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Two Aboriginal Subsistence Whaling Stocks Remain in Tested Parameter Space

G.H. Givens and D.W. Weller

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G.H. Givens[1] and D.W. Weller[2]

Abstract

The 2019 abundance estimate for Bering-Chukchi-Beaufort Seas bowhead whales and 2019/20 abundance estimate for eastern North Pacific gray whales both were notably lower than previous estimates. We examine the parameter spaces used during the development and testing of the Strike Limit Algorithms for these stocks to determine whether additional simulation testing is warranted. For bowheads, the new lower estimate is believed to be attributable to bias, and perhaps also ordinary statistical uncertainty. In terms of both bias and variation, the 2019 estimate falls within the range of what could be expected given the scenarios tested. For gray whales, the new lower estimate is believed to be attributable to a recent unusual mortality event, similar to the one that occurred in 1999-2000. That prior mortality event motivated a variety of testing scenarios that explored the impacts of similar future events. What was tested bears a remarkable resemblance to what has now occurred. Thus, for both stocks, we conclude that—despite the lower new abundance estimates—the respective Strike Limit Algorithms remain fully tested for present circumstances. We also list several future contingencies that might warrant additional testing, should they occur. Lastly, we note the importance of continuing to collect and review the necessary data to monitor the status of these stocks.

1. Introduction

Eastern North Pacific (ENP) gray whales and Bering-Chukchi-Beaufort Seas (BCB) bowhead whales are both subject to aboriginal subsistence hunting limited by the respective Strike Limit Algorithms (SLAs) developed by the IWC Scientific Committee (SC). Each SLA was rigorously tested under a wide range of simulated 100-year scenarios. The range of possibilities spanned by these scenarios (with respect to data quality, biological parameters, environmental variation, subsistence need, and so forth) is informally called the 'tested parameter space' for the SLA. Tested parameter space is described by IWC (2005) for ENP gray whales and IWC (2003) for BCB bowheads.

In order to maintain confidence in the performance of an SLA, the SC regularly checks whether current conditions, survey data, biological parameter estimates, subsistence need, and so forth remain 'in tested parameter space'. If so, then the SLA is expected to perform well, i.e., to provide safe, sustainable harvest limits that satisfy subsistence need as much as possible while ensuring stock recovery. If the current situation is not in tested parameter space, then the SC may be uncertain about SLA performance and it must decide whether further simulation trials are necessary to better understand SLA performance in the new circumstances.

[1] Givens Statistical Solutions LLC, 4913 Hinsdale Drive, Fort Collins CO 80526 USA. geof@geofgivens.com
[2] NOAA Fisheries, Southwest Fisheries Science Center, La Jolla, CA 92037 USA.

The most recent abundance estimates for ENP gray whales (Stewart and Weller 2021) and BCB bowhead whales (Givens et al., 2021a) are both lower than the respective previous estimates. Although this was unexpected, the reasons for this result are well understood in both cases. We explain those reasons in this paper. Furthermore, we review the scenarios used to develop and test each SLA, and demonstrate that the recent abundance estimates do not constitute evidence of being outside tested parameter space.

2. Bering-Chukchi-Beaufort Seas bowhead whales

The previous abundance estimate for BCB bowheads is 16,820 (CV=0.052, CI=15,176 to 18,643) in 2011 (Givens et al., 2016). The most recent abundance estimate agreed by the SC is 12,505 (CV=0.228, CI=7,994 to 19,560) for 2019 (Givens et al., 2021a). However, the 2019 estimate was challenged by several issues including highly unusual ice conditions, an unusual bowhead migration route, key periods of missed watch, and hunters' heavy use of powered skiffs that disturb the whales near the observation perch. All of these were judged by the authors to lead to substantial downward bias in the estimate. The SC concurred (IWC, 2021). Givens et al. (2021b) present a new estimate, to be considered by the SC at this meeting (2021), which estimates a correction factor to account for disturbance from power boats. The corrected estimate—which the authors believe should replace the original—is 14,025 (CV=0.228, CI=8,964 to 21,942) for 2019.

