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Science Advisory Report 2019/028

REVIEW OF NORTH ATLANTIC RIGHT WHALE OCCURRENCE AND RISK OF ENTANGLEMENTS IN FISHING GEAR AND VESSEL STRIKES IN CANADIAN WATERS

Illustration by Scott Landry

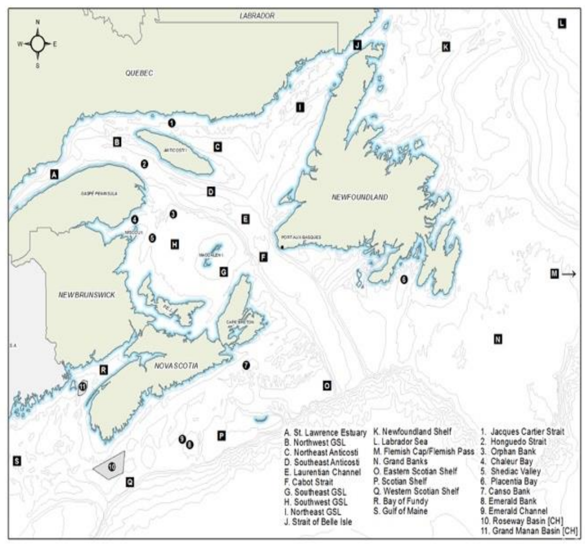


Figure 1. Place names used in this SAR

Context:

In Canada, the North Atlantic Right Whale (NARW) is listed as Endangered under Schedule 1 *of the Species at Risk Act (SARA). SARA specifies requirements for legal protection and mandatory recovery planning, which is managed by the Department of Fisheries and Oceans (DFO). The NARW SARA Recovery Strategy describes threats to the species, recovery objectives, and approaches for achieving these objectives. Recovery objectives include reducing mortality and injury from vessel strikes and entanglements in fishing gear, the two main documented sources of mortalities.*

In 2017, twelve NARW were found dead in the Gulf of St. Lawrence (GSL). Necropsies conducted on seven of these carcasses concluded that four animals died from blunt trauma consistent with vessel strikes, two from entanglement in fishing gear, and in one case the cause of death was not conclusive. In addition, there were five live entanglements documented, two of which were disentangled while one animal shed the gear. The outcome of the final two entanglements is unknown.

In response to the vessel strike mortalities, the Government of Canada implemented a voluntary 10-knot speed restriction zone for vessels greater than 20 metres [65 feet] in length navigating in the GSL beginning 10 July 2017. On 11 August, this measure was revised to a mandatory 10 knot speed restriction zone which remained in place until January 2018. In 2018, a combination of areas with no restrictions and static and dynamic speed restriction zones for vessels 20 metres or longer was established in the GSL. This management approach ran from 28 April until 15 November. After 15 November, 2018 vessels were asked to voluntarily reduce their speed to not exceed 10 knots in the presence of NARW.

In an effort to reduce the risk of entanglements of NARW in fishing gear, DFO implemented static and dynamic fisheries management zones (i.e., fishery closures) in 2017 and 2018. A static closure zone was identified in the GSL based upon the area where 90% of the NARW observations occurred during June and July 2017, while dynamic management areas were identified based upon potential foraging habitats and the NARW Critical Habitat in the Roseway and Grand Manan basins.

The objectives of this meeting were to (1) determine, to the extent possible with available data, the spatial and temporal distribution of NARW in Canadian waters, based on aerial and vessel-based surveys, acoustic data collected from moorings, buoys and autonomous underwater vehicles (gliders), and other biological data; and, (2) determine the risks to NARW from entanglement in invertebrate fishing gear and from vessel strikes in the Gulf of St. Lawrence. These objectives were met by providing answers to a series of questions that were provided.

This Science Advisory Report is from the National Marine Peer Review Committee (NMMPRC) 2018 Meeting I: Review of North Atlantic right whale occurrence and risk of interactions with fishing gear and collision with vessels, held November 26-30, 2018, in Montreal, Quebec. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

SUMMARY

- Surveillance and detection efforts for NARW increased considerably in 2018 relative to 2017. NARW have been detected acoustically in Canadian waters year-round, although the number of detections is lower in the winter. The distribution of whales was generally similar in 2018 and 2017 with large aggregations of whales observed in the southwest Gulf of St. Lawrence (GSL) and smaller but persistent numbers observed in the northwestern Gulf. Only low numbers of whales were observed in the Critical Habitat areas of Roseway and Grand Manan Basins.
- The general distribution of NARW in the southwestern Gulf of St. Lawrence was similar between 2017 and 2018, although on a finer scale, there were slight differences between the 2 years. The position of whales within their habitat varied on a short time scale. However, gaps in survey effort limit our ability to assess the seasonal and inter-annual variability.
- The data presented here confirm that there was an increase in the presence of NARW in the Gulf of St. Lawrence beginning in 2015. This increase occurred following an earlier decline in abundance and change in distribution in the Bay of Fundy which began in 2010.
- A number of factors influence the distribution of NARW. The primary driver of the presence of NARW is the density and availability of its main prey, the copepod (*Calanus* spp.). There have been significant changes in the abundance of *Calanus* in eastern Canadian waters since 2010. While there is interannual variability, biomass of *Calanus* in most areas has declined, with the greatest declines observed in the Gulf of Maine and on the Scotian Shelf.
- A NARW bioenergetic foraging model identified persistent areas in Canadian waters where *Calanus* abundance and densities may be sufficient to meet the energetic needs of NARW. However, there was considerable inter-annual variability in *Calanus* densities, with greater differences in habitat suitability observed before and after 2010. Many of the areas identified in the new analyses as potentially suitable NARW habitat were similar to those identified previously.
- Species distribution models specific to the Scotian Shelf and the Bay of Fundy predicted suitable habitat for NARW based on physical, oceanographic, and biological factors used as proxies for prey. Although areas identified varied slightly between models, the Grand Manan

Basin and Roseway Basin as well as areas in between, along with areas on the eastern Scotian Shelf and east of Cape Breton, were consistently identified as suitable habitat.

- Diverse approaches consistently identified a number of areas that would benefit from new or increased survey effort, such as the northern Gulf of St. Lawrence, northeast of Anticosti Island, Cabot Strait, northeast Newfoundland, Emerald Channel (between Emerald Basin and the Shelf Break), Labrador Sea and potential migratory pathways.
- Analysis of recent acoustic and visual survey data support the advice provided in 2017 on the timing of the movement of NARW into and out of the Gulf of St. Lawrence. Acoustic recorders indicate that NARW remained in the Gulf until late December 2017 and returned to the Gulf in late April 2018. Whales were first sighted in the Gulf in May 2018. Whales were still being detected acoustically in the Gulf as of the end of November 2018.
- Preliminary photo-identification data indicate that at least 7 individually identified NARW were present in the Bay of Fundy and at least 135 in the southwestern Gulf of St. Lawrence in 2018. Aerial surveys estimated 190 NARW (95%CI: 52-692) in the southern Gulf of St. Lawrence although this is an under-estimate due to whales that were missed when diving. This represents a substantial (~50%) proportion of the known population.
- Residency time of individual NARW in a given area can vary considerably. Based on the re-sightings of individual animals during one aerial survey program, residency time in the southwest Gulf of St. Lawrence in 2018 averaged 34 days although it was highly variable among individuals. Some of the whales were only seen on one day while others were seen over the full 69 days of aerial monitoring. Of the 51 individuals identified on the first airborne survey, 13 were re-sighted on the last survey. Previous research in Roseway Basin and the Bay of Fundy indicate that NARWs residence time averaged 136 and 75 days, respectively.
- The movement behaviour of individual NARW was highly variable. Some individuals did not move far between successive days while others moved considerable distances. Some whales in the southwestern Gulf of St. Lawrence were estimated to move as much as 50 km in a single day.
- In Canadian waters, very few NARW have been detected in water depths less than 50 m. Also, *Calanus* were not abundant in waters less than 50m. While we cannot estimate the risk of entanglement of NARW in shallow waters due to the lack of adequate data on fishing activity in these areas, it is not zero.
- The co-occurrence of NARW and fishing activities in the southern Gulf of St. Lawrence is high. A simulation study designed to estimate potential encounters between NARW and snow crab fishing gear during the years 2015 to 2017 in the southern Gulf of St. Lawrence indicated that the majority of the simulated potential encounters across all three years would have occurred in the 2018 fisheries static closure zone.
- The relative risk of a lethal vessel strike was estimated using a simulation model that incorporated data on vessel movements and speed with density and distribution of NARW in the Gulf of St. Lawrence in 2017. Risk was reduced within the mandatory speed restriction zone by 56% while in effect. However, relative risk increased northwest of Anticosti Island directly outside the bounds of the speed restriction zone due to increased vessel presence that coincided with the speed restriction in 2017. There were other areas in the Gulf where the relative vessel strike threat was high although monitoring was limited.
- In 2018, the presence of a single whale was used to trigger management actions in some areas. Alternative approaches using multiple whales to trigger management actions would

require survey methods designed to assess the number of individuals and their persistence in a given area, as well as other operational requirements.

