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Population Assessment Update for Sakhalin Gray Whales

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Population Assessment Update for Sakhalin Gray Whales

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ABSTRACT

The population assessment of gray whales *Eschrichtius robustus* feeding off Sakhalin is updated. An individually based population model, with one summer feeding area and up to two wintering areas, is fit to photo-id data collected off Sakhalin during 1995-2018 (Burdin *et al*. 2019), sex determinations from biopsies (Lang 2010), tracking of whales from Sakhalin to the eastern North Pacific (Mate *et al*. 2015), and photo-id matches of gray whales between the Sakhalin and Mexico catalogues (Urbán *et al*. 2019). The results show that the Sakhalin feeding population increased at 3.4-4.8% per year over the 20 years to 2018, but with significant inter-annual fluctuations in calving rates and calf survival. It is not possible to verify with these data whether the increase is still continuing, and recent declines in prey availability in the Piltun feeding ground, the main feeding ground for mother-calf pairs within the population, imply that a continued increase cannot be assumed.

The aged 1+ population size in 2018 of the Sakhalin feeding population is estimated at 191 whales, excluding calves (CL 171-214). The proportion of the population that migrates to the eastern North Pacific is estimated to be 45-80%, therefore it is likely that a western breeding population that migrates through Asian waters still exists.

1. INTRODUCTION

Gray whales (*Eschrichtius robustus*) have been regularly reported during the summer months (June to October) off northeastern Sakhalin Island since the early 1980's (Brownell *et al*. 1997) and have been intensively studied there every year since 1995 (Burdin *et al*. 2019).

Initially the Sakhalin gray whales were assumed to be a remnant of the western gray whale population formerly hunted in Korean and southern Japanese waters until the 1960s. The timing of gray whales catches in the Korean grounds was suggestive of a migration to a wintering ground in Asian waters (Kato and Kasuya 2002). Later, tagging results and photo-id and genetic matches showed that at least some of the Sakhalin gray whales migrate to breeding grounds in Mexican waters along with the bulk of the eastern North Pacific gray whale population (Weller *et al*. 2012; Mate *et al*. 2015; Urbán *et al*.

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2019). Also, many individuals observed off SE Kamchatka during 2006-11 and 2018 and during 1999-2019 in Baja California, Mexico, have been matched with those off Sakhalin and with each other (Yakovlev *et al.* 2013, Burdin et al. 2019, Urbán *et al.* 2019).

However, sightings of Sakhalin-matched gray whales off the Pacific coast of Japan in spring are suggestive of the possibility that at least some of the gray whales seen off Sakhalin undertake a western North Pacific migration that may lead to a western North pacific calving area whose location is unknown (Weller *et al.* 2016; Nakamura et al. 2019).

In an analysis of the data on movement between Sakhalin and the eastern North Pacific, including data from satellite tagging of individuals and photo-id matches between Sakhalin and Mexico, Cooke (2016) concluded that 30-100% of Sakhalin whales migrate in winter to the eastern North Pacific. Thus, those data alone could not confirm or exclude the possibility of a western breeding migration. The further data collected since then make it possible to refine this estimate.

This paper updates the assessment of Cooke et al. (2017) for the Sakhalin feeding aggregation, using photo-id and biopsy data from the Russian Gray Whale Project (Burdin *et al.* 2019), supplemented by data on long-range movements from tracking (Mate et al. 2015) and matches between Sakhalin and Mexico (Urbán et al. 2019), and sex determinations from biopsies (Lang 2010 and subsequent data).

2. MATERIAL AND METHODS

2.1. Data

Photo-identification data from the Russian Gray Whale Project were available for each summer season (June to September) from the Piltun area of north-eastern Sakhalin from 1997 to 2018, with some data also collected in 1994 and 1995. A total of 280 distinct individual whales had been catalogued as of 2018. The catalogue has been published and annually updated since 2006 (Weller *et al.* 2006).

Genetic sex determinations from biopsy were available for 156 whales (89 males and 67 females) for this analysis. A total of 152 calves have been identified. Of these calves, 130 could be linked to an identified mother (in all but one case by observed association, the remaining case genetically). Of the 152 observed calves, 76 have been sexed genetically: 30 female and 46 male.

