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DATE:	April 23, 2019
MEMORANDUM FOR:	Thomas Gelatt, Program Leader, MML-AEP
Cc:	Rolf Ream, Biologist, MML-AEP; Rod Towell, Statistician, MML-AEP
FROM:	Devin Johnson, Statistician, MML-AEP
SUBJECT:	Northern fur seal rookery-based PVA requested by NMFS Alaska Regional Office for pup harvest management

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This report contains the latest 10-year predictions for rookery-specific pup production in the Pribilof, Is., Alaska. The pup production forecasts are based on shear sampling collected from 1990—2018. In addition to the pup production forecasts, estimates of the probability of quasi-extinction (QEP) for each rookery are presented. Quasi-extinction is defined as pup production falling at or below 500 pups between years 2019—2018. Based on the current analysis, it appears that there are only 2 rookeries which face the danger of quasi-extinction greater than 5%, Staraya Artil on St. George I. (QEP 46%) and Ardiguen on St. Paul I. (QEP 99%). Ardiguen is extremely suseptible to QE and may have reached QE already (2018 pup production, 607 [CI: 469—805]).

Rookery-Based PVA for Northern Fur Seals in the Pribilof Islands, Alaska, 2018

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Here I present a population viability analysis (PVA) for the northern fur seal rookeries on St. George and St. Paul Islands, Alaska. This analysis makes extensive use of the `agTrend` package (Johnson and Fritz, 2014) for the `R` statistical environment (R Core Team, 2018). A brief description of the model used herein is as follows:

Notation

- n_{ij} = Estimated pup production at rookery i in year j.
- $\quad_{ij}$ = Estimated standard error of the pup production estimate for rookery i in year j.
- $\tau_{ij} = \log(1 + n_{ij}/\quad_{ij})$ = approximate standard error of $\log n_{ij}$.
- N_{ij} = True pup production at rookery i in year j.

Model

- $[\log n_{ij}|N_{ij}, \tau_{ij}] = N(\log N_{ij}, \tau_{ij}^2)$
- $[\log N_{ij}|\quad_i, \boldsymbol{\alpha}_i, \xi_i] = N(\quad_{0i} + \quad_{1i} j + \alpha_{ij}, \xi_i^2)$
- $[\boldsymbol{\alpha}_i|\quad_i] = N(\mathbf{0},\ \quad_i^2 \mathbf{Q})$, where, $\mathbf{Q}$ is a precision matrix for a random walk of order 1, i.e., the $\boldsymbol{\alpha}_i$ is a random walk time-series process where $\alpha_{i,j+1} = \alpha_{ij} + \epsilon_{ij}$ and ϵ_{ij} is a normally distributed error term.

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Pup production forecasting and quasi-extinction

Forecasting

The `R` package `agTrend` was used to fit the model to pup production estimates for all 19 rookeries in the Pribilof Is. Production estimates from 1990–2018 were used for this analysis. Once the models were fitted I evaluated the quasi-extinction probability for year 2028 (QEP). The QEP is defined as the probability that the pup production at a rookery will fall below the quasi-extinction limit (QE) at or before 2028. Formally, we define QEP as the posterior predictive probability that $N_{ij} \leq \text{QE}$ for $2018 < j \leq 2028$. The posterior predictive distribution of future pup production is defined as

$$[\mathbf{N}_i^+|\mathbf{n}_i] = \int [\mathbf{N}_i^+|\boldsymbol{\theta}_i, \mathbf{n}][\boldsymbol{\theta}_i|\mathbf{n}]\ d\boldsymbol{\theta}_i,$$

where $\mathbf{N}_i^+ = (N_{i,2019}, \ldots, N_{i,2028})'$ and $\boldsymbol{\theta}_i = (\ \ _i, \boldsymbol{\alpha}_i, \xi_i)'$. Note, for $\boldsymbol{\alpha}_i$ the j index runs to 2028. Essentially, $[\mathbf{N}_i^+|\mathbf{n}_i]$ is the probability density for future production values given the production that was observed from 1990–2018. After using `agTrend` to draw a sample from the posterior distribution $[\boldsymbol{\theta}_i|\mathbf{n}_i]$ we can then sample future production using the model in the second bullet of the model description. Following this, a sample of quasi-extinction events is sampled by recording the whether or not any of the entries in $\mathbf{N}_i^+ < \text{QE}$. The average of this sample represents the posterior predictive distribution

$$[\text{any } \mathbf{N}_i^+ <\ \text{QE}|\mathbf{n}_i]$$

The expected value of this event is QEP. On a practical note, the MCMC sampler in `agTrend` was run for 50,000 iterations after a burn in of 10,000 iterations, which were discarded. Every 5th sample was saved for posterior inference.

