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# Threat Assessment for Northern Bottlenose Whales (*Hyperoodon ampullatus*) off Eastern Canada, with a Focus on the Scotian Shelf Population

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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

This document provides an updated description of potential and known threats to Northern Bottlenose Whales (NBW, *Hyperoodon ampullatus*) off eastern Canada. There are two NBW populations that are recognized in Canada and managed separately: the Scotian Shelf (SS) population, which are listed as Endangered under the *Species at Risk Act (SARA)* and the Davis Strait-Baffin Bay-Labrador Sea (DSBBLS) population, which have not been listed under the *SARA*. The threat assessment considered 15 categories of threats to NBW, and risk was evaluated at two nested geographic scales: (1) for the Endangered Scotian Shelf population (SSDU), and (2) for both populations of NBW (SSDU and DSBBLS) in the western North Atlantic (NWA). Individual-level and population-level impacts of threats were assessed using best available information on impacts to NBW, beaked whale species and cetaceans, identifying uncertainty levels given sources ranging from published literature to expert review. The individual level of impact for both the SSDU and NWA was assessed as high or extreme for historical whaling, military sonar, entanglement, risks of depredation, vessel strike, and oil spills. For the SSDU, the population level of impact was assessed as either high or extreme for climate change, historical whaling, military sonar, entanglement, vessel strikes, and oil spills. For the NWA, the population level of impact was assessed as high for historical whaling, medium for climate change, and low for vessel noise, while the other 12 threats were assessed as unknown, primarily because there is no information on the size of the DSBBLS population. Categorization of a particular threat as unknown at the individual or population level of impact does not indicate a lack of effect or that the threat is not important. In many cases impacts are known to occur on individuals even if population-level impacts have not been or cannot be easily measured. It is likely that mortalities, injuries, and other impacts are underreported due to the offshore habitat of NBW. This threat assessment does not take into account direct impacts on NBW habitat, indirect effects or limiting factors (e.g., small population size, low genetic diversity), interactions between multiple threats, or cumulative impacts. Cumulative effects may alter the level of risk represented by individual threats. Predicted effects of climate change are particularly concerning, as they are likely to interact with other threats and despite uncertainties, may have a high level of impact on NBW.

# INTRODUCTION

Northern Bottlenose Whales (NBW; *Hyperoodon ampullatus*) are a beaked whale of the family Ziphiidae, found only in the North Atlantic Ocean and primarily occurring offshore in waters exceeding 500 m depth. There are two populations or designatable units (DUs) of NBW recognized in Canada, which are managed separately: the Scotian Shelf population, listed as Endangered under the Canadian *Species at Risk Act* (*SARA*; DFO 2016a), and the Davis Strait-Baffin Bay-Labrador Sea (DSBBLS) population, assessed as Special Concern by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC; COSEWIC 2011) but not currently listed under the *SARA*. The Scotian Shelf DU (SSDU) is estimated as approximately 175 individuals found along the edge of the Scotian Shelf off Nova Scotia and off the Grand Banks of southern Newfoundland (Figure 1; Feyrer 2021). Critical habitat for this population was identified in a Recovery Strategy (DFO 2016a) as areas in the Gully, Shortland, and Haldimand canyons of the eastern Scotian Slope, and are protected under the *SARA*. The inter-canyon areas were identified as important foraging habitat and movement corridors (DFO 2020a).There is no abundance estimate for the DSBBLS DU, where the range extends south from Baffin Bay to Labrador and Newfoundland, with a concentration of sightings in the Davis Strait (COSEWIC 2011). However, the boundary between the two DUs used by COSEWIC (2011) was chosen for administrative convenience and is not based on genetic or other data on population structure.

The Scotian Shelf NBW Recovery Strategy identifies the following as potential threats to the recovery of NBW: impacts of historical whaling, entanglement in fishing gear, oil and gas activities, acoustic disturbance (from various sources of anthropogenic noise), contaminants, changes to food supply and vessel strikes (DFO 2016a). The description of these threats has not been updated since the Recovery Strategy was originally published in 2010. The most recent COSEWIC assessment for NBW in Canadian waters identifies entanglement in fishing gear and ocean noise (i.e., anthropogenic noise) as the two principal threats to this species in Canadian waters, and states that while these threats are known to occur, the extent of harm resulting from them is uncertain (COSEWIC 2011). COSEWIC (2011) also identifies contaminant levels in tissues, possibly related to oil and gas activities, and suggests this is another threat for NBW in our waters, particularly for the Scotian Shelf population. It is important to note that while some indirect threats, such as inbreeding depression, small population size, genetic isolation, or any inherent biological characteristic that can lead to a loss of resilience could have a population-level impact, such “limiting factors” were not explicitly assessed here (COSEWIC 2019).

A Recovery Potential Assessment (RPA) completed for Scotian Shelf NBW in 2011 provided some additional information on most of these threats and also noted climate change as a potential threat (Harris et al. 2013), but did not evaluate them within a threat assessment framework as is required in more recent RPAs. The current RPA guidance describes a two-step approach to assessing and prioritizing threats to the survival and recovery of listed wildlife species, which includes evaluating the likelihood of occurrence, level of impact, causal certainty, and the risk, occurrence, frequency and extent of each threat, at both the population and species-level (DFO 2014). Fisheries and Oceans Canada (DFO) Science was requested to provide an updated description of the threats and complete a peer-reviewed threat assessment in accordance with DFO (2014) at two nested geographic scales: for the Scotian Shelf NBW population specifically, as well as for NBW throughout their range in Canadian waters. It should be noted that the SSDU represents the *SARA*-listed population; the NWA is an assessment unit that includes both the SSDU and DSBBLS populations and was created for the purpose of this threat assessment. The NWA is not a grouping that is recognized under the *SARA* or to which the *SARA* applies. This information is intended to be incorporated into an amended Recovery Strategy for Scotian Shelf NBW and will help guide future management actions and prioritization of recovery measures.

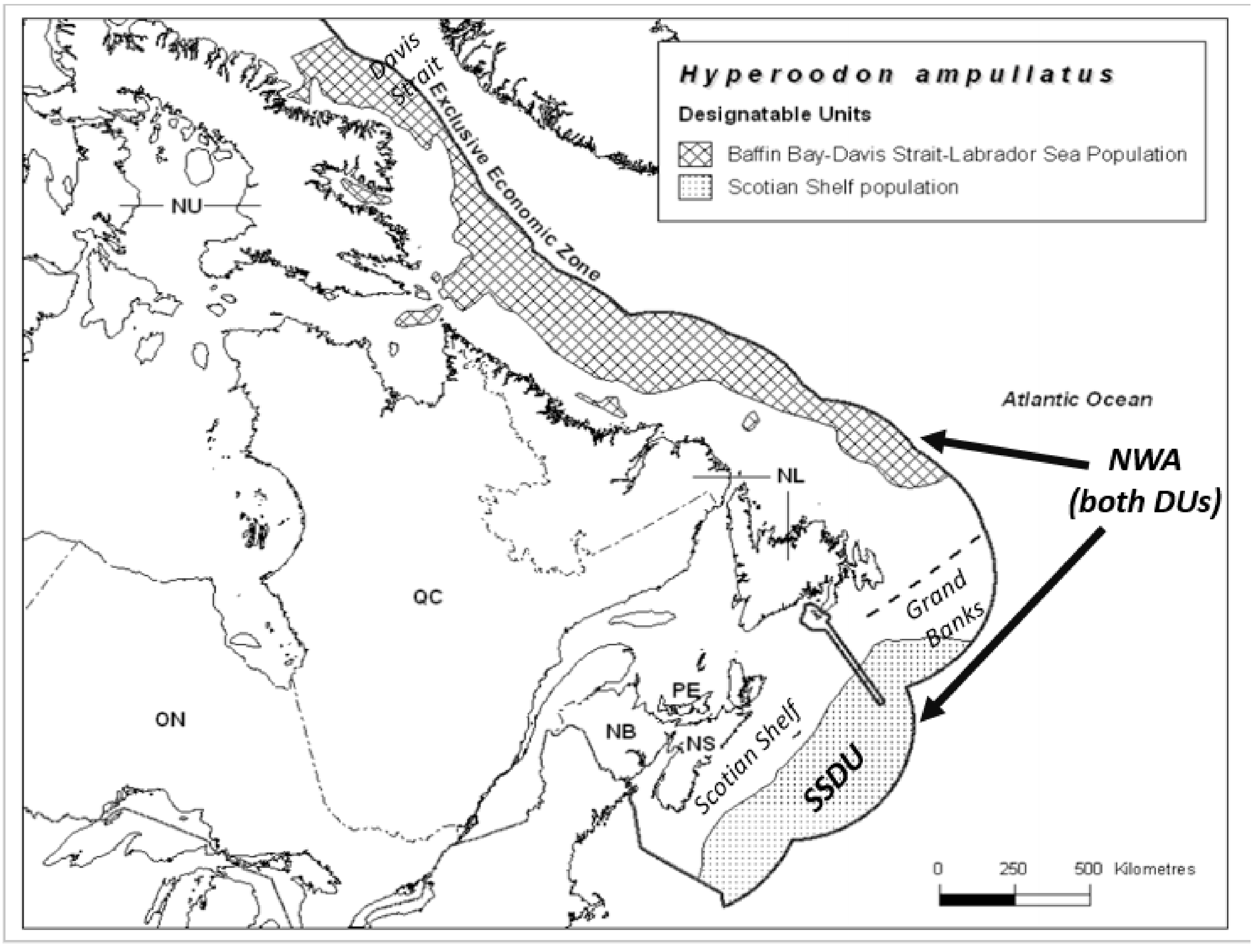


*Figure 1. Boundaries of the two Northern Bottlenose Whale (NBW) designatable units (DUs) in eastern Canadian waters; the broken line represents an arbitrary boundary between the DUs. This threat assessment considered two geographic scales: the Scotian Shelf population DU (SSDU), and the range of NBW throughout the Northwest Atlantic (NWA) which includes the DUs of both populations. Modified from COSEWIC (2011), with the Department of the Environment's permission.*

The request for this assessment specified that climate change should be included in the threat assessment table, contrary to previous guidance (DFO 2014). Climate change is recognized as an increasingly important threat to at-risk species in Canada, with marine mammals among the taxa most affected (Woo-Durand et al. 2020). However, the impacts of climate change on individual species, trophic webs, and ecosystems are complex and not well understood, and are often under-represented in assessments of risks, threats, and cumulative effects on species. The time span of retrospective assessments may be insufficient to observe the current effects of climate change on long-lived cetacean species, thus climate change is often referred to as a future or predicted threat and discussed with greater uncertainty than other threats which are more easily observed. There is no existing guidance or framework for appropriately incorporating the numerous, multifaceted, and likely cascading effects of climate change into a Species at Risk RPA. While we have included climate change as a distinct threat to NBW in this document, we have not fully addressed the scale and magnitude of this overarching issue, nor have we addressed the ways that other threats may be altered at a regional or global scale due to climate change. It is critically important that comprehensive threat assessments, such as the one presented in this document, be viewed through the lens of a rapidly changing environment.

This document addresses the following objectives:

1. Provide an updated description of threats identified for beaked whales off eastern Canada as they apply to NBW.
2. Produce a threat assessment table using the guidance set out in DFO (2014) to assess risk associated with each of the identified threats for Scotian Shelf NBW.
3. Produce a more broadly applied threat assessment table for NBW occurring throughout their range off eastern Canada, including western North Atlantic waters off Nova Scotia, Newfoundland and Labrador.

# UPDATED INFORMATION ON THREATS

As described above, several threats have been identified for NBW off eastern Canada, and specifically for the Endangered Scotian Shelf population (COSEWIC 2011, Harris et al. 2013, DFO 2016a). Previously, particular importance was placed on the impacts of anthropogenic noise/acoustic disturbance and entanglement in fishing gear. However due to the long generation time and slow reproductive rate of NBW (Feyrer et al. 2020), there is uncertainty in whether populations have recovered from the demographic impacts of intensive whaling operations over the last century (COSEWIC 2011).

The following sections describe available information on known and potential threats to NBW at the individual and population level off eastern Canada. Threats specific to NBW habitat and the environment are not directly considered in this assessment. The objective of these background sections is to describe each threat and pathways of effects (where known). More specific information on the spatial/temporal occurrence of threats and potential overlap with NBW habitat areas or critical habitat is provided below the risk assessment table within the section "Rationale for Threat Characterization." Due to a general paucity of information on individual- and population-level impacts for NBW, we also draw on the relevant literature pertaining to effects on other species of beaked whales and cetaceans.

## THREAT 1: CLIMATE CHANGE

Global climate change is altering the physical conditions and oceanographic processes that support marine ecosystems, and these changes are expected to continue at an accelerating rate throughout the 21$^{st}$ century (IPCC 2019). Range shifts and distributional changes associated with changing marine ecosystems have already been observed in cetacean species around the world (e.g., Chambault et al. 2018, Evans and Waggitt 2020), and in eastern Canada (Meyer-Gutbrod et al. 2018, Record et al. 2019). Distributional changes are predicted to continue as cetaceans respond to shifting prey resources and increasing ocean temperatures (Kaschner et al. 2011).

A global assessment of the vulnerability of marine mammals to climate change using a trait-based approach characterized NBW with a moderately high vulnerability score, falling above the mean score calculated for all marine mammal species (Albouy et al. 2020). Traits that increase sensitivity to climate change include diet and/or habitat specialization, restricted or fragmented geographic ranges or ranges that span limited latitudinal gradients, long generation times, low reproductive output, and large body mass (Albouy et al. 2020). Cetacean range models for the eastern North Atlantic predicted a northward shift in range for NBW under future climate scenarios (Lambert et al. 2014), reflecting global predictions of range shifts to higher latitudes (Kaschner et al. 2011, Silber et al. 2017).

The changing climate is likely to influence and potentially exacerbate many of the threats outlined in this document, as well as facilitate the emergence of new threats to NBW and other cetacean species. These may include increased fishing pressures, new Arctic shipping routes which alter patterns of anthropogenic noise exposure and risk of vessel strikes, changes in contaminant transport (Macdonald et al. 2003), and increasing incidence of infectious disease outbreaks (Sanderson and Alexander 2020). Range shifts could significantly alter the spatial and temporal overlap with threats off eastern Canada, undermining current management approaches (e.g., Record et al. 2019). The negative effects of climate change have been demonstrated by the multiple mortalities of highly endangered North Atlantic Right Whales (*Eubalaena glacialis*) resulting from an increased number of vessel strikes and entanglements off eastern Canada in 2017 (Daoust et al. 2017) and 2019 (Bourque et al. 2020). A shift in distribution of this species into new areas, in response to changes in prey availability caused by rapid climate-driven changes in the ecosystem, reduced the effectiveness of spatially-focused conservation strategies based on historical patterns of occurrence (Meyer-Gutbrod et al. 2018, Record et al. 2019). In the example of North Atlantic Right Whales, climate change impacts off eastern Canada have already had substantial consequences. This demonstrates the urgency and importance of considering climate-driven changes when developing conservation strategies for at-risk species.

## THREAT 2: HISTORICAL WHALING

Commercial whaling in the North Atlantic over the 19th–20th centuries was intensive, causing significant population declines of all large whale species across the region, including NBW (Roman 2003, Baker and Clapham 2004). The ecosystem impacts of large-scale biomass extraction at higher trophic levels by whaling removals is poorly understood due to shifting baselines (Pauly 1995). However, our understanding of the ecological role of whales (Pershing et al. 2010, Roman et al. 2014) and studies of large-scale removals of predators across marine ecosystems (Baum and Worm 2009) suggest that widespread whaling exploitation has impacted ecosystems, and altered carbon and nutrient cycling across the North Atlantic (Doughty et al. 2016). Such large-scale ecosystem changes have the potential to trigger regime shifts, such as trophic cascades (e.g., Springer et al. 2003) and may be limiting the recovery of some species. In light of the intersection with known climate related threats, the ecological consequences of historical whaling have likely reduced marine species resilience to change and may still be limiting the recovery of the Atlantic ecosystem (Pershing and Stamieszkin 2020).

