

Population assessment of Western Gray Whales in 2006

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ABSTRACT

A population assessment of the western gray whale (*Eschrichtius robustus*) was conducted using the photoidentification data collected off Sakhalin Island under the joint Russia-U.S. programme from 1994 to 2005. This is an update of the assessment by Reeves *et al.* (2005) which used data up to 2003, fitted to the same, individually-based population model. New median estimates of key population parameters (with 90% Bayesian confidence intervals) are 0.986 (0.975 - 0.995) for the adult survival rate; 0.72 (0.60 - 0.83) for the survival rate from calf to yearling; 3.0% *per annum* (2.1% - 4.2%) for the average annual rate of population increase over 1994-2005; 0.43 (0.37 - 0.50) for the female sex ratio and 122 whales (113 - 131) for the 1+ (non-calf) population size in 2006. The updated assessment is more optimistic than the Reeves *et al.* assessment. This is mainly due to reduced calving intervals observed in recent years, implying a higher reproductive rate. The modal calving interval has shortened from 3 years to 2 years in the most recent seasons, which is consistent with reduced disturbance from industrial activity during 2002-04. Forward projections of the population model to 2030, assuming no additional mortality or disturbance to reproduction, indicate a high probability (>99%) of population increase. Three whales (all female) were killed in fishing nets on the coast of Japan in 2005 during the northward migration. Projections of the female population incorporating extra mortality at the 2005 level indicate a high probability (~75%) of population decline and a substantial risk (>25%) of extirpation by 2030. It is important to avoid any further human-caused deaths in this depleted population.

1. INTRODUCTION

The western gray whale population is Critically Endangered and its continued ability to survive is of concern. Hunted to such low numbers by the mid 20th century that some thought it to be extinct, the population remains highly depleted today (Reeves *et al.*, 2005; Weller *et al.*, 2005). The International Whaling Commission (IWC) and the World Conservation Union (IUCN) have each expressed serious concern about the status of this population and have called for urgent measures to be taken to help ensure its protection (IWC, 2004; Reeves *et al.*, 2005).

While the breeding ground for the western population has yet to be determined, but is suspected to be off southern China, the feeding ground is known to be in the coastal waters off northeastern Sakhalin Island. To date, no other feeding area(s) outside of northeastern Sakhalin Island have been identified, making it clear that the conservation of the western gray whale is intricately related to this particular habitat. The potential impact on the population arising from the exploration and extraction of oil and gas resources in this area is a source of especial concern (Reeves *et al.*, 2005). Recently the death in 2005 of three female gray whales entangled in fishing nets on the coast of Japan highlights the existence other threats to this population (Kato *et al.*, 2005; IISG, 2006).

A joint Russia-U.S. research program on western gray whales off Sakhalin Island, Russia, was initiated in 1995 as part of the Marine Mammal Project under Area V: Protection of Nature and the Organization of Reserves within the U.S.-Russia Agreement on Cooperation in the Field of Environmental Protection (Weller *et al.*, 2005). Data from this ongoing Russia-U.S. collaborative study have highlighted the fragile state of the western gray whale population and are used for the analysis of this paper.

Using data collected under this programme, the Independent Scientific Review Panel (ISRP) appointed in 2004 by IUCN to examine the potential impact of the Sakhalin II oil and gas project on the Western Gray Whale and related wildlife, conducted a population assessment of the Western Gray Whale using the data collected through to 2003 (Reeves *et al.*, 2005).

Gray whales, like other large whales, have a multi-year calving cycle, with one or more resting years between successive calvings. Multi-stage models that take account of an individual female's reproductive stage (immature, calving, resting) have been successfully fitted to photo-identification data for right whales in the northern and southern hemispheres (Caswell *et al.*, 1999; Best *et al.*, 2001; Cooke *et al.*, 2001). The ISRP adapted the right whale stage-structure approach for application to western gray whales. The purpose of the population model was to provide a framework for further interpreting the photo-identification data so as to estimate key parameters, such as survival rates, and to determine whether the population is increasing or decreasing. The population model was also used to project the population forward under a range of scenarios. Such projections provide information relevant for determining a conservation strategy for the population.

This paper presents an update of this assessment using data collected through to 2005. Reports of the 2004 and 2005 field seasons are provided by Weller *et al.* (2005; 2006).

2. MATERIAL AND METHODS

2.1. Photoidentification and sex-determination data

Photo-identification data have been collected in the Piltun area of northeastern Sakhalin by the joint Russia-US programme from 1994 to the present, with the exception of 1996 (Weller *et al.*, 2006). Data from the seasons up to and including 2005 were available for this analysis. A total of 150 distinct individual whales (73 males, 51 females and 26 animals of unknown sex) have been catalogued. The catalogue is available as SC/58/BRG2 [CD].