- There are several potential options for monitoring NARW occurrence off eastern Canada, with strengths and limitations associated with each. All of the survey and monitoring methods used in 2018 provided relevant and complementary data for science and monitoring. The best methods to use depend on the management and science objectives and include a combination of tools. It is important to identify and prioritize the key questions and goals to develop the most effective monitoring program.

INTRODUCTION

Biology

The western North Atlantic right whale (*Eubalaena glacialis;* NARW) is a large baleen whale with adults measuring up to 17m in length and weighing approximately 60-70 tonnes. Adult females are typically a metre longer than males. NARW are generally black in colour with occasional white belly and chin patches and no dorsal fin or throat grooves. Data on longevity are limited, but the oldest individual on record was estimated to have been at least 70 years old. The average age of sexual maturity is not known, but females are seen with their first calf at approximately 10 years of age. Age at sexual maturity for males is estimated to be about 15 years of age. NARW give birth to a single calf; the interval between births has historically been around 4 years. In the 1990's, the average calving interval appeared to have increased to approximately 6 years. In 2017 the average inter-calf interval was estimated to be 10.2 years for those females that have had one or more calves and are presumed to be alive. No calves were observed during the winter 2017/2018 calving season.

The NARW population was reduced to an extremely low level by whaling. In 1990, the population was estimated to 270 individuals, but increased to approximately 482 individuals in 2010. Since then, the population declined to an estimated 458 (95% Credible interval = 444-471) individuals in 2015. In 2017, the population was estimated to be approximately 411 individuals. Of particular concern is the divergent trend in sex ratio with males becoming more abundant than females (1.46M:1F in 2015 vs 1.15M:1F in 1990) as a result of lower female survival after age 5. The recent decline in the population resulted from a combination of increased anthropogenic mortality, and decreased reproduction which was likely due to lower prey availability in some feeding areas.

NARW range from Florida to Iceland and Norway, but there is no single area within their range where all NARWs are present at the same time. Although there may be considerable individual variation, in general NARW use the more southerly areas for calving during the winter, and move to northerly areas during the summer for feeding and socializing. Some individuals may remain in northern areas year-round. NARW mainly feed on lipid-rich, late development stages of three species of *Calanus* copepods in areas where *Calanus* densities are sufficient to support their energetic needs. Although the summering location of a considerable component of the population is unknown, the regular seasonal use of some specific areas by large numbers of NARW has resulted in the designation of Critical Habitats in both Canada and the United States. In Canada, Critical Habitat has been designated in the Grand Manan Basin of the Bay of Fundy and Roseway Basin off southwest Nova Scotia (Fig 1).

NARW have been observed in the GSL for many decades (Figure 2). Based on opportunistic sightings, their numbers in the GSL were considered to be low and dispersed with occasional sightings around northern Cape Breton, east of the Gaspé Peninsula, in the Baie des Chaleurs, north of Anticosti Island and in the St. Lawrence estuary. NARW have also been reported off Newfoundland (NL). However, dedicated survey effort in Canadian waters to locate NARW outside of the Bay of Fundy and southwest Nova Scotia has been limited. Since 2015, observations of NARW in the Gaspé-Magdalen Islands-Miscou Island area (southwestern GSL) and since 2016 in the Jacques Cartier Strait north of Anticosti Island, have increased. However, it was not clear if the increase in sightings from 2015 to 2017, particularly in the southern GSL, resulted from a change in the distribution of NARW, increased survey effort, or both.

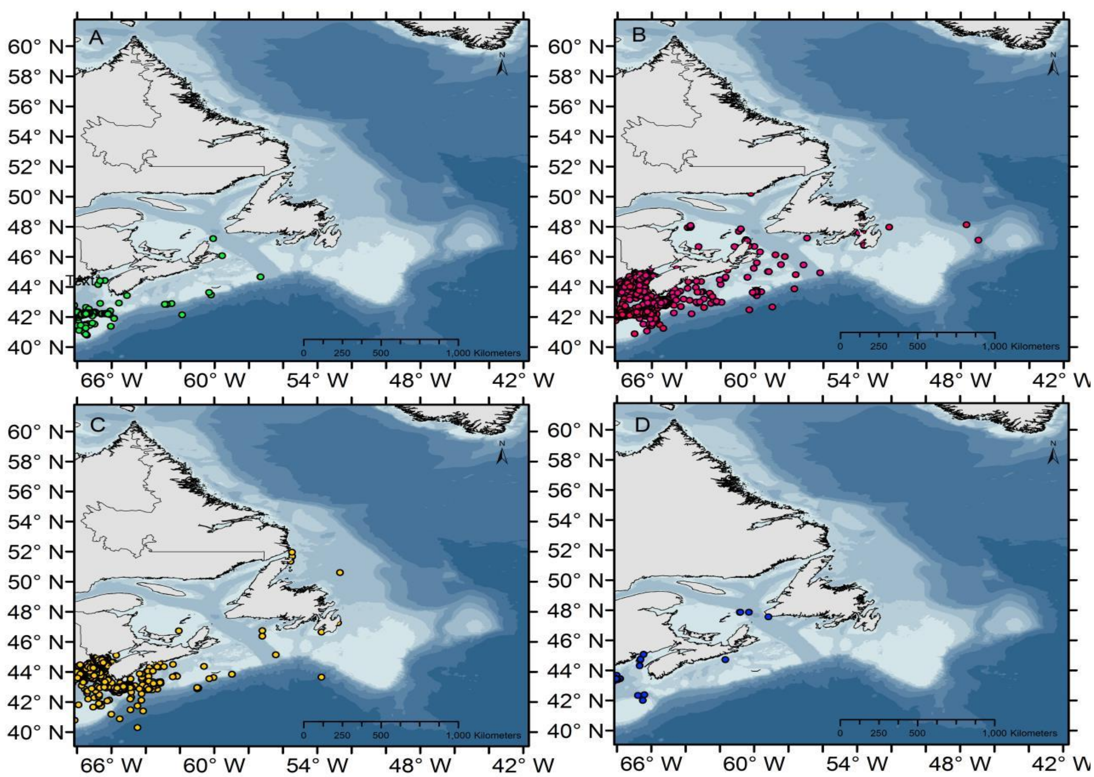


Figure 2. NARW sightings from 1975-2015 in: (A) spring (March through May; (B) summer (June through August); (C) autumn (September through November); and (D) winter (December through February). NARW sightings data from the DFO Maritimes and NL Regions, Ocean Biogeographic Information System (OBIS), and the North Atlantic Right Whale Consortium (NARWC) opportunistic sighting databases are included. Sightings that may be present in other sources of information are not included.

ASSESSMENT AND CONCLUSIONS

A. Correlation of Water Depths and NARW presence

A.1. Is there a relationship between water depth and confirmed NARW sightings?

Although there was less systematic visual survey effort in shallow waters (<50 m) than in other areas during 2017 and 2018 (~8-12%), the proportion of NARW sighted in shallow coastal-water domains in 2017 and 2018 was very low (~1% in waters <50 m and ~0.4% in waters <20 m `depth) in comparison to the amount of effort.

The primary prey of NARW, *Calanus,* are also not commonly found in shallow waters at densities estimated to be sufficient to support NARW feeding. A study modelling the abundance and distribution of *Calanus* in the GSL based upon surveys found that fewer than 5% of the sampling stations with sufficient abundance and density to meet the energetic needs of NARW were in waters shallower than 50m.

Previously published data examining NARW habitat use in the Bay of Fundy are consistent with these observations in the GSL in that few NARW were observed in shallow waters.

A.2. Is the likelihood of NARW entanglements reduced in shallow (<20 ftm/50m) waters?