NBW were the only species of beaked whale in the North Atlantic to be targeted by commercial whaling, which is estimated to have taken over 65,000 individuals between 1850–1970s (Mitchell 1977, Reeves et al. 1993). However, these estimates are considered conservative due to underreporting, incomplete and missing whaling records, and the unknown number of whales that were struck and lost (Whitehead and Hooker 2012). A small-scale hunt for NBW in the Faroe Islands has occurred since the 16th century but continues to take only a couple of whales per year (Bloch et al. 1996). Reconstructed historical population size estimates, important for understanding recovery, provide highly variable assessments ranging from 35,000–110,000 NBW across the North Atlantic (NAMMCO 1995). Models of population recovery trends across the species' range have similar levels of uncertainty and have estimated that NBW could either be fully recovered or still severely depleted as of the 1990s (NAMMCO 1995).

Understanding the recovery of historically whaled populations requires data on reproductive rates, population structure, migration, and sources of unnatural mortality. Available population recovery models have not incorporated updated population size estimates for the North Atlantic

(Rogan et al. 2017, Pike et al. 2019) or new understanding of species biology from recent studies on NBW (Feyrer et al. 2019, 2020). While there is some uncertainty surrounding pre-whaling population structure for NBW, across a species' range, demographically fragmented or evolutionarily distinct sub-populations may recover at different rates due to geographic isolation or culturally transmitted information on migration and foraging habitat. Over-exploitation of small or peripheral populations can also limit their recovery by decreasing genetic diversity, increasing the risk of inbreeding and isolation, and disrupting limited connectivity with other populations by reducing migration or individual movements. While there is a range of uncertainty on the precise demographic impacts for NBW, it is likely the legacy of historical whaling in the North Atlantic continues to provide challenges for the species' recovery.

## THREAT 3: ACOUSTIC DISTURBANCE

Beaked whales, including NBW, use sound to find prey, communicate, and sense their environment. Due to their sensitive hearing and reliance on sound for many life functions, anthropogenic noise introduced by human activities poses a threat to these species (Richardson et al. 1995, COSEWIC 2011). Sources of anthropogenic noise in the marine environment include vessel traffic, oil and gas exploration and extraction, construction, military exercises including the use of sonar and underwater detonations, low-level aircraft, and non-military active acoustic technologies such as depth sounders, multibeam sonar, and scientific echosounders. Potential effects of anthropogenic noise on beaked whales and other cetaceans may be categorized as physiological, including temporary or permanent hearing impairment, heightened levels of stress hormones, organ or tissue damage, and mortality; behavioural, including disruption of normal activities such as foraging, socializing, or resting, displacement from habitat, and stranding; and ecological, including acoustic disturbance of prey species and the effects of auditory masking, which may hamper the detection of prey, predators, and conspecifics and reduce the ability to avoid other anthropogenic threats (DFO 2015). Despite many advances in beaked whale research over past two decades, there is still significant uncertainty regarding the extent to which these effects occur, the noise source characteristics, exposure levels, and contexts that are likely to cause them, and the potential consequences for beaked whale populations (Hooker et al. 2019). Here, we summarize available information on acoustic impacts that are relevant to this threat assessment.

### Threat 3a: Military Sonar

The most extensively studied concern involving the impacts of anthropogenic noise on beaked whales is the use of military sonars, which has been linked to fatal mass strandings of beaked whales around the world (D'Amico et al. 2009, Simonis et al. 2020). Animals involved in these stranding events showed evidence of gas bubble lesions and fat emboli in blood vessels and organs, similar to decompression sickness, which likely resulted from changes in diving behaviour and a physiological "fight or flight" response (Bernaldo de Quirós et al. 2019). Controlled exposure experiments have revealed that beaked whales typically exhibit strong avoidance behaviours when exposed to simulated sonar signals, including the cessation of foraging activity, extension of dive durations, and initiation of directed, sometimes rapid movement away from the sound source (e.g., Tyack et al. 2011, DeRuiter et al. 2013). Most experimental work to date has focused on Cuvier's (*Ziphius cavirostris*) and Blainville's (*Mesoplodon densirostris*) Beaked Whales, but similar responses have been observed in Baird's Beaked Whales (*Berardius bairdii*) (Stimpert et al. 2014), and more recently in NBW (Miller et al. 2015, Wensveen et al. 2019). In a study of NBW in the eastern North Atlantic, Wensveen et al. (2019) found that tagged whales initiated strong avoidance responses to simulated sonar at relatively low received levels even when sound sources were located up to 28 km away (the maximum range tested). These findings suggest that beaked whales inhabiting relatively ‘pristine’ environments, where sonar use is uncommon, may perceive even distant sonar signals as a threat, and indicate that exposure context is an important factor determining the responses of beaked whales to sonar.

One NBW was recorded in a multi-species mass stranding linked to military exercises in the Canary Islands in 1988 (Simmonds and Lopez-Jurado 1991). More recently, an atypical mass stranding of NBW occurred in Iceland in summer 2018 (Grove et al. 2020), in conjunction with a mass stranding event occurring across the British Isles and involving multiple beaked whale species (Brownlow et al. 2018). The cause of these fatalities is still under investigation and none of the strandings have been conclusively linked to anthropogenic noise; however, the timing of the first strandings reported in Iceland in 2018 coincided with a North Atlantic Treaty Organization anti-submarine warfare training exercise conducted in the Norwegian Sea (Allied Maritime Command 2018). It is important to note that fatal strandings related to human activities are most likely to be documented in regions where beaked whales inhabit areas near populated coastlines. The effects of open-sea naval exercises on offshore beaked whale populations are difficult to observe, and cryptic mortality is more likely in these settings (Faerber and Baird 2010). Sub-lethal effects are similarly challenging to observe and quantify, but experimental research has demonstrated that exposure to sonar can cause significant disruption of normal behaviours. Studies of the distribution and foraging activity of Blainville’s Beaked Whales in a U.S. Navy training range following multi-ship naval training exercises have demonstrated cessation in foraging activity, disruption of normal dive cycles, and displacements of up to 70 km, lasting up to a few days (Tyack et al. 2011, Joyce et al. 2019). Miller et al. (2015) reported a displacement of at least 36 km for an individual NBW experimentally exposed to sonar signals and did not observe a return to baseline foraging behaviour within the duration of the study (7 h post-exposure). This scale of disturbance is likely to incur energetic costs and may result in a loss of foraging opportunities (Joyce et al. 2019, Benoit-Bird et al. 2020).

## Threat 3b: Vessel Noise

Far less research effort has focused on understanding the impacts of anthropogenic noise other than sonar on beaked whales. Vessel noise is pervasive throughout the marine environment and increasing levels of marine traffic over the past several decades have contributed to a global increase in low-frequency ambient ocean noise (Erbe et al. 2019). While the auditory masking effects of vessel noise are of greatest concern for baleen whales, which produce calls within the same frequency range as the peak sound energy emitted by large vessels (10 Hz–1 kHz), fast-moving vessels can also generate significant sound energy at higher frequencies (> 10 kHz) (Veirs et al. 2016). NBW produce echolocation clicks with peak frequencies around 26 kHz (Clarke et al. 2019) and may experience some degree of auditory masking by the higher-frequency components of vessel noise, particularly at close ranges. Little is known about the potential consequences of masking or other effects of vessel noise on most beaked whale species. Research in the Mediterranean Sea has suggested that Cuvier’s Beaked Whales avoid areas with high densities of ship traffic (Podestà et al. 2016). Direct behavioural responses to vessel noise have been noted in a single observation of a Cuvier’s Beaked Whale (Aguilar Soto et al. 2006) and a larger study of Blainville’s Beaked Whales (Pirotta et al. 2012). In both cases, animals altered their natural foraging behaviour and consequently experienced a short-term reduction in foraging efficiency. Based on the limited data available, these behavioural responses appear to be less acute than the responses observed following exposure to sonar, but may pose a cumulative concern if chronic behavioural disruption reduces the energy gain from foraging bouts over time (Pirotta et al. 2012). Unlike many other beaked whale species, NBW have a propensity to approach vessels (Gray and Flower 1882), and it is not known to what extent this behaviour is triggered by vessel noise.

### Threat 3c: Seismic Airgun Surveys

Seismic airguns used in the exploration of geophysical features, such as oil and gas reserves beneath the seafloor, are one of the largest contributors of anthropogenic noise in the marine environment, producing intense pulses of sound at high source levels for extended periods of time. Like vessel noise, the potential effects of this low-frequency noise on beaked whales and other odontocetes are poorly understood. The dominant acoustic energy produced by seismic airguns is in the frequency range of 10–120 Hz, but broadband sound energy can also be produced up to frequencies of 22 kHz or higher (Evans 1998, Goold and Fish 1998). Theriault and Moors-Murphy (2015) conducted a comprehensive review of the possible effects of seismic airguns on cetaceans, which include the potential for physiological or auditory injury, chronic stress, behavioural changes, and indirect ecological effects. Little experimental research has been conducted on NBW or other beaked whales to assess these potential impacts, and only limited data exist in the broader cetacean literature. Among odontocetes, short-term behavioural responses to seismic airgun surveys have been observed, with varying degrees of displacement, avoidance, or alteration of foraging behaviour seen in Harbour Porpoises (*Phocoena phocoena*) (Thompson et al. 2013), Sperm Whales (*Physeter macrocephalus*) (Miller et al. 2009), Pilot Whales (*Globicephala macrorynchus*) (Weir 2008b), and Atlantic Spotted Dolphins (*Stenella frontalis*) (Weir 2008a). These responses ranged from subtle changes in movement patterns during foraging dives (Miller et al. 2009) to displacement from an affected area for less than a day (Thompson et al. 2013), and no long-term effects were noted. Broad-scale multi-species studies have shown a significant decrease in odontocete sightings during seismic airgun surveys (Stone and Tasker 2006, Kavanagh et al. 2019). Any disruption to normal diving behaviour is likely to have energetic consequences for deep-diving species (such as beaked whales) due to the energetic constraints of performing deep dives; these species may also experience higher received noise levels as they enter deep sound channels where greater sound propagation occurs (Evans 1998).

One documented stranding of two Cuvier's Beaked Whales occurred in Mexico in 2002 during a nearby seismic airgun survey (Peterson 2003). Barlow and Gisiner (2006) later noted that 3.5 kHz echosounders, similar in frequency to naval sonars, were used concurrently with the seismic airguns during this survey, and the specific cause of the beaked whale stranding remains unknown. The likelihood of observing harmful effects of seismic airgun surveys, including mortality, is extremely low in offshore regions where these surveys often overlap with beaked whale habitat.

NBW and other beaked whale species may also suffer indirect effects due to the impacts of seismic airguns on prey species. NBW feed primarily on squid in the genus *Gonatus*, and may occasionally consume a variety of other squid and fish species (Hooker et al. 2001). Cephalopods and many fish species are sensitive to particle motion rather than sound pressure waves (Carroll et al. 2017), and exposure to low-frequency sound can damage the sensory systems of cephalopods (André et al. 2011). Experimental studies have demonstrated a strong startle response and changes in swimming behaviour by Southern Reef Squid (*Sepiotuethis australis*) when exposed to increasing levels of seismic airgun noise, suggesting that squid may respond behaviourally to nearby airgun use (Fewtrell and McCauley 2012). Similarly, Longfin Squid (*Doryteuthis pealeii*) exposed to pile driving noise in a laboratory setting exhibited alarm responses and disrupted feeding behaviour (Jones et al. 2021). Unusual strandings of Giant Squid (*Architeuthis* sp.) in Spain have coincided with nearby seismic airgun surveys, and these individuals were found to have extensive internal injuries (Guerra et al. 2011). Although not conclusively linked to seismic airgun use, similar strandings of Giant Squid have been anecdotally reported in Newfoundland (Guerra et al. 2011). Further research is needed to understand the potential impacts of seismic airgun surveys on the prey species of NBW and the resulting effects on habitat quality and foraging success.

### Threat 3d: Drilling Operations

In addition to geophysical surveys using seismic airguns, a variety of other noise-producing activities are associated with offshore energy development. Offshore drilling operations conducted from fixed platforms generally produce moderate levels of low to mid-frequency noise (Blackwell et al. 2004, Hildebrand 2009). Drilling from drill ships or mobile units produces higher levels of noise, due to the dynamic positioning thrusters used to maintain the ship's position throughout the operation (Hildebrand 2009). Sound source characterization studies conducted during two different exploratory drilling projects occurring off the Scotian Shelf found that the highest noise levels were produced by the dynamic positioning thrusters (MacDonnell 2017, Martin et al. 2019). Other sources of noise during these operations included noise from the drill bit and string, noise from generators and other machinery on board the drill ship and support vessels, and higher-frequency pings from locator beacons (Martin et al. 2019). There is no specific information available on the impacts of noise associated with drilling operations on NBW or other cetaceans, but the effects may be similar to those caused by vessel noise and seismic airgun surveys, although exposure will generally be more localized for drilling operations, which are stationary. In regions with extensive offshore energy development, these activities likely generate non-trivial sources of noise and contribute to the cumulative anthropogenic noise present in the oceans.

### Threat 3e: Echosounders

Active acoustic technologies such as depth sounders, acoustic sub-bottom profiling systems, commercial fish-finders, and scientific echosounders contribute additional noise to the marine environment, with the potential to impact NBW and other beaked whale species. Depth sounders and other echosounders typically operate at higher frequencies and ensonify smaller areas than tactical military sonars, due to higher absorption at those frequencies. Multibeam echosounders, used in hydrographic seafloor mapping studies, feature multiple beams arranged in a fan-shaped array designed to ensonify a wider swath of the seafloor below the vessel, perpendicular to the vessel heading. Seafloor mapping studies conducted in deep water may require relatively low frequency (e.g., 12 kHz) multibeam echosounder systems. Echosounders are generally considered to pose less risk of direct auditory injury to cetaceans than military sonars or seismic airguns, but behavioural responses are still poorly understood (Lurton and DeRuiter 2011). Cholewiak et al. (2017) found that the use of shipboard scientific echosounders during a marine mammal survey in the western North Atlantic significantly reduced the detection rate of beaked whale echolocation clicks on a hydrophone array towed behind the vessel, compared to survey periods when echosounders were not actively pinging. These results suggested that beaked whales may have altered or suspended their foraging behaviour, or actively avoided the survey vessel when echosounders were in use. Conversely, Kates Varghese et al. (2020) studied the foraging behaviour of Cuvier's Beaked Whales during a seafloor mapping survey using a 12 kHz multibeam echosounder and found no evidence of a consistent behavioural response. However, it should be noted that this study took place on the Southern California Antisubmarine Warfare Range where anthropogenic noise may be more common. Among other odontocetes, behavioural reactions to scientific echosounders have been observed in Short-Finned Pilot Whales (Quick et al. 2017), and a behavioural response to the nearby use of a high-powered 12 kHz multibeam echosounder was determined to be the most likely cause of an unusual mass stranding of melon-headed whales in Madagascar (Southall et al. 2013). More research is needed before drawing any conclusions on whether multibeam or other echosounder technologies pose a general threat to NBW or other beaked whale species. These technologies are widely used and typically occur in conjunction with other sources of anthropogenic noise, such as vessel traffic and seismic airgun surveys.

### Threat 3f: Chronic Noise Exposure

Beyond the impacts linked to the specific sources of anthropogenic noise described above, the chronic effects of exposure to multiple sources of noise over extended periods of time poses an aggregate threat to acoustically sensitive species. For example, vessel noise, seismic airgun surveys, and drilling operations occurring in the same area may cause a sustained increase in the background noise levels experienced by animals in the area, even if some of these noise sources are recurrent rather than continuous. Chronic exposure to noise has been found to trigger physiological stress responses in humans (e.g., Evans et al. 2001), birds (e.g., Blickley et al. 2012), and cetaceans (Rolland et al. 2012), among many other taxa. Increased physiological stress occurring repeatedly or over prolonged time periods is known to affect fitness (Romero and Butler 2007, Francis and Barber 2013), and chronic stress in humans can lead to adverse health effects including increased risk of cardiovascular disease (Münzel et al. 2018) and reduced immune function (Kim et al. 2017). Studying effects of noise on the physiological health of wild cetaceans remains exceedingly challenging, particularly for beaked whales and other elusive species inhabiting deep waters in offshore regions for which there is little or no baseline information against which to assess potential effects. However, anthropogenic noise is a pervasive and growing concern, which is increasingly being incorporated into population models as an important stressor affecting cetacean populations (Lacy et al. 2017, Williams et al. 2020). While there is currently no specific information available on the effects of chronic exposure to anthropogenic noise on NBW or other beaked whale species, the potential for long-term health effects and population-level consequences must be considered among the current threats to NBW off eastern Canada.

