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ESTIMATES OF THE PROBABILITY OF STRIKING A WESTERN NORTH PACIFIC GRAY WHALE DURING THE PROPOSED MAKAH HUNT: 2019 UPDATE

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EXECUTIVE SUMMARY

Observations of gray whales (*Eschrichtius robustus*) from the western North Pacific (WNP) migrating to areas off the coast of North America (Alaska to Mexico) raised concerns that this small population could be encountered during a hunt of eastern North Pacific (ENP) gray whales proposed by the Makah Indian Tribe in northern Washington, USA. In 2013, an analysis was conducted to estimate the probability of striking (i.e. killing or seriously injuring) a WNP whale under the Makah Tribe's hunt proposal (Moore and Weller 2013). This analysis was updated in 2018 (Moore and Weller 2018) to account for new data and a revised draft proposal by NOAA Fisheries for governing ENP gray whale hunts by the Makah Tribe for up to 10 years. Under the draft proposal, hunting seasons would alternate between winter-spring hunts in even-numbered years and summer hunts during odd-numbered years. It is presumed that only in even-numbered years (thus, for 5 of the 10 years) would WNP whales potentially be encountered during the hunt. In each of these years, the draft proposal would allow for up to 3 gray whales to be struck. Here, we again re-estimate the probability of striking a WNP whale based on a new (higher) population size estimate and a new (lower) and more precise estimate of the proportion of WNP whales mixing with ENP whales during migration. We used the same model as the 2018 analysis (Model 2A) to generate new estimates. We estimate that for an individual strike on a gray whale, the expected probability of it being a WNP whale is 0.005 (95% Bayesian CRI: 0.003 – 0.007), up slightly from 0.004 in the 2018 analysis. For a single year's hunt (3 strikes), the expected probability of striking ≥1 WNP whale would be 0.015 (0.009 – 0.022); this is up slightly from 0.012. Across the 10-year hunt period (15 strikes), the probability of striking ≥1 WNP whale would be 0.074 (0.045 – 0.104), up slightly from 0.058.

INTRODUCTION

Two gray whale (*Eschrichtius robustus*) populations are recognized 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) (LeDuc *et al*., 2002, Lang *et al*. 2010, 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 (Weller *et al*., 2013). These whales are collectively called the Pacific Coast Feeding Group (PCFG). The International Whaling Commission (IWC) has defined PCFG whales as individuals observed between 1 June and 30 November from 41°N to 52°N in two or more years (IWC, 2012), and NOAA Fisheries has adopted this definition in recent assessments (Weller *et al.*, 2013). The usual and accustomed (U&A) fishing grounds of the Makah Indian Tribe are off the coast of northern Washington, USA, and overlap with a portion of the PCFG summering area (Fig. 1).

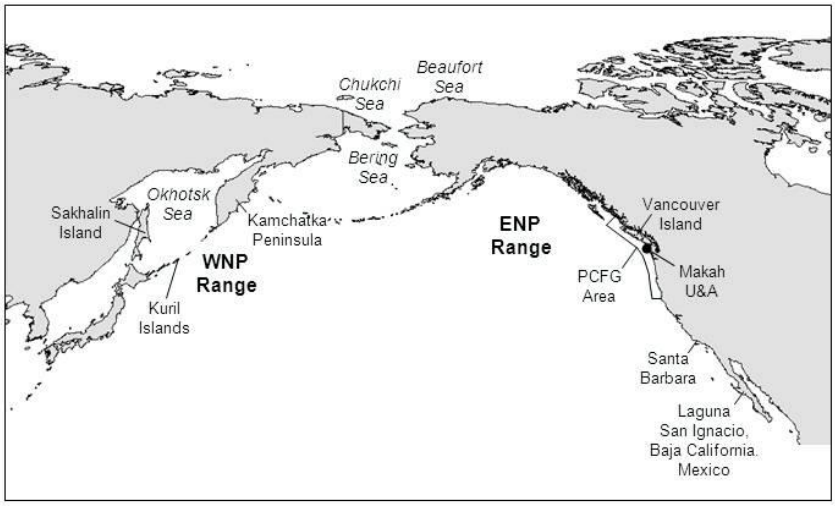

Figure 1. Areas in the western and eastern North Pacific mentioned in the report.

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). 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 been documented off the southern and eastern coast of Kamchatka (Tyurneva *et al*., 2010). A small number of 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).

