



TECHNICAL MEMORANDUM

DATE 22 March 2024

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TO Lou Kamermans, Senior Director of Sustainable Development
Baffinland Iron Mines Corporation

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RATIONALE AND METHODOLOGY FOR AVERAGING ABUNDANCE ESTIMATES FOR AERIAL REPLICATE SURVEYS COMPLETED IN SUPPORT OF BAFFINLAND'S MARINE MAMMAL AERIAL SURVEY PROGRAM (MMASP)

This technical memorandum has been prepared in response to Fisheries and Oceans Canada (DFO) Technical Comment No. DFO-TRC-01(2) (as outlined in Table 1) related to analytical methods for estimating narwhal abundance using aerial-based photographic and visual survey data. This technical comment was submitted by DFO as part of the environmental review process for Baffinland Iron Mine Corp. (Baffinland)'s Sustainable Operations Proposal (SOP) (Baffinland 2023a) undertaken in support of the Mary River Project.

Table 1: SOP Technical Comment

Commitment #	SOP Technical Comment #	Commitment Support Info
27	DFO-TRC-01(2)	<p>DFO recommends taking the average of the survey repeats and the Proponent discussing their data analysis practices with the MEWG.</p> <ul style="list-style-type: none">■ Baffinland (BIM) will include "Discussion regarding DFO proposed aerial survey repeats averaging" to the next MEWG meeting agenda and is willing to produce reports averaging aerial surveys in one or more future years, provided certain survey conditions are met (i.e., based on standard scientific methodology).■ BIM will put into the meeting agenda, after discussion with DFO, a sufficient amount of time to ensure fulsome discussion of this topic can be had at the MEWG.■ BIM will prepare, for the MEWG's benefit, a comparison table showing the difference in outcomes of the current vs DFO suggested methods of survey analysis.■ BIM will provide a plain language summary of the issues including definitions / descriptions of "certain survey conditions" at least 2 weeks prior to the next MEWG for all MEWG members.■ BIM will submit the plain language summary to DFO for review and comment 2 weeks prior to wider distribution to the MEWG members.■ If adopted by BIM according to the MEWG Terms of Reference, new analytical methodologies to be adopted by the 2024 shipping season or as recommended by the MEWG.

With respect to bullets #1 and 2 in Column 3 of Commitment #27 (Table 1), we note for the record that a discussion on this item was not able to occur at the 11-12 December 2023 MEWG meeting because DFO's marine mammal technical expert was not present at the meeting. This topic will therefore be revisited at the Q2 2024 MEWG meeting (Wed April 24 – Virtual Meeting).

With respect to bullet #3 (Table 1), a comparison table is presented in Section 2.0 which highlights the difference in outcomes when applying WSP's survey averaging protocol in contrast to DFO's survey averaging protocol.

With respect to bullet #4 and 5 (Table 1), a plain language summary is provided in Section 3.0 on how replicate aerial surveys are considered in Baffinland's calculation of narwhal abundance estimates, including a description of what conditions would lead to a survey replicate being excluded from the calculation of a regional narwhal abundance estimate.

1.0 BACKGROUND

In December 2022, as part of the Joint Disturbance Workshop of the NAMMCO Scientific Committee Working Group, Marianne Marcoux (Fisheries and Oceans Canada) submitted a Working Document entitled "Review of the 2020 and 2021 narwhal surveys in Eclipse Sound and Admiralty Inlet" (Marcoux 2022). In the report, Marcoux (2022) calculated a seasonal 'mean' abundance estimate for Eclipse Sound narwhal in 2021 that was based on the average of three replicate aerial surveys conducted by WSP during the 2021 summer season and recommended that this average be used in place of the current method employed by WSP for survey averaging, as described further in Section 3.0.

The recommendation from Marcoux (2022) fails to provide rationale as to why the practice of averaging the abundance estimates from several replicate surveys is a more scientifically acceptable approach compared to relying on abundance estimates derived for each survey independently. The follow-up discussion by the NAMMCO working group on this topic indicated: "It was noted that abundance estimates from Admiralty Inlet were quite high, raising concerns about the availability bias correction used to generate the estimates (NAMMCO 2022)". This recommendation (i.e., to take the average of all survey repeats) was recurrent in DFO's Technical Comment DFO-TRC-01(2) for the SOP and appears to be based on the belief that the correction factor used to account for undetected narwhal in the abundance estimate calculation is too low and does not account for actual variation observed during sampling (Marcoux pers. comm. 2023). Since WSP Canada Inc. (WSP) used the aerial survey with the highest abundance as the representative estimate for the Eclipse Sound summer stock in 2023 (WSP 2024), an average of the estimates from the two aerial surveys completed in 2023 (as presented in Marcoux 2022) would invariably be lower.