## THREAT 4: FISHERIES INTERACTIONS

Fisheries interactions such as entanglements, bycatch and depredation (removal of fish from fishing gear) are a globally recognized as posing serious threats to cetacean populations (Read et al. 2006, Hamer et al. 2012). Threats can be direct, such as injuries caused by interactions with gear; or indirect, resulting from NBW behavioural associations with vessels (e.g., depredation), the broader impacts of particular fishing activities (e.g., ghost gear), or as a result of fisheries removals (e.g., prey depletion). Some threats also associated with fisheries interactions are assessed separately, including vessel strikes (section 5), marine pollution (section 6), and behavioural responses and masking related to noise disturbance (see both sections 3b on vessel noise and 3f chronic noise exposure).

Due to a lack of information, we do not include a review or assess the threats related to fisheries that could impact or target NBW prey in the future. However, it has been demonstrated that where cetaceans and fisheries compete for the same food resources, outcomes have sometimes been extreme, ranging from fishery closures to protect cetaceans, to killing of marine mammals to alleviate pressure on fisheries (DeMaster et al. 2001). While there is a fishery for the Short-Fin Squid (*Illex illecebrosus*) on the central Scotian Shelf, currently, we are not aware of any fisheries directly targeting deep-water squid species (i.e., *Gonatus*, the main prey of NBW; Hooker et al. 2001). As the ongoing global expansion of fisheries is expected to continue, the resulting pressure on local ecosystems and targeting of new marine resources will likely directly or indirectly impact cetacean populations around the world (DeMaster et al. 2001), potentially including the NBW. Should *Gonatus* fisheries be proposed in the future, reductions to NBW prey resources and proximity of such fisheries to NBW critical habitats would need to be carefully considered.

While the Gully Marine Protected Area (MPA) is largely closed to fishing activities, the presence and nature of long line fishing gear (e.g., extensive kilometers of lines and hooks per set) around the Zone 1 fishing exclusion area and other regions of NBW critical habitat, may limit NBW movements. Given the restricted range of the small Scotian Shelf population, this threat could impact NBW foraging success or reproductive opportunities; however, there is currently insufficient information to assess this potential threat.

### Threat 4a: Entanglement

Entanglement is the incidental capture of animals in the ropes, lines, nets or hooks associated with fishing gear, including documented fisheries bycatch as well as animals that are injured by gear, move away with gear attached, or that become ensnared in discarded, lost, or abandoned gear ("ghost gear"). Entanglements and bycatch can cause serious injuries and mortalities (Read et al. 2006, Read 2008), and also injuries that can indirectly result in death (such as by impacting an animal's ability to swim or forage) and/or compromise health, fitness and reproduction of individuals leading to population-level effects (Dolman and Brakes 2018). Entanglement is widely recognized as one of the greatest conservation threats to cetaceans across the globe (Read et al. 2006, Read 2008), as well as a significant animal welfare issue (Dolman and Brakes 2018). Beaked whale entanglements, often resulting in mortality, have been documented for a number of species throughout the world and associated with several different types of fisheries (e.g., Garrison 2003, Carretta et al. 2008, Hamer et al. 2012, NOAA 2015, Tulloch et al. 2020).

Documented beaked whale entanglements off eastern Canada include two reports of seriously entangled Sowerby's Beaked Whales (DFO 2017) and at least 15 reports involving NBW (Table A1), which are summarized in Harris et al. (2013) and Feyrer et al. (2021). Reports involve multiple fisheries and gear types, and while some involve observations of dead animals, the outcomes for animals released alive (with or without gear attached) remain unknown. Entanglements have been reported throughout the range of NBW off eastern Canada, including ten occurrences within the SSDU boundaries (the Scotian Shelf and the southern Grand Banks of Newfoundland), and five incidents between Newfoundland and the Davis Strait (Table A1).

In addition to documented and directly observed entanglements, evidence of fishing gear interactions also exists in the form of entanglement scars on animals. Entanglement scars are caused by the rubbing or pressure of a rope or line as it is wrapped around the body or body part of an animal and can include various curvilinear patterns, indentations, and protruding scar tissue. Feyrer et al. (2021) found 6.6% of individuals had evidence of anthropogenic scars (considering a combined total of injuries attributed to entanglement or propeller-vessel strike incidents) within a long-term (1988-2019) photo-identification dataset of dorsal fins for the Scotian Shelf NBW population. Anthropogenic scars were most commonly seen in males, and probable entanglement scars were assessed as low to moderate severity. Analyses estimate the annual gain rate for anthropogenic injuries has been stable over the 31–year study period with approximately 1.7 whales per year gaining new scars. Feyrer et al.'s (2021) analyses did not consider scars around the head, or peduncle and tail flukes; however, entanglement scars have been observed on the melons and beaks of NBW from the Scotian Shelf in Mitchell (2008) and in Gowans and Whitehead (2001).

Entanglement in fishing gear is one of the few human activities that has conclusively been attributed to killing NBW off eastern Canada and is considered one of the principal threats to this species in Canadian waters (COSEWIC 2011, DFO 2016b). Relative to coastal cetacean species, which have larger populations and overlap with a higher density of fisheries, beaked whales have been assessed as less likely to become entangled in fishing gear (Brown et al. 2013). However, the relatively small number of recorded entanglement incidents involving NBW (e.g., Nemiroff et al. 2010, Benjamins et al. 2012, Themelis et al. 2016), likely also reflects underreporting. In addition to a lower density of vessels, there are few at-sea fisheries observers (ASO) aboard vessels in the offshore habitat of NBW (Hooker et al. 1997), decreasing the likelihood that incidents will be seen or reported. Large animals like NBW may also not be observed as bycatch if they break free from gear and swim away while hooked or entangled. And while strandings of NBW do occasionally occur, carcasses from offshore waters are unlikely to reach in-shore waters or be investigated, making it difficult to assign cause of death even when dead animals are found. As a result, reported incidents of entanglement from ASOs or scarring rates should be considered minimum estimates.

### Threat 4b: Risks of depredation

Depredation occurs when whales remove or damage fish from fishing gear (Read 2008, Hamer et al. 2012) and is generally considered a non-lethal anthropogenic interaction. Depredation of fisheries has been documented in multiple species of odontocetes across the globe, including Sperm Whales, Killer Whales (*Orcinus orca*), False Killer Whales (*Pseudorca crassidens*), and Pilot Whales (*Globicephala* spp.), and for toothed whales is commonly associated with longline fishing activities (Hamer et al. 2012, Schakner et al. 2014, Tixier et al. 2017, Hanselman et al. 2018); however, predation on escapees and discards from trawling has also been recognized (Oyarbide et al. 2021a; Bonizzoni et al. 2022). Depredating behaviour has become a conservation issue for some cetacean populations due to the increased risk of injuries or mortalities caused by the close proximity of whales to vessels and gear. A range of negative impacts associated with depredation include entanglement, accidental hooking, ingestion of gear, vessel strikes, and the use of lethal deterrent methods employed by fishers (Read 2008, Tixier et al. 2017, Amelot et al. 2022). However, incidental or intentional prey provisioning by fisheries may also reduce energetic foraging costs for depredating whales and has been shown to have demographic benefits in some cetacean populations (Esteban et al. 2016, Tixier et al. 2017).

Depredation behaviour by NBW occurs in Canadian waters (COSEWIC 2011), although the extent and impacts of this threat are not well understood. NBW depredation has been reported with fisheries on the Scotian Shelf (trawl), Newfoundland (trawl), Labrador and Baffin Bay (trawl and longline) (Fertl and Leatherwood 1997, COSEWIC 2011, Harris et al. 2013, Johnson et al. 2020) and Newfoundland (Oyarbide et al. 2021b). NBW have also been observed approaching fishing vessels and being hand-fed (intentional provisioning) by fishers in these regions (COSEWIC 2011).

## THREAT 5: VESSEL STRIKES

Vessel strikes and collisions are another threat to cetaceans that can result in trauma-related injuries that may directly or indirectly lead to death. For animals that survive, injuries may have long-term impacts on health, reproduction and fitness, and can result in population-level impacts (Schoeman et al. 2020). As the number of commercial and recreational vessels increase throughout the world's oceans, so does the risk of vessel strikes. While reports of vessel strikes are more commonly associated with large baleen whale species, vessel strikes involving odontocetes and smaller cetaceans are known to occur. Though reports of vessel strikes on beaked whales are generally rare, Schoeman et al.'s (2020) global review of marine animal vessel collisions identified at least nine different beaked whale species, not including NBW, involved in vessel strike incidents. For NBW, Feyrer et al. (2021) documented scar patterns on live animals consistent with vessel propeller trauma (e.g., fin amputation, large gashes in the spine). As with entanglements, there is generally lower vessel density and ASO coverage in these areas, which decreases the probability that incidents, injuries or carcasses will be seen and reported. Animals that die in offshore areas are also less likely to drift long distances to coastal waters, making it difficult to investigate and assign a cause of death (Williams et al. 2011).

There are no reports of NBW mortalities that we are aware of that can be conclusively linked to vessel strikes off eastern Canada. However, NBW are known for their curious nature and often approach and follow vessels (Mitchell 1977) and propeller-vessel strike injuries are common in species that approach vessels and bow-ride (Van Waerebeek et al. 2007) or swim in the wash of the propellers (Visser 1999). Photos of scars around the dorsal fin region of individuals in the SSDU are consistent with vessel strike injuries (Feyrer et al. 2021). Scars described as propeller slashes or indentations, mutilated or amputated dorsal fins and concave lacerations were most commonly seen in male NBW, and assessed as moderate-high severity injuries. Feyrer et al.'s (2021) annual gain rate for anthropogenic scars (i.e., 1.7 whales per year) combines vessel-strike and entanglement scar types, as it was not possible to distinguish between the two sources of injury for some severe scars. While Feyrer et al.'s (2021) analyses did not consider scars on around the melon, peduncle or tail flukes, Mitchell (2008) describes a vessel strike scar (e.g., a large indentation) observed on the melon of a mature male from the SSDU. Photographic observations do not include vessel strike injuries that are not externally apparent (such as bruising and fractures), or injuries resulting in mortality, and thus anthropogenic scarring rates (above) should be considered a minimum estimate of these injuries or interactions.

## THREAT 6: POLLUTION AND CHEMICAL CONTAMINANTS

Exposure to pollution and contaminants in the marine environment can have direct impacts on the health of cetaceans and their prey, as well as indirect impacts which degrade the quality of their marine habitat and ecosystems. Under Canada's *Fisheries Act,* marine pollutants are akin to a 'deleterious substance', which is defined as any substance having the ability to cause lethal or sub-lethal effects to fish or harm fish habitat. However, the harmful effects of pollution and chemical contaminants may only occur at certain concentrations, with prolonged exposure, in combination with other pollutants, or under degraded states, and may be highly uncertain (e.g., chemicals of emerging concern) (Stengel et al. 2006, Gall et al. 2015, Villarrubia-Gómez et al. 2018). Broad legal definitions of pollution have sometimes included noise (reviewed separately in section 3: Acoustic Disturbance) or the introduction of zoonotic diseases as pollutants or contaminants (Tomczak 1984). However, as we have little information on the pathways of disease in beaked whale species, this concern is briefly discussed in the section on other potential other threats (below). Here, we focus on describing the potential threats to NBW posed by chemical contaminants (e.g., persistent organic pollutants or "POPs", heavy metals, oil) and physical pollution (e.g., debris, microplastics). We consider a collective definition of pollution as any substance that if found in the marine environment has the potential to result in harm to marine life or degrade marine habitat quality.

There is a long list of pollutants and contaminants that may be found in the marine environment, which may have one or more contemporary or historical sources. However, for some contaminants the sources may be unknown, as specific source pathways into the marine environment or animal tissue might only be traced after encountering a significant exposure level or health impact. Contaminants linked to historical activities can be due to long residence times in marine food webs and tissues, disturbance of older deposits in marine sediments or degradation of disposed materials. Direct sources of pollution and contaminants, where substances are deposited directly into the ocean include litter, wastewater effluent, shipping ballast water exchange, military dumpsites, disposal at sea events, discharges from oil and gas activities related to drilling and spills, and fishing debris. Indirect sources can be the result of degradation or weathering of direct deposits (e.g., microplastics), industrial emissions or particulate matter entering the atmosphere and precipitating into the marine environment through the water cycle and sea ice, or deposits found in ocean sediments that can enter the ecosystem at a later date. Due to the variety of contaminants, sources and pathways, studies on the exposure and health risks to cetaceans have largely focused on detecting specific contaminants (e.g., polychlorinated biphenyls [PCBs] or dichlorodiphenyltrichloroethane [DDT]) or the impact of pollution from a single source (e.g., plastics). Here we have organized our assessment of the threats posed to beaked whales from contaminants by focusing on the well documented impacts and sources of known persistent organic pollutants (POPs), plastic pollution, toxic metals and oil spills. Other sources and contaminants that may be affecting pelagic ecosystems but are not well-understood as threats to marine species should be considered in the future as data become available.

### Threat 6a: Persistent Organic Pollutants

Persistent organic pollutants (POPs) are a large group of chemicals produced and used around the world that are known to have long-term persistence in the natural environment and are toxic to humans and wildlife (Sun et al. 2016). The prevalence of POPs in ecosystems is pervasive, resulting in their biomagnification within food chains and accumulation in the fatty tissues of animals (Mackay and Fraser 2000, Macdonald et al. 2002). National voluntary bans of most POPs occurred in the 1970s and 1980s, and in 2001 the international Stockholm Convention on POPs was signed to eliminate the manufacture and use of POPs. Major classes of POPs include PCBs), industrial chemicals used primarily as heat exchange fluids and additives in commercial products, and organochlorine pesticides such as DDT, Chlordane, Dieldrin, Toxaphene, hexachlorobenzene (HCB), hexachlorocyclohexane (HCH), and Polybrominated Diphenyl Ethers (PBDEs).

Due to their long life spans, roles as top predators, large blubber reserves, and reduced metabolic capacity to break down most POPs, marine mammals are recognized as particularly vulnerable to elevated levels of contamination (Muir and Norstrom 1994, Ross and Birnbaum 2003). Marine mammal populations living in locally contaminated areas have highlighted the effects of broad toxicity on reproduction, immunity, carcinogenicity, and ultimately survival and population growth (Helle et al. 1976, Martineau et al. 1987, De Guise et al. 1995, Ross 2002, Letcher et al. 2010, Jepson et al. 2016). Beyond local environmental intensities, contaminant concentrations typically also differ between (1) sexes, as females offload accumulations of contaminants to their offspring, (2) by species, reflecting increased concentrations at higher trophic levels, (3) migratory behaviour, reflecting mixed signals from latitudinal and regional conditions and (4) foraging depth, as mesopelagic fish and deep-sea squid are thought to be sinks for POPs (Takahashi et al. 2010, Bachman et al. 2014). As beaked whales feed on deep-water prey, it has been suggested that species that forage at depth may ingest intermediate to high contaminant loads, relative to their trophic level (Bachman et al. 2014).

Apart from some well-studied PCBs, toxicity thresholds for most POPs have not been established for marine mammals, largely due to the difficulties of controlled exposure studies for large cetaceans. Adverse health effects have been documented for PCBs through several controlled feeding studies of seals, and via studies of wild populations of seals and cetaceans living in contaminated areas (DeLong et al. 1973, Helle et al. 1976, De Guise et al. 1995, Ross et al. 1996). Toxicity thresholds for PCBs in marine mammals vary from 17 µg/g lipid weight for general immune and reproductive effects, and 41 µg/g lipid weight for reproductive impairment. Based on a suite of molecular based biomarkers (e.g., gene expression and vitamin levels) a new toxicity threshold for PCBs in marine mammals, which represents early signs of physiological changes, has been established at 1.3 µg/g lipid weight (Desforges et al. 2013, Noël et al. 2014, Brown et al. 2014). This toxicity threshold represents a biological response to PCB exposure but has not been linked to adverse effects to growth, reproduction, or disease.

