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Title: Forecasting wDPS Steller sea lion counts and quasi-extinction using the agTrend package for the R statistical environment

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Summary: Memo submitted to Leadership at the Alaska Science Center for approval of methods and results of analysis requested by the NOAA Fisheries Alaska Regional Office. In this memo aerial survey counts of Steller sea lion rookeries and haul-outs were forecast 100 years into the future to assess the probability that they will fall below an extinction threshold. Two methods were used to forecast survey counts using the R package agTrend due to the fact that many of the site surveys are missing or unobserved. First, counts were directly simulated into the future using the MCMC algorithm used by the package to simulate from the posterior distribution of the missing counts. Second, using the simulated values for missing surveys between 1990-2012, the analytical projections of Morris and Doak (2002) were used to calculate probability of extinction. Although the methods differed in the point estimates of quasi-extinction, the overall inference maintained throughout each analysis. The probability of extinction within the next 100 years for the wDPS population as a whole is essentially zero. The same is true for all but two regions, with some increased uncertainty however. The probability of extinction in the E. Gulf of Alaska region could be as high as 5%, however, the mass of likely values mostly is concentrated around zero. The W. Aleutian region possesses the greatest probability of extinction. Probability of extinction ranged from 0.46 to 1. Thus, while there is substantial range in the estimates depending on the method used, the probability of extinction in the western Aleutian is quite high for conservation standards.

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SECTION 515 PRE-DISSEMINATION REVIEW & DOCUMENTATION FORM

AUTHOR/RESPONSIBLE OFFICE: Johnson, D,

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PRE-DISSEMINATION REVIEW:

Name and Title of Reviewing Official: John Bengtson, Director, National Marine Mammal Lab

(Must be at least one level above person generating the information product) Pursuant to Section 515 of Public Law 106-554 (the Data Quality Act), this product has undergone a pre-dissemination review.

Signature [signed] Date 26 NOV 13

Name and Title of Reviewer(s): Douglas DeMaster, Director, AFSC

Tom Gelatt, Leader, Alaska Ecosystems Program

Signature [signed] Date 26 Nov 2013

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To: Tom Gelatt, Program Director Alaska Ecosystems Program, NMML, AFSC
John Bengtson, Director, NMML, AFSC
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From: Devin Johnson, Statistician (Biology), AK Ecosystems Program, NMML, AFSC

Subject: Forecasting wDPS Steller sea lion counts and quasi-extinction using the agTrend package for the R statistical environment

Date: August 8, 2013

The following memo describes the process used to forecast wDPS Steller sea lion counts and subsequent summarization of the probability that the counts fall below a quasi-extinction (hereafter, "extinction" or "QE") threshold.

Establishing Quasi-Extinction Thresholds

To begin, I established the following extinction thesholds for each wDPS sub-region (as described in the revised Steller Sea Lion Recovery Plan (NMFS 2008) as well as the U.S. wDPS as a whole:

Region	No. rookeries	Abundance QE[a]	Survey QE[d]
W ALEU	4	513	256
C ALEU	12	1538	769
E ALEU	7	897	449
W GULF	5	641	320
C GULF	6	769	385
E GULF	3	385	192
Total	37[c]	4743[b]	2372

[a] Abundance QE (AQE) = (No. rookeries/37)*4743
[b] Abundance QE used by Goodman recovery plan PVA
[c] Total number of rookeries in the wDPS
[d] Survey QE (SQE) = 0.5 x AQE for comparison with aerial survey counts

These values were derived from the wDPS extinction abundance (4,743) given by Goodman in the previous PVA within the recovery plan and proveded to me by Lowell Fritz. The wDPS total QE was then divided amongst the regions by allocating proportionally to the number of rookeries within each region. This implies that extinction is reached when the number of animals per rookery falls below 128 per rookery within a subregion. Then, the abundance QE (AQE) was halved to make the survey quasi-extinction (SQE), a value comparable to what might be observed in an aerial survey of nonpups. I.e., if the population was at the QE level, we would only expect to see 64 animals per rookery on aerial surveys. I allocated the total wDPS AQE proportionally with respect to the number of rookeries within each region, rather, than rookery size, because QE represents a hard (biological) boundary from which a population cannot recover due to inbreeding effects, etc…

Therefore, allocating proportional to current abundance within each subregion would be inappropriate as it implies that biological constraints to population recovery at QE are different in each subregion.

Assessing Probability of Quasi-Extinction

To assess the probability of QE in the future for each wDPS subreagion and the wDPS as a whole, two main methods where employed for comparison and assessment of qualitative inference. First, I used the count-based PVA methods for density-independent population growth given in Morris and Doak (2002; hereafter, MD). Second, I used the agTrend package to forecast subregion abundance and assess the probability of QE through direct sampling of future abundance values. Details of the agTrend methodology are provided in Johnson and Fritz (2013). In addition, there is a demo contained within the package that illustrates the anaysis described here such that an interested reader could duplicate the results (type `demo(wdpsNonpupsForecast)` to run)

The MD (chapter 3) methodology is based on the following abundance model:

$$N_t = N_{t-1}e^{\mu+\varepsilon_{t-1}} = N_0 e^{\mu t+\sum_{j=0}^{t-1}\epsilon_j},$$

where N_t is the population abundance at time t, μ is the growth rate parameter, and ε_t is a $N(\sigma^2)$ random variable. If μ and $\sigma^2$are known then eqns. (3.7) and (3.5) in MD (2002; chapter 3) can be used to calculate the probability of extinction at any point upto time t (QE cummulative distribution function; QECDF). For the wDPS Steller sea lions, however, direct application of the MD methodology was complicated by the fact that the count values are not directly available for each of the subregions and wDPS as a whole due to incomplete surveys within and between years. Therefore the site counts cannot be aggregated to form a subregion count for which the formulae in MD can be applied. In order to account for this uncertainty, agTrend was used to draw an MCMC sample of count values for all missing times and locations. Within each MCMC sample the direct aggregation of counts can be formed. Therefore, a sample aggregated counts is drawn. For each sample of aggregated counts the MD method is applied and the QECDF is stored. In the end, I estimated the QECDF by taking the mean values for each time t over the MCMC simulations. In addition a 90% highest probability density credible interval was also constructed. Due to changes in population pressures and management, only counts from 2000-2012 were used for the MD method due to deviations from the constant average yearly growth assumption.

