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Threat Assessment for the Critically Endangered North Atlantic Right Whale (*Eubalaena glacialis*)

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

The North Atlantic right whale (NARW, *Eubalaena glacialis*) is a critically endangered species with a population of less than 400 individuals. Between 2010 and 2020 the population experienced an estimated decline of 126 individuals. This decline has been exacerbated by low reproductive rates, declining health, and high rates of anthropogenic related, sublethal injuries. The NARW faces a plethora of threats and this assessment evaluated some of the *Historical*, *Current*, and *Anticipatory* threats that occur not only in Canadian waters, but throughout NARW core habitat areas. Threats assessed included fishing-gear entanglements, vessel strikes, vessel presence disturbance, and various sources of noise pollution, including marine traffic, seismic surveys, active acoustic technologies operation, and mid-frequency military active sonar operation, as well as other threats such as persistent organic pollutants pollution, plastics and marine debris pollution, petroleum spills, coastal and marine offshore development, drilling operations, wind energy production, climate change, scientific activities, whaling, and food supply reduction through direct harvesting of prey. The *Likelihood of Occurrence* was assessed as *Known* (>90% chance of occurring over the next 100 years) for all but two anticipatory threats (whaling, and food supply reduction through direct harvesting of prey). Due to the uncertainty in the estimation of the *Population Level of Impact*, the majority of threats had a Threat Risk (the product of *Population Level of Impact* and *Likelihood of Occurrence*) assessed as *Unknown*, although it should not be assumed that such threats do not have population level impacts. Fishing-gear entanglements had an *Extreme* ranking for the *Population Level of Impact*, while vessel strikes, petroleum spills, and climate change were ranked as *High*. To provide further insights in the impact of these threats, especially for a species that has an estimated Potential Biological Removal of less than one, the *Individual Level of Impact* was also defined and evaluated. The *Individual Level of Impact* incorporated information not only on mortalities, but also on sublethal effects (including injuries, disturbances, effects on reproduction, and increased stress) and provided further insights on *Threat Risk*. Many of the threats intersect with one another, however, the cumulative effects of the threats were not assessed. It is essential for the survival and recovery of the NARW not to focus solely on mortalities and population level impacts. Investigating individual impacts on health and reproductive rates will provide further information which can be used to inform conservation initiatives aimed at reducing threats to the survival and recovery of the NARW.

INTRODUCTION

The North Atlantic right whale (NARW, *Eubalaena glacialis,* Rosenbaum et al. 2000) is listed as critically endangered by the International Union for Conservation of Nature (IUCN, Cooke 2020) and is designated as endangered under the *Species at Risk Act* in Canada and the *Endangered Species Act* in the United States of America (USA). NARWs are considered one of the most endangered of all large whale species (Caswell et al. 1999, Kraus et al. 2005). Historically, the NARW was the subject of intense commercial whaling (Aguilar 1986) and, although internationally protected since 1935 (IWC 2001), the maximum population estimate only reached 482 individuals in 2010 (Pace et al. 2017). Between 2010 and 2020 the NARW population declined to 356 individuals (Pace et al. 2017, Pettis and Hamilton 2024). Reed et al. (2022) estimated that there were only 72 breeding female NARWs alive at the beginning of 2018 and the 2023 population abundance of NARWs was estimated at 372 individuals (credible interval: 360–383 individuals, Linden 2024).

The population decline is exacerbated by the low reproductive rates of NARWs. Females born from 2000 onwards are half as likely to transition to reproductively active females than the females born prior to 2000 (Reed et al. 2022). Between 1992 and 2016, the modelled calf counts for NARWs increased at a rate of approximately 2.0% per year (Corkeron et al. 2018). In comparison, southern right whale (*Eubalaena australis*) populations in South Africa, Southwest Australia and eastern South America that have close phylogenetic relationships, morphological, demographic, and ecological similarities to NARWs (Harcourt et al. 2019), exhibited higher growth rates, with increases of approximately 5.3%, 6.6%, and 7.2% per year, respectively (Corkeron et al. 2018). There is also considerable interannual variability in NARW calving intervals. Between 1980 and 1998, the lowest observed calving interval was 3 years with a range from 3 to 5.8 years (Knowlton et al. 1994, Kraus et al. 2001). In contrast, for the period of 2009 to 2021, the calving interval ranged between 3.3 to 10.2 years (Pettis et al. 2022), representing nearly a doubling of the maximum calving interval in approximately 20 years. Of the 260 sexually mature females identified between 1980 and 2021, 49 with ages ranging from 10 to 34 years (where known), had never been observed with a calf (Bishop et al. 2022).

A substantial contributor to the NARW population decline since 2010, is human-induced mortalities. In 2017, an unusual mortality event was declared after increased mortalities were observed in Canada and the USA (Daoust et al. 2018, Bourque et al. 2020, NOAA 2025). This event was still open as of the end of 2024. From 2017 through 2024, there have been 41 NARW observed mortalities and 39 cases of serious injuries where there is a high likelihood that the injuries will result in the death of the whale (NOAA 2025). Additionally, there have been 71 morbidity cases that include sublethal injuries or illnesses. Preliminary causes of 82% of these cases were attributed to human interaction, with 99 entanglements and 25 vessel strikes identified (NOAA 2025). While reported mortalities and serious injuries indicate a concerning trend, the actual number of NARW deaths is estimated to be higher than what is reported based on observed carcasses. Pace et al. (2021) estimated that only 36% of all NARW deaths are observed, with the majority of mortalities being cryptic.

Visual health assessment methodologies developed for NARWs allows for the use of non-invasive techniques to study the health of these whales, examine recoveries from injuries, and determine associations between health, reproduction and human-induced impacts (Pettis et al. 2004, Rolland et al. 2016). Modelling of NARW individual health (Schick et al. 2013, 2016, Rolland et al. 2016) demonstrated declining health of the whales in the population over the last 30 years, with the greatest variability in health occurring in reproductive females (Rolland et al. 2016, Schick et al. 2016). The majority of life stages of NARWs are generally in poorer body condition compared to southern right whales (Christiansen et al. 2020). Stewart et al. (2021)

found that the body lengths of NARWs have been decreasing since 1981, and Christiansen et al. (2020) found that the body lengths of adult NARWs are shorter than those of southern right whales. Poor health, reduced reproduction, and sublethal stressors, all contribute to the reduced survival of the NARW.

The decline in abundance and changes in the health of NARWs coincides with changes in their distribution and the distribution of their prey (Davis et al. 2017, Brennan et al. 2019, Davies et al. 2019, Record et al. 2019, Simard et al. 2019, Sorochan et al. 2019, Meyer-Gutbrod et al. 2021, 2023). Generally, NARWs are found along the eastern seaboard of North America (Kraus and Rolland 2007, Figure 1) with critical habitats in the USA found in the Gulf of Maine and referred to as the Northeastern U.S. Foraging Area, and off the southeast coast from Cape Fear, North Carolina, to below Cape Canaveral, Florida, an area referred to as the Southeastern U.S. Calving Area (Federal Register 2016). Canadian critical habitats include the Grand Manan and Roseway basins (DFO 2014a). NARWs may leave traditional feeding areas, such as the Roseway Basin and Grand Manan Basin, during periods of reduced prey densities (e.g., Kenney 2001, Patrician and Kenney 2010, Davies et al. 2015). Changes in ocean conditions brought on by climate change have led to shifts in the distribution of NARW prey (e.g., Grieve et al. 2017, Meyer-Gutbrod and Greene 2018, Brennan et al. 2019, Sorochan et al. 2021, Meyer-Gutbrod et al. 2021). Coincident with the observed shift in prey distribution, there have been increased detections, both visual and acoustic, of NARWs in the Gulf of St. Lawrence (Simard et al. 2019, Crowe et al. 2021) and in the waters off southern New England (Davis et al. 2017, Quintana-Rizzo et al. 2021, O'Brien et al. 2022). Plourde et al. (2019) have also identified potential suitable foraging habitats for NARWs along the coast of Cape Breton, Nova Scotia in the Cabot Strait. With changes in distribution, NARWs may occupy areas where conservation initiatives to protect the species have not been established and, as a result, they may face increased exposure to threats.

The 2014 NARW Recovery Strategy (DFO 2014a) identified whaling, vessel strikes, entanglement in fishing gear, disturbance and habitat reduction or degradation as threats to NARWs. Given the population decline and shifts in distribution since 2010, the increased number of studies that have been undertaken for NARWs since 2007, and the myriad of threats currently faced, the 2007 Recovery Potential Assessment for NARWs (DFO 2007) is considered outdated. In this context, and following the guidelines provided by Fisheries and Oceans Canada (DFO, DFO 2014b), an updated threat assessment is required to update the Recovery Potential Assessment.

The threat assessment presented in this document is more comprehensive than the previous assessment (DFO 2007), as it includes additional categories such as noise pollution, chemical contaminants, energy development and production, climate change, scientific activities, direct harvesting, and resource depletion. This threat assessment was based on the guidance developed by DFO (DFO 2014b) and assessed various threats over two intersecting regions: the Canadian Assessment Area and the Northwest Atlantic Assessment Area. A quantitative approach was taken, where possible, to present up-to-date information and a comprehensive review of the threats faced by NARWs.

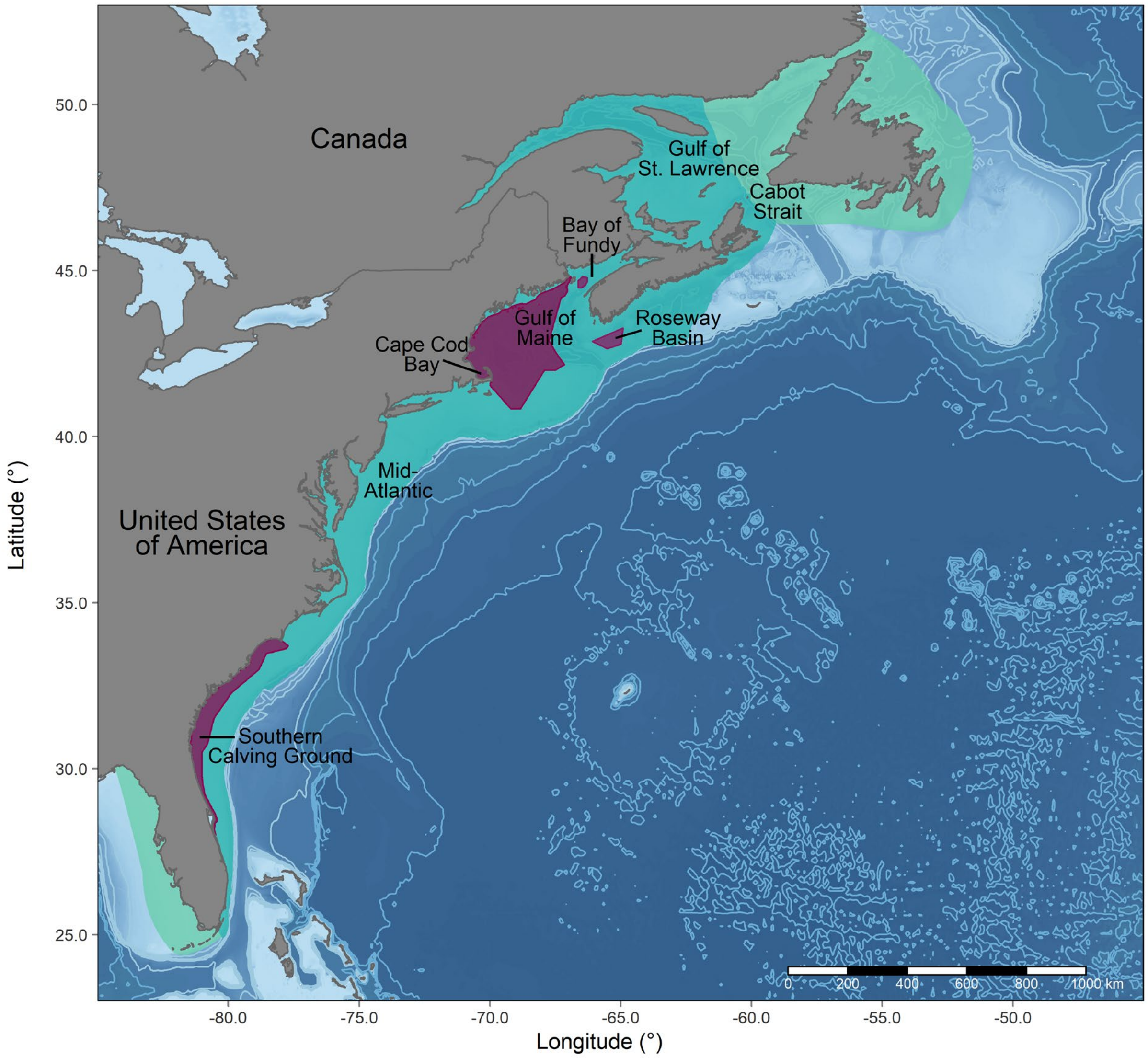

Figure 1. North Atlantic right whale distribution with their primary sightings area (seagreen polygon), occasional sightings areas (light green polygons), and critical habitats (maroon polygons). Figure modified from Figure 1 in Hamilton et al. (2022).

THREAT ASSESSMENT METHODOLOGY

THREAT DEFINITION

Within the threat assessment guidance produced by DFO, a threat is defined as "any human activity or process that has caused, is causing, or may cause harm, death, or behavioural changes to a wildlife species at risk, or the destruction, degradation, and/or impairment of its habitat, to the extent that population-level effects occur" (DFO 2014b). However, the threats identified in the 2014 NARW Recovery Strategy (i.e., vessel strikes, entanglement in fishing gear, disturbance and habitat reduction or degradation; Brown *et al.* 2009, DFO 2014a) are describing the consequences of human activities or processes, rather than the specific relevant human activities or processes involved. For example, entanglement in fishing gear (the consequence) is the result of the activity of fishing (the threat). In response to this, we reviewed threat definitions and subsequently adjusted threat categories to align more closely with these definitions.

Avila et al. (2018) defines a threat to a marine mammal as “an event that induces to the individual, disturbance, behavioural and distribution changes, disease, health problems, physical restraint, injury or death; or, at the population level, decrease breeding success, gene flow or population size”. To adhere to the common terminology that is more broadly recognized by the scientific and NARW community, we have modified Avila et al. (2018)’s definition to incorporate the human induced component of the DFO’s definition and replace the population level consequences with consequences to the individual.

This later change stems from the fact that the estimated annual potential biological removal (PBR) for NARWs has been less than or equal to one individual since 1995 (Blaylock et al. 1995, Waring et al. 1997, 1999a,b, 2000, 2001, 2002, 2004, 2006, 2007a,b, 2009a,b, 2010, 2012, 2013, 2014, 2015, 2016, Hayes et al. 2017, 2018, 2019, 2020, 2021, 2022). The resulting definition of a threat to NARWs, used throughout this document, is: any human-induced event or environmental modification that results in disturbance, behavioural changes, distributional changes, harassment, disease, decreased health, physical restraint, injury, or death, to an individual.

Threats into the categories listed in Avila et al. (2018) and included an additional category to capture new and emerging threats from renewable energy development and production. Under this classification scheme, it is possible for identified threats to be associated with multiple threat categories. For example, vessel-noise pollution could be categorized as vessel traffic and/or acoustic pollution. Similarly, entanglement in abandoned, lost, or otherwise discarded fishing gear could be categorized as incidental catch and fishing-gear interactions or pollution. In all cases, we attempted to categorize the threats closest to their source. Climate change was included as a threat at the request of the Species at Risk Program.

GENERATION TIME

A key component of the threat assessment is the generation time of the species in question. Under the DFO guidance, threat evaluation criteria should be examined over 10 years or three generations, whichever is shorter (DFO 2014b). In contrast, both the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) and the International Union for Conservation of Nature recommend examination over 10 years or three generations, whichever is longer (up to a maximum of 100 years into the future), when evaluating the status of endangered species and conducting threat assessments (IUCN 2016, COSEWIC 2021).

Taylor et al. (2007) estimated the generation length for NARWs as 23.3 years based on the contemporary growth rate ($r = 0.05$) and 35.7 years for a stable population ($r = 0$). However, Runge et al. (2023) assumed that the generation time for NARWs used in a population viability analysis under stable conditions was at least 33.3 years (i.e., three generations were approximately 100 years). Given that the generation time of NARWs exceeds 10 years, we propose that using a 10-year evaluation period, as per DFO’s guidance, does not represent a biologically meaningful timeframe for assessing threats to this species. Furthermore, 10 years does not match the time frame associated with PBR assumptions (100 years, Wade 1998). Therefore, we evaluated the threats to NARWs using an assumed generation time of 33.3 years representing 100 years for 3 generations. This approach is consistent with the population viability analysis (Runge et al. 2023), the Northern bottlenose whale (*Hyperoodon ampullatus*) threat assessment (Moors-Murphy et al. 2024), and follows the recommended timeframes for evaluation by both COSEWIC and the IUCN.

GENERAL OVERVIEW: SCALES OF THE ASSESSMENT

The DFO guidance on threat assessments (DFO 2014b) outlines a two-step process for evaluating threats: at the population level and at the species level.

NAWRs represent a single population with no designatable units (defined as “species, subspecies, variety, or geographically or genetically distinct population that may be assessed by COSEWIC, where such units are both discrete and evolutionarily significant”). As such, we make no distinction between population and species level. Thus, the *Threat Risk, Timing of Occurrence, Threat Frequency*, and *Geographic Extent of the Threat* are only considered at the population level. To reduce redundancy, we removed the Population-Level and Species-Level descriptors for the *Threat Risk*, *Timing of Occurrence*, *Threat Frequency*, and *Geographic Extent of the Threat*.

NARWs are a transboundary species with conservation initiatives implemented in both Canada and the USA to protect and promote the recovery of this critically endangered species. Threats in this assessment are evaluated at two different geographic scales: a Canadian Assessment Area and a Northwest Atlantic Assessment Area.

The Canadian Assessment Area includes the waters of the following bioregions: Gulf of St. Lawrence, the Scotian Shelf, and a portion of the Newfoundland-Labrador Shelves (DFO 2009a, Figure 2). For the purpose of this analysis, only areas of the Newfoundland-Labrador Shelves below 52.0 decimal degrees North were considered, since very few NARW observations/acoustic detections have been documented along the Labrador Shelf. Although known threats do occur along the Labrador Shelf, we considered the level of risk to be limited due to the infrequent detection of NARWs in the area.

The Northwest Atlantic Assessment Area is a southward expansion of the Canadian Assessment Area including the Canadian Assessment Area as well as waters along the eastern shore of the USA out to the exclusive economic zone (EEZ, Figure 3). It should be noted that the Northwest Atlantic Assessment Area does not encompass the full geographic extent of all NARW sightings and acoustic detections. Since the 1920s there have been extralimital observations or acoustic detections of NARWs outside their contemporary range including to the south in Bermuda and the Caribbean; to the north in the Davis Strait and Iceland, as well as in the eastern North Atlantic, including but not limited to Norway, Iceland, France, and Greenland (Knowlton et al. 1992, Martin and Walker 1997, Jacobsen et al. 2004, Mellinger et al. 2011, Silva et al. 2012, Hayes et al. 2023).

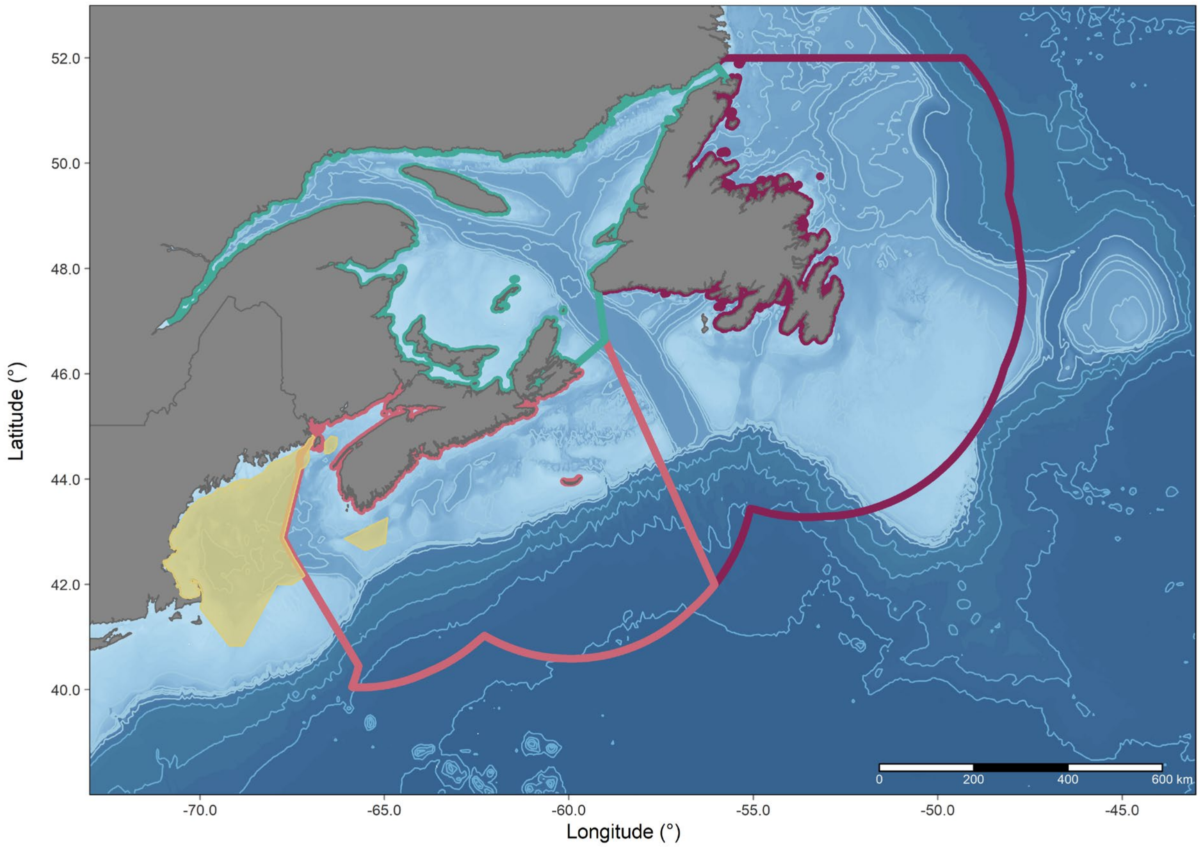

Figure 2. The Canadian Assessment Area depicted by the Gulf of St. Lawrence Bioregion (green polygon), the Scotian Shelf Bioregion (pink polygon), and a modified Newfoundland-Labrador Shelves Bioregion (burgundy polygon). Also depicted are the North Atlantic right whale critical habitats (yellow-shaded polygons) in Roseway Basin, Grand Manan Basin and the Gulf of Maine.

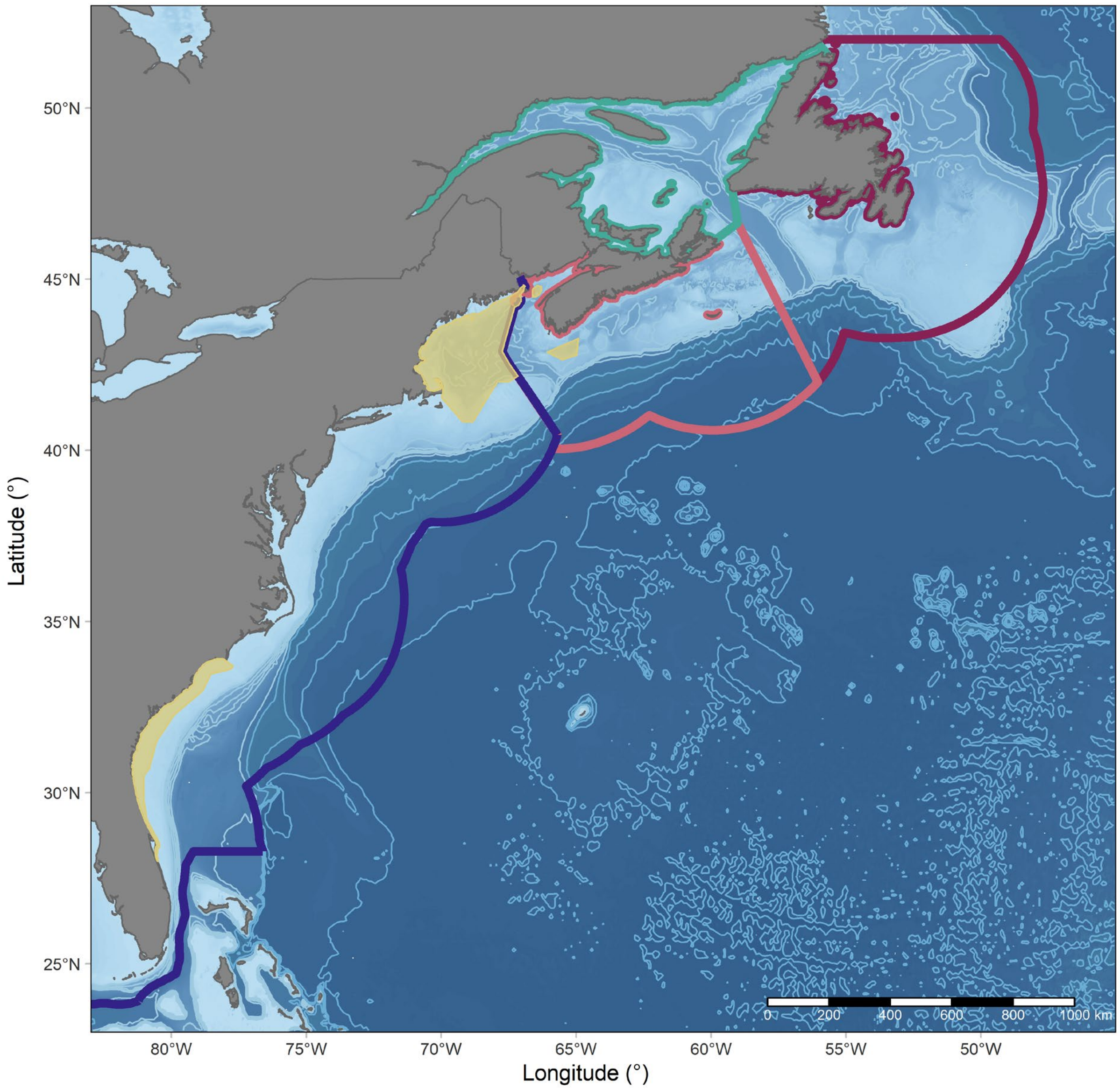

Figure 3. The Northwest Atlantic Assessment Area depicted by the Gulf of St. Lawrence Bioregion (green polygon), the Scotian Shelf Bioregion (pink polygon), a modified Newfoundland-Labrador Shelves Bioregion (burgundy polygon) and the waters off the east coast of the United States of America (USA) to the exclusive economic zone (indigo line). Also depicted are the North Atlantic right whale critical habitats (yellow-shaded polygons) in Roseway Basin, Grand Manan Basin, the Northeastern U.S. Foraging Area, and the Southeastern USA Calving off the coast of South Carolina, Georgia, and northeastern Florida.