Studies of contaminants in beaked whales typically have small sample sizes, with data collection limited to single individuals or small stranding events, making comparisons across species and broader generalizations difficult (Bachman et al. 2014, Law 2014, Desforges et al. 2021). However, for NBW there are two studies that have examined POP concentrations found in blubber biopsies: an analyses by Hooker et al. (2008) between 1997–2003, and a comparative analysis of NBW tissues collected in 2019 (Desforges et al. 2021). Despite small sample sizes, these two studies provide relatively good information that the concentration of POPs in NBW appear similar to other toothed whales in the North Atlantic and below the high levels of PCBs observed in Cuvier's Beaked Whales sampled in the Mediterranean (Baini et al. 2020, Tables 1 and 3 in Desforges et al. 2021). For Scotian Shelf NBW, levels of most POPs were higher when compared to NBW sampled in the Arctic, likely due to the closer proximity to populated centers along coastal North America (Hooker et al. 2008, Desforges et al. 2021). Overall levels of DDT were higher than PCBs in NBW, suggesting a possible local environmental source of DDTs in the region (Hooker et al. 2008, Desforges et al. 2021). Temporal trends suggest that POPs have increased overall since 1997; however, patterns between individual years are less clear due to low sample sizes and where differences in concentrations found between males and females confound further comparisons (Desforges et al. 2021).

### Threat 6b: Toxic metals

Other chemical contaminants that are persistent, bioaccumulate and can have long-term health effects in mammals are toxic concentrations of heavy metals (Gall et al. 2015). Many metals are naturally occurring at low levels in the marine environment; however, anthropogenic sources including the emissions of industrial activities, mining, agricultural run-off and waste dumps can elevate concentrations to toxic levels (Bruland and Franks 1983) and globally there have been documented increases in anthropogenic sources of heavy metals in the marine environment since the pre-industrial period (Lamborg et al. 2014). Mercury, cadmium, lead, arsenic, barium, copper, nickel, selenium, and zinc are examples of metals that can be toxic for marine life even at low levels, either on their own or in combination with other organic materials (Ansari et al. 2004). Heavy metals are typically found in higher concentrations in sediment deposits but may become entrained in marine waters in association with other nutrients, due to disturbance or as part of oceanographic circulation (Bruland and Franks 1983).

The difficulty of conducting toxicological research on cetaceans also limits our understanding of toxicity thresholds for metals and trace elements (Monteiro et al. 2016). There are additional complexities with understanding the toxicity of individual metals due to chemical interactions (occurring between metals and with other organic compounds) and differences in tissue specific concentration patterns. Our interpretation of health effects, using concentrations that would otherwise be considered toxic to land mammals or humans, is also challenged by the adaptations of marine mammals to metabolize or detoxify higher concentrations, which naturally occur in marine ecosystems (e.g., selenium, mercury) (Frouin et al. 2012). Despite the uncertainties in assessing toxicity and impacts for all the metals in the periodic table, the toxicity and health effects of some metals (e.g., mercury), have been relatively well studied in cetacean populations known to be at risk from other contaminants. High mercury concentrations in Beluga Whales (*Delphinapterus leucas*) have altered cellular and neurological processes, causing kidney damage, and immune system dysfunction (Frouin et al. 2012). In addition, sub-lethal concentrations may be more detrimental to prey or other ecosystem components, leading to indirect impacts for marine predators.

## Threat 6c: Plastics

The types of plastic waste entering the ocean encompasses an incredibly diverse array of items, including fishing gear, bottles, bags, packaging, cigarette butts, industrial pellets, and cosmetic microbeads, to name a few (Gallo et al. 2018). Given that the persistence of plastic is almost indefinite, these larger plastic items can only degrade into increasingly smaller pieces and eventually become particles of microplastics (< 5 mm) and nanoplastics (1 to 1000 nm) (Andrady 2011, Gigault et al. 2018). While marine debris can drift offshore from coastal sources (e.g., helium balloons), fishing activities are assumed to be the main source of marine plastics in the remote regions where beaked whales live (Secchi and Zarzur 1999, Lusher et al. 2018). Large plastic debris has been found in the digestive tracts of many species of cetaceans, which can cause blockages and result in eventual starvation (Jacobsen et al. 2010). Although coastal and pelagic species may be exposed to larger sources and densities of plastic debris, Benjaminsen and Christenson (1979) documented plastic in the stomachs of NBW caught by whalers in 1967 and 1971 off Iceland and Labrador, Fernández et al. (2014) describes plastics found in two animals from the eastern North Atlantic, and Lusher et al. (2018) found that the digestive tracts of deep-diving species contained more plastic items than pelagic species, notably plastic bags. As plastic bags were the most common item in the digestive tracts of beaked whales they assessed, Lusher et al. (2015) speculated that these whales may be confusing plastic bags for their cephalopod prey. Despite being the sole source of information on plastic ingestion, necropsies and published reports on the stomach contents of stranded whales are limited sources of data. Given stranded animals may have underlying health conditions, reported plastic contents (if any) cannot be assumed to reflect population-level patterns. In addition, stomach content analysis often focuses on characterizing prey species, which may overlook or omit documentation of other non-biological items such as plastic debris. There are few published reports available on the stomach contents of NBW from the western North Atlantic, however we are aware of three individuals that stranded in southern Newfoundland in 2019, 2021 and 2022 that had plastic items in their stomachs or digestive tracts (Ledwell et al. 2020, Kelly et al. 2023). Identifiable plastic items included a cup, jar lid, fishing line, net, a fishing glow stick, and a glove as well as a number of unidentified hard plastic fragments (Ledwell et al. 2020).

Although methods for detecting microplastics in animal tissues and digestive tracts are relatively recent, microplastics have been identified in every ocean (Villarrubia-Gómez et al. 2018) and in the tissues of many cetaceans, including True’s and Cuvier’s Beaked Whales (Lusher et al. 2018). The pathway in these cases is unclear, but particles would have originated either from the ingestion and breakdown of ingested macroplastics or from prey sources (e.g., fish, zooplankton, [Cole et al. 2013]) that may have fed on and retained microplastic particles. Aside from the physical and nutritional health impacts of ingesting and accumulating non-nutritive microplastics, particles contain or may attract other chemical contaminants that then become additional sources of exposure (Gallo et al. 2018). It is thought that incidentally consuming microplastics may increase the rates of chemical bioaccumulation in tissues and lead to health effects associated with those contaminants, such as POPs (Lusher et al. 2018).

## Threat 6d: Oil Spills

Pollution related to oil and gas development, extraction, and transportation activities are a notable threat for marine species. There are a number of sources of oil entering the marine environment; of primary concern here are spills that may occur from vessels, offshore platforms, drilling rigs, wells, or pipelines. Causes of spills are varied but include vessel collisions, groundings, hull failures, equipment failures (corrosion, over pressuring), fire or explosions, loading, discharging, bunkering, ballasting and other events such as heavy weather and human error. Historically, most large tanker spills (> 7 tons) have been caused by collisions or groundings, while small-medium spills, accounting for 95% of all spills recorded globally, are known to be underreported, and are primarily attributed to spills occurring during loading, discharging or unknown operations (ITOPF 2021).

Petroleum products, ranging from heavy crude to refined fuels, are known to be toxic to marine life at low levels if ingested, inhaled or aspirated, due to concentrations of polycyclic aromatic hydrocarbons (PAHs) and heavy metals. The impacts of oil spills in the marine environment can vary depending on the properties and composition of the product, the bulk volume, the location (at the surface or at depth) and conditions at sea (e.g., wind speeds) (Zhang et al. 2019). The effects of crude oil in the marine environment are perhaps the most well documented and are the focus of our review. However, other pollutants and by-products associated with oil and gas exploitation are of concern, including those related to the fossil fuel extraction process (e.g., drilling fluids, chemical additives, anti-fouling paints, and construction materials), products related to spill clean-up, such as chemical dispersants and the weathering products of oil, such as tar balls.

If oil spills are small or disperse quickly under rough weather conditions, they may be less likely to be encountered in toxic concentrations by cetaceans in the area. However, for cetaceans that directly encounter oil slicks, the impacts of exposure to toxicity can have fatal or long-term consequences to individuals including lung disease, poor reproductive success, stress responses and immune system dysfunction. Because cetaceans breathe at the surface, where oil and volatile organic compounds (VOCs) are most concentrated and become aerosolized, their skin, eyes and respiratory systems are common pathways for exposure. The unique nature of cetacean respiratory physiology means that toxic VOCs and oil are not filtered during inhalation and are absorbed directly into the blood through the lungs (Murawski et al. 2021). Ingestion of contaminated prey is also thought to be a potential pathway for exposure, although the impacts of this source are less well understood (Zhang et al. 2019). Behavioral observations of bottlenose dolphins after the Deepwater Horizon (DWH) spill in 2010 and Killer Whales after the Exxon Valdez spill in 1989 suggest that cetaceans are unlikely to “avoid” swimming through surface oil (Matkin et al. 2008, Aichinger Dias et al. 2017). This leaves species or populations with high site fidelity particularly vulnerable to spills that occur in their habitat (Murawski et al. 2021). Finally, the ecosystem impacts of spills, such as contamination and die-offs at lower trophic levels and the settling of oil in benthic sediments, seen in the DWH or Exxon Valdez spills, can result in lagged, chronic and indirect legacy effects that may last decades but are difficult to directly observe (Peterson et al. 2003, Murawski et al. 2021).

## OTHER POTENTIAL THREATS

We recognize that other potential threats to NBW may exist off eastern Canada and are worth mentioning for future consideration. These include introduced zoonotic diseases, invasive species, munitions dump sites, marine cables, deep sea mining, exploitation of the mesopelagic zone, and potentially others we are not aware of. With little information currently available and a poor understanding of the pathway of effects for any of these possible threats, we could not assess their potential impacts to NBW individuals or populations. In addition, indirect impacts to NBW, such as anthropogenic ecosystem changes affecting NBW prey, are difficult to study and assess but should also be considered as part of the broader context for this threat assessment. As more data are collected and our knowledge increases, additional important threats to NBW may arise. This assessment should be periodically revisited to address the potential impacts of new or emerging threats.

## CUMULATIVE EFFECTS

Interactions between the various threats to NBW outlined above may be complex and the effects of multiple stressors are not well-understood for most cetaceans (National Academies of Sciences, Engineering, and Medicine 2017). The cumulative effects of identified threats on populations may vary over space and time, and past threats may continue to influence the present status of NBW (Maxwell et al. 2013). Synergistic or antagonistic interactions between multiple threats may result in a larger or smaller response than a simple additive combination of impacts (National Academies of Sciences, Engineering, and Medicine 2017). While cumulative effects are important to address, this threat assessment framework was not designed to give them full consideration. Recognizing this, we consider the potential for cumulative effects to be a factor that may increase NBW vulnerability, which should be considered in the assessment of other threats. Additional guidance (and likely additional research) is needed to consider cumulative effects in future risk assessments for NBW.

# THREAT ASSESSMENT FOR NORTHERN BOTTLENOSE WHALES

Threats to NBW were assessed to the extent possible by prioritizing information available in the peer-reviewed scientific literature and drawing on grey literature (including industry or government technical reports), unpublished data, or other supporting information when necessary.

The methods used for the threat assessment were guided by DFO (2014). Our specific interpretation and any deviations from the guidance (e.g., where the suggested approach was not applicable to the biology of this species) are described in the “Methods” section, along with our rationale.

## METHODS

### General Approach

Our knowledge of potential threats to NBW off eastern Canada varies from well-known threats with substantial information available, to emerging or sub-lethal threats for which we currently have very little information. This threat assessment primarily focused on threats for which there was at least some information available to support the conclusion that the threat has, is, or will likely impact the population(s) to some degree. When there was enough information available, threats were linked to specific activities, such as sources of acoustic disturbance or types of contaminants and pollutants. It is important to note that while sub-lethal effects are often suspected, there is very little information on such effects in cetaceans as they are challenging to observe and quantify. We considered sub-lethal threats when it was possible to take them into account based on available data, and sub-lethal effects were identified in our assessments of military sonar, entanglement, and chemical contaminants. However, as the final threat assessment was based on the highest level of impact, in all cases sub-lethal effects were surpassed by the potential for direct mortality.

We were requested to assess each threat within the context of the Scotian Shelf NBW population specifically, and for beaked whales off eastern Canada more generally. As many of the criteria described in the DFO (2014) threat assessment framework required some information on population abundance and trends, it was not possible to apply this assessment to other beaked whale species with very limited data. Rather than a general beaked whale risk assessment, we considered threats for NBW at two different geographic scales: (1) for the Scotian Shelf NBW population (the geographic range of which extends from the Scotian Shelf to the Grand Banks, as defined in COSEWIC 2011), and (2) more broadly for NBW in Canadian waters in the Northwest Atlantic. This broader regional assessment includes the Scotian Shelf population as well as the Davis Strait-Baffin Bay-Labrador Sea population (and any additional populations that have yet to be defined within the Northwest Atlantic), and the geographic range considered extends from the Scotian Shelf to the Canadian Arctic. This broad assessment will help address issues with uncertainty around the exact geographic boundaries of the two populations (COSEWIC 2011) as well as connectivity between populations and provides a more national perspective on threats to NBW. These two assessments are identified in Table 1 under the “Geographic Scale” column as either “SSDU” (the range of the Scotian Shelf population) or “NWA” (the range of NBW throughout Canadian waters in the Northwest Atlantic).

For each threat, the following threat evaluation criteria were assessed based on DFO (2014), with some modifications: likelihood of occurrence, individual level of impact, population level of impact, threat risk, timing of occurrence, threat frequency, and geographic extent of threat. We modified the “level of impact” criterion and split it into two separate criteria: “individual level of impact” and “population level of impact”. We also provided a data quality rating score associated with each of the level of impact criteria, which captured the intent of the causal certainty criterion in DFO (2014). We changed the DFO (2014) term “population-level threat occurrence” to “timing of occurrence”, “population-level threat frequency” to “threat frequency”, and “population-level threat extent” to “geographic extent of threat”. The sections below provide more detail on how each of these criteria were defined and assessed, including justifications for any deviations from the DFO (2014) guidance, such as changes to the terminology or modifications in interpretation and application.

As has been the case in other threat assessments, the precautionary approach was applied when assessing threats for which limited or inconclusive information was available, or in cases of uncertainty (e.g., see Leatherback Sea Turtle [*Dermochelys coriacea*] threat assessment [DFO 2020b]). As well, in cases where a threat could result in several different impacts of varying severity, the most severe impact was assessed. For example, military sonar has been linked to several potential impacts on beaked whales, ranging from brief behavioral reactions in individuals to mass stranding events, thus this threat was assessed from the perspective that military sonar can cause mortality.

Sources of information that were considered when conducting this assessment include primary literature/scientific journal articles, Canadian Science Advisory Secretariat documents, grey literature (e.g., non-peer reviewed publications, government reports, news articles), anecdotal reports and unpublished data. In all aspects of this largely qualitative threat assessment, some level of expert judgement was used when interpreting, synthesizing, and applying available information from all sources.

## Likelihood of Occurrence

DFO (2014) 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.” The estimated generation time of NBW is in the range of 15–17.8 years (COSEWIC; Taylor et al. 2007). A timespan of three generations for this species was therefore considered to be in the range of 45–51 years. Although DFO (2014) recommends using 10 years in this situation, using a time frame that only covers part of one generation will not be biologically meaningful for assessing threats to species recovery. COSEWIC recommends using three generations for threat assessments[1], and thus we opted to apply a timeframe that would span three generations (45+ years for NBW). Our definition for likelihood of occurrence for this assessment was therefore the probability of a specific threat occurring for a given population over 45 years. When evaluating this criterion, we considered activities that have occurred within the past 45 years, current/ongoing activities, and activities that are anticipated to occur in the next 45 years.

Likelihood of occurrence of a given threat was defined by DFO (2014) using the following levels:

- Known — "this threat has been recorded to occur 91–100%". We interpreted this to mean that 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."

### Individual Level of Impact

The level of impact criterion in DFO (2014) is defined 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".

For NBW, as is the case for most cetacean species, there is often information available about the potential impacts of threats on individuals, while population-level impacts are generally poorly understood. By only assessing threats at the population level, valuable information on known impacts to individuals may be overlooked—such information could be helpful for understanding the potential importance or magnitude of a particular threat. We therefore assessed level of impact at two different scales: the individual level (addressed in this section) and the population level (described in the next section). For determining the threat risk criteria, we used the population level of impact.

