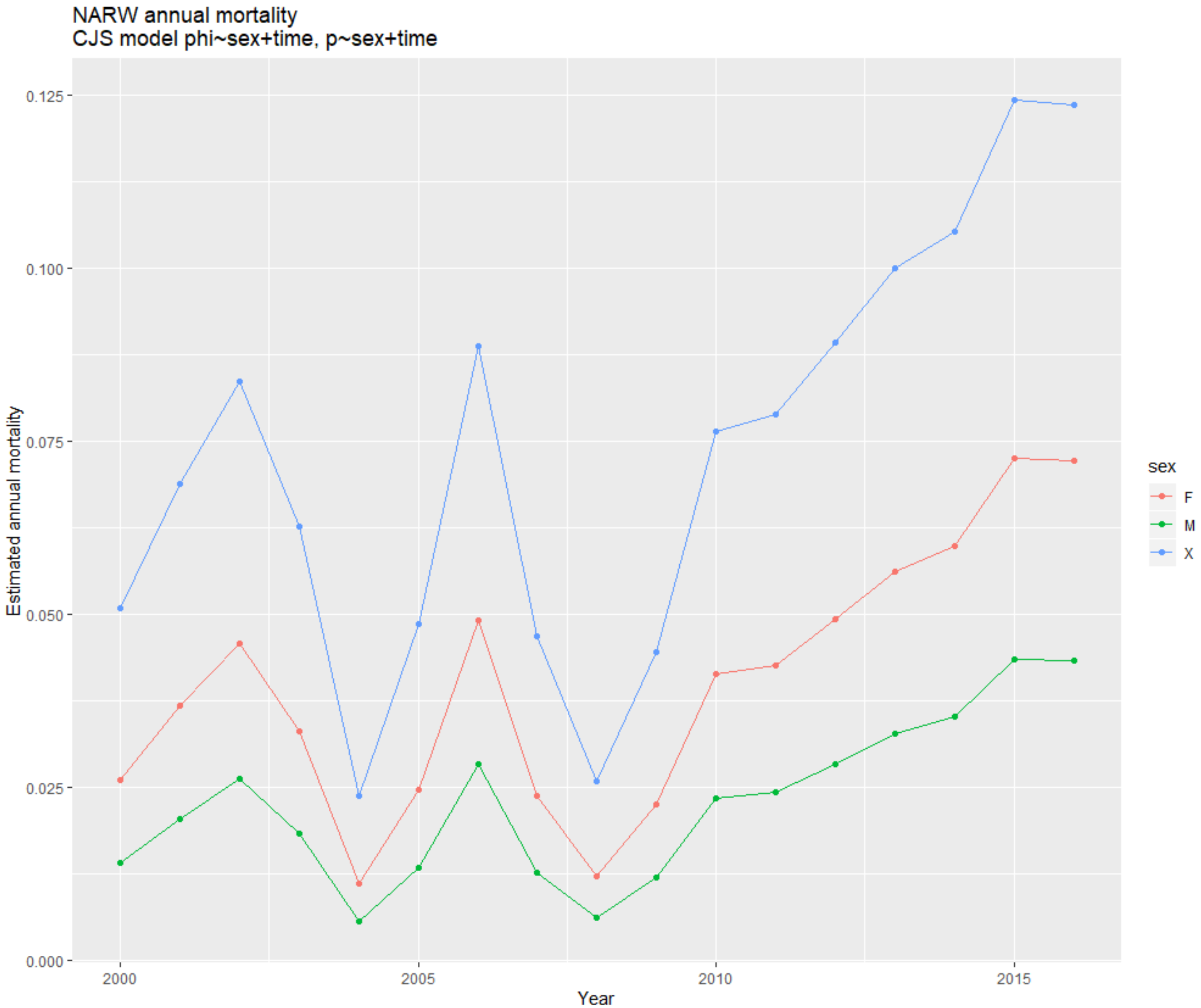
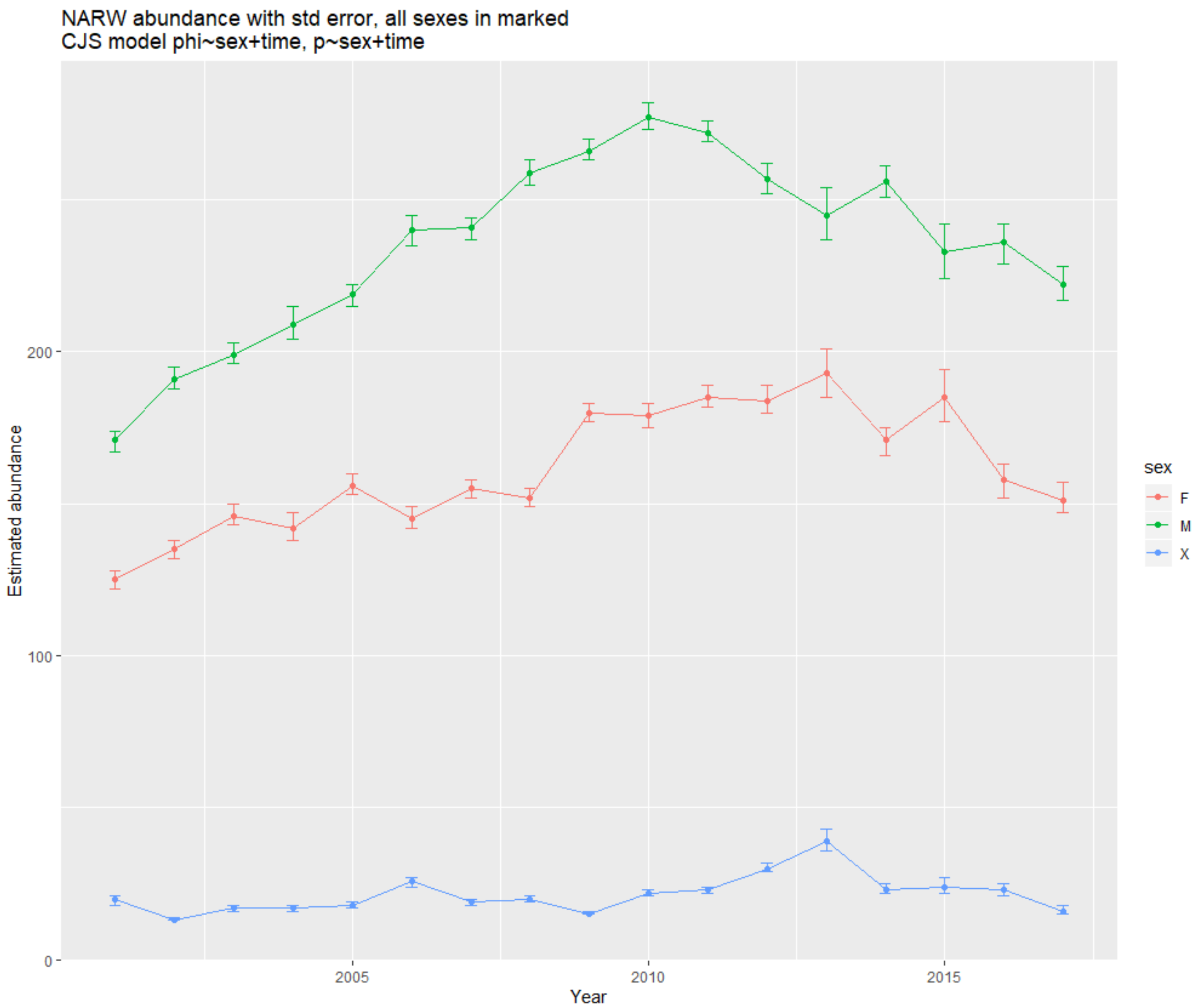
CJS: mortality



