



# CONSIDERATIONS FOR A NEW NARWHAL MANAGEMENT SYSTEM: SUSTAINABILITY OF NARWHAL AROUND NORTHERN AND EASTERN BAFFIN ISLAND

## CONTEXT

The Qikiqtaaluk Wildlife Board (QWB) submitted a Request for Decision to the Nunavut Wildlife Management Board (NWMB) in June 2020 and March 2022. They proposed an evidence-based modification to the existing management system for the Baffin Bay narwhal (*Monodon monoceros*). The NWMB acknowledged concerns that the assumptions used to determine the narwhal stock boundaries and the harvest allocation model used to inform the 2013 Integrated Fisheries Management Plan (IFMP) do not reflect Inuit Qaujimagatuqangit (IQ), specifically narwhal movement patterns. The NWMB called on co-management partners to consider the evidence about narwhal stock definitions presented by the QWB while revising the narwhal IFMP. In order to revise the IFMP in a manner that addresses these concerns, Fisheries and Oceans Canada (DFO) Science advice is requested regarding new information to support narwhal stock delineation, and assessing the risks of managing the Baffin Bay narwhal population based on combining different narwhal stocks with and without seasonal harvesting windows. The results from this meeting will contribute to future revisions to the IFMP for narwhal in the Nunavut Settlement Area.

The objectives of this peer review will be to provide Science advice on the sustainability of Baffin Bay narwhal by:

1. Reviewing assumptions and currently available scientific evidence related to stock delineation;
2. Conduct a risk assessment for each of the scenarios listed below to inform sustainability:
  - a) Four independent stocks (East Baffin Island [EBI], Eclipse Sound [ES], Admiralty Inlet [AI], and Somerset Island [SI]): An updated version of the 2011 Harvest Allocation Model (HAM) (Richard 2011) based on the latest scientific knowledge (including narwhal movements between management units as described in DFO 2020), both with (1A) and without (1B) separate seasons.
  - b) Three separate management units without summer and migratory seasons:
    - i) combined EBI and ES, ii) AI, and iii) SI stocks.
  - c) Three separate management units without summer and migratory seasons:
    - i) combined ES and AI, ii) EBI, and iii) SI stocks.
  - d) Two separate management units without summer and migratory seasons:
    - i) combined EBI, ES and AI, and ii) SI stocks.
  - e) A single management unit comprised of the EB, ES, AI and SI stocks without summer and migratory seasons.
  - f) Sustainability of the current harvest in ES without summer and migratory seasons.

- g) The maximum sustainable harvest that could be allocated to any hunting region in Baffin Bay.

3. Identifying uncertainties, challenges, and limitations to the risk assessment.

This Science Response Report results from the Canadian Science Advisory Secretariat (CSAS) regional peer review held on January 14, 2025, on the Considerations for a New Management System: Sustainability of Narwhal in Northern and Eastern Baffin Island.

## **REVIEWING ASSUMPTIONS AND CURRENTLY AVAILABLE SCIENTIFIC EVIDENCE RELATED TO STOCK DELINEATION**

Narwhals are mid-sized toothed whales that live in the Atlantic part of the Arctic Ocean. In the summer, they can be found in the inshore bays and fjords of the Canadian Arctic archipelago and Greenland (Watt 2017). When autumn arrives and fast ice forms, narwhals migrate to Baffin Bay and Davis Strait (Figure 1; Shuert et al. 2022). In the spring, narwhals gather along the ice edges on the east coast of Baffin Island and along the ice edges of West Greenland (Heide-Jørgensen et al. 2013). Narwhals are hunted during their spring and fall migration from communities along the migration route.

Sustainable management of hunting typically divides species into management units, or stocks (hereafter referred to as stocks) that are thought to be self-sustaining, and often defined using a multiple lines of evidence approach (Hobbs et al. 2019, IWC 2000, IWC 2002) that may include genetic indicators, residency time, site-fidelity, or other life history characteristics (Begg et al. 1999, Hobbs et al. 2019). Movement of animals among hunting regions, and hunting regions in which hunters have access to more than one stock, pose a particular challenge for ensuring individual stocks are managed sustainably (Allen and Singh 2016). Management units should be defined such that local decline in abundance is avoided, and that local stock declines will recover to healthy levels on a management timescale (the timeframe within which recovery is expected or idealized); the scale of 'local' (geographic area) depends on management objectives. Preservation of stocks is advantageous because variability in genetics and/or culture provides species resiliency (Brakes et al. 2019), which is particularly important in the Arctic, where the climate is changing at an unprecedented rate (Rantanen et al. 2022). In cases where stock delineation is complex, it is generally more precautionary to assume greater subdivision than to assume less (Taylor 1997, Taylor and Dizon 1999). Localized stock declines are probable if site fidelity is not expressly considered in harvest management (Cope and Punt 2009).

Richard (2010) summarized the history of stock designations for Canadian narwhal. Two management stocks were initially identified: the High Arctic stock (later named the Baffin Bay stock) and the Northern Hudson Bay stock (Strong 1988). Tracking evidence of individual fidelity to summer aggregation areas supported the refining of the Baffin Bay stock into further sub-units. Richard (2010) used four types of information to define summer stocks: 1) seasonal range and aggregations based on local knowledge and reports (not reviewed herein as it is outside the scope of DFO Science's review to evaluate Inuit Qaujimagatuqangit), 2) appearance and behaviour (not reviewed herein as it is outside the scope of DFO Science's review to evaluate Inuit Qaujimagatuqangit), 3) genetics and contaminants, and 4) seasonal range and aggregations based on satellite telemetry data. Evidence from genetic, contaminant and tracking data supports the definition of the Northern Hudson Bay summer aggregation as a separate stock, while the evidence for defining Baffin Bay stocks was strongest from tracking data and weakest from genetics and contaminants; however, Richard (2010) argued that differences among stocks may be overshadowed by the fact that many landed animals are

caught during seasons of migration, thus resulting in a mix of different stocks being sampled. Ultimately, Richard (2010) recommended an approach to reduce the chances of a localized stock decline by considering summer aggregations as separate stocks to provide scientific advice on Total Allowable Landed Catch (TALC). Richard (2011) developed a decision tool for resource managers, referred to as the Harvest Allocation Model (HAM). The allocation tool is based on a spatial model of the source and degree of stock mixtures that are hunted and produces possible solutions that maximize the catch, particularly for communities with large historic narwhal catches, while minimizing the risk of over-exploitation of any one stock. The major assumption of this tool is that whales are available to hunters in other regions during migration based on their migration route and in proportion to their summer stock size. This tool was considered an improvement over assuming that harvesters only take from the summer aggregation in their local area (Richard 2011).

As a result of that science advice and subsequent consultation, management of narwhal in Canada currently considers seven stocks, including six in the Baffin Bay population (Doniol-Valcroze et al. 2015) plus one in northern Hudson Bay (excluded in this response). Management of harvests by summer stocks is considered a precautionary approach (Richard 2010, Doniol-Valcroze et al. 2015). The Precautionary Approach is a general philosophy to managing threats of serious or irreversible harm where there is scientific uncertainty (DFO 2006, 2009). The Government of Canada developed the Federal Framework for the Precautionary Approach to ensure that caution would be applied consistently across disciplines in the government, and this became policy in 2003 (DFO 2006, 2009). Under this policy, risk tolerance levels are defined (e.g., <5% risk of decline is very low risk, 25-50% is moderate risk, and 75-95% is high risk), and management is responsible for choosing their risk tolerance level.

The six Baffin Bay narwhal stocks currently recognized in Canada are: 1) Somerset Island (SI), 2) Admiralty Inlet (AI), 3) Eclipse Sound (ES), 4) East Baffin Island (EBI), 5) Jones Sound (JS), and 6) Smith Sound (SS) (Richard 2010, Doniol-Valcroze et al. 2015) (Figure 1). All six summer stocks were surveyed in 2013 (Doniol-Valcroze et al. 2015). There are two other Baffin Bay summering aggregations, in Melville Bay and Inglefield Bredning, but these two stocks are found only in Greenland during the summer and are not considered in DFO's management of Canadian narwhal harvests. Scientific evidence for the stock delineation in Baffin Bay narwhal relies on multiple lines of evidence, which are reviewed below.