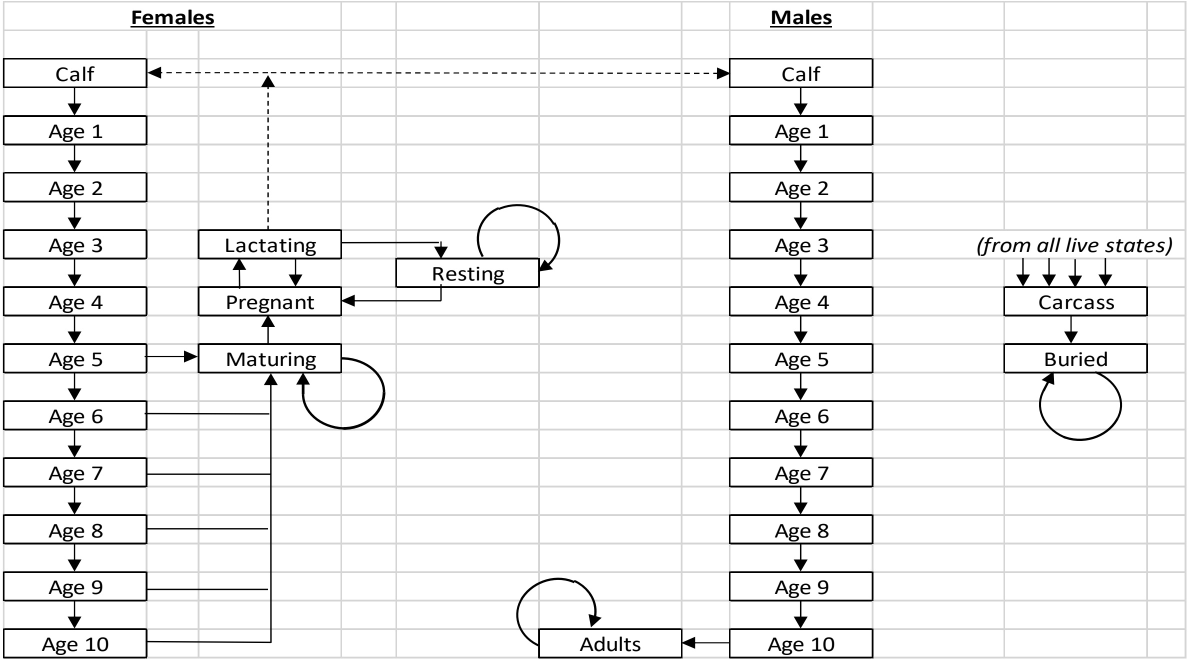
The three records of known whales successfully satellite-tracked from Sakhalin to the eastern North Pacific (Mate *et al.* 2015) were used.

A matching exercise comparing the Sakhalin catalogue for 1994-2016 and the Mexican catalogues for 1999-2019 found 34 individuals common to Sakhalin and Mexico (Urbán *et al.* 2013). As noted by Cooke (2016), very few young animals from Sakhalin are observed in the Mexican lagoons. For this analyses, whales that had been seen off Sakhalin at least 6 years previously were considered candidates for matching with the Mexican catalogues, and the Mexican samples for 2006-19 were used. These criteria resulted in 41 annual sightings of Sakhalin whales in Mexico of 27 different individuals.

2.2. Model structure

2.2.1 Population model

The population model is an individually-based stage-structured population model, as shown in Fig. 1. The model runs in discrete time with a time step of one year, except that the Mexican sightings, which are made in winter, occur between two summer seasons off Sakhalin.



Two breeding stock hypotheses are considered: (i) all whales migrate to the eastern North Pacific in winter (1-stock hypothesis); (ii) some whales migrate to the eastern North Pacific and some to another wintering ground, presumed to be in the western Pacific or Asian coastal waters (2-stock hypothesis).

The reproductive females in a stock are divided into three stages: pregnant, lactating, and resting. Females are assumed not to be simultaneously pregnant and lactating. A female can become pregnant immediately following lactation, resulting in a 2-year calving interval (the minimum observed). Optionally, a female can enter the resting phase for one or more years, resulting in a 3-year or longer calving interval. The minimum age at first (successful) pregnancy is 7 years; thereafter, the probability of becoming pregnant is assumed to increase as a logistic function of age, reaching a plateau at age 12.