We defined individual level of impact as the potential magnitude of the impact of a given threat on individuals, where magnitude is determined by the type of impact, from mortality on the higher end of the scale to harassment, disturbance or increased stress and other similar impacts on the lower end of the scale.

The individual level of impact for each threat was defined as follows:

- Extreme — the threat has been linked to or demonstrated to cause mass mortality (mortality of multiple individuals caused by one event).
- High — the threat has been linked to or demonstrated to cause mortality of single individuals.
- Medium — the threat has been linked to or demonstrated to cause injury or harm directly affecting physical health or reproduction in one or more individuals.

[1] See COSEWIC wildlife species assessment: quantitative criteria and guidelines, Table 2. Committee on the Status of Endangered Wildlife in Canada (COSEWIC) quantitative criteria and guidelines for the status assessment of wildlife species. [Accessed 15 February 2021]

- Low — the threat has been linked to or demonstrated to cause harassment, disturbance, increased stress and/or other similar impacts to one or more individuals.
- Unknown — the effect of the threat on individuals is presently unknown.

It was necessary to consider the amount and type of data available to select an appropriate level of impact for each threat. Understanding the quality of the information used in this assessment provides important context for those reviewing and applying the threat assessment table. We thus included a data quality rating (DQ; indicated as a number in brackets in Table 1) with this criterion. Definitions for the data quality rating were adapted from the levels of causal certainty defined in DFO (2014) and the data quality ratings defined in Hare et al. (2016):

- (1) Considerable data — substantial data are available to support the assessment, which have been observed, modeled or empirically measured for NBW and come from peer-reviewed sources.
- (2) Adequate data — some data are available that have been observed, modeled or empirically measured for NBW or other beaked whales and come from peer-reviewed sources.
- (3) Limited data — there is a higher degree of uncertainty with the available data, which may be based on other cetacean species or may come from non-peer-reviewed sources.
- (4) Expert judgement — the assessment is based on traditional and local knowledge or general scientific knowledge that has been extrapolated to apply to the species and their relative role in the ecosystem.
- (5) Insufficient data — impacts are possible, but very few data exist, or little is known about the impacts of the activity on the species or other cetacean species, and there is no basis for forming an expert opinion or making an assessment.

Because the individual level of impact criterion assessed possible impacts at the individual level without regard to the population size, the individual level of impact for each threat and the associated data quality rating were the same across both geographic scales considered (SSDU and NWA).

## Population Level of Impact

We defined population level of impact as the likelihood that if a threat occurs, it will have a negative effect on the survival or recovery of the population.

DFO (2014) defines specific levels of impact using either a quantitative assessment of population decline resulting from the threat or a qualitative assessment of likelihood of jeopardizing population survival or recovery (e.g., “high = substantial loss of population [31–70%] or threat would jeopardize the survival or recovery of the population”). We found it generally difficult to apply the more quantitative definitions (i.e., the proportion of the population affected), as it is difficult to study impacts or estimate the number of mortalities associated with any given threat for such a remote species, and limited quantitative data exist. As indicated above, mortalities, injuries, and other interactions are difficult to directly observe and are likely underreported. As well, the long-term effects of many impacts (such as stress caused by chronic exposure to noise or entanglements, for example) are not well known. It is also difficult to predict the magnitude of a potential population decline resulting from an event that has not yet happened. We therefore only applied the qualitative part of the original level of impact descriptions (e.g., likelihood of jeopardizing survival or recovery) to our assessment.

The population level of impact for each threat was defined as follows:

- Extreme — the threat would result in a severe population decline with the potential for extirpation.
- High — the threat is highly likely to jeopardize the survival or recovery of the population.
- Medium — the threat is likely to jeopardize the survival or recovery of the population.
- Low — the threat is unlikely to jeopardize the survival or recovery of the population.
- Unknown — the effect of the threat on the population is unknown.

In the case of the relatively small Scotian Shelf NBW population, which occurs entirely in Canadian waters, the estimated Potential Biological Removal (PBR) is very low at 0.3 individuals/year (DFO 2007a). If a threat were linked to mortality of individuals, it would likely jeopardize survival and recovery of the population as the human-induced death of even one individual every year would result in a population decline. For NBW in the NWA, the population size and thus PBR is unknown, as is the connectivity of populations to areas outside of Canada. It was more difficult to assess potential impacts of threats on survival and recovery at this broader scale, and in most cases the designation of population level of impact as "unknown" reflects the lack of information on population size, rather than a lack of information on the potential impacts of the threat.

As was the case for individual level of impact, it was necessary to consider the amount and type of data available for assessing population level of impact. Understanding the quality of the information used in this assessment provides important context for those reviewing and applying the threat assessment table. We applied a similar data quality (DQ) rating (indicated as a number in brackets) to this criterion. The definitions for this data quality rating incorporate population-level considerations:

- (1) Considerable data — substantial data are available to support the assessment, which have been observed, modeled, or empirically measured for NBW within the study area/population of interest and come from peer-reviewed sources.
- (2) Adequate data — some data are available that have been observed, modeled, or empirically measured for NBW or other beaked whales within the study area/population of interest and come from peer-reviewed sources.
- (3) Limited data — there is a higher degree of uncertainty with the data available, which may come from outside the study area, may be based on other cetacean species, or may come from non-peer-reviewed sources.
- (4) Expert judgement — the assessment is based on traditional and local knowledge or general scientific knowledge that has been extrapolated to apply to the species and their relative role in the ecosystem.
- (5) Insufficient data — impacts are possible or known to occur, but very few data exist, and little is known about the population or the impacts of the activity on the population, and there is no basis for forming an expert opinion or making an assessment.

### Threat Risk

DFO (2014) defines threat risk as "the product of level of impact and likelihood of occurrence as determined using a risk matrix approach." There is a standard matrix provided in DFO (2014) to determine the threat risk, which can be ranked as low, medium, high, or unknown (Figure 2). In DFO (2014), the "causal certainty" rating is included in brackets next to the threat level. We applied the threat risk matrix approach using the product of our assessments for likelihood of occurrence and population level of impact and included the data quality rating for population level of impact in brackets.

Assessing the population level of impact and assigning a threat risk requires knowledge of population abundances. As population size of NBW populations outside of the Scotian Shelf area remain unknown, the number of animals in the broader NWA is also unknown, and therefore the threat risk for the NWA is often unknown. As highlighted above, this is largely driven by gaps in our knowledge of population sizes, not necessarily lack of evidence for impacts caused by a given threat.

| | | Level of Impact | | | | |
|---|---|---|---|---|---|---|
| | | Low | Medium | High | Extreme | Unknown |
| Likelihood of Occurrence | 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 2. Threat risk matrix from DFO (2014).*

## Timing of Occurrence

DFO (2014) defines “population-level threat occurrence” as “the timing of the occurrence of the threat”. We removed the words “population-level” as we considered the entirety of the population for each criterion and this term was redundant. We used the term “timing of occurrence” to clearly indicate what this criterion represents (when a threat occurs, not whether a threat occurs).

The categories associated with timing of occurrence, one or more of which may be applicable to a given threat, were defined by DFO (2014) as the following:

- 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”.

When assessing threats using this criterion, we considered the timing of the threat activity itself, not the impact, which may be much more long-lasting than the threat activity. For example, we considered the timing of occurrence for the threat of whaling to be historical, as whaling activities occurred in the past and are not presently occurring, even though we note that there were lasting genetic effects caused by whaling that still impact the population today.

### Threat Frequency

Population-level threat frequency is defined by DFO (2014) as "the temporal extent of the threat over the next 10 years or three generations, whichever is shorter." Again, we removed the word population-level from this criterion as we considered the entirety of the population for each criterion and the term is redundant.

The categories associated with threat frequency were defined by DFO (2014) as the following:

- Single — "the threat occurs once".
- Recurrent — "the threat occurs periodically, or repeatedly" (we considered intermittent and seasonal activities to fall within this category).
- Continuous — "the threat occurs without interruption".
- Not applicable — none of the above categories apply. This category was added specifically for the case of whaling, as whaling itself no longer occurs even though it was a recurrent event in the past.

### Geographic Extent of Threat

Population-level threat extent is defined by DFO (2014) as "the proportion of the population affected by a given threat". We removed the term "population-level" as we considered the entirety of the population for each criterion and the term is redundant. In this assessment, it was largely impossible to estimate the proportion of the population affected by a given threat, as the number of individuals affected depends on the location and timing of the activity relative to where the animals are. While some areas of core habitat have been identified, there is limited information on the distribution of NBW within habitat areas relative to the occurrence of threats off eastern Canada. Assessing the threat extent based on proportion of population affected would therefore result in the extent of many threats being assessed as "unknown". As a more informative assessment, we provided a qualitative estimate of the proportion of NBW habitat likely to be affected by a given threat. We note that geographic overlap of a threat with NBW habitat is not a direct proxy for proportion of population affected, because we are not assuming the population to be uniformly distributed throughout all habitat areas at all times. However, this is the only criterion that considers the spatial extent of threats and potential overlap with NBW habitat, which is an important factor to consider when assessing potential risk to a species.

The geographic extent of each threat was assessed using the following definitions:

- Extensive — a very high proportion (71–100%) of population's habitat is likely affected by the threat.
- Broad — a high proportion (31–70%) of the population's habitat is likely affected by the threat.
- Narrow — a moderate proportion (11–30%) of the population's habitat is likely affected by the threat.
- Restricted — a low proportion (< 10%) of the population's habitat is likely affected by the threat.

## THREAT ASSESSMENT TABLE FOR NBW

*Table 1. Summary of threat assessment for Northern Bottlenose Whales (NBW) in Canadian waters. This threat assessment considers both the Scotian Shelf (SS) NBW population within the boundaries of the designatable unit (DU) as defined by COSEWIC (2011), which includes deep waters off Nova Scotia and southern Newfoundland (geographic scale = SSDU), as well as NBW off eastern Canada in the broader range of deep waters from the Scotian Shelf to the Canadian Arctic, encompassing the range of both the Scotian Shelf population and the Davis Strait- Baffin Bay-Labrador Sea population (geographic scale = Northwest Atlantic, NWA). Definitions for each of the threat evaluation criteria (from DFO 2014) and the methods applied to assign values to each of these criteria are provided in the sections above. Numbers in brackets (#) refer to the data quality (DQ) rankings on which the assessments were based. Timing of occurrence refers to Historical (H), Current (C) or Anticipatory (A). The individual level of impact was the same for both the SSDU and NWA, by definition.*

| Threat | Geographic Scale | Threat Evaluation Criteria Likelihood of Occurrence | Threat Evaluation Criteria Individual Level of Impact (DQ) | Threat Evaluation Criteria Population Level of Impact (DQ) | Threat Evaluation Criteria Threat Risk | Threat Evaluation Criteria Timing of Occurrence (H, C, A) | Threat Evaluation Criteria Threat Frequency | Threat Evaluation Criteria Geographic Extent of Threat |
|---|---|---|---|---|---|---|---|---|
| **Threat 1: Climate Change** | | | | | | | | |
| 1: Climate Change | SSDU | Known | Unknown (5) | High (4) | High (4) | H, C, A | Continuous | Extensive |
| 1: Climate Change | NWA | Known | Unknown (5) | Medium (4) | Medium (4) | H, C, A | Continuous | Extensive |
| **Threat 2: Historical Whaling** | | | | | | | | |
| 2: Historical Whaling | SSDU | Known | Extreme (1) | Extreme (1) | High (1) | H[2] | Not applicable[3] | Extensive |
| 2: Historical Whaling | NWA | Known | Extreme (1) | High (2) | High (2) | H[2] | Not applicable[3] | Extensive |
| **Threat 3: Acoustic Disturbance** | | | | | | | | |
| 3a: Military sonar | SSDU | Known | Extreme (2) | High (3) | High (3) | H, C, A | Recurrent | Unknown |
| 3a: Military sonar | NWA | Known | Extreme (2) | Unknown (5) | Unknown (5) | H, C, A | Recurrent | Unknown |
| 3b: Vessel noise | SSDU | Known | Low (3) | Low (4) | Low (4) | H, C, A | Continuous | Extensive |

[2] Impacts of whaling are ongoing, see rationale section below for more detail.

[3] Whaling could become an issue if individuals were to be taken as part of sustenance hunts in Canada in the future (not currently an issue in Canada but does occur outside of Canada).

| Threat | Geographic Scale | Threat Evaluation Criteria Likelihood of Occurrence | Threat Evaluation Criteria Individual Level of Impact (DQ) | Threat Evaluation Criteria Population Level of Impact (DQ) | Threat Evaluation Criteria Threat Risk | Threat Evaluation Criteria Timing of Occurrence (H, C, A) | Threat Evaluation Criteria Threat Frequency | Threat Evaluation Criteria Geographic Extent of Threat |
|---|---|---|---|---|---|---|---|---|
| 3b: Vessel noise | NWA | Known | Low (3) | Low (4) | Low (4) | H, C, A | Continuous | Broad |
| 3c: Seismic airgun surveys | SSDU | Known | Medium (3) | Unknown (5) | Unknown (5) | H, C, A | Recurrent | Extensive |
| 3c: Seismic airgun surveys | NWA | Known | Medium (3) | Unknown (5) | Unknown (5) | H, C, A | Recurrent | Extensive |
| 3d: Drilling operations | SSDU | Known | Unknown (5) | Unknown (5) | Unknown (5) | H, C, A | Recurrent | Restricted |
| 3d: Drilling operations | NWA | Known | Unknown (5) | Unknown (5) | Unknown (5) | H, C, A | Recurrent | Restricted |
| 3e: Echosounders | SSDU | Known | Low (3) | Unknown (5) | Unknown (5) | H, C, A | Recurrent | Restricted |
| 3e: Echosounders | NWA | Known | Low (3) | Unknown (5) | Unknown (5) | H, C, A | Recurrent | Restricted |
| 3f: Chronic noise exposure | SSDU | Known | Medium (3) | Unknown (5) | Unknown (5) | H, C, A | Continuous | Extensive |
| 3f: Chronic noise exposure | NWA | Known | Medium (3) | Unknown (5) | Unknown (5) | H, C, A | Continuous | Extensive |
| **Threat 4: Fisheries Interactions** | | | | | | | | |
| 4a: Entanglement | SSDU | Known | High (1) | High (1) | High (1) | H, C, A | Continuous | Extensive |
| 4a: Entanglement | NWA | Known | High (1) | Unknown (5) | Unknown (5) | H, C, A | Continuous | Broad |
| 4b: Risks of depredation | SSDU | Likely | High (3) | Unknown (5) | Unknown (5) | H, C, A | Recurrent | Unknown |
| 4b: Risks of depredation | NWA | Known | High (3) | Unknown (5) | Unknown (5) | H, C, A | Recurrent | Restricted |
| **Threat 5: Vessel Strikes** | | | | | | | | |
| 5: Vessel strike | SSDU | Known | High (1) | High (1) | High (1) | H, C, A | Continuous | Extensive |

| Threat | Geographic Scale | Threat Evaluation Criteria Likelihood of Occurrence | Threat Evaluation Criteria Individual Level of Impact (DQ) | Threat Evaluation Criteria Population Level of Impact (DQ) | Threat Evaluation Criteria Threat Risk | Threat Evaluation Criteria Timing of Occurrence (H, C, A) | Threat Evaluation Criteria Threat Frequency | Threat Evaluation Criteria Geographic Extent of Threat |
|---|---|---|---|---|---|---|---|---|
| 5: Vessel strike | NWA | Known | High (1) | Unknown (5) | Unknown (5) | H, C, A | Continuous | Extensive |
| **Threat 6: Pollution and Chemical Contaminants** | | | | | | | | |
| 6a: POPs | SSDU | Known | Medium (2) | Unknown (5) | Unknown (5) | H, C, A | Continuous | Broad |
| 6a: POPs | NWA | Known | Medium (2) | Unknown (5) | Unknown (5) | H, C, A | Continuous | Broad |
| 6b: Toxic metals | SSDU | Likely | Medium (3) | Unknown (5) | Unknown (5) | H, C, A | Continuous | Broad |
| 6b: Toxic metals | NWA | Likely | Medium (3) | Unknown (5) | Unknown (5) | H, C, A | Continuous | Broad |
| 6c: Plastics | SSDU | Known | Medium (2) | Unknown (5) | Unknown (5) | H, C, A | Continuous | Broad |
| 6c: Plastics | NWA | Known | Medium (2) | Unknown (5) | Unknown (5) | H, C, A | Continuous | Broad |
| 6d: Oil spills | SSDU | Known | High (3) | High (3) | High (3) | H, C, A | Recurrent | Narrow |
| 6d: Oil spills | NWA | Known | High (3) | Unknown (5) | Unknown (5) | H, C, A | Recurrent | Narrow |

## RATIONALE FOR THREAT CHARACTERIZATION

The following sections provide a rationale for the assessment associated with each threat. Note that threat risk does not require a rationale, as it is based on the risk matrix approach outlined in DFO (2014) that combines likelihood of occurrence and level of impact. As well, no rationale is provided for the timing of occurrence.