The precision of an abundance estimate can be improved by measuring the same population multiple times and taking the average of these measurements. In other words, the average of several measurements of a 'defined population' is likely to be more precise than a single measurement of that population. An assumption of this method, however, is that the population of interest is equally available for measurement during each replicate survey. As applied to narwhal surveys, this would require that all narwhals belonging to the population of interest remain present (in equal numbers) in the defined survey area (i.e., available for detection) during each of the surveys (i.e., it assumes no animals leave the defined survey area or no new animals enter the defined study area during the combined survey period). It is generally understood that narwhals can migrate through one or more summering grounds during their annual in- and out- migratory movements during the open-water season (late

July to October), that narwhal numbers on the summer grounds generally peak in mid-August, and that narwhal numbers in their respective summering grounds start to decline in late August as animals begin their out-migration (Heide-Jorgensen et al. 2002; Watt et al. 2012; DFO 2012, 2024; Golder 2019). The potential benefit from averaging multiple repeat surveys to improve precision of an abundance estimate must be considered against the potential bias of averaging surveys that are not true replicates of one another because the number of animals available for detection in the defined study area are not the same (due to uncontrollable factors such as migratory behaviour). Similarly, the more time that passes between successive surveys, the higher likelihood that animal movement in and out of the defined study area will occur. This is the primary reason why Baffinland strives to complete a full survey in as short of a time possible to minimize the effect that animal movement may have on biasing survey results. This is achieved by using two aircraft to simultaneously collect survey data in the Eclipse Sound and Admiralty Inlet stock areas over a 2-to-3-day period.

2.0 COMPARISON OF PROTOCOLS FOR SURVEY AVERAGING

Baffinland has prepared, for the benefit of the MEWG, a comparison table (Table 2) showing the difference in outcomes when applying WSP's survey averaging protocol against DFO's survey averaging protocol.

Table 2: Comparison of DFO vs. WSP averaging methods for annual narwhal abundance estimates.

Stock	Year	WSP Averaging Method				DFO Averaging Method			
		# Replicate Surveys	Abundance	CV	95% CI	# Replicate Surveys	Abundance	CV	95% CI
Eclipse ¹	2004	1	20,225	0.36	9,471 – 37,096	1	20,225	0.36	9,471 – 37,096
Eclipse ²	2013	1	10,489	0.24	6,342 – 17,347	1	10,489	0.24	6,342 – 17,347
Eclipse ³	2016	1	12,039	0.23	7,768 – 18,660	1	12,039	0.23	7,768 – 18,660
Eclipse ⁴	2019	2	9,931	0.05	9,009 – 10,946	3	8,370	0.0423	7,705 - 9,092
Eclipse ⁵	2020	1	5,018	0.03	4,736 – 5,317	2	4,266	0.0217	4,088 - 4,451
Eclipse ⁶	2021	1	2,595	0.33	1,369 – 4,919	3	2,053	0.146	1,543 - 2,731
Eclipse ⁷	2022	2	4,592	0.1	3,754 – 5,617	3	3,413	0.0934	2,843 - 4,097
Eclipse ⁸	2023	1	10,492	0.046	9,578 – 11,494	2	10,015	0.0336	9,378 - 10,696
Admiralty ¹	2003	1	5,362	0.50	1,920 – 12,199	1	5,362	0.50	1,920 – 12,199
Admiralty ⁸	2010	2	18,049	0.23	11,613 – 28,053	2	18,049	0.23	11,613 – 28,053
Admiralty ²	2013	1	35,043	0.42	14,188 – 86,553	1	35,043	0.42	14,188 – 86,553
Admiralty ⁴	2019	2	28,746	0.15	21,545 – 38,354	3	24,209	0.118	19,220 - 30,492
Admiralty ⁵	2020	1	31,026	0.14	23,406 – 41,126	2	23,988	0.114	19,209 -29,958

Stock	Year	WSP Averaging Method				DFO Averaging Method			
		# Replicate Surveys	Abundance	CV	95% CI	# Replicate Surveys	Abundance	CV	95% CI
Admiralty ⁶	2021	1	72,582	0.09	61,333 – 85,895	3	50,391	0.0723	43,742 - 58,050
Admiralty ⁷	2022	2	43,042	0.15	32,218 – 57,502	2	43,042	0.15	32,218 – 57,502
Admiralty ⁸	2023	1	30,214	0.15	22,559 – 40,467	1	30,214	0.15	22,559 – 40,467
Combined ²	2013	1	45,532	0.33	22,440 – 92,384	1	45,532	0.33	22,440 – 92,384
Combined ⁴	2019	2	38,677	0.11	31,155 – 48,015	3	32,578	0.0885	27,402 - 38,733
Combined ⁵	2020	1	36,044	0.12	28,267 – 45,961	2	28,254	0.0966	23,390 - 34,130
Combined ⁶	2021	1	75,177	0.08	63,795 – 88,590	3	52,444	0.0697	45,755 - 60,110
Combined ⁷	2022	1	46,408	0.13	36,129 – 59,611	3/2	46,449	0.138	35,511 - 60,758
Combined ⁸	2023	1	40,706	0.11	32,711 – 50,655	2/1	40,229	0.113	32,266 - 50,157