A total of 55 calves were identified, of which 32 were male, 15 female and 8 of unknown sex. Sex determinations have been by biopsy, except that one unbiopsied whale was identified as female on the basis of an accompanying calf. Twenty-three individual females, none of known age, have been observed with a calf. Seven identified calves could not be assigned to a mother. Twenty-five inter-birth intervals have been observed, consisting of thirteen 2-year intervals, nine 3-year intervals, two 4-year intervals and one five-year interval (Table 1). The apparent 4 and 5-year intervals may be genuine intervals, or may be the result of failing to observe an intermediate calving, failure to assign a calf to its mother, or the loss of a calf before it could be observed and recorded.

Table 1. Lengths of observed calving intervals by end year

Total	Length of interval (years)				Interval ends
	5	4	3	2	
1				1	1997
1			1		1998
0					1999
1			1		2000
4			4		2001
3		2	1		2002
4			1	3	2003
6	1		1	4	2004
5				5	2005
25	1	2	9	13	Totals

Shaded cells represent intervals that are unobservable because they would have begun before the research started

The following information on each identified whale were used for this analysis:

- the year first seen, and whether first seen as a calf (and whether accompanied or unaccompanied) or as a non-calf;
- the subsequent years in which the individual was seen, and the subset of these years in which it was seen with a calf;
- sex, if known.

2.2. Population model

The Population model is illustrated in Fig. 1 and described in more detail in the ISRP report (Reeves *et al.*, 2005) and in SC/57/BRG22 (Cooke *et al.*, 1995). The male population is divided into just three stages: calves (weaned and unweaned) and animals aged 1+. On the assumption that reproduction is not limited by the number of males, more detail is not needed for the males. The female population is divided into: calves (weaned and unweaned); age classes 1 through 4; immature animals aged 5+; mature animals which are resting or receptive (before their first calf or between calves); mature animals which have been resting for at least one year; and calving mothers (divided into those still accompanying their calf and those who have already weaned it). The time resolution of the model is one year, and the stages refer to the state of animals during the summer study season off Sakhalin Island.

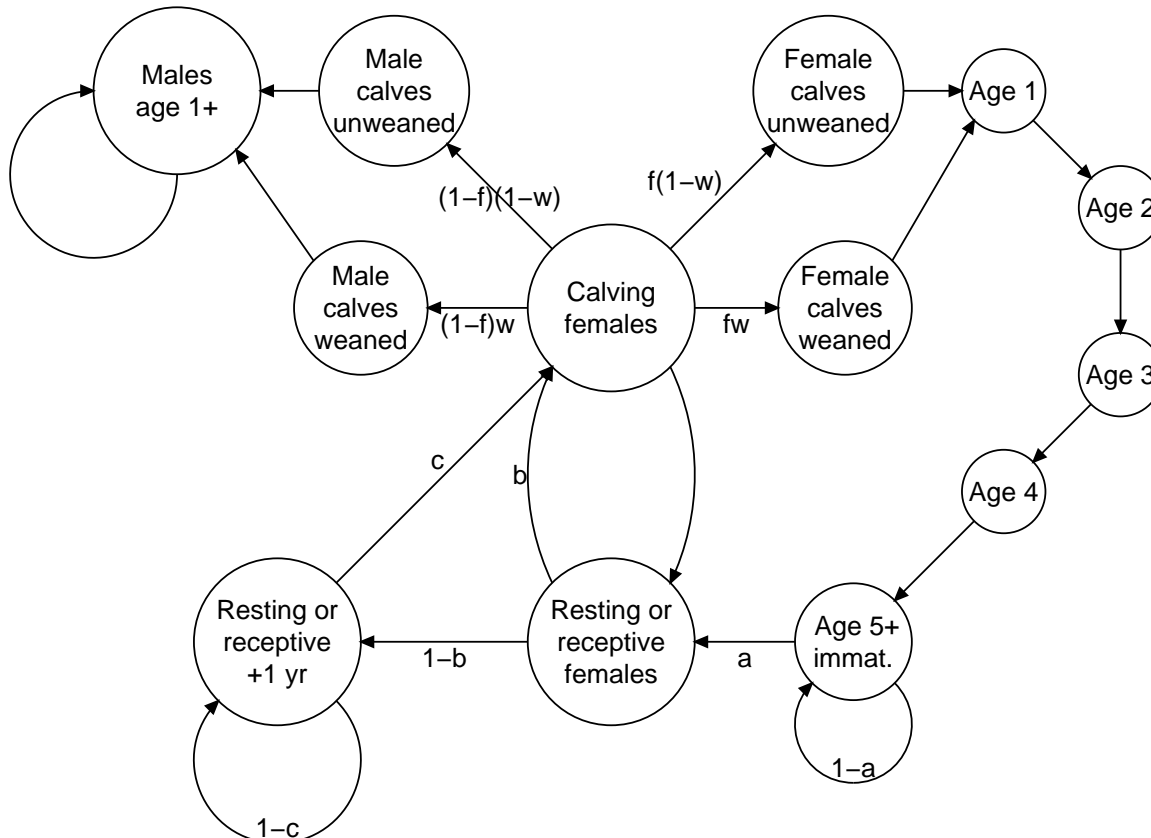


Fig. 1. Structure of population with transition probabilities/rates between classes (excluding mortality).

The distinction between weaned and unweaned calves has no demographic significance but is necessary for fitting the data because some calves have already separated before the Piltun study season and cannot be assigned to a mother.

