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

Jeffery E. Moore and David W. Weller

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Jeffery E. Moore and David W. Weller

Protected Resources Division
Southwest Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
8901 La Jolla Shores Drive
La Jolla, CA 92037-1022 USA

U.S. Department of Commerce
Rebecca M. Blank, Acting Secretary

National Oceanic and Atmospheric Administration
Jane Lubchenco, Undersecretary for Oceans and Atmosphere

National Marine Fisheries Service
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National Marine Fisheries Service
National Oceanic and Atmospheric Administration
8901 La Jolla Shores Drive
La Jolla, CA 92037-1022 USA

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EXECUTIVE SUMMARY

Recent observations of gray whales (*Eschrichtius robustus*) identified in the western North Pacific (WNP) migrating to areas off the coast of North America (Alaska to 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 striking (i.e. killing or seriously injuring) a WNP whale during the Makah hunt using six models from 4 model sets that varied based on the assumptions and 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 sets 3 and 4 used only the sightings data. Within 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). We consider Model 2B the most plausible of all models because model set 2 makes use of all available information and 2B contains fewer assumptions than 2A. Based on model 2B, the probability of striking ≥1 WNP whale in a single season ranges from 0.007 to 0.036, depending on if the median or upper 95th percentile estimate is used and on which maximum is used for the total number of whales struck. The probability of striking ≥1 WNP whale out of 5 seasons ranges from 0.036 to 0.170 across the same scenarios. The expected number to be struck in a single year ranges from 0.01 to 0.04 and from 0.04 to 0.19 across 5 years. For context, these strike estimates were compared to different possible values of Potential Biological Removal (PBR). We also summarized analogous estimates for the number of WNP whales that would be "taken" non-lethally, in terms of the number of attempted but unsuccessful strikes as well as the number of animals approached and pursued during the hunt.

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 wintering areas in Baja California, Mexico, to feeding areas in the Bering, Beaufort, and Chukchi Seas (Fig. 1). An exception to this generality is the relatively small number (100s) of whales that summer and feed along the Pacific coast between Kodiak Island, Alaska, and northern California (Calambokidis *et al*. 2012). These whales are collectively called the Pacific Coast Feeding Group (PCFG). U.S. domestic policy defines the PCFG as gray whales observed between 1 June and 30 November from Northern California through Northern British Columbia. The International Whaling Commission (IWC) has refined this definition to be: PCFG whales are those observed between 1 June and 30 November from 41°N to 52°N in two or more years (IWC, 2012). The WNP population feeds in the Okhotsk Sea off Sakhalin Island, Russia (Weller *et al*., 1999; Weller *et al*. 2012), and in nearshore waters of the southwestern Bering Sea off the southeastern Kamchatka Peninsula (Tyurneva *et al*., 2010).

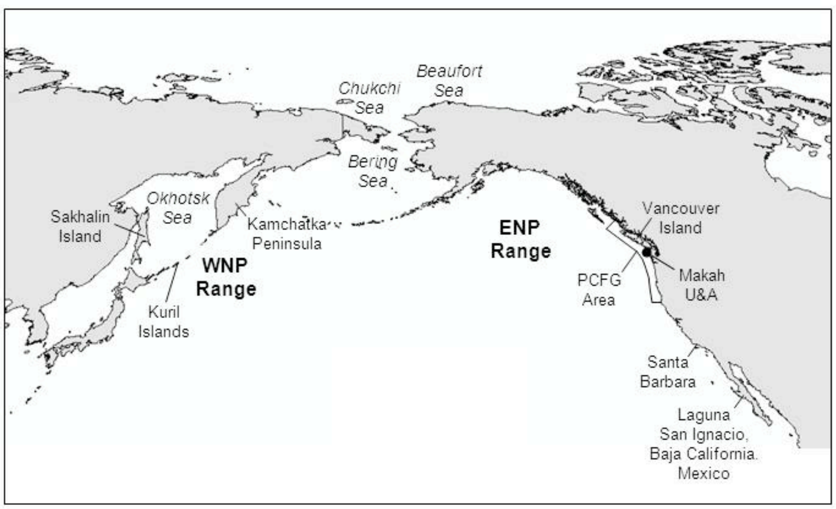

Figure 1. Areas in the western and eastern North Pacific mentioned in the report.

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 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 (Weller *et al*., 2012). 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 three whales from the WNP to the ENP (Mate *et al*., 2011; IWC, 2012). 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*., 2012, 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).