¹ Richard et al. 2010, ² Doniol-Valcroze et al. 2015, ³ Marcoux et al. 2019, ⁴ Golder 2020, ⁵ Golder 2021, ⁶ Golder 2022, ⁷ WSP 2023, ⁸ WSP 2024.

Trend Analysis using WSP Averaging Method:

A resampling simulation method was used to estimate the trend in abundance estimates in Eclipse Sound over the past 20 years using aerial survey results that follow WSP's recommended survey averaging protocol. A subset of 100 iterations was used to generate a plot showing the individual trends calculated during the resampling process (Figure 2-1). The orange line shows the fitted trend based on only mean annual abundance estimates, and the red line shows extrapolation for 2024 based on the estimated trends (Figure 2-1). For Eclipse Sound, 86% of the iterations had an overall significant temporal trend, which suggests evidence of a significant temporal trend in abundance in the area. Following the trend analysis, the slopes at each sampling year were summarized as percent change in narwhal abundance per year (Figure 2-2). Note that slope estimates may be driven by abundance values in previous or subsequent years, and they do not represent the extent of difference between the estimated abundance values from one survey year to the next one. Rather, they are the estimates of the angle of the spline at the survey year. In Eclipse Sound, estimated slopes in 2004, 2013, and 2016 were small (-12% per year, +2% per year, and +11% per year, respectively). In 2019, 2020, and 2021, estimated slope values were -37% per year, -52% per year, and -18% per year, respectively. This period was followed by positive slopes in both 2022 and 2023, with estimates of +119% per year and +207% per year, respectively. The negative slopes estimated for 2019 and 2020 and the positive slopes estimated for 2022 and 2023 were significant in 93%-98% of the simulations. Note that in 2019, the slope was estimated to be negative due to the low abundance recorded in 2020 as opposed to strictly changes from 2016, the previous sampling year. The remainder of the slopes were significant in <50% of the 5,000 simulations, suggesting little support for changes in abundance in those years.

For Admiralty Inlet, the estimated slopes in 2019 and 2020 were +30% per year and +43% per year, respectively, mirroring the negative slopes in Eclipse Sound during those years. In 2022 and 2023, when Eclipse Sound abundance trended up, the Admiralty Inlet values slopes were estimated to be -29% per year and -39% per year, respectively. For the combined Eclipse Sound and Admiralty Inlet estimates, the negative slope estimated for 2023 (value of -32% per year) was due to the reduction from the high abundance estimated in 2021 (Figure 2-1) and does not signify an actual large decline in abundance in 2023.