The basic version of the model contains a total of 24 living stages per stock: calves (2 stages: male and female); immature and maturing males (11 stages); adult males (1 stage); immature and maturing females (11 stages); and adult females (3 stages). In addition, there is an unborn stage, a “freshly dead” stage (where a carcass might be found and identified), and a “buried” stage (no further possibility of being found). This makes a total of 27 stages for the 1-stock hypothesis and 52 stages for the 2-stock hypothesis. In models with individual heterogeneity in availability, each living stage is further subdivided into 3 availability classes, resulting in 75 or 148 stages for the 1- and 2-stock hypotheses respectively.

2.2.3 Sampling model

2.2.3.1 Photo-id sampling

An animal is ‘sampled’ in a given year when it is photographed in that year, and the photographs have been processed and assigned to an existing known whale in the catalogue, or to a new whale which is added to the catalogue. A lactating (or post-lactation) female may be sampled alone or with its calf; likewise, a calf may be sampled alone or with its mother. The probability that a mother-calf pair has separated before it is recorded is a parameter of the model.

The sampling probabilities off Sakhalin are parameters of the model that are allowed to vary by year, stage and individual. Individual (as opposed to stage-related) heterogeneity in sampling probability is modelled by assigning each individual with equal probability to one of three availability strata. The sampling probability may also depend on various interactions between the above factors, as determined by the model-selection process.

The annual sampling probability for Mexico was estimated externally by Cooke (2016). The sampling probability of an “adult” whale (i.e. one meeting the age criteria defined above) in the Mexican breeding grounds was estimated at 0.054 per year for the years 2006-12. In the absence of an updated capture-recapture analysis of the Mexican data, the annual sampling probability is assumed to have remained constant since 2012. It would be desirable for this estimate to be updated at the earliest opportunity.

2.2.3.2 Satellite tracking

We assume that the tracking success probability is independent of breeding location. That is, we assume that if the three whales tracked from Sakhalin to the eastern North Pacific had instead migrated south in the western North Pacific, they would have been tracked there too. With this assumption, we condition on the actual number and identity of whales successfully tracked, and do not need to model the tracking probability.

This approach implies a qualitative difference in the evidentiary value of satellite-tracked animals versus long-range photo-id matches: for photo-id, the relevant sampling probability must be known or estimated, but this is not necessary for tracked animals.

2.3. Likelihood, model fitting and model selection

Table 1 lists the factors/terms included in each of the alternative models fitted. Each model was first fitted by maximum likelihood (REML) to produce estimates of model parameters and of the population trajectory. The factors/terms to include in the model were selected using the AIC criterion, to identify a preferred model. The Bayesian posterior distribution of the population trajectory was sampled for the preferred model.

In summary, each individual has a range of potential biographies, each of which consist of a time series of its putative true state in each year. Some aspects of the state are assumed to remain constant over its lifetime, such as sex and membership of a feeding and/or breeding group. Other aspects, such as age, reproductive status, live vs. dead, change from year to year according to the transition probabilities.

In addition, each individual has an observed history. The observed history may be null for some individuals (i.e. individuals that exist but have not yet been sampled). The likelihood is calculated by comparing each putative biography with the observed history. Some aspects of the comparison are probabilistic. For example, whether an individual is sampled in a given area in a given year: the likelihood depends on the relevant sampling probabilities. Other aspects, such as sex or membership of a breeding stock, are of an either/or nature. For example, if a whale is tracked to the eastern North Pacific, all its potential biographies that involve it being a western breeder are assigned a zero likelihood. Likewise, if a whale is determined through genetic sampling to be male, all the potential biographies that involve it being female get assigned a zero likelihood.

Full details of the model and fitting procedure are given by Cooke (2018).

3. RESULTS

3.1. Model selection

Table 1 shows the results of fitting various models sequentially. Because the 2-stock model provided a much better fit, it was taken as the base case, and the 1-stock model fitted as an alternative. Case A represents the minimal reasonable sampling model for the two-stock biological model: the sampling probability at Sakhalin varies by year (to account for variable research effort, due to weather, logistics and other factors) but is the same for all individuals. Allowing the sampling probability to differ between population components (subadult, male, female with calf, calf, female without calf, calf) (case B) substantially improves the fit (ΔAIC = –26.8). Allowing the relative availability of the different population components to vary by year (i.e. including a component-year interaction) (case C) further improves the fit substantially (ΔAIC –56.9). Allowing for individual heterogeneity in availability (case

D) improves the fit yet further (ΔAIC = –147.9). Including an interaction term between population component and individual availability (case E) further improved the fit somewhat (ΔAIC = –6.8).

