SC/38/PS19

Reanalysis of Rate of Change in the California-Chukotka Gray Whale Stock, 1967/68 – 1979/80

S. B. Reilly

Southwest Fisheries Center, NMFS, NOAA, P.O. Box 271, La Jolla, CA 92038, USA

ABSTRACT

A statistical analysis of the relationships among annual population estimates, mean annual visibility and mean distance offshore of passing whales from the 1967-1980 Monterey gray whale censuses indicates that there was in fact a significant positive rate of change in gray whale abundance during those years.

INTRODUCTION

The rate of change in size of the eastern Pacific gray whale population during recent years is a topic of interest to both US and international resource management organizations. An earlier analysis of the 13 year consecutive shore census series from Monterey, California concluded that the population had shown a net positive rate of change of about 2.5% per year from 1967/8 through 1979/80. A survey of other time series of gray whale population indices (Reilly, 1984) concluded that these other data sources were less reliable.

In a subsequent, brief review of information relevant to the net recruitment rate of eastern Pacific gray whales, Cooke (1986) suggested that the significant increase of 2.5% per year was an artifact of a statistical confounding of population estimates with the mean estimated distance offshore of passing whales, which had not been taken into account in the original trend analysis (Reilly *et al.*, 1983). Cooke included in his analysis only data collected during the first 11 years of the Monterey series, as published in Reilly *et al.* (1980). The present study was undertaken to test Cooke's (1986) result, given the additional two consecutive years' data available.

In examining factors relevant to variation in the mean estimated distance offshore of passing whales, one must include sighting or visibility conditions. It is in keeping with both sighting theory and common sense that as visibility conditions worsen, more whales far from shore will be missed, and mean recorded distance will decrease. In this paper I report on a simple statistical examination of the relationships among the annual population estimates, estimated mean offshore distances and mean visibility conditions, and the time sequence of the estimates.

METHODS

The data analyzed here were from the US National Marine Mammal Laboratory's Monterey gray whale census data base. The procedures used and the variables recorded in the Monterey censuses were described in Reilly *et al.* (1980, 1983) for the years 1967-1980. The population estimates and their variances were also taken from Reilly *et al.* (1983).

Population estimates for the 1984/85 and 1985/86 Monterey censuses were not included in this analysis because they are not strictly comparable with the estimates for 1967/68 through 1979/80. In estimating total abundance from the actual counts Breiwick and Dahlheim (1986) did not include correction for whales missed offshore. The offshore distances recorded in the later two censuses appeared to differ markedly from those recorded during the 13 year series from 1967/8 through 1979/80, so correction factors estimated during the earlier series were of questionable relevance.

The data used in this analysis were annual estimates of abundance, mean estimated offshore distance of passing whales and average sighting conditions. The annual average visibility codes and distance estimates were computed from data collected on 'good' visibility days. The data from 'poor' visibility days were excluded here from the computation of mean visibility and distance. This follows the population estimation procedure of Reilly *et al.* (1983) where the number of whales passing on 'poor' days was estimated from a gamma probability model (which had been previously fitted to the time sequence of daily counts) rather than from the the raw data. That is, a day's count data were included here (in the computation of annual mean visibility and distance) if the average visibility code for the day was 4.0 or less, on a scale from 1 (excellent conditions) to 6 (very bad) following Reilly *et al.* (1983). Table 1 lists the annual population estimates, mean visibility and distance estimates (and accompanying statistics) used in the trend analysis.

Table 1

Annual population estimates (N), their std. deviations (sd(N)), mean visibility codes (V) recorded on 'good' visibility days (see text for definition), their std. errors (se(V)), mean estimated distances (D) of pods sighted on 'good' visibility days their std. errors (se(D)) and sequence number of the year (T). All statistics are from the Monterey gray whale censuses.