Once a female has reached age 5, it is assumed thereafter to have a constant annual probability a of becoming mature. On maturity it then enters the first Resting/Receptive class where it has an annual probability b of having a calf the following year, and a probability $1 - b$ of entering the second Resting/Receptive class (females which have been resting for at least one year). After resting for a year, the whale has a probability c of having a calf the following year, and a probability $1 - c$ of resting for a further year. The youngest age a female can become mature is 6 years and the youngest age it can have a calf is 7 years. After having a calf, females return to the Receptive/Resting class. The probabilities b and c of “having a calf” actually refer to the probability that a calf is born and survives the migration to the study area. The minimum interval between calves in the data and the model is two years.

The calving probabilities b and c are allowed to vary randomly from year to year, as in the ISRP assessment. Since b and c must take values between zero and one, their variation is modelled on the logit scale. We write:

$$b_t = \frac{\exp(\beta + \sigma v_t)}{1 + \exp(\beta + \sigma v_t)} \quad c_t = \frac{\exp(\gamma + \sigma v_t)}{1 + \exp(\gamma + \sigma v_t)}$$

where β is a parameter determining the median calving probability without resting, γ is a parameter determining the median calving probability after resting, and σ determines their inter-annual variance. For each year, v_t is an independently distributed standard normal random variable which expresses the extent to which the favourability of external circumstances for reproduction differ from the average. The external factors that affect reproduction are still largely unknown, and we make no assumptions about their nature, apart from assuming that the variation in their effects on reproduction can be modelled as specified here.

The model has just two survival parameters: the calf survival probability S_j for calves to age 1; and the non-calf survival probability S . The “calf” survival rate S_j represents survival from the animal’s first summer season to the next summer season (*i.e.* age 6-18 months). Calf mortality before the first summer season is subsumed into the calving probability, which reflects the probability of producing a calf that survives to the first summer season.

2.3. Additional information

One female, apparently a yearling, died in a net in Tokyo Bay in May 2005 (Kato *et al.*, 2005). Two more whales (a mother and a female calf) were taken in a net near Enoshima, Oshika peninsula, northeastern Honshu, Japan in July 2005 (IISG, 2006). In the absence of genetic samples from the dead animals, it was not possible to determine whether the two non-calf animals were previously known individuals from Sakhalin, but we assume that the whales are from the population feeding off the northeastern coast of Sakhalin Island. The losses were accounted for in the population assessment by deducting one potentially calving female and one female yearling chosen randomly from the corresponding population components in the model before the 2005 field season, excluding individuals seen in the 2005 season from the random selection.

2.4. Fitting the model to the data

The data used for fitting the model consisted of the observation histories of each of the 150 individuals. Each observation history consists of the list of years in which the individual was seen, with the indication of the whether the individual was a calf or had a calf in the given year. The sex of the individual, where known, was also used. The fitting of the model to the data is Bayesian, as detailed in Annex F of Reeves *et al.* (1995) the ISRP report. The prior distributions of the parameters as specified in Table 1 are combined with the likelihood according to Bayes’ rule to produce the joint posterior distribution of parameters and population states in the years 1994-2006. A Monte Carlo Markov Chain algorithm was used to compute a random sample from the posterior distribution.

The formulation of the likelihood function reflects the assumptions made about the relationship between the whales’ actual biographies and the data. Because survey effort has been variable, we do not assume that all whales are present in the study every year, nor that they are necessarily identified in every year that they are present, nor do we assume that the probability that a whale is identified in a season is constant from year to year. Calves tend to separate from their mothers as the season progresses, and we do not always determine the mother of an observed calf. We therefore do not assume that whales seen without calves did not have a calf in the season. The probability of observing a whale in a given year is allowed to depend on the sex and life stage of the whale (*e.g.* immature, calving, resting) and to vary annually, as documented in the ISRP report.

2.5. Projections

Stochastic projections of the population forward to 2030 were generated by sampling randomly from the posterior distribution of parameter values and population states in 2006. Each sampled population state was simulated forwards on an individual whale basis as described by Reeves *et al.* (2005). For each year forward to 2030, the 1st, 5th, 10th, 25th and 50th percentiles of the distribution of population sizes was extracted from the sample of simulations for the following population components: total non-calf (aged 1+) population; reproductively mature females; aged 1+ females; and calves.

Two sets of projections were generated. The base case scenario assumed no additional sources of mortality apart from the 3 whales taken in 2005. The alternative scenario assumed that female population continues to be subject to the 2005 level of additional mortality (3 animals per year). The extra mortality was drawn randomly without replacement from the female population in each year from 2006 onwards, prior to the field season. Although it is not necessarily considered likely that the 2005 level of extra mortality will continue, the purpose of the scenario is to investigate the consequences that this level of mortality for the population.

