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Summary: This memo describes a simulation examining the behavior of pup/nonpup ratios (pup:np) calculated from aerial survey data when used as a proxy or index for natality. In addition, we provide some estimates of pup/nonpup ratios for the WDPS of Steller sea lion using current survey data collected by NMFS from 1990-2012. In scenarios that included a decline in natality, the pup:np was generally a powerful proxy for natality as long as the decline in natality was relatively steep. When natality did not change, the error rates were also generally low. However, the simulations illustrate that pup:np can decline when natality remains constant. Thus, if inference about pup:np were being used as a substitute for inference on the natality process, an error (i.e., statistical type I error) would be made in concluding that natality had declined as pup:np had declined. However, this occurred in only one of 7 scenarios tested where both nonpup counts and the pup:np ratios declined in unison. In this scenario, juvenile survival declined precipitously in the beginning followed by a gradual climb to pre-decline levels. Trends in pup:np were non-significant for all regional aggregations of the real Steller sea lion survey data, with some decreasing and others increasing. The pup:np ratio in the western Aleutian Islands, the region of highest concern, declined most steeply of any WDPS region, but the decline was not statistically significant.

The findings and conclusions in the paper are those of the author(s) and do not necessarily represent the views of the National Marine Fisheries Service.





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SECTION 515 PRE-DISSEMINATION REVIEW & DOCUMENTATION FORM

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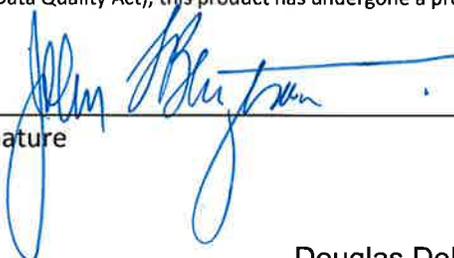
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PRE-DISSEMINATION REVIEW:

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

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Date

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

Tom Gelatt, Leader, Alaska Ecosystems Program


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26 Nov 2013
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DATE: September, 2013

MEMORANDUM FOR: Tom Gelatt, Program Leader, AEP, NMML
John Bengtson, Director, NMML
Doug DeMaster, Director, Alaska Fisheries Science Center

FROM: Devin S. Johnson, Statistician (Biology), AEP, NMML
Lowell Fritz, Research Biologist, AEP, NMML

SUBJECT: Pup/Nonpup ratios in WDPS Steller sea lion population

Summary

This memo describes a simulation examining the behavior of pup/nonpup ratios (pup:np) calculated from aerial survey data when used as a proxy or index for natality. In addition, we provide some estimates of pup/nonpup ratios for the WDPS Steller sea lion stock using current survey data collected by NMFS from 1990-2012. The simulations illustrate that pup:np can decline when natality has remained constant. Thus, if inference about pup:np were being used as a substitute for inference on the natality process, an error (i.e., statistical type I error) would be made in concluding that natality had declined as pup:np had declined. However, there was only one scenario tested where this would occur when nonpup survey counts and pup:np declined in unison. In this scenario, juvenile survival declined precipitously in the beginning followed by a gradual climb to pre-decline levels. Trends in pup:np were nonsignificant for all regional aggregations of the real Steller sea lion survey data, with some decreasing and others increasing. In recent years, the region of highest concern is the western Aleutian Islands (W ALEU). The pup:np ratio declined most steeply there, but, the decline was not statistically significant. In addition, average pup:np values for each region 2000—2012 centered on 0.34 with a range 0.22—0.61.

Introduction

There are at least 5 demographic rates, including natality, that can affect counts of pups and non-pups through time, and hence the ratio of the two (Table 1). For the numerator (pup counts), if natality (the average number of pups born per adult female) or neonate survival (rate of survival





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between birth and when we survey) are increasing and all other factors remain stable, then the pup:np ratio will also increase; the ratio will decrease if the two rates are decreasing. By contrast, any demographic rate that increases the NP count (denominator) will decrease the pup:np ratio (and vice versa). Thus, if adult/juvenile survival is increasing (and all other rates are stable), the pup:np ratio will decrease. This is also true for immigration (movement factor increases) and availability (the proportion hauled out to be counted): if the number of nonpups immigrating into the study area or the availability is increasing, we would not only have a declining pup:np ratio, but we could also be given the false impression that the population is increasing.