Year	N	sd(N)	V	se(V)	D	se(D)	T
1967/8	13095	1276	2.46	0.153	0.60	0.114	1
1968/9	11954	1545	2.28	0.170	0.45	0.082	2
1970/1	11177	1625	2.58	0.105	0.57	0.085	4
1971/2	10414	918	2.45	0.110	0.73	0.126	5
1972/3	14534	1348	2.63	0.103	0.67	0.099	6
1973/4	14676	1558	2.68	0.133	0.62	0.112	7
1974/5	13110	1366	2.22	0.136	0.82	0.144	8
1975/6	15919	1803	3.47	0.111	0.46	0.085	9
1976/7	16621	1798	2.73	0.113	0.41	0.066	10
1977/8	14811	2272	3.48	0.153	0.38	0.106	11
1978/9	13676	1127	2.14	0.122	0.73	0.107	12
1979/80	17577	2364	2.55	0.127	0.64	0.113	13

The basic method used to investigate trends in the population estimates with time was stepwise multiple regression. The correlation matrix is also presented (Table 2).

Table 2

Correlation matrix. N is annual population estimate. SD(N) is std. deviation of the N. V is mean visibility code recorded during 'good' visibility days. SE(V) its std. error. D is the mean estimate of offshore distance of counted pods. SE(D) its std. error. T is the year, with 1967/8 scaled as 1. * Significantly different from zero at alpha < 0.05.

	N	SD(N)	V	SE(V)	D	SE(D)	T
N	1.000						
SD(N)	0.681*	1.000					
V	0.435	0.600*	1.000				
SE(V)	–0.164	0.172	–0.092	1.000			
D	–0.287	–0.600*	–0.667*	–0.293	1.000		
SE(D)	–0.215	–0.305	–0.322	0.093	0.778*	1.000	
T	0.719*	0.487	0.282	–0.343	0.027	0.076	1.00

Five simple models were examined: (1) annual population estimate (N) as the dependent variable in a simple linear model, with no weighting; (2) N, weighted by 1/var(N); and (3) an exponential model, made linear by transforming N to ln(N), with weights N^2/var(N) (see Reilly *et al.*, 1983 for derivation). In these first three models, the following variables were available for inclusion in the predictor set: time (T, in years, with 1967/68 defined as 1), average annual visibility code (V), and average offshore distance of sighted pods (D). In the exponential models, ln(D) and ln(V) were used in place of D and V. Variables were selected for inclusion in the model if the alpha level was 0.05 or less from a test of the hypothesis that the variable's regression coefficient was equal to zero.

Model 4 was the same as model 2 except that D and V were included in the regression regardless of their contribution to model fit (i.e. forced), to examine the resultant slope of N on time. Model 5 was the same as model 3 except for the forced inclusion of ln(D) and ln(V).

RESULTS

Six variable correlations were significantly different from zero (Table 3). Two of these were correlations of estimates with their dispersion statistics (N with SD(N) and D with SE(D)), and were to be expected. The other four are noteworthy. There was a high, positive correlation of population estimate with time ($r = 0.72$), and no significant correlations of N with D or V. There was, however, a large negative correlation of V with D ($r = -0.67$), that is, as visibility conditions became worse (the average code recorded increased) the mean estimated offshore distance decreased. There were also significant correlations of D and V with the standard deviation of the population estimates. Higher SD(N)s were associated with worse visibility conditions and mean distance estimates closer to shore.

Neither D nor V were included in a stepwise regression (Table 3) with N in the first three models, under a standard entry criterion of alpha < 0.05. In the simple model (no. 4) where D and V were included in the regression there was a small increase in the estimated rate of increase in comparison to model 2 which included only N and T (b = 344 vs 313 whales per year, where b is the slope of the regression). In the exponential model where ln(D) and ln(V) were forced (no. 5) there was no change in the estimated rate of increase in relation to model 3, which did not include D and V.

DISCUSSION

Given the population estimates and variances from Reilly *et al.* (1983) we find a significant increase in population size indicated for the period 1967-1980, even when the annual mean visibility conditions and mean offshore distance estimates were taken into account. The significant negative correlation of offshore distance estimates and mean visibility conditions, along with the correlations of these variables with the standard deviation of the population estimates is understandable. As visibility conditions worsen, more whales far from shore are missed. This pattern remains even after discarding all data from days with poor average visibility conditions.

A higher mean visibility code on the 'good' days is almost certainly associated with more 'bad' days in a year. Also, there is a large variance contribution (in the abundance estimation procedure of Reilly *et al.*, 1983) from using the gamma model to estimate a day's number of whales passing rather than using the actual count. Thus a higher variance (or standard deviation) for an annual abundance estimate would be associated with a higher mean visibility code.