To evaluate the new 2019 estimate, it is useful to consider what would have been expected for 2019 based on prior data. Givens et al. (2016) estimated the 1978-2011 annual rate of increase as 3.7% (CI 2.9% to 4.6%). Assuming no density-dependent slowing to this increase rate, a range of projections would be:

$$\begin{aligned} 15176 \times 1.029^8 &= 19076 \\ 16820 \times 1.037^8 &= 22493 \\ 18643 \times 1.046^8 &= 26716 \end{aligned} \tag{1}$$

using the low, central, and high values for abundance and increase rate. Clearly the boat-corrected 2019 estimate of 14,025 is unexpectedly low. However, the 2019 confidence interval (8,964 to 21,942) wholly encloses the 2011 interval, and overlaps with the range of projections. Thus, the 2019 estimate is not statistically inconsistent with a hypothesis of "no change" or even "some increase" from 2011. Moreover, Givens et al. (2021a) provide detailed reasons why the 2019 abundance is expected to be biased downward, even after correcting for boats. Also, Stimmelmayr et al. (2020) provide several additional indicators that the stock is generally healthy. Harvested bowheads did not exhibit an obvious reduction in overall health. The 2019 ice-based census saw normal calf counts, and the 2019 aerial survey saw near-record numbers of calves compared to the 40-year time series of such surveys. There is no evidence of an unusual mortality event. In fact, bowhead strandings (live or dead) are quite rare.

When considering tested parameter space, the question isn't really whether an abundance estimate is higher or lower than a previous one: it is whether the variation and bias in abundance estimates is greater than what was tested.

The Evaluation Trials for the bowhead SLA considered an abundance estimate CV of 0.25 (which in some trials was assumed to be underestimated as 0.10). Robustness Trials included CV=0.10 and CV=0.34. The 2019 survey estimated CV=0.228 is less than the baseline tested value, so the 2019 survey precision remains in tested parameter space. However, other survey methods, such as the aerial survey described by Ferguson (2020) can have CVs larger than 0.25. It may be wise for the SC to consider testing the Bowhead SLA with larger CVs, to accommodate future changes in survey methods as ice-based surveys become less feasible in the changing climate.

Even though the precision of the 2019 estimate is consistent with past testing, we can also ask whether the estimate itself deviates from the past abundance and trend by more than what would be expected in the testing framework.

If the low estimate for 2019 is considered to be an instance of natural variation, does it represent greater variation than was tested? The answer is no. Consider an unbiased estimate centered at the anticipated 2019 abundance of 22,493 with a CV of 0.25. That estimate would vary between 13,780 and 36,716 ninety-five percent of the time. The 2019 estimate of 14,025 falls in that range. Moreover, this thought experiment was based on the central projection of 22,493, ignoring the possibility that the true 2011 abundance and/or rate of increase is in the lower portion of its confidence interval. Using the lower and upper values in equation (1) as hypothetical true abundance and considering an unbiased estimator with CV of 0.25, a possible 2019 survey should land between 12,072 and 43,609. Again, the observed 2019 abundance is within the plausible range of variation. Clearly the SLA was tested with substantial potential variation in abundance estimates, and the actual 2019 estimate is consistent with tested parameter space.

The other possibility is that the low estimate for 2019 is considered to be an instance of a biased estimate, rather than unbiased natural variation. The Evaluation Trials for the bowhead SLA considered future survey bias factors changing from 1 (unbiased) to either 0.67 or 1.5 in year 25 of the simulation (2019 is year 16 since SLA adoption in 2003). Additional Evaluation Trials, including BE13 (the most difficult trial upon which much attention was focused during SLA development and testing) assumed bias of 1.5 at all times. One Robustness Trial involved time-varying bias ranging from about 1.5 to 0.6.

Using the central values for 2019 estimated abundance and anticipated abundance, the evident bias factor would be 14025/22493=0.624. The linear bias trend in the Evaluation Trials would allow a bias factor of 0.788 in year 16. Thus, using central values, the hypothesized 2019 bias is larger (i.e., more negative) than what was tested. However, accounting for uncertainty in the abundance estimate and projected abundance as in equation (1), the range of hypothesized bias is clearly consistent with what was tested. For example, using opposite extremes, the 2019 survey could be biased *upwards* (21942/19076=1.15).

More severe downward survey bias was not included in tested parameter space for several reasons. The convergence of negative factors due to changes to the ice, bowhead behavior, and hunting boats was not anticipated. More importantly, downward survey bias was not considered to be much of a conservation problem because if the whales are undercounted, hunting limits from an SLA will generally be lower than what could be sustained, thereby leading to greater whale population growth.

3. Eastern North Pacific Gray Whales

Shore-based surveys to estimate the abundance of ENP gray whales have been conducted by NOAA Fisheries since 1967. These estimates are obtained from visual survey data collected off central California between December and February during the gray whale southward migration, and provide regular updates to a now 50+ year time series of estimates (see Laake *et al*. 2012, Durban *et al*. 2015; 2017; Stewart and Weller 2021). Surveys have recorded a generally increasing trend in ENP gray whale abundance, with the most recent estimate from 2016 of 26,960 whales, indicating that the population has roughly doubled since 1967/68 when it was estimated at 13,426 whales (Fig. 1).