In this memo we present some simulation results which seek to illuminate the behavior of the pup:np ratio from a survey-sampled population similar to the WDPS Steller sea lion population. After a short period of stable growth, we perturbed the population with various experimental treatments involving juvenile survival and natality. Our goal was to determine under a limited set of scenarios if some general patterns or problems could be observed for using pup:np ratios as a proxy for natality when investigating a declining population. Specifically, we were interested in cases where pup:np ratios might decline even when natality remained unchanged. In those cases, significant declines in pup:np ratios would lead to the type I error that natality had declined as well.

Methods

Demographic models

We based the initial population on the 1970s era age-structured matrix population model used by Holmes et al. (2007) (hereafter, HFYS). This model has a growth rate of 1.0, therefore, represents a stable population. Following the HFYS parameterization of survival and natality through time, we modeled female survival, $S_{a,t}^f$, for age a animals at time t as

$$S_{a,t}^f = \phi_a p_{a,t},$$

where, ϕ_a is the 1970's era stable survival for age a and $p_{a,t}$ is an adjustment to survival at time t that depends on the experimental treatment. We modeled male SSL dynamics by assuming a 50/50 sex ratio at age 0, and a fixed ratio r_a between female and male survival (i.e., $S_{a,t}^m = S_{a,t}^f r_a$). For this





experiment, we used r_a as calculated from the ratio of male to female survival estimates in Calkins et al. (1982). Natality was modeled as

$$f_{a,t} = \eta_a q_{a,t},$$

where η_a is the 1970s era natality rate for age a animals and $q_{a,t}$ is an adjustment that depends on the experimental treatment.

Survey sampling

Following the method of Conn et al. (2013) we simulated the case where the population is sampled by annual SSL aerial surveys that count the total number of pups and non-pups (age 1+). The non-pup survey value, I_t was simulated by

$$I_t = p \left\{ \sum_{a=1}^{30} (N_{a,t}^f + N_{a,t}^m) \right\} \exp(\varepsilon_t),$$

where $N_{a,t}^f$ is the number of females of age a in the population at time t , $N_{a,t}^m$ is the number of age a males, p is the proportion of non-pups available for sampling, and ε_t is mean zero Gaussian distributed noise with standard deviation set to the desired CV of 0.05. The availability proportion was set to a constant $p = 0.5$. This is a reasonable value relative to the haul-out proportions reported in Appendix E of Holmes et al. (2007). We also simulated surveys of SSL pups, where generated pup counts, P_t , were simulated from a binomial distribution with success probability 0.95:

$$[P_t] = \text{Binomial}(N_{0,t}, 0.95),$$

where $N_{0,t}$ is the number of pups present at time t . We assumed all pups were available for detection, but, 5% were missed on average. The pup:np ratio was then calculated as $R_t = P_t/I_t$ for each year that the population was surveyed.

We recognize that this sampling simulation underestimates the true uncertainty in actual surveys because of sites with missed surveys (e.g., Johnson and Fritz, 2013) and differing availability through time and space. However, there is little information with which to base alterations, so, we used a CV=0.5. The main goal of this experiment is to determine how pup:np ratios behave under certain demographic conditions. So, with that target in mind, the larger CVs will only serve to further muddle results.





Simulation experimental design

There are, for all practical purposes, an infinite number of possible combinations of alterations to survival and natality that could be examined in an effort to investigate the properties of the pup:np ratio with respect to the actual natality process occurring in the population. However, here we investigated only 18 scenarios that provide a general picture of how R_t behaves. First, there has not been any evidence of a dramatic decline in adult survival for SSL, so we forced adult survival to remain at stable levels throughout the experiment, i.e., $p_{a,t} = 1$ for $a \geq 4$. Next, juvenile survival was altered as a unit, i.e., $p_{a,t} = p_{J,t}$ for $a < 4$. Natality was altered identically for all ages, i.e., $q_{a,t} = q_t$.

Using the previous guidelines we examined the 18 scenarios that are listed in Table 2. In the first scenarios (i.e. treatments), we simulate changes in survival and natality similar to the estimated changes in the optimal model observed by HFYS ($p_{J,t}$ and q_t estimates given in HFYS Table 3). In Table 2 these are denoted with “HFYS” in the juvenile survival and natality columns. Second, we held natality constant at stable levels and allowed juvenile survival to decline by -10%, -30%, and -60% over the course of the sampling period. Next, we reversed the treatment and allowed survival to remain at stable levels and let natality decline by -10%, -20%, and -30% over the course of the sampling period. In the next set of scenarios we allowed juvenile survival and natality trends to progress in opposite directions, e.g., juvenile survival increased 20%, while natality declined 20% over the course of sampling. Survival and natality were made to decline together in scenarios 15 and 16, Finally, survival increased while natality remained constant in scenarios 17 and 18.