Quasi-extinction level (QE)

The quasi-extinction level for an individual rookery was set to 500 pups. This value was originally decided on for the previous analysis of St. George in the following way. First values were adapted from Olesiuk (2012) for effective population size (N_e = 1,000 or 1,800 pups) and minimum viable population size (7,000 adults or about 3,600 pups). These values were then partitioned among the six rookeries of St. George I., resulting in minimum values of 300 and 600 pups, respectively. This established a threshold range for comparison to empirical data. Pup numbers at four rookeries in the Pribilof Islands occurred in this threshold range during the period 1912–1922, when the fur seal population had begun recovering from vast, unregulated commercial harvests. Three of these rookeries fully recovered but one rookery did not; after reaching a high of just over 500 pups, this rookery eventually became extinct. Since the number falls within the threshold range, and as the high number of pups born at

a rookery that subsequently became extinct, a threshold of 500 pups was used to estimate the probability of quasi-extinction within 10 years.

Results

Table 1. provides values of QEP. Only Staraya Artil (St. George I.) and Ardiguen (St. Paul I.) exceed the quasi-extinction probability of 0.05, which Gerber and DeMaster (1999) define as a *dangerously high* probability of quasi-extinction. Figures 1 and 2 illustrate the estimates of $\log N_{ij}$ from 1990–2028.

Table 1: Rookery based estimates of QEP. QEP is the estimated probability that rookery pup production falls below 500 pups by or before year 2028

ISLAND	RCOD	QEP
St George	ECL	0.00
St George	ERE	0.00
St George	NOR	0.00
St George	SGZ	0.00
St George	SOU	0.00
St George	STA	0.48
St Paul	ARD	0.99
St Paul	GOR	0.00
St Paul	KIT	0.00
St Paul	LUK	0.00
St Paul	LZA	0.00
St Paul	MOR	0.00
St Paul	PCL	0.00
St Paul	POL	0.00
St Paul	REE	0.00
St Paul	TOL	0.00
St Paul	VOS	0.00
St Paul	ZAP	0.00
St Paul	ZAR	0.00

Acknowledgments

The findings and conclusions in the paper are those of the authors and do not necessarily represent the views of the National Marine Fisheries Service, NOAA. Reference to trade

names does not imply endorsement by the National Marine Fisheries Service, NOAA.

References

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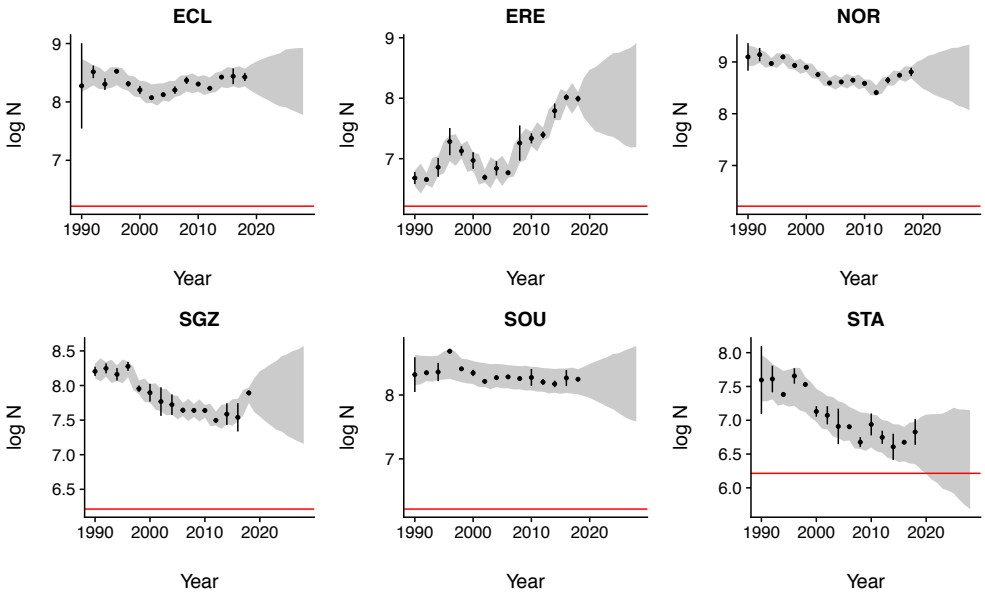

Figure 1: Projected pup production at St. George Island rookeries. Points with lines represent log pup production estimate $\pm$ 2 SE. The gray envelop represents the 95% credible interval for $\log N_{ij}$, the true production. Red line indicates quasi-extinction level of 500 pups.