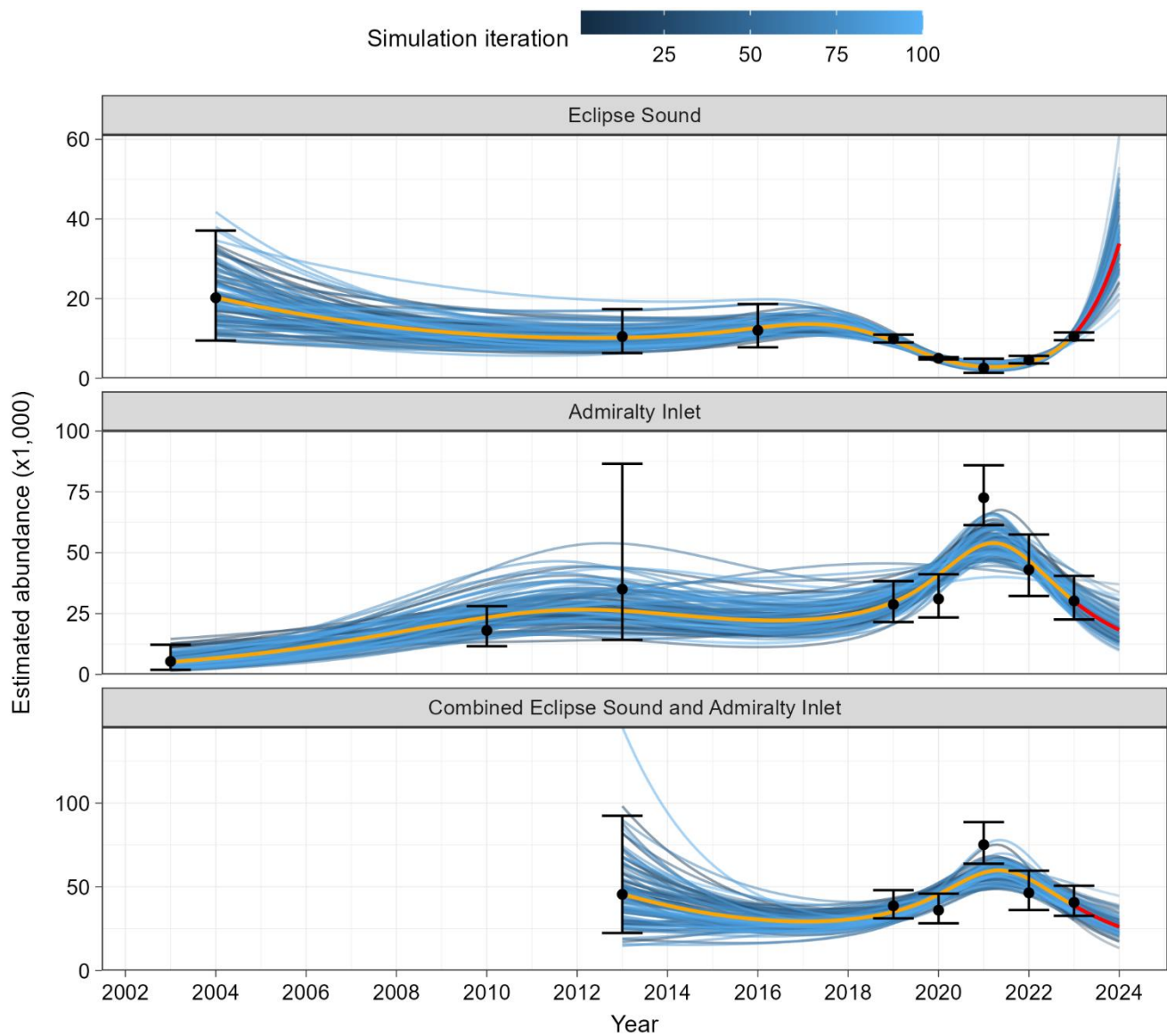


Figure 2-1: Trend analysis for Eclipse Sound, Admiralty Inlet, and the combined Eclipse Sound and Admiralty Inlet stock estimates using a resampling simulation method based on WSP's recommended survey averaging protocol.