3. RESULTS

3.1. Parameter estimates

Estimated distributions for the key population parameters in the base-case model are shown in Table 2. The median parameter estimates are 0.987 for the annual adult survival rate, 0.72 for the “calf” survival rate (*i.e.* survival from first to second summer season), 0.43 for the sex ratio (female proportion) and 3.0% per annum for the rate of population increase over the data series (1994-2005). Approximate 90% confidence limits are 0.975-0.995 for the adult survival rate, 0.69-0.83 for the calf survival rate, 0.37-0.50 for the female sex ratio and 2.1%-4.1% for the annual rate of population increase. The median estimate for the non-calf population size in 2006 is 122 animals (90% confidence interval 113-131). The median estimate of the number of mature females in 2006 is 30 with 90% confidence limits 26 to 35.

The distribution of the estimates of annual maturation probability of age 5+ females is hardly different from the assumed prior range (0.2–0.5). This implies that the data contain essentially no information on this parameter. This is because no known-age western gray females have yet been observed to have a calf. The prior range corresponds to a range for the population mean (not individual) age at maturity from approximately 7 to 10 years. If this series of western gray whale surveys is continued, then we would expect to start to see known age females reproducing over the next few years, which will substantially improve estimation of this parameter. The oldest known-age female observed in 2005 was seven years old.

The distributions for most of the other population parameters are clustered well within the prior ranges, and hence are not constrained by the assumed prior ranges. However, the data do not seem to place a well-defined upper bound on the variance of the annual calving probabilities.

3.2. Projections

The results of the base-case projections (no additional mortality or disturbance to reproduction) for four components of the population are shown in Figs 2a-d. The median projections show a substantial increase in the population by 2030. Even the 1st percentile of population sizes shows an increase, which implies a greater than 99% chance of a population increase to 2030, if the assumptions of this scenario hold. The projected population in 2030 is still substantially below estimated pre-whaling population levels (Weller *et al.*, 2002).

Under the assumption that the 2005 level of offtake continues, the female population is predicted to decline (Fig. 3), with a substantial probability (>25%) of extirpation by 2030. The trajectory of the 75th percentile (not shown) is approximately level, which implies a probability of ca. 75% for a decline in this scenario. While this is not necessarily a likely scenario, it does imply that the 2005 level of offtake is unsustainable.

4. DISCUSSION

The results of this modelling exercise demonstrate the utility of the data collected during the ongoing joint Russia-US programme in terms of estimating key population parameters and to draw inferences about the current status of the population and its likely future trend under different scenarios.

This assessment is more optimistic than the ISRP assessment (Reeves *et al.*, 2005), which used data only up to 2003. The new median estimate of the 1+ population size in 2004 is 114 animals, compared with 102 animals in 2004 in the ISRP assessment. In addition, the population is estimated to have increased from 114 to 122 animals between 2004 and 2006. These estimates compare with ordinary mark-recapture abundance estimates (not incorporating population structure) of 98 whales (95% CI=89-110) in 2002 and 99 (95% CI = 90-109) in 2003 (Wade *et al.* 2002; Weller *et al.*, in prep).

The main cause of the more optimistic assessment appears to be the shortening of calving intervals observed in the most recent years (Table 1.) The modal calving interval has reduced from 3 to 2 years and the proportion of 2-year intervals has increased. Of the observed intervals ending in 2004 and 2005, 9 out of 11 were just two years in length.

The good numbers of calves present during 2003-05 presumably reflect conditions during 2002-04. It is not possible to assign a specific cause to the variations in calf production, but the data are consistent with calf production tending to be good in years with little disturbance, because the 2002-04 seasons were apparently relatively quiet with little or no seismic surveying or construction work (IISG, 2006). However, the number of skinny whales observed in 2005 is notably higher than was recorded in the 2002 to 2004 period (Brownell and Weller 2001; Weller *et al.*, 2006) which might impact calf production in 2006.

Offshore construction work for the Sakhalin II project resumed in 2005 and continues in 2006 (IISG, 2006). If calf production is negatively impacted by disturbance due to construction work, then lower calf production might be expected in 2006 and 2007. However, in the absence of more direct evidence for such a relationship, this factor was not considered in the population projections.

The unsustainability of the 2005 level of net-caused mortality is a source of concern in such a small population. If this level of mortality continues, the population is projected to decline towards extirpation. Every effort should be made to avoid a recurrence of these mortality events and to minimise or eliminate human-caused mortalities in this depleted population.