The simulations were run using the SSLfish package (Conn et al., 2013) in the R statistical environment (R Development Core Team, 2013). Each simulation treatment was allowed to run at 1970s stable levels for 10 years to “burn in.” Following burn-in, the simulation was run for 22 years approximating yearly surveys from 1990 through 2012. Treatments were all replicated 4,000 times. For each replication, a linear model was fit to $\log R_t$ vs. year t . This was done to test the power (scenarios with declining natality) or type I error (scenarios with increasing or constant natality) for a hypothetical one-tailed statistical test of negative change in R_t as a proxy for negative change in natality.





Analysis of actual SSL survey data

In this section we outline the analysis of actual data from NMFS surveys of the WDPS population of Steller sea lions in Alaska. The data were analyzed using the agTrend (Johnson and Fritz, 2013; <http://nmml.github.io/agTrend/>) package for the R statistical environment (R Development Core Team, 2013). The Bayesian posterior distributions for P_t and I_t , hence R_t , were approximated with the MCMC sampling algorithm in agTrend for various site aggregations of the WDPS range. Next, the posterior distribution for the linear trend of $\log R_t$ from 2000-2012 was evaluated for each subregion using the MCMC algorithm in agTrend. In addition, the average R_t was evaluated for the years 2000-2012. There is demonstration code in the agTrend package for analyzing this data. The data is also available in the agTrend package.

Results

Simulation experiment

The results of the simulation are provided in Table 2. There are a few notable results. The first being scenario 2. In this scenario natality remained constant throughout the survey period, while juvenile survival declined according to the schedule presented in HFYS; a dramatic initial drop followed by an up-and-down climb back to nominal 1970s levels. In virtually every replication a significantly negative trend in R_t was recorded, leading to the erroneous conclusion that natality declined as well through that period. Figure 1 illustrates the distribution of simulated R_t values for scenario 2. If juvenile survival remained constant, R_t was a fairly powerful proxy for natality with power > 0.9 . Under mild decline in natality, R_t was a less powerful proxy (power = 0.38). In fact, if natality remains constant and juvenile survival declines, then R_t actually increases though time, as one might expect. When juvenile survival and natality decline in unison, power is extremely low for detecting the decline in natality (approximately 1%). The type I error rate for declaring a decline in natality when survival is increasing and natality is constant is also quite high ($>50\%$).

WDPS survey data





The results for analysis of the real survey data for the WDPS population of Steller sea lions are presented in Tables 3 and 4. Trend in $\log R_t$ are presented in Table 3. There were no significant relationships in the trend analysis. As a whole, for the WDPS, R_t was declining at a nonsignificant rate. When further divided in to subregions, there were mixed results with some areas increasing and some decreasing (Figure 2). The W ALEU region is the area of most concern. The decline there was $2.28\% y^{-1}$; the greatest decline of all the regions, yet not statistically significant.

Discussion

Overall, while the pup:np ratio is far from a perfect proxy for natality, under many situations it works well. If no other information on natality is available, it can be used but it is important that all caveats and information about other factors outlined in Table 1 should be noted and appropriate weight given to this information. The main reason that pup:np ratios are better than initially thought is that we are usually interested in limiting the situations where there is conservation concern, e.g., a declining abundance.

The results illustrate that a decline in natality is not always necessary to produce a decline in pup:np ratios. For pup:np ratios to produce erroneous inference on the natality process, i.e., show decline when the corresponding decline in natality does not exist, the number of nonpups that are not associated with pups must initially decline then regain relative abundance later, while the population as whole declines and natality remains constant. Scenario 2 illustrates that a large initial decline in juvenile survival followed by a gradual return to higher survival will produce a spike in R_t that reduces as juveniles continue to survive at a higher rate. In scenarios that included a decline in natality the R_t metric produced a generally powerful proxy as long as the decline in natality was relatively steep. When natality did not change, the error rates were low aside from scenarios 2, 17, and 18. Of those three, only scenario 2 should give concern as it is the only one that results in a declining population.