The likelihood of entanglements in a given area depends upon both the fishing activity and presence of whales. Due to the unavailability of data on fishing activity in shallow waters at the meeting, we were unable to estimate the risk of entanglement in shallow waters. Available data indicate that NARW are rare in shallow waters, although it should also be noted that NARW may use shallow waters to transit among deep-water foraging areas. Therefore, although NARW appear to be relatively rare in shallow waters, the risk of entanglement is not zero and entanglements could occur if NARW co-occur with fishing gear in these shallow water areas.

B. Foraging Areas

B.1. What are the biological and physical factors that influence the distribution of NARW and how have they changed over time?

There is considerable inter-annual variability in NARW occupancy and distribution in Canadian waters. Nearly four decades of research in the Bay of Fundy and Roseway Basin have demonstrated right whale occurrence within Canadian habitats is highly variable due to variation in their food supply, social behavior and life history. Occurrence in the Bay of Fundy has varied between from a low of at least 7 to a high of at least 215 identified individuals over the years.

The known biological factors that influence the distribution of NARW include whale demographics (e.g., age, sex, reproductive status), social behaviour (which often is poorly understood) and foraging behaviour. Availability of their preferred prey species (*Calanus*) is critical for the survival and reproductive success of NARW, and is an important driver of NARW distribution in Canadian waters.

Physical factors will also influence the distribution of NARW indirectly, primarily through their influence on the density and distribution of their prey. These can include bathymetry, water mass characteristics (e.g., strength or magnitude of water mass transport, tidal cycle), sea surface temperature, chlorophyll levels, and salinity. For example, a large and sudden shift in environmental conditions beginning during the 2008-2010 period in the Bay of Fundy resulted in reduce abundance of *Calanus* which, in turn, impacted NARWs.

However, it must be noted that each year a considerable portion of the NARW population is not observed in the known summer feeding areas and therefore some of the factors influencing their distribution are unknown.

B.2. Based upon data collected in 2017 and 2018, is there evidence to suggest that the areas identified based upon *Calanus* densities in 2017 (i.e. ‘potential foraging zones’) are important foraging areas for NARW in the Gulf of St. Lawrence and on the Scotian Shelf?

The ‘potential foraging zones’ identified in 2017 were estimated based upon historical (1980-2015) densities of *Calanus*. A refined estimate of ‘suitable’ *Calanus* biomass in the GSL was developed based on a NARW bioenergetic foraging model that was not previously available. This bioenergetic model identifies areas where *Calanus* abundance and densities are considered sufficient to meet the energetic needs of NARW. Many of the areas identified in 2018 are similar to those identified in 2017. However, considerable seasonal and inter-annual variability in *Calanus* distribution was identified.

A separate series of models specific to the Scotian Shelf and the Bay of Fundy identified suitable habitat for NARW based on the various physical and biological factors, such as depth, sea surface temperature, chlorophyll, salinity and complexity of the bottom, which were used as proxies for prey presence. Although areas identified varied slightly between models, the Grand Manan Basin and Roseway Basin as well as areas in between, areas on the eastern Scotian Shelf, and east of Cape Breton were consistently identified as suitable habitat. The areas identified were consistent with the 2017 analyses of prey availability.

The areas identified by these independent modelling exercises based upon suitable prey density to meet the energetic requirements of NARW, and habitat suitability based on physical and biological proxies, were consistent with known NARW feeding areas, including the areas identified as Critical Habitat.

Given that our knowledge of NARW occurrence in Canadian waters is incomplete, additional important foraging habitats may exist that remain to be identified. However, our ability to identify such areas is limited by the spatial and temporal extent of NARW survey and *Calanus* sampling effort, the dynamic nature of marine ecosystems, and the fact that we do not observe all individually identified NARW every year.

B.3. What factors influence the distribution of *Calanus* and is there any indication of changes in *Calanus* distribution or abundance?

Three *Calanus* species are abundant in Atlantic Canadian waters. *Calanus finmarchicus* is abundant across all areas, while *C. hyperboreus* is most abundant in the GSL and on the northeast NL shelves. *C. glacialis* is the least abundant of the three species with its highest abundances being on the northeast NL shelf and lowest on the Scotian Shelf. *C. hyperboreus* is the dominant contributor to *Calanus* biomass throughout the GSL, whereas *C. finmarchicus* is the dominant contributor to biomass outside the GSL, although *C. hyperboreus* is also important on the northern NL shelf.

Local abundance of *Calanus* is influenced by temperature and salinity, bathymetry, microplankton abundance (prey), diel and seasonal vertical distribution in the water column, and survival. *Calanus* distribution is influenced by local production, transport (supply), and retention.

Species-specific *Calanus* abundance has changed in many areas across eastern Canada, effectively resulting in a change in distribution. In general, the biomass of *Calanus* has declined since 1999, and was negatively correlated with sea surface temperature in the Gulf of Maine, Georges Bank, and on the Scotian Shelf. A ‘regime shift’ to lower biomass of *Calanus* was observed in the Gulf of Maine in 2009-2010 and on the Scotian Shelf in 2011. As a result, the probability of NARW encountering high prey densities in the areas they have inhabited in the past may be decreasing. *Calanus* abundance has also decline in the GSL but the overall biomass is greater than on the Scotian shelf.

These changes in prey density should be considered in relation to the energetic needs of NARW at various life history stages (e.g., reproduction and lactation), which may alter the threshold of prey density required for profitable foraging for NARW.

B.4. Are NARW still using the Grand Manan and Roseway Basin areas to the same extent and if not, is there any indication of why there was a shift?

On average, NARW occurrence and length of residency time in the Grand Manan Basin has declined since 2010 which is consistent with the decline in *Calanus* in the area, although there is high inter-annual variability. There is also some evidence to suggest that within the Bay of Fundy, there may be a northwestern shift in the distribution of some whales to areas outside of the Grand Manan Basin Critical Habitat as seen during the early 1980s.

Acoustic data on the presence of NARW in Roseway Basin have been collected in 2004, 2005, and yearly since 2013. Visual surveys have been conducted for a total of 21 years since 1981. Based upon these data, there appears to be high interannual variability in NARW use of the area. NARW were consistently detected when acoustic recorders were deployed during the summer and autumn periods of 2015-2016. However, detections were more sporadic in 2017 and no NARWs were detected in 2018 by the acoustic gliders. However, full analysis of the acoustic data from 2018 in Roseway Basin has yet to be completed and one right whale was seen. Overall, there has been a decline in NARW sightings and more recently, an apparent decline in acoustic detections, suggesting that fewer right whales are using the area. This is consistent with the lower biomass of *Calanus* observed in the area in recent years.

B.5. Considering the factors that influence the distribution of NARW, are there areas within Canadian waters that are not currently surveyed that NARW may utilize?

Diverse approaches (e.g., acoustic detections of NARW, models of *Calanus* densities, species distribution models) consistently identified a number of areas where NARW may occur that would benefit from new or increased survey effort. These include the northern part of the GSL, including northeast of Anticosti Island, Cabot Strait, northeast of Newfoundland, north and south of the Magdalen Islands especially in June, Emerald Channel, and offshore areas such as the Flemish Pass and Flemish Cap, Labrador Basin and western Davis Strait, as well as migratory pathways among these areas (Fig 1). The migratory routes of NARW among known feeding areas are also poorly known and would require additional survey effort.

C. Monitoring (Acoustic/Visual)

Information on NARW distribution and abundance in Canadian waters was collated from multiple sources; some monitoring programs have been in place for several years (e.g., Bay of Fundy, Roseway Basin), while other programs have been implemented more recently (e.g., GSL surveys). These programs included acoustic data from fixed bottom-moored hydrophones and mobile autonomous underwater gliders, deployed by DFO, JASCO Applied Sciences and Dalhousie University, as well as visual observations from aerial surveys that included systematic, focused and opportunistic design methodologies completed by DFO, Transport Canada (TC), and the US National Oceanic and Atmospheric Administration (NOAA). Additional information, mainly vessel-based observations, were provided by Non-Governmental Organizations including the Canadian Whale Institute (CWI), Mingan Island Cetacean Study (MICS), New England Aquarium (NEAQ), and DFO vessels. Opportunistic sightings reported to DFO were also examined.