Allowing annual variability in the calving rate (case F) also improved the fit (ΔAIC = –10.6), and allowing variability in the calf survival rate (case G) improved the fit still further (ΔAIC = –10.7). This was the best-fitting model of those considered for the 2-stock hypothesis. The 1-stock version of this model (case P) resulted in a poorer fit to the data (ΔAIC = +16.3).

The 1-stock model can, therefore, be rejected. The accepted model has two breeding stocks, annual variability in both calf production and survival, and considerable heterogeneity in availability of whales for sampling.

Table 1. Results of sequential fitting of variois models

Case	Stocks	Calf mortality	Calf production	Sighting probability	Log-like	d.f.	AIC	ΔAIC
A	2	**1**	**1**	**Year**	-2071.9	31.7	4207.2	
B	2	**1**	**1**	**Year** + PopCpt	-2054.5	35.8	4180.5	-26.8
C	2	**1**	**1**	**Year** + PopCpt + Year*PopCpt	-1955.0	106.8	4123.6	-56.9
D	2	**1**	**1**	**Year** + PopCpt + Year*PopCpt + Class	-1882.1	105.7	3975.8	-147.9
E	2	**1**	**1**	**Year** + PopCpt + Year*PopCpt + Class*PopCpt	-1876.1	108.3	3968.9	-6.8
F	2	**1**	**1** + Year	**Year** + PopCpt + Year*PopCpt + Class*PopCpt	-1861.9	117.2	3958.4	-10.6
G	2	**1** + Year	**1** + Year	**Year** + PopCpt + Year*PopCpt + Class*PopCpt	-1847.4	126.4	3947.7	-10.7
H	1	**1** + Year	**1** + Year	**Year** + PopCpt + Year*PopCpt + Class*PopCpt	-1853.6	128.4	3963.9	+16.3

Bold: term fitted as fixed effects (free parameters)

Others fitted as frandom effects.

Selected model

3.2. Population size and trajectories

Table 2 lists estimates of some key demographic parameters with confidence limits. A random sample of 50 trajectories from the posterior distribution of population trajectories for the best-fitting model is shown in Fig. 2 for (a) the aged 1+ population and (b) reproductive females only. In each plot the trajectories are shown for (i) the entire Sakhalin feeding population; (ii) the western North Pacific breeding subset of the Sakhalin feeding population.

The results show that the Sakhalin feeding population has been increasing at 4.1% p.a. (CI 3.4-4.8% p.a.) over the 20 years to 2018. The aged 1+ (non-calf) population is estimated at 191 whales in 2018 (95% CI 171 - 214) and the mature female population is estimated at 45 whales (95% CI 40 - 53). The Proportion of the Sakhalin feeding aggregation that migrates to the eastern North Pacific is estimated at 45-80%, meaning that at least 20% probably migrate elsewhere, likely to wintering areas in Asian waters, given the non-occurrence of gray whales off Sakhalin in winter, when the feeding grounds are usually covered by sea ice.

4. DISCUSSION

The aged 1+ population size estimates presented here are slightly lower than those provided by Cooke (2018) for the same year and comparable stock definition, because that analysis included observations from the offshore feeding ground off Sakhalin and from eastern Kamchatka. However, the estimates of the mature female population size are approximately equal in the two studies, which reflects the fact that the main data used in this paper were collected in the main feeding area for mothers with calves.

The fitted model shows that the population of gray whales has been increasing. However, it is difficult from individual identification data alone to detect in the short term whether a past increasing trend is still continuing. Demographic parameters such as calf survival can only be reliably estimated some years in retrospect, because calves which apparently failed to return may be feeding elsewhere.

Recently, Labay et al. (2019) reported a much lower abundance of amphipoda, the main gray whale prey type, in the benthos of the Piltun feeding ground during 2013-16 compared with previous years (2002-2012), while the abundnace of prey in the offshore feeding ground has remained high. There has also been a shift in distribution of gray whales such that the occurrence of whales (other than calves and mother-calf pairs) in the Piltun ground has decreased, with a concomitant increase in whales in the offshore feeding ground, but mother-calf pairs continue to be observed exclusively on the Piltun feeding ground and not offshore (Yakovlev et al. 2019). Within the Piltun feeding ground, there has been a progressive southward shift of the distribution asway from the mouth of Piltun lagoon, that was especially marked in 2018 (Burdin *et al*. 2019).