The W ALEU is currently the primary region of concern. In the W ALEU, counts of pups declined faster ($-9.35\% y^{-1}$) than non-pups ($-7.23\% y^{-1}$) between 2000 and 2012 (Johnson and Fritz 2013), which is the primary reason why the pup:np ratio also declined (from ~ 0.35 to ~ 0.27 , but at a non-significant rate of $-2.28\% y^{-1}$). To get even an uncertain decline in the pup:np





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ratio over time regardless of the population trend, natality or neonate survival must be declining, and/or non-pup survival must initially decline followed by recovery, numbers of nonbreeding non-pups (e.g., juveniles) must be immigrating to the W ALEU, or non-pup availability must be increasing (the 'Ratio decreasing' cells in Table 1 and pup:np trend column of Table 2). Let's examine three of these for the declining W ALEU population:

- Neonate survival decrease: While we have limited data to address this, there is no evidence to suggest that neonate survival has decreased in the 2000s: we have not observed increasing numbers of dead pups during our pup counts, aerial surveys, or other visits to the W ALEU rookeries.
- Non-pup availability increase: If non-pups hauled out more frequently during the day through the early 2000s, this would tend to increase the non-pup count, yet non-pup counts declined. This is also logically inconsistent with both declining pup and non-pup counts, since it suggests that foraging efficiency improved.
- Increasing number of immigrating juveniles and non-reproducing adults: Similar to a hypothetical increase in availability, an increase in the number of immigrating non-pups is also inconsistent with declining regional non-pup counts.

Thus, the non-significant decline in the W ALEU pup:np ratio appears to be reflecting changes in natality (decline) or NP survival (increase), or both over the last 12 years, and perhaps since 1990 (when the ratio was ~0.41). If we examine the population growth and pup:np trend columns of Table 2, there are only 7 scenarios in our simulation experiment (1-3, 9-10, and 15-16) that have the potential to describe the W ALEU dynamics, declining nonpup counts and declining (nonsignificantly) pup:np ratios. Of these 7 scenarios, 6 involve a declining natality process, with scenario 2 being the exception.

We do not have complete independent information on either survival or natality for Steller sea lions in the W ALEU. However, there is some preliminary information on survival. In June 2011, NMFS branded 54 Steller sea lion pups at Gillon Point rookery on Agattu Island (173°E) in the western Aleutians. Between June and November 2012, 26 of these 54 branded animals were observed, indicating that at a minimum, 48% survived at least one year, which is greater than the average first year minimum survival rate (39%) for all sea lions branded in 2000-





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2005 east of Samalga Pass (range of 9-60%; Fritz et al. in review). Adding 9 or 10 more years of sightings improved the estimated survival to age 1 y of the east of Samalga Pass cohorts and should similarly improve estimates of survival to age 1 y in the western Aleutians. Preliminary information from the Commander Islands, Russia, indicates that adult female survivorship may be similar to western DPS survivorship in the region east of Samalga Pass in AK (Altukhov et al., in preparation; Fritz et al. in review), despite the lack of recovery in the Commander Islands and the surrounding western Bering Sea (V. Burkanov, personal communication). If adult and age 1 y survival is not compromised in the W ALEU, then juvenile age 2 and 3 y survival, natality, or both must have dropped given that pup and non-pup counts declined significantly and the pup:np ratio has had an uncertain decline since 1990.

Some of the pup:np ratios in Tables 3 and 4 and Figures 2-3 appear to be counter-intuitive given the regional population trends. Examination of some of these will show how animal movement and regional definition can affect pup:np ratios. For instance, the E GULF has the lowest ratio (0.22) yet has increasing pup and non-pup counts, RCA 3 has the highest ratio (0.61) yet has a declining population, and the east of Samalga Pass region (0.32 with increasing population) has a lower average pup:np ratio than west of Samalga Pass (0.38 with decreasing population). The low ratio in the E GULF may be explained by the large number of haul-outs and few rookeries in the region (large non-pup population not associated with pups), and immigration of juveniles from the C GULF as evidenced by sightings of branded animals (Fritz et al. 2013). The high ratio in RCA 3 may result from the opposite condition as the E GULF: large number of rookeries and few haul-outs in the region (small non-pup population not associated with pups). As for comparing the regions east and west of Samalga Pass, both have approximately the same ratio in 1990 (0.36). The east Samalga ratio drops in the 1990s, possibly reflecting an improvement in survival, followed by ratio stabilization as population abundance increased. There is no drop in the ratio in the 1990s or 2000s west of Samalga Pass, suggesting little to no improvement in survival and perhaps erosion in natality as abundance declined (similar to scenarios 15-16 in Table 2).