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. Between 2010 and 2012 three whales outfitted with satellite transmitters were tracked moving from Sakhalin in the WNP to the ENP (Mate *et al*., 2015). Finally, photographic matches between the WNP and ENP, including matches between Sakhalin, Vancouver Island and Laguna San Ignacio and other nearby lagoons in Baja California, Mexico (Fig. 1), have further confirmed use of areas in the ENP by whales identified in the WNP (Weller *et al*., 2012, Urbán *et al*., 2019). Despite this level of mixing, significant mtDNA and nuclear genetic differences between whales in the WNP and ENP have been found (LeDuc *et al*. 2002, Lang *et al*., 2011).

In 1995, following the 1994 delisting of ENP gray whales under the U.S. Endangered Species Act, the Makah Indian Tribe notified NOAA Fisheries of its interest in re-establishing limited ceremonial and subsistence whale hunting. The decision-making history on this issue is complex and not described here except to note that in 2005, the Makah Tribe submitted a detailed proposal for hunting ENP gray whales in the coastal portion of its U&A off northern Washington, USA, as part of a request for a waiver of the U.S. Marine Mammal Protection Act's (MMPA) take moratorium (16 USC 1371(a)(3)(A)). Subsequently, observations of WNP gray whales migrating through areas off the coast of North America (Alaska to Mexico) emphasized the need to evaluate the probability of a WNP gray whale being encountered in aboriginal hunts for ENP gray whales (IWC, 2012). Following recommendations of the Scientific Committee of the International Whaling Commission (IWC), analyses were conducted to estimate such probability in the context of the Makah Tribe's hunt proposal (Moore and Weller, 2013). These analyses informed a draft Environmental Impact Statement (DEIS), completed in 2015 (NMFS, 2015), pertaining to the Makah Tribe's MMPA waiver request.

NOAA Fisheries is presently considering a MMPA waiver and associated draft proposal that would govern a modified version of the Tribe's hunt proposal. The objective of the analysis reported here was to provide updated estimates of the probability that one or more WNP whales might be subjected to strikes[1], unsuccessful strike attempts (i.e., harpoon throws that do not penetrate), and vessel approaches during hunts and hunt training exercises considered in the draft proposal. This report is based on the methods used by Moore and Weller (2013, 2018) and incorporates updated information about the population sizes of ENP and WNP gray whales and their occurrence within the proposed hunt area.

METHODS

Hunt proposal

NOAA Fisheries' draft proposal would govern a Makah Tribe hunt of ENP gray whales in the coastal portion of the U&A (i.e., the "hunt area") over a 10-year hunt period. In odd-numbered years, the hunt would take place from 1 July through 31 October, a period when no sightings of WNP whales have been recorded in the ENP, and when gray whales generally (apart from PCFG

[1] As described in NOAA Fisheries' DEIS (NMFS, 2015), the term "strike" is interpreted to be consistent with the IWC Schedule definition as meaning "to penetrate with a weapon used for whaling."

animals) are in northern feeding areas. Thus, hunted animals in these odd-numbered years would presumably belong to the PCFG and it is assumed that WNP whales would not be at risk from proposed hunt operations. In even-numbered years, the hunt would take place from 1 December through 31 May. This period coincides with both the southward (December to mid-February) and northward (mid-February to late May) migration of ENP whales and overlaps with the time when WNP gray whales have been sighted in the ENP. Thus, in even-numbered years there is a potential risk to WNP whales from proposed hunt operations. In each of the even-numbered years, a maximum of 3 gray whales per year could be struck (including "struck and lost" animals). Over the 10-year period of the proposed hunt, a maximum of 15 whales could be struck (in even-numbered years) that would have some probability of being WNP whales. We therefore evaluate the probability of striking at least one WNP whale per even-numbered year (out of 3 strikes) and for the 10-year period (out of 15 strikes). We also evaluate associated rates of WNP whales being subjected to aforementioned "unsuccessful strike attempts" (i.e., harpoon throws that do not penetrate) and "approaches" (i.e., whales approached by vessels during hunts and hunt training exercises).

Data

Abundance estimates - The ENP abundance estimate (for 2015/2016) is 26,960 (CV = 0.05) (Durban *et al.*, 2017). The combined Sakhalin-Kamchatka WNP abundance estimate (for 2016) is 290 (CV = 0.035) for the 1+ population (i.e., excluding calves) (Cooke 2017, Cooke 2018). This is revised from the estimate of 200 that was used by Moore and Weller (2018). We multiplied the WNP 1+ estimate by 1.099 to account for calves, thereby producing an abundance estimate for the entire population. This multiplier is based on the ratio of the population size with and without calves in 2012 (IUCN, 2012).