The most recent estimate of abundance for ENP gray whales migrating southward off the central California coast was derived from data collected between December and February 2019/20[3] (Stewart and Weller 2021). The median estimate of total gray whale abundance for 2019/20 was 20,580 (95% Confidence Interval = 18,700-22,870; Fig. 2). This estimate is considerably lower than the next most recent estimate of 26,960 (95% Confidence Interval = 24,420-29,830) in 2016.

Although the time series of abundance estimates for ENP gray whales has recorded generally increasing numbers, this trend has been punctuated by occasional declines such as the one observed between 1997 and 2000 (Fig. 1). In that period, estimated abundance declined from 21,135 in 1997 to 16,033 in 2001 (Laake *et al*. 2012). This decline coincided with an unusual mortality event (UME)[4] that occurred in 1999 and 2000 when higher than usual strandings and mortalities of gray whales were observed along the west coast of the United States, Mexico and Canada. In total, 651 dead gray whales were reported with 283 observed in 1999 and 368 in 2000 (Gulland *et al*. 2005). While the cause of this UME was not determined, some stranded whales were in poor body condition leading to questions about whether the population of approximately 21,000 ENP gray whales had reached carrying capacity (Moore *et al*. 2001). Subsequently, the population recovered from decline and in 2016 the abundance was estimated at nearly its all-time high of 27,000 whales.

In 2019, NOAA's National Marine Fisheries Service declared another UME for ENP gray whales[5]. As of March 2021, 418 stranded whales were recorded with 214 in 2019 and 174 in 2020. While the number of stranded whales detected during this UME appears to be slightly lower than for the 1999-2000 UME, the estimated population decline is similar. The current UME corresponds to a

[3] Gray whale southward migration spans two calendar years, starting in the final quarter of one year and extending into the first quarter of the following year. For example, the survey reported here counted whales in December of 2019 and January/February of 2020 and is denoted as 2019/20. This same convention is applied to previous surveys.

[4] Under the Marine Mammal Protection Act (MMPA), an unusual mortality event (UME) is defined as "*a stranding that is unexpected; involves a significant die-off of any marine mammal population; and demands immediate response*"

[5] https://www.fisheries.noaa.gov/national/marine-life-distress/2019-2020-gray-whale-unusual-mortality-event-along-west-coast-and

decline of 23.7% in estimated abundance from 2016 to 2020 (i.e. 26,960 whales in 2015/16 and 20,580 whales in the 2019/20). This decline is comparable to that reported during the 1999-2000 gray whale UME, when estimated abundance declined from 21,135 whales in 1997 to 16,369 whales in 2000, or 22.6% over three years.

The pattern of population growth and decline represented in the time series of abundance estimates for ENP gray whales suggests that large-scale fluctuations of this nature are not rare. The observed declines in abundance appear to represent short-term events rather than long-term trends. That is, despite occasional declines in abundance since the time-series of data began in 1967, the overall trend has remained positive and neared peak numbers as recently as 2016 when the population was estimated at about 27,000 whales.

The range of estimated CVs used in Evaluation and Robustness trials for the gray whale SLA is difficult to extract from IWC (2005) because there is a complex model for time-varying true and estimated CVs which depends on a number of factors and random variables. This model was necessary because the time-series of abundance estimates varies more than would be expected from the CVs of the corresponding point estimates. For the purposes of this paper, we can refer to three other sources of information. First, the trial design attempted to replicate the level of uncertainty seen in the time series of abundance estimates, 1967/68 to 2001/02, which was available at that time. The (total) annual CVs in that time series ranged from 0.044 to 0.101, with a median of 0.053. Second, the random CV model was generated from a starting point of 1967/68 assuming a CV of 0.075. Third, IWC (2005) includes a set of Cross-Validation Trials, which were used at the final stage of SC evaluation. These assumed a base case value of CV=0.075 multiplied by a random factor between 0.5 and 1.

The CV for the 2019/20 abundance estimate is 0.050. This is quite typical compared to the time series of past CVs, and clearly within tested parameter space.

More important is how tested parameter space covered potential UMEs. Evaluation Trials included four variants that assumed a 40% mortality event in 1999-2000. This was a worst-case scenario encompassing the 1999-2000 UME. The future extent and recovery from that UME were not known at the time the Gray Whale SLA was developed and tested. There were also several trials modeling future mortality events like the two ENP gray whale UMEs. These ‘episodic events’ trials assumed that there would be three events in the first 75 years of management where 20% of the whales die, and at least two of these events would occur in the first 50 years. The actual years of the events were randomly generated. The 20% mortality was generated by applying the death rate uniformly across age classes.