Level of Impact

Threats can impact species at both the individual and population level. Impacts on individuals may include direct mortality or sublethal effects that alter their health and breeding success through serious injuries or morbidity. Population level impacts can lead to changes in abundance and/or distribution.

Population Level of Impact

The DFO guidelines (DFO 2014b) define Level of Impact as “the magnitude of the impact caused by a given threat, and the level to which it affects the survival or recovery of the population”. This provides a quantitative as well as qualitative assessment of impacts on population status and trend (Table 1). Each threat is scored on a scale ranging from 5 (*Extreme*) to 1 (*Unknown*).

Table 1. Categories of Level of Impact and the associated score linked to a threat provided from the DFO guidance on assessing threats (DFO 2014b). Level of Impact refers to the magnitude of the impact caused by a given threat over three generations or approximately 100 years, and the level to which it affects the survival or recovery of the population. The estimated absolute population loss is based on the estimated abundance for 2023 (Linden 2024).

Level of Impact	Definition	Estimated Population Loss
Extreme (5)	Severe population decline (e.g., 71-100%) with the potential for extirpation	261–372 individuals
High (4)	Substantial loss of population (31-70%) or Threat would jeopardize the survival or recovery of the population	113–260 individuals
Medium (3)	Moderate loss of population (11-30%) or Threat is likely to jeopardize the survival or recovery of the population	37–112 individuals
Low (2)	Little change in population (1-10%) or Threat is unlikely to jeopardize the survival or recovery of the population	4–36 individuals
Unknown (1)	No prior knowledge, literature or data to guide the assessment of threat severity on population	unknown

Survival (acceptable likelihood for long-term survival) under the Canadian *Species at Risk Act* is interpreted as a stable or increasing population that is not at significant risk of extirpation or extinction (ECCC 2020). Although there is no formal definition of recovery under the *Species at Risk Act*, human interventions and conservation initiatives to support the species would be minimized once the species is recovered (ECCC 2020).

The *Population Level of Impact* was further defined based on a quantitative assessment of population loss calculated from the 2023 NARW abundance estimate. The estimates of the absolute population loss explicitly assume that the population abundance will remain stable over the next 100 years. In addition, the estimates of absolute population loss may change with future adjustments to the population model used to determine abundance.

For some of the threats that NARWs face, there is a paucity of information regarding the impacts to the population. It is important to recognize that threats categorized as *Unknown* could be having effects on the population.

The level of impact based on population loss percentages does not incorporate sublethal effects of threats. Sublethal effects include serious injuries, morbidity, harassment, disturbance, increased stress, and effects on reproduction. None of these impacts are captured by the definition of *Population Level of Impact* provided by the DFO guidelines (DFO 2014b). Therefore, we have included an additional metric that focuses on the impact of the threats to the individual.

Impacts on Individuals

Threats can impact individuals to varying degrees. For example, the impact from a vessel strike can range from no apparent injury to serious injury, to mortality. As a result, it can be difficult to quantify a threat's impact on an individual. Therefore, rather than associating an impact-level score only to the severity of the injury, we used a rank-based approach where the number of impacts observed for an individual define the score (i.e., the higher number of different impacts observed the higher the score). For each level of impact, all of the effects listed must have occurred or be possible but the effects could be observed across many individuals (i.e., they do not all have be observed on a single individual).

Using this approach, impacts at the individual level for each threat are as follows:

- *Extreme* (5) - the threat has been linked to or demonstrated to cause mortality, serious injury, morbidity, harassment, disturbance, increased stress, and affected reproduction, in one or more individuals;
- *High* (4) - the threat has been linked to or demonstrated to cause mortality, serious injury, morbidity, harassment, disturbance, and increased stress in one or more individuals;
- *Medium* (3) - the threat has been linked to or demonstrated to cause morbidity, harassment, disturbance, and increased stress, in one or more individuals;
- *Low* (2) - the threat has been linked to or demonstrated to cause harassment, disturbance, and increased stress in one or more individuals;
- *Unknown* (1) - the effect of the threat on individuals is presently unknown.

The *Species at Risk Act* states "No person shall kill, harm, harass, capture or take an individual of a wildlife species that is listed as an extirpated species, an endangered species or a threatened species" (SC 2002, c 29). However, there is no formal definition for harm, and "harm" could be interpreted with varying degrees. To avoid confusion, we have not included harm in the definitions of *Individual Level of Impact*.

Much of the data presented below were collected from various publications from the National Oceanic and Atmospheric Administration (NOAA) and the National Marine Fisheries Service (NMFS). The formal definition of serious injury used by NOAA is "any injury that will likely result in mortality," and NMFS interprets this as any injury that is "more likely than not" to result in mortality, or any injury that presents a greater than 50 percent chance of death to a marine mammal (NOAA 2012, 2022, 2023).

Morbidity cases are the sublethal injuries or illness and, thus, morbidity is defined as the condition of suffering from a disease or medical condition. Morbidity is therefore interpreted as an injury or illness that does not lead to death but could reduce or impair well-being including growth and reproduction (i.e., sublethal effects, NOAA 2025). Knowlton et al. (2016, 2022) provide further information on categorizing injuries from entanglements, where minor and moderate injuries include superficial skin abrasions and extensive skin abrasions or cuts that extend into the blubber, and severe injuries are defined as cuts > 8 cm deep or that extend into muscle or bone. Vessel strike injuries can also be classified as superficial, shallow or deep cuts, or blunt injury (Pirotta et al. 2023).

There is a paucity of information about the effects of some of the threats assessed, even at the individual level. Similar to the *Unknown Population Level of Impacts*, threats categorized as *Unknown* at the individual level could be having effects on individuals.

Likelihood of Occurrence

The DFO guidance (DFO 2014b) defines *Likelihood of Occurrence* as "the probability of a specific threat occurring for a given population over 10 years or 3 generations, whichever is shorter." As previously established, we evaluated threats to NARWs using an assumed generation time of 33.3 years representing 100 years for 3 generations (see Generation Time above).

Following Moors-Murphy et al. (2024) we defined the *Likelihood of Occurrence* of a given threat as:

- *Known* – "there is a 91-100% chance that the threat has, is or will be occurring";
- *Likely* – "there is 51-90% chance that this threat is or will be occurring";
- *Unlikely* – "there is 11-50% chance that this threat is or will be occurring";
- *Remote* – "there is 1-10% or less chance that this threat is or will be occurring";
- *Unknown* – "there are no data or prior knowledge of this threat occurring now or in the future".

For some of the threats, the probability of threat occurrence can be quantitatively estimated. Following the methodology of Vanderlaan et al. (2009), the probability of a vessel strike or a fishing-gear entanglement can be estimated using a Poisson probability distribution model. This model depends on four assumptions:

1. the threat can occur at any time or place within a given area of interest assuming the whales are present;
2. an entanglement or vessel strike is a rare event, i.e., the probability of a vessel strike or fishing-gear entanglement is small;
3. vessel strike or fishing-gear entanglements are independent events; and
4. the average number of events (vessel strike or fishing-gear entanglement) are constant over time or at least for defined periods.

As in Vanderlaan et al. (2009), we assume that the population is stable over the defined periods examined, however this may not be valid for all time periods considered (Pace et al. 2017).

We estimated the Poisson parameter (μ) that represents the average number of vessel strikes or fishing-gear entanglements (n) per year over a given period (T) as:

$$\hat{\mu} = \frac{n}{T}. \qquad (1)$$

The probability (P) that X vessel strikes or fishing-gear entanglements will occur in a given year is calculated as:

$$P(X = k|\hat{\mu}) = \frac{exp^{\hat{\mu}} \cdot \hat{\mu}^k}{k!}, \qquad (2)$$

where k = 0, 1, 2,… and $\hat{\mu} > 0$.

We applied Webster's method (Legendre and Legendre 1998) to identify discontinuities in the time series of observed vessel strikes and vessel-strike mortalities. This involved using either a 3 + 3 or a 4 + 4 smoothing window-width, along with $\alpha = 0.1$ for determining significant discontinuity. Vessel strike data for NARWs were compiled to estimate the probability of a vessel striking a NARW and the probability of vessel-strike mortality for NARWs. These data were compiled from Best et al. 2001, Laist et al. 2001, Jensen and Silber 2003, Moore et al. 2004, Cole et al. 2005, 2006, Nelson et al. 2007, Glass et al. 2008, 2009, 2010, 2011,2012, Henry et al. 2013, 2014, 2015, 2016, 2017, 2019, 2020, 2021, 2023, Henry 2022, Sharp et al. 2019, Pettis et al. 2021, 2022. There are published records of vessels strikes to NARWs dating back to the early 1970s and we used the full timeseries to detect discontinuities, but have focused on, and presented the data for 1990 onwards.

All statistical uncertainties are presented as ± 1 standard deviation.

Timing of Occurrence

The DFO guidelines (2014b) define three categories describing the *Timing of Occurrence*:

- *Historical* – “a threat that is known to have occurred in the past and negatively impacted the population”;
- *Current* – “a threat that is ongoing and is currently negatively impacting the population”;
- *Anticipatory* – “a threat that is anticipated to occur in the future and will negatively impact the population”.

One or more of these categories may apply to a given threat, and we retained the original definitions for the *Timing of Occurrence*. As such, the definition of “Current” relates to the time at which the threat assessment and associated analyses were completed. The duration of the threat’s impact was not considered when defining *Timing of Occurrence*, although impacts to individuals may range from instantaneous to prolonged periods, spanning days, months, or years.

Threat Frequency

The DFO guidelines (DFO 2014b) define *Threat Frequency* as “the temporal extent of the threat over the next 10 years or three generations, whichever is shorter”. As above, we evaluated each threat using an assumed generation time of 33.3 years representing 100 years for 3 generations (see Generation Time above).

The DFO guidelines (DFO 2014b) define three categories of *Threat Frequency*:

- *Single* – “the threat occurs once”;
- *Recurrent* – “the threat occurs periodically or repeatedly”;
- *Continuous* – “the threat occurs without interruption”.

In the case of *Recurrent* threats, we considered seasonal activities or events and/or intermittent activities or events.

Geographic Extent of the Threat

The DFO guidelines (DFO 2014b) define the extent of a threat as “the proportion of the population affected by a given threat”. With the exceptions of vessel traffic or incidental catch and fishing-gear interactions, many threats will not leave evidence that can be readily documented or assessed. Additionally, this assessment does not specifically examine the spatiotemporal distribution of each threat in relation to the spatiotemporal distribution of NARWs. As a result, it is difficult to estimate the proportion of the population affected by a given threat. Transboundary distribution models currently being developed for NARWs, and tools such as NOAA's Decision Support Tool (Miller et al. 2024) could be expanded into Canadian waters to allow for such calculations; however, these were not available at the time of this analysis. A density surface model for NARWs is available for the USA (Roberts et al. 2024) that would allow for the estimation of the proportion of the population affected by a given threat in a portion of the Northwest Atlantic Assessment Area. However, there are still large areas where data are unavailable and many threats would be assessed as "*Unknown*" using the DFO guidelines (DFO 2014b). Other threat assessments have interpreted the *Geographic Extent of the Threat* as the overlap of species distribution with the extent of the threat (DFO 2020) or the proportion of the study site affected by the threat (DFO 2019). We followed, though slightly modified, the definitions used by Moors-Murphy et al. (2024) for northern bottlenose whales to provide a qualitative estimate of the proportion of the NARW habitat that a given threat likely occurs in.

The *Geographic Extent of the Threat* was assessed using the following definitions:

- *Extensive* –the threat occurs in a very high proportion (71-100%) of the population's habitat;
- *Broad* – the threat occurs in a high proportion (31-70%) of the population's habitat;
- *Narrow* – the threat occurs in a moderate proportion (11-30%) of the population's habitat;
- *Restricted* – the threat occurs in a low proportion (<10%) of the population's habitat;
- *Unknown* – the threat occurs in an unknown proportion of the population's habitat.

Causal Certainty

To support the assessment of the different threats to NARWs, DFO's guidance (DFO 2014b) proposed using a ranking system for *Causal Certainty* that reflects "the strength of evidence linking the threat to the survival and recovery of the population. Evidence can be scientific, traditional ecological knowledge, or local knowledge." Similarly to Moors-Murphy et al. (2024), we have modified the definitions of *Causal Certainty* to reflect the data and data quality available that includes the *Likelihood of Occurrence* as well as Level of Impact. We defined *Causal Certainty* and its associated rank (in parentheses) as follows:

- *Very high* (5) – very strong scientific evidence in the form of substantial data to support the assessment of the threat. There have been observed, modelled, or empirically measured effects of the threat to NARWs that are published and available from peer-reviewed sources.
- *High* (4) – some evidence in the form of adequate data to support the assessment of the threat. There have been observed, modelled, or empirically measured effects of the threat to other large baleen whale species that are published and available from peer-reviewed sources.
- *Medium* (3) – there is limited data available to support the assessment of the threat and there is higher uncertainty associated with the assessment which may be based on other cetaceans or may come from non-peer-reviewed resources.
- *Low* (2) – the assessment is based on expert judgement, general scientific knowledge, traditional ecological knowledge or local knowledge, and has been extrapolated to apply to NARWs.

- *Unknown* (1) – insufficient data or information to inform the assessment, impacts of the threat are possible, but very few data exist, or little is known about the impacts of the threat to NARWs or other cetacean species with no basis to inform expert opinions.

Threat Risk

The DFO guidelines (DFO 2014b) define the *Threat Risk* as "the product of level of impact and likelihood of occurrence as determined using a risk matrix approach" and represent it in a graphic matrix form (Figure 4). *Threat Risk* can take on values of *Unknown*, *Low*, *Medium*, or *High*. Using the *Population Level of Impact* and the *Likelihood of Occurrence* for each threat, we applied this methodology to define the *Threat Risk*.

		Level of Impact				
		Low	*Medium*	*High*	*Extreme*	*Unknown*
Likelihood of Occurance	*Known*	*Low*	*Medium*	*High*	*High*	*Unknown*
	Likely	*Low*	*Medium*	*High*	*High*	*Unknown*
	Unlikely	*Low*	*Medium*	*Medium*	*Medium*	*Unknown*
	Remote	*Low*	*Low*	*Low*	*Low*	*Unknown*
	Unknown	*Unknown*	*Unknown*	*Unknown*	*Unknown*	*Unknown*

Figure 4. The Threat Risk matrix defined from DFO (2014b).

RESULTS

We assessed 23 threats (Table 2) in the following seven threat categories: incidental catch and fishing-gear interactions, vessel traffic, pollution, ocean physics alteration, resource depletion, direct harvesting, and scientific activities. The pollution threat category included three subcategories: noise pollution, energy development and production, and chemical contaminants. Many of these threats could be characterized under several different threat categories.

Table 2. Summary of threat assessment for North Atlantic right whales (NARWs) in the Northwest Atlantic Assessment Areas and the Canadian Assessment Area. Definitions for each of the threat evaluation criteria (from DFO 2014b) and the methods applied to assign categories to each of these criteria are provided in the sections above. A level of impact assessment of "Unknown" does not mean effects on individuals or the population of NARWs are inconsequential.

Threat Category	**Threat**	**Assessment Area(s)**	***Likelihood of Occurrence***	***Individual Level of Impact (Causal Certainty)***	***Population Level of Impact (Causal Certainty)***	***Threat Risk*****	***Timing of Occurrence***	***Threat Frequency***	***Geographic Extent of Threat***
Incidental Catch and Fishing-Gear Interactions	Fishing-Gear Entanglement - Fixed Gear	Canadian, Northwest Atlantic	*Known*	*Extreme (Very High)*	*Extreme (Very High)*	*High*	*Historical, Current, Anticipatory*	*Continuous*	*Extensive*
Incidental Catch and Fishing-Gear Interactions	Fishing-Gear Entanglement - Pot/Trap Fisheries	Canadian, Northwest Atlantic	*Known*	*Extreme (Very High)*	*Extreme (Very High)*	*High*	*Historical, Current, Anticipatory*	*Continuous*	*Extensive*
Incidental Catch and Fishing-Gear Interactions	Fishing-Gear Entanglement - Gillnet	Northwest Atlantic	*Known*	*Extreme (Very High)*	*Extreme (Very High)*	*High*	*Historical, Current, Anticipatory*	*Continuous*	*Broad*
Incidental Catch and Fishing-Gear Interactions	Fishing-Gear Entanglement - Gillnet	Canadian	*Known*	*Extreme (Very High)*	*Extreme (Very High)*	*High*	*Historical, Current, Anticipatory*	*Continuous*	*Extensive*
Incidental Catch and Fishing-Gear Interactions	Fishing-Gear Entanglement - Hook and Line/Longline	Canadian	*Known*	*Extreme (Very High)*	*Extreme (Very High)*	*High*	*Historical, Current, Anticipatory*	*Continuous*	*Extensive*

Threat Category	**Threat**	**Assessment Area(s)**	***Likelihood of Occurrence***	***Individual Level of Impact (Causal Certainty)***	***Population Level of Impact (Causal Certainty)***	***Threat Risk*****	***Timing of Occurrence***	***Threat Frequency***	***Geographic Extent of Threat***
Incidental Catch and Fishing-Gear Interactions	Entrapment – Weirs	Canadian, Northwest Atlantic,	*Known*	*Low (Very High)*	*Unknown (Very High)*	*Unknown*	*Historical, Current, Anticipatory*	*Recurrent*	*Restricted*
Incidental Catch and Fishing-Gear Interactions	Fishing-Gear entanglement (Aquaculture)	Canadian	*Known*	*Extreme (Medium)*	*Unknown (Unknown)*	*Unknown*	*Historical, Current, Anticipatory*	*Continuous*	*Restricted*
Incidental Catch and Fishing-Gear Interactions	Fishing-Gear Entanglement in Abandoned, Lost, or Otherwise Discarded Fishing Gear	Canadian, Northwest Atlantic	*Known*	*Extreme (Very High)*	*Extreme (Very High)*	*High*	*Historical, Current, Anticipatory*	*Continuous*	*Broad*
Vessel Traffic	Vessel Strike	Canadian, Northwest Atlantic	*Known*	*Extreme (Very High)*	*High (Very High)*	*High*	*Historical, Current, Anticipatory*	*Continuous*	*Extensive*
Vessel Traffic	Vessel Presence and Vessel Noise Pollution	Canadian, Northwest Atlantic	*Known*	*Low (High)*	*Unknown (Unknown)*	*Unknown*	*Historical, Current, Anticipatory*	*Continuous*	*Extensive*

Threat Category	***Threat***	***Assessment Area(s)***	***Likelihood of Occurrence***	***Individual Level of Impact (Causal Certainty)***	***Population Level of Impact (Causal Certainty)***	***Threat Risk*****	***Timing of Occurrence***	***Threat Frequency***	***Geographic Extent of Threat***
Pollution Subcategory: Noise Pollution	Seismic Surveys (Airguns)	Canadian, Northwest Atlantic	*Known*	*Medium (Medium)*	*Unknown (Unknown)*	*Unknown*	*Historical, Current, Anticipatory*	*Recurrent*	*Extensive*
Pollution Subcategory: Noise Pollution	Active Acoustic Technology Operation	Canadian, Northwest Atlantic	*Known*	*Low (Medium)*	*Unknown (Unknown)*	*Unknown*	*Historical, Current, Anticipatory*	*Recurrent*	*Broad*
Pollution Subcategory: Noise Pollution	Mid-frequency Military Active Sonar Operation	Canadian, Northwest Atlantic	*Known*	*High (Medium)*	*Unknown (Unknown)*	*Unknown*	*Historical, Current, Anticipatory*	*Recurrent*	*Narrow*
Pollution Subcategory: Chemical Contaminants	Persistent Organic Pollutants Pollution	Canadian, Northwest Atlantic	*Known*	*Unknown (Unknown)*	*Unknown (Unknown)*	*Unknown*	*Historical, Current, Anticipatory*	*Continuous*	*Broad*
Pollution Subcategory: Chemical Contaminants	Plastics and Marine Debris Pollution	Canadian, Northwest Atlantic	*Known*	*High (High)*	*Low (High)*	*Low*	*Historical, Current, Anticipatory*	*Continuous*	*Broad*
Pollution	Petroleum Spills	Canadian, Northwest Atlantic	*Known*	*Extreme (Medium)*	*High (Medium)*	*High*	*Historical, Current, Anticipatory*	*Recurrent*	*Restricted*

Threat Category	**Threat**	**Assessment Area(s)**	***Likelihood of Occurrence***	***Individual Level of Impact*** ***(Causal Certainty)***	***Population Level of Impact*** ***(Causal Certainty)***	***Threat Risk****	***Timing of Occurrence***	***Threat Frequency***	***Geographic Extent of Threat***
Subcategory: Chemical Contaminants									
Pollution Subcategory: Chemical Contaminants	Heavy Metals Pollution	Canadian, Northwest Atlantic	*Known*	*Unknown (Unknown)*	*Unknown (Unknown)*	*Unknown*	*Historical, Current, Anticipatory*	*Continuous*	*Broad*
Subcategory: Energy Development and Production	Coastal and Marine Offshore Development	Canadian, Northwest Atlantic	*Known*	*High (Medium)*	*Unknown (Unknown)*	*Unknown*	*Historical, Current, Anticipatory*	*Recurrent*	*Narrow*
Subcategory: Energy Development and Production	Drilling Operations	Canadian, Northwest Atlantic	*Known*	*Low (Unknown)*	*Unknown (Unknown)*	*Unknown*	*Historical, Current, Anticipatory*	*Recurrent*	*Restricted*
Subcategory: Energy Development and Production	Wind Energy Production	Canadian	*Known*	*Unknown[+] (Unknown)*	*Unknown (Unknown)*	*Unknown*	*Anticipatory*	*Continuous*	*Narrow*
Subcategory: Energy Development and Production	Wind Energy Production	Northwest Atlantic	*Known*	*Unknown[+] (Unknown)*	*Unknown (Unknown)*	*Unknown*	*Current, Anticipatory*	*Continuous*	*Narrow*

Threat Category	***Threat***	***Assessment Area(s)***	***Likelihood of Occurrence***	***Individual Level of Impact (Causal Certainty)***	***Population Level of Impact (Causal Certainty)***	***Threat Risk****	***Timing of Occurrence***	***Threat Frequency***	***Geographic Extent of Threat***
Ocean-Physics Alteration	Climate Change	Canadian, Northwest Atlantic,	*Known*	*Unknown (Unknown)*	*High (Very High)*	*High*	*Historical, Current, Anticipatory*	*Continuous*	*Extensive*
Scientific Activities	Scientific Activities	Canadian, Northwest Atlantic	*Known*	*Low (High)*	*Low (High)*	*Low*	*Historical, Current, Anticipatory*	*Recurrent*	*Broad*
Direct Harvesting	Whaling (Harvest or Hunt)	Canadian, Northwest Atlantic	*Remote*	*Extreme (Very High)*	*Low[*] (Very High)*	*Low*	*Historical, Anticipatory*	*Not applicable*	*Narrow*
Resource Depletion	Food Supply Reduction (Directed Fishing – Copepods)	Canadian, Northwest Atlantic	*Remote*	*Unknown (Unknown)*	*Unknown (Unknown)*	*Unknown*	*Anticipatory*	*Not applicable*	*Unknown*

[*] This remains true only if the precautionary approach is applied if/when future hunting occurs

[+] For the noise pollution aspect specifically of the threat of wind energy production the *Individual Level of Impact* is expected to be *Low*.

** The *Threat Risk* is a product of *Population Level of Impact* and *Likelihood of Occurrence*.

THREAT CATEGORY 1: INCIDENTAL CATCH AND FISHING-GEAR INTERACTIONS

Threat 1.1.1: Fishing-Gear Entanglement – Fixed Gear

Any cetacean can become entangled or entrapped in fishing gear. Entanglements in fishing gear cause the majority of mortalities in large whales (Reeves et al. 2003, van der Hoop et al. 2013). Here, we examine the threat of fixed fishing gear activities including pot/trap fisheries, gillnet fisheries, hook and line/longline fisheries, weirs, and aquaculture fisheries, as well as abandoned, lost, or otherwise discarded fishing gear.

Not all fishing-gear entanglements occur in the location where animals are first observed. Some entanglements are only detected through photographic documentation of individual NARW injuries after the whale has self-disentangled (Knowlton et al. 2012). It can also be difficult to determine gear type, and whether or not the gear was actively being fished, as often the only gear remaining on an entangled whale is line or rope (Johnson et al. 2005). For these reasons, entanglement and mortality rates used in this assessment were not broken down geographically or by gear type. Therefore, we only assessed the *Likelihood of Occurrence* and the Level of Impacts for the Northwest Atlantic Assessment Area and assumed it is consistent across assessment areas.