Mixing proportions based on sightings in the Makah Hunt Area - During spring surveys (March to May) in 1996-2012 there were 181 observed whale-days in the Makah hunt area (Calambokidis *et al*., 2014). To clarify the term "whale-day" – 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). None of the 181 whale-days observed included WNP whales[2]; 73 (40.3%) were considered PCFG whales; and the rest (108, or 59.7%) were assumed to be migrating ENP whales.

However, rather than use 40.3% as the expected PCFG proportion in the hunt area during an even-year hunt, we use 28% for this mixing proportion (i.e. 72% of animals encountered during an even-year hunt are likely to be non-PCFG animals). This value is based on analyses summarized in a 2018 IWC workshop (IWC, 2018).

Proportion of WNP whales migrating with ENP whales - The proportion of the WNP population that migrates along the North American coast is unknown but Moore and Weller (2018) used a uniform distribution with minimum of 0.37 and maximum of 1.00. The lower bound was based on analysis by Cooke (2015) and reported to a 2015 IWC workshop on gray whale population

[2] Although not in the Makah hunt area, 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.

structure (IWC, 2016). The upper bound reflected the uncertain possibility that perhaps all animals migrated with the ENP population. More recently, Cooke et al. (2019) used results from an updated ENP-WNP photo-identification catalog comparison (Urbán *et al*., 2019) to estimate that approximately 0.60 (95% CI: 0.45 – 0.80) of the WNP population migrates to the North American coast.

Model

Moore and Weller (2013) considered four models in their analysis but they based final inferences on what they termed Model 2B. Moore and Weller (2018) used Model 2A instead (see their paper for justification), and we do so here as well.

Model 2A makes use of the mixing proportion/sightings data for the Makah hunt area, 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 struck is the probability that the struck whale is 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 ($P_{WNP|mig}$). Thus, $P_{WNP} = P_{mig}P_{WNP|mig}$.

P_{mig} is defined as $1 - P_{PCFG}$, where P_{PCFG} is given by an informative prior: $P_{PCFG} \sim$ Beta (5.3648, 13.7952) which has a mean of 0.28 and SD of 0.1 (IWC 2018).

We assume that the per-capita likelihood of a migrating (non-PCFG) whale in the hunt area being a WNP whale (i.e., $P_{WNP|mig}$) is simply given by the proportion of the migrating population made up of WNP whales. This proportion depends on what fraction of the WNP population migrates along the U.S. West Coast, which we call m, and the relative size of the WNP to the ENP population. Thus, $P_{WNP|mig} = mN_{WNP}/(mN_{WNP} + N_{ENP})$. We described m as broadly uniformly distributed in our earlier analysis (Moore and Weller 2018). Here, let $m \sim$ Beta (17.18, 11.45), based on Cooke *et al.* (2019). This Beta distribution has median and mean of 0.60 with 95% CRI of 0.42 – 0.77 (note that Cooke reported a maximum likelihood estimate of 0.56, median of 0.60, and 95% CRI of 0.45 to 0.80; these values cannot be described exactly by a Beta distribution, but the distribution we use is a close approximation) . N_{WNP} and N_{ENP} are treated as lognormally distributed variables with means and CVs as given above.

Estimation

Earlier analyses (Moore and Weller, 2013) used Bayesian estimation. In the 2018 analysis and current exercise, analysis was conducted using OpenBUGS software, but estimation was not strictly Bayesian because there are no new data updating the informative prior inputs. Rather, these more recent analyses were essentially Monte Carlo procedures, with distributions for the parameters of interest (e.g., probability of striking a WNP whale) being derived from random draws from informed prior distributions for the input parameters. Derived parameter distributions were summarized from two MCMC chains, each 25,000 samples in length (50,000 samples total).

Derived parameters

The key parameter of interest is the per-strike probability of striking a WNP whale. Derived from this parameter are the probabilities of striking at least one WNP out of 3 gray whale strikes (i.e.,

the annual probability of striking a WNP whale, for the even-numbered years) or out of 15 gray whale strikes (i.e., probability for the whole 10-year period). These are calculated as $P(x > 0) = 1 - (1 - P_{WNP})^X$, where X is 3 or 15. Additionally, we can derive the expected number of WNP strikes as $E(x) = P_{WNP}X$. Using data collected during previous hunts (NMFS, 2015), the following two assumptions were used to calculate analogous estimates for vessel approaches and unsuccessful strike attempts: (1) there will be 353 vessel approaches per year (3530 across all 10 years)[3], and (2) there will be 6 unsuccessful strike attempts for every strike in an even-year hunt[4].