While the unweighted regression of N on T (model no. 1) resulted in a better fit to the data, the weighted models are

Table 3

Summary of stepwise multiple regressions of population estimates (N), on time (T), average estimated offshore distance of sighted pods (D) and average visibility code (V).

Model/ Depend. var.	Weight	Selection criterion	Variables included	B values	SE(B)	P(t)	Model F	P(F)
(1) N	none	0.05	intercept	11,112.00			11.74	0.006
			T	390.29	113.9	0.006		
(2) N	1/ var(N)	0.05	intercept	11,132.57			5.44	0.039
			T	313.52	134.41	0.039		
(3) ln(N)	N^2/ var(N)	0.05	intercept	9.3313			6.80	0.024
			T	0.0251	0.0096	0.024		
(4) N	1/ var(N)	force V,D,T	intercept	13,114.29			3.81	0.052
			V	691.36	1731.38	0.699		
			D	–6,240.38	4691.97	0.216		
			T	344.06	125.36	0.023		
(5) ln(N)	N^2/ var(N)	force V,D,T	intercept	9.0354			3.59	0.061
			ln(V)	0.2236	0.3594	0.535		
			ln(D)	–0.1700	0.2139	0.411		
			T	0.0253	0.0092	0.024		

preferable, since they included the effect of a heterogeneous variance structure in the population estimates, and thus better met the assumptions of the regression model.

Given the lack of significant statistical association of annual mean distance and annual mean visibility statistics with the time trend of abundance estimates, there was no apparent reason to further consider (in this specific analysis) these factors, or the models into which they were forced. This does not imply that all possible effects on abundance estimation or trend analysis from variation in visibility conditions and offshore distance estimates have been considered and accounted for. Annual means may not contain sufficient information to fully reflect underlying processes.

The rates of increase estimated here were 2.29% per year (with 95% c.l. 0.33, 4.24) from the simple linear model weighted by the reciprocal of the variances (no. 2), and 2.51% per year (0.59, 4.43) from the weighted exponential model (no. 3). In both cases the coefficient of determination was somewhat low (0.33 and 0.38, respectively) and this was reflected in the broad confidence intervals. Model 3 reported here is the same model and results reported earlier in Reilly *et al.* (1983).

ACKNOWLEDGEMENTS

Thanks are due to Justin Cooke for suggesting this reanalysis, to Jeff Breiwick, Randall Peterman and Pierre Kleiber for helpful discussions. Randall Peterman (Simon Fraser University, Burnaby, B.C. Canada), Douglas Chapman (University of Washington, Center for Quantitative Science, Seattle, WA USA), Daniel Goodman (Montana State University, Bozeman, Montana USA), Justin Cooke (University of York, Heslington, York, UK) and Jean Michalski (Southwest Fisheries Center) provided useful comments on the draft.

REFERENCES

Breiwick, J.M and Dahlheim, M.E. 1986. Preliminary results from the 1985/86 gray whale census. Paper SC/38/PS14, presented to the IWC Scientific Committee, May 1986 (unpublished).

Cooke, J. G. 1986. On the net recruitment rate of gray whales with reference to inter-specific comparisons. *Rep. int. Whal. Commn* 36: 363-6.

Reilly, S.B. 1984. Observed and maximum rates of increase in gray whales, *Eschrichtius robustus*. *Rep. int. Whal. Commn* (special issue 6): 389-99.

Reilly, S.B., Rice, D.W. and Wolman, A.A. 1980. Preliminary population estimate for the California gray whale based upon Monterey shore censuses, 1967-68 to 1978-79. *Rep. int. Whal. Commn* 30: 359-68.

Reilly, S.B., Rice, D.W. and Wolman, A.A 1983. Population assessment of the gray whale, *Eschrichtius robustus*, from California shore censuses, 1967-1980. *Fish. Bull. U.S.* 81(2): 267-81.

Rugh, D., Ferrero, R. and Dahlheim, M. 1986. Inter-observer count discrepancies in a shorebased census of gray whales. Paper SC/38/PS15, presented to the IWC Scientific Committee, May 1986 (unpublished).