Observations of gray whales identified in the WNP migrating to areas off the coast of North America (Alaska to Mexico) raise concern about placing the WNP population at potential risk of being harmed or killed incidental to the ENP gray whale hunt proposed by the Makah Indian Tribe off northern Washington, USA (IWC, 2012). Given the ongoing concern about conservation of the WNP population, in 2011 the Scientific Committee of the International Whaling Commission (IWC) emphasized the need to estimate the probability of a western gray whale being killed during aboriginal gray whale hunts (IWC, 2012). Additionally, NOAA is required to prepare an Environmental Impact Statement (EIS) pertaining to the Makah's request for a waiver under the U.S. Marine Mammal Protection Act (MMPA) in order to hunt gray whales (NOAA, 2008). The EIS will include an estimate of the likelihood of Makah hunters approaching, pursuing, and attempting to strike a WNP whale in addition to the likelihood of actual strikes (assumed to result in death or serious injury).

The objective of this analysis was therefore to estimate the probability that one or more whales identified in the WNP might be lethally or non-lethally "taken[1]" during the hunt proposed by the Makah Indian Tribe. This report updates the analysis of mortality risk provided by Moore and Weller (2012), by incorporating feedback from the IWC Scientific Committee on that report and by including an analysis of the likelihood of non-lethal as well as lethal take.

METHODS

The probability of striking or taking a WNP whale during the proposed Makah hunt was estimated using four different sets of models (6 models total). Models were based on the following information: (1) the most recent estimates of WNP and ENP population abundance; (2) sightings data from spring 1999-2010 off the coast of northern Washington (NWA) in the Makah Usual and Accustomed (MUA) fishing grounds, where the proposed hunt would take place; and (3) minimum estimates of the proportion of the WNP population that migrate to ENP areas along the North American coast.

Data

Abundance estimates

The most recent WNP abundance estimate (for 2012) is 155, with 95% CI = 142 – 165 (IUCN, 2012). The most recent ENP estimate (for 2007) is 19,126, 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 $\mu_{ENP} = 9.856$, $\sigma_{ENP} = 0.0709$.

[1] Under the U.S. Marine Mammal Protection Act, "take" is defined as "harass, hunt, capture, kill or collect, or attempt to harass, hunt, capture, kill or collect."

Sightings in the Makah Usual and Accustomed (MUA) Fishing Grounds
During spring surveys (1 March to 31 May) in 1999-2009, there were 118 "whale-days" in the MUA off the NWA coast (Calambokidis *et al*., 2012), where all sightings of an individual on a particular day collectively count 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 included WNP whales[2]; 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). Therefore, we assumed in this analysis that the absence of WNP sightings is not likely due to false negative identification (although it is possible that WNP whales were missed during days when MUA surveys were or were not conducted).

Proportion of WNP whales migrating with ENP whales
The proportion of the WNP population that migrates along the North American coast is unknown but based on recent photo-identification, telemetry, and genetic matches of WNP whales to ENP areas, we estimate the value to be at least 0.15, based on there being 23 known matches out of an estimated population size of 155 (Mate *et al*., 2011; IWC, 2012; Urbán *et al*., 2012; Weller *et al*. 2012).

Models
Model set 1
Model set 1 makes use of the ENP and WNP abundance estimates but ignores information obtained from sightings in the MUA off the NWA coast. The potential justification for ignoring the sightings data is that these may not be 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 migrating through the MUA area -- WNP and ENP -- are assumed to be equally available to the hunt, so that the probability of taking a WNP whale is:

$$P_{WNP} = mN_{WNP}/N_{ENP}$$
$$m \sim \text{uniform}(0.15, 1)$$
$$N_{WNP} \sim \text{log-normal}(\mu_{WNP}, \sigma_{WNP})$$
$$N_{ENP} \sim \text{log-normal}(\mu_{ENP}, \sigma_{ENP}),$$

where m is the proportion of WNP whales that migrate with ENP whales along the North American coast and abundance parameters are as above (see Data section). The lower limit for m, 0.15, is based on genetic and photo-identification matching data (see Data section). The upper limit of 1 for m is precautionary, as the true value is unknown but could be high. We used Monte Carlo simulation based on drawing 100,000 random samples from the above distributions to estimate the distribution for P_{WNP}.