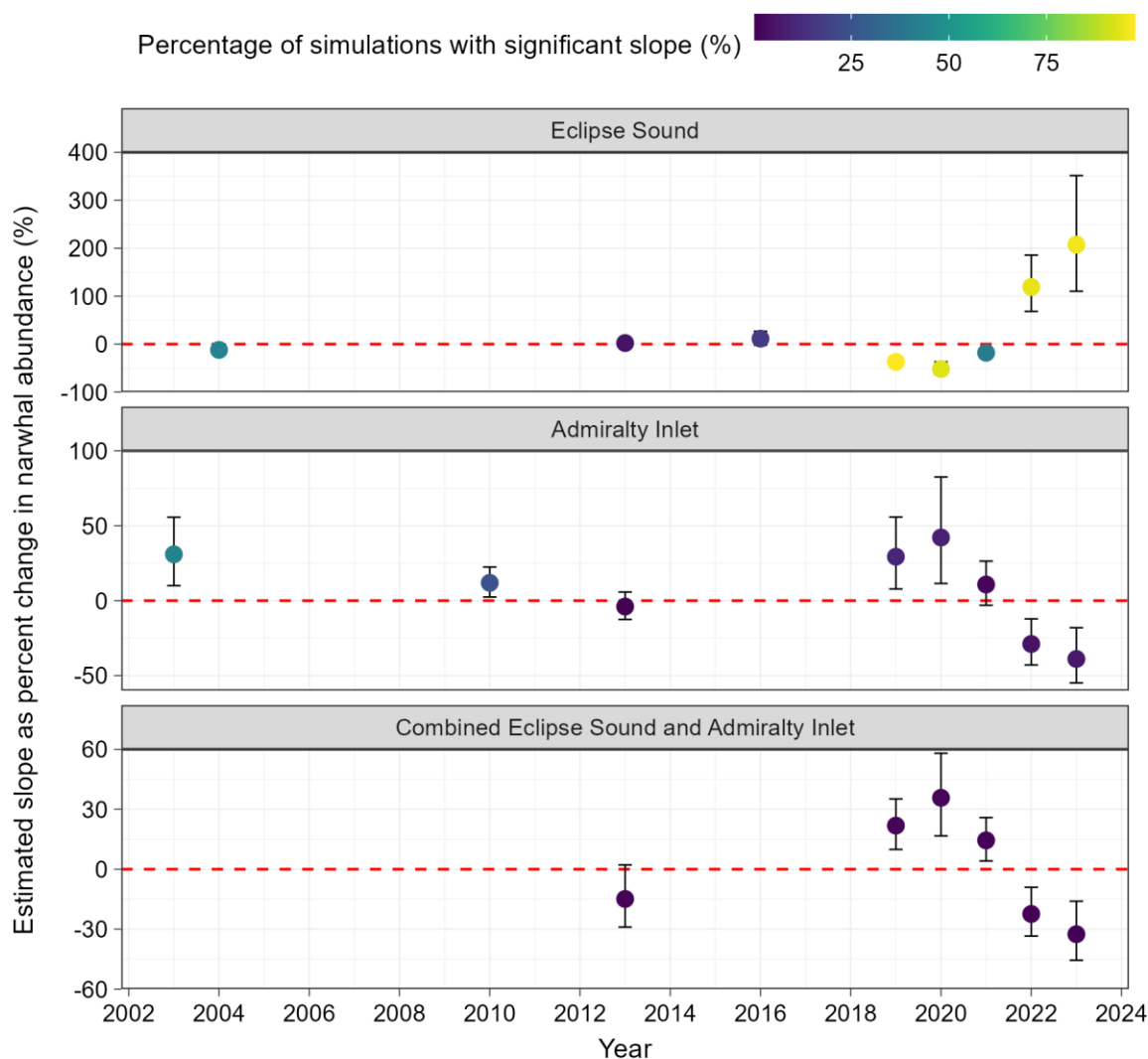


Figure 2-2: Estimated slopes (as percent change in narwhal abundance) from trend analysis. Error bars are 95% confidence intervals based on WSP's recommended survey averaging protocol.

Trend Analysis using DFO Averaging Method:

A resampling simulation method was used to estimate the trend in abundance estimates in Eclipse Sound over the past 20 years using results from DFO's recommended survey averaging protocol. A subset of 100 iterations was used to generate a plot showing the individual trends calculated during the resampling process (Figure 2-3). The orange line shows the fitted trend based on only mean annual abundance estimates, and the red line shows extrapolation for 2024 based on the estimated trends (Figure 2-3). For Eclipse Sound, 99% of the iterations had an overall significant temporal trend, which suggests evidence of a significant temporal trend in abundance in the area. Following the trend analysis, the slopes at each sampling year were summarized as percent change in narwhal abundance per year (Figure 2-4). Note that slope estimates may be driven by abundance values in previous or subsequent years, and they do not represent the extent of difference between the estimated abundance values from one survey year to the next one. Rather, they are the estimates of the angle of the spline

at the survey year. In Eclipse Sound, estimated slopes in 2004, 2013, and 2016 were small (-12% per year, +2% per year, and +10% per year, respectively). In 2019, 2020, and 2021, estimated slope values were -41% per year, -56% per year, and -19% per year, respectively. This period was followed by positive slopes in both 2022 and 2023, with estimates of +145% per year and +259% per year, respectively. The negative slopes estimated for 2019 and 2020 and the positive slopes estimated for 2022 and 2023 were significant in >98% of the simulations. Note that in 2019, the slope was estimated to be negative due to the low abundance recorded in 2020 as opposed to strictly changes from 2016, the previous sampling year.

For Admiralty Inlet, the estimated slopes in 2019 and 2020 were +23% per year and +36% per year, respectively, mirroring the negative slopes in Eclipse Sound during those years. In 2022 and 2023, when Eclipse Sound abundance trended up, the Admiralty Inlet values slopes were estimated to be -15% per year and -24% per year, respectively. For the combined Eclipse Sound and Admiralty Inlet estimates, the negative slope estimated for 2023 (value of -17% per year) was due to the reduction from the high abundance estimated in 2021 (Fig1) and does not signify an actual large decline in abundance in 2023.

