Population Declines of Harbor Porpoise (*Phocoena phocoena*) in Inside Waters of Southeast Alaska

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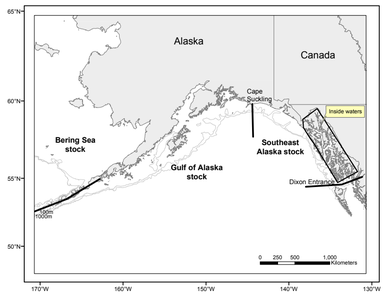

Figure 1. Stocks of harbor porpoise in Alaska.

Harbor porpoises (*Phocoena phocoena*) are widely distributed in coastal waters along the entire western coast of North America. In Alaska, three stocks are currently recognized (Fig. 1). The Southeast Alaska stock includes individuals from offshore areas as well as from inside waters ranging from Icy Strait/Glacier Bay to southern Clarence Strait. The latest estimate of abundance for this stock (1997) was ~11,000 (CV=0.24) individuals (Hobbs and Waite, 2010), but no reliable estimates of trends are available.

Between 1991 and 2010, the National Marine Mammal Laboratory conducted shipboard surveys in inside waters of Southeast Alaska to investigate distribution and abundance of marine mammals. Surveys in 1991, 1992, 1993, 2006, 2007 and 2010 were conducted using standard line transect methodology (Fig. 2) during three different seasons (spring, summer and fall) following a stratified survey design. Exploratory analysis revealed that there was no significant seasonal variation in distribution of harbor porpoise in this region (Dahlheim et al., 2009). Therefore, data from all seasons were pooled to compute year-specific estimates of abundance for all strata surveyed every year using conventional and multiple covariate distance sampling methods (Table 1). These abundances are treated as indices of relative abundance because they are not corrected for animals missed in the trackline (*g[0]*).

Table 1. Estimates of harbor porpoise abundance and CVs in SE Alaska Inland Waters and in three selected regions of historical occurrence.

	SE Alaska Inland Waters		Glacier Bay/Icy Strait		Frederick Sound		Wrangell	
Year	N	CV	N	CV	N	CV	N	CV
1991	1062	0.16	376	0.24	145	0.32	475	0.28
1992	524	0.14	342	0.26	120	0.31	149	0.23
1993	821	0.16	375	0.19	47	0.55	268	0.24
2006	391	0.19	192	0.23	48	0.39	139	0.27
2007	529	0.17	-	-	46	0.63	152	0.21
2010	563	0.18	512	0.25	36	0.39	149	0.28

CV = coefficient of variation

Trends in abundance for comparable areas were investigated with a Bayesian exponential model (Box 1) assuming the variances of the abundance estimates were known (Model 1). An additional model was specified by adding a parameter CV_{add}, which represented unexplained variance between annual estimates of abundance (Model 2). This additional variance was considered constant across years and was incorporated in the model as an additive variance term to the CV of the abundance estimates (Box 1). The two models were compared using the Bayes Factor and model uncertainty was incorporated by computing model-averaged posterior probabilities for parameter estimates (Box 1). Population trends were obtained for the entire survey area (overall estimate) and for three selected regions (Glacier Bay/Icy Strait, Frederick Sound and waters west of Wrangell, Fig. 2), of historical concentrations of harbor porpoise (Dahlheim et al., 2009).

Posterior probability distribution of population trends and probability of decline is presented in Table 2 and illustrated in Fig. 3. Model-averaged population model trajectories are illustrated in Fig. 3. Results show an overall decline of 2.8% per year in inside waters of Southeast Alaska. The regional estimates indicated a much greater decline in Frederick Sound (6.3% per year) and the Wrangell region (3.8% per year) than in Glacier Bay/Icy Strait (0.9% per year). The probability of decline is very high (>90%) for the overall estimate and for two (Frederick Sound and Wrangell) of the three regional estimates.

Table 2. Estimates of harbor porpoise decline in inland waters of Southeast Alaska between 1991 and 2010.

	Model 1 (without CV add)			Model 2 (with CV add)			Bayes Factor	Model Averaged		
Region	*r*	95% PI	PD	*r*	95% PI	PD	Model $^2/_1$	*r*	95% PI	PD
Overall	-0.025	(-0.042, -0.009)	99.7%	-0.031	(-0.091, 0.021)	92.7%	4.47	-0.029	(-0.090, 0.017)	93.9%
Glacier Bay/Icy Strait	-0.008	(-0.032, 0.018)	71.8%	-0.010	(-0.089, 0.060)	64.2%	1.96	-0.009	(-0.078, 0.048)	67.4%
Frederick Sound	-0.062	(-0.094, -0.019)	99.9%	-0.064	(-0.113, -0.019)	99.2%	0.26	-0.063	(-0.097, -0.029)	99.8%
Wrangell	-0.035	(-0.059, -0.009)	99.8%	-0.042	(-0.110, 0.014)	94.7%	1.51	-0.038	(-0.102, 0.004)	96.6%

r = population trend, PI = probability interval, PD = probability of decline

Conclusions

Results indicate that the population of harbor porpoise in inland waters of Southeast Alaska has declined significantly since the early 1990s. The reasons for the negative trends are not yet understood and could include one or a combination of the following factors:

- Bycatch from local fisheries
- Changes in prey distribution
- Shift in distribution outside the survey area (e.g. due to habitat degradation)
- Predation

Further studies are needed to assess the causes of the observed decline of harbor porpoise in inside waters of Southeast Alaska. It is noteworthy, however, that the greatest regional declines were estimated for Frederick Sound and Wrangell areas where drift gillnet and purse seine fisheries for various species of salmon have been operating (Davidson et al., 2010, 2011). Fishing operations of these types are known to cause the mortality of cetaceans worldwide (e.g. Reeves et al., 2003), including of harbor porpoise in Southeast Alaska (Angliss and Lodge, 2003). Monitoring of the fisheries to assess harbor porpoise bycatch levels is therefore recommended in

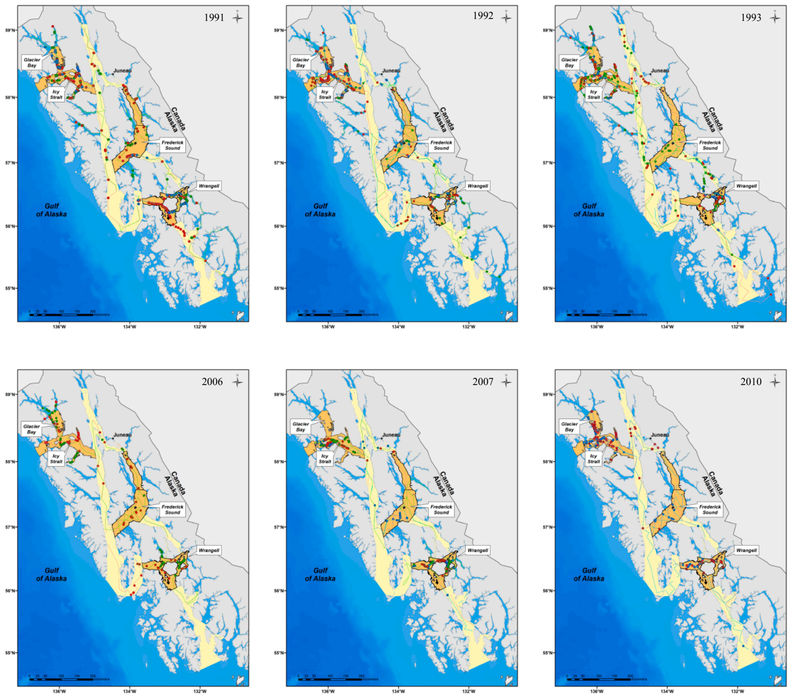

Figure 2. Harbor propoise sighting and line transect effort distribution in inside waters of Southeast Alaska. The three regions for which individual trend estimates were computed are highlighted in orange.