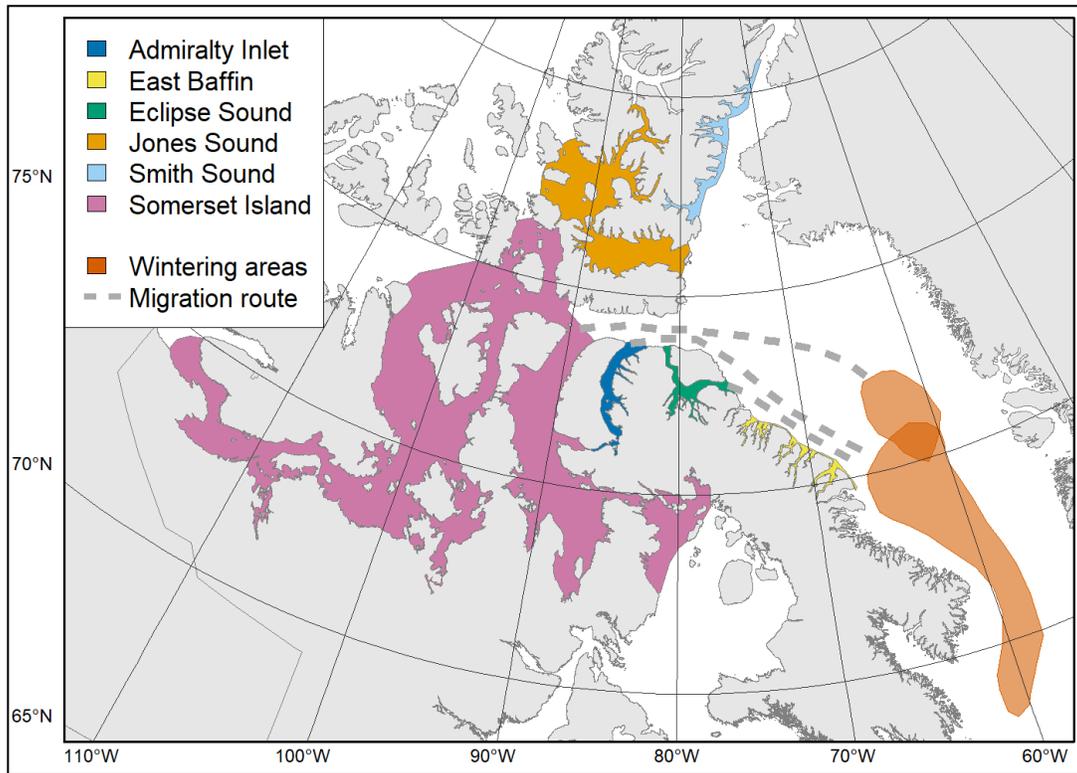


Figure 1. Map of the current summer management areas in Canada for narwhal from Baffin Bay with approximate wintering areas and migration routes (adapted from Heide-Jørgensen et al. 2013). Blue is Admiralty Inlet, yellow is East Baffin, green is Eclipse Sound, orange is Jones Sounds, light blue is Smith Sound, pink is Somerset Island, dark orange is the overwintering areas, and the dashed line is the migration route.

### Contaminant Data

Analysis of pollutant loads in marine mammal tissues has been useful for discriminating between populations of marine mammals with limited knowledge on migration patterns (Frank et al. 1973, Taruski et al. 1975). Contaminant concentrations vary due to prey composition in different foraging locations and can be used to discriminate marine mammal populations (Aguilar 1987). A study using organochlorine contaminants showed that narwhals from several different hunting locations, including JS, ES, and EBI, had different contaminant profiles (de March and Stern 2003). The study included 125 narwhal samples, 18 from JS, 25 from ES, and 64 from EBI.

### Stable Isotope and Trace Element Data

Chemical composition of tissues can act as a biological tag to discriminate among groups of animals that inhabit different areas (Kerr and Campana 2014). Watt et al. (2012a) used discriminant analysis of stable isotopes of nitrogen and carbon in narwhal skin and found a significant difference between the AI and ES stocks in the spring and summer, and in a model that included all hunting areas regardless of season (Watt et al. 2012a). This study relied on 129 samples from ES and 76 samples from AI (Watt et al. 2012a). Following this, stable isotope and trace element analyses were used in conjunction with narwhal skin from five stocks in the eastern Canadian Arctic based on collections from 1990 to 2015 (Watt et al. 2019a). In this study, they defined biomarkers representing the migratory season as those from hunts occurring

from 26 April to 31 July, although this also integrates some of the signal from the wintering area; they refer to this time frame as the migratory period. They defined the summer residency period as 1 August to 30 September, and there were no samples collected after 30 September (Watt et al. 2019a). Discriminant analysis showed a significant difference between AI (n=19) and ES (n=47) stocks in the summer residency period, and both differed from JS (n=31) and SI (n=14) (Watt et al. 2019a). During the spring migration season (n=55), there was more overlap and less distinction among stocks, but 75% of whales were still classified correctly to their defined summer stock in both the migration and summer residency periods (91% for ES, 68% for AI, and 64% for SS; Watt et al. 2019a). Stable isotopes and trace element analysis provide a promising method to distinguish stocks, but these analyses were limited based on sample size and did not include narwhal harvested in summer in East Baffin Island (Watt et al. 2019a). A strong harvest sampling program that provides information on the location and timing of sample collection is needed to explore these methods further.

## Genetic Data

Genetic studies on narwhals have focused both on nuclear (nDNA) and mitochondrial (mtDNA) DNA. Population geneticists use nDNA to identify genetic populations (Waples and Gaggiotti 2006), but mtDNA allows identification of geographic patterns in maternally inherited loci, which is particularly important for narwhal because they are hypothesized to be matrifocal in social structure (Palsbøll et al. 1997, Whitehead 1998).

### nDNA

Petersen et al. (2011) genetically profiled 268 narwhals using 15 microsatellite markers and, using principal component analyses (PCA), were able to differentiate some summer narwhal aggregations. The analysis suggested that narwhals from JS (n=42) and SI (n=12) summering stocks were differentiated, but there was no discrimination among the Baffin Island narwhal stocks (n = 89) (Petersen et al. 2011). In 2024, de Greef et al. (2024) used whole genome sequencing of tissues of 60 narwhals and found that despite low overall genetic variation there was evidence of genetic structure supporting two groupings in the Baffin Bay population: 1) JS and SI (western Baffin Island (Aujittuq (Grise Fiord; n=10), Qausuittuq (Resolute Bay; n=8), and Taloyoak (n=5)); and 2) AI, ES, and EBI (Panniqtuuq (Pangnirtung; n=1), Qikiqtarjuaq (n=4), Kangiqtugaapik (Clyde River; n=2), Mittimatalik (Pond Inlet; n=4), Ikpiarjuk (Arctic Bay; n=9), Kugaaruk (n=3), Igloodik (n=2)) (de Greef et al. 2024). Identification of these groups remained consistent in PCAs that were filtered for different time frames for harvesting months.

### mtDNA

Narwhal mtDNA has also been explored, and despite overall low genetic variation, the frequencies of common haplotypes differed between eastern Canada and Greenland. Still, samples from Canada were grouped (n=29) (Palsbøll et al. 1997). Another study evaluating mtDNA in 433 narwhals found that narwhals from JS (n = 39) were weakly differentiated from those hunted in other Canadian locations, but no differences were found among Canadian harvest locations (de March et al. 2003). Postma (2017) re-evaluated mtDNA in 93 narwhal samples and found that narwhals had low genetic variability (only 1.3% variability within their DNA) and did not detect any structure. However, both authors acknowledged that the power to detect differences may have been low because of small sample sizes (de March et al. 2003, Postma 2017). A re-investigation into narwhal mtDNA from a greater number of samples in Canada may assist in genetic delineation, as it has in beluga whales (*Delphinapterus leucas*), the narwhal's closest living relative (Montana et al. 2024). However, samples from subsistence

harvests, environmental DNA, or remote biopsy of free-ranging narwhal are needed to conduct such a study.

## Satellite Telemetry Data

### Annual site fidelity

Nine satellite-linked tags equipped on narwhals transmitted for a full year, allowing for the assessment of inter-annual site fidelity based on individuals that returned in spring to the summering area where they were tagged the previous year (Table 1). Six of the eight whales re-entered the area where they were tagged the previous year. Two other whales were close to (and heading toward) the summering area where they had been tagged the previous summer, but contact with the transmitter was lost before they were inside the summering range (Heide-Jørgensen et al. 2013). The last narwhal that had a tag for over a year was tagged in ES in late August 2010, and it did not return to ES the following summer (Table 1; Watt et al. 2012b).