Likelihood of Occurrence: Known

Fishing-gear entanglements are a documented source of injury and mortality for NARWs (Knowlton et al. 2012, van der Hoop et al. 2013, Moore et al. 2004, Sharp et al. 2019). Using photographs of individual NARWs, Knowlton et al. (2012) estimated that 26% (± 10%) of the adequately photographed whales (photographed both in the entanglement year and the year prior) are entangled annually, representing a minimum estimate of new annual entanglements in the population. These estimates ranged from 19 to 39% for the years of 2010 through 2018 with an average of 30% (± 5.4; data from Hamilton et al. 2020 as cited in Hayes et al. 2023). Based on the 2023 population estimate and these two estimates of entanglement rates, between 97 (± 3.8) and 112 whales (± 2.0) are entangled annually. This is a minimum estimate, as the annual entanglement rate is based solely on photographed individuals and there is variability in the proportion of the population that is photographed each year (Pace et al. 2017). Using the Poisson model (Equation 2) with 97 and 112 whales as an estimate for the average number of entanglements per year (Figure 5), there is 100% chance that at least one entanglement will occur annually over the next 100 years (three generations, Figure 5). Thus, the *Likelihood of Occurrence* was evaluated as *Known* for fishing activities with fixed-fishing gear.

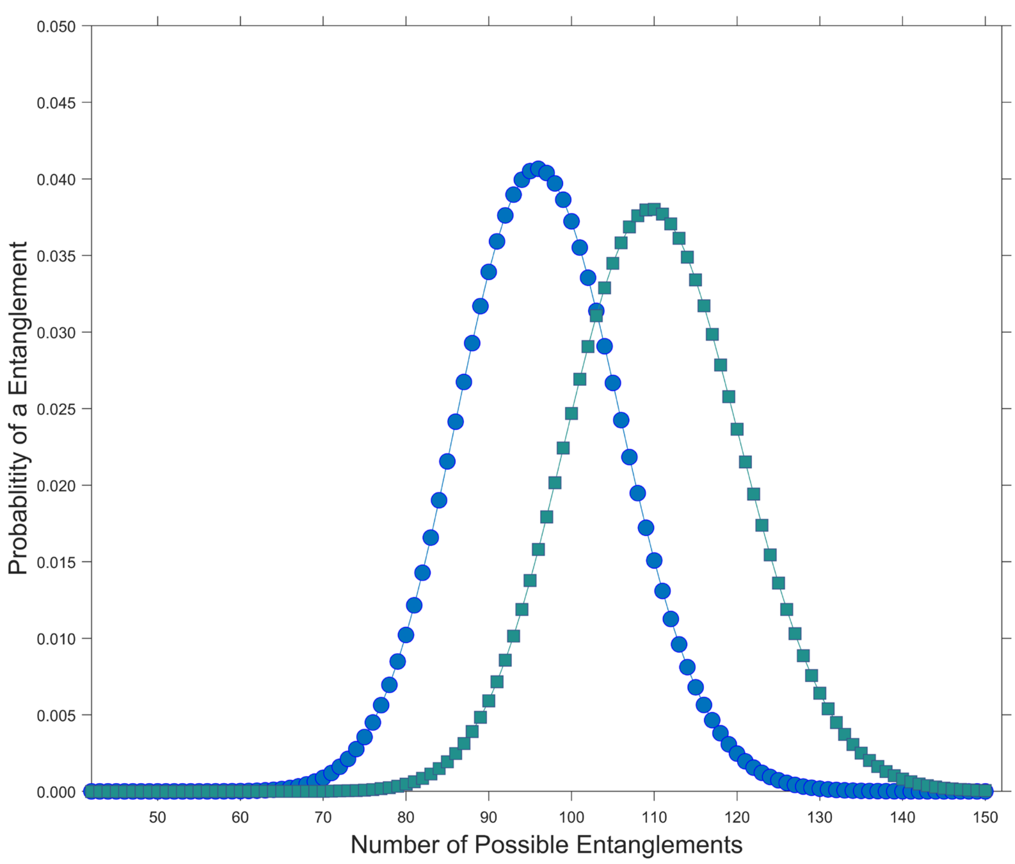

Figure 5. The probability density function of annual entanglement probabilities based on a minimum 26% (blue circles and line) and an average 30% (teal squares and line) of the North Atlantic right whales being entangled annually (Knowlton et al. 2012 and Hamilton et al. 2020 as cited in Hayes et al. 2023).

Individual Level of Impact: Extreme

Fishing-gear entanglements have various impacts on NARWs, including with morbidities, minor, moderate, serious injuries, severe injuries that could lead to mortalities, as well as mortalities (Moore et al. 2004, Sharp et al. 2019, Knowlton et al. 2012; Knowlton et al. 2022, NOAA 2025). Between the start of the unusual mortality event declared for NARWs in 2017 and the end of 2024 there have been 10 mortalities, 35 serious injuries, and 54 morbidity cases attributed to fishing-gear entanglements (NOAA 2025). NARW health and reproduction, as well as calf survival, have also been affected by fishing-gear entanglements (Robbins et al. 2015, van der Hoop et al. 2016, Knowlton et al. 2022, Stewart et al. 2022, Pirotta et al. 2023). Females that have survived severe fishing-gear injuries had the lowest birth rates and increased calving intervals compared to females with minor or moderate injuries (Knowlton et al. 2022). NARWs are capable of dragging entangling gear, on average for 6 months, resulting in increased drag, increased stress, severe tissue damage, infections, and emaciation (Clapham et al. 1999, Cassoff et al. 2011, Moore and van der Hoop 2012, van der Hoop et al. 2016, 2017a,b, Rolland et al. 2017). Fishing-gear entanglements can also have less severe effects on NARWs. Many whales appear to self-release (Johnson et al. 2007) and the only evidence are the marks or scars left on the body (Figure 6). These marks and scars can range from minor to moderate to severe with known effects from the moderate and severe injuries. Due to the number and documented severity of the effects of fishing-gear entanglement, the *Individual Level of Impact* was assessed as *Extreme* with a *Causal Certainty* of *Very High*.

Figure 6. Photographs of North Atlantic right whale EgNo 4180 (Dyad) that was seen in the southern Gulf of St. Lawrence nine times during June, July, and August of 2018. A photograph of one of her early sightings (A) and then a subsequent photograph with evidence of interaction with fishing gear and clear rope wrap marks across her body and at her tail stock (B). Photo Credits: DFO/NOAA Joint Aerial Survey Team.

Population Level of Impact (Population Loss): Extreme

The annual number of mortalities and serious injuries (where serious injuries are assumed to ultimately lead to the death of the whale) due to fishing-gear entanglements averaged 2.5 per year for NARWs during the period of 1999 to 2009 (Pace et al. 2014). This estimate increased to 5.7 whales, on average, per year for the period of 2016 through 2020 (Hayes et al. 2023). Projecting these estimates over the next 100 years (three generations), and assuming conservation initiatives and population size remains constant, would result in a loss of 250-570 individuals, which is unsustainable unless the population becomes substantially larger. The *Population Level of Impact* was assessed as *Extreme* with a *Causal Certainty* of *Very High*.

Threat Frequency: Continuous

Various fisheries operate in the Canadian Assessment Area throughout the year, and although there are different seasons depending on the fishery, there is fixed-fishing gear in the water during all months in the Maritimes region (Vanderlaan et al. 2009, Butler et al. 2019, Rozalska and Coffen-Smout 2020). There are several different management areas across the Canadian Assessment Area and during 2021, 2022, and 2023, there was at least one open fixed-gear fishery every month (DFO unpublished data). Thus, the *Threat Frequency* was assessed as *Continuous.*

Geographic Extent of Threat: Extensive

Fishing effort occurs across the entire Canadian Assessment Area, and Figure 7 shows the landings for all commercial species between 2012 through 2021. Figure 8 shows the landings for all species caught with fixed-fishing gear. While these figures do not indicate the amount of gear in the water column, they do provide information on the spatial distribution of fishing locations and can be used as a representation of fishing intensity. These data have many caveats associated with them including: the data may represent many fishing events from several vessels over the ten year period; the landings are only from Canadian vessels greater than 35-ft and do not include landings from international fishing vessels (i.e., St-Pierre et Miquelon); the data may contain errors in fishing locations, landed weights, as well, as species identification as it is derived and unaltered from logbook data; in some fisheries, only one location is given for each fishing event therefore, fishing activities such as trawls or longline sets that can cover a large area are only mapped to a single location here; the data from some fisheries may not include all records or species locations due to regional differences in permissions for mapping or reporting locations as logbook areas, i.e., only partially georeferenced.

Fixed-fishing gear (Figure 8) is a concern for the entanglement of NARWs as the gear is not tended. There is considerable fishing intensity in the southern Gulf of St. Lawrence where, on average, 133 (± 1.5 for the period of 2015-2019) NARWs aggregate to socialize and feed (Crowe et al. 2021). Similarly, there is considerable fishing intensity in between the Bay of Fundy and Roseway Basin Critical Habitats (Figure 8).

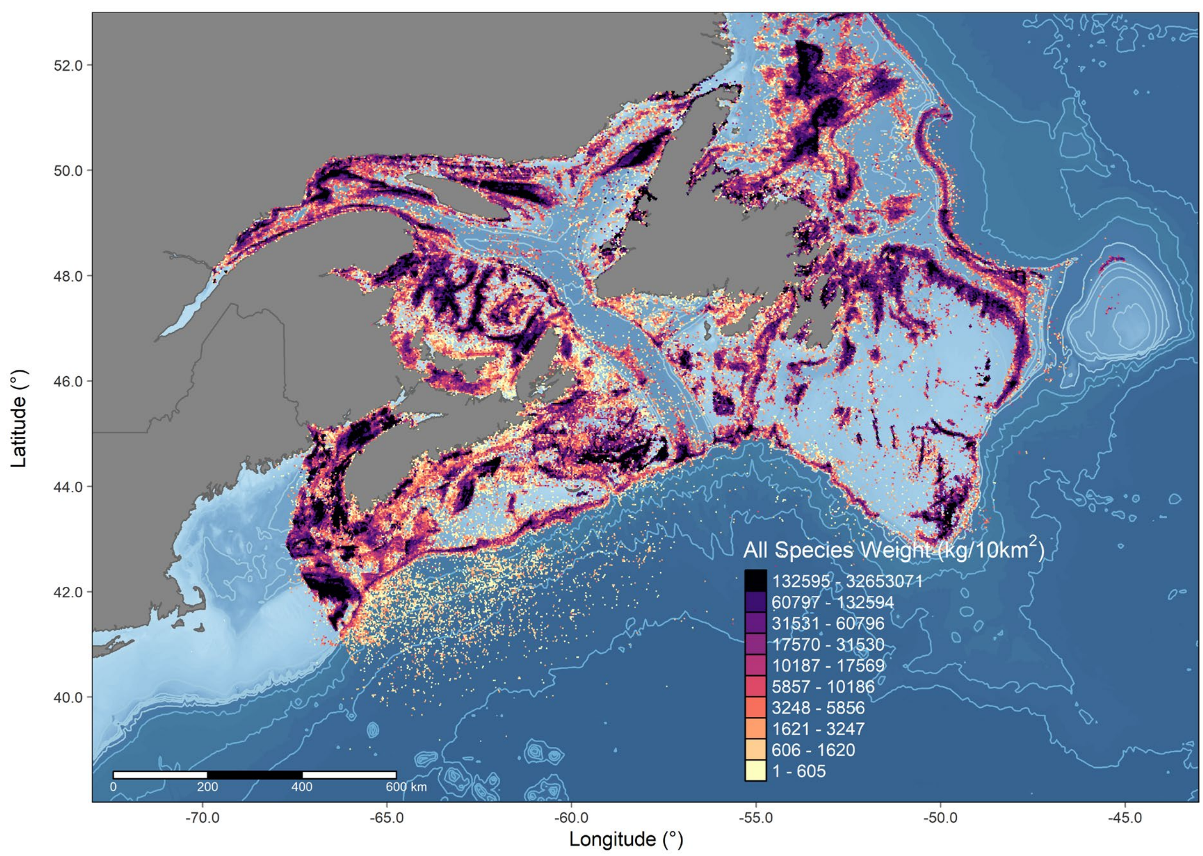

Figure 7. Eastern Canada commercial fishing landings from 2012 through 2021. Data extracted from Fisheries and Oceans Canada's (DFO) Newfoundland and Labrador, Maritimes, Gulf, Quebec and Eastern Arctic regions. The value of each grid cell is equal to the total species/gear type landings in kg from 2012 to 2021 in a 2 minute hexagonal grid (approx. 10 km² cell). The data included both fish and invertebrates caught with both fixed fishing gear and mobile gear. The data are available on Canada's Open Data Portal (https://open.canada.ca/en).

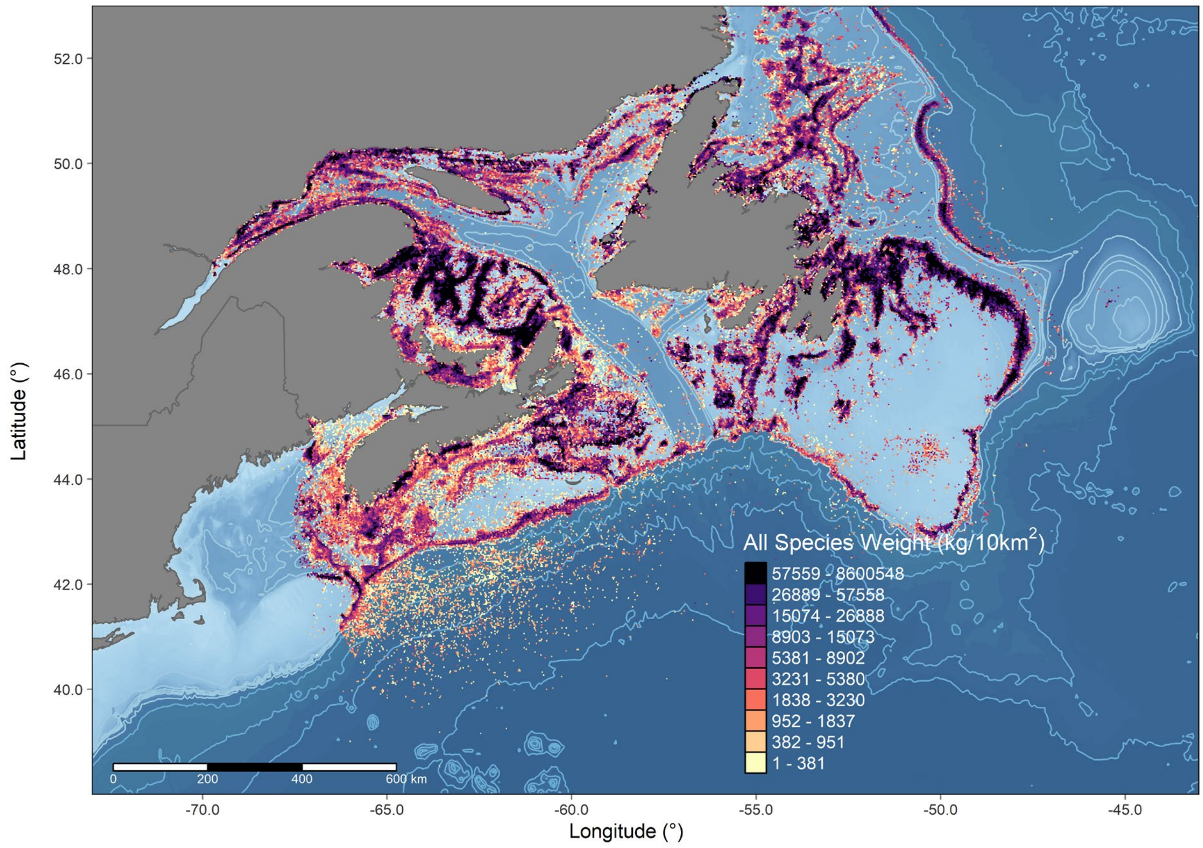

Figure 8. Eastern Canada commercial fixed gear fishing landings from 2012 through 2021. Data extracted from Fisheries and Oceans Canada's (DFO) Newfoundland and Labrador, Maritimes, Gulf, Quebec and Eastern Arctic regions are included. The value of each grid cell is equal to the total species landings in kg from 2012 to 2021 in a 2 minute hexagonal grid (approx. 10 km^2 cell). The data included both fish and invertebrates caught with fixed fishing gear. The data are available on Canada's Open Data Portal (https://open.canada.ca/en).

This type of data is not available for all commercial fisheries or all fixed-gear fisheries in the USA. However, there is some information in the NOAA's Decision Support Tool (Miller et al. 2024) that is designed to examine entanglement risk to NARWs. The Decision Support Tool (Miller et al. 2024) focuses on gillnets and trap/pot fisheries, and their spatiotemporal distribution at a monthly scale. Gillnet fisheries occur across all months as does the pot/trap fisheries. However, the density of fishing gear is not as extensive in the USA, and the majority occurs in the Gulf of Maine for the pot/trap fisheries and in the upper mid-Atlantic waters for the gillnet fisheries. Based on these two input layers for the decision support tool, we assessed the *Geographic Extent of Threat* as *Broad* and the *Threat Frequency* as *Continuous* in the Northwest Atlantic Assessment Area.

Gear Types and Fishing-Gear Entanglements

We were asked to complete the threat assessment for various types of fixed-fishing gear including pot/trap fisheries, gillnet fisheries, hook and line/longline fisheries, weirs, aquaculture fisheries, and abandoned, lost, or otherwise discarded fishing gear. Most of our analyses were based on published literature where quantitative estimates on entanglement rates and associated mortality rates were available. To further examine and evaluate the threat of the different fixed-gear fisheries, we compiled records of NARW fishing-gear entanglements (1988-2023, n = 213) from various sources (Cole et al. 2005, 2006, Moore et al. 2004, Pettis and Hamilton 2006, 2007, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, Nelson et al. 2007, Glass et al. 2008, 2009, 2010, 2011 2012, Pettis 2009, Henry et al. 2013, 2014, 2015, 2016, 2017, 2019, 2020, 2021, 2022, 2023, Pettis et al. 2018a, 2018b, 2020, 2021, 2022, 2023; Morin et al. 2019, 2020, 2021, Sharp et al. 2019, DFO 2021, Henry 2022, Moise et al. 2022, 2023a, 2023b, DFO 2023a,b,c). In the majority of published records on entanglements examined above, 55% the fishing gear was not identifiable and there was no gear present in another 29% of the records. These records are an underrepresentation of the known NARW entanglements as there are an additional 1598 records of entanglements between 1935 and 2021 in the North Atlantic Right Whale Consortium Anthropogenic Database (NARWC 2024a). We do not present the numbers on the types of gear involved in entanglements as these numbers have not been corrected for fishing effort and most gear involved in entanglements is of unknown origin. The general types of gear include pot/trap gear, gillnets, seines, and weirs (entrapment), in addition to abandoned, lost, or otherwise discarded fishing gear. There have been efforts in both Canada and the USA to increase in the information on the type of gear involved entanglements. The DFO has implemented gear marking of all non-tended fixed gear fisheries in Atlantic Canada, where the gear marking must identify region, fishery, and, for lobster and crab fisheries only, the specific fishing area (DFO 2024). The USA has also implemented gear marking to improve information on where and how NARWs become entangled (NOAA 2024).

With the exception of weirs (see below), we provided the same evaluation for *Likelihood of Occurrence*, and all *Levels of Impact* for fixed fishing gear. Longline gear has not been identified as being involved in a NARW entanglement; however, all other gear types have been identified in at least one NARW entanglement. With limited information on the type of gear involved in entanglements, it is difficult to assess each gear type independently.

There is very limited spatiotemporal information available on fisheries in the USA with the exception of lobster trap gear and gillnets that have been presented in the Decision Support Tool (Miller et al. 2024). Even the data presented in the Decision Support Tool (Miller et al. 2024) required extensive modelling efforts to represent the spatiotemporal distribution of these fisheries. There is some information on Black Sea Bass (*Centropristis striata)* pot gear off the southeast USA (Farmer et al. 2016), but range-wide distributions by gear type are generally not available. For this reason, we did not evaluate the *Threat Frequency* or *Geographic Extent of Threat* for individual fisheries for the Northwest Atlantic Assessment Area.

Threat 1.1.2: Fishing-Gear Entanglement – Pot/Trap Fisheries

Pot/trap fisheries in the Canadian Assessment Area target several species including snow crab *(Chionoecetes opilio),* Jonah crab *(Cancer borealis),* Atlantic rock crab *(Cancer irroratus),* red crab *(Chaceon quinquedens),* toad crab *(Hyas araneus*)*,* spider crab *(Maja squinado*)*,* American lobster *(Homarus americanus*)*,* common whelk (*Buccinum undatum*), and Atlantic hagfish (*Myxine glutinosa*). Although these fisheries each have different fishing seasons in different areas, over the years 2021-2023 there has been at least one open pot/trap fishery operating within the Canadian Assessment Area across all months of the year (DFO unpublished data). For this reason, we evaluated the *Threat Frequency* of pot/trap fisheries as *Continuous*.

Threat 1.1.3: Fishing-Gear Entanglement – Gillnet Fisheries

Gillnet fisheries exist in all parts of the Canadian Assessment Area. From 2021-2023, some management areas in the gillnet fisheries on the Scotian Shelf and the waters off Newfoundland and Labrador were open year-round. In the Gulf of St. Lawrence, gillnet fisheries are closed from January through March. Although there is regional variation regarding when gillnet fisheries are active, some part of this fishery is open year-round within the Canadian Assessment Area. Thus, we evaluated the *Threat Frequency* of gillnet fisheries as *Continuous*.

Threat 1.1.4: Fishing-Gear Entanglement – Longline (or Hook and Line) Fisheries

Longline (or hook and line) gear has not been identified in the NARW entanglement reports. However, entanglements in longline ropes and the hooking of humpback whales (*Megaptera novaeangliae*) and gray whales (*Eschrichtius robustu*s*)* have been reported (Forney 2004, Lowry et al. 2018). Johnson et al. (2007) stated that the configuration and deployment of longline gear provides the potential for entanglement. Thus, we assigned the same *Level of Impact* for longline (or hook and line) fisheries as the fixed-gear fishing threats.

Longline fisheries exist in all parts of the Canadian Assessment Area. From 2021-2023, management areas for the longline fisheries on the Scotian Shelf were open year-round. In the Gulf of St. Lawrence and the waters off of Newfoundland and Labrador, longline fisheries are closed from November through March. Although there is regional variation regarding when longline fisheries are active, on the Canadian portion of the Scotian Shelf the fishery is open year-round. Thus, we evaluated the *Threat Frequency* of longline fisheries as *Continuous*.

Threat 1.1.5: Entrapment in Fishing Weirs

Fishing with weirs occurs in the Canadian Assessment Area and extend to the Northwest Assessment Area. There have been recorded cases of NARWs trapped in weirs within the Canadian Assessment Area. As trapped whales can generally be released from fishing weirs, we assessed entrapments in weirs as *Low* for *Individual* and *Population Levels of Impact*. As weir fishing occurs in very small coastal areas, we evaluated the *Geographic Extent of Threat* for weirs to be *Restricted*.

Threat 1.1.6: Fishing-Gear Entanglement – Aquaculture

Large baleen whale species, including North Pacific right whales *(Eubalaena japonica),* southern right whales, humpback whales, minke whales (*Balaenoptera acutorostrata*) and Bryde’s Whales *(Balaenoptera edeni),* have been entangled in aquaculture gear (Bath et al. 2023 and references therein). It is reasonable to expect that NARWs could also become entangled in various aquaculture gear, and that it would have similar impacts to individuals as other fishing-gear. The majority of aquaculture sites in the Canadian Assessment areas are restricted to coastal operations and occupy a very limited proportion of the Assessment Areas

(Pinchin 2023), therefore, we evaluated the *Geographic Extent of the Threat* Aquaculture to be *Restricted*.

Threat 1.1.7: Abandoned, Lost, or Otherwise Discarded Fishing Gear

Abandoned, lost, or otherwise discarded fishing gear can be an entanglement risk for cetaceans. In 2018, in the Gulf of St. Lawrence, a dead NARW (EgNo 4504) was discovered entangled in gear that contained an old trap with rope of varying age/condition attached (Daoust et al. 2018). At the time, it could not be determined whether the gear was actively fishing or derelict. Since 2018, there have been at least four cases of NARWs (EgNo 1226, 3812, 4545, and 4615) becoming entangled in fishing gear in the Gulf of St. Lawrence after the fishing season was over.

It became mandatory in 2020 for all commercial fisheries in Canada to report lost fishing gear to the DFO. Between 2020-2024 there were 19,841 reports of lost gear (a report could include multiple units of gear) in the Quebec, Gulf, Newfoundland and Labrador, and Maritimes DFO Regions corresponding to 75,792 gear units; less than half (49%) of those gear units were retrieved (DFO 2025). The majority of the reports in Canadian waters were from the lobster fisheries (71%) with another 27% reported from crab fisheries (snow crab, rock crab, dungeness crab *(Metacarcinus magister,* DFO 2025). Given that lost gear reports occur throughout the Canadian Assessment Area (Figure 9) and that fisheries operate throughout the year in all areas, we assess the ghost-gear fishing threat as *Broad* for the *Geographic Extent* and *Continuous* for *Threat Frequency*.