Model 1B – Rather than assuming P_{WNP} to be directly proportional to the ratio of abundances (N_{WNP}/N_{ENP}), we express our uncertainty in P_{WNP} as a uniform distribution with the upper limit

[2] Although not in the MUA, Weller *et al*. 2012 report observing three WNP whales on 2 May 2004 and three more on 25 April 2008 near Barkley Sound off the west coast of southern Vancouver Island, British Columbia, Canada.

for P_{WNP} based on the maximum (99th percentile) estimate for the number of WNP whales available to the hunt divided by a minimum (1st percentile) estimate for the ENP population, i.e.,

$$P_{WNP} \sim \text{uniform}(0, P_{max})$$
$$P_{max} = m \cdot N_{99,WNP}/N_{01,ENP}.$$

The interpretation of this model is that, within some plausible upper bound (defined as P_{max}), we have no information about the per capita probability of taking a WNP whale, given unknown differences in migration patterns between WNP and ENP animals. Just as for Model 1A, we use a Monte Carlo approach (100,000 samples) to estimate a distribution for P_{WNP}. For each sample, P_{WNP} is drawn from the uniform distribution specified by P_{max}. P_{max} varies with each sample based on the draw for m, while the ratio $N_{99,WNP}/N_{01,ENP}$ is fixed. Analysis for Model set 1 was conducted in R.

Model set 2

Model sets 2, 3, and 4 differ from Model set 1 in that they use the information from the sightings data in the MUA. In these models, it is assumed that the sightings data from the MUA are representative of the composition of whales (three groups: 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 MUA 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 whale from the PCFG), multiplied by the conditional probability of being a WNP whale given that it is a migrant ($P_{WNP|mig}$), i.e., $P_{WNP} = P_{mig}P_{WNP|mig}$. P_{mig} is estimated using Bayesian MCMC methods assuming that $n_{mig} \sim$ Binomial (N, P_{mig}), where n_{mig} is the number of non-PCFG migrants (83) out of N (118) sightings in the MUA sightings data set. Models 2A and 2B differ in how the conditional probability $P_{WNP|mig}$ is estimated.

<u>Model 2A</u> - The distribution for $P_{WNP|mig}$ is given by the estimator for P_{WNP} in Model 1A. Thus, it is assumed the per capita probabilities of an ENP or WNP whale being taken are the same.

<u>Model 2B</u> - The distribution for $P_{WNP|mig}$ is given by the estimator for P_{WNP} in 1B. Thus, this model asserts that we have no information (apart from specifying a reasonable upper bound) about the per capita likelihood of a WNP whale being killed relative to that of an ENP whale.

Model 3

This uses the MUA sightings data but does not make use of information about WNP population size or the proportion of WNP whales that migrate with ENP whales. Thus, P_{WNP} estimates are solely based on the proportion of animals in the MUA sightings data set that are from the WNP. The posterior distribution for P_{WNP} is estimated using MCMC methods assuming that $n_{WNP} \sim$ Binomial (N, P_{WNP}), where $n_{WNP} = 0$, and N = 118. 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 than ENP whales due to differences in migration timing or behavior, such that our knowledge about the WNP population being very small is irrelevant to the estimates.

Model 4
Model 4 is a variant of Model 3, explained below.

Bayesian estimation
Analyses for Models 2, 3, and 4 were conducted in WinBUGS. Posterior distributions for parameters were summarized from two MCMC chains, each 50,000 samples in length (100,000 samples total) following a burn-in of 20,000 samples. These simple models converged quickly and clearly (chains well mixed) in all cases (Fig. 2). A uniform [0, 1] prior was used for P_{mig} in model set 2 and for P_{WNP} in model 3 and 4; these are the only parameters for which the prior is updated by data (the MUA sightings data) to obtain a new posterior. The posterior distributions for $P_{WNP|mig}$ in Models 2A and 2B were not informed by the sightings data and thus are essentially determined by informative priors given by the above estimators for these parameters.

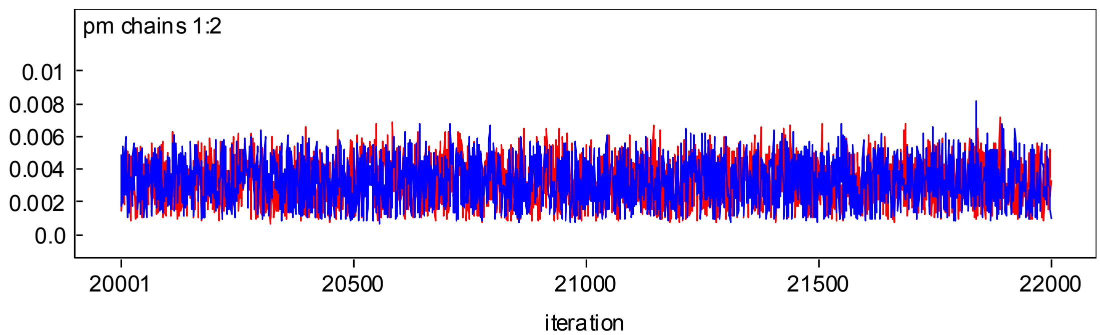

Figure. 2. Example from Model 2A of two MCMC chains (red and blue) mixing for the parameter P_{WNP}.