*Table 1. Satellite tags that have lasted over one year to provide information on narwhal site fidelity (adapted from Heide-Jørgensen et al. 2013, with additions from Watt et al. 2012b).*

Putative stock	Years	n	Observation	Reference
Somerset Island	2001-2002	2	Two whales tagged in 2001 returned to the summering area the following year	Heide-Jørgensen et al. 2003
Somerset Island	2001 & 2006	1	One whale tagged in 2001 was resighted in Lancaster Sound 5 years later while on its return migration toward Somerset Island	Heide-Jørgensen et al. 2008
Admiralty Inlet	2004-2005	1	One whale tagged in 2004 returned to the ice edge at Admiralty Inlet in June–July 2005 but departed again and went east in Lancaster Sound, passing the ice edge at Navy Board Inlet en route to the north coast of Baffin Island. Contact was lost before the August destination could be determined.	Dietz et al. 2008
Admiralty Inlet	2009-2010	1	One whale migrated back to the mouth of Admiralty Inlet and was last recorded a few tens of kilometres inside the inlet in June 2010	Heide-Jørgensen et al. 2013
Eclipse Sound	2010-2011	1	One female narwhal tagged in August 2010 in Eclipse Sound, overwintered in the Davis Strait, and when she returned north, she continued travelling west, past Eclipse Sound and into Admiralty Inlet on July 28, 2011. This female remained in Admiralty Inlet for at least two months until the tag stopped transmitting on October 10, 2011	Watt et al. 2012b
Northern Hudson Bay	2006-2007	2	Two whales tagged in Lyon Inlet in 2006 were tracked back to the same general area in June the following year	Westdal et al. 2010
Melville Bay	2007-2008	1	One whale tagged in 2007 returned the following year to the exact same area	Heide-Jørgensen et al. 2013

**Summer site fidelity**

One hundred and three satellite tags have provided information on the summer site fidelity of narwhal in Canada to summering grounds. These tags show that most (99/103; 96%) narwhals tend to remain in the summer aggregation areas where they were captured in the summer season (Dietz et al. 2001, Dietz et al. 2008; Marcoux and Watt 2021; Table 2). However, four narwhals (three in 2017 and one in 2010) tagged in ES visited the AI management area within the summer (24 July to 24 August) or the summer they were tagged. In 2017, this corresponded to 36 days spent in the AI management area out of the total 250 days (14%) of the summer period, during which the nineteen narwhals were tagged (Marcoux and Watt 2021).

*Table 2. Total number of satellite tags equipped on narwhal in the summer (24 July to 24 August) and the proportion of those tags that were available to hunters in another summer aggregation in the summer season. Note that whales were not usually tagged at the beginning of the defined summer period and therefore only represent a portion of the summer season (see Table A1 for tagging dates and the contribution of each of the tags to the summer season; see Figure A1 and A2 for tagging tracks in the summer and outside of the summer, respectively).*

<b>Stock</b>	<b>Number available</b>	<b>Total tagged narwhal</b>	<b>Comments</b>
Somerset Island	0	16	All narwhal tags remained in the Somerset Island management area in the summer.
Admiralty Inlet	0	40	All narwhal tags remained in the Admiralty Inlet management area in summer.
East Baffin Island	NA	NA	No whales have been satellite tagged in East Baffin Island
Eclipse Sound	4	47	4 of 47 narwhal tagged in Eclipse Sound were available to hunters in the Admiralty Inlet management area in summer. Another 11 satellite tags have been equipped on narwhal from Eclipse Sound, but they were not equipped until fall and therefore do not contribute information on the proportion available in another management area in summer.

**CONDUCT A RISK ASSESSMENT FOR EACH OF THE SCENARIOS**

DFO Science was requested to assess the risk of managing narwhal under seven different scenarios that separate or amalgamate management units as defined above. The requested scenarios only involve four of the six Baffin Bay narwhal stocks that are currently recognized in Canada, and as a result, Jones Sound and Smith Sound stocks are not evaluated herein.

The goal of this assessment was not to redefine narwhal stocks, but rather to assess the risk of decline associated with each scenario based on the existing stock delineation used for narwhal management in Canada (Richard 2010). The risk assessment aims to evaluate the impact of each scenario on the sustainability of the narwhal. How DFO considers sustainability depends on whether the stock is data-rich or data-poor. For a stock to be considered data-rich, it requires three or more abundance estimates over a 15-year period, the last estimate being  $\leq 5$  years old, and current information on fecundity and/or mortality; in this case, sustainable levels of harvest are considered using reference points based on maximum sustainable yield (Hammill and Stenson 2007). For data-poor stocks, such as narwhal, DFO uses the potential biological

removal (PBR) to determine sustainability (Hammill and Stenson 2007). The goal of PBR is to allow the stock to reach its maximum sustainable population size (the number of animals that will result in maximum productivity of the population) (Wade 1998). In the assessment of each scenario below, we rely on PBR to evaluate the level of harvest that would maximize the productivity of the stock.

In all cases, the PBR was calculated following Wade (1998) (see below) for each scenario, and the PBR was then divided by the loss rate (1.28 [Richard 2008]) to calculate a revised total allowable landed catch (TALC) for all possible scenarios.

$$PBR = 0.5 * R_{Max} * N_{Min} * F_R$$

Where:  $N_{Min} = N / \exp(z \sqrt{\ln(1+CV^2)})$

the 20<sup>th</sup> percentile of the log-normal distribution of the estimated population size (Table 1) (Wade 1998) calculated from N, the abundance estimate, and its associated coefficient of variation (CV).

$z$  = a standard normal variate and equals 0.842 for the 20<sup>th</sup> percentile.

$R_{Max}$  = maximum rate of increase for the stock. The default for cetaceans when the rate is unknown is 0.04. It is then multiplied by 0.5 to simulate the effect of logistic density-dependent growth.

$F_R$  = recovery factor set to 1.0 for a healthy stock (Wade and Angliss 1997) to be consistent with the recovery factor used in the most recent published science advice (Doniol-Valcroze et al. 2015).

$$TALC = PBR / \text{loss rate (1.28)}$$

Where loss rate is the total hunting mortality (considers the number of animals landed, the animals struck and lost, and the number of animals wounded and escaped, divided by two (assuming half of the animals wounded and escape later die of their wounds)) divided by the landed catch (Richard 2008).

Abundance estimates and CVs from the individual stocks were added together; for instance, for Scenario 2, EBI and ES abundances were added together (from Table 2), which results in a smaller CV, larger  $N_{Min}$ , and a larger PBR for combined stocks (Wade 1998).

We then used a model, first described by Wade (1998) and later used by Richard and Young (2015) and by Watt et al. (2019b), to evaluate the risk of decline of the smallest stock (Eclipse Sound) based on the new PBRs calculated. The population dynamics model uses a discrete form of the generalized logistic equation minus PBR. In the model, we assume the full TALC is taken every year, and we do not recalculate PBR since the time-lag for revising quotas is unknown.

The population model used here includes a random parameter for process error,  $W_t$ , to reflect natural variation in population processes:

$$N_{t+1} = W_t * (N_t + N_t * R_{max} [1 - (N_t / K)^{\theta}] - PBR)$$

where:

$$W_t = \exp(z * 0.05 - 0.05^2 / 2)$$

$z$  = is a random normal deviate =  $(-2 * \text{Log}(\text{Uniform}(0, 1))) * \text{Cos}(2 * \pi * \text{Uniform}(0, 1))$

Since there is little evidence for what a realistic fixed value for defining process error is for any marine mammal population, we used the same arbitrary value of 0.05 used by Richard and Young (2015). This value is consistent with the hypothesis that population dynamics of long-lived narwhals are not highly variable (Richard and Young 2015).

$N_t$  = stock size at year  $t$ ;  $N_0$  for ES starts at 2016 with an abundance estimate of 12,039 (Marcoux et al. 2019)

$R_{max}$  = maximum net recruitment rate set as the default value for cetaceans of 0.04 (see above)

$K$  = the pre-exploitation size or carrying capacity of the stock, assumed at 25,000 (Richard and Young 2015)

$\theta$  = the density-dependent shape parameter, 1 in this case for maximum net productivity at 50%  $K$  (logistic growth)

We ran 10,000 model simulations and present the median and 95% confidence interval of the stock abundance projection for each scenario. We also estimated the probability that the stock declines 20 years in the future.