In 2018, the aerial and visual sightings and track-lines, as well as glider acoustic detections and track lines, were plotted on Whale Map, a Dalhousie/DFO initiative that automatically collated and publicly displayed NARW survey data from all monitoring platforms as soon as they became available (usually within a day; WhaleMap).

C.1. Is the distribution of NARW observed in 2018 the same as that reported in 2017?

At a broad scale, the overall distribution of NARW in Canadian waters was similar between 2017 and 2018 with a large concentration of whales observed in the southwest GSL. This general distribution was also similar to that observed in 2015 and 2016 although the amount of sighting effort was considerably lower in these earlier years.

Smaller but persistent numbers were observed in the northwest GSL as well as in the Critical Habitat areas of the Roseway Basin and Grand Manan Basin in both 2017 and 2018.

At the finer scale of the southwestern GSL, the NARW aggregations appeared to have shifted further north in the Shediac Valley in late summer 2017 (Fig 3). Such a movement did not occur in 2018. Similarly, animals may have been distributed slightly westward in 2018. However, given that there are fewer than two full years of survey data, and considerable differences in the amount, spatial distribution, and timing of survey effort between 2017 and 2018, it is not possible to determine if the apparent shifts reflect actual differences in the whales' seasonal or annual distribution patterns, simple variability in movements within the general area, or variability in survey effort (Fig. 3). The monthly intensity and distribution of survey effort within and between 2017 and 2018 makes it difficult to determine movements and comprehensive distributions of right whales in the southern GSL.

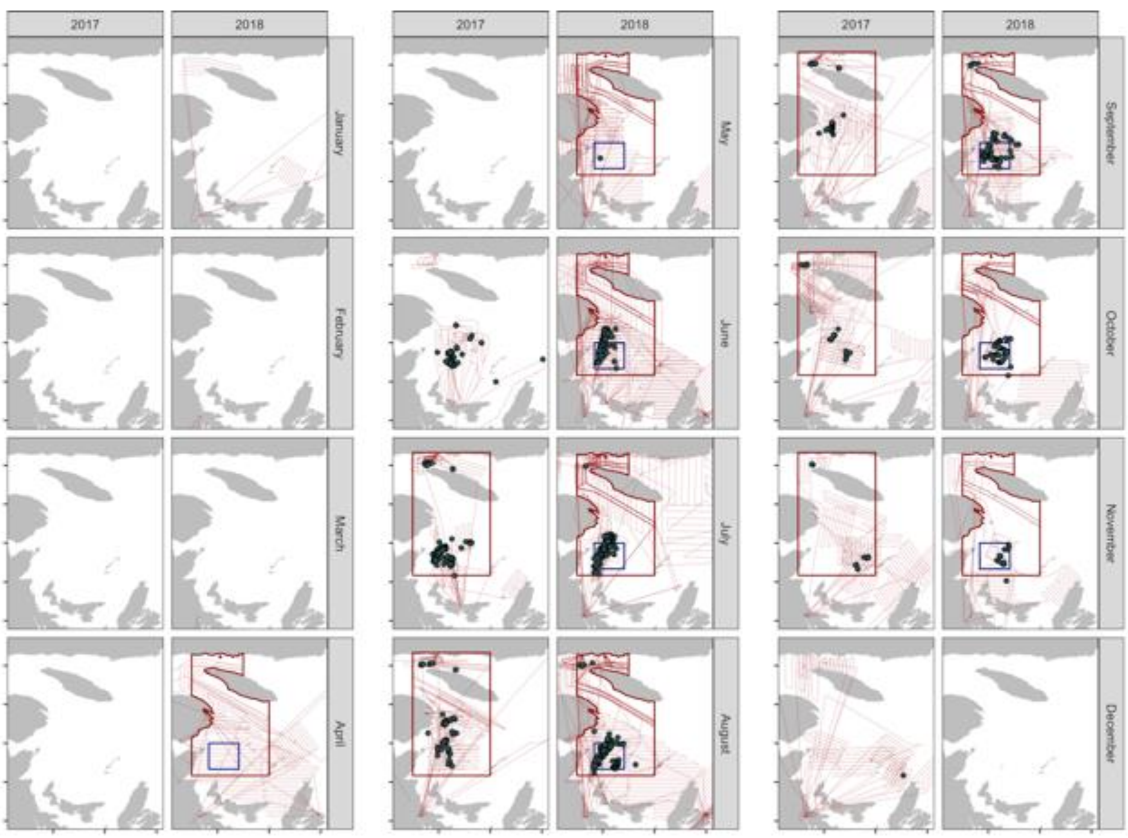


Figure 3. Distribution of confirmed visual observations (black dots) and track-line effort of dedicated survey platforms (brown lines) by month in 2017 versus 2018 in the Gulf of St. Lawrence. Static fishery (blue box) and vessel (red box) management areas used in 2018 are shown for context.

C.2. Are there new data that can be used to update the previous Science Special Response (2017/042) that can provide advice on the timing and distribution of NARW in Canadian waters?

The distribution of NARW in the GSL was reviewed in late 2017 (DFO 2017). Since then, considerable new information on the distribution of NARW in the GSL as well as elsewhere in Canadian waters has been collected.

Acoustic data from fixed acoustic recorders and glider deployments in the GSL, and along the Scotian Shelf (Fig. 4) indicated that NARW are present in Canadian waters throughout the year, although acoustic detections tend to be fewer in winter months (Fig. 5). A large number of vocalizations were recorded on the western Scotian Shelf, and in the GSL (Figs 5,6). Lower numbers of vocalizations were recorded on the eastern Scotian Shelf and in the Cabot Strait.

Acoustic detections indicate the presence of whales, if they are calling and close enough to the recorder to be detected. However, while they can indicate that whales are in the area, the lack of calling does not necessarily mean that whales are not present. Using acoustic detections to estimate the number of whales in an area is difficult because it requires knowledge of calling rates of individuals. For example, a high number of detections (over a given time period) can indicate either the presence of a large number of animals or fewer animals that are vocalizing more frequently. However, the persistence of acoustic detections over time suggests frequent use of these areas (Fig. 5,6).

The periods when the acoustic recorders were active are shown in Figures 5 and 6. Analyses of acoustic data from the additional recorders on the Scotian Shelf, Grand Banks and Labrador are still underway.