Estimated parameters
Based on estimates of P_{WNP} for each model, we calculated the probability of striking at least one WNP whale (i.e., P(x>0)) out of X total strikes (strikes are treated as lethal takes), the probability of non-lethally taking at least one WNP whale out of Y strike attempts (P(y>0)), or the probability of non-lethally taking at least one WNP whale out of Z approaches (P(z>0)). We also estimated the expected number of WNP takes out of X, Y or Z total takes. These are calculated as follows:

$$P(x > 0) = 1 - (1 - P_{WNP})^X$$
$$P(y > 0) = 1 - (1 - P_{WNP})^Y$$
$$P(z > 0) = 1 - (1 - P_{WNP})^Z$$
$$E(x) = P_{WNP}X$$
$$E(y) = P_{WNP}Y$$
$$E(z) = P_{WNP}Z$$

For model sets 1, 2, and 3, let X = X* = 5, 7, 20, and 35 gray whale strikes. These were based on the description of the Makah Tribe's proposed gray whale hunt (IWC, 2012 Annex D), which 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.

For model sets 1, 2, and 4, let X = X** = 3 or 4 strikes in one year and 15 or 20 strikes in 5 years of *non-PCFG whales*. The justification for considering this scenario is that, given other management measures within the Makah plan – most importantly the provision to cease the annual hunt if a certain number of PCFG whales are struck – it may be unlikely that the maximum strike limits in the proposal will be achieved. Implementation trials conducted by the Aboriginal Whaling Management Procedure (AWMP) subgroup of the IWC scientific committee suggest that, when management measures are considered, the expected number of strikes per year *to non-PCFG whales* would typically be between 3 and 4 (J. Scordino, pers. comm.).

For Model set 1, estimates for when X = X** are calculated the same as for when X = X*. For Model set 2, since it is given that X** are for *non-PCFG* whales (i.e., migrant whales), then it follows that $P_{mig} = 1$, so the model 2 estimators for P_{WNP} reduce from $P_{mig}P_{WNP|mig}$ to just $P_{WNP|mig}$, which are the same estimators as for Model set 1. When X = X**, we use Model 4 as a variant of Model 3 (which is for X = X*). In Model 3, $n_{WNP} \sim$ Binomial (N_{tot}, P_{WNP}), where $n_{WNP} = 0$, and $N_{tot} = 118$ total whale-day sightings, 35 of which were PCFG whales and 83 of which were migrating ENP whales. In Model 4, $n_{WNP} \sim$ Binomial (N_{mig}, $P_{WNP|mig}$), where $N_{mig} = 83$ whale-day sightings of non-PCFG migrant whales (i.e., we are only evaluating conditional probability of being a WNP whale given being migrant whale.

Values of Y for each model were calculated as 4X, and values for Z were calculated as 20X. In other words, for every struck whale, there are an estimated 4 strike attempts and 20 whales approached in attempt to strike. These numbers are based on the Makah tribe's experience in the 1999 and 2000 hunts, for which they stated that for every struck whale, there would be approximately 4 attempted strikes and 10 individuals pursued, which are assumed to affect 20 whales, given an average pod size of two whales (NOAA, 2008).

Comparison to Potential Biological Removal (PBR)

To contextualize the Table 1 estimates of lethal takes, we provide 5-year estimates of PBR[3]) for comparison. PBR is conventionally calculated as $0.5R_{max}N_{min}F_R$, where R_{max} is the maximum productivity rate estimate for the population (we used 0.062 based on the 2012 Draft Stock Assessment Report; NMFS, 2012), N_{min} is the 20th percentile abundance estimate (we used 150 based on WNP abundance parameters), and F_R is a recovery factor. We provide PBR estimates for F_R = 0.1, 0.5, and 1.0. F_R = 0.1 is typically used for stocks of endangered species, noting that the WNP gray whale stock is listed as Endangered under the U.S. Endangered Species Act and Critically Endangered on the IUCN Red List. F_R = 0.5 is a recommended default for most stocks (NMFS 2005), whereas F_R = 1.0 may be appropriate for stocks with known and favorable population status. The PBR estimate is also supposed to take into the account (be discounted by) the proportion of the stock using US waters and the proportion of time it is there (NMFS, 2005). The proportion of the WNP migrating in the ENP range is unknown but characterized in our models by a uniform (0.15, 1) distribution. The proportion of time spent in US waters is difficult to estimate for migratory animals but is probably on the order of 3 months or 0.25 years. Thus, for each value of F_R, we calculated a distribution for the 5-year PBR estimate, by multiplying the standard equation by 0.25 and by a uniform (0.15, 1) distribution.