We caution direct statistical comparisons of absolute values of pup:np ratios (Table 4) between regions with respect to natality inference. In the simulations, we assumed constant nonpup availability through time (i.e., $p = 0.5$) and used only a single closed population. The





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number of nonpups to be sampled will depend on quantities such as the relative number of known haul-outs and rookeries in a region and inter-regional dynamics. We feel that making assumptions in space (e.g., multiple neighboring closed populations with identical availability) is too tenuous and that region-to-region comparisons of pup:np ratios with the goal of making inferences to actual natality should be avoided. Comparison of pup:np ratios over time (i.e., trends) within regions only requires the more palatable assumption of constant availability within each region over time, but allows different availability between the regions.

Additional avenues of research for the general use of pup:np ratios are the issues of availability and animal movement. This experiment assumed that availability remained at $p = 0.5$. In reality, animals could become more or less available to be counted if there are changes in at-sea foraging trip durations. Due to the fact that many areas of concern have declining pup and nonpup counts, this would be analogous to a situation where availability declines through time and the real population is stable or increasing. That situation would also be similar to a decrease in survival which implies fewer nonpups and a higher pup:np ratio, as was observed in scenarios 4–6 (but not in the W ALEU). Furthermore, if emigration is permanent, then it will behave similarly to reductions in survival. Those animals that leave the simulated study area, in essence, have “died” with respect to the simulated population, and the pup:np ratio would increase even with no change in natality; immigration of juveniles would have the opposite effect.

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Table 1.

Summary of Effect on pup:np ratio of each of 5 factors assuming no change in the other 4

Factor	Factor Increases	Factor Decreases
Natality	Ratio increases	Ratio decreases
Pup (neonate) survival	Ratio increases	Ratio decreases
NP Survival	Ratio decreases	Ratio increases
NP Movement	Ratio decreases	Ratio increases
NP Availability	Ratio decreases	Ratio increases





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Table 2.

Results of the simulation experiment. In the first three scenarios “HFYS” refers to the model fit by Holmes et al. (2007). In the remaining scenarios the numeric values represent the percentage change over the course of the survey period. The arrows in the growth and pup:np columns indicate general pattern of trend over the simulations. Black arrows represent situations similar to the W ALEU region where population growth and pup:np ratios trends have been negative.

Scenario	Survival	Natality	Population growth ^b	pup:np trend	Power	Type I Error rate ^a
1	HFYS ^d	HFYS	↓	↓	1.0	
2	HFYS	0	↓	↓		1.00
3	0	HFYS	↓	↓	1.0	
4	-60	0	↓	↑		0.00
5	-30	0	↓	↑		0.00
6	-10	0	↓	↑		0.00
7	0	0	–	–		0.03
8	0	-10	–	↓	0.38	
9	0	-20	↓	↓	0.94	
10	0	-30	↓	↓	1.00	
11	+10	-10	↑	↓	0.95	
12	+20	-20	↑	↓	1.00	
13	-10	+10	↓	↑		0.00
14	-20	+20	↓	↑		0.00
15	-10	-10	↓	–	0.01	
16	-20	-20	↓	–	0.01	
17	+10	0	↑	↓		0.52
18	+20	0	↑	↓		0.97

^a 1-tailed test of declining log pup:np ratio

^b Population growth for the last 12 years of the simulation. If the cell is blank, the trend was approximately level

^c Trend for all 22 years of the simulation. If the cell in blank, the trend was approximately level.

^d HFYS represents the step-function changes given by the best model in Holmes et al. (2007)





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Table 3.
Results for trend analysis of WDPS pup:np ratios in various regional aggregations for the years 2000–2012.