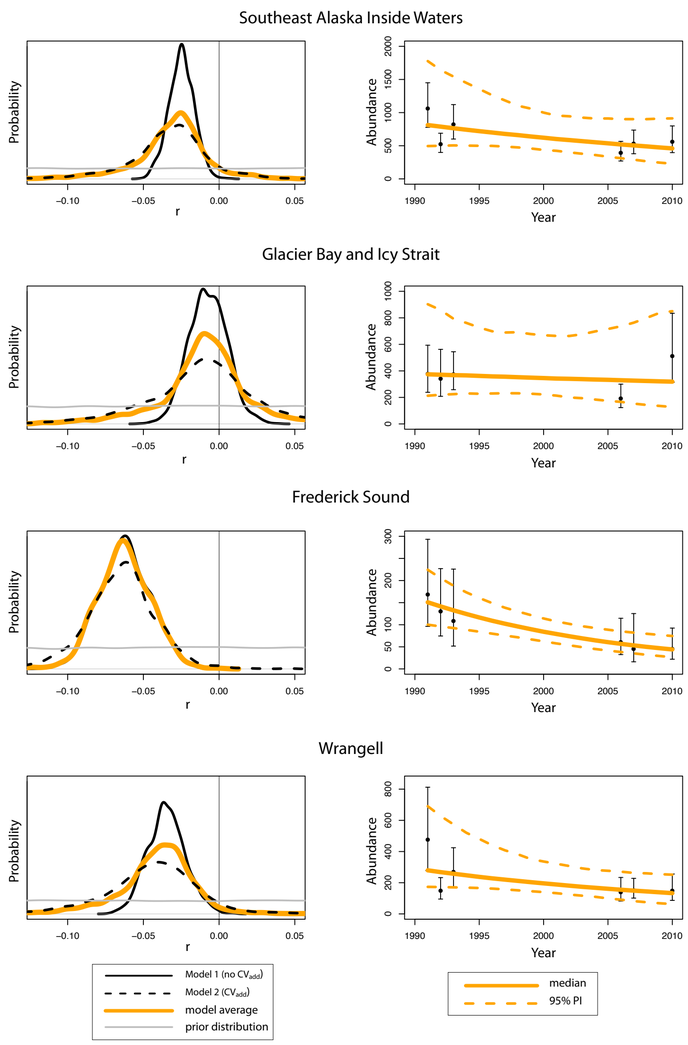

Figure 3. Posterior probability distribution of the estimated trend (parameter *r*) of harbor porpoise in Southeast Alaska inside waters from 1991 to 2010 (left panel). Observed abundances (black dots with 95% CIs) and predicted median population trajectories (with 95% PIs) (right panel).

Box 1

MODELING APPROACH

The Exponential Model

In this study, a Bayesian statistical framework was used to estimate model parameters and quantities of interest (e.g. Gelman et al., 1995, Punt and Hilborn, 1997). A two-parameter exponential population model was fit to the time series of abundance estimates. The model is represented as:

$$N_t = N_{t+1} \cdot e^{rt}$$

where:

- N_t = Population size at time *t*
- *r* = population rate of change (trend)

The Likelihood Function

The error distribution of the abundances was assumed to be log-normally distributed. The negative of the logarithm of the likelihood is represented as follows:

$$-\ln(L) = \sum_{t=1}^{n} \ln\left(\sigma_{N_t^{obs}}\right) + \ln(N_t^{obs}) + 0.5 \cdot \frac{(\ln(N_t^{pred}) - \ln(N_t^{obs}))^2}{\sigma^2_{N_t^{obs}}}$$

where:

- N_t^{obs} = line-transect estimated abundance
- N_t^{pred} = model predicted abundance
- $\sigma_{N_t^{obs}} = \sqrt{\ln(1 + CV_t)}$ and:
- $CV_t = CV_{N_t^{obs}}$ for Model 1 (with no additional variance)
- $CV_t = CV_{N_t^{obs}} + CV_{add}$ for Model 2 (with additional variance)

The Priors

In Bayesian statistical models probability is used as a measure of uncertainty. Within this paradigm, unknown model parameters have probability distributions based on previous knowledge (the priors), which are then updated using the data to derive the posterior distributions, the keystone of Bayesian inference. Priors were specified for *r*, N_0 and, when applicable, CV_{add} (Table A). The lower and upper bounds of these priors were fixed to a value thought to be greater than the greatest possible value in the posterior probability distribution, but small enough to limit computational time (Wade, 2002). Although the choice of these bounds may seem arbitrary, their values were assessed not to be important, as they do not influence the results.

Table A: Prior distribution for model parameters to estimate population rate of change for Southeast Alaska harbor porpoise.

Parameter	Prior distribution
r	U(-0.15, 0.1)
N_0	Global estimate: U(0, 6000)
	Regional estimates: U(0, 1500)
CV_{add}	U (0, 2)

Statistical Framework

The integration of the prior distributions of the parameters and the likelihood function was approximated by the Sampling-Importance-Resampling (SIR) algorithm of Rubin (1988). A total of 500,000 samples of the joint prior distribution were obtained and 2,000 re-samples were used to compute the posterior distribution of parameters of interest.

Model Comparison and Model Averaging

Models with and without CV_{add} were compared using the Bayes factor (Kass and Raftery, 1995) which was computed as:

$$B_{21} = \frac{pr(D|H_2)}{pr(D|H_1)}$$

where:

- $pr(D|H_1)$ and $pr(D|H_2)$ correspond to the probability of the data given the hypothesis (models) 1 and 2, respectively and were computed as the average likelihood of the samples of the joint prior for each model (Wade, 2002).

Model uncertainty is accounted for by calculating the posterior probability of each model conditioned on the data and the priors, and then combining results across models as a weighted average of the posterior densities for a quantity of interest (Kass and Raftery, 1995). The posterior probability of models 1 and 2 was computed as (Brandon and Wade, 2006):

$$pr(H_k|D) = \frac{pr(D|H_k) \cdot pr(H_k)}{\sum_{i=1}^{2} pr(D|H_i) \cdot pr(H_i)}$$

The posterior model probabilities were then used to determine a model-averaged posterior probability of model outputs (θ) as follows:

$$pr(\theta|D) = \sum_{i=1}^{K} pr(\theta|H_k, D) \cdot pr(H_k|D)$$

In the context of the SIR algorithm used here, Bayesian model averaging was accomplished by selecting a number of random draws from the posterior for each model and combining them to form a model-averaged posterior.

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