[3] Under the U.S. Marine Mammal Protection Act, PBR level is defined as "the maximum number of animals, not including natural mortalities, that may be removed from a marine mammal stock while allowing that stock to reach or maintain its optimum sustainable population."

a b

RESULTS

Take estimates

Estimated parameters from all model sets are in Tables 1 – 3. Table 1 presents estimates for the probability of striking a WNP whale during a single strike event (P_{WNP}), and of striking at least one WNP whale ($P(x>0)$) and the expected number of WNP whales ($E(x)$) that would be struck given $X = X^*$ (number of gray whales struck) or X^{**} (number of *non-PCFG* whales struck). Table 2 presents the analogous estimates for the number of attempted strikes ($Y = Y^*$ or Y^{**}), and Table 3 presents the analogous estimates for the number of whales approached ($Z = Z^*$ or Z^{**}). We present median estimates and, for precautionary purposes, 95th percentile estimates from the Monte Carlo or Bayesian posterior distributions.

For $X = X^*$, $Y = Y^*$, and $Z = Z^*$ (i.e., out of the total number of events affecting gray whales, irrespective of the putative stock affected), parameter estimates were higher for Model set 1 than Model set 2. Within these models sets, median parameter estimates were higher for version A than B, although upper (95th percentile) estimates were similar. Estimates for Model 3 were higher than for the other models, particularly when looking at upper bound (95th percentile) estimates, because of the highly skewed and unconstrained posterior for P_{WNP} (Fig. 3).

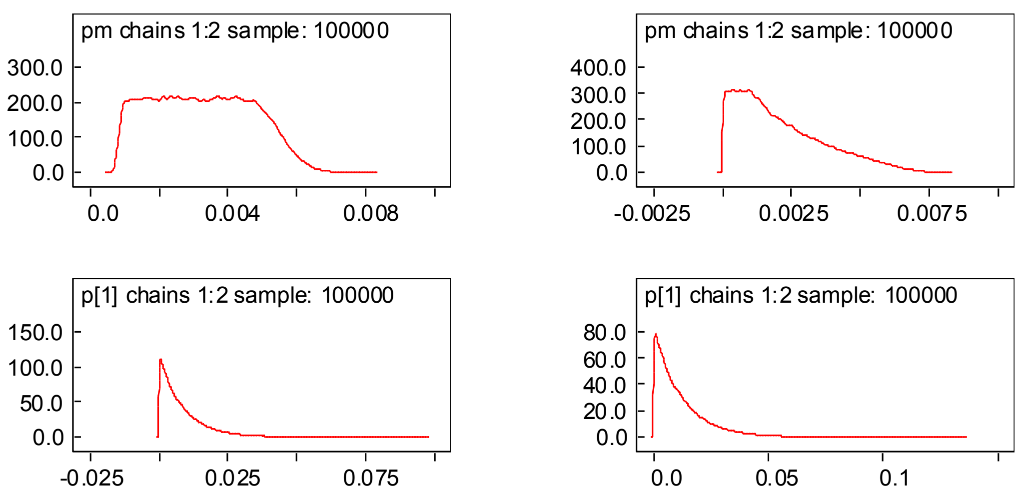

Figure 3. Comparison of Bayesian posterior distributions for P_{WNP} for Models 2A (a), 2B (b), 3 (c), and 4 (d).

For $X = X^{**}$, $Y = Y^{**}$, $Z = Z^{**}$ (i.e., out of the total number of events affecting *non-PCFG* whales), model set 1 and model set 2 results are the same (because the estimators are the same), but median estimates were higher for version A than B in these model sets (although 95th percentile estimates were similar). Estimates for Model 4 were higher than for the other models.

In Tables 1 – 3, we highlight (bold) estimates from Model 2B because Model set 2 makes the greatest use of available information (i.e., uses all datasets), and model 2B is based on fewer assumptions than 2A, and thus we favor Model 2B estimates as the most plausible (see Discussion). Estimates from this model for the proposed 5-year hunt period are as follows. The median (and 95th percentile) probability of striking a WNP whale within the 5-year permit period ranged from 0.036 (0.107) to 0.058 (0.170) as X increased from 15 *non-PCFG* whales to 35 whales of any putative stock, and the expected number of whales that would be struck ranged from 0.04 (0.11) to 0.06 (0.19). The probability of an attempted strike on a WNP whale ranged from 0.136 (0.365) to 0.212 (0.524), and the expected number of attempts on WNP whales ranged from 0.15 (0.45) to 0.24 (0.74). Finally, the probability that a WNP whale would be pursued or approached by a hunter ranged from 0.519 (0.897) to 0.697 (0.976), and the expected number of WNP whales that would be approached ranged from 0.73 (2.26) to 1.19 (3.70).