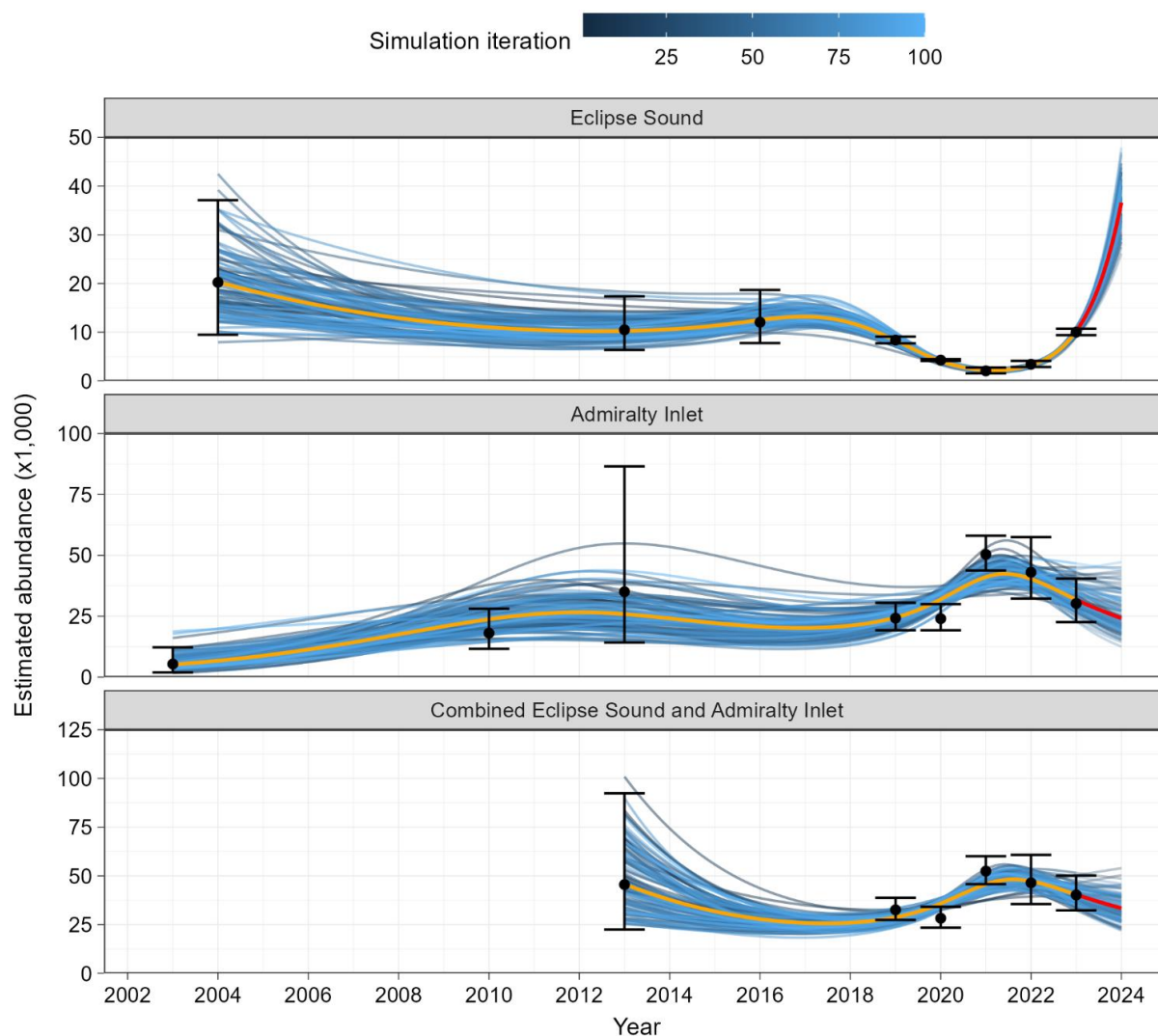


Figure 2-3: Trend analysis for Eclipse Sound, Admiralty Inlet, and the combined Eclipse Sound and Admiralty Inlet stock estimates using a resampling simulation method based on DFO's recommended survey averaging protocol.

