Probability of taking a western North Pacific gray whale during the proposed Makah Hunt

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ABSTRACT

Recent observations of gray whales (*Eschrichtius robustus*) identified in the western North Pacific migrating to areas off the coast of North America (Vancouver, California, Mexico) raise concern about the possibility of the small western population being subjected to the gray whale hunt proposed by the Makah Indian Tribe in northern Washington, USA. To address this concern, we estimated the probability of taking a WNP whale during the Makah hunt using five models from 3 model classes that varied based on the types of data used for estimation. Model set 1 used WNP and ENP abundance estimates. Model set 2 used these abundance estimates, as well as sightings data from the proposed hunt area. Model set 3 used only the sightings data. With model sets 1 and 2, two models (A and B) differed based upon whether migrating ENP and WNP whales were assumed to be equally available to the hunt per capita (A) or whether this assumption is relaxed (B). All models made the precautionary assumption that all WNP gray whales migrate to the North American coast and are thus potentially available to be hunted by the Makah. We consider Model 2B the most plausible model. Based on this model, the probability of taking ≥1 WNP whale in a single season ranges from 0.014 to 0.050, depending on if the median or upper 97.5th percentile estimate is used and whether 5 or 7 whales are struck. The probability of taking ≥1 WNP whale out of 5 seasons ranges from 0.056 to 0.225 across these same variables. The expected number to be taken in a single year ranges from 0.014 to 0.051 and 0.057 to 0.254 across 5 years.

KEYWORDS: GRAY WHALE: PACIFIC OCEAN; ABORIGINAL WHALING

INTRODUCTION

Gray whales (*Eschrichtius robustus*) are recognized as comprising two populations in the North Pacific Ocean. Significant mitochondrial and nuclear genetic differences have been found between whales in the western North Pacific (WNP) and those in the eastern North Pacific (ENP) (Lang *et al*., 2011). The ENP population ranges from calving areas in Baja California, Mexico, to feeding areas in the Bering, Beaufort, and Chukchi Seas. The WNP population feeds in the Okhotsk Sea off Sakhalin Island, Russia, and in nearshore waters of the southeastern Kamchatka Peninsula (southwestern Bering Sea).

The historical distribution of gray whales in the Okhotsk Sea greatly exceeded what is found today (Reeves *et al*., 2008). Whales associated with the Sakhalin feeding area can be absent for all or part of a given feeding season (Bradford *et al*., 2008), indicating they probably use other areas during the summer and fall feeding period. Some of the whales identified feeding in the coastal waters off Sakhalin, including reproductive females and calves, have also been documented off the southern and eastern coast of Kamchatka (Tyurneva *et al*., 2010). Whales observed off Sakhalin have also been sighted off the northern Kuril Islands in the eastern Okhotsk Sea and Bering Island in the western Bering Sea (Weller *et al*., 2003).

Recently, mixing of whales identified in the WNP and ENP has been observed. Lang (2010) reported that two adult individuals from the WNP, sampled off Sakhalin in 1998 and 2004, matched the microsatellite genotypes, mtDNA haplotypes, and sexes (one male, one female) of two whales sampled off Santa Barbara, California in March 1995. Mate and colleagues (Mate *et al*., 2011) satellite-tracked a whale from the WNP to the ENP in 2010/2011. Finally, photographic matches between the WNP and ENP, including resightings between Sakhalin and Vancouver Island and Laguna San Ignacio, have further confirmed use of areas in the ENP by whales identified in the WNP (Weller *et al*., 2011, Urbán *et al*., 2012). Despite this level of mixing, significant mtDNA and nuclear genetic differences between whales in the WNP and ENP have been found (Lang *et al*., 2011).

Recent observations of gray whales identified in the WNP migrating to areas off the coast of North America (Vancouver, California, Mexico) raise concern about placing the WNP population at potential risk of incurring mortality incidental to the ENP gray whale hunt proposed by the Makah Indian Tribe off northern Washington, USA (see IWC, 2011a; IWC 2011b). Given the ongoing concern about conservation of the WNP population, in 2011 the

Scientific Committee of the IWC emphasized the need to estimate the probability of a western gray whale being taken during aboriginal gray whale hunts (IWC, 2011b). The objective of this analysis was therefore to estimate the probability that one or more whales identified in the WNP might be taken during the hunt proposed by the Makah Indian Tribe.