## Scenario 1

*Four independent stocks (EBI, ES, AI, and SI): An updated version of the HAM (Richard 2011) based on the latest scientific knowledge and including narwhal movements between management units as described in DFO (2020), both with (1A) and without (1B) separate seasons.*

The first part of this Scenario (1A) assumed that the EBI, ES, AI and SI are independent stocks as described in Richard (2011) and that hunters from Pond Inlet, Arctic Bay, Qikiqtarjuaq and Clyde River have access to a mix of stocks during the fall and spring migration (i.e., with separate seasons). The assumption from Richard (2011) that narwhals do not mix in the summer was updated to account for a small proportion of narwhals from ES that visit AI during the summer (9.76%; see Table 2).

The HAM tool (Richard 2011) was used to evaluate this scenario. As suggested in Richard (2011), catches were fixed for the western communities (Resolute Bay, Gjoa Haven, Taloyoak, Kugaaruk, Igloodik and Hall Beach), using the value of their current quota (450 narwhals; DFO 2023); however, for Pangnirtung and Iqaluit we did not fix catches but instead included them within EBI since the summer hunt of narwhal comes from this stock.

One of the inputs of this tool is the proportion of the hunt in each stock that occurs in the summer. For this input, we calculated the proportion of the hunt in summer from catch statistics from the most recent publicly available data (2006 to 2015; Watt and Hall 2018), where summer was defined as 24 July to 24 August. Summer dates are currently defined by the individual Hunters and Trappers Organizations/Associations in Canada; however, the dates of 24 July-24 August are being used in these scenarios as they are defined based on narwhal telemetry data collected over the past 30+ years that show that some narwhal move among stocks after 24 August. Additionally, these dates are used by the joint scientific working group of the North Atlantic Marine Mammal Commission (NAMMCO) on the Population Status of Narwhal and Beluga in the North Atlantic and the Canada/Greenland Joint Commission on Conservation and Management of Narwhal and Beluga (JCNC) (NAMMCO-JCNC Joint Working Group 2021).

Based on these dates, the proportion of the harvest taken in the summer was 0.47, 0.48 and 0.24 for communities in AI, ES, and EBI, respectively.

The TALC was based on the most recent abundance estimates and science advice available for this population (Doniol-Valcroze et al. 2015, Marcoux et al. 2019) (Table 3). The current quotas, however, are decided upon through co-management and are currently 450 for Somerset Island, 195 for Admiralty Inlet, 190 for Eclipse Sound, and 300 for East Baffin Island (DFO 2023).

Based on the tagging information presented above, we assumed that 9.76% of the narwhals from ES moved to AI during the summer. Therefore, the narwhal hunt from AI is a mix of both stocks, the abundance of the AI stock (N) plus the number of narwhals (9.76% of 12,049 or 1,175) that move from ES to AI.

We explored iterations of the tool, starting with catches 50 below the TALC up to the value of the TALC, without exceeding it. We sought to optimize solutions that 1) maximize the sum of all the catches, 2) maximize the catch in AI, 3) ES and 4) EBI, while maintaining the total catch per stock below the TALC (Table 4, Figure 2). In this scenario, there is a 38.5% probability that the ES stock declines in the next 20 years.

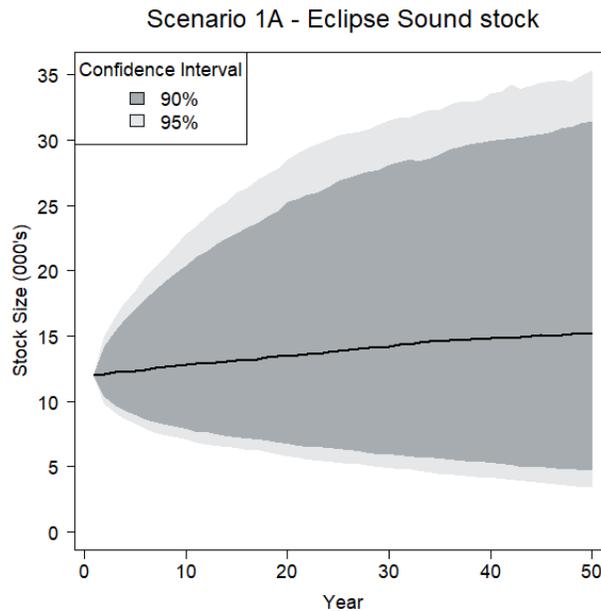


Figure 2. Stock abundance median projection for Scenario 1A that maximizes catch in Eclipse Sound (ES) while maintaining the total catch per stock below the TALC.

For the second part of the Scenario (1B), if there are no migratory harvest tags (i.e., without separate seasons), then we assume that the entire catch comes from summering aggregations of four stocks: AI, ES, EBI and SI narwhal. In this case, the PBRs and TALCs for each stock are indicated in Table 4. For this scenario to be sustainable, the entire hunt should take place during the summer season, as defined from 24 July to 24 August. With that scenario, there is a 38.5% chance that the ES stock declines in the next 20 years. Alternatively, we evaluated a scenario where the harvest only occurs during the migratory season (i.e., before 24 July and after 24 August) and calculated sustainable TALCs (Table 4).

For scenarios 2-5, we were not provided information on how the TALCs from the newly calculated PBRs would be allocated across management units. As a result, we have run three

theoretical possibilities to evaluate risk under each scenario. The first is a worst case scenario (A) in which the entire PBR is allocated to Eclipse Sound, (B) represents allocation to management units in proportion to their abundance (which is an assumption of the HAM as well), and (C) represents if harvests were allocated to management units proportionally to the number of people living in communities included in the management unit (albeit excluding the census for Iqaluit, which is the only city in Nunavut and that only harvests narwhal occasionally).

*Table 3. Potential biological removal (PBR) and Total Allowable Landed Catch (TALC) for the Admiralty Inlet (AI), Eclipse Sound (ES), East Baffin Island (EBI), and Somerset Island (SI) narwhal stocks using the most recent published abundance estimates and coefficient of variance (CV) for narwhal stocks in Canada. \*Indicates the largest TALC which could be sustainably allocated to any hunting region in Canada, regardless of the time of year.*

Stock	Year	Abundance (CV)	PBR	TALC
AI	2013	35043 (0.42)	498	389
ES	2016	12039 (0.23)	150	117*
EBI	2013	17555 (0.35)	264	206
SI	2013	49768 (0.20)	842	658

*Table 4. Potential biological removal (PBR) and Total Allowable Landed Catch (TALC) using the most recent published abundance estimates for narwhal stocks in Canada. The summer proportions used in the Harvest Allocation Model were 0.47, 0.48 and 0.24 for Admiralty Inlet (AI), Eclipse Sound (ES), and East Baffin Island (EBI), respectively, and the resulting TALCs for the migratory season (TALC<sub>M</sub>) and summer season (TALC<sub>S</sub>) are presented. Scenarios were explored up to the maximum TALC for AI, ES, and EBI stocks, while also considering that 9.76% of ES whales are available in AI.*

Scenario	Stock	PBR	TALC <sub>M</sub>	TALC <sub>S</sub>	TALC <sub>M+S</sub>
1A With season - maximizes cumulative harvest and the harvest in AI and EBI	AI	498	208	181	389
	ES	132	54	49	103
	EBI	264	157	49	206
	SI	576	-	-	450 <sup>±</sup>
With season - maximizes harvest in ES	AI	434	181	158	339
	ES	150	61	56	117
	EBI	233	138	44	182
	SI	576	-	-	450 <sup>±</sup>
1B Without season – summer hunt only	AI	513	0	400	400
	ES	135	0	104	104
	EBI	264	0	206	206
	SI	842	0	450 ±	450 <sup>±</sup>
Without season – migration hunt only - maximizes harvest in AI and EBI	AI	444	347	0	347
	ES	73	57	0	57
	EBI	264	206	0	206
	SI	576	450	0	450 <sup>±</sup>
	AI	421	329	0	329

**Arctic Region**

Scenario	Stock	PBR	TALC <sub>M</sub>	TALC <sub>S</sub>	TALC <sub>M+S</sub>
Without season – migration	ES	96	75	0	75
hunt only - maximizes harvest in ES and EBI	EBI	264	206	0	206
	SI	576	450	0	450 <sup>±</sup>

<sup>±</sup> As suggested in Richard (2011), the TALC for Somerset Island (SI) was fixed to reflect the current quota.