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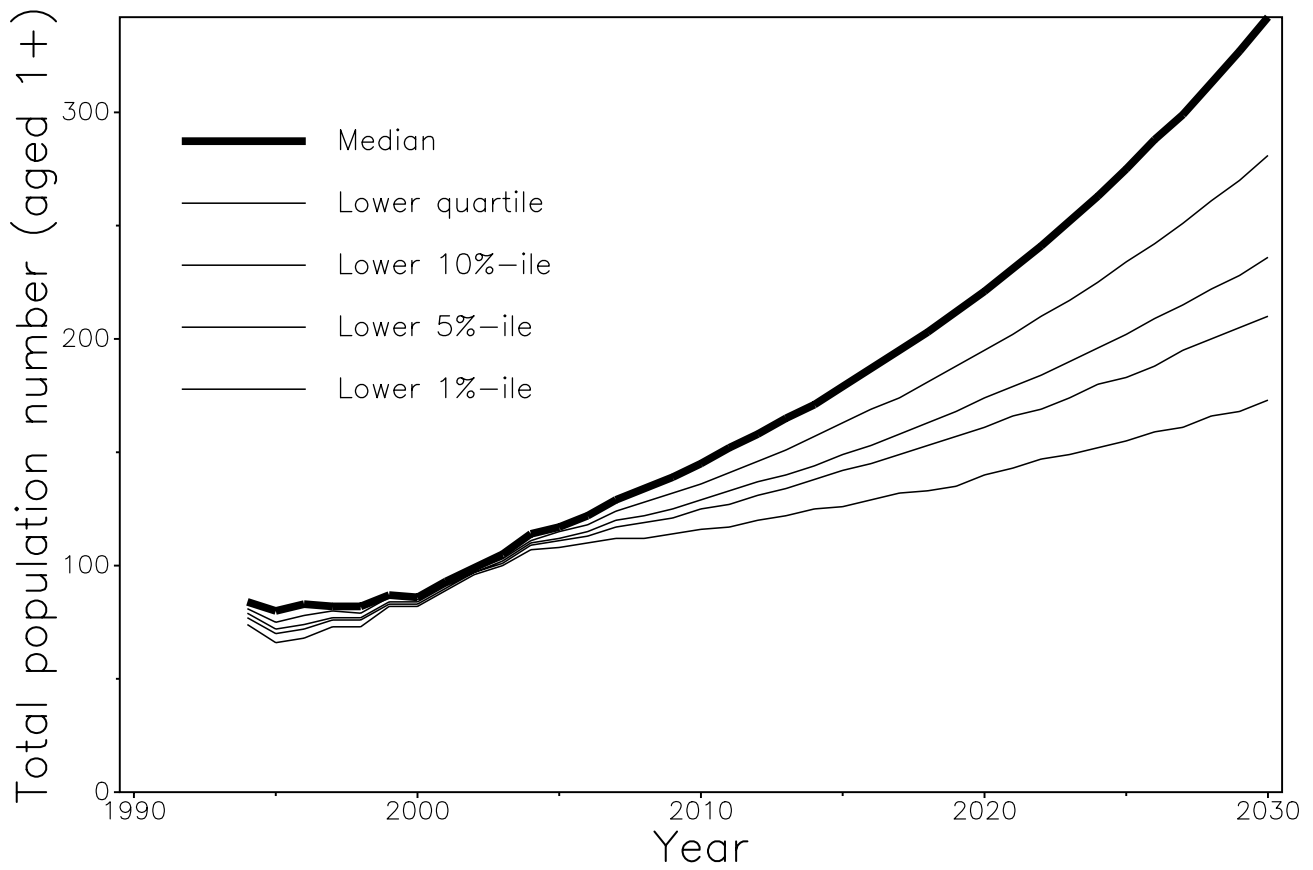