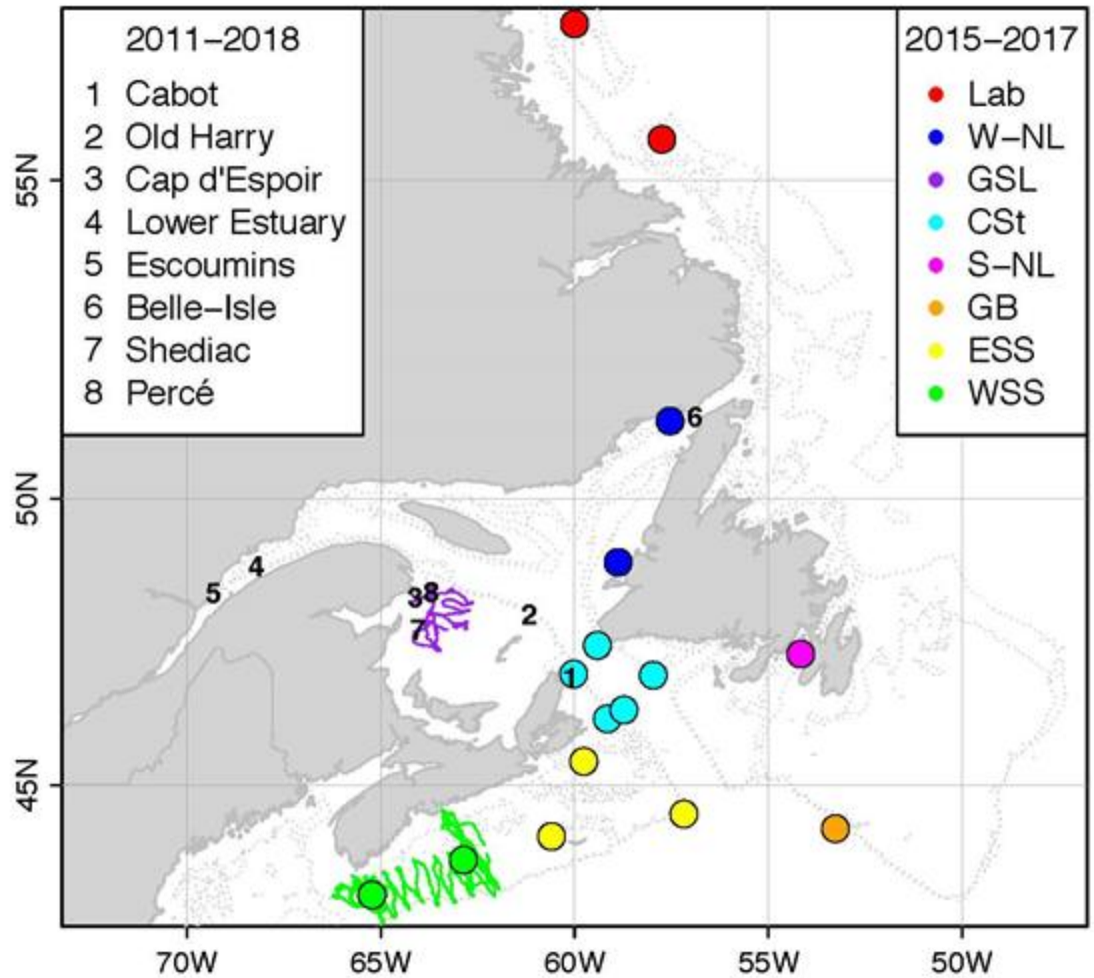


Figure 4. Locations of passive acoustic monitoring (PAM) platform deployments in the GSL from 2011-2018, on the Scotian Shelf and in Newfoundland-Labrador waters, 2015-2017. Track lines indicate movements of the PAM Slocum gliders while closed circles indicate the location of fixed hydrophones. Colour coding of circles indicates the different regions; 1) Labrador Coast (Lab), 2) Strait of Belle Isle (W-NL), 3) Gulf of St. Lawrence (GSL), 4) Cabot Strait (CSt), 5) Southern Newfoundland (S-NL), 6) Grand Bank (GB), 7) Eastern Scotian Shelf (ESS) and 8) Western Scotian Shelf (WSS). Numbers indicates locations of fixed PAM recorders deployed in GSL from 2011-2018. See Figures 5 and 6 to determine when recorders were active.

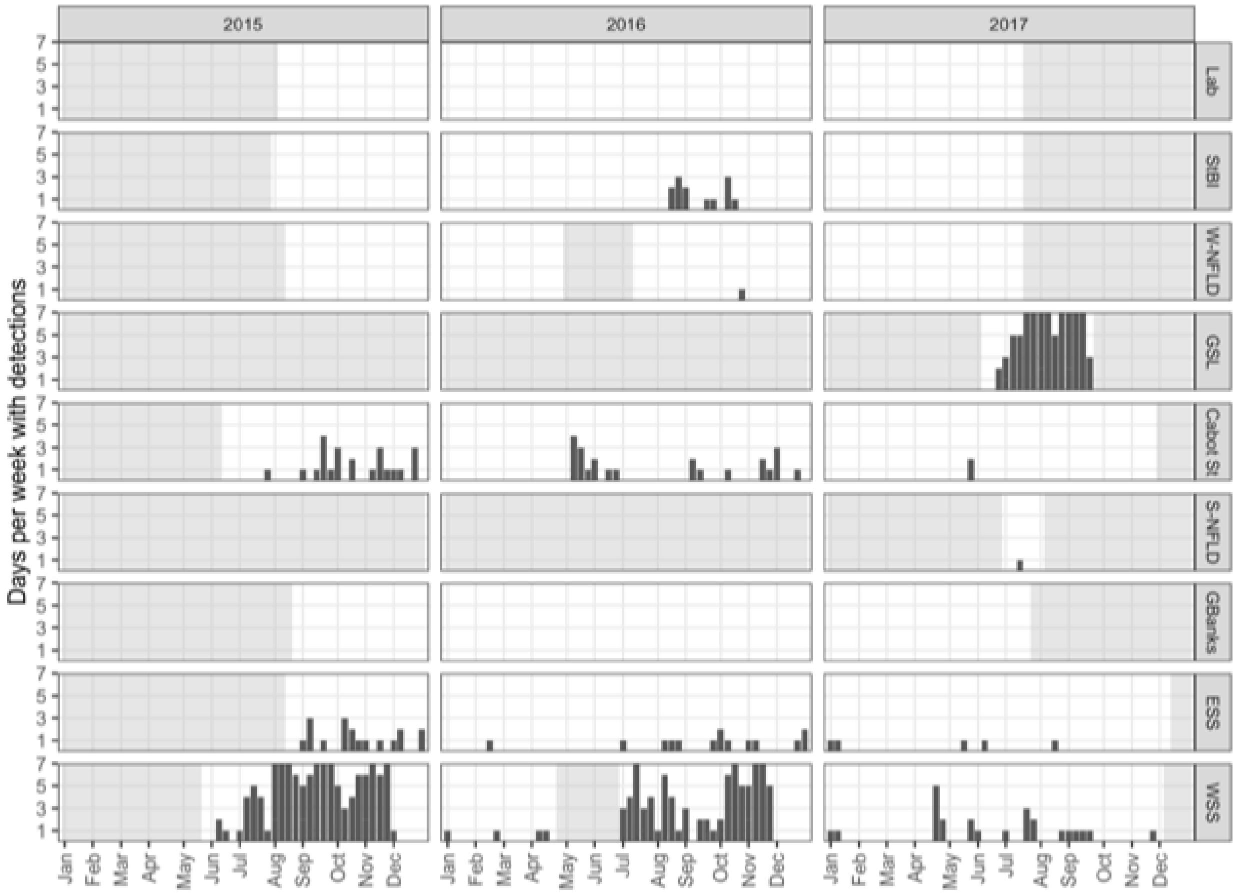


Figure 5. Preliminary results indicating the number of days per week with at least one true NARW upcall detection on a given day (2015-2017) from the recorders indicated by circles and track lines in Fig 4. Grey polygons indicate periods with no acoustic effort (i.e. days with no PAM recordings). Refer to Figure 1 for location of regions. Note: The shown data are not standardized for effort (the number of recorders per region varies) and differences in recording platforms (e.g. moored vs glider mounted hydrophones). Analyses have not yet been completed for some stations and years.