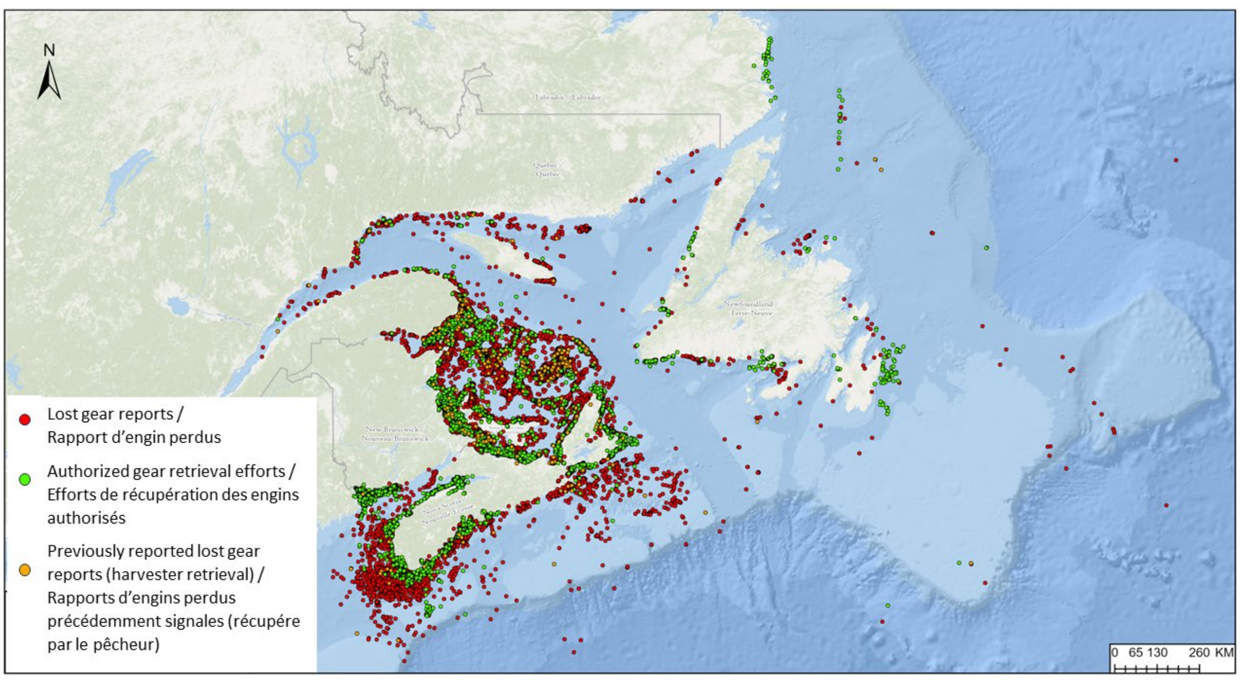

Figure 9. Locations of lost (red dots) and retrieved (green dots) fishing gear on the Atlantic coast from 2020-01-01 to 2024-10-31, where each dot may include multiple units of gear. This figure was prepared by the Atlantic Marine Mammal Hub of the Gulf Region, Fisheries and Oceans Canada (DFO) and is available at: https://www.dfo-mpo.gc.ca/fisheries-peches/management-gestion/ghostgear-equipementfantome/reporting-declaration-eng.html

THREAT CATEGORY 2: VESSEL TRAFFIC

Threat 2.1.1: Vessel Strikes

Vessel strikes are one of the leading causes of mortality for examined NARW deaths and was the presumed cause of death for 47% and 42% of necropsied NARWs between 1970 and 2003 (Moore et al. 2004), and 2003 and 2018 (Sharp et al. 2019), respectively. On a per capita basis, NARWs are observed to be struck by vessels more often than any other large whale species (Vanderlaan and Taggart 2007). Vessel strikes can cause blunt and sharp trauma. Sharp trauma is caused by underwater protuberances that come in contact with a whale, whereas blunt trauma results when the whale is struck by the hull of the vessel (Campbell-Malone et al. 2008). Vessel strikes can result in the death, serious injury, and sublethal effects such as shallow or superficial cuts (Moore et al. 2021).

Not all vessel strikes are observed in the location that they occur, and vessels have arrived in port with a dead whale on the bow unbeknownst to the vessel operators (Laist et al. 2001). Furthermore, some injuries are only detected through photographic documentation of individual NARWs. Blunt force trauma from a vessel strike may not result in the immediate death of the whale. For example, there have been cases where there was evidence of a bone fracture beginning to heal prior to the death of the whale (Campbell-Malone et al. 2008) indicating that the whale survived for some period after the trauma. This whale could have moved a considerable distance before succumbing to its injuries and, as a result, the location of the recovered carcass would not have been close to where the initial trauma occurred. By only assessing the threat statistics associated with vessel strikes by region, the true impacts on this transboundary species may not be accurately represented. Therefore, we assessed the *Likelihood of Occurrence* and the different *Levels of Impact* for the Northwest Atlantic Assessment Area and assumed it was consistent across assessment areas.

When estimating vessel strike risk (e.g., Vanderlaan & Taggart 2009, Nichol et al. 2017, Stepanuk et al. 2021, Rockwood et al. 2021, Redfern et al. 2024, Bloudin et al. 2025) and addressing vessel strike threat, there has been a focus on large vessels (Schoeman et al. 2020). However, even vessels <15 m can cause fatal injuries to cetaceans when traveling at high speed (Ritter 2012). All vessel size classes (unmotorized and motorized small (<15 m); unmotorized and motorized medium (15-30 m); motorized medium, large (30-80 m) and motorized very large (>80 m)) have been documented to be involved in vessel strikes with marine animals (Schoeman et al. 2020), and modelling efforts indicate that vessels of any size can generate forces that are capable of causing lethal injuries to NARWs (Kelley et al. 2021). When examining the *Geographical Extent of the Threat* and *Threat Frequency* for vessel strikes, we focused on published sources of Automatic Identification System (AIS) data as it is readily available; however, AIS data underrepresents smaller vessels (<300 gross tonnage) as it is not required under the International Maritime Organization's International Convention for the Safety of Life at Sea. Therefore, the information used to assess the *Geographical Extent of the Threat* and *Threat Frequency* is a minimum estimate of vessel traffic spatiotemporal distribution in both the Canadian Assessment Area and the Northwest Atlantic Assessment Area.

Likelihood of Occurrence: Known

Historical records of lethal vessel strikes of large whales first appear in the late 1800s, and NARWs commonly appear in the records (Laist et al. 2001). Since 1990, there have been a maximum of eight NARW vessel strikes observed in a single year (2011) with 1990 being the only year in which no vessel strikes were observed for this species (Figure 10). There was considerable interannual variability in the number of observed NARWs struck by vessels between 1990 and 2023. Using Webster's Methods for detecting discontinuities based on the entire times series (1972 through 2023), we estimated there were six periods since 1990 during which the number of vessel strikes were stationary (Table 3, Figure 10). The average annual number of vessel strikes within each of these periods ranged from 1.50 (± 0.71) to 5.50 (± 2.08). Using the annual observed vessel strike rate within each of the six periods, the probability of at least one vessel strike occurring for each time period (Table 3) was estimated. With the exception of the last period (2021-2023), the probability of observing at least one vessel strike per year is greater than 0.80. If we average these probabilities across the time periods, then the average probability of observing at least one vessel strike per year is 0.90. Although there is considerable interannual variation (Figure 10), we assess the *Likelihood of Occurrence* for vessel strikes in the Northwest Atlantic Assessment Area as *Known* with a probability of 0.90 that at least one vessel strike will occur annually over the next 100 years. Based on the probability density functions for each of the six time periods examined, it is likely that greater than one vessel strike will be observed annually in the Northwest Atlantic Assessment Area over the next 100 years (Figure 11).

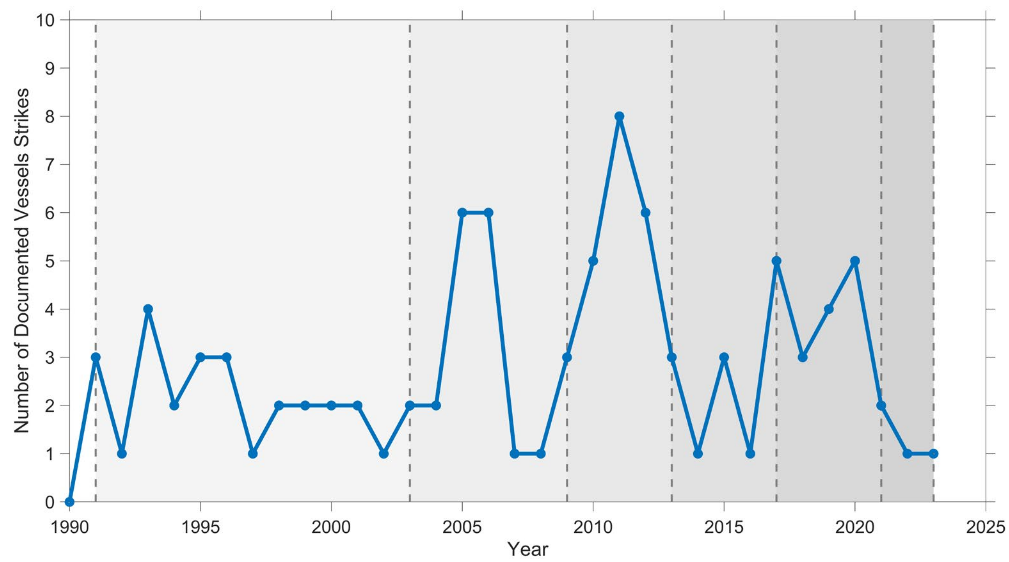

Figure 10. Number of vessel strikes of North Atlantic right whales (NARWs,1990-2023) documented throughout its range in the Northwest Atlantic Ocean (data were compiled from Best et al. 2001, Laist et al. 2001, Jensen and Silber 2003, Moore et al. 2004, Cole et al. 2005, 2006, Nelson et al. 2007, Glass et al. 2008, 2009, 2010, 2011, Henry et al. 2013, 2014, 2015, 2016, 2017, 2019, 2020, 2021, 2022, 2023, Sharp et al. 2019, Pettis et al. 2021, 2022). Vertical lines and grey shading indicate the six time periods during which the number of documented NARW vessel strikes were estimated to be stationary using Webster's Methods for detecting discontinuities with a 4 + 4 smoothing window-width and α = 0.1.

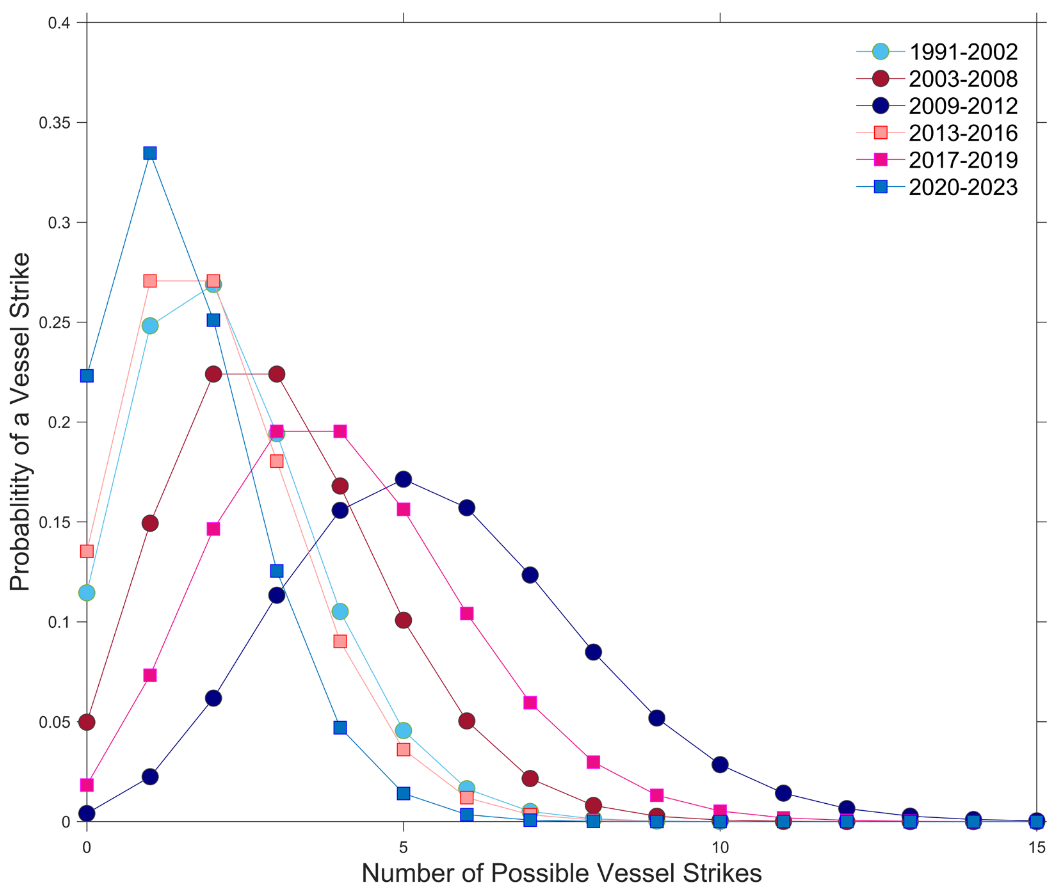

Figure 11. The probability density functions for annual vessel strike probabilities based on the six time periods between 1991 and 2023 during which the number of documented North Atlantic right whale vessel strikes were estimated to be stationary using Webster's Methods for detecting discontinuities with a 4 + 4 smoothing window-width and α = 0.1.

Table 3. The average annual vessel strike rate and associated standard deviation for the six time periods between 1991 and 2023 during which the number of documented North Atlantic right whale vessel strikes were estimated to be stationary using Webster's Methods for detecting discontinuities. The probability (P) of at least one vessel strike occurring within a year during the time period is also presented.

Time Period	Average Annual Vessel Strike Rate	Standard Deviation of Annual Vessel Strike Rate	P (at least one vessel strike)
1991-2002	2.17	0.94	0.885
2003-2008	3.00	2.37	0.950
2009-2012	5.50	2.08	0.996
2013-2016	2.00	1.15	0.865
2017-2019	4.00	1.00	0.981
2020-2023	1.50	0.71	0.777

Individual Level of Impact: Extreme

Between 1990 and 2023, there were 49 confirmed NARW mortalities and serious injuries attributed to vessel strikes (Best et al. 2001, Laist et al. 2001, Jensen and Silber 2003, Moore et al. 2004, Cole et al. 2005, 2006, Nelson et al. 2007, Glass et al. 2008, 2009, 2010, 2011, Henry et al. 2013, 2014, 2015, 2016, 2017, 2019, 2020, 2021, 2022, 2023, Sharp et al. 2019, Pettis et al. 2021, 2022, Pettis and Hamilton 2024). Depending on the injury type (i.e., superficial, shallow, deep, or blunt force trauma), there can be varying degrees of injuries and impacts from vessel strikes on health, survival, and reproduction of NARWs (Pirotta et al. 2023). For example, a NARW (EgNo 2143, "Lucky") survived and recovered from a vessel strike as a calf, only to die 14 years later during her first pregnancy as a result of the wound reopening due to increased abdominal pressure caused by the growing fetus; this resulted in an abscess formation and presumed sepsis which led to her death and the death of the full-term fetus (Sharp et al. 2019). Due to the many potential impacts of vessel strikes on individual NARWs, we assessed *Individual Level of Impact* of vessel strikes as *Extreme* with a *Causal Certainty* rating of *Very High*.

Population Level of Impact: High

Vessel strikes are one of the leading causes of death in the NARW population (Moore et al. 2004, Sharp et al. 2019). The number of observed vessel strike mortalities and serious injuries per year between 1990 and 2023 varied between one and five (Figure 10). Using Webster's Methods for detecting discontinuities, we estimated that there were five periods between 1990 and 2023 during which the number of vessel-strike mortalities and serious injuries were stationary (Figure 12 and Table 4). The average annual vessel strike mortality and serious injury rate within each of these periods ranged from 0.63 (± 1.07) to 3.33 (± 1.53, Table 4). To estimate the expected number of vessel strike mortalities over three generations, we took the average of the annual vessel strike mortality rates for the five periods and multiplied by 100 years. Over three generations, we would expect 172 vessel strike mortalities and serious injuries. Based on an estimated population size of 372 individuals in 2023 (Linden 2024), and assuming no substantial changes in the population over time, this number of mortalities and serious injuries corresponds to a ranking of *High* for the *Population Level of Impact* with a *Causal Certainty* rating of *Very High*.

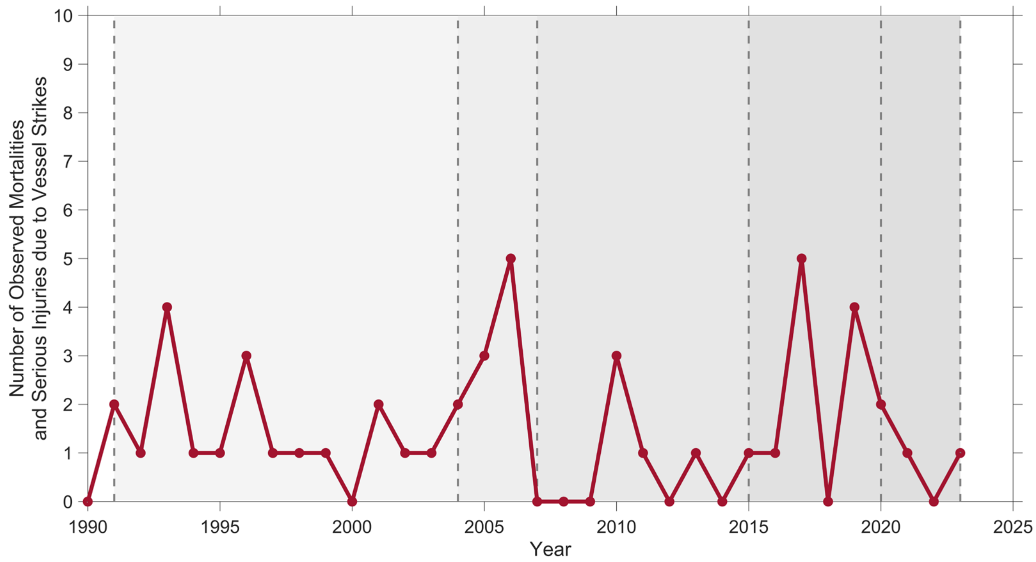

Figure 12. The number of observed vessel strikes mortalities and serious injuries of the North Atlantic right whale (NARW, 1990-2023) throughout its range in the Northwest Atlantic Ocean (data were compiled from Best et al. 2001, Laist et al. 2001, Jensen and Silber 2003, Moore et al. 2004, Cole et al. 2005, 2006, Nelson et al. 2007, Glass et al. 2008, 2009, 2010, 2011, Henry et al. 2013, 2014, 2015, 2016, 2017, 2019, 2020, 2021, 2022, 2023, Sharp et al. 2019, Pettis et al. 2021, 2022). Vertical lines and grey shading represent five time periods during which the number of observations of NARW vessel strike mortality and serious injury were estimated to be stationary using Webster's Methods for detecting discontinuities with a 3 + 3 smoothing window-width and α = 0.1.

Table 4: The average annual vessel strike mortality and serious injury rate and associated standard deviation for North Atlantic right whales (NARWs) for five time periods between 1990 and 2023. During each period the number of observations of NARW vessel strike mortalities and serious injuries were estimated to be stationary using Webster's Methods for detecting discontinuities with a 3 + 3 smoothing window-width and α = 0.1.

Time Period	Average Annual Vessel Strike Mortality and Serious Injury Rate	Standard Deviation of Annual Vessel Strike Mortality and Serious Injury Rate
1991-2003	1.46	1.05
2004-2006	3.33	1.53
2007-2014	0.63	1.07
2015-2020	2.20	2.17
2021-2023	1.00	0.82

Threat Frequency: Continuous

Although there are monthly and seasonal changes in vessel operations throughout the assessment areas (Simard et al. 2014, Veinot et al. 2023, Redfern et al. 2024), vessel operations occur year-round in both the Canadian Assessment Area and the Northwest Atlantic Assessment Area. The amount of vessel traffic (measured as the sum of vessel transit distances) within core NARW habitat in the Northwest Atlantic Assessment Area is highest in July and lowest in February; however it is never less than 2,000 km /1,000 per 10 km × 10 km grid (Redfern et al. 2024). Therefore, we assessed the *Threat Frequency* of vessel strikes as *Continuous*.

Geographic Extent of Threat: Extensive

Vessels operate throughout the range of the NARWs in both the Canadian Assessment Area (Figure 13, Simard et al. 2014, Veinot et al. 2023) and the Northwest Atlantic Assessment Area (Vanderlaan et al. 2009, Crum et al. 2019, Garrison et al. 2022, Redfern et al. 2024). Habitual traffic patterns (self-determined paths, routes or lanes in the ocean travelled by vessels that connect one or more geographic locations; see Vanderlaan et al. 2009), occur throughout the Canadian Assessment Area; some of which have 10 or more vessels transit through them per day per km^2. Similar habitual traffic patterns are seen along the east coast of the USA, with much of the coastal areas of the mid-Atlantic having 10,001-497,971 km transited per 1,000 km^2 in 2019 (see Figure 1 in Redfern et al. 2024). In a global study of vessel-strike risk, 91.5% of all grid cells that contained either blue (*Balaenoptera musculus)*, fin (*Balaenoptera physalus*), humpback, or sperm whale (*Physeter macrocephalus*) ranges also contained vessel activity of large ships (Nisi et al. 2024). Therefore, we classified the *Geographic Extent of the Threat* for vessel strikes to NARWs as *Extensive*.

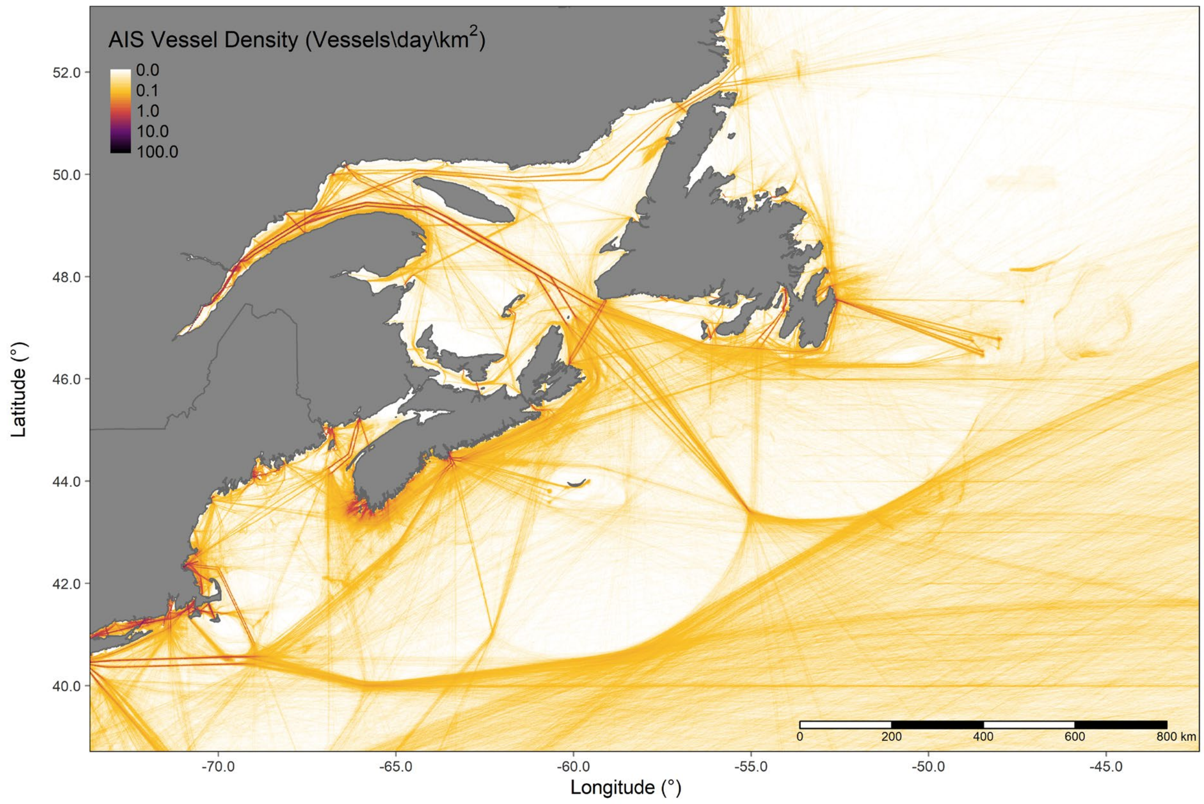

Figure 13. Vessel density map for all vessel classes in 2019 based on Automatic Identification System (AIS) data that incorporated both satellite-based and terrestrial-based receivers (data from Veinot et al. 2023).

Threat 2.1.2: Vessel-Presence Disturbances and Vessel Noise Pollution

In the 2014 NARW Recovery Strategy, both vessel presence and acoustic disturbance were identified as threats to NARWs (DFO 2014a). Many studies do not differentiate between vessel noise and vessel presence (Erbe et al. 2019), as it is often difficult to attribute the reaction of the whale to one or the other (but see Pirotta et al. 2015). Controlled exposure experiments that employ playback techniques (e.g., Nowacek et al. 2004, Southall et al. 2019) could provide greater differentiation for determining source of the impacts; however, it is not always possible to study NARWs in this manner. We, therefore, combined these two threats.

Likelihood of Occurrence: Known (Canadian Assessment Area and Northwest Atlantic Assessment Area)

Both vessel-presence disturbances and vessel-noise pollution are a result of vessel traffic that occurs throughout the assessment areas (see above). In addition, the world's vessel fleet has increased substantially since the 1970s (Vanderlaan et al 2009, UNCTAD 2023). This increase in the number of ships in the world fleet corresponds to a concurrent increase in the levels of low-frequency noise in the world’s oceans (Erbe et al. 2019). Over the past 50 years, for instance, increased shipping has led to an estimated 32-fold rise in low-frequency noise along major shipping routes (Duarte et al. 2021, and references therein) and in some areas there has been an absolute sound increase of 15 to 20 dB over the last 50-60 years due increases in low frequency shipping noise (Possenti et al. 2024 and references therein). Considering the increasing trends in the world’s fleet and low frequency noise attributed to shipping, the *Likelihood of Occurrence* was assessed as *Known*.