Fig. 2a. Western Gray Whale population trajectories 1994–2030: 1+ population

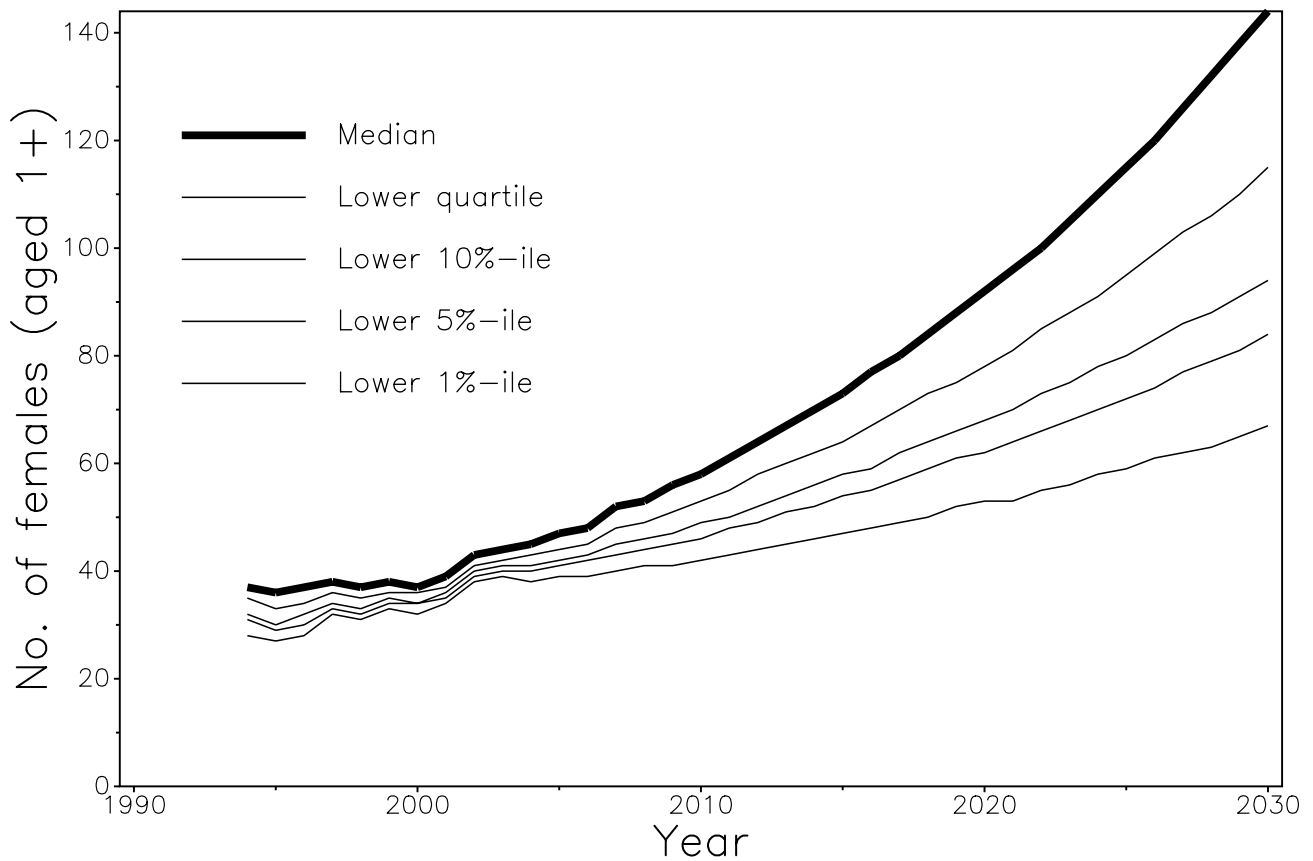


Fig. 2b. Western Gray Whale population trajectories 1994–2030: Female 1+ population