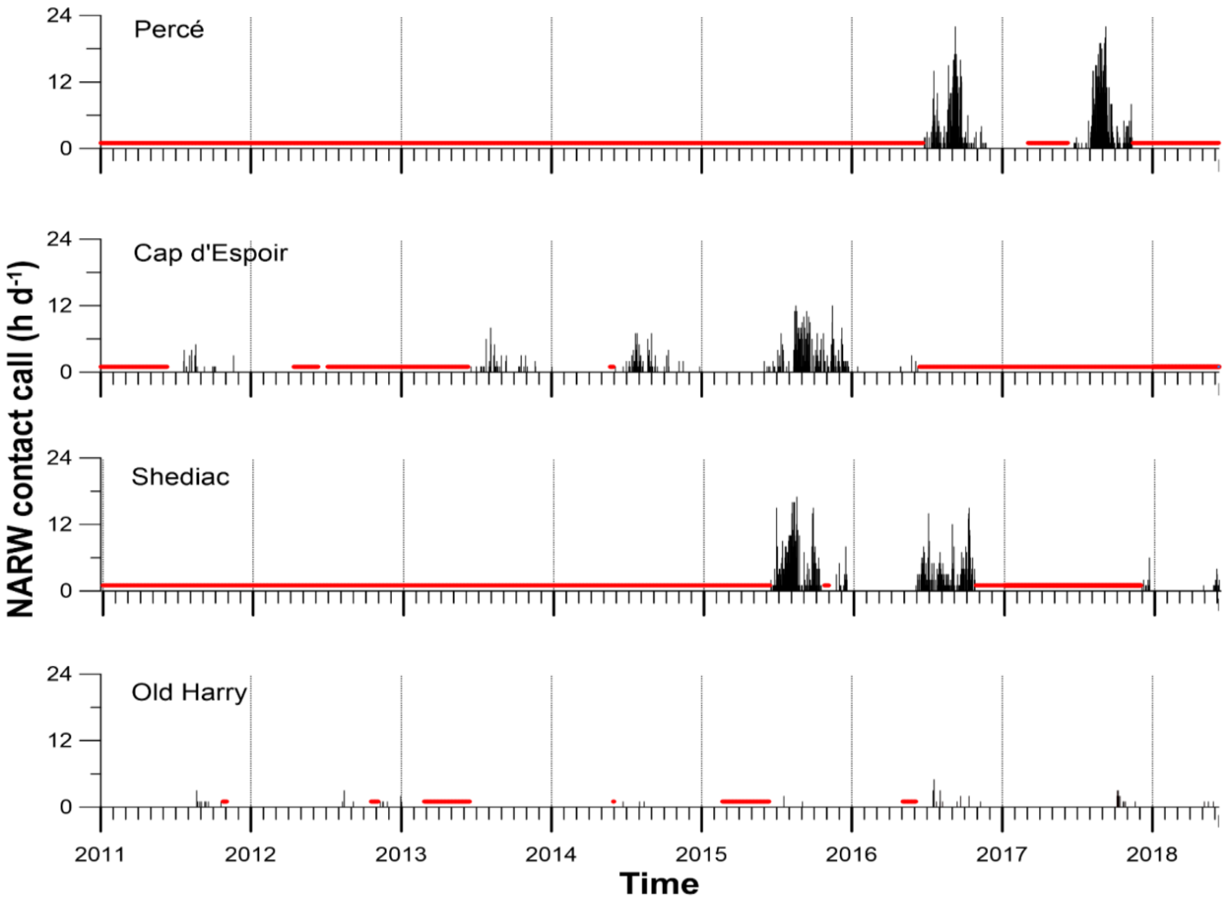


Figure 6. Time series of NARW daily detection hours at the 4 PAM stations in the GSL indicated by numbers in Figure 4 where NARW contact calls were detected. Red lines indicate non-recording periods.

A more thorough analysis of acoustic data from the GSL confirms the timing of NARW entering the GSL presented in the Science Special Response (2017/042). The first acoustic detections of NARW in the GSL occurred in late April (Cap d'Espoir 28 April, 2016; Shediac 30 April, 2018), although the frequency of detections increased substantially in May (Fig 6). The first visual observations of NARW in the GSL occurred in mid-May (13 May 2017, 19 May 2018). During the 2018 systematic aerial surveys, NARW were first seen in the northwestern GSL in late July and in the northeastern GSL by August.

As previously noted (DFO 2017/042) some individuals remain in the GSL into the fall and early winter. NARW vocalizations have been detected in the southern GSL into early January (Fig 6) and in the Cabot Strait until December (Figs 5,6). Whales were still being detected acoustically in the GSL during the peer review meeting at the end of November in 2018.

The data presented here confirm the preliminary findings in 2017 (DFO 2017/042) that there has been a shift in the summer distribution of NARW within Canadian waters. Beginning in 2010 the abundance of NARW using the Bay of Fundy area declined. This decline coincides with an observed decline in *Calanus* abundance in the area. Although NARW were observed in the GSL prior to 2015 they were thought to be relatively rare. In 2015, however, there appeared to be a marked increase in NARW abundance in the southwestern GSL area, although it was difficult to confirm due to the limited visual and acoustic effort during this period. However, a detailed examination the available acoustic dataset confirms that there was an increase in the presence of NARW in the GSL beginning in 2015.

The migratory pathways of NARW into, and out of, the GSL are poorly known. One difficulty is that acoustic detections of NARW in the Cabot Strait area will be hampered by high ambient noise. Acoustic recorders deployed and retrieved in the Strait of Belle Isle prior to 2011 did not detect NARW but this was a period when NARW presence in the GSL was considered to be low. More recent deployments have detected NARW in both the northern GSL and near the Strait of Belle Isle in 2016 (western Newfoundland), and in Cabot Strait in 2015 and 2016 (Fig 5).

C.3. What are the advantages and disadvantages of the different methods (e.g., Boat, TC Dash, C&P planes, Science planes, NOAA planes, acoustic gliders, static acoustic recorders) and technologies used to survey and monitor the presence of NARW?

NARW surveillance in 2018 involved multiple platforms including DFO Science multi-species (aerial and vessel) surveys and fixed acoustic stations, DFO Conservation and Protection (C&P) enforcement aircraft and vessels, TC aircraft, US Government (NOAA) aircraft, DFO/Industry/university autonomous acoustic gliders, NGO (e.g. NEAq/CWI, MICS) research vessels, and opportunistic observations.

The best tool to survey and monitor the presence of NARW depends on the objective to be achieved; clearly defined research, monitoring, management goals determine the method(s) best suited to address needs. In most cases, multiple survey and detection platforms will provide the best approach to meet a range of objectives.

Each research and monitoring method employed has strengths and weaknesses. For example, one of the objectives of the DFO Science surveillance aircraft was to collect information on all marine megafauna (marine mammals, turtles and basking sharks) and to identify if NARW aggregations occurred outside of the known areas. Thus, the survey design for this platform did not focus solely on the aggregations in the GSL or on collecting information on individual whales.

In contrast, the NOAA platform focused efforts on the southwestern GSL aggregation area to identify as many individual NARW as possible to understand the number and movements of whales in this area. Therefore, little effort and few sightings outside of this area were obtained from this platform.

The TC aircraft focused on detecting NARW in the dynamic shipping lanes. Only limited information on other marine species was collected and little effort was expended outside of this zone.

Similarly, there are technical challenges associated with each platform. For example, aerial and vessel surveys can only be carried out when sighting conditions are suitable and require trained personnel. Animals can only be detected during the day, if they are at the surface, and are within visibility range. Further, survey protocols and observer experience can vary widely among platforms. However, vessel and aerial surveys collect data that can be used to estimate abundance, and contribute to life history information on individual whales that are important to monitor births, deaths, and reproduction. Additionally, vessel surveys provide an opportunity to collect biopsy and fecal samples for ongoing genetic and endocrine studies.

In comparison, acoustic recorders are able to detect animals nearly continuously provided that they vocalize within the detection range of the instruments. The detection range of a recorder will be affected by ambient noise, the instrument specifications (e.g. hydrophone sensitivity), the acoustic properties of the water column, and the characteristics of the signal to be detected (e.g. frequency range, source level). Further, acoustic analysis protocols and analyst experience can vary widely among platforms. The development of 'real time' detectors are underway and some acoustic platforms can provide near real-time (daily) information that can be rapidly transmitted with a known quality control. However, collecting and analyzing the large amounts of data obtained from long-term moored acoustic recorders can take months.

Visual surveys provide immediate information that can be rapidly transmitted, but cannot be re-analyzed unless photographs are collected. Photographic and acoustic platforms generate considerable data that require large storage capacity and can incur delays to complete analyses, although each can provide hard records suitable for reanalysis and confirmation.

An overarching issue with many of the survey methods and technologies is the need for supporting data management protocols and data storage options. For example, acoustic and video monitoring result in the accumulation of very large datasets. Currently, no national data storage protocols or economically viable data storage solutions exist for such large data sets (at least within the federal government). Standardized data storage, sharing, and processing protocols need to be implemented.

For example, photographic data on NARW for individual identification and some survey effort calculations are stored and accessed through the North Atlantic Right Whale Consortium.

A table describing the types of data collected as well as the technical advantages and disadvantages of the various technologies currently being used to detect and monitor NARW is presented in Appendix 1. Economic considerations associated with the various technologies were not included.

C.4. Should the monitoring methods used in 2018 be altered to provide more precise data on timing and distribution of NARW in Canadian waters?

All survey and monitoring methods used in 2018 provided relevant scientific and monitoring data, and should not be discontinued, although they may be modified as objectives change.

The way these methods are used may vary depending on management and research objectives, acknowledging that some questions also require the combination of two or more methods to answer. It is essential to identify the key questions that need to be addressed and how these can be prioritized. A review of DFO Science surveillance and research efforts completed in 2018 is planned for early in 2019. This review will directly contribute to Science planning by describing new and ongoing Science needs and inform adjustments in the survey and monitoring methods.

C.5. Based upon the identification of individual NARW, how many individuals used the GSL and Bay of Fundy in 2018 and can the migratory movements of individuals provide any information on the timing and rate of movements of NARW into Canadian waters

Identification of individual NARW in 2018 has not been completed. However, preliminary photo-identification data indicate that at least 135 individual NARW were photographed in the southwestern GSL in 2018. Mark-recapture analyses of known individuals identified from the NOAA aerial surveys estimated that the total population present in the southwestern GSL during their survey period (4 June – 12 August) was 138. If different individuals occupied parts of the

GSL not surveyed, or entered later in the summer (beyond the above survey dates), the number of individual whales identified by NOAA would be an underestimate.