In addition to the MD method I also used the forecasting ability of agTrend to simulate future values of survey counts. The count model used by agTrend is slightly different that the MD model and is given by

$$N_t = N_0 e^{\mu t+\alpha_t+\epsilon_t},$$

where N_0 is a baseline count, $\alpha = (\alpha_1, \dots, \alpha_T)$, is a random walk process (of order 2 for a smooth time series), and ϵ_t is a $N(0, \sigma^2)$ random variable. The main difference is that the agTrend model allows autocorrelated change in yearly growth, while the MD only has independent identically distributed growth around the μ parmeter. Once the forecasted counts were drawn the QECDF was calculated by assessing the number of survey tracks that reached the SQE level at or before time t. I ran two different versions of this approach. First, because I am modeling on the log scale, random outliers can cause the predicted abundance to go well beyond reasonable values, therefore, I capped the maximum value at $\max(N_{observed})\times 1.05^{50}$, where $N_{observed}$ is the observed count for a site. This was chosen because 5% growth for a span of 50 years (from the maximum count observed) seemed to be a realistic upper bound. To determine what effect this might have on estimates, I also ran the approach un capped as well. All counts from 1990-2012 were used for the agTrend forecast beause the method is not restricted to a constant average yearly growth assumption.

There is a subtle difference between the two versions of QECDF for each method. In the MD approach, the QECDF is an analytical calculation based on the log-linear random walk model, hence, the quantity calculated is conditioned on the parameters used to make the calculation. So, the average is over different parameter values. Whereas, with agTrend one count trajectory is simulated for every parameter value therefore, the posterior mean represents the unconditional QECDF, there is no interval around this value.

As far as assumptions go, MD (2002) outline the assumptions for their approach on pp 91-97. The agTrend approach assumptions differ in the following ways:

1. *The parameters μ and σ^2 do not change over time*. While this is technically true for the agTrend approach as well, the parameters are not really equivalent. The average growth is allowed to vary through time due to the smooth autocorrelated nature of the α time series (see 2 below as well)
2. *No environmental autocorrelation*. This is not an assumption of the agTrend model. The annual growth is positively autocorrelated.
3. *No catastrophies or bonanzas*. This is also true of agTrend. While the average annual growth is positively autocorrelated, it cannot change rapidly.
4. *No observation error*. This is not true of agTrend in general, but for the wDPS SSL analysis, counts were assumed to be accurate. There is no readily available external data for assessing observation error.

Results

The 50 and 100 year results using each method are provided in the following table.

Region	**P[QE ≤ 50 yrs]**			**P[QE ≤ 100 yrs]**		
	MD	*agTrend (restricted)*	*agTrend (unrestricted)*	*MD*	*agTrend (restricted)*	*agTrend (unrestricted)*
W ALEU	0.99 (0.97-1.0)	0.75	0.46	1	0.89	0.46
C ALEU	0	0	0	0.03 (0.0-0.08)	0	0
E ALEU	0	0	0	0 (0.0-0.01)	0	0
W GULF	0	0	0	0	0	0
C GULF	0	0	0	0 (0.0-0.01)	0	0
E GULF	0.01 (0.0-0.02)	0	0	0.02 (0.0-0.05)	0	0
Total	0	0	0	0	0	0

Along with the 50 and 100 year results, the full QECDE is available in the 2014 Groundfish Biop Google Drive (2014 Groundfish Biop > NMML Analyses > NMML PVA). Note that the 50 agTrend result is slightly different than I presented at the Seattle meeting. I ran the model for 100 years in this analysis and the RW2 model changes with longer forecast length.

Discussion

The results for each method are qualitatively the same. Essentially, current long-range pobability of extinction for each region is ≈ 0, except for W ALEU, where the probability of extinction is substantial even in the short-term. The agTrend model has lower probabilities of extinction due to the fact that the average annual growth rate can change through time. So, several count trajectories increased in quadratic fashion curving upward before reaching SQE, which equates to a lower probability of extinction. This is probably due to the 2^{nd} order random walk model in the agTrend method. All of the subregions experienced precipitous decline in the 1990s that tapered to a slower decline or positive growth in the 2000s. , the RW2 model therefore has a tendancy to complete this quadratic curve. Because the change in growth rates (2^{nd} derivitive of the growth curve) is positive (i.e., growth rates are becoming increasingly positive) the RW2 continues this process into the future and hence, a lower probability of extinction is realized with this model. Whereas the MD model maintains the same constant growth rate, thus, the W ALEU decline is continued forever into the future with no hope of recovery.

So, when comparing the two models, one should look at the MD forecast as maintaining *status quo*, while the agTrend model allows for the possibility of improving growth rates. The agTrend model also allows for declining growth rates, but, the observed counts show a positive change in growth rate from the 1990s through the 2000s, so, it weights a continued positive change in growth over a declining change. In addition, even though the posterior mean of QECDF is >0 for some subregions, the mean and the mode are = 0 for all subregions. This implies that the vast majority of the QEVDF posterior mass for all subregions (except W ALEU) lies at 0.00. Hence, the lower CI bound of 0 for all subregions, save W ALEU.

References

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