CJS: abundance by sex



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Cormack-Jolly-Seber results

- **Best-fit model included time-varying survival, separate for sexes**
  - Removing "X" sex gave second-best fit as Phi~sex*time
  - 478 in 2010, 479 in 2011 (cf 481/482)
- **Survival declines post-2008**
  - Mortality increase predates abundance decline
  - Substantial decline prior to 2014 & possible GoSL effect!
- **Roughly 6-fold increase in mortality post-2008**
  - That's a lot for a large mammal
- **Abundance: 417 NARW at the start of 2017**
  - 428 Pace et al, 409 JS model
  - 158 females, 236 males, 23 unknown
  - Indicates just under 170 females start 2017
- **~392 at the start of 2018?**
  - ~ 160 females?

Concluding thoughts

- **Pace et al model remains the best available science**
  - This work needs further validation
    - CJS abundance biased slightly low?
    - Need to account for transience in data still
- **Consistent finding that survival in declining is a concern**
  - Something in the Pace model that's missing current changes in survival?
    - How does this feed into abundance estimates?
  - Increasing rate of mortality indicates this problem is worse than we realize

    And these are pre-2017 data

  Life history of large mammals & what this means

    Lack of calves is bad, but dead mothers are worse
- **What about abundance?**
  - Maybe the CJS model is biased a bit low, but it may also be that the Pace model is biased a bit high
  - Need to move away from giving abundances to the individual whale
  - Bias and uncertainty are different things
  - No way that there are more right whales than the Pace et al model estimates