In summary, we estimate based on Model 2B a fairly high probability that at least one WNP would be taken in the broadest sense of being pursued or approached by Makah hunters (i.e., $P(z>0) = 0.52 – 0.98$, depending on Z and whether the median or upper estimate is used). The probability of an attempted strike on least one WNP whale in 5 years was relatively moderate (i.e., $P(y>0) = 0.14 – 0.52$). The probability of actually striking at least one WNP whale during the 5-year period was relatively low but non-trivial (i.e., $P(z>0) = 0.04 – 0.17$).

Table 1. Summary statistics for six models from four model sets. P_{WNP} is probability of taking (striking) a WNP whale during a given take event. $P(x>0)_X$ are probabilities of striking at least 1 WNP whale out of X events. $E(x)_X$ is the expected number of struck WNP whales out of X total events. X=X** indicates that events are known to affect *non-PCFG* whales (otherwise X = X*, the number of events to gray whales in general). Cell entries are median and upper (95th percentile) probabilities.

	Model 1A	Model 1B	Model 2A	**Model 2B**	Model 3	Model 4
P_{WNP}	0.005 (0.008)	0.002 (0.008)	for X = X* 0.003 (0.006) for X = X** 0.005 (0.007)	**for X = X*** **0.002 (0.005)** **for X = X**** **0.002 (0.008)**	0.006 (0.025)	0.008 (0.035)
1 year						
$P(x>0)_{3**}$	0.014 (0.024)	0.007 (0.023)	0.014 (0.023)	**0.007 (0.022)**	NA	0.024 (0.102)
$P(x>0)_{4**}$	0.018 (0.031)	0.010 (0.030)	0.018 (0.031)	**0.010 (0.030)**	NA	0.033 (0.134)
$P(x>0)_5$	0.023 (0.039)	0.012 (0.037)	0.016 (0.028)	**0.008 (0.026)**	0.029 (0.119)	NA
$P(x>0)_7$	0.032 (0.054)	0.017 (0.052)	0.022 (0.039)	**0.012 (0.036)**	0.040 (0.162)	NA
$E(x)_{3**}$	0.01 (0.02)	0.01 (0.02)	0.01 (0.02)	**0.01 (0.02)**	NA	0.03 (0.11)
$E(x)_{4**}$	0.02 (0.03)	0.01 (0.03)	0.02 (0.03)	**0.01 (0.03)**	NA	0.03 (0.14)
$E(x)_5$	0.02 (0.04)	0.01 (0.04)	0.02 (0.03)	**0.01 (0.03)**	0.03 (0.13)	NA
$E(x)_7$	0.03 (0.06)	0.02 (0.05)	0.02 (0.04)	**0.01 (0.04)**	0.04 (0.18)	NA
5 year						
$P(x>0)_{15**}$	0.067 (0.113)	0.036 (0.108)	0.067 (0.112)	**0.036 (0.107)**	NA	0.117 (0.416)
$P(x>0)_{20**}$	0.089 (0.147)	0.048 (0.141)	0.089 (0.146)	**0.048 (0.141)**	NA	0.152 (0.512)
$P(x>0)_{20}$	0.089 (0.147)	0.048 (0.141)	0.063 (0.106)	**0.034 (0.101)**	0.110 (0.397)	NA
$P(x>0)_{35}$	0.151 (0.244)	0.082 (0.233)	0.107 (0.178)	**0.058 (0.170)**	0.185 (0.587)	NA
$E(x)_{15**}$	0.07 (0.12)	0.04 (0.11)	0.07 (0.12)	**0.04 (0.11)**	NA	0.12 (0.53)
$E(x)_{20**}$	0.09 (0.16)	0.05 (0.15)	0.09 (0.16)	**0.05 (0.15)**	NA	0.17 (0.70)
$E(x)_{20}$	0.09 (0.16)	0.05 (0.15)	0.06 (0.11)	**0.03 (0.11)**	0.12 (0.50)	NA
$E(x)_{35}$	0.16 (0.28)	0.09 (0.26)	0.11 (0.20)	**0.06 (0.19)**	0.20 (0.87)	NA

Table 2. Summary statistics for six models from four model sets. P_{WNP} is probability of taking (attempted strike) a WNP whale during a given take event. $P(y>0)_Y$ are probabilities of attempting to strike at least 1 WNP whale out of Y events. $E(y)_Y$ is the expected number of attempted-struck WNP whales out of Y total events. Y=Y** indicates that events are known to affect *non-PCFG* whales (otherwise Y = Y*, the number of events to gray whales in general). Cell entries are median and upper (95th percentile) probabilities.