Individual level of impact: Low

Vessel-noise pollution has been linked to NARW disturbances and has been shown to reduce the distance over which NARWs can communicate, i.e., through auditory masking (Hatch et al. 2012, Cholewiak et al. 2018, Matthews and Parks 2021). NARWs have been shown to change their behaviour in noisy environments (due to vessel traffic) by increasing the start frequency and amplitude of their upcalls (Tennessen and Parks 2016). This change was positively attributed to vessel noise by comparing the contemporary calls of NARWs to historical recordings of NARW calls from periods with lower noise levels, calls of NARWs exposed to lower noise conditions, and calls of southern right whales in quieter habitats (Matthews and Parks 2021). Furthermore, decreased levels of stress hormones have been observed in NARWs in response to decreased levels of daily vessel traffic (Rolland et al. 2012). While Nowacek et al. (2004) found that NARWs did not alter their dive behaviour in response to the playback of vessel noise, they did respond to an alert signal by swimming "strongly" to the surface. Whale-watching vessels have been shown to cause disturbances and harassment (significant decrease of the proportion of time resting) in southern right whales (Sprogis et al. 2023), although, it is uncertain whether these impacts were due to vessel presence or vessel noise. Vessel noise has also been shown to disrupt foraging behaviour in other baleen whales (Blair et al. 2016). Considering the observed disturbance of southern right whales and other baleen whales resulting from vessel presence/vessel noise, and changes in the behaviour and stress levels of NARWs, the *Individual Level of Impact* was assessed as *Low* with a *Causal Certainty* rating of *High.*

Population Level of Impact: Unknown

There have been no studies demonstrating that vessel-noise pollution or vessel presence causes mortalities in NARWs. Loss of communication space due to vessel noise could cause reduced contact and hinder identification of potential mating partners in NARWs (Parks and Tyack 2005, Parks et al. 2005, Parks et al. 2011, Matthews and Parks 2021). However, it is unknown if vessel-noise pollution or vessel presence will jeopardize the survival or recovery of the population and, thus, the *Population Level of Impact* was assessed as *Unknown* for this threat.

Causal Certainty: High and Unknown

For the *Individual Level of Impact* there are some data available to assess this threat, both for NARWs and other large baleen whale species and thus the *Causal Certainty* was assessed as *High*. However, there is little information available to assess the *Population Level of Impact* and *Causal Certainty* was assessed as *Unknown*.

Threat frequency: Continuous and Geographic Extent of Threat: Extensive

As threats of vessel presence and vessel-noise pollution are linked to vessel traffic and operation, we used the same justification as vessel strikes (above) and evaluated the *Threat Frequency* as *Continuous* and the *Geographic Extent of the Threat* as *Extensive.*

THREAT CATEGORY 3: POLLUTION

Subcategory 3.1: Noise Pollution

Sound is an effective way of propagating energy through the ocean, and marine mammals have evolved to use sound efficiently. For example, baleen whales use long-range acoustic signals to communicate for mating and social interactions, and some baleen whales produce complex song patterns that go on for hours to days (Hildebrand 2005). Anthropogenic sound introduced into the ocean can have negative impacts on marine mammals (Hildebrand 2005) including altered behaviour, increased stress, and can inhibit communication in large whales (Hatch et al. 2008, 2012, Madsen et al. 2006, Van Parijs et al. 2021). A modelling study investigating the impact of soundscapes on the migration patterns of baleen whales, revealed that noise pollution could also render certain migration routes inaccessible (Johnston and Painter 2024). Ocean-noise pollution is increasing due to natural and anthropogenic activities (Chahouri et al. 2022), with various effects on cetaceans. When evaluating the impacts of noise pollution, we focused on data and information from baleen whales, as different cetacean hearing groups exhibit varying response patterns to specific sound sources (Gomez et al. 2016).

Anthropogenic noise pollution typically stems from two main sources: impulsive sounds exemplified by seismic surveys (airgun), pile driving, and military sonar (characterized by high peak sound pressure, short duration, fast-rise time, and broad-frequency content) and non-impulsive steady-state noise, such as that generated during vessel operations (NMFS 2016). Both seismic operations and vessel operations have been demonstrated to disrupt the normal behaviors and movements of cetaceans (Richardson et al. 1995). We assessed the threats of noise pollution from seismic surveys (airguns), active acoustic technologies operation, and mid-frequency military active sonar operations. Noise pollution associated with pile driving, drilling operations, and vessel operations are considered elsewhere in the threat assessment.

Threat 3.1.1: Seismic Surveys (Airguns)

Seismic surveys (airguns) are a fundamental tool for the exploration of geophysical features, such as oil and gas reserves beneath the seafloor. The 'airguns' are the most commonly used sound sources (Affatati and Camerlenghi 2023) and produce sound waves from compressed air sources that penetrate the ocean floor (Nelms et al. 2016). A single pass of a survey area is referred to as a two-dimensional survey, while surveys that conduct multiple passes or consist of multiple survey vessels operating at the same time for days to weeks are referred to as three-dimensional surveys (Affatati and Camerlenghi 2023). Seismic surveys (airguns) are a concern for NARWs due to their high source level and because peaks in the power spectrum coincide with the hearing range of NARWs (Nowacek et al. 2007, Matthews and Parks 2021, Thorne and Wiley 2024).

Likelihood of Occurrence: Known

Seismic, side scan, bathymetry, and low kHz bathymetry surveys have been conducted throughout the Canadian Assessment Area since the 1960s, including in areas designated as NARW critical habitats (Geological Survey of Canada's Canadian National Marine Seismic Data Repositor, Figure 14). Two dimensional seismic surveys have also been conducted in the Northwest Atlantic Assessment Area since the 1960s (Figure 15, Triezenberg et al. 2016), primarily along the continental shelf and shelf break off the eastern coast of the USA. Given that the noise generated by these surveys can potentially propagate over long distances (thousands of kilometers including records where airgun were heard almost 4,000 km from the survey vessel, Nieukirk et al. 2012), NARWs could be affected along their transit corridors as well as in their feeding and calving grounds. Considering that seismic surveys have been conducted for more than 60 years and are likely to continue, the *Likelihood of Occurrence* was assessed as *Known.*

Individual Level of Impact: Medium

The noise pollution from seismic survey may affect a variety of cetaceans and can elicit masking of vocalisation, habitat displacement, behavioural responses, changes in acoustic repertoires, chronic stress, and potential auditory damage (Nowacek et al. 2015, Hatch et al. 2012, Tennessen and Parks 2016, Affatati and Camerlenghi 2023). Changes in respiration and movement patterns, avoidance behaviour, and call cessation have all been observed in bowhead whales (*Balaena mysticetus,* Richardson et al.1999, Blackwell et al. 2013, Robertson et al. 2013). Altered singing behaviours have been observed in humpback (Cerchio et al. 2014) and fin whales (Castellote et al. 2012). In a systematic literature review of the effects of marine seismic surveys on free-ranging fauna, there were no studies presented on NARWs (Affatati and Camerlenghi 2023). Therefore, based on information for other baleen whales, we assessed the *Individual Level of Impact* as *Medium* with a *Causal Certainty* of *Medium*.

Population Level of Impact: Unknown

There is insufficient information for NARWs to assess the *Population Level of Impact* and the information required to estimate the parameters needed to determine the population-level consequences of seismic activity are not available for large baleen whales (Harwood et al. 2016). Therefore, we assessed the *Population Level of Impact* as *Unknown* with a *Causal Certainty* ranking as *Unknown*.

Threat Frequency: Recurrent (Canadian Assessment Area and Northwest Atlantic Assessment Area)

Seismic surveys have been conducted in the Canadian Assessment Area and Northwest Atlantic Assessment Area since the 1960s (Geological Survey of Canada's Canadian National Marine Seismic Data Repositor, Triezenberg et al. 2016). In Atlantic Canadian waters, 7,455 surveys were conducted between 1960 and 2020 (Figure 14). The number of surveys per year ranged from 0 to 689, with a median of 67 surveys per year. Although there are many seismic surveys per year, the timing and the duration of the surveys are variable and not continuous; therefore, the *Threat Frequency* was assessed as *Recurrent*.

Geographic Extent of Threat: Extensive (Canadian Assessment Area and Northwest Atlantic Assessment Area)

In Atlantic Canadian waters at least 645,400 km of seismic surveys have been conducted between 1960 through 2020 (Geological Survey of Canada's Canadian National Marine Seismic Data Repositor, Figure 15). However, this is an underrepresentation of all seismic surveys conducted since data owned by investor groups or seismic companies are not always included in open data sources like the Geological Survey of Canada's Canadian National Marine Seismic Data Repository. The surveys illustrated in Figures 14 and 15 coincide with NARW critical habitats, aggregation areas and transit corridors (Ratelle and Vanderlaan et al. 2025). The majority of seismic surveys have been conducted outside the boundaries of NARW critical habitats (Figure 2, Figure 3, Figure 14, and Figure 15). However, in the waters off the east coast of the USA, seismic surveys have occurred throughout the transit corridors between the Southeastern U.S. Calving Area Critical Habitat and the Northeastern U.S. Foraging Area Critical Habitat (Figure 3).

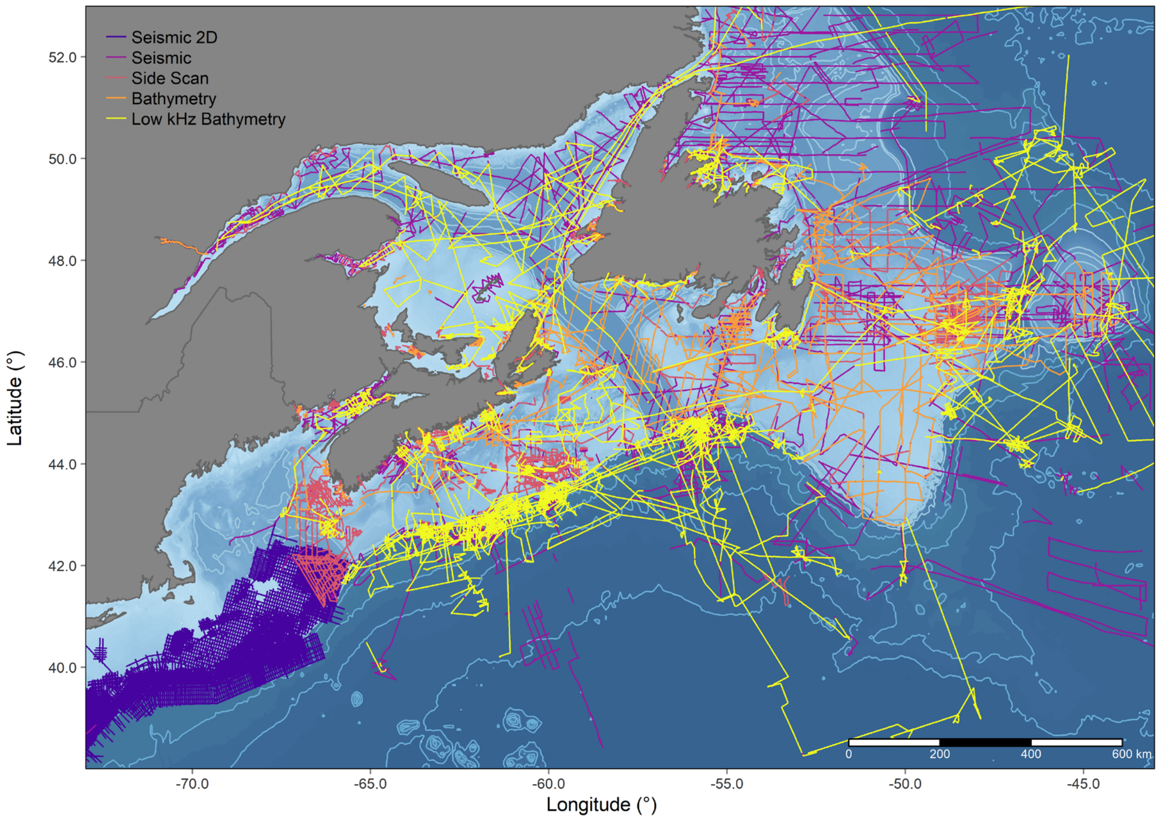

*Figure 14. **Partial seismic** survey effort in the Canadian Assessment Area from 1960 through to 2020. Data for seismic surveys, side scan sonar surveys, seismic surveys for bathymetry, and low kHz bathymetry surveys are from the Geological Survey of Canada's Canadian National Marine Seismic Data Repository. Data for two dimensional seismic surveys conducted primarily in the United States of America waters but extended into Canadian waters are from Triezenberg et al. (2016).*

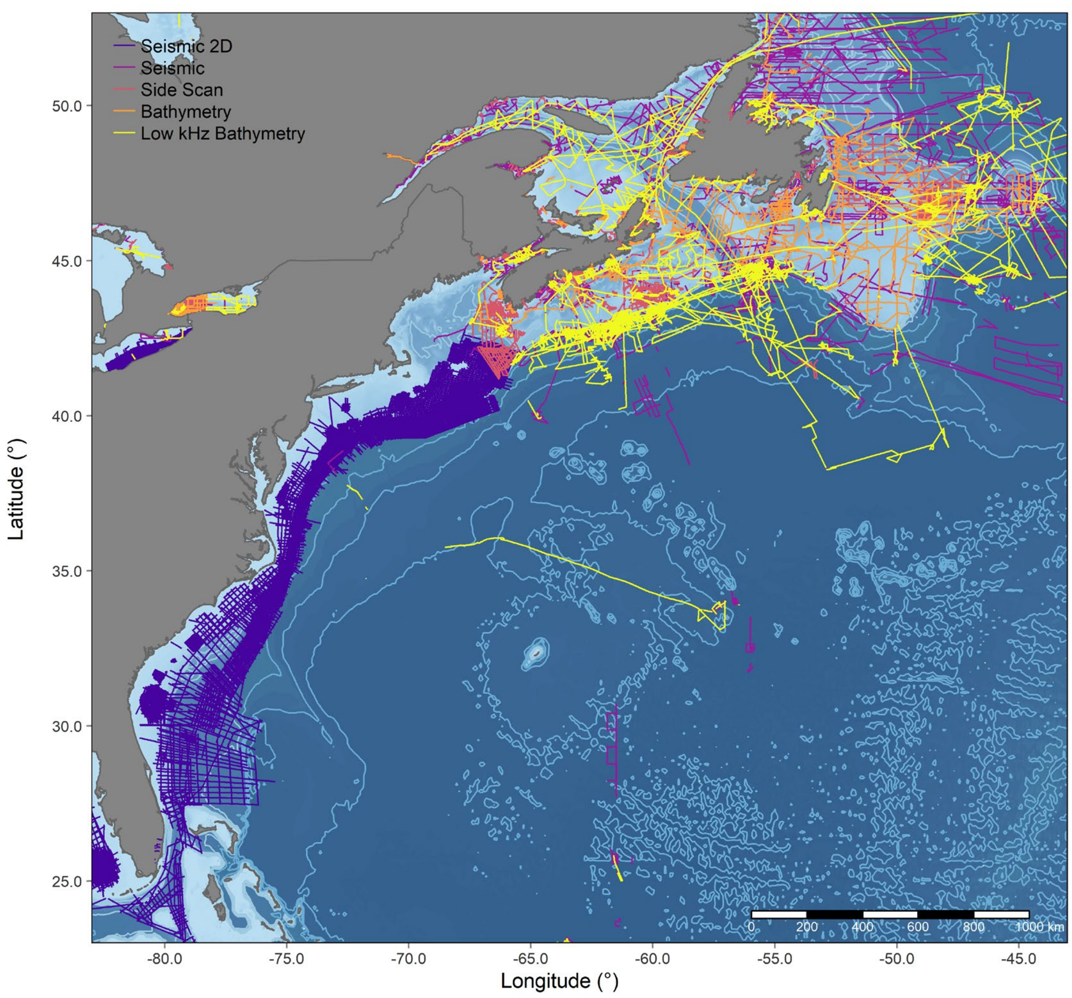

Figure 15. Partial seismic survey effort in the Northwest Atlantic Assessment Area from 1960 through to 2020. Data for seismic surveys, side scan sonar surveys, seismic surveys for bathymetry, and low kHz bathymetry surveys are from the Geological Survey of Canada's Canadian National Marine Seismic Data Repository. Data for two dimensional seismic surveys conducted in the United States of America waters are from Triezenberg et al. (2016).

Threat 3.1.2: Active Acoustic Technologies Operation

Likelihood of Occurrence: Known

Active acoustic technologies include instruments such as depth sounders, multibeam sonar, split-beam sonar, and scientific echosounders. The use of active acoustic technologies is widespread and includes scientific research (sampling on zooplankton and gas venting, as well as studying mixing and suspended sediment in the ocean), commercial and recreational fishing, aquaculture, navigation, hydrography, sea-floor mapping and geophysical exploration (Colbo et al. 2014, Burnham et al. 2022 and references within). There is a greater than 90% chance this threat occurs in both the Canadian Assessment Area and the Northwest Atlantic Assessment Area.

Individual Level of Impact: Low

There is no information available for the impact of active acoustic technologies operations on NARWs. However, active acoustic technologies likely have limited impacts on NARWs since mysticetes are unlikely to detect the frequencies used by these instruments, with the exception of the lowest frequency (12 kHz; Lurton and DeRuiter 2011). Behavioral responses in the form of decreased singing activity were measured in humpback whales in response to pulses during the Ocean Acoustic Waveguide Remote Sensing experiment that operated a low-frequency fisheries sonar 200 km away (Risch et al. 2012). However this system was designed to continuously monitor fish population over thousands of km^2 (Jagannathan et al. 2009), which is a much larger area than typical depth sounders and echosounders. During ship-based surveys with active scientific echosounder (Simard EK60) operation, beaked whales were significantly less likely to be detected acoustically, were detected for less time visually, and consequently tracked over a smaller range of bearings relative to the ship (Cholewiak et al. 2017). Short finned pilot whales (*Globicephala macrorhynchus*) were observed to change their heading more frequently when a scientific echosounder was operating (Quick et al. 2017). Based on these behavioural observations from other cetacean species, we assessed the *Individual Level of Impact* as *Low* with *Causal Certainty* ranked as *Medium* for this threat.

Population Level of Impact: Unknown

There is insufficient information available to assess the *Population Level of Impact* of active acoustic technologies operation on NARWs, therefore, we assessed it as *Unknown* with *Causal Certainty* also ranked as *Unknown* for this threat.

Threat Frequency: Recurrent

Echosounders and other active acoustic technologies are typically used on vessels that transit through both the Canadian and Northwest Atlantic Assessment Areas. There are areas within both the Canadian Assessment Area and the Northwest Atlantic Assessment Area, such as shipping lanes in the Gulf of St. Lawrence and into the New York Harbour where this *Threat Frequency* could be considered *Continuous* due to the high number of vessels that transit through these habitual traffic patterns on a daily basis. However, because most areas with the Canadian Assessment Area have less than one vessel per day per km^2 transiting through them, we considered this threat to be *Recurrent* rather than *Continuous* across the Canadian Assessment Area and Northwest Assessment Area.

Geographic Extent of Threat: Broad

The area affected by active acoustic technologies varies depending on the instrument type. For example, Burnham et al. (2022) demonstrated that most of the acoustic energy associated with recreational-grade echosounders was within 100 m from the source in shallow waters. Lurton and DeRuiter (2011) note that scientific echosounders will have limited impacts on baleen whales and are typically effective within a range of a few hundred meters, although the sound may be audible at distances up to several kilometers from the instrument. The sounds from an EK60 scientific echosounders can be detected at 800 m depth out to a distance of at least 1.3 km (Cholewiak et al. 2017). Although the majority of active acoustic technology instruments have limited range, we assessed the *Geographic Extent of Threat* as *Broad* as vessels transit and operate these instruments throughout both the Canadian Assessment Area and the Northwest Assessment Area.

Threat 3.1.3: Mid-Frequency Military Active Sonar Operation

One of the high priority, understudied, acoustic concerns for many whale species is the impacts of mid-frequency military active sonar (Goldbogen et al. 2013, Southall et al. 2019, Chouinard & Binder 2023). Mid-frequency military active sonar has a frequency range of 1 kHz-10 kHz (Simmonds & Lopez-Jurado 1991, Frantzis 1998, Cox et al. 2006, Nowacek et al. 2007). One of the most frequently used systems that has been associated with stranding events, is the AN/SQS 53C system (3.5 kHz with most energy in the 2.5 kHz-4.5 Hz range) with a source level of 235 dB rms re 1 µPa @ 1m (Parsons 2017). Low-frequency military sonar operations may also be a concern for baleen whales; however, they are not addressed here.

Likelihood of Occurrence: Known

In Canadian waters, the large-scale, multinational antisubmarine warfare training exercise "Cutlass Fury" has been conducted on the Scotian Shelf and in the waters off of Newfoundland in 2016, 2019, 2021, and 2023 usually over a two-week period (Stanistreet et al. 2022, Royal Canadian Navy 2023, Moors-Murphy et al. 2024). Additional short duration military exercises (hours to days) that may include the use of mid-frequency military active sonar also occur in eastern Canadian waters and in Department of National Defence operations areas. Given the high likelihood of periodic exercises continuing, we assessed the *Likelihood of Occurrence* as *Known*.

Individual Level of Impact: High

The effects of mid-frequency military active sonars have been of high interest; however, there has been limited directed research conducted on cetaceans and the majority of those efforts have focused on odontocetes (Goldbogen et al. 2013). Effects examined include changes to behaviours such as diving, surfacing and heading patterns, as well as changes in the types or timing of vocalizations. Physiological responses that investigate auditory threshold shifts and stress are much harder to evaluate (Nowacek et al. 2007).

Mid-frequency military active sonar studies that have been conducted on mysticetes suggested that blue and humpback whales experienced negative impacts (Goldbogen et al. 2013, Sivle et al. 2016, Southall et al. 2019), while fin whales showed more limited responses (Southall et al. 2023). For instance, Goldbogen et al. (2013) found that blue whales that were surface feeding displayed no change in behaviour; however, deep-feeding whales started feeding mid-water, and non-feeding whales moved away to avoid the acoustic signal. These behavioural changes could reduce foraging efficiency. Once the acoustic signal stopped the whales returned to their pre-signal behaviours. Other studies on blue whales demonstrated that they decreased their calling rates in the presence of mid-frequency military active sonar events (Melcon et al. 2012), and altered their behaviour while in deep feeding states during controlled exposure experiments (Southall et al. 2019).

There have been cases of northern minke whale strandings during sonar-related mass stranding events (Filadelfo et al. 2009 and references therein). Parsons et al. (2000) noted that minke whale sighting rates significantly decreased during naval exercises and Sivle et al. (2015) observed that minke whales exhibited high speed avoidance when exposed to 1–2 kHz sonar signals.

Impacts of mid-frequency military active sonar have been well documented in odontocetes as there have been multiple mass strandings that may have been caused by nearby sonar activity (Simmonds and Lopez-Jurado 1991, Fernández et al. 2005, Frantzis 1998, Cox et al. 2006, Nowacek et al. 2007). Beaked whales in particular have experienced major impacts due to nearby mid-frequency military active sonar operation (Chouinard and Binder 2023).

Although there have been no studies conducted on the impacts of mid-frequency military active sonar operations specifically on NARWs, a study by Nowacek et al. (2004) found that NARWs react to alert sounds (ranging from 500 to 4,500 Hz) by surfacing more rapidly and remaining there for longer periods. This could suggest that uncommon sound sources such as military sonars could elicit similar behavioural responses. Furthermore, sonar and other anthropogenic noise may interfere with NARW communication, reducing their ability to avoid predators and other threats (Chouinard and Binder 2023). The impacts of this threat on other baleen species have ranged from short-term behavioural responses to strandings, thus we assessed the *Individual Level of Impact* as *High* with a *Causal Certainty* of *Medium*.

Population Level of Impact: Unknown

Research on other large baleen whales informed the assessment of the *Individual Level of Impact* of mid-frequency military active sonar operation on individual NARWs. As there is insufficient information for NARWs to assess the *Population Level of Impact*, we assessed it as *Unknown*. The *Causal Certainty* was also given a rank of *Unknown* for this threat.

Threat Frequency: Recurrent

Military exercises such as “Cutlass Fury” are a biennial exercise that occur in the Canadian Assessment Area. Although there is limited information on other mid-frequency military active sonar activities in the Canadian Assessment Area, Navigational Warnings published by the Canadian Coast Guard (CCG) indicated that 67 surface, subsurface, and underwater operations took place between August 2019 and June 2024 (CCG NAVWARNs 2024). Limited information is available for the larger Northwest Atlantic Assessment Area; however, Chouinard and Binder (2023) provide information on operational studies examining mid-frequency military active sonar effects on cetaceans. As exercises using mid-frequency military active sonar occur repeatedly, the *Threat Frequency* was evaluated as *Recurrent* for both assessment areas.

Geographic Extent of Threat: Narrow

Although the exact locations of mid-frequency military active sonar use in either the Canadian Assessment Area or the Northwest Assessment area are unknown, the CCG Navigational Warnings are generally for a small area. Operational studies of the impacts of mid-frequency military active sonar operations have taken place during military exercise (Chouinard and Binder 2023) and the information available indicates only a moderate proportion of the NARWs habitat in the two study areas is affected by this threat. Thus, the *Geographic Extent of Threat* was assessed as *Narrow*.

Subcategory 3.2: Chemical Contaminants

In general, marine mammals are subject to some of the highest levels of environmental contaminants, especially compared to other wildlife (Desforges et al. 2016, Schaap et al. 2023). Cetaceans can be exposed to chemical contaminants through both air and water pollution and the transfer of pollutants can occur at the air-sea interface through several processes (Wania et al. 1998). For this subcategory, contaminants found in the ocean are the main focus for this assessment, although we recognized that air pollution will also affect NARWs in this subcategory. Contaminants have been detected in NARWs; however, the overall effect on individual NARWs remains unclear and no definitive causal connections between these substances and the health and reproduction has been established for NARWs (Kraus and Rolland 2007). Furthermore, the effects of contaminants on NARW body condition, growth, reproduction, and survival have been problematic to parameterize in population viability models for this species (Moore et al. 2021). To further assess this threat, we chose four general categories of chemical contaminants: persistent organic pollutants, heavy metals, plastics and marine debris, and petroleum spills.

Threat 3.2.1: Persistent Organic Pollutants Pollution

Persistent organic pollutants are a diverse group of anthropogenic chemicals that have long half-lives, are resistant to metabolism and degradation, and can be transported over long ranges (O'Shea 1999, Lohmann et al. 2007). Persistent organic pollutants can include several classes of chemicals including polychlorinated biphenyls (PCBs), various organochlorine pesticides (e.g., dichlorodiphenyltrichloroethanes (DDTs), chlordanes (CHLDs), hexachlorocyclohexanes (HCH), and flame retardants such as polybrominated diphenyl ethers (PBDEs; Baugh et al. 2023).