METHODS

The probability of taking a WNP whale during the proposed Makah hunt was estimated using three different sets of models (5 models total). The proportion of WNP whales migrating along the North American coast is uncertain but based on recent photo-identification and genetic matches is estimated be a minimum of about 10% (Weller *et al.* 2011, Urbán *et al.*, 2012). Given this uncertainty, all models make the highly precautionary assumption that all whales photo-identified in the WNP are potentially available to the hunt. Models were based to different degrees on two sets of information: (1) the most recent estimates of WNP relative to ENP population size; and (2) sightings data from spring 1999-2010 off the coast of northern Washington (NWA), where the proposed hunt would take place.

Abundance estimates
The most recent WNP abundance estimate (for 2012) is 155 (median), with 95% CI = 142 – 165 (IUCN, 2012). The most recent ENP estimate (for 2007) is 19,126 (mean), with CV = 0.071 (Laake *et al.*, 2009). In the models, these estimates were expressed as log-normally distributed random variables with parameters $\mu_{WNP} = 5.043$, $\sigma_{WNP} = 0.0387$, and $\mu_{ENP} = 9.856$, $\sigma_{ENP} = 0.0709$.

Sightings in the Makah Usual and Accustomed Fishing Grounds
During surveys in spring 1999-2009, there were 118 "whale-days" in the Makah "Usual and Accustomed Fishing Grounds" (MUA) off the NWA coast, where every sighting of an individual on a particular day counts as 1 "whale-day" (e.g., multiple sightings of the same individual on the same day count as just 1 whale-day, but the same individual seen the next day would count as a second whale-day). There were 9 gray whale sightings in March. All other sightings were in April or May. None of the 118 whale-days observed WNP whales; 35 (29.7%) were considered "Pacific Coast Feeding Group" (PCFG) whales; and the rest (83, or 70.3%) were assumed to be migrating ENP whales. The photo-identification catalog for whales identified in the WNP off Sakhalin Island is characterized by extremely high (> 95%) resighting rates since 2002 (Burdin *et al.*, 2012), so it is assumed in this analysis that the absence of sightings of WNP whales in the MUA during spring surveys is not likely due to false negative identification.

Model set 1
Model set 1 only makes use of the ENP and WNP abundance estimates, ignoring information obtained from sightings off the NWA coast. The justification for this would be if spring sightings data in the MUA are not considered representative of the whale compositions that would be encountered by hunters, perhaps because of a timing mismatch (if hunt does not occur in April/May) or if whales approached by field researchers in motorized boats behave fundamentally differently than those approached by hunters in non-motorized boats.

Model 1A - All whales in the WNP and ENP are assumed to be equally available to the hunt, so that the probability of taking a WNP whale, $P_{WNP} = N_{WNP}/N_{ENP}$, where $N_{WNP} \sim$ log-normal $(\mu_{WNP}, \sigma_{WNP})$, and $N_{ENP} \sim$ log-normal $(\mu_{ENP}, \sigma_{ENP})$.

Model 1B - The probability of taking a WNP whale is unknown and thus treated as a uniformly distributed random variable, but with an upper limit given by the maximum (99th percentile) estimate of N_{WNP} (approx 170) divided by the minimum (1st percentile) estimate for N_{ENP} (approx 16,000). Thus, $P_{WNP} = $ Uniform [0, max], where max = 170/16000 = 0.0106. The justification for this model is that, within what is considered a plausible upper bound, we have no information about the per capita probability of taking a WNP whale, given the unknown proportion of the WNP that actually comes to the North American coast and given unknown differences in migration patterns between WNP and ENP animals.

Model set 2
Model sets 2 and 3 assume that the sightings data from the NWA coast are representative of the composition of whales (ENP, WNP, PCFG) that would be available to the hunt. In other words, whales that are most likely to be photographed (i.e., approachable in a small boat) are also the most likely to be approached by hunters.

Model set 2 makes use of the NWA coast sightings data, as well as WNP and ENP abundance estimates. WNP whales are assumed to be moving with the ENP migrants, so that the marginal probability of a WNP whale being

taken is the probability of being a migrant, P_{mig} (i.e., probability of not being a PCFG whale), multiplied by the conditional probability of being a WNP whale given that it is a migrant ($P_{WNP|mig}$).

Model 2A - Let $P_{WNP} = P_{mig} P_{WNP|mig}$. The distribution for the conditional probability $P_{WNP|mig}$ is given by the distribution of N_{WNP}/N_{ENP}, where the abundance terms are log-normally distributed (see Model 1A). Thus, it is assumed the per capita probabilities of an ENP or WNP whale being taken are the same. The posterior distribution for P_{mig} is estimated using MCMC methods assuming that $n_{mig} \sim$ Binomial (N, P_{mig}), where n_{mig} is the number of migrants (83) out of N (118) sightings in the data set. A uniform [0,1] prior was used for P_{mig}. The posterior distribution for P_{WNP} is estimated by the MCMC process, whereby for each MCMC iteration, a random variable for $P_{WNP|m}$ is multiplied by the sample P_{mig}.