	Model 1A	Model 1B	Model 2A	**Model 2B**	Model 3	Model 4
P_{WNP}	0.005 (0.008)	0.002 (0.008)	for Y = Y 0.003 (0.006) for Y = Y* 0.005 (0.007)	**for Y = Y** **0.002 (0.005)** **for Y = Y*** **0.002 (0.008)**	0.006 (0.025)	0.008 (0.035)
1 year						
$P(y>0)_{12**}$	0.054 (0.091)	0.029 (0.087)	0.054 (0.090)	**0.029 (0.087)**	NA	0.094 (0.349)
$P(y>0)_{16**}$	0.072 (0.120)	0.039 (0.114)	0.072 (0.119)	**0.038 (0.114)**	NA	0.124 (0.436)
$P(y>0)_{20}$	0.089 (0.147)	0.048 (0.141)	0.063 (0.106)	**0.034 (0.101)**	0.110 (0.397)	NA
$P(y>0)_{28}$	0.122 (0.200)	0.066 (0.192)	0.086 (0.145)	**0.047 (0.138)**	0.151 (0.507)	NA
$E(y)_{12**}$	0.06 (0.10)	0.03 (0.09)	0.06 (0.09)	**0.03 (0.09)**	NA	0.10 (0.42)
$E(y)_{16**}$	0.07 (0.13)	0.04 (0.12)	0.07 (0.13)	**0.04 (0.12)**	NA	0.13 (0.56)
$E(y)_{20}$	0.09 (0.16)	0.05 (0.15)	0.06 (0.11)	**0.03 (0.11)**	0.12 (0.50)	NA
$E(y)_{28}$	0.13 (0.22)	0.07 (0.21)	0.09 (0.16)	**0.05 (0.15)**	0.16 (0.70)	NA
5 year						
$P(y>0)_{60**}$	0.244 (0.380)	0.137 (0.366)	0.243 (0.377)	**0.136 (0.365)**	NA	0.391 (0.883)
$P(y>0)_{80**}$	0.311 (0.472)	0.178 (0.455)	0.310 (0.468)	**0.178 (0.454)**	NA	0.484 (0.943)
$P(y>0)_{80}$	0.311 (0.472)	0.178 (0.455)	0.228 (0.360)	**0.127 (0.346)**	0.373 (0.877)	NA
$P(y>0)_{140}$	0.479 (0.673)	0.291 (0.655)	0.364 (0.543)	**0.212 (0.524)**	0.558 (0.971)	NA
$E(y)_{60**}$	0.28 (0.48)	0.15 (0.45)	0.28 (0.47)	**0.15 (0.45)**	NA	0.49 (2.11)
$E(y)_{80**}$	0.37 (0.64)	0.20 (0.61)	0.37 (0.63)	**0.20 (0.60)**	NA	0.66 (2.82)
$E(y)_{80}$	0.37 (0.64)	0.20 (0.61)	0.26 (0.45)	**0.14 (0.42)**	0.47 (2.00)	NA
$E(y)_{140}$	0.65 (1.11)	0.34 (1.06)	0.45 (0.78)	**0.24 (0.74)**	0.82 (3.49)	NA

Table 3. Summary statistics for six models from four model sets. P_{WNP} is probability of taking (approaching) a WNP whale during a given take event. $P(z>0)_Z$ are probabilities of approaching at least 1 WNP whale out of Z events. $E(z)_Z$ is the expected number of approached WNP whales out of Z total events. Z=Z** indicates that events are known to affect *non-PCFG* whales (otherwise Z = Z*, the number of events to gray whales in general). Cell entries are median and upper (95th percentile) probabilities.