Likelihood of Occurrence: Known

Persistent organic pollutants occur in varying concentrations in the North Atlantic (Sun et al. 2016). Organochlorine pollutants are among the most persistent chemical contaminants present in the marine environment (Tilbury et al. 2002). Humpback whales residing in the Gulf of Maine (an important habitat area for NARWs) have been shown to have the highest concentration of persistent organic pollutants compared to other populations along the coast of the USA (Elfes et al. 2010). The *Likelihood of Occurrence* for persistent organic pollutants was assessed as *Known* in both the Canadian Assessment Area and the Northwest Assessment Area.

Individual Level of Impact: Unknown

Mortalities, reduced reproductive capabilities, and susceptibility to diseases through immunosuppression and endocrine disruption have all been suggested as potential biological effects of persistent organic pollutants in marine mammals (O'Shea 1999, Waring et al. 2009c). Some types of persistent organic pollutants, such as PCBs, have been found to suppress immune function in marine mammals (Desforges et al. 2016). Persistent organic pollutant concentrations have been measured in other baleen whale species, including humpback whales (Gauthier et al. 1997, Ryan et al. 2013, Baugh et al. 2023 Remili et al. 2024), bowhead whales (Hoekstra et al. 2002), fin (Remili et al. 2024), minke (Remili et al. 2024) and southern right whales (Torres et al. 2015). However, there is limited information on the effects of persistent organic pollutants for these species. Weisbrod et al. (2000) found no evidence that NARWs bioaccumulate hazardous concentrations of organochlorines. Woodley et al. (1991) found that the levels of DDT, PCBs, and other organochlorine contaminants were lower in NARWs compared to other baleen whale species. The effects of contaminants on NARW health, reproduction, and survival have been difficult to parameterize in modelling efforts (Moore et al. 2021) and thus we assessed the *Individual Level of Impact* as *Unknown*.

Population Level of Impact: Unknown

There is insufficient information available to assess the effects of persistent organic pollutants on NARWs or other large cetacean species at the population level. Thus, the *Population Level of Impact* was assessed as *Unknown* with a *Causal Certainty* of *Unknown*.

Threat Frequency: Continuous

Persistent organic pollutants occur throughout both the Canadian Assessment Area and the Northwest Atlantic Assessment Area. Some of these chemical contaminants are the most prevalent and persistent compounds in the oceans. It has been 20 years since the implementation of the Stockholm Convention on Persistent Organic Pollutants, a global treaty aimed at eliminating or reducing persistent organic pollutants pollution. However, due to the stable nature of these chemicals, this threat continues for NARWs.

Geographic Extent of Threat: Broad

The presence of persistent organic pollutants in the northwest Atlantic Ocean can vary by area, with higher concentrations of some types of persistent organic pollutants found in the Gulf Stream compared to the open ocean, where levels may decrease to below detectability (Lohmann and Belkin 2014). Persistent organic pollutants have also been shown to be at higher concentrations in coastal areas compared to the open ocean (Iwata et al. 1993), thus, NARW habitats and transit corridors are more likely to have higher concentrations of persistent organic pollutants.

Threat 3.2.2: Plastics and Marine Debris Pollution

Marine debris is widespread across the oceans, with plastics typically making up the majority of floating litter (Galgani et al. 2015). Debris and plastic pollution is a serious threat to the marine environment when not properly disposed of or recycled (Monteiro et al. 2018). When plastics are degraded and become brittle, they can break down into smaller fragments or microplastics (plastic debris <5 mm in size (Rochman and Hoellein 2020). Ingesting or becoming entangled in marine debris and plastics can lead to both chronic and acute injuries, increase contaminant exposure, and result in higher rates of morbidity, injury, and mortality (Baulch and Perry 2014, Fossi et al. 2020 and references therein). Thus, marine debris, macroplastics, and microplastics pose a serious threat to cetaceans including the NARW.

Likelihood of Occurrence: Known

The amount of marine debris around the world is increasing (e.g., Law et al. 2010) and plastic debris is found in various particle sizes and concentrations across the North Atlantic (Cózar et al. 2014). Of the three most commonly littered plastics (polyethylene, polypropylene, and polystyrene), it is estimated that 11.6–21.1 million tonnes of microplastics (size class 32–651 µm) are suspended in the top 200 m of the Atlantic Ocean (Pabortsava and Lampitt 2020). Jambeck et al. (2015) estimated that 4.8 to 12.7 million tonnes of microplastics are entering the world's oceans annually. Eighty per cent of marine plastic pollution is land based (Almroth and Eggert 2019). Based on this information and the current global dependence on plastics, there is a greater than 90% chance that this threat occurs or will occur and we, therefore, classified it as *Known*.

Individual Level of Impact: High

There is still considerable information required to determine the full impacts of the ingestion of marine debris and plastics on baleen whales (Fossi et al. 2012), and ingestion of marine debris and plastic has not been directly investigated in NARWs. However, almost two-thirds of cetacean species have been found to have ingested macroplastics (Fossi et al. 2020) and protocols have been developed to further study the effects of the ingestion of micro and macro plastics (e.g., Lusher et al. 2014, 2015). Plastics of various sizes have been found in many species of baleen whales including southern right, gray, fin, Bryde's, sei (*Balaenoptera borealis*), minke, and humpback whales (Werth et al. 2024 and references therein). Marine debris, plastics, and their associated chemicals can reduce an individual's health and fitness and even a small amount of ingested plastic can be fatal (Kühn et al. 2020). Macroplastics have been found in the digestive tract of a stranded southern right whale (Alzugaray et al. 2020). The ingestion of a broken DVD case contributed to the death of a juvenile sei whale (Henry et al. 2019). A necropsied fin whale had 45 anthropogenic items (all plastic) in the digestive tract and, although this may not have been the cause of death, large amounts of plastics can lead to obstructions in the gut and cause death as observed in a minke whale (Jauniaux et al. 2014). There have been cases where sperm whales have ingested pieces of fishing nets, ropes, and other plastic debris (Jacobsen et al. 2010, Simmonds 2012). NARW entanglements often involve gear in the mouth (Cassoff et al. 2011) with the ingestion of rope contributing to one whale's death (Johnson et al. 2005). While baleen whales that feed on copepods, like the NARWs, generally have a lower risk of microplastic ingestion (Burkhardt-Holm & N'Guyen 2019), Werth et al. (2024) demonstrated that the baleen of right whales has ability to collect plastic pollution of all sizes. Marine debris and plastic ingestion of all sizes may still affect an individual whale's health and survival. Based on the mortalities, injuries, and health effects observed in other baleen whales the *Individual Level of Impact* was scored as *High* with a *Causal Certainty* of *High*.

Population Level of Impact: Low

Although there have been no NARW deaths attributed to the ingestion of plastics or marine debris, there have been cases documented in other baleen whale species (Jauniaux et al. 2014, Henry et al. 2021). As mortality could occur from the ingestion of marine plastics and debris over the next 100 years and a few deaths were observed in other baleen whales, the *Population Level of Impact* was assessed as *Low*.

Causal Certainty: High

The level of impact categories assessed for marine debris, and macro- and microplastics are entirely based on publications for other baleen whales as there is a paucity of data specifically for NARWs.

Threat Frequency: Continuous

Plastics and marine debris pollution, in various forms and sizes, occurs throughout the Atlantic Ocean and is increasing (Law et al. 2010, Cózar et al. 2014, Rochman 2018)) thus, we assessed the *Threat Frequency* as *Continuous*.

Geographic Extent of Threat: Broad

Plastics and marine debris severely pollute the environment (Kurniawan et al. 2021) and, as the majority of the pollution is land based, it can be found in nearshore and coastal areas. Plastics and marine debris also migrate toward and accumulate in the subtropical gyres (Eriksen et al. 2019). Based on this information the *Geographic Extent of Threat* was assessed as *Broad*.

Threat 3.2.3: Petroleum Spills or "Oil" Spills

The release of fossil fuels and related refined products into the environment, whether marine or otherwise, is commonly known as an "oil spill." Oil spills include a wide range of petroleum releases, with the composition and chemicals involved varying depending on the source of the oil. Below we use the term oil spills to represent crude oil and oil derived products.

Likelihood of Occurrence: Known

In Canada, it is reported that 12 oil spills occur per day with a volume greater than 4,000 L and that at least one of these spills will occur in maneuverable waterways (Michel an Fingas 2016). In the USA, there are 15 spills per day of this size in maneuverable waterways (Michel and Fingas 2016). There have been major oil spills off the coast of Nova Scotia. Examples include the sinking of the tanker "Arrow" in Chedabucto Bay and the Kurdistan spill off northern Cape Breton Island (Steward and White 2001). One of the largest oil spills (at the time) occurred 1,300 km off the Nova Scotian coast in 1988 when 132,157 tons of crude oil were released into the North Atlantic when a tanker (the *Odyssey*) split in two and sank (Brown 2010). Furthermore, the National Aerial Surveillance Program detected 1,148 oil spills in Canadian Waters between 2011 and 2016, during which time there was increased surveillance in Atlantic Canada (TC 2019). The probability of at least one oil spill occurring in the next 100 years in the Canadian Assessment Area or the Northwest Assessment Area is greater than 90% and, therefore, the *Likelihood of Occurrence* is Known.

Individual Level of Impact: Extreme

Cetacean exposure to oil spills can occur through inhalation, aspiration, ingestion (directly or through contaminated prey), and dermal contact (Helm et al. 2014, Jarvela Rosenberger et al. 2017, Takeshita et al. 2017). Each pathway could cause various physiological conditions that could affect the heath and survival of cetaceans (Helm et al. 2014). Data on large baleen whales and the effects of oil pollution are limited (Claphman et al. 1999), and there are no defined species-specific physiological thresholds of oil exposure (Jarvela Rosenberger et al. 2017). With that in mind, Jarvela Rosenberger et al. (2017) developed a risk based conceptual framework to evaluate the vulnerability of marine mammals to oil spills. The likelihood of individual exposure was based on the five exposure pathways (listed above). North Pacific right whales were ranked as high in every category with the exception of adhesion/dermal contact (ranked medium). Based on results for North Pacific right whales, individual NARWs are likely to experience a high likelihood of exposure when an oil spill occurs in their habitat. After exposure to an oil spill, cetaceans exhibit a wide range of effects including mortalities, reproductive failures, poor body condition, inflammation, and organ damage (Takeshita et al. 2017, Godard-Codding and Collier 2018 and references therein). Due to the wide range of impacts observed in several cetacean species we assessed the *Individual Level of Impact* as *Extreme* with a *Causal Certainty* of *Medium*.

Population Level of Impact: High

Jarvela Rosenberger et al. (2017) estimated oil spill risk scores at the population level for all baleen whale species in coastal British Columbia based on biological, ecological, and demographic features. North Pacific Right whales share some similar features with the NARW (specialised diet of copepod, long lived species, small population estimate) and were given a medium score of likelihood for population level effects (Jarvela Rosenberger et al. 2017). However, the framework and characteristics used in that study are not comparable with ,the definitions used in this threat assessment. Large oil spills, such as the 2010 Deepwater Horizon oil spill, resulted in a 35% increase in deaths and a 46% increase in reproduction failure for bottlenose dolphins (*Tursiops truncatus*) leading to a substantial loss of the Barataria Bay, Louisiana population as well as a 22% population decline in the endemic population of Rice's Whale (*Balaenoptera ricei,* Ramírez-León et al. 2023). Due to the substantial loss of individuals from a cetacean population resulting from the Deepwater Horizon Oil Spill, the *Population Level of Impact* was assessed as *High* with a *Causal Certainty* of *Medium* as the assessment was based on effects observed for other species.

The supporting information in the *Level of Impacts* sections is biased toward large oil spills. There could be substantial variability in the potential impacts based on the volume of the spill, the type of the petroleum, and the location of the spill. Small spills that are seen on a day-to-day basis in either assessment area will not have the same effects as catastrophic spills like the Deepwater Horizon oil spill or the Exxon Valdez oil spill off the coast of Alaska.

Threat Frequency: Recurrent

Large-scale oil spills (>30 tonnes) from vessels such as the Odyssey, the Exxon Valdez, and the Deepwater Horizon oil platform occur rarely (0.1% of incidents, Fingas 2011). Nonetheless, small oil spills occur daily in both the Canadian Assessment Area and the Northwest Atlantic Assessment Area. The majority of spills (72%) are small-scale spills that account for <1% of the total spillage (Fingas 2011). Thus, there are *Recurrent* small-scale oil spills in NARW habitats and transit corridors.

Geographic Extent of Threat: Restricted

The majority of oil spills are small in volume, and the effects of a marine oil spill are determined by the location of the spill, the extent of the physical forces that act on the spill and the proximity of the spill to species and their habitats (Zhang et al. 2019). It is possible for wind and waves to dilute the concentration of an oil spill and, due to the small volume of most spills, only a minor proportion of the NARW habitat may be affected.

Threat 3.2.4: Heavy Metal Pollution

Likelihood of Occurrence: Known

Heavy metals like chromium, mercury, nickel, cadmium, lead, and arsenic are persistent in the environment and have been detected in notable concentrations in the marine environment, including in marine mammal tissues, for decades (Schaap et al. 2023 and references therein).

Individual Level of Impact: Unknown

Data on the impacts of heavy metal pollution in marine mammals is poorly standardized and available for only a few species, making it difficult to draw conclusions about the impact on individuals or overall population health and emphasizing the need for more comprehensive research (Bowles 1999, López-Berenguer et al. 2020, Schaap et al. 2023). Furthermore, the adaptive ability of marine mammals to effectively process higher concentrations of heavy metals complicates the assessment of potential health impacts (Chen et al. 2009, López-Berenguer et al. 2020).

There is a lack of information on heavy metal concentrations in NARWs that has been exacerbated by the challenge of gathering comprehensive data due to their small population size. For example, in a study by Wise et al. (2019) investigating heavy metal levels in baleen whales (humpback, fin, and minke whales) in the Gulf of Maine, NARWs were excluded from sampling due to their limited population size. The baleen whales inhabiting the same areas in the Gulf of Maine exhibited significantly higher levels of chromium and nickel, known for their potential toxicity, when compared to southern right whales (Wise et al. 2019); however, diets of these three species are not the same as NARWs or southern right whales. Skin biopsies from NARWs in the Bay of Fundy revealed the presence of chromium at levels that have been shown to be cytotoxic and genotoxic for NARW lung and testes cell cultures (Wise et al. 2008). Chromium-induced cytotoxicity and genotoxicity in primary cultured lung and skin fibroblasts from NARWs further underscores the health potential concerns associated with chromium exposure (Chen et al. 2009). Exposure of NARW kidney cells to cadmium has also been shown to result in changes in gene expression for genes related to metal toxicity (Ierardi et al. 2021).

Although the concentration of some heavy metals in NARWs could be impacting cell functions, there has been no direct link made between the cytotoxicity and genotoxicity observed in cell cultures with morbidity or increased stress. As such, the *Individual Level of Impact* was assessed as *Unknown*.

Population Level of Impact: Unknown

Due to the limited information available on the effects of heavy metal pollution, we were unable to assess the *Population Level of Impact* at this time and it is, therefore, *Unknown*.

Threat Frequency: Continuous

Some heavy metals occur naturally in the ocean (Krishna et al. 2003); however, the global increase observed in oceanic levels of heavy metals is due to anthropogenic sources (Ross et al. 2017). Agricultural fertilizer and pesticide use, fossil fuel consumption, mining, and waste disposal all contribute to a *Continuous* release of toxic metals into the oceans (Ansari et al. 2004).

Geographic Extent of Threat: Broad

Concentrations of heavy metals can vary substantially between the surface and deep-sea waters and across oceans (Mart et al.1982). The variation in concentration of these elements is even greater in coastal waters that are particularly impacted by anthropogenic inputs (Mart et al. 1982). NARWs primarily occur in Northwest Atlantic coastal waters on the continental shelf where the concentrations of the different heavy metals will depend on the source (Ansari et al. 2004). Due to the variation in concentration of heavy metals across the Canadian Assessment Area and the Northwest Atlantic Assessment Area we assessed the *Geographic Extent of Threat* as *Broad*.

Subcategory 3.3: Energy Development and Production

The world's oceans are experiencing expanding industrialization, and new and changing innovations and technologies are contributing to further development (Jouffray et al. 2020, Winther et al. 2020). Coastal and marine offshore developments, drilling operations by industrial platforms, and wind energy production all pose various threats to the NARW through noise pollution, vessel traffic, chemical contaminants, and the alteration of habitats.

Threat 3.3.1: Coastal and Marine Offshore Development

Acoustic-noise pollution generated during the construction phase of coastal and offshore marine developments, including wind turbines and oil and gas platforms, can include noises originating from pile driving, pole drilling, explosives, dredging, trenching, and sediment mining. This type of noise pollution has been increasing in the oceans around the world (Kusku et al. 2018). The construction of offshore wind farms and other structures may pose a threat to cetaceans primarily due to noise associated with pile driving (Madsen et al. 2006, Bailey et al. 2010; Dolman and Simmonds, 2010, Dähne et al. 2013, Thompson et al. 2020), which can be one of the most intense sources of underwater noise (Madsen et al. 2006, Thomsen et al. 2006). Pile driving emits intense, impulsive noise that radiates into the surrounding environment as the turbines or other structural components of developments are hammered into the sea floor (Amaral et al. 2020). A vibratory pile driving hammer typically produces sounds in the 15-35 Hz range (Dahl et al. 2015) with peak sound energy levels occurring in the 100 Hz to 2 kHz frequency band. However, sound energy up to 10 kHz can be produced (Bailey et al. 2010, Haelters et al. 2013). For the assessment of the threat of Coastal and Marine Offshore Development, we focused on pile driving as the main threat due to the intense noise associated with this activity.

Likelihood of Occurrence: Known

Renewable, green resources such as solar panels and offshore wind energy have been a high priority that is undergoing rapid development (Bailey et al. 2010, Davis et al. 2023). There are new developments off the southern New England area (Davis et al. 2023) including two wind farms that started construction in 2022: Vineyard Wind 1, located 24 km south of Martha's Vineyard with 62 wind turbines, spaced 1 nautical mile apart (Vineyard Wind 2024); and South Fork Wind Farm (South Fork Wind 2024), off the coast of Long Island, New York with 12 planned turbines. Additional wind lease areas with wind farms at various stages of planning, review, and permitting are shown in Figure 16. As of January 1, 2024, there were no offshore wind farms in the Canadian Assessment Area. However, Atlantic Canada Offshore Developments has announced the development of four offshore wind projects, one in each of the Atlantic provinces and state that there is great potential for development on the Atlantic coast and in the Gulf of St. Lawrence (Norton Rose Fulbright 2023). Thus, there are studies underway examining possible offshore wind construction sites that could be suitable off the shores of Nova Scotia, Canada (Eamer et al. 2021, Cunanan et al. 2022, Daborn et al. 2025). Given that there are operational wind farms off the eastern coast of the USA, with more under construction, and that there are plans in both assessment areas for further development of offshore wind farms, we assessed this threat as *Known*.

Individual Level of Impact: High

Before a coastal or marine offshore development can begin, studies need to be completed on noise propagation modelling, marine mammal noise exposure criteria, densities of local species, the number of individuals potentially impacted, and the potential long-term population consequences of the development (Thompson et al. 2020). High-intensity, impulsive blasts from pile driving can damage cetacean ears and reduce their communication range, interfere with foraging, increase their vulnerability to predators, and result in erratic behaviours, which could, in turn, impact migration, mating, and potential for stranding (Ketten et al. 1993, Thomson et al. 2020). The impulsive noise created by pile driving can also result in the death of cetaceans (Thompson et al. 2020). The *Individual Level of Impact* was assessed as *High* with a *Medium* rating for *Causal Certainty*.

Population Level of Impact: Unknown

There is insufficient information for NARWs to assess the *Population Level of Impact*; therefore, it was assessed as *Unknown* with a *Causal Certainty* ranking as *Unknown*.

Threat Frequency: Recurrent

Generally, pile driving is conducted over a smaller time scale than other threats. Bailey et al. (2010) measured pile-driving operations in the Moray Firth (inlet of the North Sea) and estimated that operations took between 108-157 minutes, with a mean duration of 135 minutes per pile over five days. Each pile required 5,000-7,000 blows of the hammer (mean of 6,223 blows). The hammer struck the pile approximately once per second (mean=0.8 strikes/second). Although the noise travelled a long distance, the impact was only for a matter of days and could be mitigated to occur during months with lower densities of marine mammals. Thus, due to the repeated nature of pile driving required we assessed the *Threat Frequency* as *Recurrent*.

Geographic Extent of Threat: Narrow

Although coastal and marine offshore development is increasing, contemporary offshore wind farm developments occupy a low proportion of the NARW's habitat. The shift in the distribution of NARWs has resulted in aggregations of whales feeding, socializing, and transiting in an area off the southern New England, creating an area of special concern due to the development of offshore windfarms west of Nantucket Shoals (Leiter et al. 2017, Stone et al. 2017, O'Brien et al. 2022). The *Geographic Extent of the Threat* of coastal of marine offshore developments was assessed as *Narrow* in both the Canadian Assessment Area as well as the Northwest Atlantic Assessment Area.

Threat 3.3.2: Drilling Operations

Drilling operations can produce a variety of sounds, some of which are nearly constant, at low to mid-frequencies (700 to 1400 Hz, Hildebrand 2009). In another study the peak energy of drilling operations occurred at 45 Hz with further high energy at the frequency band above 1 kHz (Huang et al. 2023). In the eastern Beaufort Sea, the noise from drilling operations can be difficult to separate from natural background noise (Blackwell et al. 2017).

Likelihood of Occurrence: Known

Offshore oil and natural gas extraction have been ongoing in the Canadian Assessment Area for over 25 years and, although some operations have been decommissioned, the industry remains active in this area (Moors-Murphy et al. 2024 and references therein). The majority of drilling operations in waters off the USA generally occur outside the Northwest Atlantic Assessment Area.

Individual Level of Impact: Low

There is a paucity of information available to evaluate the effects of noise generated by drilling operations on NARWs. Measurements of noise emitted from drilling operations on the Scotian Shelf fall within the range of 130–190 dB per 1 µPa and are not likely to result in auditory injury to marine mammals (MacDonnell 2016). However, the frequency range of the sounds emitted during drilling operations is within the estimated hearing range of NARWs (from 20 Hz-22 kHz; Matthews and Parks 2021). Bowhead whales have exhibited varied reactions to drill ships and dredging sounds (both operational and in playback experiments) including orienting away/moving away from the sound, feeding cessation, and altered surfacing, respiration, diving behaviour (Richardson et al. 1990), and changes in calling rates (Blackwell et al. 2017). Due to the behavioural effects observed in bowhead whales, as well as those related to other vessel noises and other noise pollution, we assessed the *Individual Level of Impact* as *Low* with a *Causal Certainty* of *Low* due to the lack of data available on the impact of this noise source on other baleen whale species.

Population Level of Impact: Unknown

There was insufficient information available to assess the *Population Level of Impact* for the effect of ocean drilling on NARWs.

Threat Frequency: Recurrent

Offshore oil and natural gas exploration and drilling in the waters off Nova Scotia and Newfoundland and Labrador began in 1969. It is expected that parts of Atlantic Canada will continue to be active participants in the oil and gas sector for many years to come.

There have been three developments offshore of Nova Scotia: Deep Panuke (five project wells), Sable Island (21 development wells were drilled in five fields), and Cohasset-Panuke (total of 14 production wells) with active production between 1992-2018 (CNSOPB 2023). These projects included both oil and natural gas wells and were in active production between 1992-2018. All of which are now decommissioned and abandoned (CNSOPB 2023).

There are five offshore platforms drilling off Newfoundland including Hibernia, Hebron, Terra Nova, White Rose, and North Amethyst, all of which are currently active (CNLOPB 2023).

Geographic Extent of Threat: Restricted

Sound source characterization studies conducted on the Scotian Shelf indicate that the noise from drilling operations has a limited propagation area (Moors-Murphy et al. 2024 and references therein) and, thus, it is very unlikely that drilling operations will affect much of the Canadian Assessment Areas. The majority of drilling operations in waters off the USA generally occur in the Gulf of Mexico and are outside the Northwest Atlantic Assessment Area. Thus, for both assessment areas the *Geographic Extent of Threat* was assessed as *Restricted*.

Threat 3.3.3: Wind Energy Production

Offshore wind farms generate renewable energy but can have environmental consequences, both positive and negative, for the habitats in which they operate. Major concerns related to wind farms include increased noise levels, risk of increased vessel strikes to marine mammals, collisions with seabirds, changes in the benthic and pelagic habitats where they are installed, changes to food webs, and increased pollution due to increased traffic and the release of contaminants from the seabed (Bailey et al. 2014). Potential benefits to the environment from wind farms include artificial reef support on the base structures of the individual turbines, shelter effects, and the exclusion of some or all fishing effort (Bailey et al. 2014). However, more research is needed to fully assess the impacts of wind farms.

This threat assessment focused on the operational phase of energy production for wind farms. The development and construction phases of wind farms are associated with a number of threats to NARWs. Such threats include noise pollution from pile driving and seismic surveys, increased vessel operations, and pollution from chemical contaminants released from the sediments, where some heavy metals accumulate (Ansari et al. 2004, Bailey et al. 2014). Operational activities of wind energy production will also result in changes in vessel traffic patterns (Culloch et al. 2016, Yu et al. 2020) and the associated threats.

Likelihood of Occurrence: Known

In the Northwest Atlantic Assessment Area, there are two wind farms operating off the coast of the USA: the Block Island wind farm, consisting of 5 turbines, and the Coastal Virginia Offshore Wind project, with two turbines operating as of August 2023, and another 150 turbines planed by 2026 (NASEM 2023, Energy.gov 2023). Additional wind lease areas with wind farms at various stages of planning, review, and permitting are shown in Figure 16.