### Threat 1: Climate Change

*Likelihood of occurrence:* **Known** (SSDU & NWA)

- Climate change is a clear, present, and increasing threat to global ocean ecosystems. The rate of ocean warming has more than doubled since 1993, and the absorption of carbon dioxide by the world's oceans is causing increased surface acidification, enhanced stratification, and oxygen loss (IPCC 2019).
- Biogeographical shifts have been observed for marine organisms ranging from phytoplankton to marine mammals in response to ocean warming and biogeochemical changes (IPCC 2019). These shifts have changed community composition and altered interactions between species, affecting the structure and function of marine ecosystems (IPCC 2019).

*Individual level of impact:* **Unknown**

- The effects of climate change on NBW at the individual level are difficult to observe or predict. Unlike many other threats, where data on individual-level impacts are used to infer population-level consequences, the impacts of climate change on NBW are likely to become more apparent at the population level, when examined over longer time scales. The specific pathways of effects remain largely unknown, and many of the potential impacts may be indirect, multifaceted, and interconnected with other existing or emerging threats.

*Population level of impact*: **High** (SSDU), **Medium** (NWA)

- There is little information available to assess the impacts of climate change on NBW populations off eastern Canada, so this assessment is based on expert judgement, broad-scale assessments of the vulnerability of cetacean species and species groups to climate change, and current predictions for global-scale changes to ocean ecosystems and processes (DQ = 4).
- Assessments of the vulnerability of marine mammal species to climate change have ranked NBW with moderately high vulnerability based on traits such as geographic range, habitat and prey specificity, generation time, reproductive output, and body size (Albouy et al. 2020).
- Northward range shifts have been predicted for NBW in the eastern North Atlantic (Lambert et al. 2014), as well as cetacean species in the northern hemisphere more broadly. NBW in the SSDU may be particularly vulnerable to shifting prey resources and warming ocean temperatures since they occupy the southern portion of the species range for NBW, have an extremely small population size, and rely on specific habitat areas such as the Gully MPA. Northward shifts in the distribution of this population could significantly alter the frequency, extent, and severity of other anthropogenic threats encountered.

*Threat frequency:* **Continuous** (SSDU & NWA)

- Climate change is a current and continuous threat.

*Geographic extent of threat:* **Extensive** (SSDU & NWA)

- Climate change is a global threat. Impacts and rates of change may vary regionally, but a global decrease in marine animal biomass and shifts in species composition are expected to occur in all ocean ecosystems during the 21st century (IPCC 2019).

### Threat 2: Historical Whaling

*Likelihood of occurrence:* **Known** (SSDU & NWA)

- Commercial whaling operations for NBW occurred off Nova Scotia, Newfoundland and Labrador, as well as across the North Atlantic (Holt 1977, Mitchell 1977, Bloch et al. 1996).

*Individual level of impact:* **Extreme**

- Whaling involves the direct killing of individuals, and there were no seasonal catch limits or restrictions on killing females or calves. Given reductions to overall population size across the North Atlantic (Whitehead and Hooker 2012) and the slow reproductive rate of NBW (Feyrer et al. 2020), recovery is limited, particularly for the isolated SSDU which exists at the edge of species southern range. There are substantial data on this threat (DQ = 1).

*Population level of impact:* **Extreme** (SSDU)**, High** (NWA)

- There are considerable data on the population level of impact of whaling and the population size of the Scotian Shelf population (DQ = 1).
- There are adequate data on the population level of impact of whaling on NBW across the NWA, based the individual level of impact and knowledge of the Scotian Shelf population, however the size of the NBW population outside the SSDU is not known (DQ = 2).
- Approximately 65,000–100,000 NBW were commercially whaled in the 19th–20th centuries. Between 1962–1971, commercial whaling took at least 87 NBW from the Scotian Shelf (> 60% of current population size estimates) and over 800 from northern Labrador (Christensen 1977, Mitchell 1977, Whitehead and Hooker 2012). However, catch statistics are underestimated due to years with missing data and inconsistencies in reporting struck but lost animals (Whitehead and Hooker 2012).
- Although whaling ceased over three generations ago, NBW recovery will be affected by their slow reproductive rate (Feyrer et al. 2020), the species' resilience to ecosystem change (Pershing and Stamieszkin 2020) and connectivity between sub-populations (Feyrer et al. 2019, 2020).
- Outside the SSDU there is limited information on the recovery of NBW across their range in Canada after whaling for the species ended in 1972.
- Our appreciation of genetic population structure for NBW suggest the Scotian Shelf population is distinct, supporting its current management as a subpopulation (Feyrer et al. 2019). The most recent mark recapture estimates suggest that the Scotian Shelf NBW population maintained a small but relatively stable population size during the period of 1988–2011 (O'Brien and Whitehead 2013).
- Small peripheral populations, such as the SSDU, are expected to be less resilient to further reductions in genetic diversity due to reduced connectivity and increased potential for inbreeding (Feyrer et al. 2019).

- There was a notable decline in genetic diversity in the Scotian Shelf population, which was temporally coincident with the impacts of whaling (Feyrer et al. 2019). This decline in genetic diversity was not apparent in NBW from northern regions; however, the study by Feyrer et al. (2019) relied on historical samples (taken during whaling operations), which may bias analyses of subsequent impacts to genetic diversity for this population.

*Threat frequency:* **Not applicable**

- Commercial whaling was a historical threat for NBW but ended in Canada in 1971. However, whaling could become an issue if individuals were to be taken as part of subsistence hunts in Canada or elsewhere in the future. NBW are still occasionally harvested in the Faroe Islands, but typically only opportunistically (e.g., live stranded animals or nearshore animals) (Bloch et al. 1996, Whitehead and Hooker 2012).
- Although whaling activities are not occurring at the present time, historical whaling activities continue to impact current populations and have an ongoing legacy as a threat due to demographic impacts resulting from overall reductions across the species' range and the risks of low genetic diversity (Feyrer et al. 2019).

*Geographic extent of threat:* **Extensive** (SS & NWA)

- Whalers from the eastern North Atlantic pursued NBW west when stocks became depleted. There were targeted commercial hunts and incidental takes across core areas of NBW habitat in the western North Atlantic, including the Gully, the southern Grand Banks and northern Labrador (Whitehead and Hooker 2012).

## Threat 3: Acoustic Disturbance

### 3a: Military Sonar

*Likelihood of occurrence:* **Known** (SSDU & NWA)

- The large scale multi-national antisubmarine warfare training exercise "CUTLASS FURY" was conducted along the Scotian Shelf in 2016, 2019, and 2021, and is anticipated to occur biennially.
- Other military exercises occur off eastern Canada in the Department of National Defence operations areas and may include the use of sonar.

*Individual level of impact:* **Extreme**

- Some experimental studies have been conducted to assess the behavioural responses of NBW to sonar, and there are substantial data available on this threat for related beaked whale species (DQ = 2).
- Mass strandings of beaked whales have been conclusively linked to military sonar use and at least one NBW has died in a sonar-linked stranding (Simmonds and Lopez-Jurado 1991, Bernaldo de Quirós et al. 2019).
- Experimental behavioural response studies conducted in the eastern North Atlantic have shown that NBW are highly sensitive to sonar and exhibit strong reactions similar to those seen in other beaked whale species (Miller et al. 2015, Wensveen et al. 2019).
- The individual level of impact of military sonar is considered extreme due to the potential for this threat to cause mass mortality.

*Population level of impact*: **High** (SSDU), **Unknown** (NWA)

- There are no data or observations on the population level of impact of military sonar on the Scotian Shelf population, and this assessment is based on the individual level of impact and knowledge of the Scotian Shelf population, with some degree of uncertainty (DQ = 3).
- Due to the small population size, the death of one whale in the Scotian Shelf NBW population represents a significant impact, with the Potential Biological Removal (PBR) estimated at 0.3 individuals per year (DFO 2007a). Military sonar activity is known to occur in this region and has the potential to cause behavioural disturbance, injury, or mortality to individuals, so the potential population-level impact is considered high.
- It is not possible to assess the population level of impact of military sonar for the broader NWA region, as we do not have information on the abundance of NBW throughout this region, nor do we have information on the extent to which military sonar exposure may occur beyond the activities known to occur along the Scotian Shelf (DQ = 5).

*Threat frequency:* **Recurrent** (SSDU & NWA)

- CUTLASS FURY occurred in 2016, 2019, and 2021 and is anticipated to continue to occur approximately biennially, usually during a two-week period in September.
- We do not have access to information on the frequency of other military sonar activities occurring throughout the SSDU or NWA region, but Navigational Warnings (NAVWARNs) published by the Canadian Coast Guard (2021) include notices of military exercises occurring in designated operations areas, including “subsurface operations” and “underwater survey operations”. In 2019, there were 44 notices of military exercises in areas overlapping with potential NBW habitat, usually lasting one to five days each, for a total of 54 days.

*Geographic extent of threat:* **Unknown** (SSDU & NWA)

- We do not have access to information on the locations where military sonar exercises occur off eastern Canada; however, Department of National Defence "sub-surface operations areas” off Nova Scotia and Newfoundland overlap with potential NBW habitat, particularly along the eastern Scotian Shelf near the Laurentian Channel and off the southern Grand Banks south of Newfoundland (Department of National Defence 2021).

**3b: Vessel Noise**

*Likelihood of occurrence:* **Known** (SSDU & NWA)

- Shipping traffic occurs throughout the region and generates significant low-frequency noise. Increasing levels of marine traffic over the past several decades have contributed to a global increase in low-frequency ambient ocean noise (Erbe et al. 2019).

*Individual level of impact:* **Low**

- There is no information available on the impacts of vessel noise on NBW specifically, but a few studies have examined the behavioural responses of other beaked whale species to vessel noise. This assessment is based on limited data from other species and includes some degree of uncertainty (DQ = 3).
- Direct behavioural responses to vessel noise have been observed in Cuvier’s Beaked Whales (Aguilar Soto et al. 2006) and Blainville’s Beaked Whales (Pirotta et al. 2012). Altered foraging behaviour resulted in a short-term reduction in foraging efficiency.

- Vessel noise is unlikely to cause direct injury or mortality to NBW, but has the potential to cause harassment, disturbance, or increased stress in individuals.

  *Population level of impact:* **Low** (SSDU & NWA)

- There is no information available on the population level of impact of vessel noise on NBW, and this assessment is based on expert judgement (DQ = 4).
- At present, vessel noise is unlikely to jeopardize the survival or recovery of the population, but there is significant uncertainty around population-level consequences of repeated disturbance.
- This threat is linked to chronic noise exposure (Threat 2f, discussed below).

  *Threat frequency:* **Continuous** (SSDU & NWA)

- Vessel traffic, including recreational and fishing vessels as well as commercial shipping, is regularly present throughout the year in deep-water slope areas that overlap NBW distribution.
- Vessel noise encompasses a far wider area than ship tracks, and there is a high likelihood that NBW are continuously exposed to vessel noise.

  *Geographic extent of threat:* **Extensive** (SSDU), **Broad** (NWA)

- As noted above, vessel traffic is widespread throughout the western North Atlantic, and low-frequency noise can travel large distances underwater. The area impacted by vessel noise extends far beyond the tracks of individual vessels and is likely to affect most habitat areas used by Northern Bottlenose Whales.

**3c: Seismic Airgun Surveys**

*Likelihood of occurrence:* **Known** (SSDU & NWA)

- Extensive seismic airgun surveys have been conducted throughout the SSDU and broader NWA region since the 1960s (Canada-Nova Scotia Offshore Petroleum Board [CNSOPB], Canada-Newfoundland and Labrador Offshore Petroleum Board [CNLOPB]).

  *Individual level of impact:* **Medium**

- Noise generated by seismic airgun surveys has the potential to impact cetaceans in various ways, as reviewed by Theriault and Moors-Murphy (2015), but there are no available data on impacts to NBW, specifically. This assessment is based on limited data, mainly from other species, and a large degree of uncertainty remains (DQ = 3).
- Limited research on the effects of seismic airgun surveys on other odontocete species has demonstrated behavioural responses including avoidance and short-term displacement (e.g., Thompson et al. 2013), suggesting that seismic airgun surveys have the potential to disturb odontocetes even though most of the sound energy is produced at low frequencies.
- There is one anecdotal observation of a stranding of Cuvier's Beaked Whales which coincided with nearby seismic airgun use (Gordon et al. 2003, Peterson 2003). Seismic airgun surveys have not been conclusively linked to acute injuries or mortalities of beaked whales, but if such impacts were to occur in an offshore region, they are highly likely to go unobserved.

- Squid may be sensitive to seismic airguns (e.g., Guerra et al. 2011, Fewtrell and McCauley 2012), and any effects on local populations of squid or other prey species could impact the food supply for NBW.

*Population level of impact:* **Unknown** (SSDU & NWA)

- There is insufficient information available to assess the population level of impact of seismic airgun surveys on NBW (DQ = 5).
- As noted above, seismic airgun surveys may impact the food supply for NBW, leading to habitat degradation and indirect population-level effects.
- This threat is linked to chronic noise exposure (Threat 2f, discussed below).

*Threat frequency:* **Recurrent** (SSDU & NWA)

- Extensive seismic airgun survey activity has occurred off eastern Canada since the 1960s. The duration and timing of past and present seismic airgun survey activities are variable throughout the region.
- The most recent seismic airgun surveys conducted off Nova Scotia occurred in 2013, when Shell Canada Ltd. conducted a wide-azimuth 3D seismic airgun survey covering more than 10,000 $km^2$ for their Shelburne Basin Deepwater Exploration Program, and in 2014, when BP Canada conducted a similar seismic airgun survey over approximately 7,700 $km^2$ for their Scotian Basin Exploration Project (CNSOPB).
- Off Newfoundland and Labrador, there is an active offshore oil and gas industry, and seismic airgun surveys are ongoing, including within areas off southern Newfoundland that overlap with the SSDU (CNLOPB).

*Geographic extent of threat*: **Extensive** (SSDU & NWA)

- Seismic airgun survey activity off eastern Canada has overlapped extensively with NBW habitat (CNSOPB, CNLOPB).
- Low-frequency noise propagates efficiently in deep water, and pulses from seismic airguns have been recorded as far as 3,000 km from the source (Nieukirk et al. 2004). Noise from seismic airgun surveys occurring in deep waters off eastern Canada is therefore likely to affect most habitat areas used by NBW.

**3d: Drilling Operations**

*Likelihood of occurrence:* **Known** (SSDU & NWA)

- Offshore oil and natural gas production has occurred off eastern Canada for more than 25 years and continues to be an active industry in this region.

*Individual level of impact:* **Unknown**

- There is no information available to assess the impacts of noise from drilling operations on NBW (DQ = 5), and no data on the effects of this source of noise on other cetaceans.

*Population level of impact*: **Unknown** (SSDU & NWA)

- There is no information available to assess the population level of impact of noise from drilling operations on NBW (DQ = 5).

- When drilling operations occur repeatedly within NBW habitat, this threat may be linked to chronic noise exposure (Threat 2f, discussed below).

*Threat frequency:* **Recurrent** (SSDU & NWA)

- Since 1967, more than 200 wells have been drilled offshore of Nova Scotia for exploration, delineation, and development purposes. Active petroleum production commenced near Sable Island in 1992, and subsequent production projects continued to operate in this area until 2018. All active production facilities off Nova Scotia have been decommissioned as of 2020 (CNSOPB).
- Recent drilling operations occurring in deep waters off Nova Scotia include two exploratory wells drilled by the Shell Canada Shelburne Basin Venture Exploration Drilling Project in 2016, and one exploratory well drilled by the BP Scotian Basin Exploration Drilling Project in 2018. All of these were subsequently plugged and abandoned (CNSOPB).
- Off Newfoundland and Labrador, active oil production began in 1998 and has expanded in subsequent decades, with four production facilities currently active and numerous exploratory and delineation wells drilled throughout the region (CNLOPB). Drilling operations are ongoing in many areas.