The cause of the reduction in prey has not been definitely determined. Depletion of the prey by the gray whales themselves and other predators has been proposed, while concern has also been expressed about potential effects of construction activity across the mouth of Piltun lagoon. Unfortunately, no benthos data were collected in 2017-18, and no collection is planned for the 2019 season. The Western Gray Whale Advisory Panel has strongly recommended resumption of the benthic sampling (WGWAP 2019).

Because of the dependence of mother-calf pairs on the inshore feeding ground, the recent reduction of prey availability might be expected to influence calf survival. However, for the reasons given above, this would require more years of monitoring for reliable detection of a change. The WGWAP has also strongly recommended continuation of the RGWP photo-identification programme.

The updated assessment in this paper strengthens the evidence for a continued western breeding population, because the number of matches of Sakhalin whales with whales in the Mexican catalogues is still less than would be expected if all Sakhalin whales would migrate to the eastern North Pacific in winter. However, an updated analysis of the full Mexican catalogues is needed to refine the estimate of the annual proportion of the eastern gray whale population that is identified.

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Table 2. Estimates of key biological parameters.

	Maximum likelihood		Posterior distribution percentiles		
	estimate	SE	2.5%	median	97.5%
Population size in 2018					
Aged 1+					
Total Sakhalin	191	12	171	189	214
Western Breeding Stock	87	15	54	72	109
Reproductive females					
Total Sakhalin	45	3	40	50	53
Western Breeding Stock	19	3	10	16	27
Proportion of Sakhalin whales migrating to ENP	0.56		0.45	0.60	0.80
Growth rate 1998-2018 (Aged 1+, Sakhalin)	0.041		0.034	0.041	0.048
Survival rate					
Calves	0.65	0.07			
non-calves	0.975	0.005			

