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ESTIMATES OF THE PROBABILITY OF STRIKING A WESTERN NORTH PACIFIC GRAY WHALE DURING THE PROPOSED MAKAH HUNT: 2023 UPDATE

Jeffrey E. Moore, David W. Weller, and Aimée R. Lang

NOAA Fisheries, SWFSC Marine Mammal and Turtle Division
8901 La Jolla Shores Drive, La Jolla, California 92037 USA

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Estimates of the probability of striking a western North Pacific gray whale during the proposed Makah hunt: 2023 Update

Jeffrey E. Moore, David W. Weller, Aimée R. Lang

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 (Moore and Weller 2018, 2019) to account for new data and a proposed rule by NOAA Fisheries for governing ENP gray whale hunts by the Makah Tribe for up to 10 years (80 FR 13604, April 5, 2019). Under the proposed regulations, hunting seasons would alternate between winter-spring hunts in one year and summer hunts during the next. It is presumed that only in every other year (for 5 of the 10 years, during winter-spring hunts) 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 (lower) population size estimate for ENP whales and an updated estimate of the likelihood of encountering migrating vs. Pacific Coast feeding group (PCFG) animals during the hunt. We used the same model as recent analyses (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 0.008 (95% Bayesian CRI: 0.005 – 0.010). For a single year's hunt (3 strikes), the expected probability of striking ≥1 WNP whale would be 0.023 (0.016 – 0.031). Across the 10-year hunt period (15 strikes), the probability of striking ≥1 WNP whale would be 0.111 (0.077 – 0.146).

Given recent and potentially ongoing population decline of ENP whales, we also provided estimates under a hypothetical scenario where the population decreases to 11,000, representing the lowest estimate recorded since monitoring began in 1967/68, which would maximize the likelihood of a migrating animal being a WNP rather than ENP animal (if the WNP population remained stable during the same timeframe). Under this scenario, the per-strike probability of it being a WNP animal would be 0.012 (0.008 – 0.015). The expected probability of striking ≥1 WNP whale during a single year would be 0.035 (0.024 – 0.045). Across the 10-year hunt period (15 strikes), the probability of striking ≥1 WNP whale would be 0.163 (0.116 – 0.207).

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*. 2021; Brüniche-Olsen et al. 2018, 2021). 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 (hundreds) 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).

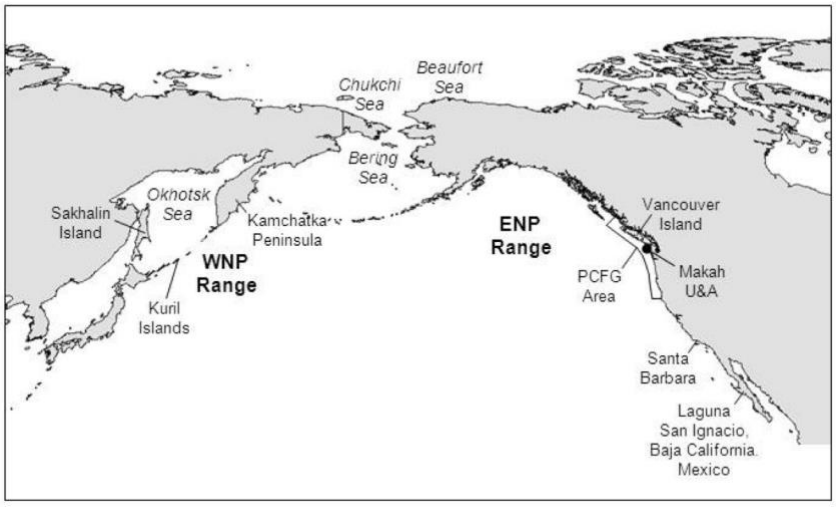

Figure 1. Areas in the western and eastern North Pacific mentioned in the report.

The WNP population feeds in the Okhotsk Sea off Sakhalin Island, Russia and in nearshore waters of the southwestern Bering Sea off the southeastern Kamchatka Peninsula (Weller *et al*., 1999, 2012; NMFS 2023). 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). Under the U.S. Endangered Species Act (ESA), WNP gray whales are recognized as a Distinct Population Segment (DPS) and classified as Endangered (NMFS, 2023; Weller et al. 2023).