DFO Science aerial surveys estimated a total of 190 NARW (95%CI: 52-692) in the entire southern GSL in mid-June 2018. This is likely an underestimate due to missing whales that were diving although the extent of this negative bias is unknown. This indicates that a considerable proportion (~50%) of the estimated NARW population was present in the GSL in 2018.

At least one NARW was observed in Roseway Basin during the 2018 aerial surveys. At least 7 individuals were seen in the Bay of Fundy, five of which were observed in the Grand Manan Basin and northwest of the Critical Habitat during systematic vessel surveys carried out between early June and late September. The other two whales were reported as opportunistic sightings. The first NARW sighting occurred on the first survey day (June 16) while the last NARW sighting was reported on September 5$^{th.}$. There were no acoustic detections in Roseway in 2018 (Jan and Aug-Nov).

It is difficult to determine to what extent the movements of individuals can provide information on the timing and rate of movements of NARW into Canadian waters. Some individuals that were identified in the GSL were previously seen in northeast US waters (Cape Cod Bay, Great South Channel (GSC)) and in other Canadian habitats (e.g., Bay of Fundy) earlier in the same year. However, not all of the whales seen in Canadian waters were previously seen in Cape Cod Bay and GSC. Preliminary matching of individuals found that 66 of the 208 individuals photographed by NOAA off the Northeast USA in spring 2018 were seen again in the GSL in summer. This suggests that many of the 135 individuals identified in the GSL in 2018 may not have been seen in northeast US waters earlier in the same year, although some of these individuals may have been seen during surveys in other areas of the USA. It is also likely that some subgroups of the population migrate differently and therefore their movements are not predictable. Sightings and acoustic data suggest a near year-round presence of NARW in Canadian waters and so some individuals may not leave our waters.

D. Management Areas

D.1. What is the typical duration a NARW spends in a given location once it arrives in a potential foraging area?

Since their main objective was to photograph and identify NARW as part of their mark-recapture census, the NOAA aerial survey team focused on returning to locations in the southwestern GSL where NARW were expected to be present. Based on the identification of individual whales, they determined that the amount of time individual NARW spent in the southwest GSL was quite variable with some whales being seen on only one day, while others were seen over the entire 69-day study period. Thirteen of the 51 individuals identified on the first flight in June were re-sighted on the last survey in August. The average residency was 34 days (SE=68 days) although this estimate may be affected by the length of the study.

An analysis of sighting data on individual NARW collected from 1980 through 2005 found that NARW have an average residence time of 75 days (±10) in the Bay of Fundy and 136 days (± 71) in Roseway Basin.

D.2. What is the typical range of movement a NARW will undertake once in a foraging area?

Movements of individual NARW can vary greatly, depending on the circumstances. For example, if they are migrating or moving from one feeding area to another, they may move long distances (10-100 k) over relatively short periods. Even within one foraging area, the movement behaviour of individual NARW is highly variable; re-sighting of known individuals in the southwestern GSL has shown that some individuals do not move far between successive days while others move considerable distances (Fig 7). Based on resightings from the NOAA aerial survey program, some whales in the southwestern GSL moved up to 50 km between sighting on consecutive days.

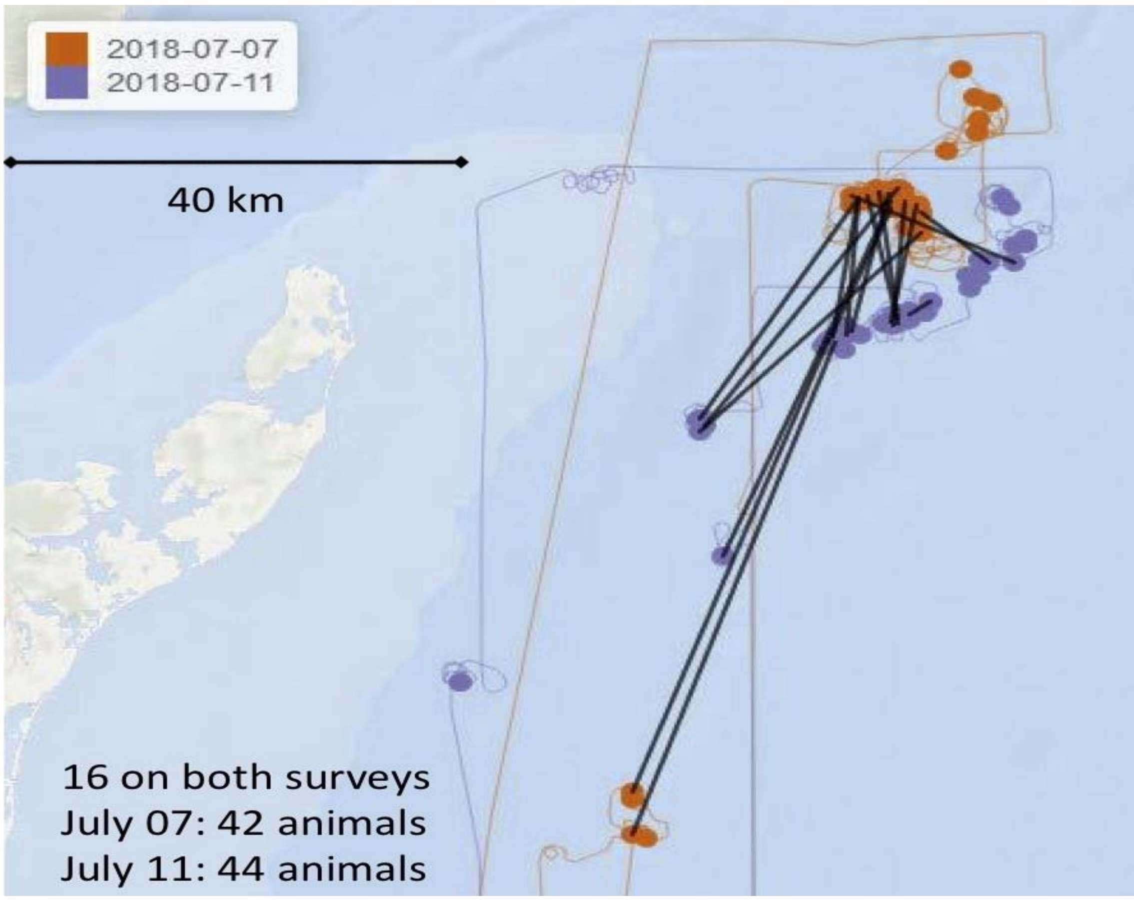


Figure 7. An example of the movements of individual NARW in the SW GSL between two successive NOAA aerial surveys, carried out four days apart. Coloured lines indicate the aerial survey effort, and coloured points the locations of NARW sightings. Black lines indicate the extent of movement of the same whale between surveys.

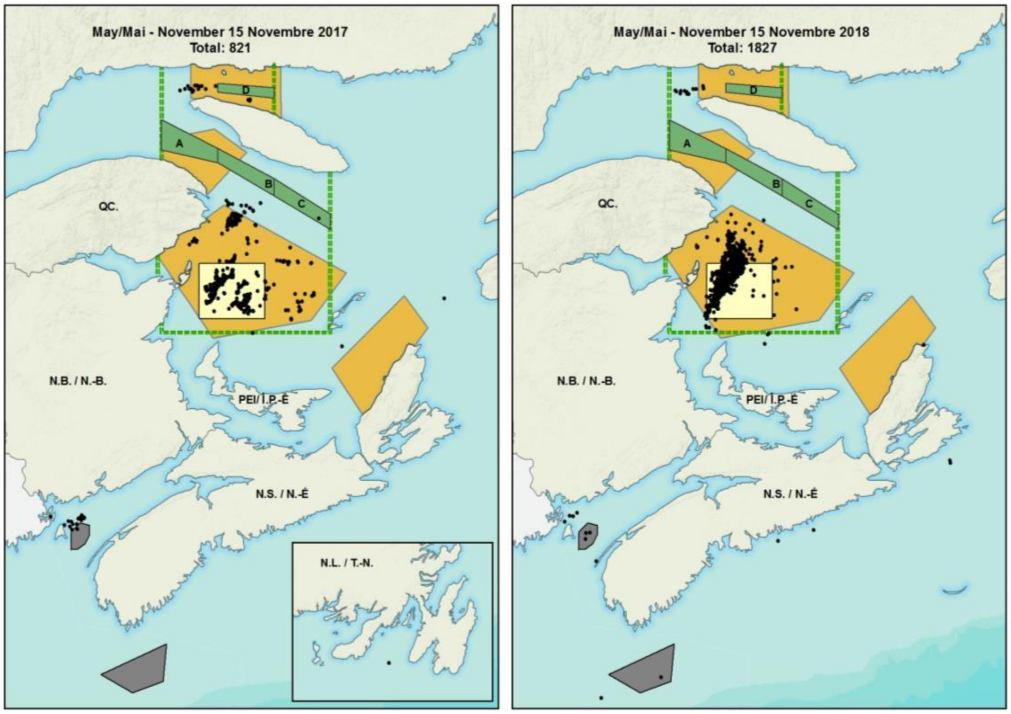
Analysis of data from 18 satellite tags deployed on NARW in the lower Bay of Fundy over 1989-1991 and 2000 also indicated that residency and movement behaviour of tagged animals was highly variable among years, with much longer residency in 2000 compared with 1989-1991. The tagged animals that left the Bay moved an average of 79 km per day during which they moved extensively among the Gulf of Maine, Scotian Shelf and northern mid-Atlantic Bight