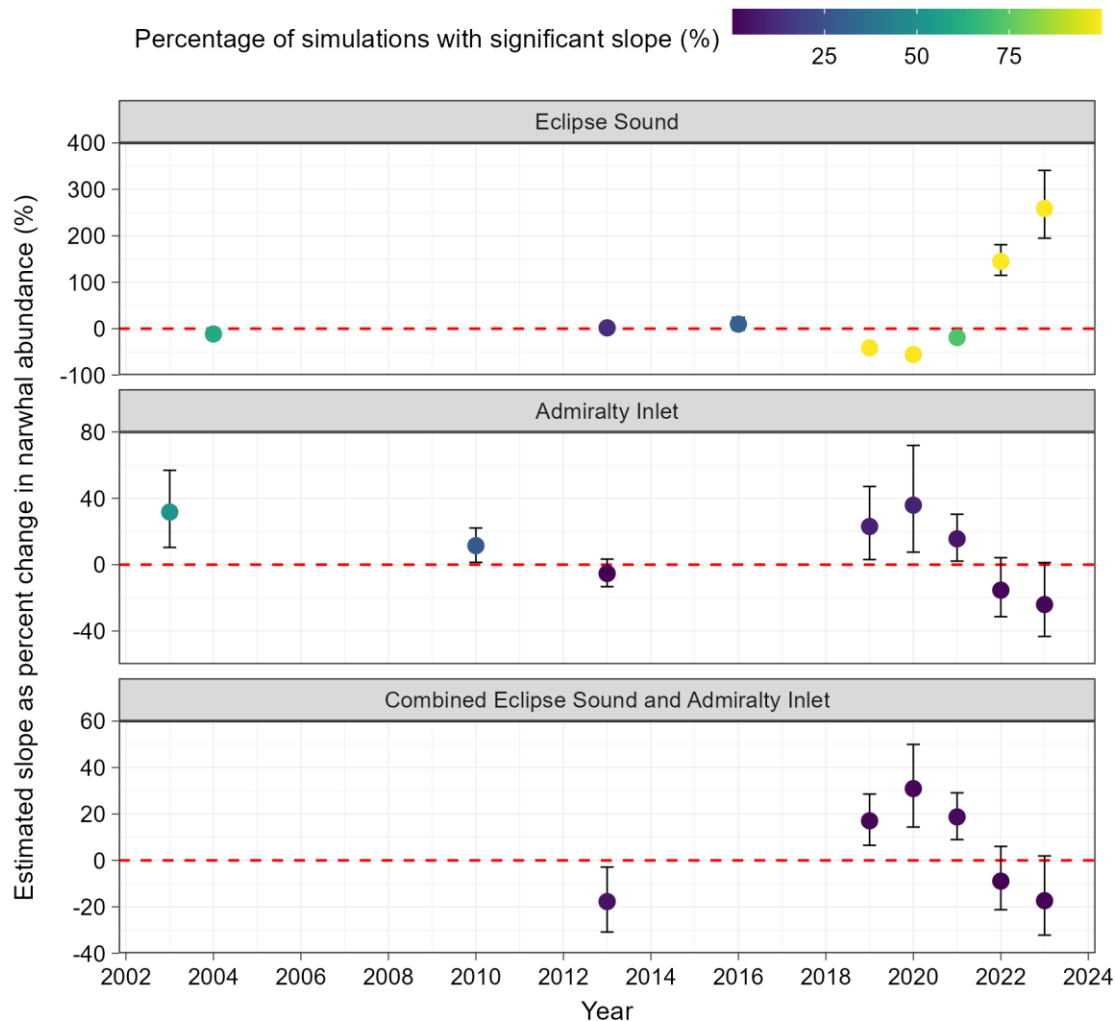


Figure 2-4: Estimated slopes (as percent change in narwhal abundance) from trend analysis. Error bars are 95% confidence intervals based on DFO's recommended survey averaging protocol.

Comparison of Results:

Trends in Eclipse Sound narwhal abundance over time were the same using either survey averaging protocol, with narwhal abundance in Eclipse Sound decreasing in 2019 and 2020 (relative to baseline conditions), remaining stable in 2021, and increasing in 2022 and 2023. Similarly, trends in Admiralty Inlet narwhal abundance over time were the same using either survey averaging protocol, showing an inverse trend to that observed for Eclipse Sound. Using either survey averaging method, there was no significant difference between the 2023 Eclipse Sound abundance estimate and the 2013 baseline condition. Similarly, using either survey averaging method, there was no significant difference between the 2023 Eclipse Sound abundance estimate and the 2019 abundance estimate¹.

¹ High-risk threshold in Marine Mammal Trigger Action Response Plan (TARP) = >25.0% decrease in Eclipse Sound narwhal abundance relative to the 2019 aerial survey abundance (Baffinland 2021, 2023b).

3.0 CONDITIONS REQUIRED FOR SURVEY AVERAGING

Baffinland has established a set of survey criteria required for survey replicates to be included in averaging for the purpose of deriving an abundance estimate for narwhal (Table 2). These criteria are consistent with methods previously adopted by DFO (Asselin et al. 2011; Marcoux et al. 2019) and other research institutions in the High Arctic (Heide-Jørgensen 2010) when calculating narwhal abundance estimates based on multiple aerial survey replicates (Heide-Jørgensen 2010). For example, DFO applied survey averaging when calculating narwhal abundance estimates for the Admiralty Inlet summer stock in 2010 (Asselin et al. 2011). In this case, the results of two replicate surveys completed three days apart were averaged to avoid potential bias in the estimate introduced by animal movement patterns documented during the surveys. Narwhal movement was observed primarily in the same direction as the completion of survey lines (north to south) during the first survey and in the opposite direction of the survey lines during the second survey. Asselin et al. (2011) anticipated that averaging the positive and negative biases would cancel one another out and result in a more accurate abundance estimate. Additionally, abundance estimates derived for each of the two replicate surveys were not significantly different from one another.