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; Martínez-Aguilar et al. 2022). 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*., 2021; Brüniche-Olsen et al. 2018, 2021).

In 1995, following the 1994 delisting of ENP gray whales under the U.S. ESA, 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), as well as a Supplemental DEIS (SDEIS), completed in 2022 (NMFS 2022), 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, 2019) and incorporates updated information about the population size of ENP gray whales and the likelihood of ENP and WNP gray whale occurrence within the proposed hunt area.

METHODS

Hunt proposal

[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."

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 using an alternating hunt season scheme wherein winter/spring hunts would occur during the migration season (December 1 through May 31) to reduce the risk to PCFG whales, and summer/fall hunts would occur during the feeding season (July 1 through November 30) to reduce risk to the WNP population. Only one hunt season would be authorized each year; however, the winter/spring hunts may start in the same calendar year as a summer/fall hunt. This results in a 1-month gap (November) between the end of a summer/fall hunt and the start of a winter/spring hunt, and a 13-month gap between the end of a winter/spring hunt and the start of the next summer/fall hunt, and so on. Therefore, over the course of the proposed 10-year waiver period only 5 winter/spring hunts and 5 summer/fall hunts would be authorized.

In summer/fall hunt 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 animals) are in northern feeding areas. Thus, hunted animals in these years would presumably belong to the PCFG and it is assumed that WNP whales would not be at risk from proposed hunt operations. In winter/spring hunt 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 these years there is a potential risk to WNP whales from proposed hunt operations. In each of the winter/spring hunt 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 winter/spring hunt years) that would have some probability of being WNP whales. We therefore evaluate the probability of striking at least one WNP whale per winter/spring hunt year (out of 3 strikes) and for the 10-year period (out of 15 strikes). We also evaluate strike risk over a 6-year time frame, corresponding to the quota period for the International Whaling Convention (IWC). Finally, for each of these three evaluation periods (1 year, 6 years, 10 years), 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 2021/2022 is 16,650 (CV = 0.0485) (Eguchi et al., 2022), down from the previously used prior estimate (for 2015/2016) of 26,960 (CV = 0.05) (Durban *et al.*, 2017).

The most recent combined estimate of Sakhalin-Kamchatka WNP abundance (for 2016) is 291 (CV = 0.042) for the 1+ population (i.e., excluding calves) (Cooke 2017, Cooke 2018). A more recent abundance of nearly 200 animals was provided by Cooke et al. (2019), and this was used by Moore and Weller (2018); however; it is only for animals using the Sakhalin area. Moore and Weller (2019) used the estimate of 291 because it is for animals using Sakhalin and Kamchatka, and also provides a more precautionary area of risk (in terms of the likelihood of encountering a WNP animal. In this report, we also use the estimate of 291. Moore and Weller (2019) multiplied this estimate by 1.099 to account for calves and provide an estimate of the entire WNP population. However, hunting calves is a prohibited act under the hunt regulations.

Moreover, during the Feb – May portion of the winter hunt, calves would be traveling alongside northbound mothers and thus not encountered independently. So, it does not make sense to include calf numbers as part of the abundance-based risk calculations.

Mixing proportions based on sightings in the Makah Hunt Area – Harris et al. (2022) evaluated photo ID data collected in coastal waters between northern California and northern British Columbia (NCA-NBC area). Inference from this area is used as a proxy for what would be encountered within the Makah U&A where the hunt would occur (this is consistent with the Supplemental DEIS issued July 1, 2022 (NMFS 2022)). Of 417 unique whales sighted in the region before June 1 (i.e., during migration), 113 (27.1%) were also observed at least once after June 1 and thus potentially PCFG animals. 102 (24.5%) were sighted after June 1 in at least two years and are thus more assuredly PCFG animals. We use the latter value (i.e., 102 of 417) to estimate the likelihood of an encountered animal being a PCFG vs non-PCFG animal, because it provides more precautionary inference concerning WNP risk (i.e., implies a higher likelihood of an encountered animal being a non-PCFG and therefore possibly WNP animal). This is similar to the value of 28% used by Moore and Weller (2019).