**Scenario 2**

Three separate management units without summer and migratory seasons: i) combined EBI and ES, ii) AI, and iii) SI stocks.

If there are no migratory harvest tags, then we assume the entire catch comes from a fully mixed summering aggregation of three stocks: EBI-ES, AI, and SI narwhal, respectively. If the assumption that the whales in ES-EBI are fully mixed is not met, a worst-case scenario is that the whole harvest of the ES-EBI sustainable take is allocated to the smallest portion of that stock (ES). The model simulations for this scenario indicate that the ES stock would reach zero in approximately 39 years (Figure 3A) and has an 84.1% chance of decreasing in the next 20 years. If harvest is allocated in proportion to stock or population abundance and the assumption that whales in ES-EBI are fully mixed is not met, the ES stock has a 46.2% and 43.2% probability of decline in the next 20 years, respectively (Figure 3B and C).

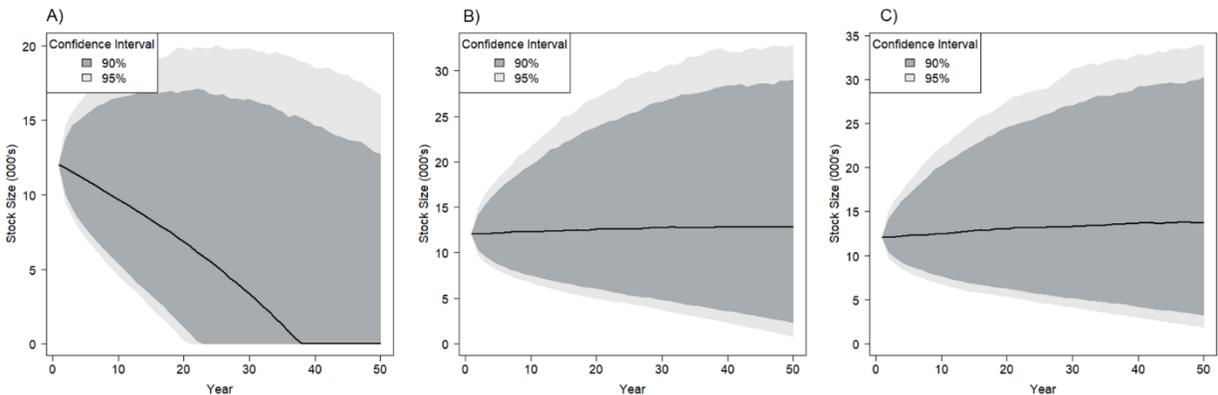


Figure 3. Stock abundance median projection for Eclipse Sound (ES) (the smallest stock) for Scenario 2 if the assumption that the ES and the East Baffin Island (EBI) narwhals mix in summer is incorrect and BRPBR is allocated A) fully to the ES summering ground, B) in proportion to the stock abundance, or C) in proportion to census population for each management unit.

**Scenario 3**

Three separate management units without summer and migratory seasons: i) combined ES and AI, ii) EBI, and iii) SI stocks.

If there are no migratory harvest tags, then we assume the entire catch comes from a fully mixed summering aggregation of three stocks: AI-ES, EBI and SI narwhal, respectively. If the assumption that the whales in AI-ES are fully mixed is not met, a worst-case scenario is that the whole harvest of the AI-ES sustainable take is allocated to the smallest portion of that stock (ES), and this would drive the ES stock to zero in approximately 23 years (Figure 4A) and has a 96.5% chance of decreasing in the next 20 years. If harvest is allocated in proportion to stock or

population abundance and the assumption that whales in AI-ES are fully mixed is not met, the ES stock has a 44.0% and 78.6% chance of decline in the next 20 years, respectively (Figure 4B and C).

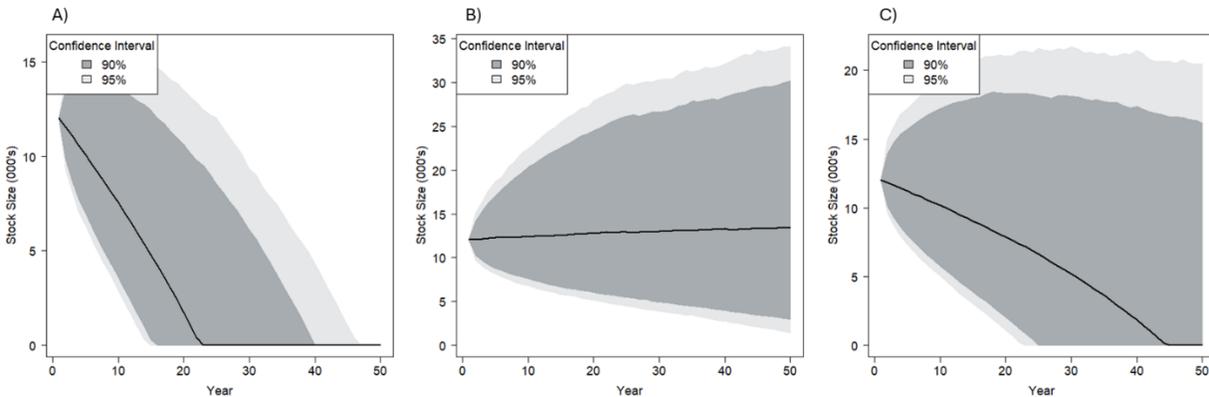


Figure 4. Stock abundance median projection for Eclipse Sound (ES) (the smallest stock) for Scenario 3 if the assumption that the ES and Admiralty Inlet (AI) narwhals mix in summer is incorrect and Potential Biological Removal (PBR) is allocated A) fully to the ES summering ground, B) in proportion to the stock abundance, or C) in proportion to census population for each management unit.

**Scenario 4**

Two separate management units without summer and migratory seasons: i) combined EBI, ES and AI, and ii) SI stocks.

If there are no migratory harvest tags, then we assume the entire catch comes from a fully mixed summering aggregation of two stocks: EBI-ES-AI and SI narwhal, respectively. If the assumption that the whales in EBI-ES-AI are fully mixed is not met, a worst-case scenario is that the whole harvest of the EBI-ES-AI sustainable take is allocated to the ES portion, and this would drive the ES stock to zero in approximately 15 years (based on median prediction, Figure 5A) and has a 99.7% chance of decreasing in the next 20 years. If harvest is allocated in proportion to stock or population abundance and the assumption that whales in EBI-ES-AI are fully mixed is not met, the ES stock has a 46.2% and 57.8% chance of decline in the next 20 years, respectively (Figure 5B and C).

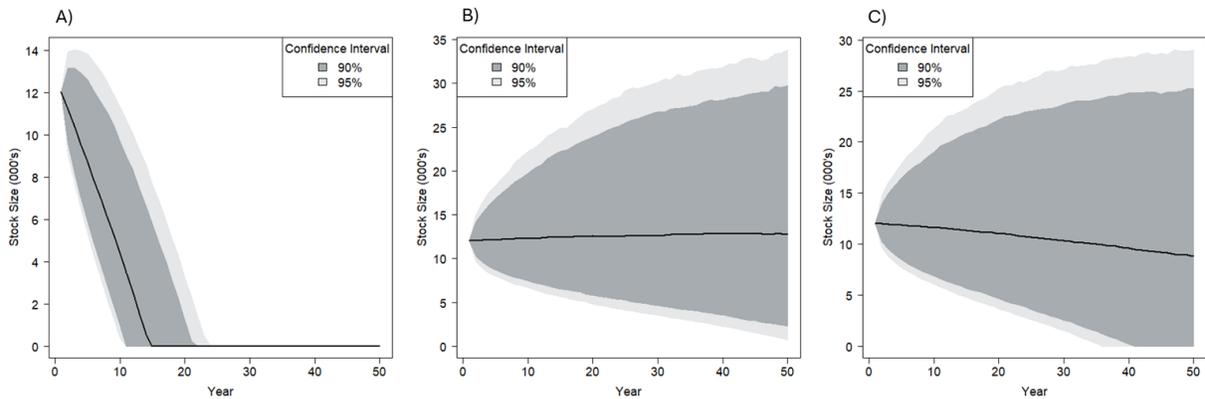


Figure 5. Stock abundance median projection for Eclipse Sound (ES) (the smallest stock) for Scenario 4 if the assumption that the ES, East Baffin Island (EBI), and Admiralty Inlet (AI) narwhals mix in summer is incorrect and Potential Biological Removal (PBR) is allocated A) fully to the ES summering ground, B) in proportion to the stock abundance, or C) in proportion to census population for each management unit.