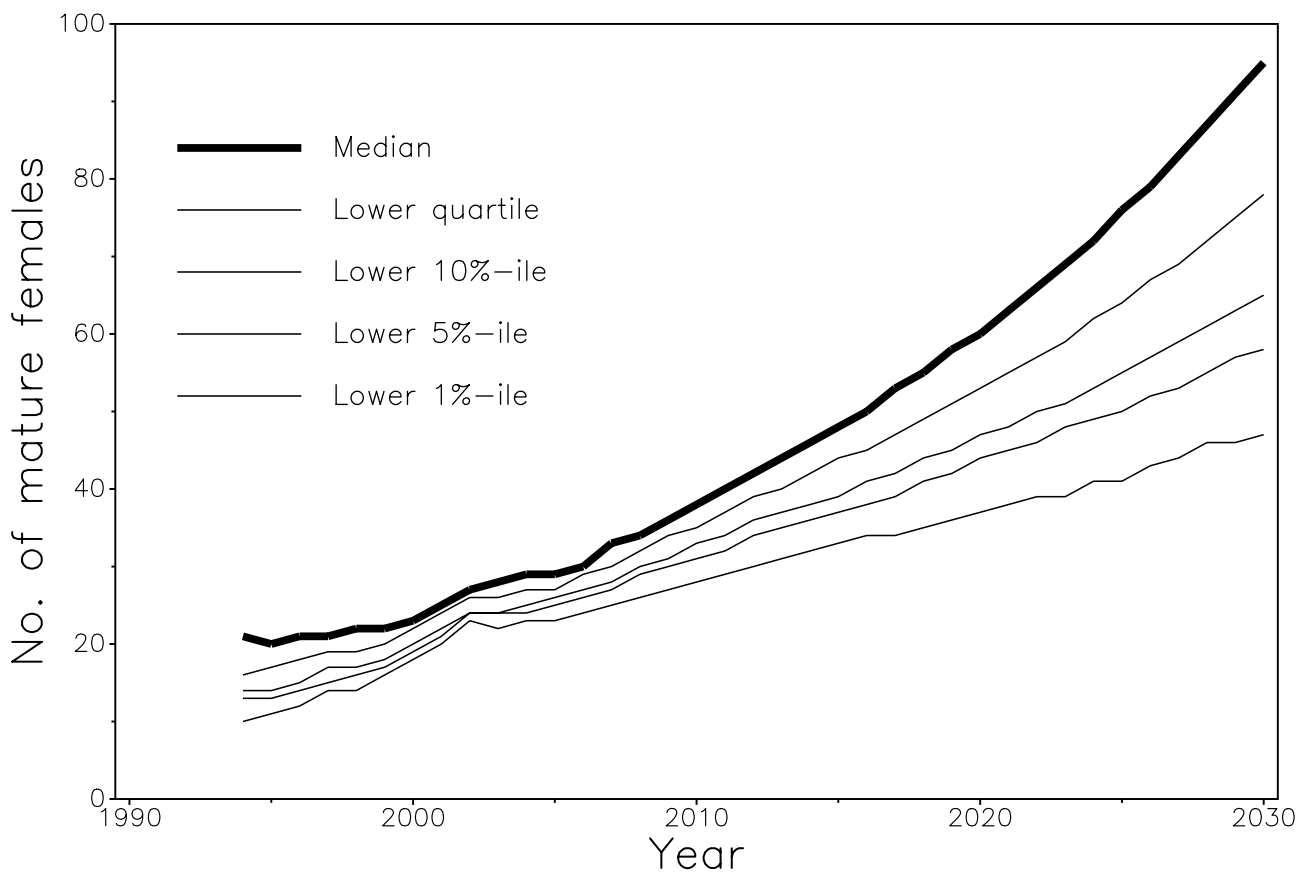


Fig. 2c. Western Gray Whale population trajectories 1994–2030: Mature females

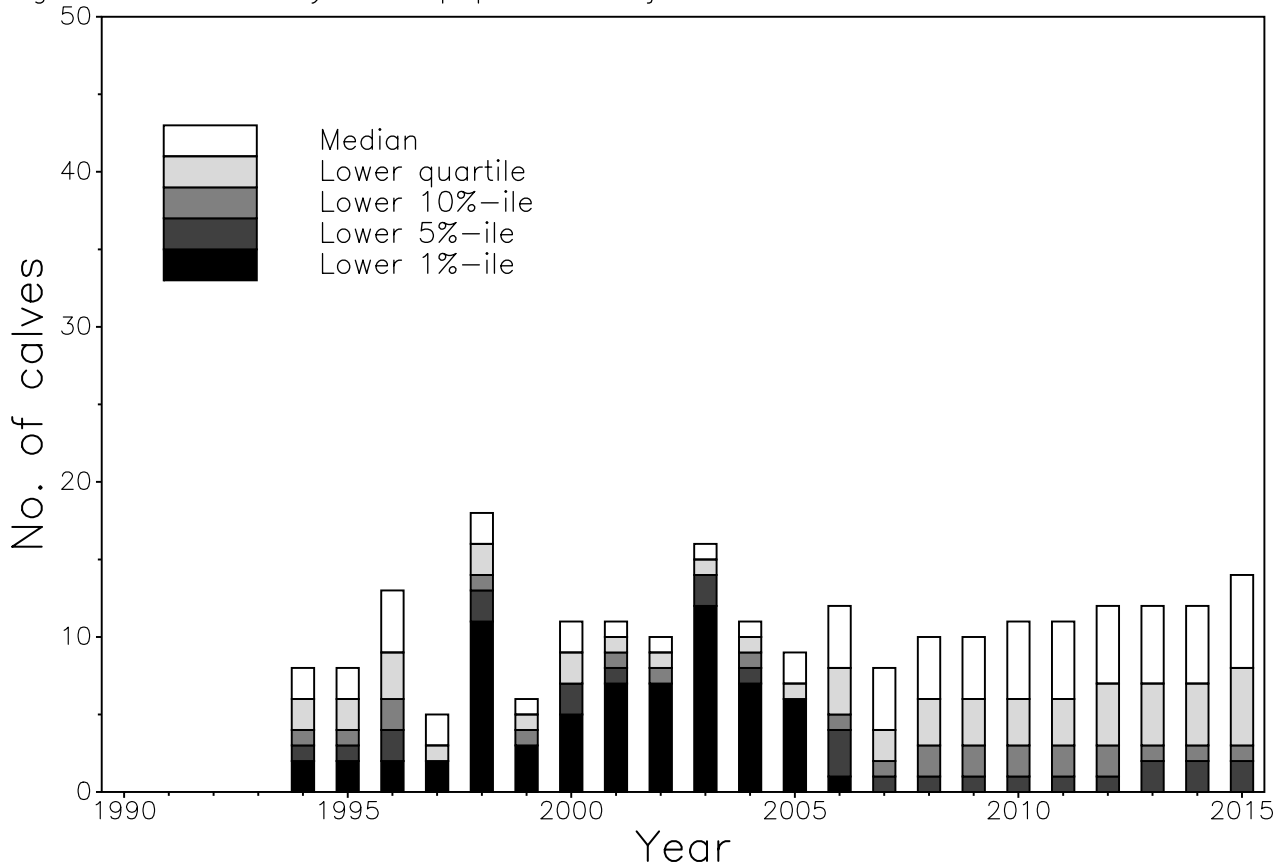


Fig. 2d. Western Gray Whale population trajectories 1994–2015: Calves

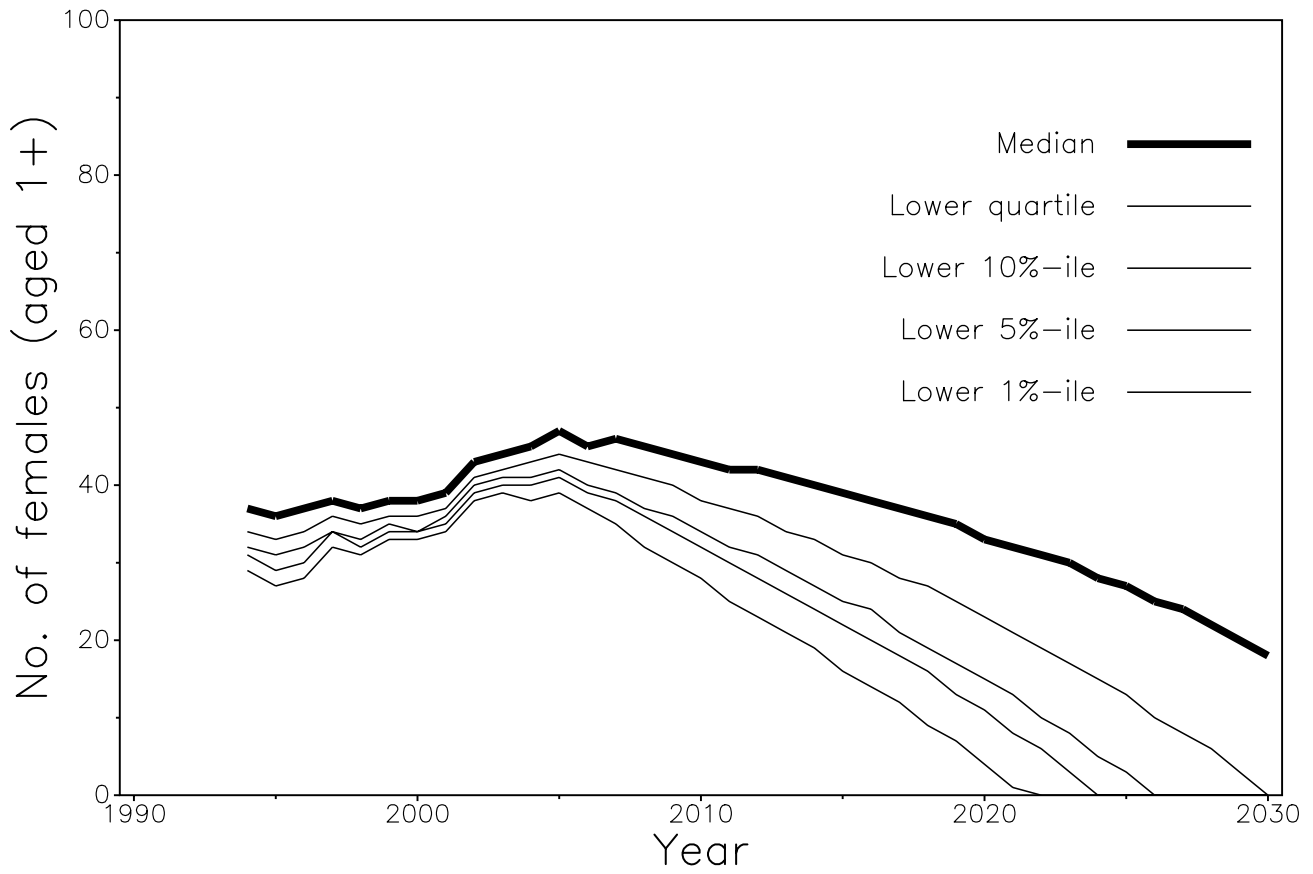


Fig. 3. Western Gray Whale population trajectory (1+ females) 1994–2030
Assuming annual additional mortality at 2005 levels (3 animals)

Table 2. Parameters of the models, prior ranges and percentiles of posterior distributions

Parameter	Prior range		Percentiles of posterior								
	Min	Max	1	5	10	25	50	75	90	95	99
<i>Population model parameters</i>											
Population 1994 P_0	50	250	55	60	63	67	73	79	84	87	93
Annual survival non-calf S	0.8	1	0.970	0.975	0.978	0.983	0.987	0.990	0.993	0.995	0.998
Calf survival S_j	0	1	0.551	0.600	0.628	0.674	0.722	0.767	0.804	0.828	0.876
Female sex ratio f	0	1	0.337	0.367	0.380	0.406	0.435	0.465	0.490	0.507	0.533