Proportion of WNP whales migrating with ENP whales – Cooke et al. (2019) estimated approximately 0.60 (95% CI: 0.45 – 0.80) of the WNP population migrates to the North American coast. This was used by Moore and Weller (2019). The estimate has not been updated and is thus also used in the current analysis reported here.

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, 2019) used Model 2A, 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 the probability that a whale encountered during the winter hunt is a PCFG animal. The data likelihood for this parameter is $n_{PCFG} \sim$ Binomial (N, P_{PCFG}), where n_{PCFG} is the number of photo-identified animals assumed to be from the PCFG (102) out of N (417) total animals identified in the NCA-NBC area (based on Harris et al. 2022; see above).

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, $P_{WNP|mig} = mN_{WNP}/(mN_{WNP} + N_{ENP})$. Following Moore and Weller (2019), 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).

Inferences were based on two different inputs for ENP abundance. The first was to use the most recent empirical estimate (Eguchi et al. 2022; above). Given low CV's of the WNP and ENP abundance estimates, N_{WNP} and N_{ENP} are treated as normally distributed variables with means and CVs as given above. The second inference was to fix the ENP abundance estimate at 11,000. Given recent and potentially ongoing population decline for ENP whales, this value represents a hypothetical scenario of ENP whales declining to their lowest previously recorded state, which would maximize the likelihood of a migrating animal being a WNP rather than ENP animal.

Estimation

Analysis was conducted using OpenBUGS software. Derived parameter distributions were summarized from two MCMC chains, each 10,000 samples in length (20,000 samples total), following a burn-in of 1000 samples per chain.

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 winter-hunt years) or out of 9 strikes (6-year period, corresponding to length of IWC hunt quota), 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, 9 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, irrespective of hunt season because training will still occur (thus 2118 across 6 years, 3530 across all 10 years)[2], and (2) there will be 6 unsuccessful strike attempts for every strike in a winter/spring hunt (and thus 18 attempts, 54 attempts, and 90 attempts the 1-, 6- and 10-year periods, respectively)[3].

RESULTS

Parameter estimates

Estimated parameters from all model sets are in Table 1 (inference based on the most recent ENP abundance estimate) and Table 2 (ENP abundance hypothetically assumed to be 11,000 animals). Figure 2 shows the distribution for P_{WNP} (under the first inference).

[2] This number is conservative because it assumes that all approaches (hunting and training) in any year 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 summer-hunt years, when hunting approaches are restricted to July - October.

[3] We expect zero in summer-hunt 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.

Table 1. Distribution summaries for key model parameters, given most recent abundance estimates for the ENP gray whale population. "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.

Parameter	Posterior mean	2.5% CRI	97.5% CRI
Prob(WNP) for a single interaction, i.e., P_{WNP}	0.008	0.005	0.010
Prob(WNP|3 strikes in 1 yr)	0.023	0.016	0.031
Prob(WNP|9 strikes in 6 yrs)	0.068	0.047	0.090
Prob(WNP|15 strikes in 10 yrs)	0.111	0.077	0.146
Prob(WNP|18 unsuccessful strike attempts in 1 yr)	0.132	0.092	0.172
Prob(WNP|54 unsuccessful strike attempts in 10 yrs)	0.345	0.252	0.432
Prob(WNP|90 unsuccessful strike attempts in 10 yrs)	0.504	0.383	0.611
Prob(WNP|353 approaches in 1 yr)	0.931	0.845	0.975
Prob(WNP|2118 approaches in 6 yr)	~ 1.0	~ 1.0	~ 1.0
Prob(WNP|3530 approaches in 10 yrs)	~ 1.0	~ 1.0	~ 1.0
Expected WNP|3 strikes in 1 yr	0.024	0.016	0.031
Expected WNP|9 strikes in 6 yrs	0.071	0.048	0.094
Expected WNP|15 strikes in 10 yrs	0.118	0.080	0.156
Expected WNP|18 unsuccessful strike attempts in 1 yr	0.141	0.096	0.188
Expected WNP|54 unsuccessful strike attempts in 6 yrs	0.424	0.289	0.563
Expected WNP|90 unsuccessful strike attempts in 10 yrs	0.706	0.482	0.939
Expected WNP|353 approaches in 1 yr	2.769	1.889	3.681
Expected WNP|2118 approaches in 6 yr	16.600	11.32	22.07
Expected WNP|3530 approaches in 10 yrs	27.690	18.89	36.81

Table 2. Distribution summaries for key model parameters, given a hypothetical abundance estimate of 11,000 for the ENP gray whale population. "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.