**Scenario 5**

A single management unit comprised of the EB, ES, AI and SI stocks without summer and migratory seasons.

If there are no migratory harvest tags, then we assume the entire catch comes from a fully mixed single stock; EBI-ES-AI-SI. If the assumption that the whales in EBI-ES-AI-SI are fully mixed is not met, a worst-case scenario is that the whole harvest of the EBI-ES-AI-SI sustainable take is allocated to the ES portion, and this would drive the ES stock to zero in approximately 8 years (Figure 6A) and has a 100% chance of decreasing in the next 20 years. If harvest is allocated in proportion to stock or population abundance and the assumption that whales in EBI-ES-AI-SI are fully mixed is not met, the ES stock has a 48.6% and 54.6% chance of decline in the next 20 years, respectively (Figure 6B and C).

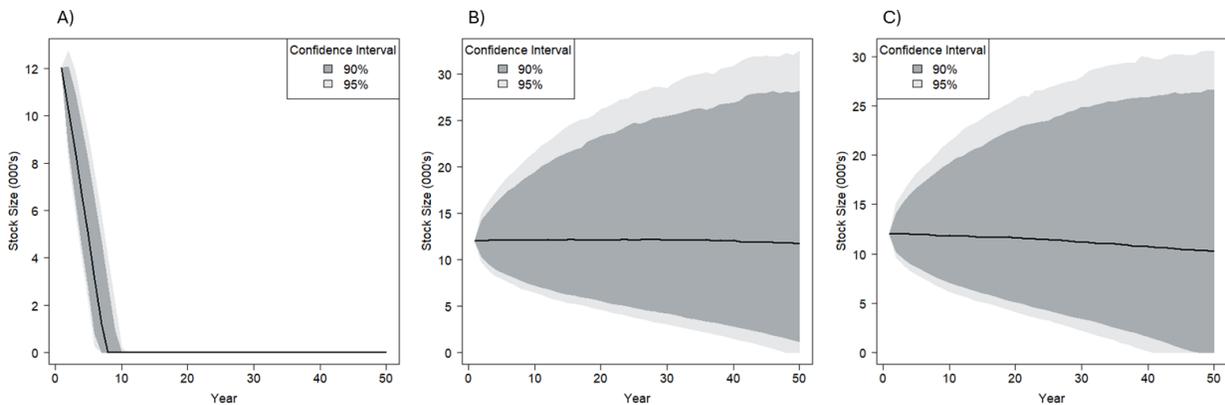


Figure 6. Stock abundance median projection for Eclipse Sound (ES) (the smallest stock) for Scenario 5 if the assumption that the ES, East Baffin Island (EBI), Admiralty Inlet (AI), and Somerset Island (SI) narwhals mix in summer is incorrect and Potential Biological Removal (PBR) is allocated A) fully to the ES summering ground, B) in proportion to the stock abundance, or C) in proportion to census population for each management unit.

## Scenario 6

*Sustainability of the current harvest in ES without summer and migratory seasons.*

We were also requested to evaluate the sustainability of the current harvest and assess risk to the Eclipse Sound stock, considering the median harvest over the last ten years, irrespective of the harvest dates. At this level of harvest, there is a 42.9% chance of decline in the next 20 years (Figure 7).

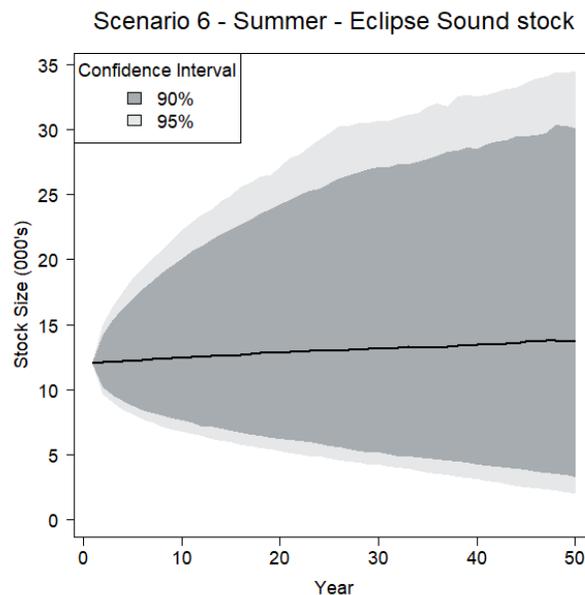


Figure 7. Stock abundance median projection for Eclipse Sound (ES) for Scenario 6.

## Scenario 7

*The maximum sustainable harvest that could be allocated to any hunting region in Baffin Bay.*

This scenario was difficult to assess; however, we interpreted this as the maximum number of narwhal that could be harvested regardless of location, season, or management unit. The maximum sustainable TALC which could be taken anywhere at any time of year is 117 total for SI, AI, ES, and EBI together (Table 3). This is much less than the total annual harvests that could be sustainable if harvests are allocated with consideration of location, season, and management unit.

## IDENTIFYING UNCERTAINTIES, CHALLENGES, AND LIMITATIONS TO THE RISK ASSESSMENT

All of the methods described above that have been used as evidence for narwhal stock delineation are limited by sample size. Many of the chemical methods rely on harvest samples that are provided by hunters on a voluntary basis. The number of animals that have been satellite tagged is also limited due to ethical, logistical, and financial considerations. Investigations of annual site fidelity rely on only a few tags ( $n = 9$ ) that have lasted over a year. Summer site fidelity relies on more tags, but these whales were only tagged for a portion of the summer season (Table A1). For instance, if a whale was tagged on August 22 and remained in its summering area during summer, this site fidelity only represents a few days post-tagging.

Finally, while there have been > 100 satellite tags deployed on narwhals, this is only a small fraction of the total narwhal population (estimated at ~ 142,000; Doniol-Valcroze et al. 2015).

The drivers of narwhal movements are still not well understood, but are probably influenced by a combination of different factors. Narwhals in Eclipse Sound may be displaced by an increased level of vessel traffic from mining and cruise ships (Dawson et al. 2018), ice breaking, and anthropogenic development (Mayette et al. 2024). In addition, killer whales (*Orcinus orcas*) frequent Arctic waters in the summer and can impact narwhal movement and behaviour (Breed et al. 2017). None of these factors were considered in this assessment.

It was challenging to run a risk assessment without knowing how the harvest may be allocated; therefore, some assumptions needed to be made to conduct the risk assessments. We assumed a worst-case scenario where A) all takes are attributed to the smallest stock (ES), and other scenarios where allocations occurred in proportion to B) the estimated stock abundance, and C) the census population for communities within the management areas. These may or may not be realistic, but without an understanding of how allocations would be considered, it was the most reasonable approach. The modelled scenarios presented are also constrained by some sources of uncertainty. PBR calculations were based on assuming a recovery factor of 1 and a maximum productivity rate of 0.04. We used a recovery factor of 1 for all the scenarios, but if we combine management units, a lower recovery factor may be considered since there is added uncertainty in stock delineation with combined units. Regarding maximum productivity rates, Taylor et al. (2007) calculated a maximum population growth rate of 0.03, which may be more applicable for long-lived narwhal. For the scenarios presented here, we used the same values utilized in previous DFO Science Advice for calculating PBR for narwhal in Canada for comparability (Doniol-Valcroze et al. 2015); however, we acknowledge that more consideration into the values of these factors is warranted for advising on sustainable harvest levels, which is outside the scope of this assessment.

Scenarios 1A and 1B are based on the current HAM used to allocate narwhal to hunting regions in Canada. Our assessment of the scenario only evaluated possible iterations up to the TALC for each summering area. However, scenarios that exceed the TALC in some stocks (e.g., AI) are possible and could have also been explored.