	Model 1A	Model 1B	Model 2A	**Model 2B**	Model 3	Model 4
P_{WNP}	0.005 (0.008)	0.002 (0.008)	for Z = Z 0.003 (0.006) for Z = Z* 0.005 (0.007)	**for Z = Z** **0.002 (0.005)** **for Z = Z*** **0.002 (0.008)**	0.006 (0.025)	0.008 (0.035)
1 year						
$P(z>0)_{60**}$	0.244 (0.380)	0.137 (0.366)	0.243 (0.377)	**0.136 (0.365)**	NA	0.391 (0.883)
$P(z>0)_{80**}$	0.311 (0.472)	0.178 (0.455)	0.310 (0.468)	**0.178 (0.455)**	NA	0.484 (0.943)
$P(z>0)_{100}$	0.373 (0.550)	0.218 (0.532)	0.276 (0.428)	**0.157 (0.412)**	0.442 (0.920)	NA
$P(z>0)_{140}$	0.479 (0.673)	0.291 (0.655)	0.364 (0.543)	**0.212 (0.524)**	0.558 (0.971)	NA
$E(z)_{60**}$	0.28 (0.48)	0.15 (0.45)	0.28 (0.47)	**0.15 (0.45)**	NA	0.49 (2.11)
$E(z)_{80**}$	0.37 (0.64)	0.20 (0.61)	0.37 (0.63)	**0.20 (0.60)**	NA	0.66 (2.82)
$E(z)_{100}$	0.47 (0.79)	0.25 (0.76)	0.32 (0.56)	**0.17 (0.53)**	0.58 (2.50)	NA
$E(z)_{140}$	0.65 (1.11)	0.34 (1.06)	0.45 (0.78)	**0.24 (0.74)**	0.81 (3.49)	NA
5 year						
$P(z>0)_{300**}$	0.753 (0.909)	0.521 (0.898)	0.752 (0.906)	**0.519 (0.897)**	NA	0.916 (1.000)
$P(z>0)_{400**}$	0.845 (0.959)	0.625 (0.952)	0.844 (0.958)	**0.624 (0.952)**	NA	0.963 (1.000)
$P(z>0)_{400}$	0.845 (0.959)	0.625 (0.952)	0.725 (0.893)	**0.494 (0.880)**	0.903 (1.000)	NA
$P(z>0)_{700}$	0.962 (0.996)	0.821 (0.995)	0.896 (0.980)	**0.697 (0.976)**	0.983 (1.000)	NA
$E(z)_{300**}$	1.40 (2.48)	0.74 (2.27)	1.39 (2.36)	**0.73 (2.26)**	NA	2.47 (10.56)
$E(z)_{400**}$	1.86 (3.18)	0.98 (3.03)	1.85 (3.15)	**0.98 (3.02)**	NA	3.29 (14.07)
$E(z)_{400}$	1.86 (3.18)	0.98 (3.03)	1.29 (2.23)	**0.68 (2.12)**	2.33 (9.98)	NA
$E(z)_{700}$	3.26 (5.56)	1.72 (5.30)	2.26 (3.90)	**1.19 (3.70)**	4.07 (17.46)	NA

Comparison to PBR

Table 4 provides 5-year estimates of PBR based on F_R = 0.1, 0.5, and 1.0. Uncertainty in the estimates (e.g., 95% CI) reflects uncertainty in the proportion of the WNP stock that migrates with the ENP stock. For F_R = 0.1, striking one WNP whale in the 5-year period would exceed PBR. For F_R = 0.5, one WNP strike could exceed PBR, depending on how many WNP individuals migrate with the ENP stock. Fewer WNP whales in U.S. waters would mean higher chance that one strike would exceed PBR, but it would also translate into lower probability of there being a WNP strike in the first place (i.e., lower than reflected in the Table 1 estimates). For F_R = 1, striking one WNP whale in the 5-year period would not exceed PBR.

Table 4. Estimates of PBR (5-year total) for the WNP gray whale stock under three different values of F_R. Uncertainty in the estimates reflects uncertainty in the proportion of the WNP that uses U.S. waters; the lower estimate corresponds to a little more than 0.15 of the WNP stock migrating in ENP areas, whereas the upper estimate corresponds to nearly all WNP animals migrating in ENP areas.

	F_R = 0.1	F_R = 0.5	F_R = 1.0
2.5%	0.10	0.50	0.99
median	0.33	1.67	3.35
97.5%	0.57	2.85	5.69

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 MUA from the NWA coast area as well as relative abundance of the WNP vs. ENP. In contrast, Model set 1 ignores the MUA sightings information, and Models 3 and 4 ignore our knowledge of the WNP being small relative to the ENP. We also feel that, within Model sets 1 and 2, 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 most useful estimates.

Models 3 and 4 are probably the least justifiable, since by ignoring information about the WNP population size they allow 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 16,000-22,000 ENP animals, then the upper estimate for Model 4 of P_{WNP} = 0.035 corresponds to a WNP population estimate of nearly 560-770 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 is the case.

Estimates from our analysis are considered precautionary since they assume 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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