Parameter	Posterior mean	2.5% CRI	97.5% CRI
Prob(WNP) for a single interaction, i.e., P_{WNP}	0.012	0.008	0.015
Prob(WNP|3 strikes in 1 yr)	0.035	0.024	0.045
Prob(WNP|9 strikes in 6 yrs)	0.101	0.071	0.130
Prob(WNP|15 strikes in 10 yrs)	0.163	0.116	0.207
Prob(WNP|18 unsuccessful strike attempts in 1 yr)	0.192	0.138	0.243
Prob(WNP|54 unsuccessful strike attempts in 10 yrs)	0.471	0.358	0.566
Prob(WNP|90 unsuccessful strike attempts in 10 yrs)	0.652	0.523	0.751
Prob(WNP|353 approaches in 1 yr)	0.981	0.945	0.996
Prob(WNP|2118 approaches in 6 yr)	~ 1.0	~ 1.0	~ 1.0
Prob(WNP|3530 approaches in 10 yrs)	~ 1.0	~ 1.0	~ 1.0
Expected WNP|3 strikes in 1 yr	0.035	0.025	0.046
Expected WNP|9 strikes in 6 yrs	0.106	0.074	0.138
Expected WNP|15 strikes in 10 yrs	0.177	0.123	0.230
Expected WNP|18 unsuccessful strike attempts in 1 yr	0.212	0.147	0.276
Expected WNP|54 unsuccessful strike attempts in 6 yrs	0.637	0.442	0.828
Expected WNP|90 unsuccessful strike attempts in 10 yrs	1.062	0.736	1.381
Expected WNP|353 approaches in 1 yr	4.165	2.889	5.415
Expected WNP|2118 approaches in 6 yr	24.97	17.32	32.46
Expected WNP|3530 approaches in 10 yrs	41.65	28.89	54.15

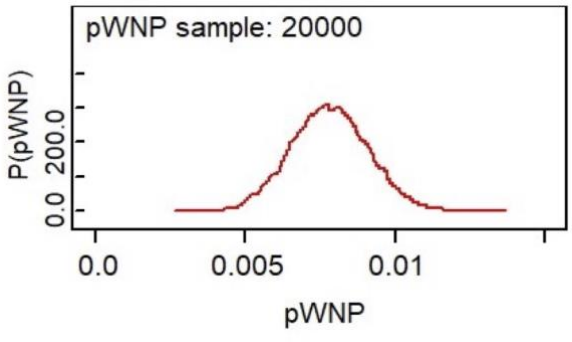

Figure 2. Posterior distribution for probability that any given strike is a WNP whale.

DISCUSSION

WNP risk estimates are higher in the current analysis than recent reports. For example, the current estimate for the likelihood that a single event involves a WNP animal is 0.008 (Table 1), compared to 0.005 in the previous analysis (Moore and Weller 2019). This change is largely driven by change in the abundance estimate for ENP population size, which is 38% lower in the current analysis than in the previous one. This result should be intuitive, as the risk estimate is substantially driven by the ratio of WNP to ENP population size. Should the ENP gray whale population begin to recover as it has following previous periods of decline, the WNP risk estimate would be expected to decline as well. 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 during migration. The likelihood of striking a WNP whale is overestimated if fewer total animals are ultimately struck than allowed, or if in reality the WNP animals use a different migration corridor and are less likely to travel through the Makah hunt area. Whether photo-ID data from the NCA-NBC are representative of what would be encountered during the actual hunt is a source of uncertainty. 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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