The two UMEs are remarkably similar to what has been tested. They occurred 20 years apart, which is entirely consistent with the timing assumed in the episodic events trials. The apparent magnitude of the population decline for the two UMEs, 23.7% and 22.6% is quite close to the simulated level of 20%, and the 1999-2000 decline turned out to be much less than the worst case envisioned during SLA testing.

4. Discussion

For BCB bowheads, the question of whether the current situation remains in tested parameter space reduces to asking whether the statistical uncertainty and possible bias in the 2019 estimate exceed what was tested. We have shown above that uncertainty is well within tested limits, and potential bias is not proven to be outside tested limits, although it may be somewhat anomalous. As described above, however, the *direction* of bias is downward, which was not a serious conservation concern to the SC when developing and testing SLAs. In reality, we believe that the explanation for the apparent low estimate in 2019 is due to both bias (as articulated by Givens et al. 2021a) and variance (in both the 2019 and 2011 estimates). The predominant factor is probably bias.

Willoughby et al. (2020) report on killer whale predation of bowheads. Eighteen bowhead carcasses over 10 years were categorized as probable killer whale predation. Although killer whale predation may be increasing with the changing arctic environment, this level of mortality is nowhere near the boundaries of tested parameter space, which included a broad range of mortality rates (most likely annual mortality rate of 1% with random values up to about 5%).

We conclude that BCB bowheads remain in tested parameter space, and no further SLA testing needs to be done. There are two caveats. First, to accommodate potential future surveys with greater imprecision, it might be advisable for the SC to test larger survey CVs (e.g. up to 0.5). Second, if aboriginal subsistence need for bowheads were to increase, then it might be desirable to test more extreme downward survey bias factors. Currently, however, need is being met and the potential downward bias in the 2019 survey leads to unproblematic 'excess conservation'.

For ENP gray whales, the question of whether the current situation remains in tested parameter space revolves around the extent to which periodic UMEs (and similar hypotheses) were tested during SLA development and evaluation. The observed ENP gray whale UMEs are remarkably similar in magnitude and frequency to what was tested during SLA development. Technically, the observed UMEs are slightly more severe and more frequent than tested. However, the SLA development group was generating speculative scenarios about future episodic events and therefore picked round numbers like a 20% decline to capture the broad effects of such scenarios. These were ballpark numbers not intended as strict upper limits[6]. If future UMEs are significantly more severe (e.g. 35% decline) or more frequent (e.g. every 10 years), perhaps additional testing would be warranted. Considering the current apparent level and frequency of UMEs, we conclude that ENP gray whales remain in tested parameter space, and no further SLA testing needs to be done.

Looking at Fig. 1 in isolation suggests an alternative to the UME hypothesis. One might argue that ENP gray whale abundance has remained fairly steady around 20,000 since the mid 1990s, with two outlier abundance estimates in 2014/15 and 2015/16. Those two exceptional estimates could be biased, or a result of sampling variation. Under this hypothesis, the magnitude of supposed positive bias or excess variation may exceed what was tested for the Gray Whale SLA. However, we reject this alternative hypothesis. There is no reason to suspect large positive bias in the two

[6] For example, the development group already knew that the 1999-2000 UME magnitude was 22.6% when it chose 20% for simulation testing.

high estimates. It is very unlikely to have two adjacent estimates both be such large overestimates by chance alone, given the individual CVs and the levels of uncertainty seen in the time series. Most importantly, there is direct evidence (elevated stranding levels) of a UME. If, in the future, evidence mounts to support this alternative hypothesis, perhaps additional SLA trials would be warranted. Given the current evidence, however, the UME hypothesis is clearly justified and was well-tested in the existing Gray Whale SLA simulation scenarios, providing the rationale for concluding that ENP gray whales remain in tested parameter space.

Lastly, we emphasize the importance of the respective abundance data time series and, in turn, the requisite need for continuing these field programs as a means to continue monitoring abundance and trends of these stocks. For the SC to provide subsistence whaling management advice, it is important that the SC has continued opportunities to evaluate new estimates of abundance, life history parameters, environmental and anthropogenic impacts, and other factors. This ongoing review process is best achieved with frequent, comprehensive SC meetings where scientists gather to discuss the latest relevant scientific data.

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Figure 1. Estimated abundance of eastern North Pacific gray whales 1967-2020. Estimates are plotted for January of the survey season (e.g., 2020 corresponds to data collected December 2019 to February 2020). Open circles, with 95% confidence intervals are from Laake *et al*., 2012). Filled circles are medians or best estimates of annual abundance collected by Southwest Fisheries Science Center, vertical lines are 95% confidence intervals.