RESULTS

Parameter estimates

Estimated parameters from all model sets are in Table 1. For comparison, we also show the posterior mean from the 2018 analysis. Figure 2 shows the distribution for P_{WNP}. It is straightforward to integrate across the uncertainty in P_{WNP} to obtain a single probability estimate. We did this for the probability of striking ≥ 1 WNP whale over the entire 10-year hunt period (i.e., out of 15 strikes). This probability was 0.074 (posterior mean).

Table 1. Distribution summaries for key model parameters. "Prob(WNP)" is the probability of at least 1 WNP animal being struck or subjected to unsuccessful strike attempts or vessel approaches given the specified number of events. For comparison, we also show the posterior mean from the 2018 analysis.

	2018	2019 Analysis			
Parameter	Posterior mean	Posterior mean	2.5% CRI	Posterior median	97.5% CRI
Prob(WNP) for a single interaction, i.e., P_{WNP}	0.004	0.005	0.003	0.005	0.007
Prob(WNP|3 strikes in 1 yr)	0.012	0.015	0.009	0.015	0.022
Prob(WNP|15 strikes in 10 yrs)	0.058	0.074	0.045	0.073	0.104
Prob(WNP|18 unsuccessful strike attempts in 1 yr)	0.070	0.088	0.054	0.087	0.124
Prob(WNP|90 unsuccessful strike attempts in 10 yrs)	0.299	0.365	0.243	0.367	0.483
Prob(WNP|353 approaches in 1 yr)	0.735	0.823	0.665	0.833	0.925
Prob(WNP|3530 approaches in 10 yrs)	~ 1.0	~ 1.0	~ 1.0	~ 1.0	~ 1.0
Expected WNP|3 strikes in 1 yr	0.012	0.015	0.009	0.015	0.022
Expected WNP|15 strikes in 10 yrs	0.060	0.076	0.046	0.076	0.110
Expected WNP|18 unsuccessful strike attempts in 1 yr	0.072	0.092	0.056	0.091	0.132

[3] This number is conservative because it assumes that all approaches (hunting and training) in both even and odd years occur during the winter/spring period when WNP whales may be present. Realistically we would expect a substantial number of approaches to occur outside this period, i.e., during the summer when ocean conditions are more favorable and, in odd years, when hunting approaches are restricted to July - October.

[4] We expect zero in odd years because the draft proposal limits training strikes (which count as unsuccessful strike attempts) to the summer-fall hunting season, when WNP whales are not expected to be present.

Parameter	2018	2019 Analysis			
	Posterior mean	Posterior mean	2.5% CRI	Posterior median	97.5% CRI
Expected WNP|90 unsuccessful strike attempts in 10 yrs	0.361	0.458	0.278	0.455	0.658
Expected WNP|353 approaches in 1 yr	1.416	1.796	1.091	1.786	2.579
Expected WNP|3530 approaches in 10 yrs	14.16	17.96	10.91	17.86	25.79

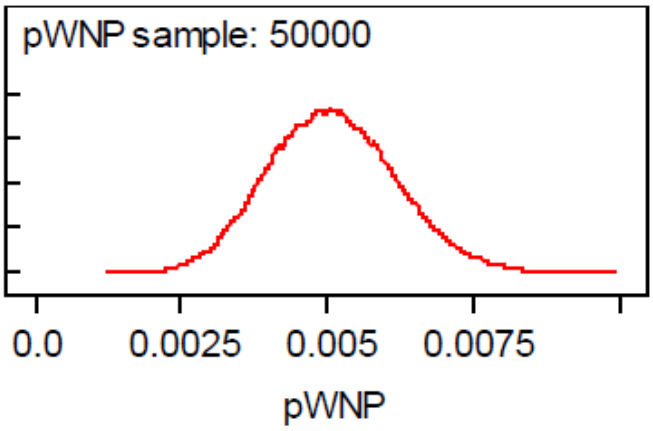

Figure 2. Posterior distribution for probability that any given strike is a WNP whale.

DISCUSSION

Estimates from our analysis may be precautionary since they assume that the Makah hunt will achieve proposed maximum strike limits, and because the assumption of Model 2A is that WNP whales are homogenously mixed with ENP whales. The likelihood of striking a WNP whale is overestimated if fewer total animals are struck or if in reality the WNP animals use a different migration corridor and are less likely to travel through the Makah hunt area. Given uncertainties associated with the model and scenario assumptions, these results serve as a rough approximation of the potential for WNP gray whales to be subjected to strikes, unsuccessful strike attempts and vessel approaches during a Makah hunt operating under a draft proposal currently being considered by NOAA Fisheries.

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