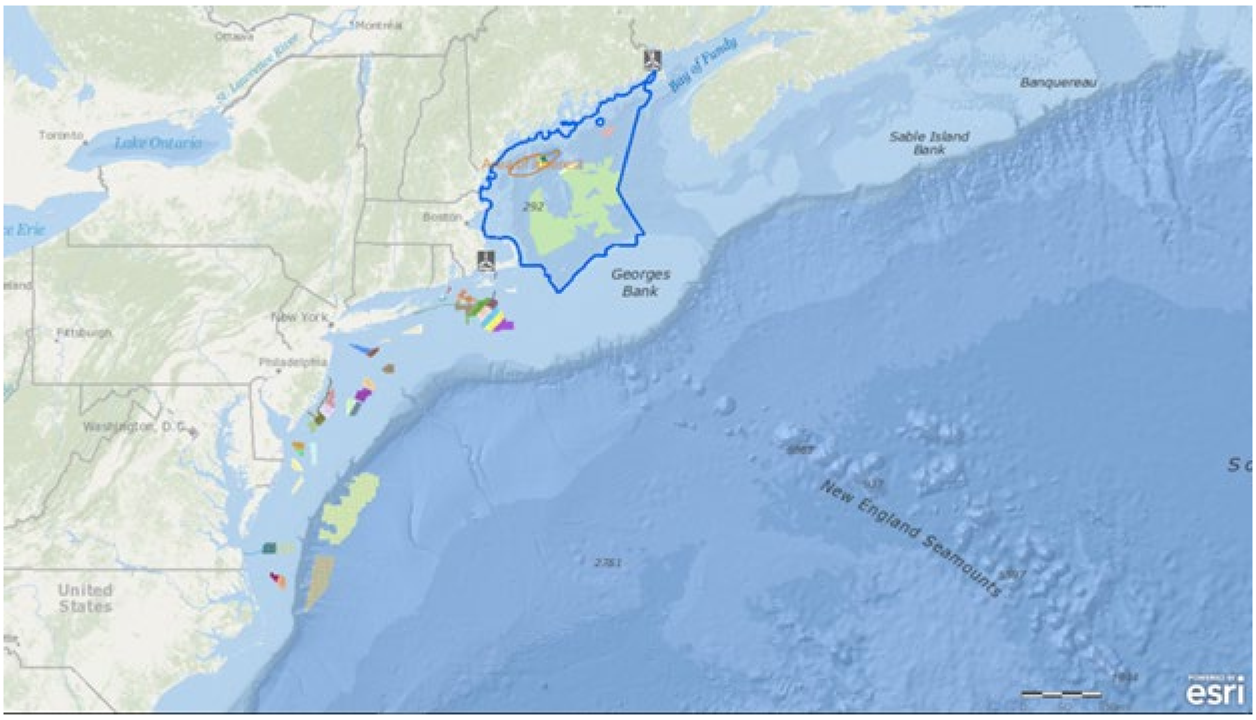

Figure 16. The locations of proposed and existing energy facilities and transmission infrastructure areas of wind farms at various stages of planning, review, permitting, and operation (from: https://www.northeastoceandata.org/data-explorer/?energy-infrastructure|planning-areas). Data are from authoritative sources including the Bureau of Ocean Energy Management, Federal Energy Regulatory Commission, the New England states, and marinecadastre.gov.

Areas off of the coast of Nova Scotia, including Sydney Bight, French Bank, Middle Bank, Sable Island Bank and Western Emerald Bank in the Canadian Assessment Area have all been recommended for immediate consideration as prospective wind farm areas (Figure 17, Daborn et al. 2025). Misaine Bank, LaHave Basin and Canso Bank area also being considered; however, these areas require additional investigation and consultation (Daborn et al. 2025). Construction of offshore wind farms is expected to start in 2031 and operations could be initiated in 2033 (Daborn et al. 2025). Given that there are operational wind farms off the eastern coast of the USA, with more under construction, and that there are plans in both assessment areas for further development of offshore wind farms, we assessed this threat as *Known*.

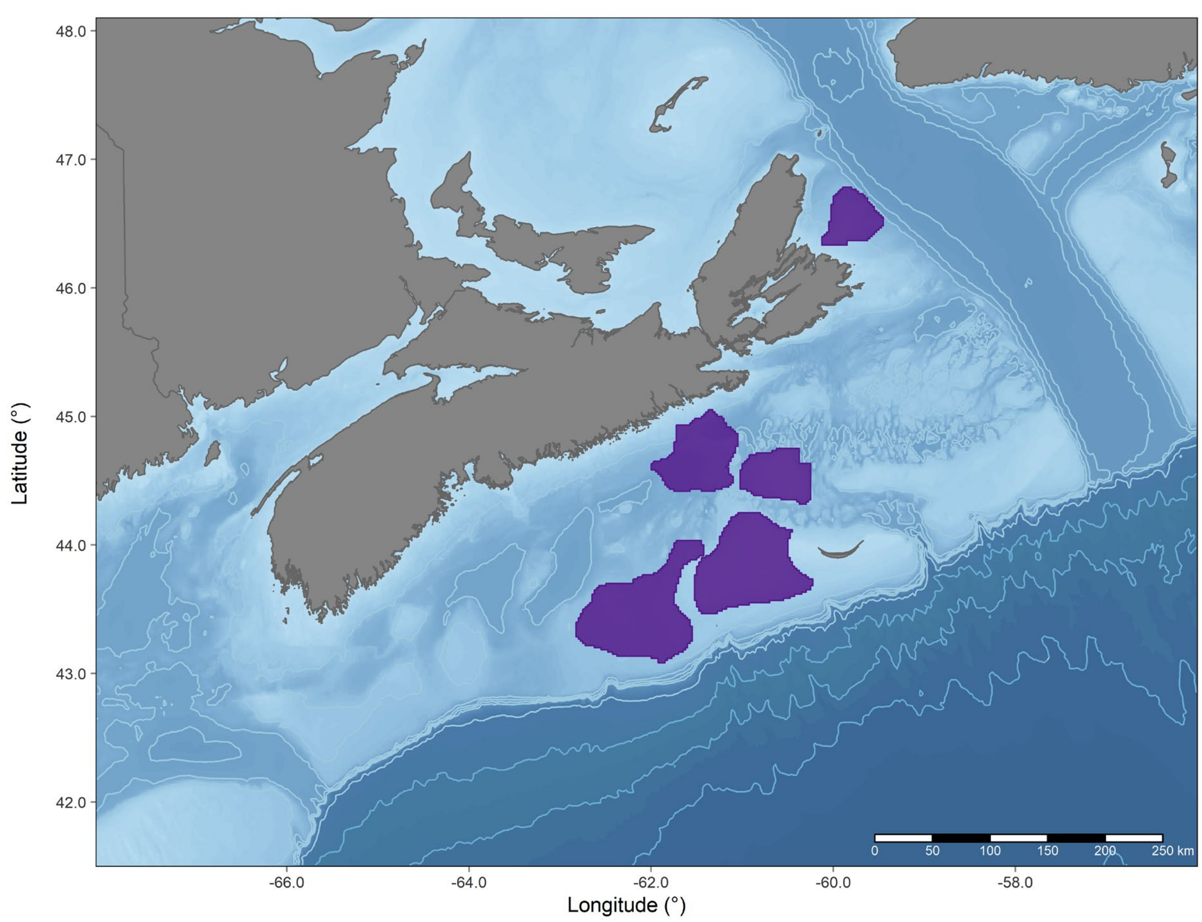

Figure 17. Proposed areas (as of March 2025) considered for development as Wind Energy Areas (purple polygons) on the Scotian Shelf.

Individual Level of Impact: Unknown

NARWs are dependent on the biophysical processes that supply and accumulate their prey (Sorochan et al. 2021). Offshore wind farms in the North and Irish Seas have been shown to contribute to increases in net primary production and zooplankton (van der Molen et al. 2014) through impacts on water column stratification (Carpenter et al. 2016, Cazenave et al. 2016). If NARWs shift their distribution to capitalize on local increases in prey in the vicinity of offshore wind farm developments they could be exposed to increased risk of vessel strikes due to vessel traffic associated with the offshore wind farms, and an increased potential for entanglement in regional fishing gear or gear that could accumulate at the base of the monopiles (NASEM 2023). However, whether the observations from the North and Irish Seas are representative of the oceanographic conditions for offshore wind farms on the east coast of the USA or Atlantic Canada is unclear. The hydrodynamic effects of offshore wind farms could also result in decreased zooplankton production or there could be no effect at all (NASEM 2023). If local zooplankton production decreases in response to the presence of wind farms, NARWs could have reduced fecundity, since periods of low prey availability for NARWs have corresponded to decreased calving rates (Greene and Pershing 2004, Meyer-Gutbrod et al. 2015). Given the uncertainty of the impacts of offshore wind farms on the primary prey of NARWs, the indirect impacts on individual NARWs are unknown.

In terms of direct impacts of offshore wind farms to NARWs, there is the possibility of NARWs becoming entangled in the lines of floating wind farms (Harnois et al. 2015) that could have similar impacts on individual whales as fishing-gear entanglements. These types of wind farms are not used in the Canadian Assessment Area or the Northwest Atlantic Assessment Area at the time of this assessment; however, the Government of Nova Scotia is considering both floating and fixed offshore wind structures (Daborn et al. 2025) and there is the possibility of entanglement in any ropes of these mooring systems.

Another threat posed by offshore wind farms is noise pollution as the turbines generate continuous noise during operations that include broadband and tonal components with harmonics below 1,000 Hz which is equivalent the noise of a large commercial ship (Mooney et al. 2020). As offshore windfarms are stationary, this will be a nearly constant source of noise added to the acoustic environment of NARWs.

Most of the impacts of offshore wind farms are hypothesized to indirectly affect NARWs and are thought to be behavioural (Madsen et al. 2006). However, the long-term effects of offshore wind farms are largely unknown (Madsen et al. 2006, Silber et al. 2023). Although the constant noise generated by wind turbines is a potential threat to NARWs, there is still a large uncertainty of all the indirect effects of operations on NARWs, thus the *Individual Level of Impact* was assessed as *Unknown* with a *Causal Certainty* of *Unknown*.

Population Level of Impact: Unknown

Contemporary estimates of population loss due to offshore wind farms are not available for the NARW and it is much more likely that the indirect effects of offshore wind farms will have a greater impact on NARWs than the direct effects. Therefore, the *Population Level of Impact* was assessed as *Unknown*.

Threat Frequency: Continuous

Once installed, offshore wind farms will operate continuously, until decommissioned, for a period of approximately 30 years (Mooney et al. 2020), thus the *Threat Frequency* was assessed as *Continuous*.

Geographic Extent of Threat: Narrow

Contemporary offshore wind farms occupy a low proportion of the NARW's habitat, with only two farms operational in the mid-Atlantic. New offshore wind farms are planned in the Northwest Atlantic Assessment Area as are expansions to the current offshore wind farms. The *Geographic Extent of the Threat* of energy production through windfarms was assessed as *Narrow* in both the Canadian Assessment Area and the Northwest Assessment Area.

THREAT CATEGORY 4: OCEAN-PHYSICS ALTERATIONS

Threat 4.1.1: Climate Change

Climate change affects many aspects of the oceans including heat budget, ocean circulation, pH, phytoplankton productivity, oxygen content, nutrients, and sea-level (Reid et al. 2009). Ocean acidification can lead to increases in the distances both anthropogenic noise and whale sounds (below 10 KHz) can travel (Brewer and Hester 2009). Climate change has also caused changes in the distribution of cetaceans and their prey (Poloczanka et al. 2016, van Weelden et al. 2021). These shifts in distributions can result in changes to ecosystem structure, function, and species interactions (Doney et al. 2012), and may change the exposure of NARWs to various threats such as vessel strikes and fishing-gear entanglements (Meyer-Gutbrod et al. 2021).

Likelihood of Occurrence: Known

Climate change have resulted in substantial transformations of coastal and open ocean ecosystems (IPCC 2023). Not only has the global ocean warmed substantially since the 1950s, the rate of warming has also approximately doubled from the 1960s to the 2010s (Cheng et al. 2022). Regional localized changes have also been recorded. The Gulf of Maine, an important habitat for NARWs, experienced one of the fastest rates of warming of any ocean ecosystem between 2004-2013 (Pershing et al. 2015). Townsend et al. (2023) demonstrated that, since 2010, the Gulf of Maine has a new baseline of warmer temperatures and higher salinities. Climate change simulation modelling for the Northwest Atlantic includes increases in sea surface temperatures for the years 2070-2099 as well as other changes including the maximum depth of warming, shifts in the Gulf Stream, and changes in surface salinities (Alexander et al. 2020). Climate change is occurring in the northwest Atlantic and will continue to occur, thus the *Likelihood of Occurrence* was assessed as *Known*.

Individual Level of Impact: Unknown

The indirect effects of climate change, such as changes in food supply and shifts in distribution have been well documented for NARWs (reviewed in Ratelle and Vanderlaan et al. 2025). Distributional shifts expose NARWs to additional threats as they move into new areas where conservation initiatives may not be in place. The observed distributional shifts from the designated critical habitats in Canadian waters to the southern Gulf of St. Lawrence are likely to be associated with increased energy expenditures; however, changes in energy expenditures are not generally associated with threat impacts.

Climate change may be causing stress in individual NARWs. Trumble et al. (2018) determined that anomalies in the sea-surface temperature (from 1970 through 2016) were positively associated with baleen whale (fin, humpback, and blue whales) cortisol levels. However, other impacts to individual whales, such as disturbance, morbidity, mortality, etc., have not been directly associated with climate change.

Climate change is interconnected to many of the other threats addressed here and the *Individual Level of Impact* for the direct effects of climate change is difficult to estimate, thus the *Individual Level of Impact* was assessed as *Unknown* with a *Causal Certainty* of *Unknown*.

Population Level of Impact: High

The effects of climate change on cetaceans include changes in foraging opportunities leading to habitat loss and changes in distribution (Kebke et al. 2022). This has already been observed for NARWs as they are exposed to increased threats due to distribution changes associated with prey availability. Tulloch et al.'s (2019) modelling efforts in the Southern Ocean demonstrated that future climate change would threaten the recovery of the baleen whales that feed there. Furthermore, cetaceans may be directly affected by climate change through loss of suitable habitat for functional behaviours (Kebke et al. 2022). For example, Derville et al. (2019) estimated that many breeding sites of humpback whales will become unsuitably warm (greater than 28°C) by the end of the 21st century.

Climate change over the next 100 years will affect prey availability and possibly suitable habitat; however, contemporary estimates of population loss due to climate change are not available for the NARW. Climate change vulnerability studies can provide insights into the vulnerability of the NARW population to climate change. Albouy et al. (2020) assessed the sensitivity of 122 marine-mammal species to climate change based on 15 traits in the following categories: feeding, habitat, reproduction, social behaviour, and biology. Sensitivity to climate change ranged from 0 to 1. The sensitivity of NARWs was estimated at 0.88, which is in the 95th percentile of all species considered (Albouy et al. 2020). Similarly, in a climate change vulnerability study by Lettrich et al. (2023), NARWs scored very high for overall vulnerability, a relative measure calculated from biological sensitivity (ability to tolerate climate-driven changes in environmental conditions), and climate exposure (magnitude of environmental change). Due to the high vulnerability of NARWs to climate change, as well as the indirect and direct effects of climate change, the *Population Level of Impact* was assessed as *High* with a Causal Certainty of *Very High*.

Threat Frequency: Continuous

Climate change is a threat that is occurring without interruption and was assessed as *Continuous*.

Geographic Extent of Threat: Extensive

Climate change is occurring across the globe and although there is spatial variation in the impacts and rates of change across the Canadian Assessment Area and the Northwest Atlantic Assessment Area, the *Geographic Extent* of climate change was assessed as *Extensive*.

THREAT CATEGORY 5: SCIENTIFIC ACTIVITIES

Threat 5.1.1: Scientific Activities

Whale researchers in the 1950s considered the NARW essentially extinct or very nearly extinct (Kraus and Rolland 2007). Researchers from the Woods Hole Oceanographic Institute, Bill Watkins and Bill Schevill, observed a few NARWs in the Cape Cod Bay when performing acoustic studies on other species in the 1960s. Over the following 20 years, these two researchers made observations of the behaviour and the biology of these animals. Since the 1980s, research on NARWs has greatly expanded using a vast array of techniques, instruments, and platforms.

Various activities are included under the threat of scientific activity, each having different effects on individuals and the population. Scientific activities include but are not limited to: aerial and vessel-based surveys, invasive and non-invasive tagging, skin and blubber biopsies, close vessel approaches, uncrewed aerial vehicle (UAV) over flights, and acoustic playback experiments including conspecific and other sounds, including simulated sonar, vessels, and alert signals.

Likelihood of Occurrence: Known

From 2014 through 2023 there were 60 research articles published with *Eubalaena glacialis* in the title (Web of Science search 05 Nov 2024). The number of articles increased to 141 if *Eubalaena glacialis* was replaced with North Atlantic right whale with the same search parameters. These publications in the primary literature demonstrate the continued research on NARWs.

Furthermore, there have been continued funding commitments from both the Government of Canada and the federal government in the USA. The Government of Canada introduced a five-year $167.4 million Whales Initiative funding to support many governmental departments in the recovery of Canada's endangered whale populations including the NARW (TC 2022). In 2021, the Government of Canada awarded a total of $5.3 million to five Canadian companies advancing innovative solutions for protecting NARWs (CSA 2021). In 2023, the Biden-Harris Administration announced a historic $82 million of funding for NARWs (Wagner 2023).

The 2024 Annual North Atlantic Right Whale Consortium (NARWC) meeting hosted approximately 300 in-person attendees and an additional 200 virtual participants. The event provided a platform for presenting and discussing research, new techniques, management strategies, and other key aspects related to the conservation of right whales.

Research activities to support the conservation and recovery of NARWs were assessed as *Known*, with a 90-100% chance of occurring over the next 100 years.

Individual Level of Impact: Low

Given the wide range of scientific activities that could pose a threat to NARWs, we assessed each general activity at the *Individual Level of Impact* and used the highest Level of Individual Impact score as a measure for threat of Scientific Activities.

Aerial Surveys

Limited quantitative studies have examined the effects of aerial surveys on NARWs with Richardson et al. (1995) noting that right whales often seem to tolerate a light single-engine aircraft circling overhead, although some disturbances were also observed. Fairfield (1990) noted that small groups of NARWs (≤ 3) would dive during overflights that were conducted during the Cetacean and Turtle Assessment Program aerial surveys flown at approximately 305 meters. A low number of behavioural responses from bowhead whales were observed when a Bell 212 helicopter operated at an altitude of 150–460 m during over-flights, at 30–300 m within 2 minutes of landing and take-off, and when stationary on the ice with engine running; and when a Twin Otter operated at 150–460 m, circled the whales at 460 m or flew overhead (Luksenburg and Parsons 2009 and references therein). Responses included: abrupt dives, breaching, tail slapping, turning or heading away, and brief surfacing and occurred in 14% of observations from the Bell 212 helicopter and 2.2% of the observations from the Twin Otter (Luksenburg and Parsons 2009 and references therein). Southern right whales rarely reacted strongly to circling aircraft overhead (Payne et al. 1983 as cited in Richardson et al. 1995) and, similar to bowhead whales, southern right whales swam rapidly or dove, and the reactions were brief (Richardson et al. 1995). The Impact to Individuals from aerial surveys was assessed as *Low* with a *Causal Certainty* of *High*.

Vessel-Based Surveys

The impact to individuals of vessel-based surveys and close-vessel approaches is addressed above in the Threat Category of Vessel Traffic. It should be noted that two known and documented vessel strikes of NARWs were collisions with research vessels (Wiley et al. 2016).

Tagging

Electronic tracking and biologging devices (tags) are essential tools in cetacean research, providing valuable data on physiology, behavior, and ecology. This information supports management and conservation initiatives aimed at protecting endangered cetaceans (Andrews et al. 2019). Both invasive and non-invasive tags are available for scientific research, with invasive tags varying in size, configuration and degree of penetration into the hypodermal layer of the integument (blubber) and fascia layer (Andrews et al. 2019). Invasive tagging of large whales, including NARWs, poses potential risks to the health and welfare of a tagged individual (Andrews et al. 2019). There have been a few studies conducted on the impact of invasive tags on baleen whales that could be used to assess the *Individual Level of Impact*. Non-invasive tags, usually attached with suction cups, do not require subdermal attachment and were not considered in this assessment.

Localised and regional swelling, depression at tag site, blubber extrusion, skin loss, and pigmentation colour change have been observed in tagged baleen whales including NARWs, southern right whales, gray whales, and blue whales (Kraus et al. 2000, Moore et al. 2013, Best et al. 2015, Gendron et al. 2015, Norman et al. 2018, Andrews et al. 2019, Charlton et al. 2023). In humpback and southern right whales, there have been no observed effects on reproduction for invasively-tagged whales (Robbins et al. 2013, Charlton et al. 2023) and Best et al. (2015) demonstrated no effects of tagging on either reproduction or mortality rates in southern right whales. Pirotta and Thomas (2024) examined effects of older and more invasive technology on NARW, and noted no clear effect on health or calving probability due to small sample size and confounding factors. Gendron et al. (2015) reported that a blue whale experienced reproductive failures during the period the whale was experiencing broad swelling caused by a broken subdermal attachment of a tag. However, Charlton et al. (2023) discussed the need to explain the variation in reproduction reported by Gendron et al. (2015), as there could be many factors contributing to reproductive failure, and that the body condition of the animal in question was not discussed in the paper.

Invasive tags have been deployed on hundreds of large whales, including humpback, bowhead, fin, blue, North Atlantic, North Pacific, and southern right, gray, minke, and sperm whales (Gulland et al. 2024 and references therein) and there have been no deaths attributed to an invasive tag. However, there was a recorded case of an invasively tagged killer whale (*Orcinus* orca) dying from a fungal infection (mucormycosis) that was linked to spores introduced via the percutaneous attachment of a satellite tag (Huggins et al. 2020). Marine-mammal mortalities linked to mucormycosis in the northwest Pacific is unusual and unexplained (Huggins et al. 2020) and is not considered in the assessment of this threat.

Under NOAA's UME criteria for inclusion of morbidity, swelling and depressions by themselves are not enough to classify an injury as either medium severity or high severity under the morbidity category (Costidis et al. 2023). The observed swellings and depressions caused by invasive tagging would not be included as a morbidity count under the UME for NARWs. Thus, the *Individual Level of Impact* was assessed as *Low* with a *Causal Certainty* of *High*.

Skin and Blubber Biopsies

Skin and blubber biopsies can provide valuable information on genetics, epigenetics, diet, and hormones relating to pregnancy and stress (Frasier et al. 2007a, Graham et al. 2021, Moore et al. 2021 and references therein, Crossman et al. 2024). In a review of cetacean biopsy techniques, Noren and Mocklin (2012) concluded that biopsy sampling of baleen whales resulted in low-to-moderate short-term behavioural responses such as humpback whales displaying tail flicks and fin whales submerging (Gauthier and Sears 1999). In another study, the majority of humpback whales did not exhibit any response to biopsy sampling (Garrigue and Derville 2022). Based on the behavioural reactions of other baleen whales to skin and blubber biopsies the *Individual Level of Impact* was assessed as *Low* with a *High Causal Certainty*.

Uncrewed Aerial Vehicle Over Flights

There is increasing use of UAVs in cetacean research. Various types of UAVs have been used to investigate thermal physiology, collect photogrammetry data, samples of blows, and even to attach biologging tags (Durban et al. 2016, Pirotta et al. 2017, Christiansen et al. 2019, 2022, Lonati et al. 2022, Wiley et al. 2023, O'Mahony et al. 2024, Pirotta et al. 2024). A few studies provided anecdotal or limited evidence that baleen whales do not demonstrate behavioural responses to UAV activities (e.g., Christiansen et al. 2016, Durban et al. 2016, Pirotta et al. 2017, Torres et al. 2018). In an in-depth study of southern right whale mother-calf pairs, Christiansen et al. (2020) detected no behavioural responses to the close approaches of UAVs thus the *Individual Level of Impact* for the NARW was assessed as *Low* with a *Causal Certainty* of *High*; noting that it is not possible to assign no effect based on the criteria.

Acoustic Playback Experiments

Mathews and Parks (2021) provide a summary of the responses of NARWs to playback experiments that included conspecific vocalisations, sounds from southern right whales, vessel noise and a man-made alert signal. Behavioural responses included changes in swimming direction and orientation, dive behaviours and foraging (Mathews and Parks 2021 and references therein). Thus, the *Individual Level of Impact* from acoustic playback experiments for the NARW was assessed as *Low* with a Casual Certainty of *Very High*.

We assessed six different scientific activities that could pose a threat to NARWs. In both Canada and the USA, scientific activities are rigorously reviewed through animal care committees and permitting processes to ensure that impacts are acceptable and account for the population status. As all six scientific activities were assessed as *Low*, the *Individual Level of Impact* was assessed as *Low* with a *Causal Certainty* of *High.*

Population Level of Impact: Low

Given the generally low levels of impact on individual NARWs due to scientific activities with no known mortalities observed and no observed changes in reproduction for NARW or closely related species, the *Population Level of Impact* was assessed as *Low*. Scientific activities will result in little change to the population and the threat is unlikely to jeopardize the survival or the recovery of the species. The *Causal Certainty* was assessed as *High*, as most of the information for the *Individual Level of Impact* was also assessed as *High*.

Threat Frequency: Continuous

Research focusing on NARWs occurs continuously, especially with the archival passive acoustic monitoring that takes place for this species. Various research programs overlap in time and space and there is a spatiotemporal progression of surveys. Aerial surveys for NARWs usually start in the southern calving ground mid-November and continue through to mid-April. In the mid-Atlantic, surveys start in November and continue through June, and in the northeast waters of the USA and the Gulf of Maine surveys are conducted October through September. In Canadian waters, aerial surveys are generally conducted mid-April through mid-November with vessel-based surveys generally taking place June through September. Many other research projects are conducted during the surveys listed, therefore, the *Threat Frequency* was assessed as *Continuous*.