Model 2B - This model is like 2A, except that $P_{WNP|mig} \sim$ Uniform [0, max], where max is as in model 1B. This contrasts with Model 2A by not assuming that WNP and ENP whales are equally likely to be taken. Rather, like in Model 1B, this model asserts that we have no information (apart from specifying a reasonable upper bound) about the relative per capita likelihood of a WNP whale being killed relative to that of an ENP whale.

Model set 3
There is only one model in this set, which uses the sightings data off the NWA coast but does not make use of information about WNP population size. Thus, P_{WNP} is simply estimated based on the proportion of animals in the sightings data set that are from the WNP. The posterior distribution for P_{WNP} is estimated using MCMC methods based on the assumption that $n_{WNP} \sim$ Binomial (N, P_{WNP}), where $n_{WNP} = 0$, and N = 118 (as above). A uniform [0, 1] prior was used for P_{WNP}. The justification for this model (i.e., for ignoring information about WNP abundance) would be that the relative per capita probability of taking WNP vs. ENP animals is totally unknown apart from the information contained in the sightings data set. For example, WNP whales could be much more (or less) available to the hunt that ENP whales due to differences in migration timing or behavior, such that our knowledge about the WNP population being very small is irrelevant.

Estimated parameters
Parameter distributions were estimated in R (model set 1, 100 thousand samples) or WinBUGs (model sets 2 and 3, 20 thousand samples). In addition to estimating P_{WNP} for each model, we estimated the probability of striking at least one WNP whale out of Y total strikes, as well as the expected number of WNP strikes out of Y total. For the former, $P(x > 0) = 1 - (1 - P_{WNP})^Y$. For the latter, $E(x) = P_{WNP} Y$. Values of Y considered were 5, 7, 20, and 35. The description of the Makah Tribe's proposed gray whale hunt (see Annex D, IWC 2011a) states the following: 5 is the maximum allowable number of landed whales per year; 7 is the maximum number of struck whales allowed per year; 20 is the maximum number allowed to be landed over a 5-year period; and 35 is the maximum number that could be struck over a 5-year period.

RESULTS

Estimated parameters from the 5 models are presented in Table 1. We present median estimates and, for precautionary purposes, 97.5[th] percentile estimates from the posterior distributions.

Median parameter estimates were higher for model set 1 than model set 2, and higher for version A of each of these models than for version B. Median estimates for model 3 were more or less identical to those of model 2A. Upper estimates were also higher for model set 1 than model set 2, but in contrast with the pattern for median estimates, upper estimates were higher for version B than for version A models, reflecting higher uncertainty in B models associated with specification of $P_{WNP|mig}$ as a uniformly distributed variable (Fig. 1). Upper estimates were much higher for model 3 than any of the other models because of the highly skewed and unconstrained posterior for P_{WNP} (Fig. 1).

Making inference based on median estimates, all models suggest less than about a 1% – 6% chance of striking a WNP whale within a single season, less than a 6% – 15% chance of striking 1+ WNP whale out of 20 landed whales in a 5-year period, or less than a 10% − 25% chance of striking 1+ WNP whale out of a max 35 struck whales in a 5-year period. The expected number of WNP whales struck varies from 0.01 to 0.28 across models and levels of Y.

Obviously, the chances of striking a WNP whale are substantially higher if making inference based on the upper 97.5[th] percentile estimates for P_{WNP}, particularly for B versions of the models, and most notably for model 3, where the upper estimate for the probability of striking 1+ WNP whale out of 35 exceeds 0.50 and the expected number of WNP whales to be struck out of 35 whales exceeds 1 (Table 1). Apart from model 3, however, the probability of striking 1+ WNP whales is fairly low even when using the 97.5[th] percentile estimates (e.g., less than 7% chance in

one year, less than about 30% chance in 5 years), with the upper estimate for the expected number of WNP whales struck being ≤ 0.07 for one year, or ≤ 0.36 for 5 years, across all models from sets 1 and 2.