*Geographic extent of threat:* **Restricted** (SSDU & NWA)

- Off Nova Scotia, drilling operations have been concentrated in shelf waters around Sable Island, west of the Gully MPA. Fewer wells have been drilled in deep waters beyond the shelf edge, and most of these, including the recent exploratory drilling operations by Shell in 2016 and BP in 2018, were located off the western Scotian Shelf and not near the designated Critical Habitat areas for NBW (CNSOPB).
- Similarly, much of the oil and gas development activity off Newfoundland and Labrador is located in shallower waters on the continental shelf and Grand Banks, but drilling operations are also occurring in deep waters, particularly around the Sackville Spur, where aggregations of NBW have recently been observed (CNLOPB).
- Sound source characterization studies indicate that noise from drilling operations is relatively localized (MacDonnell 2017, Martin et al. 2019), and current drilling operations are unlikely to affect a large proportion of NBW habitat in the SSDU or broader NWA region. This assessment could change in the future depending on where drilling operations occur relative to NBW habitat.

**3e: Echosounders**

*Likelihood of occurrence:* **Known** (SSDU & NWA)

- Active acoustic echosounder technologies are commonly used for navigation, hydrography, seafloor mapping, fisheries applications, and oceanographic research. These activities are known to occur within the SSDU and broader NWA region.

*Individual level of impact:* **Low**

- There is no information available on the potential impacts of echosounders on NBW, specifically. This assessment is based on the limited data available for other beaked whale species (DQ = 3).
- Echosounders are unlikely to cause direct auditory injury in NBW due to the relatively low source levels (compared to military sonars or seismic airguns), the short durations of pulses

emitted, and the high angular directivity of these systems, which limits the total area of ensonification (Lurton and DeRuiter 2011).

- There is some evidence of behavioural responses to echosounders among beaked whales and other odontocetes, which may include altered foraging behaviour (e.g., Cholewiak et al. 2017).

*Population level of impact*: **Unknown** (SSDU & NWA)

- There is insufficient information available to assess population level of impact of echosounders on NBW.
- Repeated or prolonged disturbances, particularly those that affect foraging behaviour, may have longer-term population-level consequences (e.g., New et al. 2013), so we do not consider this threat to be negligible and further research is needed.

*Threat frequency:* **Recurrent** (SSDU & NWA)

- Echosounders are typically used on vessels, which may pass through or spend time in the habitat of Northern Bottlenose Whales. Due to the transient nature of these sources, the threat is unlikely to be continuously present in NBW habitat.

*Geographic extent of threat:* **Restricted** (SSDU & NWA)

- The area affected by echosounders is limited, and impacts are usually only on the order of kilometers from the source (Lurton and DeRuiter 2011). The threat is unlikely to impact more than 10% of NBW habitat in the SSDU or NWA region.

**3f: Chronic Noise Exposure**

*Likelihood of occurrence:* **Known** (SSDU & NWA)

- As detailed above, NBW are exposed to various sources of anthropogenic noise throughout their range.

*Individual level of impact:* **Medium**

- There is little information available to assess the level of impact of chronic noise exposure on NBW or other beaked whales, and the assessment is therefore based on limited data, including data from other species (DQ = 3). We expect this threat to have a medium impact on individuals, but there is considerable uncertainty in this assessment.
- Research conducted on other marine and terrestrial organisms suggests that chronic noise exposure can increase physiological stress and have long-term consequences on health and fitness.

*Population level of impact*: **Unknown** (SSDU & NWA)

- There is insufficient information to assess the population level of impact of chronic noise exposure in NBW, as the impacts on individual health and the potential population-level consequences are poorly understood.

*Threat frequency:* **Continuous** (SSDU & NWA)

- The threat of chronic noise exposure is continuous by definition, since it refers to impacts experienced over time due to recurring, prolonged, or continuous exposure to multiple sources of anthropogenic noise.
- Among the sources of noise described in this assessment, vessel noise is characterized as continuous, while most other sources are recurrent. Recurrent noise exposure may be prolonged, such as seismic airgun survey activity occurring for months at a time.

*Geographic extent of threat:* **Extensive** (SSDU & NWA)

- The geographic extent of vessel noise and noise from seismic airgun surveys is considered to be extensive across the SSDU and NWA regions, and NBW are exposed to various other sources of anthropogenic noise throughout their range, which overlap in space and time.

## Threat 4: Fisheries Interactions

### 4a: Entanglement

*Likelihood of occurrence:* **Known** (SSDU & NWA)

- Entangled NBW have been reported off Nova Scotia, Newfoundland and Labrador (Harris et al. 2013, Feyrer et al. 2021), and entanglement scars have been observed in Scotian Shelf NBW (Feyrer et al. 2021).

*Individual level of impact:* **High**

- There are substantial empirical data, including direct observations of entanglements and entanglement scars, to indicate that entanglements have resulted in injuries and mortality of NBW off eastern Canada (DQ = 1).
- Multiple mortalities and injuries attributed to entanglements have been documented for NBW off Nova Scotia, Newfoundland and Labrador (Harris et al. 2013, Feyrer et al. 2021), providing evidence that these interactions occur and that individuals have been impacted by this threat (see Table A1).
- Such mortalities are likely to be underreported due to the remote offshore region inhabited by this species and lack of observer effort in these areas.

*Population level of impact*: **High** (SSDU), **Unknown** (NWA)

- There are substantial empirical data to support that NBW entanglements have occurred within the SSDU at a rate that is highly likely to have population-level impacts (DQ = 1).
- Multiple NBW mortalities have been conclusively linked to entanglements within the SSDU. Based on annual entanglement rates, there is evidence that more than one individual in the Scotian Shelf population has been impacted every year (Feyrer et al. 2021). Given the rate of interactions and unobserved mortalities, lethal entanglements are likely occurring at a rate that exceeds PBR (estimated at 0.3 individuals per year; DFO 2007a).
- In addition to mortality, entanglements can cause non-lethal injuries to cetaceans that can have long-term consequences for individuals such as reduced health, fitness and reproductive success, potentially leading to population-level impacts such as reduced population growth rates (Dolman and Brakes 2018).
- Though entanglements have also been reported in more northern waters (Harris et al. 2013), it is not possible to assess the population level of impact of entanglements for the

broader NWA area, as we do not have information on the population size or PBR for the DSBBLS population (DQ = 5).

*Threat frequency:* **Continuous** (SSDU & NWA)

- Fisheries that overlap with NBW habitat in the SSDU include bottom and pelagic longline, bottom and mid-water trawls, and other fisheries using gear that NBW and other whales have previously been reported entangled in (DFO 2005, Butler et al. 2019, Rozalska and Coffen-Smout 2020).
- Fishing efforts occur throughout the year, though effort within a given fishery and area often varies by season (Butler et al. 2019, Rozalska and Coffen-Smout 2020). For example, though groundfish fisheries operate year-round off Nova Scotia, fishing activity becomes wider-spread and catches are higher in the July to September period (Rozalska and Coffen-Smout 2020). Longline fisheries for large pelagics (swordfish, tuna, marlin and sharks) have substantial overlap with the SSDU, and operate primarily from April to December (Rozalska and Coffen-Smout 2020).
- Similar temporal trends in fishing efforts occur throughout the broader NWA.

*Geographic extent of threat:* **Extensive** (SSDU), **Broad** (NWA)

- As described above, a number of different fisheries occur throughout Nova Scotia waters with efforts extending along deep-water areas of the Scotian Slope (DFO 2005, Butler et al. 2019, Rozalska and Coffen-Smout 2020), including in and around the identified important and Critical Habitat of the Scotian Shelf population of NBW. Though fishing activities are prohibited from Zone 1 of the Gully MPA (part of NBW Critical Habitat), fishing does still occur in other areas of the Gully. These fishing efforts overlap with most other NBW habitat in the SSDU.
- Some of the fishing effort maps presented in Rozalska and Coffen-Smout (2020) also show efforts occurring in deep waters off Newfoundland and Labrador that overlap the distribution of NBW in the broader NWA (e.g., halibut bottom longline, redfish otter trawls). DFO (2007b) provide maps of fishing effort that demonstrate overlap with NBW habitat off eastern Newfoundland. Fishing efforts in deep waters overlapping NBW habitat within the broader NWA are also demonstrated in other fishing effort maps[4]. These fisheries effort maps suggest widespread occurrence of fishing activities throughout large areas of the NWA, though overlap with NBW habitat in this broader area does not appear to be as extensive as overlap in the smaller SSDU.

**4b: Risks of depredation**

*Likelihood of occurrence:* **Likely** (SSDU), **Known** (NWA)

- NBW have been observed following trawls to feed while gear was being hauled back off Nova Scotia (Fertl and Leatherwood 1997).
- There are a number of reports of NBW depredation, including whales being hand-fed by fishers and associated with trawl and longline fisheries in Newfoundland, Labrador and

[4] See Figure 2 from Groundfish Newfoundland and Labrador Region NAFO Subarea 2 + Divisions 3KLMNO. [Accessed 12 February 2021]

Baffin Bay (Oyarbide Cuervas-Mons 2008, COSEWIC 2011, Harris et al. 2013, Johnson et al. 2020).

*Individual level of impact:* **High** (SSDU & NWA)

- As the result of depredation behaviour, NBW increase their risk of injuries, harm and mortality from entanglements, ingestion of hooks or other gear, vessel strikes and retaliation by fishers. However, evidence that depredation has directly resulted in these or other adverse impacts is based on limited data (DQ = 3).
- As NBW are a social species with loose short-term associations (Gowans et al. 2001), the number of NBW individuals engaging in depredation behaviour is likely to increase with increasing population trends due to the positive energetic benefits of depredation and social learning.

*Population level of impact*: **Unknown** (SSDU & NWA)

- There is insufficient information to assess the population level of impact of depredation for NBW, as there is no information on what proportion of NBW mortalities or injuries can be attributed to the risks associated with depredation behaviour (DQ = 5)

*Threat frequency:* **Recurrent** (SSDU & NWA)

- Depredation is likely to occur seasonally, with increased trawling and longline activity.

*Geographic extent of threat:* **Unknown** (SSDU), **Restricted** (NWA)

- Depredation behaviour is associated with particular fisheries (trawl and longline) in more northern waters, and thus appears to be more restricted in geographic scope for the NWA than the broader threat of entanglement. Less is known about the geographic scope of depredation behaviour in the SSDU.

### Threat 5: Vessel Strikes

*Likelihood of occurrence:* **Known** (SSDU & NWA)

- Scars attributed to vessel-propeller strikes have been documented in Scotian Shelf NBW (Feyrer et al. 2021).

*Individual level of impact:* **High**

- There are substantial empirical data to support that vessel strikes can cause mortality of beaked whales, and that injuries to NBW caused by vessel strikes have occurred off eastern Canada (DQ = 1).
- Vessel strikes often result in death of cetaceans through sharp and blunt force injuries, while less severe vessel strikes may cause non-lethal injuries that can have long-term consequences for individuals such as reduced health, fitness, and reproductive success, and potentially lead to population-level impacts such as reduced population growth rates (Schoeman et al. 2020).
- Beaked whale mortalities caused by vessel strikes have been documented (e.g., Deaville et al. 2018, Díaz-Delgado et al. 2018).

- Moderate and severe vessel-propeller scars, including dorsal fin mutilations and amputations, have been documented in the SSDU (Feyrer et al. 2021), providing evidence that these interactions occur and that individuals have been impacted by this threat.
- Although no known NBW mortalities have been conclusively linked to vessel strikes off eastern Canada or elsewhere, such mortalities are likely to be underreported due to the remote offshore region inhabited by this species and lack of observer or search effort in these areas.

*Population level of impact*: **High** (SSDU), **Unknown** (NWA)

- There are substantial empirical data to support that non-fatal NBW vessel strikes have occurred within the SSDU, at a rate that is likely to have population-level impacts on the Scotian Shelf population (DQ = 1).
- While no known NBW mortalities have been conclusively linked to vessel strikes within the SSDU, such mortalities are likely to be underreported. Moderate and severe vessel-propeller scars have been documented in the Scotian Shelf population with stable annual gain rates over the last 30 years (1988–2019), providing evidence that these interactions do occur in the SSDU (Feyrer et al. 2021). Due to the small population size, the death of even one whale in the Scotian Shelf population represents a significant impact, with the PBR estimated at 0.3 individuals per year (DFO 2007a).
- It is not possible to assess the population level of impact of vessel strikes for the broader NWA region, as we do not have information on the population size or PBR for the DSBBLS population (DQ = 5).

*Threat frequency:* **Continuous** (SSDU & NWA)

- Vessels, which include recreational and fishing vessels as well as commercial ships, are regularly present throughout the year in deep-water slope areas that overlap with NBW distribution.
- An analysis of automatic identification system (AIS) data from 2018 and 2019 showed that commercial vessels were present in the Gully MPA, which includes the core Critical Habitat of Scotian Shelf NBW, at least 30% of days in a year, with vessel presence occurring in all months of the year (McConney et al.2023). This report also showed regular presence of fishing vessels in the MPA.
- Many main vessel traffic routes cross over or follow along the Scotian Slope, particularly enroute to or from the major ports of Halifax and Port Hawkesbury, or into the Gulf of St. Lawrence, and commercial shipping traffic maps show regular passages of commercial vessels occurring over deep-water areas off Nova Scotia (DFO 2005). Similarly, as described above, fishing vessels are also regularly present in these deep water areas throughout the year, though individual fisheries may occur seasonally (DFO 2005).
- Commercial shipping and fishing vessels occur throughout the year in deep water areas off Newfoundland, Labrador and more northern waters.
- Further, Feyrer et al. (2021) show that between 1988–2019, NBW in the SSDU gained vessel-propeller scars each year at a steady rate, supporting that this is a regularly occurring threat.

*Geographic extent of threat:* **Extensive** (SSDU & NWA)

- As stated above, vessels occur in all areas off eastern Canada, including in deep-water slope areas throughout the distributional range of NBW. Vessel transits and other vessel-based activities commonly occur in areas considered to be NBW habitat (slope waters deeper than 500 m), though there is a voluntary slow down zone in the Gully MPA. Because of the widespread occurrence of vessels of all types throughout the SSDU and NWA, this threat is considered to extensive in geographic scope.

## Threat 6: Pollution and Chemical Contaminants

### 6a: POPs

*Likelihood of occurrence:* **Known** (SSDU & NWA)

- POPs are found in varying concentrations across the North Atlantic, including the deep water habitat of NBW (Sun et al. 2016).

*Individual level of impact:* **Medium**

- There are adequate data on impacts of POPs for other species of cetaceans and two studies on concentrations in NBW to support the assessment of individual level of impact (DQ = 2).
- While studies on NBW found a few individuals with PCBs approaching the lower toxicity threshold for adverse health effects, currently none have surpassed it (Desforges et al. 2021).
- The average concentration in NBW was found to be above the molecular toxicity threshold, suggesting that PCBs may be affecting physiological responses at a molecular and cellular level (Desforges et al. 2021).

*Population level of impact*: **Unknown** (SSDU & NWA)

- Sample sizes are insufficient in studies on POP concentrations in NBW to distinguish whether differences in concentrations over time or between individuals are representative of the region or population (DQ = 5).
- While studies indicate individual NBW have been exposed to PCBs and DDT, the measured concentration levels have uncertain health impacts, and consequences at a population level are unknown (Desforges et al. 2021).

*Threat frequency:* **Continuous** (SSDU & NWA)

- POPs occur continuously within the marine environment. Although there may be periodic releases through burning and waste sites, most sources are land-based, atmospheric or historic. However, the production of many POPs ceased after voluntary bans over 30 years ago (Sun et al. 2016).

*Geographic extent of threat:* **Broad** (SSDU & NWA)

- POPs occur broadly within the marine environment at different concentrations depending on oceanographic and climatic conditions and proximity to point sources (Macdonald et al. 2003).
- Although NBW across the NWA were found to have some level of exposure, increased concentrations of POPs in the SSDU are thought to reflect differences between the proximity of habitat areas to larger land-based sources (Desforges et al. 2021).