		Trend Estimate ^a	lower 95% CI	upper 95% CI
Region	W ALEU	-2.28	-4.75	0.28
	C ALEU	0.09	-1.33	1.65
	E ALEU	0.87	-1.11	3.06
	W GULF	-0.95	-3.27	1.63
	C GULF	0.6	-1.65	2.87
	E GULF	-0.52	-4.11	3.36
RCA	1	-2.28	-4.75	0.28
	2	-0.36	-3.64	3.44
	3	1.59	-0.66	3.87
	4	2.04	-1.31	5.50
	5	-1.74	-4.31	0.95
	6	0.83	-1.22	2.92
	7	-1.23	-3.66	1.29
	8	-1.82	-6.22	3.21
	9	1.86	-0.89	4.26
	10	-0.21	-3.59	3.23
Total		-0.22	-1.26	0.74
K2K ^b		0.02	-1.00	1.10
E/C GULF		-0.17	-2.29	1.90
E/A ALEU		-0.04	-1.65	1.58
Samalga Pass ^c	East	-0.09	-1.40	1.17
	West	-0.07	-1.50	1.24

^a Estimates and CI are in % growth form

^b Kenai to Kiska

^c Samalga Pass = aggregating sites east and west of the pass





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Table 4.
*Average pup:np ratios for aggregated regions in the WDPS
 Steller sea lion range for the years 2000–2012.*

		pup:np Estimate	lower 95% CI	upper 95% CI
Region	C ALEU	0.38	0.36	0.41
	C GULF	0.37	0.34	0.41
	E ALEU	0.34	0.31	0.37
	E GULF	0.22	0.19	0.25
	W ALEU	0.30	0.27	0.34
	W GULF	0.32	0.29	0.35
RCA	1	0.30	0.27	0.34
	2	0.30	0.25	0.36
	3	0.61	0.54	0.66
	4	0.28	0.24	0.32
	5	0.41	0.36	0.47
	6	0.33	0.30	0.36
	7	0.33	0.30	0.37
	8	0.31	0.23	0.39
	9	0.39	0.35	0.43
	10	0.22	0.19	0.25
Total		0.33	0.32	0.35
K2K ^a		0.35	0.34	0.37
E/C GULF		0.31	0.28	0.33
E/A ALEU		0.33	0.31	0.35
Samalga Pass ^b	East	0.32	0.30	0.34
	West	0.38	0.35	0.40

^a Kenai to Kiska

^b Samalga Pass = aggregating sites east and west of the pass



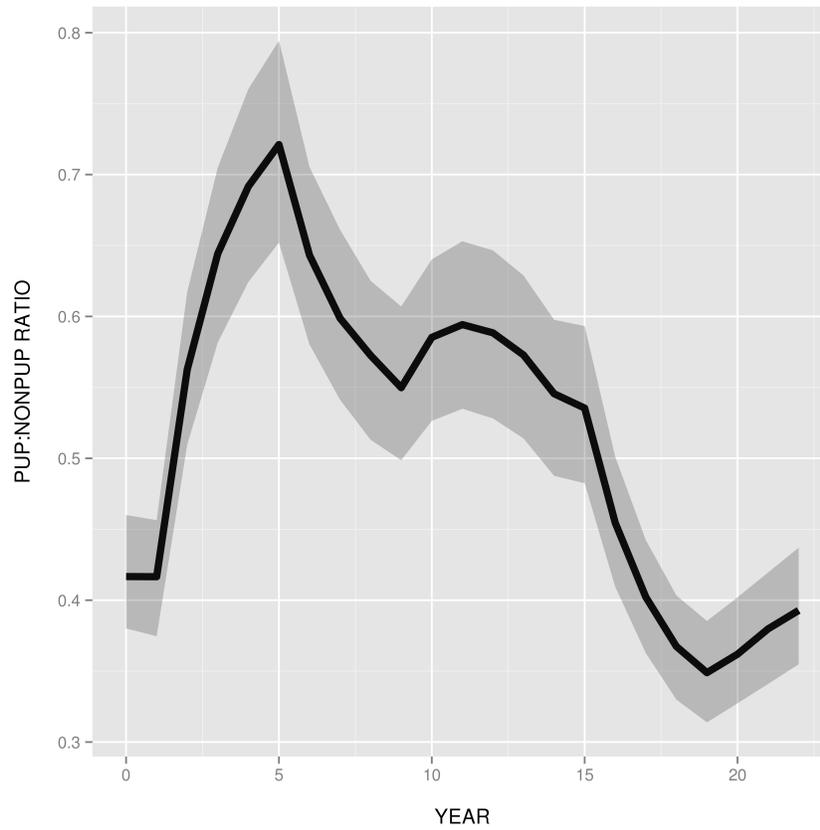


Figure 1. Simulated pup:np ratios under scenario 2 where natality was constant and juvenile survival changed according to the step function of Holmes et al. (2007). The black line represents the simulation mean and the grey envelope represents a 90% simulation interval. The YEAR axis represents years post burnin.