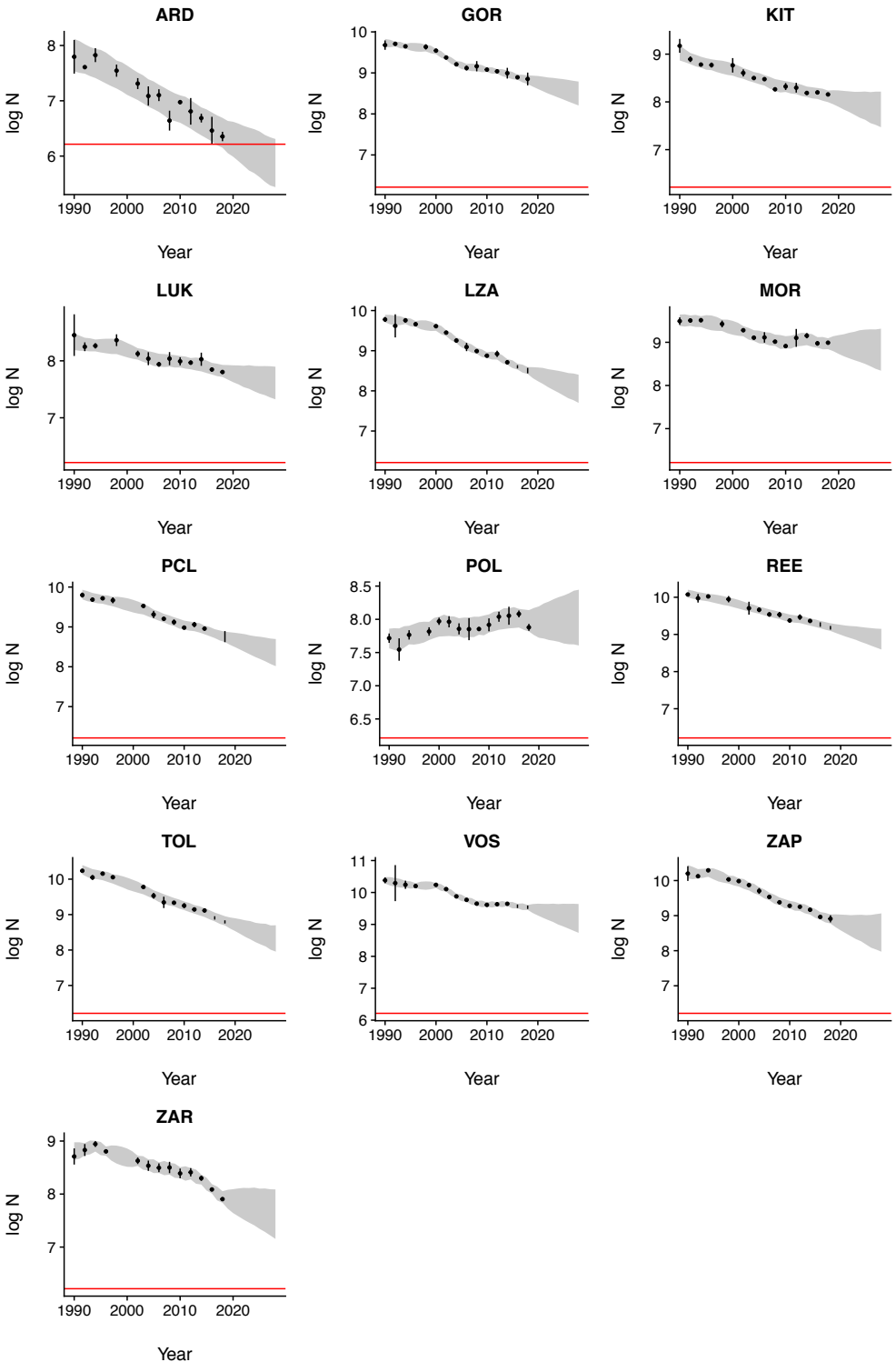

Figure 2: Projected pup production at St. Paul Island rookeries. Points with lines represent log pup production estimate ± 2 SE. The gray envelop represents the 95% credible interval for $\log N_{ij}$, the true production. Red line indicates quasi-extinction level of 500 pups.