The hypothetical scenarios depend upon the dates defined as summer versus migration. For this exercise, we chose dates that align with the timing of the aerial surveys and movement of narwhal based on available telemetry data. However, there is evidence that the timing of fall migration has changed (Shuert et al. 2022), and although there are no consistent trends in the harvest dates for narwhal hunts (Watt and Hall 2018), this change in migration could impact timing of hunts. These are important considerations, but were outside the scope of this assessment.

## CONCLUSIONS

The modelled scenarios presented here for narwhal surrounding Baffin Island demonstrate that there is a risk of decline (probabilities ranging from 43-100% in Scenarios 2-5) in local areas if the narwhal aggregations are not fully mixing in the summer and the full TALC is hunted from the smallest portion of the stock (i.e., worst case scenario), or in proportion to stock size or population abundance. Canada's precautionary approach to fisheries management suggests a 5-25% risk of decline is a low-risk category (DFO 2009) and all of the scenarios that amalgamated stocks (Scenarios 2-5) resulted in a > 43% probability of decline. Even considering the current median harvest (Scenario 6), there is still a 42.9% chance of stock decline in 20 years in ES; this results in a medium risk of decline because the current quotas

are based on an abundance estimate from 2004 (Richard et al. 2010) rather than on newer abundance estimates from 2013 (Doniol-Valcroze et al. 2015) or 2016 (Marcoux et al. 2019), while our assessment used the best available current published information (from 2016; Marcoux et al. 2019). Therefore, scenarios that propose to amalgamate currently defined management units, or those that do not use the most up-to-date abundance information, pose a serious risk to narwhal.

Stable isotopes, trace elements, contaminants, annual site fidelity from 8/9 satellite tags (89%) which lasted over a year, summer site fidelity from 99/103 (96%) satellite tags equipped on whales in the summer, and new genetic evidence (De Greef et al. 2024) corroborate separation among some summering aggregations. DFO’s precautionary approach framework suggests we should be cautious if scientific information is uncertain, unreliable, or inadequate (DFO 2006) and therefore, narwhal should be managed on the smallest scale for which there exists some evidence of stock structure. In this assessment, we did not consider mixing on the wintering grounds where whales are available to Greenland hunters, and we would strongly urge managers to consider that whales from summering aggregations in Canada are harvested annually on the wintering grounds in Greenland (ranging anywhere from ~ 200-550 whales annually; NAMMCO 2023). In addition, the current narwhal management framework assumes that narwhal are available in proportion to their abundance. However, narwhals exhibit divergent fall migration strategies with some individuals choosing an offshore route while others select an inshore route (Shuert et al. 2023). For beluga whales, smaller at-risk populations have been shown to migrate closer to shore compared to large not-at-risk populations, which predisposes them to greater hunting mortality (DFO 2024). A more advanced model that considers Greenland harvests and the proportion of whales that are realistically available to hunters in different hunting regions based on movement (Watt et al. 2020) should be considered and has been developed by the NAMMCO-JCNB Joint Working Group (2021). A time-series of abundance estimates for narwhal, as well as information from harvested narwhals (e.g., samples to evaluate genetics, reproductive parameters, and age and sex structure of the hunt), would significantly improve our confidence in modeling the population dynamics of these stocks.

A high Arctic cetacean survey of all the Baffin Bay narwhal stocks in Canada was conducted in August 2023 and is currently being analyzed. These additional abundance estimates will add to a time-series of estimates for all of the narwhal stocks, which may allow a model-based precautionary approach for developing science advice for management in these regions (Hammill and Stenson 2003). It is recommended that management of Baffin Bay narwhals be based on currently defined summering stock aggregations until a better understanding of mixing and site fidelity within the population has been developed. Otherwise, there is a risk of local decline, as shown in the scenarios above. This stock delineation approach is consistent with previous science advice and the precautionary approach.

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## APPENDIX

Table A1. Dates of satellite tag deployment in Somerset Island (SI), Admiralty Inlet (AI), and Eclipse Sound (ES) and the number of days within the total defined summer (July 24-August 24) where tags provided information on summer site fidelity.

Stock	Individual ID	Deployment Date (yyyy/mm/dd)	Duration (days)	# of summer days out of 32 days (July 24-Aug 24)
SI	1	2000-08-14	65	11
SI	2	2000-08-14	99	11
SI	3	2000-08-17*	9	8*
SI	4	2000-08-16	74	9
SI	5	2000-08-17	104	8
SI	6	2000-08-17	118	8
SI	7	2000-08-17	89	8
SI	8	2000-08-19	15	6
SI	9	2000-08-23	421	2
SI	10	2000-08-24	381	1±
SI	11	2001-08-12	47	13
SI	12	2001-08-12	74	13
SI	13	2001-08-07	134	18
SI	14	2001-08-12	12	13
SI	15	2001-08-09	134	16
SI	16	2001-08-09	84	16
SI	17	2001-08-08	12	17
AI	1	2003-08-14*	131	11*
AI	2	2003-08-16	136	9
AI	3	2003-08-16	210	9
AI	4	2003-08-18	133	7
AI	5	2003-08-18	134	7
AI	6	2003-08-16	73	9
AI	7	2003-08-18	236	7
AI	8	2003-08-21	83	4
AI	9	2003-08-20	26	5
AI	10	2003-08-20	51	5
AI	11	2003-08-21	113	4
AI	12	2003-08-21	23	4
AI	13	2003-08-21	33	4
AI	14	2004-08-11	37	14
AI	15	2004-08-13	108	12
AI	16	2004-08-15*	140	10*

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Stock	Individual ID	Deployment Date (yyyy/mm/dd)	Duration (days)	# of summer days out of 32 days (July 24-Aug 24)
AI	17	2004-08-13	280	12
AI	18	2004-08-24*	161	1*±
AI	19	2004-08-22	128	3
AI	20	2004-08-22	169	3
AI	21	2004-09-07*	23	NA**±
AI	22	2004-09-07*	21	NA**±
AI	23	2004-09-10*	12	NA**±
AI	24	2005-08-17*	148	8*
AI	25	2005-08-17*	175	8*
AI	26	2005-08-18*	132	7*
AI	27	2005-08-18*	220	7*
AI	28	2005-08-19*	133	6*
AI	29	2005-08-20*	15	5*
AI	30	2005-08-21*	64	4*
AI	31	2005-08-22*	117	3*
AI	32	2005-08-22*	24	3*
AI	33	2005-08-22*	9	3*
AI	34	2005-08-22*	95	3*
AI	35	2005-08-22*	163	3*
AI	36	2005-08-23*	151	2*
AI	37	2005-09-02*	18	NA**±
AI	38	2009-08-15	193	10
AI	39	2009-08-15	260	10
AI	40	2009-08-17	291	8
AI	41	2009-08-17	299	8
AI	42	2009-08-18	145	7
AI	43	2009-08-17	320	8
AI	44	2009-08-16	176	9
AI	45	2009-08-17	723	8
ES	1	1997-08-22*	16	4*
ES	2	1997-08-08	30	17
ES	3	1998-08-19	46	6
ES	4	1997-08-21	14	4
ES	5	1997-08-24	76	1
ES	6	1998-08-14	7	11
ES	7	1998-08-21	165	4
ES	8	1998-08-25	71	0
ES	9	1998-08-25	40	0

**Arctic Region**

**Consideration for a New Narwhal Management System**

Stock	Individual ID	Deployment Date (yyyy/mm/dd)	Duration (days)	# of summer days out of 32 days (July 24-Aug 24)
ES	10	1999-08-12	80	13
ES	11	1999-08-13	69	12
ES	12	1999-08-15	80	10
ES	13	1999-08-15	84	10
ES	14	1999-08-21	45	4
ES	15	1999-08-21	211	4
ES	16	1999-08-21	5	4
ES	17	2010-08-21	252	4
ES	18	2010-08-21	292	4
ES	19	2010-08-22	410	3
ES	20	2010-08-22	189	3
ES	21	2010-08-24	151	1
ES	22	2011-08-16	128	9
ES	23	2011-08-16	180	9
ES	24	2011-08-16	314	9
ES	25	2011-08-19	126	6
ES	26	2011-08-19	302	6
ES	27	2011-08-18	201	7
ES	28	2011-08-18	221	7
ES	29	2012-08-13	30	12
ES	30	2012-08-14	128	11
ES	31	2012-08-17	128	8
ES	32	2012-08-18	124	7
ES	33	2012-08-19	119	6
ES	34	2016-08-22	81	3
ES	35	2016-08-18	3	7
ES	36	2016-08-22	86	3
ES	37	2016-08-29	9	NA <sup>±</sup>
ES	38	2016-08-29	20	NA <sup>±</sup>
ES	39	2017-07-31	126	25
ES	40	2017-08-01	57	24
ES	41	2017-07-31	78	25
ES	42	2017-08-03	84	22
ES	43	2017-08-03	84	22
ES	44	2017-08-03	218	22
ES	45	2017-08-05	64	20
ES	46	2017-08-12	77	13
ES	47	2017-08-16	50	9