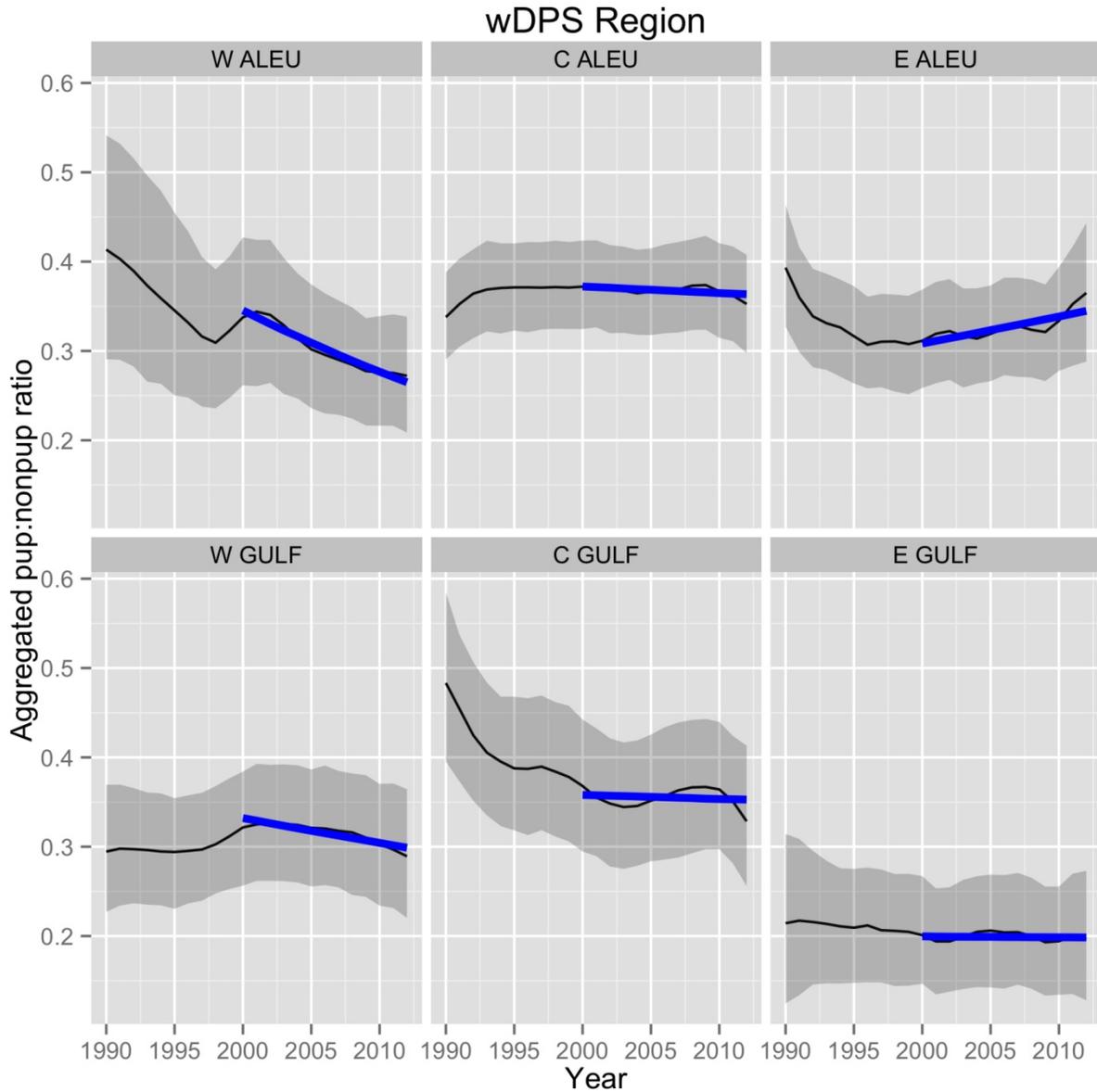


Figure 2. Estimated pup:np ratios from 1990-2012 by region in the western DPS in Alaska. Blue line is average rate of change for the 2000-2012 period. Black line is median estimate, and the gray zone is the 90% credible interval.





Figure 3. *Estimated pup:np ratios from 1990-2012 in regions east and west of Samalga Pass in the western DPS in Alaska. Blue line is average rate of change for the 2000-2012 period. Black line is median estimate, and the gray zone is the 90% credible interval.*