Table 3: Criteria for determining when replicate survey averaging is appropriate for abundance estimates.

Criteria	
1	Replicate surveys should be undertaken within several days of one another to minimize the potential for sampling a population that has changed in composition between successive surveys (due to animal movement in and out of the summering ground).
2	There should be no statistically significant difference between replicate surveys.
3	Surveys occurring during early or late summer when narwhal migratory movements are known to occur should not be included in averaging since results are likely to reflect narwhal abundance before or after peak abundance levels on the summering/calving grounds. The exact dates considered as 'early' or 'late' will vary from year to year depending on ice conditions and other factors affecting the timing of narwhal movements in the region.

For aerial surveys undertaken of the Eclipse Sound stock in 2016 (Marcoux et al. 2019), DFO averaged the results of two replicate surveys of Tremblay Sound that were completed two days apart (7 and 9 August). Although not discussed in the manuscript, the abundance estimates derived for each of the two replicate surveys were not significantly different. An additional replicate survey of Tremblay Sound was completed on 21 August, but the corresponding abundance estimate was not included in averaging due to the extended period between the 21 August survey and the previous two surveys (Marcoux et al. 2019).

Unless survey averaging is considered appropriate (as per above criteria), the survey selected as the representative abundance estimate is based on survey timing (i.e. nearest to mid-August), relative abundance (highest abundance at peak season on the assumption that replicates with lower abundances occurred prior to, or after, peak narwhal abundance levels on the summering grounds), and survey accuracy. We do not support averaging narwhal estimates that are shown to be significantly different from one another. Precise abundance estimates can stand alone and may better approximate peak abundance values for the region. Including survey replicates that do not meet the criteria in Table 1 (when calculating an average abundance) has the potential to underestimate or overestimate true narwhal abundance in the Regional Study Area (RSA).

DFO has recently proposed a new availability bias correction factor value that is based on survey results collected outside of the Canadian High Arctic region (e.g. 3.22 with 20% CV versus 3.18 with 3.4% CV; revised and original instantaneous correction factors, respectively; Marcoux 2022; Watt et al. 2015), which Baffinland is presently evaluating for inclusion in the abundance estimate calculations for Eclipse Sound and Admiralty Inlet. When applied, this new correction value's higher CV will increase the level of uncertainty associated with the resulting abundance estimates. This will potentially have its own implications on survey averaging since a higher level of uncertainty will make detecting significant differences between survey results more difficult (i.e., and therefore increase the likelihood of averaging survey results). A comparison of abundance estimates generated by Golder (2020, 2021) with those calculated using replicate averaging and revised availability bias reported in Marcoux (2022) are presented in Table 3. The inclusion of the availability correction factor with more uncertainty (increased CV) can be balanced against the effect of averaging (reduced CV due to resamples) as seen for Admiralty inlet in 2020 when comparing the results of the two methods (similar CVs; Table 3). If the CV of the abundance estimate is low as per the example in Golder (2021, 2022) for the 2020 Eclipse Sound estimate (3% CV), the method proposed by Marcoux (2022) will increase the CV (Table 2), while the opposite is true if the estimate's CV is high as per the example in Golder (2021, 2022) for the 2021 Eclipse Sound estimate (33% CV). Baffinland has not yet had an opportunity to discuss with DFO how integration of the new correction factor would impact DFO's recommendation on survey averaging. However, the logic behind the criteria established for when to apply survey averaging or not remains the same regardless of which correction factor is applied.

Table 3: Comparison of Narwhal Abundance estimates calculated using different methods.

Region	Year	Source ¹	Narwhal Abundance Estimate \pm CV	Lower 95% Confidence Interval	Upper 95% Confidence Interval
Eclipse Sound	2020	Golder 2021, 2022	5,018 \pm 0.03	4,736	5,317
		Marcoux 2022	4,381 \pm 0.14	3,357	5,717
	2021	Golder 2021, 2022	2,595 \pm 0.33	1,369	4,919
		Marcoux 2022	2,081 \pm 0.17	1,482	2,922
Admiralty Inlet	2020	Golder 2021, 2022	31,026 \pm 0.14	23,406	41,126
		Marcoux 2022	25,166 \pm 0.15	18,786	33,712
	2021	Golder 2021, 2022	72,582 \pm 0.09	61,333	85,895
		Marcoux 2022	48,652 \pm 0.16	35,642	66,337

¹ WSP selected the replicate with highest abundance while Marcoux averaged replicates. WSP used availability correction factor from Watt et al. 2015 and Marcoux used correction factor from Marcoux 2021 and a correction factor CV from Hobbs 2021.

4.0 CLOSURE

We trust the above information addresses the relevant information request. If you have any questions or require additional information, please contact the undersigned.

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