Table 1. Summary statistics for five models from three model sets. P_{WNP} is probability of striking a WNP whale (for each strike event). $P(x>0)_Y$ are probabilities of striking at least 1 WNP whale out of Y events. $E(x)_Y$ is the expected number of struck WNP whales out of Y total events. Cell entries are median and upper (97.5th percentile) probabilities.

|	Model 1A	Model 1B	Model 2A	Model 2B	Model 3
P_{WNP}	0.0081 (0.0095)	0.0053 (0.0102)	0.0057 (0.0069)	0.0029 (0.0073)	0.0056 (0.0302)
$P(x>0)_5$	0.040 (0.047)	0.026 (0.050)	0.028 (0.034)	0.014 (0.036)	0.028 (0.142)
$P(x>0)_7$	0.055 (0.065)	0.036 (0.069)	0.039 (0.047)	0.020 (0.050)	0.039 (0.193)
$P(x>0)_{20}$	0.150 (0.174)	0.100 (0.186)	0.107 (0.129)	0.056 (0.136)	0.107 (0.458)
$P(x>0)_{35}$	0.248 (0.284)	0.168 (0.302)	0.180 (0.214)	0.096 (0.225)	0.179 (0.658)
$E(x)_5$	0.041 (0.048)	0.026 (0.051)	0.028 (0.034)	0.014 (0.036)	0.028 (0.151)
$E(x)_7$	0.057 (0.067)	0.037 (0.072)	0.040 (0.048)	0.020 (0.051)	0.039 (0.211)
$E(x)_{20}$	0.162 (0.190)	0.105 (0.205)	0.113 (0.137)	0.057 (0.145)	0.113 (0.604)
$E(x)_{35}$	0.284 (0.333)	0.183 (0.358)	0.198 (0.241)	0.101 (0.254)	0.197 (1.056)
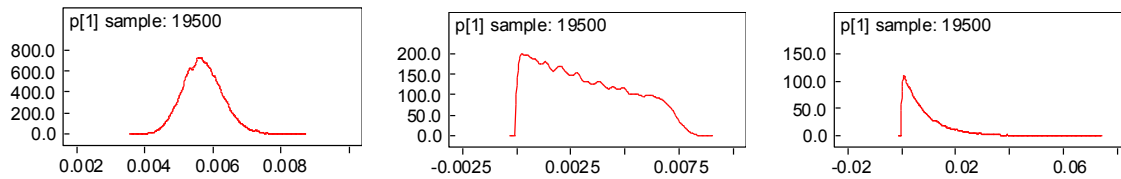
Figure 1. Comparison of posterior distributions for P_{WNP} for models 2A, 2B, and 3.

DISCUSSION

In general, we consider model set 2 the most plausible of the model sets used, because it makes use of information from sightings in the NWA coast area as well as relative abundance of the WNP vs. ENP. In contrast, model set 1 ignores the NWA coast sightings information, and Model 3 ignores our knowledge of the WNP being small relative to the ENP. We also feel that the B-versions of each model are more appropriate than A-versions, because the B models make fewer assumptions. The B models assume no prior knowledge about $P_{WNP|mig}$, except to specify a reasonable upper bound, whereas the A models assume that WNP and ENP migrants are equally available to the hunt on a per capita basis. Therefore, Models 2A and 2B, but especially 2B, may be considered the best estimates.

Model 3 is probably the least justifiable, since by ignoring information about the WNP population size it allows for upper parameter estimates that are likely implausible. For example, if we assume that WNP and ENP animals are equally available to the hunt and there are 16000-22000 ENP animals, then the upper estimate of $P_{WNP} = 0.0302$ corresponds to a WNP population estimate of nearly 483-664 animals, which far exceeds existing estimates. Alternatively, WNP animals would need to be far more available to hunters on per capita basis than ENP animals for behavioral reasons, and there is no reason presently to expect this would be the case.

Based on Model 2B, the probability of taking ≥ 1 WNP whale in a single season ranges from 0.014 to 0.050, depending whether the median or upper estimate is used and whether 5 or 7 whales are struck. The probability of taking ≥ 1 WNP whale in 5 seasons ranges from 0.056 to 0.225 across these same variables. The expected number to be taken in a single year ranges from 0.014 to 0.051, or across 5 years ranges from 0.057 to 0.254.

Estimates from our analysis are considered precautionary since they assume that all WNP whales are available to the hunt (i.e., all migrate between the WNP and ENP) and that the Makah will achieve their proposed maximum strike limits. That being said, the results herein offer a conservative initial step in assessing the potential risk of WNP gray whales incurring mortality incidental to the proposed hunt on the ENP population by the Makah Indian Tribe.

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