**6b: Toxic Metals**

*Likelihood of occurrence:* **Likely** (SSDU & NWA)

- Toxic metals are found in varying concentrations across the North Atlantic. The concentrations of mercury have increased over all ocean basins, including in the deep-water habitat of NBW (Bruland and Franks 1983, Lamborg et al. 2014).
- Toxic metals are found in association with industrial activities and petroleum products. Given that offshore oil and gas activities occur in NBW habitat across the NWA region, this threat is likely to occur (Ansari et al. 2004, Gall et al. 2015).

*Individual level of impact:* **Medium**

- There are limited data on the effects of toxic metals for other species of cetaceans, but no studies on concentrations or effects for NBW, limiting evidential support for an assessment of impact (DQ = 3).
- Studies on other cetacean species indicate a range of uncertainty on the effects of toxic metals, which may be due to limited data, species biology or study specific conditions (Ansari et al. 2004, Frouin et al. 2012).
- However, for some well-studied metals (e.g., mercury), toxicity levels have been established and are linked to adverse health effects for individuals (Frouin et al. 2012).

*Population level of impact*: **Unknown** (SSDU & NWA)

- There are no data on toxic metal concentrations in NBW to assess population-level impacts (DQ = 5).

*Threat frequency:* **Continuous** (SSDU & NWA)

- Toxic metals are continuously present at some level within the marine environment. Although there may be periodic releases, such as during a spill event, most sources are likely continuously released as part of industrial processes (Ansari et al. 2004).

*Geographic extent of threat:* **Broad** (SSDU & NWA)

- Toxic metals occur broadly within the marine environment at different concentrations depending on the source (Ansari et al. 2004).
- Although NBW across the NWA may face some level of exposure from offshore industries, habitat is generally far from larger land-based industrial sources (Bruland and Franks 1983).

**6c: Plastics**

*Likelihood of occurrence:* **Known** (SSDU & NWA)

- Plastic debris is found in varying concentrations and particle sizes across the North Atlantic, including the deep-water habitat of NBW (Dufault and Whitehead 1994, Lusher et al. 2018, Rochman 2018).

*Individual level of impact:* **Medium**

- There are adequate data on impacts of plastics for other species of beaked whales and cetaceans, and some unpublished records of plastics ingested by NBW to support the assessment of individual level of impact (DQ = 2).

- While there are no current studies on the impact of plastics to NBW, the harmful health effects of plastic ingestion observed in other cetacean species indicate that the impacts include nutritional deficiencies and physical blockages and may eventually lead to starvation (Jacobsen et al. 2010). Microplastics ingested may result in increased exposure to other associated contaminants and cause nutritional deficiencies (Lusher et al. 2018).

*Population level of impact*: **Unknown** (SSDU & NWA)

- There are insufficient data or studies on the occurrence or concentrations of plastics in NBW to make an assessment of population level of impact (DQ = 5).
- While unpublished reports indicate that individual NBW have ingested plastic materials, the broader impacts and consequences at a population or regional level are unknown.

*Threat frequency:* **Continuous** (SSDU & NWA)

- Plastics in some form or particle size are now thought to occur nearly continuously within the marine environment (Rochman 2018).

*Geographic extent of threat:* **Broad** (SSDU & NWA)

- Plastics occur broadly within the marine environment at different concentrations depending on the size and source (Rochman 2018).
- Although NBW across the NWA may face some level of exposure drifting from nearby land-based sources, plastics encountered in their offshore habitat may also come from ocean-based sources including commercial shipping, fishing activities and long-range circulation patterns (Galgani et al. 2015).

**6d: Oil Spills**

*Likelihood of occurrence:* **Known** (SSDU & NWA)

- Small oil spills regularly occur across the North Atlantic, including surrounding the deep-water habitat of NBW (CNSOPB, Allard et al. 2015).

*Individual level of impact:* **High**

- There are adequate data on impacts of large oil spills for other species of cetaceans; however, there are few studies on the impacts of more frequent small spills. Although biological responses are unlikely to differ for beaked whales or NBW, there is limited information on the impacts of small or large spill events on beaked whales (DQ = 3).
- Oil and its components are toxic and the impacts of large oil spills on cetaceans has been documented to cause mortalities, reproductive impacts, and other long term health effects, including an increase in lung disease and other health conditions (Murawski et al. 2021). The impacts of small spills on individuals will vary depending on the location, size, frequency, environmental conditions and composition of oil products spilt.

*Population level of impact*: **High** (SSDU) **Unknown** (NWA)

- For the SSDU, this assessment is based on the individual level of impact resulting from large spills and knowledge of the Scotian Shelf population, with some degree of uncertainty given the unknown number of small spills potentially occurring in NBW habitat (DQ = 3).

- Large oil spills can lead to multiple mortalities and long-term health effects, and small oil spills may elevate ongoing exposures to toxic metals and other contaminants increasing harmful health effects (Ansari et al. 2004, Hooker et al. 2008, Murawski et al. 2021). Given the PBR of 0.3 for the SSDU, we assessed the threat of population-level impacts as high.
- Despite the risks of mortality, it is not possible to assess the population level of impact of oil spills for the broader NWA, as we do not have information on the population size or PBR for the DSBBLS population (DQ = 5).

  *Threat frequency:* **Recurrent** (SSDU & NWA)

- Small oil spills occur regularly from vessels, during ballast water exchange, and during the operations of the oil and gas industry (CNSOPB, Allard et al. 2015). Large oil spills have decreased globally over the last decade; however, there are increased risks in areas nearby tanker traffic routes, ports and offshore drilling operations (ITOPF 2021). There are two large oil tanker ports within the Maritimes Region: Saint John and the Bay of Fundy, New Brunswick, and Port Hawkesbury-Canso Strait, Nova Scotia.

  *Geographic extent of threat:* **Narrow** (SSDU & NWA)

- The extent and fate of oil spilled into the marine environment depends on many factors, including volume, the type and source of petroleum product, weather, and spill response strategies (Zhang et al. 2019). While different concentrations may occur at varying distances from a single source, the extent of any one spill would likely only affect a narrow proportion of NBW habitat in the NWA.

# DISCUSSION

## THREAT ASSESSMENT PROCESS

The focus of this threat assessment was to evaluate distinct threats to NBW at the population level; however, there remain many gaps in our understanding of the longer-term population-level consequences of threats for cetaceans in general, and particularly for remote offshore species such as NBW, which are especially challenging to observe and study. It can be difficult to measure and assess the health and fitness of cetaceans, and there is typically limited information available on how the sub-lethal and/or indirect effects of a threat may affect longer-term survival and reproduction. While a quantitative evaluation of threat risk at the population level would be ideal, such information is generally not available for cetacean populations, even when it is evident that negative impacts on individuals are occurring. Cetaceans are long-lived species, and it may take many years, or even decades, before the significant impacts of a present threat on the broader population can be observed. High impact threats may affect the recovery of small, endangered populations long before the time frame that is necessary to fully understand these impacts at the population level.

Assessing the impact of each threat individually may not represent an accurate assessment of impacts on a population, and the cumulative effects of multiple threats (including over both space and time) may result in a higher overall threat risk for NBW than any individual threat on its own. Another important consideration is that the impacts of a threat may be broader than the spatial and/or temporal occurrence of the threat itself. For example, although whaling for NBW has not occurred since the 1970s, removal of large proportions of populations during historical whaling activities have resulted in lasting genetic effects that are still impacting NBW populations today, which may exacerbate the impacts of other threats that are currently present. Climate change is also likely to interact with other threats, and a changing climate could affect food supply and cause distribution shifts, which may result in increased interaction with human activities (as has recently occurred with North Atlantic Right Whales in Canadian waters).

The threat assessment guidance outlined in DFO (2014) was challenging to apply to an assessment of threats to NBW (and would likely be difficult to apply to any cetacean) due in part to inconsistencies and lack of clarity in the definitions and explanations provided. Perhaps more problematic is that the threat assessment approach as outlined relies heavily on quantitative thresholds and is not easily applied to data-poor species. The threat assessment framework would benefit from revision to address the situation where quantitative assessments are not possible and/or for which we lack data on population-level effects. The impacts of threats on individuals and habitat, and the potential uncertainty in pathways for population-level impacts should be considered. Additional guidance is needed to account for impacts on habitat, indirect effects, interactions between effects, and the cumulative impact of multiple threats. Improving the clarity and consistency of definitions within the guidance would also be beneficial. The approach applied to this NBW threat assessment incorporated modifications to the DFO (2014) guidance in an initial attempt to address some of these issues.

Finally, while it is beyond the scope of this threat assessment to prioritize specific management actions, clarification on how the assessment table may be interpreted and used to inform management priorities is needed, particularly for the cases when impacts or threat risk are assessed as “low” or “unknown”. From a scientific perspective, the assessment of threat risk as “low” does not imply that the threat is negligible—all threats assessed are known or expected to have some level of impact. The assessment of threat risk as “unknown” usually reflects the need for more data but does not preclude management actions aimed at reducing the potential threat risk even in the absence of further study. Greater transparency in the current guidance on management implications would help to ensure consistent interpretation and accurate, unbiased science advice.

## THREAT ASSESSMENT RESULTS

This threat assessment covers a wide range of threats to NBW for both the SSDU and broader NWA; however, it may not capture all threats to this species in Canadian waters and it is possible that additional threats may emerge in the future. Of the threats assessed, almost all are known to occur in both the SSDU and broader NWA; all are historical, current and anticipatory (with the exception of historical whaling); all are either recurrent or continuous; and many occur over broad or extensive geographic scopes.

Table 2 summarizes the results of the individual and population level of impact assessments. Overall, climate change, historical whaling, military sonar, entanglement, vessel strike, and oil spills (in no particular order) are threats presenting high risk to NBW off eastern Canada, while the risks of other threats assessed are largely unknown and require further study. Primarily because there is no information on the size of the DSBBLS population of NBW, the population level of impact of 12 of the threats is unknown for the NWA (Table 2). Lack of evidence for a particular population level of impact should not be assumed to be lack of effect, as in many cases it can be demonstrated that there are impacts occurring on individuals. As well, there is almost no ability to observe and record the impacts of many of these threats due to the remote offshore habitat of this species, and it is highly likely that mortalities, injuries, and other impacts are underreported.

*Table 2. Summary of the level of impact assessments for each of the 15 threats assessed for Northern Bottlenose Whales (NBW). At the individual level of impact, the assessments are the same for both the Scotian Shelf Designatable Unit (SSDU) and the broader Northwest Atlantic (NWA). The assessments may vary between the SSDU and NWA at the population level of impact. Dashed line (-) indicates no threats categorized at that level.*

| Rank Category | Individual Level of Impact SSDU & NWA | Population Level of Impacts SSDU | Population Level of Impacts NWA |
|---|---|---|---|
| **Unknown** | (2 threats) climate change, drilling operations | (8 threats) seismic airgun surveys, drilling operations, echosounders, chronic noise, risks of depredation, persistent organic pollutants, toxic metals, plastics | (12 threats) military sonar, seismic airgun surveys, drilling operations, echosounders, chronic noise, entanglement, risks of depredation, vessel strike, persistent organic pollutants, toxic metals, plastics, oil spills |
| **Extreme** | (2 threats) historical whaling[5], military sonar | (1 threat) historical whaling[5] | - |
| **High** | (4 threats) entanglement, risks of depredation, vessel strike, oil spills | (5 threats) climate change, military sonar, entanglement, vessel strike, oil spills | (1 threat) historical whaling[5] |
| **Medium** | (5 threats) seismic airgun surveys, chronic noise, persistent organic pollutants, toxic metals, plastics | - | (1 threat) climate change |
| **Low** | (2 threats) vessel noise, echosounders | (1 threat) vessel noise | (1 threat) vessel noise |

It is important to note that the impacts of all threats combined likely result in a higher overall threat risk for NBW than any individual threat on its own. Climate change is a particularly important threat which may affect and alter the level of risk of various other threats to NBW, especially the SSDU, being a small population occurring at the southern part of the species' range. It is inadequate to treat this as a single distinct threat, when it is actually a driver of multiple, interconnected threats and an important factor in determining the extent, frequency, impact, and risk of most of the other threats assessed in this document. Designing future studies and monitoring efforts to increase understanding of how climate change impacts NBW and assessing other threats to this species within the context of climate change are important

[5] Historical whaling is not a current threat, but the impacts of whaling are ongoing.

steps towards developing an adaptive and flexible management plan to account for a rapidly changing environment.

## FUTURE WORK AND RESEARCH NEEDS

There are several important knowledge gaps identified where additional information would improve future assessments. Management of threats to NBW would benefit from additional studies to address the following research objectives:

- Estimating the size of the DSBBLS population, which is currently unknown.
- Improving our understanding of the distribution, movements and population structure of NBW off eastern Canada, especially the potential for substructure within the DSBBLS in the intermediary areas of Newfoundland and Labrador.
- Explaining the biological distinction between populations to support a science-based rationale for the location of DU boundaries, which are currently arbitrarily chosen.
- Understanding the individual- and population-level impacts of threats; noting that there will likely be a continued need to draw upon knowledge of other species given the challenge of conducting such studies on beaked whales.
- Quantitative assessment of the spatiotemporal overlap between the occurrence of NBW and threats, including cumulative impacts, to improve risk assessments and better inform management measures and mitigation activities.
- Understanding the current and future impacts of climate change on NBW and assessing threats to NBW within the context of climate change.

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Feyrer, Laura J., Stanistreet, Joy E., and Moors-Murphy, Hilary B. 2024. Navigating the Unknown: Assessing Anthropogenic Threats to Beaked Whales, Family Ziphiidae. Royal Society Open Science 11 (4): 240058.

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# APPENDIX

*Table A1. Records of Northern Bottlenose Whale (NBW) entanglements off eastern Canada, organized by population. N indicates the number of animals associated with the entanglement description.*

| N | Description | References |
|---|---|---|
| ***Entanglements associated with the Scotian Shelf population*** | | |
| 1 | Entanglement in squid gear reported by an at-sea fishery observer (referenced as “discard”) in 1981. | (Harris et al. 2013) |
| 3 | Entanglements in silver hake/trawl gear reported by at-sea fishery observers (two of which were referenced as “discard”) between 1990–1993. | (Hooker et al. 1997, Harris et al. 2013, Feyrer et al. 2021) |
| 1 | Serious entanglement in swordfish/longline gear reported by researchers in 1999, in which the individual had longline wrapped around its beak to a degree that would prevent feeding and was presumed fatal. | (Whitehead Lab 1999, Gowans et al. 2000, Harris et al. 2013, Feyrer et al. 2021) |
| 1 | Entanglement of a juvenile in pelagic swordfish/longline gear reported by an at-sea fishery observer in 2001, animal was released hooked but alive. | (Wimmer and Whitehead 2004, Harris et al. 2013, Feyrer et al. 2021) |
| 1 | Fatal entanglement between 2008–2014 associated with gear described as “net” from opportunistic reports off Atlantic Canada. | (Themelis et al. 2016, Feyrer et al. 2021) |
| 1 | Fatal entanglement in 2001 associated with longline gear on the Grand Banks. | (Garrison 2003, Feyrer et al. 2021) |
| 1 | Decomposed NBW found in trawl on the Grand Banks, at some point before 2007. | (Feyrer et al. 2021, Oyarbide et al. 2021a) |
| 1 | Live stranded NBW in 2005, died later in Milltown, Newfoundland, with gear marks on tail. | (Ledwell and Huntington 2005, Feyrer et al. 2021, Kelly et al. 2003) |
| ***Entanglements associated with the Davis Strait-Baffin Bay-Labrador Sea population*** | | |
| 1 | Entangled in squid trap, released alive in Dildo Arm, Trinity Bay. | (Lien et al. 1990) |
| 1 | Entanglement in Greenland halibut/trawl gear reported by an at-sea fishery observer in 2002. | (Harris et al. 2013) |
| 1 | Entanglement in Greenland halibut/longline gear reported by an at-sea fishery observer in 2003, animal was released alive. | (Harris et al. 2013, Feyrer et al. 2021) |
| 1 | Fatal entanglement in Greenland halibut/gillnet gear reported by a fisherman in 2008, in which the animal was entangled by its caudal peduncle. | (Harris et al. 2013) |
| 1 | Stranded NBW with old deep scar ½ way between the dorsal and peduncle on the back ridgeline and scarring on the peduncle at the joining to the flukes. Scars appear fishing gear entanglement related. | (Ledwell et al. 2021) |