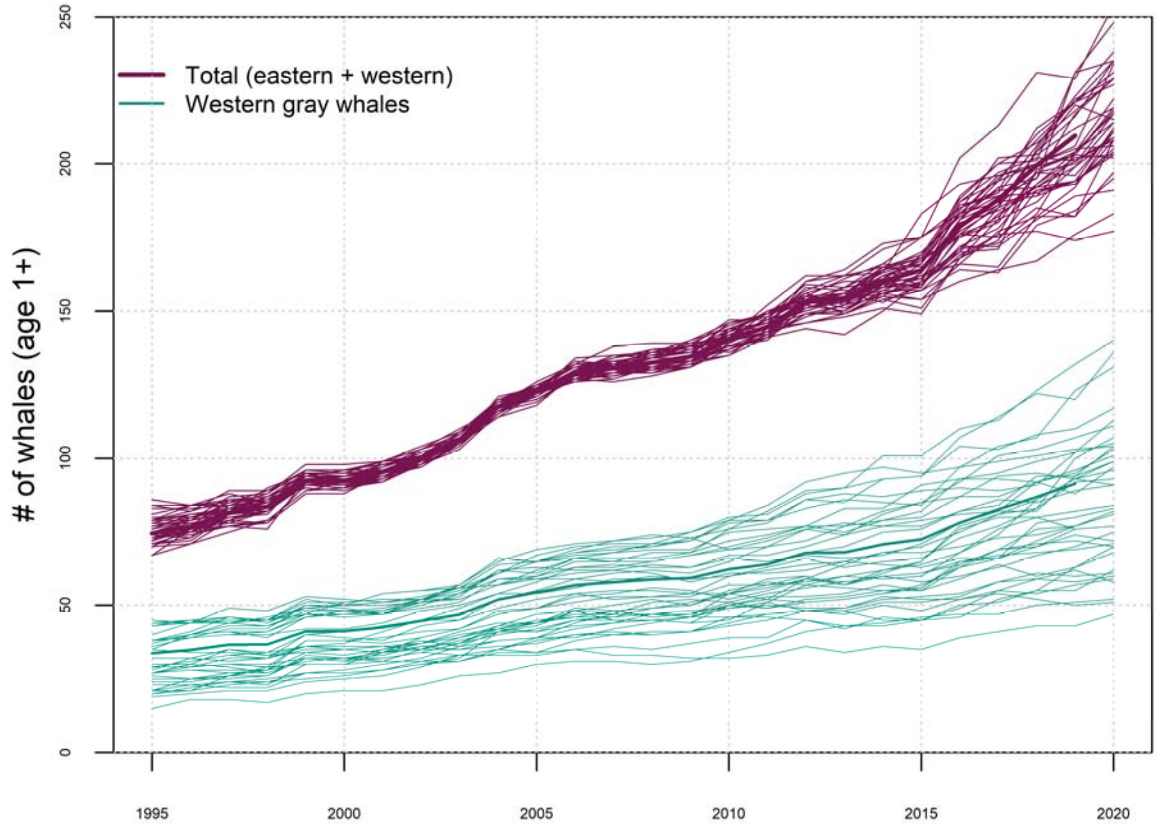

Fig. 2a. Sakhalin gray whales. Maximum likelihood population trajectory and random posterior sample of trajectories for the aged 1+ population.

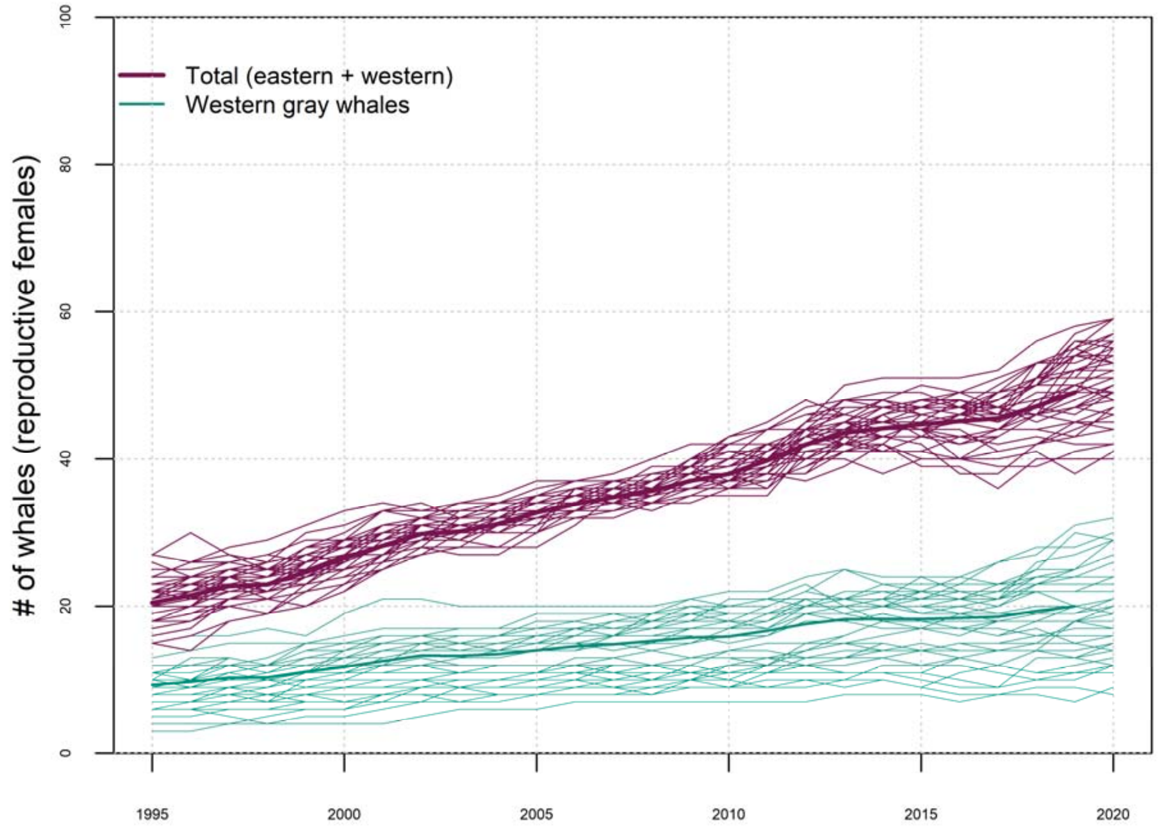

Fig. 2b. Sakhalin gray whales. Maximum likelihood population trajectory and random posterior sample of trajectories for the reproductive female population.

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