Maturation probability a	0.2	0.5	0.205	0.211	0.219	0.245	0.307	0.381	0.428	0.448	0.472
Median calving prob. b	0	1	0.179	0.240	0.280	0.355	0.442	0.523	0.589	0.626	0.693
Median calving prob. c (rested)	0	1	0.382	0.515	0.586	0.695	0.815	0.920	0.968	0.985	0.994
Calving prob SD σ	0	2	0.22	0.41	0.52	0.74	1.03	1.40	1.79	1.92	1.99
<i>Derived parameter</i>											
Annual rate of increase 1994-2005			0.017	0.021	0.023	0.026	0.030	0.034	0.038	0.041	0.046
<i>Observation model parameters</i>											
Probability weaned w	0	1	0.07	0.09	0.10	0.13	0.16	0.20	0.23	0.26	0.31
Sight prob SD τ	0	2	0.34	0.40	0.44	0.50	0.59	0.69	0.80	0.87	1.04
Median sampling prob. Cows&Calves	0	1	0.39	0.45	0.48	0.54	0.60	0.66	0.72	0.76	0.81
Median sampling prob. immatures	0	1	0.28	0.34	0.38	0.47	0.59	0.69	0.77	0.81	0.87
Median sampling prob. Resting	0	1	0.42	0.48	0.51	0.56	0.63	0.69	0.74	0.77	0.81
Median sampling prob. Males 1+	0	1	0.45	0.51	0.54	0.58	0.63	0.68	0.72	0.74	0.79