Stock	Individual ID	Deployment Date (yyyy/mm/dd)	Duration (days)	# of summer days out of 32 days (July 24-Aug 24)
ES	48	2017-08-30	66	NA <sup>±</sup>
ES	49	2017-09-02	84	NA <sup>±</sup>
ES	50	2017-09-02	40	NA <sup>±</sup>
ES	51	2017-09-03	44	NA <sup>±</sup>
ES	52	2017-09-03	69	NA <sup>±</sup>
ES	53	2017-09-10	53	NA <sup>±</sup>
ES	54	2017-09-11	52	NA <sup>±</sup>
ES	55	2017-09-11	72	NA <sup>±</sup>
ES	56	2017-09-11	66	NA <sup>±</sup>
ES	57	2018-08-17	55	8
ES	58	2018-08-17	80	8

\*For most tags, deployment date and number of days in the summer was calculated based on the date narwhals were captured. For a few individuals (\*), this information was not available and the date of the first transmission of a location was used as deployment date.

<sup>±</sup>Deployment was too late to contribute to assessment of summer residency.

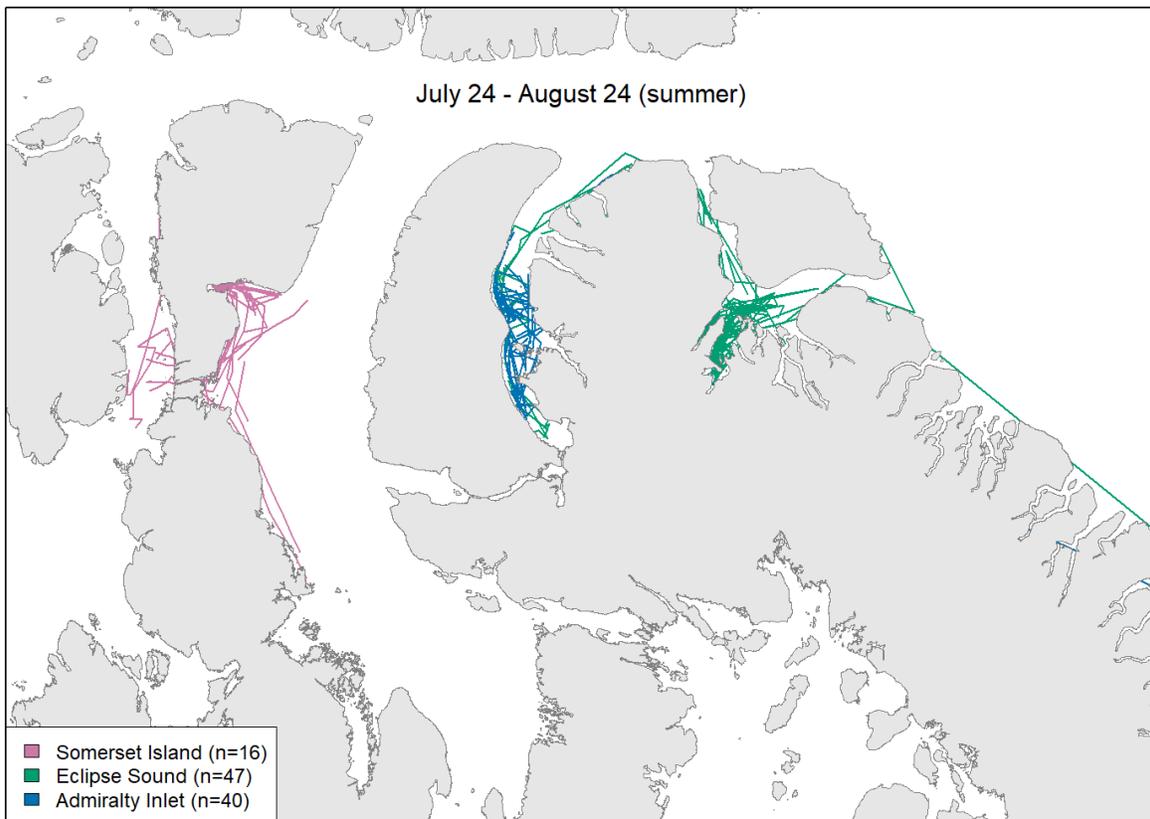


Figure A1. Telemetry tracks of all satellite tags from Somerset Island (pink), Admiralty Inlet (blue), and Eclipse Sound (green) from Table A1 for summer (July 24-August 24).

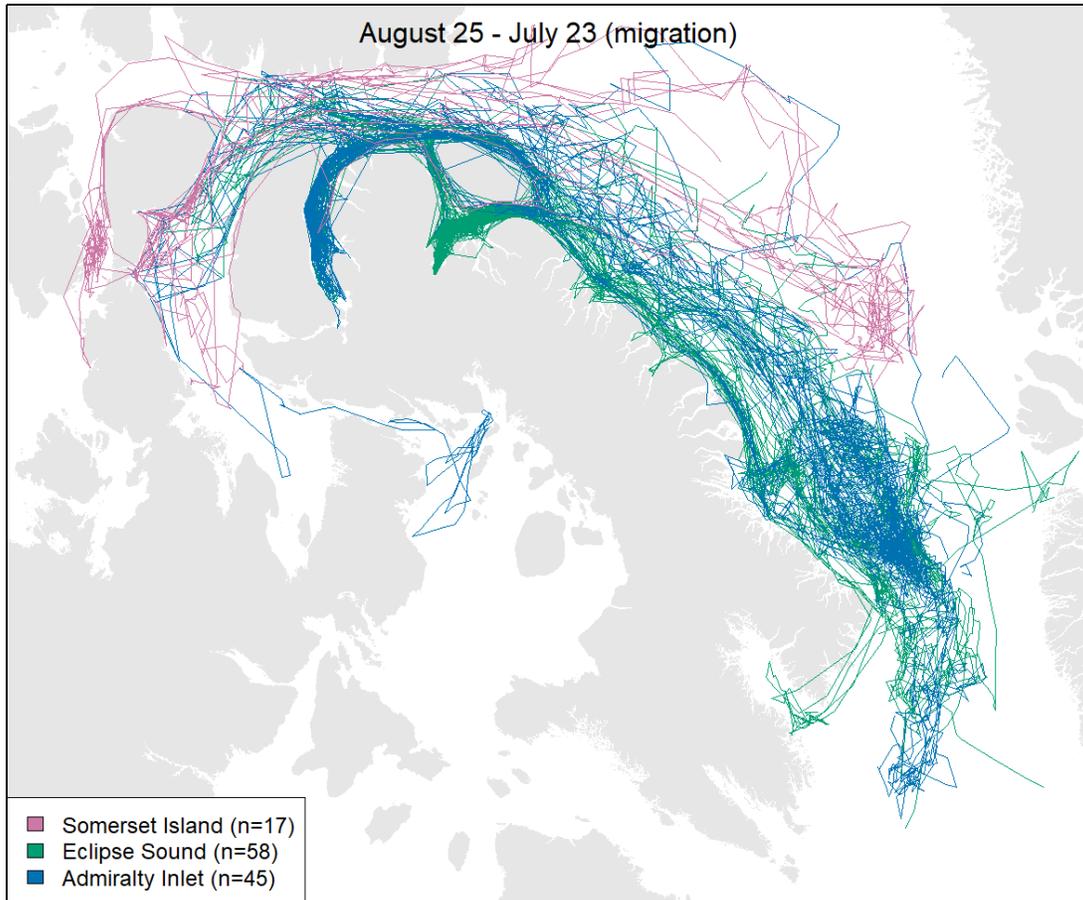


Figure A2. Telemetry tracks of all satellite tags from Somerset Island (pink), Admiralty Inlet (blue), and Eclipse Sound (green) from Table A1 for outside of the summer season (migration August 25-July 23).