Geographic Extent of Threat: Broad

Research and monitoring for NARWs occurs throughout its range in both Canada and the USA. Monitoring for NARWs includes aerial systematic and mark re-capture surveys, vessel-based surveys, and passive acoustic monitoring through the use of archival systems and near-real time buoys and gliders (NARWC 2024b).

Invasive and non-invasive tagging studies have been undertaken in many NARW habitats, such as the Bay of Fundy, southern Gulf of St. Lawrence, Cape Cod Bay, Great South Channel, and in the southern calving ground (e.g., Mate et al. 1997, Matthews et al. 2001, Baumgartner and Mate 2003, McCordic et al. 2016, Root-Gutteridge et al. 2018, Wright et al. 2024).

Other NARW research and associated prey studies have occurred throughout the species' range (e.g., Weinrich et al. 2000, Baumgartner et al. 2003, Pershing et al. 2009, Hlista et al. 2009, Patrician & Kenney 2010, Mussoline et al. 2012, Davies et al. 2014, Gowan & Ortega-Ortiz 2014, Rice et al. 2014, Hodge et al. 2015, Durette-Morin et al. 2019, Sorochan et al. 2019, Brennan et al. 2021, Ross et al. 2021, Sorochan et al. 2021, Helenius et al. 2024, Johnson et al. 2024). However, the majority of research activities focus on critical habitats and NARW aggregation areas and, thus, the *Geographic Extent of the Threat* was assessed as *Broad*.

THREAT CATEGORY 6: DIRECT HARVESTING

Threat 6.1.1: Whaling (Harvest or Hunt)

The NARW was the subject of intense historical whaling dating back to the 11th century (Aguilar 1981, 1986). Hunted originally by the Basques, right whales were also hunted by several seafaring nations throughout the North Atlantic Ocean (Allen 1908, Aguilar 1986). Whaling was especially fervent in the 16th and 17th centuries; however, diminishing stocks and low catches soon afterwards signaled the over-exploitation and near-eradication of the eastern North Atlantic population by the late 17th century, and of the western North Atlantic population by the mid-18th century (Allen 1908, Aguilar 1981, 1986, Reeves & Mitchell 1986b, Reeves 2001).

In the 19th century, whaling continued along the eastern USA, particularly in the southeast USA centered along the coasts of South Carolina and Georgia (Reeves et al. 1978, Reeves and Mitchell 1986a,b). At least 150 NARW were killed by American whalers between the 1850s and 1890s in the southeastern USA, the Cape Farewell Ground (Greenland), the Cintra Bay Ground

(West Africa), and other areas offshore (Reeves et al. 2007). In 1950, two whales were taken in the Gulf of St. Lawrence by the Gaspé sailing vessel fishery (Mitchell and Reeves 1983). Modern shore whaling in the British Isles, Ireland, Iceland, Norway, the Faroes, and eastern Canada between 1889 and 1951 resulted in approximately 140–150 kills, although this is likely underestimated (Reeves et al. 2007).

During the 20th century, catches in the eastern North Atlantic and along the eastern USA continued (Reeves et al. 1978, Brown 1986, Reeves et al. 1999, Reeves 2001). Approximately 135 NARW were killed in the northeast Atlantic Ocean between 1900 and 1937 (Brown 1986). Three catches were made in Canada, the last of which was off Newfoundland in 1951 (Sergeant 1966, Mead 1986, Mitchell and Reeves 1983).

Likelihood of Occurrence: Remote

Right whales were given international protection in 1935 by the International Convention for the Regulation of Whaling, although this was not observed by all whaling countries. A new agreement was established in 1946 and remains active for all members of the International Whaling Commission (Brown 1986). Although NARWs are internationally protected from whaling, there is a remote chance that indigenous subsistence whaling, which is approved by the International Whaling Commission (Nussbaum Wichert and Nussbaum 2017), could occur within the next 100 years. Thus, we assessed the *Likelihood of Occurrence* as *Remote*.

Individual Level of Impact: Extreme

After a millennium of whaling of NARWs, low genetic diversity has been observed in the species (Malik et al. 2000, Waldick et al. 2002, Frasier et al. 2007b, Crossman et al. 2023). The population shows relatively high rates of recent inbreeding (Crossman et al. 2023) the result of which could be poor reproductive success due to inbreeding depression (Crossman et al. 2024). The loss of genetic diversity due to whaling continues to affect NARWs (Malik et al. 2000, Rosenbaum et al. 2000) and a resumption of whaling could further exacerbate the poor reproductive success of NARWs.

Pre-modern whaling technology involved a substantial number of lost whales. Struck (harpooned) whales were categorized as: 1) struck, killed, and processed, 2) struck but escaped, presumably survived, 3) struck but escaped moribund (lance and/or spouting blood; whaling gear attached), and 4) struck, killed, but not processed (IWC 1986). These whales were often referred to as struck but lost or struck and lost. Struck and lost whales that survived ranged from slightly injured and recovered, to severely injured and eventually dead (Vighi et al. 2021). Furthermore, in indigenous subsistence whaling of bowhead whales, there continues to be reports of struck and lost whales (Suydam et al. 2006, Reeves and Lee 2022 and references therein). While the fate of struck and lost whales is mostly unknown throughout whaling history, it was estimated that the majority of the struck and lost whales from the Alaskan subsistence hunt had a poor chance of survival (Suydam et al. 2006). The effect of the injuries sustained by struck and lost whales on subsequent reproduction is unknown. However, the Alaskan subsistence hunt for bowhead whales has taken pregnant females at various stages, including those carrying full-term fetuses, as well as lactating females (e.g., Suydam et al. 2019, Scheimreif et al. 2022). Thus, we assessed the *Individual Level of Impact* as *Extreme* with a *Causal Certainty* of *Very High*.

Population Level of Impact: Low

We categorized *Population Level of Impact* as *Low* and *Causal Certainty* as *Very High*, assuming that a precautionary approach would be applied if and when future whaling occurs and, therefore, only a few animals would be taken resulting in little change in population size.

Threat Frequency: Recurrent

In Canada, NARWs are protected by the Marine Mammal Regulations under the *Fisheries Act* (RSC 1985, c F-14) and the *Species at Risk Act* (SC 2002, c 29). Commercial whaling is very unlikely to occur over the next 100 years given the population size and protected status of NARWs. However, there is a remote possibility that indigenous subsistence whaling could occur over the next 100 years. In Canada, the hunting of cetaceans focuses mainly on bowhead whales, beluga whales *(Delphinapterus leucas),* Narwhals *(Monodon monoceros),* harbour porpoises *(Phocoena phocoena),* white beaked dolphins *(Lagenorphynchus albirostris),* and Atlantic white sided dolphins *(Lagenorhynchus acutus)* (e.g., Freeman et al. 1992, Reeves 2002, Harley Eber 1989, Nunny and Simmonds 2022). NARWs have not been the target of subsistence hunts (e.g., IWC 1977, Freeman et al. 1992, Suydam and George 2021). As there is a remote possibility of subsistence whaling of NARWs could occur periodically the *Threat Frequency* was assessed as *Recurrent*.

Geographic Extent of Threat: Narrow

Historically, whaling of NARWs occurred throughout the northern Atlantic Ocean including areas of the Canadian Assessment Area and larger areas along the east coast of the USA. However, historical records of indigenous whaling are inconclusive for both Canada and the USA (Reeves et al. 2007 and references therein). Under the assumption that a precautionary approach would be applied if and when future whaling occurs, and hunting areas would be limited due to the small number of whales taken; we assessed the *Geographic Extent* of whaling as *Narrow* in both Assessment Areas.

THREAT CATEGORY 7: RESOURCE DEPLETION

Threat 7.1.1: Food Supply Reduction Through Directed Fisheries

NARWs primarily feed on lipid-rich, late copepodite stages of *Calanus* species, with *Calanus finmarchicus* being the dominant species (Wishner *et al.* 1988, 1995, Murison and Gaskin, 1989, Mayo and Marx 1990, Beardsley et al.1996, Baumgartner et al. 2003, Baumgartner and Mate 2003, Michaud and Taggart 2007, Davies et al. 2015). The three most abundant species of *Calanus* in the North Atlantic include *C. finmarchicus* (especially in the Northwest Atlantic), *C. glacialis and C. hyperboreus* (found predominantly in the Arctic Ocean, Parent et al. 2011). *C. hyperboreu*s is a large calanoid copepod that inhabits arctic and subarctic regions of the Atlantic and contributes to the zooplankton community in deep areas of the Gulf of St. Lawrence, Gulf of Maine, and Scotian Shelf (Runge and Simard 1990, Sameoto and Herman 1990, Johnson et al. 2018). *Calanus finmarchicus* dominates the abundance and biomass in most of the NARW habitats except in the Gulf of St. Lawrence where *C. hyperboreus* is more abundant (Sorochan et al. 2019). NARWs can also supplement their diet with other zooplankton species, including *Pseudocalanus* spp., *Centropages typicus*, and euphausiids (Collett 1909; Watkins and Schevill, 1976, Mayo and Marx 1990).

Historically, commercial zooplankton fisheries focused on approximately 20 different species, including copepods, mysids, euphausiids, sergestids, and Scyphomedusae, with copepods used as food for pet fish and cultured salmonids (Omori 1978). There has been a renewed interest in using zooplankton species, especially *C. finmarchicus*, as an alternative to fish oils as a source of the omega-3 fatty acids eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA, Prado-Cabrero and Nolan 2021). A copepod fishery could also provide a sustainable high-protein feed or supplement for aquaculture in Atlantic Canada.

Likelihood of Occurrence: Remote

Commercial fishing of the *C. finmarchicus* copepod has been operational in several regions on a small scale since at least the1960s with reported annal catches of approximately 18-45 tonnes (Omori 1978). In comparison, euphausiids have been more extensively fished in Antarctic waters (>9,072 tonnes per year in some cases), although a search for alternatives began after whale stocks started to show signs of decline (Prado-Cabrero and Nolan 2021).

In Norway, there has been a recent push to significantly expand copepod fisheries with an increased interest in targeting *C. finmarchicus (*FiskerForum 2019, Gairn 2023, Johansen 2023). However, despite the number of licenses granted to harvesters and a large annual quota, there has been little uptake. In 2020 and 2021 there were no catches of *C. finmarchicus* and the 2022 copepod catch was only approximately 900 tonnes despite the 254,000 tonne quota (FiskerForum 2019, Gairn 2023, Johansen 2023).

An investigation conducted by the International Council for the Exploration of the Sea estimated that the consumption of *C. finmarchicus* by pelagic and mesopelagic fish and invertebrates alone does not leave enough biomass for the existence of a fishery (Prado-Cabrero and Nolan 2021). Furthermore, bycatch levels of a copepod fishery are thought to be enough to significantly reduce the biomass of eggs and larval fish, e.g., Atlantic Cod (*Gadus morhua*, Prado-Cabrero and Nolan 2021), and the location of a directed copepod fishery should take place in areas that would reduce this bycatch.

In Canada, under DFO’s Policy on New Fisheries for Forage Species (DFO 2009b), any new fisheries directed toward a forage species like copepods would have to meet the five following objectives:

1. maintenance of target, bycatch, and ecologically dependent species within the bounds of natural fluctuations in abundance;
2. maintenance of ecological relationships (e.g., predator-prey and competition) among species affected directly or indirectly by the fishery within the bounds of natural fluctuations in these relationships;
3. minimization of the risk of changes to species’ abundances or relationships which are difficult or impossible to reverse;
4. maintenance of full reproductive potential of the forage species, including genetic diversity and geographic population structure; and
5. allowance of opportunities to conduct commercially viable fisheries.

The first objective may be difficult to achieve given the indirect effects of climate change on NARWs and changes observed in the distribution due to changing prey sources.

Due to both the low reported catches and low interest in commercial fisheries for copepods in other jurisdictions, as well as the requirements of the DFO Policy on New Fisheries for Forage Species (DFO 2009b) the *Likelihood of Occurrence* was assessed as *Low*.

Individual Level of Impact: Unknown

Assessing the potential impacts of a fishery targeted toward NARW prey is challenging. Studies have shown that variability in prey abundance affects the health of individual NARWs, with long-term survival and reproductive trends linked to changes in the prey index developed by Pirotta et al. (2023). Given that natural variation in prey abundance and distribution is having measurable effects on the health, survival, and distribution of NARWs, further removal of prey species through a directed fishery could exacerbate these observed effects. A directed *Calanus* fishery could have a significant negative impact on NARWs if it was large scale, sustained, and coincided spatially and temporally with feeding aggregations. However, there is insufficient information to fully assess the *Individual Level of Impact* of direct fisheries on NARW prey as there is no information available on the operation of this type of fishery, thus, this threat was classified as *Unknown*.

Population Level of Impact: Unknown

NARWs are a highly mobile species and are capable of adapting to variability in the distribution of their prey on regional scales (Baumgartner et al. 2017). Changes in NARW distribution related to shifts in *Calanus* distribution have already been observed. Reductions in the abundance of prey species due to a directed fishery could lead to further distributional shifts as NARWs search for the dense patches of prey essential to their energic requirements. However, potential impacts of a directed fishery would depend on the scale and the spatiotemporal occurrence of the fishery.

To estimate changes in the probability of the quasi-extinction of NARWs, Runge et al. (2023) examined the effects of NARW prey returning to the abundance to levels observed prior to 2010. They found that increasing prey availability, while holding the effects of fishing-gear entanglements and vessel strike threats constant, reduced the probability of quasi-extinction for NARW by 6% (Runge et al. 2023), suggesting that further reductions in prey availability could have population level consequences for this species. In the absence of information on the scale, spatial extent, and timing of a directed fishery, the *Population Level of Impact* was assessed as *Unknown*.

Causal Certainty: Unknown and Unknown

For the *Individual Level of Impact* there is little available information to assess this threat, either for NARWs or other cetaceans. It has been hypothesized that competition with fisheries for prey species has led to malnutrition in bottlenose dolphins (Bearzi et al. 2003) and was a key factor in a large die-off of Mediterranean striped dolphins (*Stenella coeruleoalba,* Aguilar 2000). However, Plagányi and Butterworth (2009) state that it is “virtually impossible to wholly substantiate claims that predation by marine mammals is adversely impacting a fishery or *vice versa*.” Therefore, the *Causal Certainty* for both *Individual Level of Impact* and *Population Level of Impact* was assessed as *Unknown*.

Threat Frequency: Recurrent

Assuming all five objectives under DFO’s Policy on New Fisheries for Forage Species (DFO 2009b) were met, there is a remote possibility a directed fishery for NARW prey species could occur over the next 100 years. It is unknown how this type of fishery would operate, but given the seasonality in the life stages of copepods the *Threat Frequency* was assessed as *Recurrent*.

Geographic Extent of Threat: Unknown

As directed fisheries on NARW prey is an anticipatory threat and has not occurred historically, there is little information available on which species, or which associated areas would be targeted. Thus, the *Geographic Extent of Threat* was assessed as *Unknown* for both the Northwest Atlantic and Canadian Assessment Areas.

DISCUSSION

THREAT ASSESSMENT RESULTS

NARWs are nicknamed the “urban whale” (Kraus and Rolland 2007) as they tend to live in heavily industrialized waters and face multiple threats. This threat assessment evaluated some of the current and anticipatory threats that occur not only in Canadian waters but throughout the major habitat areas of the NARW. Most of the threats identified occur continuously and extensively throughout the NARW’s core habitats and transit corridors. There could be additional threats identified in the future, and the evaluation of the impact of contemporary and future threats could change with the implementation of increased and/or new conservation initiatives to support the survival and the recovery of the species.

The threat of petroleum spills was rated as *High* for the *Population Level of Impact* and *Extreme* for the *Individual Level of Impact*, however, it should be noted that this assessment was based on large spill events such as the Deepwater Horizon oil spill and the Exxon Valdez oil spill. The dose-response relationship for oil spills is generally unknown for cetaceans and much smaller spills that occur more frequently may have less severe consequences for NARWs.

The threat of whaling no longer occurs; however, indigenous subsistence whaling could occur within the next 100 years. Historical whaling had substantial impacts on NARWs at the population level and may still be impacting the population as NARWs have extremely low levels of genetic diversity with signs that inbreeding is occurring (Frasier et al. 2013, Crossman et al. 2023). Many of the other threats addressed here could similarly have long-term impacts on the population that have not been observed or measured thus far.

Approximately half (52%) of the threats were ranked as having *Unknown* impacts at the population level. Within the NARW population it is estimated that there are cryptic mortalities occurring with only approximately 37% of mortalities being directly observed (Pace et al. 2021). Furthermore, 23% of observed mortalities between 2003-2018 had an undetermined cause of death (Sharp et al. 2019). Unobserved mortalities and observed deaths with unknown or undetermined causes could be the result of threats whose potential impact cannot be assessed at this time due to a lack of information. Thus, it should not be assumed that threats ranked as *Unknown* do not have individual or population level impacts.

CUMULATIVE IMPACTS

The absence of a cumulative effects analytical approach hinders our ability to assess how multiple threats impact NARWs (Harcourt et al. 2019). All identified threats in this assessment were evaluated independently; however, almost all of the threats occur continuously throughout the major habitat areas of the NARW and the effects of these threats could be cumulative. Moreover, many whales have experienced these threats multiple times and in combination. Knowlton et al. (2012) estimated that 59% of NARWs had been entangled more than once and one individual had been observed entangled seven times. Expanding the time series from the Knowlton et al. (2012) study and including the years 1990-2021 (NARWC 2024a), EgNo 1507 (“Manta”) has been entangled nine separate times including a severe injury in 2020. EgNo 3590 (“Dog-Ear”) has been struck by a vessel three separate times and has been entangled once. There are 71 NARWs in the NARWC Anthropogenic Database that have encountered both vessel strike and entanglement threats multiple times (Figure 18) and these are threats where the majority of the cases leave physical evidence. In contrast, chemical pollution from persistent organic pollutants, plastics and marine debris, heavy metals, petroleum spills, and noise pollution from vessels, seismic surveys, active acoustic technology operations, drilling operations, and wind energy production, are difficult to assess or track through current visual health assessments and modelling (e.g., Pettis et al. 2004, Schick et al. 2013, 2016, Rolland et al. 2016).

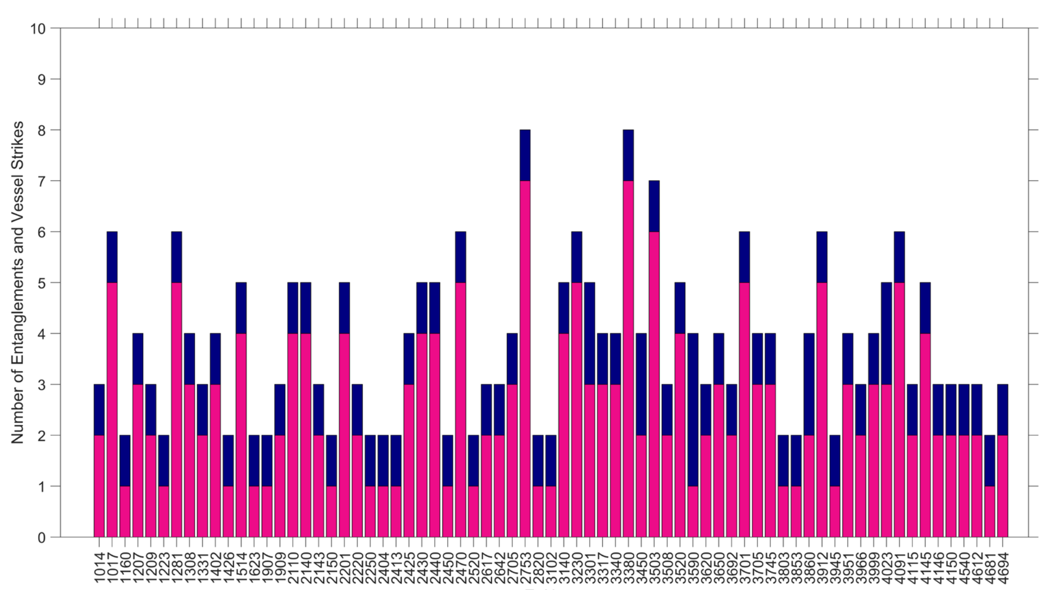

Figure 18. Individual North Atlantic right whales (EgNo = North Atlantic right whale catalog number) that have experienced both vessel strikes (navy) and entanglements (pink) multiple times between the years 1990 through 2021 (NARWC 2024a).

Climate change and some other threats such as drilling operations and wind energy production are also difficult to assess as they can have pervasive effects on NARW habitat and habitat use by altering ecosystem processes or the characteristics of the habitat. A threat causing distributional shifts of NARW or a change in environmental characteristics, including prey availability, could undermine management efforts and conservation initiatives that have been implemented to protect the NARW (e.g., Record et al. 2019).

THREAT ASSESSMENT GUIDANCE

DFO's guidance for threat assessments (DFO 2014b) tends to be qualitative, can be interpreted in different ways, and is sometimes difficult to evaluate. We modified several definitions provided by the guidance document and adapted them to be more appropriate for NARWs. Even with these modifications, there are several aspects of NARW demography, reproductive biology, and individual health that are not considered in the *Threat Risk* assessment. Furthermore, NARWs are a long-lived species and, although the threats were assessed over three generations or 100 years, the long-term effects of some of the threats in the pollution and energy development and production categories are unknown at the time of this report and may take several generations to be fully observed and quantified.

The threat assessment guidance (DFO 2014b) assesses threats over a qualitative scale, with several threats potentially rating similarly. Vessel strikes, fishing-gear entanglements, and petroleum spills were all rated as *High* or *Extreme* for their level of impact for NARWs. However, for some species, additional information may exist that allows for the relative importance of similarly-rated threats to be ordered. In the case of NARWs, entanglements were shown to represent a higher risk compared to vessel strikes (Knowlton et al. 2012, Linden et al. 2024, Runge et al. 2023). When formally assessing the Recovery Potential of a population following DFO guidelines (DFO 2014c), there is provision to examine the benefits from mitigating separately each threat and assess their relative impact on the population. However, in cases where the threat assessment is done separately, these types of information are not captured by the prescribed methodology.

Moors-Murphy et al. (2024) also had difficulties with the framework, although for different reasons (e.g., limited information for an offshore species). For some species there are even greater limitations on the amount of available data. For NARWs, the abundance of information on some of the threats led to a number of other challenges. For instance, having two distinct metrics to quantify *Population Level of Impact* resulted in the same threat having different rankings when model estimates or PBR were used to quantify the "jeopardize the survival or recovery of the population" of the definition.

In our assessment, the *Population Level of Impact* mainly focused on using the loss of individuals in the population to quantitatively assess each *Threat Risk.* In the northern bottlenose whale threat assessment (Moors-Murphy et al. 2024), the focus was on the qualitative assessment of the level of impact for the population, i.e., the level to which a threat jeopardizes the survival or recovery of the species (Table 1). However, neither of these approaches for quantifying the *Population Level of Impact* considered the sublethal impacts a threat can have on individuals (DFO 2014b). Sublethal effects of threats to NARWs include serious injuries, morbidity, harassment, disturbance, increased stress, and effects on reproduction, all of which may also impact the survival and recovery of the species. This information should be incorporated into the threat assessment.

Although only the *Population Level of Impact* was used in the calculation of the *Threat Risk*, we also assessed the *Individual Level of Impact* for each threat, similarly to Moors-Murphy et al. 2024 (Table 2). There is generally more information available to assess the impact of threats at the level of the individual, including sublethal impacts, potentially resulting in fewer threats being evaluated as having an *Unknown* impact. For example, if the *Threat Risk* for NARW was based on the *Individual Level of Impact*, only persistent organic pollutants pollution, heavy metals pollution, wind energy production, climate change, food supply reductions (directed fishing – copepods) would be classified as *Unknown*. There are different ways to incorporate this metric, such as the methodology used in climate change vulnerability studies (e.g., Hare et al. 2016), or by simply replacing the *Population Level of Impact* with the *Individual Level of Impact*. In this threat assessment, if the *Individual Level of Impact* was used in the *Threat Risk* calculation, the change in methodology would result in 52% (12 of 23) of the threats being assessed as *High*, one threat would be assessed as *Medium*, and five threats would be assessed as *Low*, representing a change of 48% of threats in terms of *Threat Risk* levels. Individual effects are essential for assessing the impact of the threat at the population level (Hague et al. 2022, Pirotta et al. 2022, Tyack et al. 2022) and should be considered for incorporation into *Threat Risk* methodologies.

The other metric in the *Threat Risk* calculation is the *Likelihood of Occurrence*, and in the guidance (DFO 2014b) it is unclear whether the percentage of chance provided in the definition is for the threat occurring once, at least once, or any number of times over three generations.

These represent very different probabilities. For example, the probability of one fishing-gear entanglement occurring annually is almost zero (8.3×10^{-39}) while the maximum probability of an annual fishing-gear entanglement (0.041) occurs at 92 entanglements (Figure 5). As we were evaluating the *Likelihood of Occurrence* over three generations to ensure we are using a biologically relevant time frame for NARWs, almost all threats were categorized as *Known*, making this metric non-discriminatory and less useful for the assessment.

OTHER CONSIDERATIONS

This threat assessment focused solely on anthropogenic threats to NARWs and did not consider limiting factors such as natural variation in prey availability, predation, biotoxins and toxic algae blooms, diseases, or inbreeding (see Vanderlaan et al. 2025).

CONCLUSIONS

NARWs face a plethora of threats including: historical threats that are still affecting the species; current threats despite implemented conservation initiatives; and anticipatory threats that are either under development or have not yet emerged. Some threats have extreme impacts on NARWs, while others have impacts that were difficult to assess. Many of the threats intersect each other and the cumulative effects of the threats were not assessed. It is essential for the survival and recovery of the NARW not to focus solely on mortalities and population level impacts. Investigating individual heath and reproductive rates will provide further information to inform conservation initiatives. Modelling efforts are essential to identify the impact of threats to the status and trend of the NARW population (Moore et al. 2021) as well as to determine which threats are contributing most to changes in health, reproduction, and survival and to better understand the cumulative effects of multiple threats.

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