D.3. Is there any additional information to aid in a further delineation of the size of the static zones (i.e. where NARW are reasonably expected to be found for significant periods)?

The 2017 NARW mortalities and entanglements resulted in a significant increase in monitoring efforts in the GSL in 2017, particularly late in the summer. In 2018, surveillance involving multiple platforms was initiated in April. Results of these efforts indicated that overall, the majority of NARW observed in Canadian waters were aggregated in the southwestern GSL which is an area where zooplankton resources were abundant. These results were similar to observations made since 2015 when surveillance effort was much lower. While most of the NARW occurred in the southwestern GSL, some whales occurred in the northwest GSL (north of Anticosti Island), as well as in the Bay of Fundy and in Roseway Basin.

Within the southwest GSL, there appeared to be a slight shift in NARW distribution between 2017 and 2018 (see question C1). However, given the mobility of whales and the differences in survey effort and timing between years, it is not possible to determine if the differences observed reflect actual changes in distribution, survey effort, or movements of individual whales.

In other areas, such as Roseway Basin and Bay of Fundy, several decades of data were available to evaluate seasonal and inter-annual variability in distribution and used to identify Critical Habitat for NARW in these areas. Additional years of data will be required to determine how the distribution of NARW in the GSL may vary among years. Given the uncertainty associated with the relative importance of changes in effort and possible seasonal and inter-annual changes in distribution within the GSL, incorporating all of the available sightings data is considered to be most appropriate approach to delineate the population’s current distribution.



Source : Michael Elliott

Figure 8. NARW Sightings in 2017 and 2018. Dark grey boxes identify NARW Critical Habitat. Shapes in Gulf of St. Lawrence show static (yellow) and dynamic (orange) fisheries management areas in 2018. Green shapes indicate Transport Canada static (dotted line) and dynamic (polygons A, B, C and D) management zones.

D.4. Is there any evidence of a significant seasonal shift in NARW locations within the static fishing and shipping zones and dynamic shipping zone?

Based on acoustic and visual surveys, NARW are present in eastern Canadian waters throughout the year. In 2017 it appeared that a shift in the distribution of sightings within the GSL to an area north of the static fishing zone occurred later in the summer. As described above (question C1), the overall distribution of NARW was similar between 2017 and 2018, but there were slight shifts in the distribution of sightings within the southern GSL (Fig 8). However, because of differences in the monitoring effort and timing between years, and the potential for whales' distribution to change quickly, it is not possible to determine if NARW exhibit a seasonal shift in distribution.

Based on data from 2017 and 2018, the relative probability of sighting NARW among regulated shipping zones was very low in the Jacques Cartier Strait (Zone D) and Honguedo Strait (Zones A-C) dynamic speed-restriction zones although it was slightly higher in other portions of the static speed zone such as in the area immediately west of the Jacques Cartier Strait dynamic speed-restriction zone. However, there is some interannual variability as, for example, NARW had been seen in the dynamic zone D prior to 2017.There were differences in the observed presence of NARW in the southern GSL and the area north of Anticosti Island between 2017 and 2018, and the timing of observations in the northern GSL was variable amongst the 2 years. Because there were differences in the timing and distribution of sighting effort in the two years we are not able to draw conclusions about seasonal movements. However, once photo analysis is complete there may be data available on individual right whales seen in both the northern and southern Gulf that can be examined to determine if there are seasonal movements between the two areas.

D.5. What data are required to develop a multiple-whale trigger and associated management actions?

In 2018, the presence of a single NARW was used to trigger fisheries closures and vessel speed-restrictions in some Canadian waters to reduce the likelihood of NARW entanglements and vessel strikes. However, NARW persisting in a given area are considered to be more exposed to human activities than a whale in transit. Therefore, a potential alternative may be to consider a trigger that requires multiple whales to be present and persistent in an area before management action is taken. For example, the USA uses an approach that identifies a minimum density of whales to infer the likelihood of persistence of NARW in an area to trigger voluntary measures.

Presently, there are insufficient information to develop a multi-whale management trigger specific to Canadian waters. A more specific description of the form this trigger may take is needed. Also, data on NARW over multiple years will be required to assess the probability of reliably detecting NARW, as well as NARW persistence, habitat use, and behaviours in Canadian waters to determine if the approach used in the US is appropriate to the Canadian situation.

Implementing a multi-whale trigger would require clearly defined criteria for when the trigger would be implemented (e.g., numbers of whales or density, area considered, time frame, etc.). To meet these criteria, it may require specifically designed surveys, detection approaches and coordination to consistently and repeatedly locate and count NARW. Detection approaches which provide presence-absence information without quantification would limit the implementation and effectiveness of a multi-whale trigger. Additional considerations for a multi-whale trigger include: the ability to determine if sightings are different individuals, the development of methods to integrate data collected from multiple sources unless a single platform is used, and the ability to promptly analyse and disseminate findings.

Uncertainty in our ability to detect NARW (e.g., diving, unsuitable weather conditions for surveillance, variable and unclear acoustic vocalization, etc.) and to differentiate between a lone NARW versus an aggregation of NARW, presents significant challenges to any management approach founded on timely NARW detections and enumeration. The use of any approach requiring identification of multiple whales increases these challenges.

E. Human Interactions

E.1. What is the likelihood of NARW being struck by a vessel in the GSL?

The probability of a lethal vessel strike depends on the spatial density, distribution and speed of vessels, as well as the spatial density, distribution, and behaviour of NARW. The absolute probability of a lethal vessel strike in the GSL has not been quantified although the relative probability of a lethal vessel strike was estimated before and during the implementation of the mandatory speed restrictions in 2017.

The relative risk of a lethal vessel strike was highest in the areas east of Miscou Island and northwest of Anticosti Island before the 2017 mandatory speed restriction was enacted. Within the mandatory speed restriction zone the relative risk of a lethal strike was reduced by 56% compared to the period before the speed restriction was put into place. However, during the speed restriction period, the relative risk increased northwest of Anticosti Island directly outside the boundary of the speed restriction zone due to increased vessel traffic. Elsewhere within the domain, risk was reduced during the speed restriction.

Vessels transiting along a commonly used corridor between eastern PEI and northeast NB (and nearby areas) showed an increase in speed before they reached the boundary of the mandatory speed restriction zone, likely in anticipation of reducing their speed once within the zone. This resulted in a near 100% chance of NARW lethality should a strike occur. The location and extent of such ‘edge effects’ will likely change as alternations to area-based, speed-related, management measures occur.

It is unknown whether the NARW sighted northwest of Anticosti Island arrive at that location by traveling north or south of Anticosti Island, or both. This knowledge gap has important implications for vessel-strike risk, especially considering the increase in density of vessels traveling north of Anticosti and through the Strait of Belle Isle observed during the 2017 speed restriction period.

In 2018, the extent of the speed restriction zone was reduced north of eastern Anticosti Island (65°- 63°W vs 65°– 62°W), though this area is associated with a high level of relative risk of lethal vessel strike. Unfortunately, survey effort in many potentially high-risk areas has been low and it is not possible to determine if NARW regularly occupy these areas. For example, limited monitoring effort exists in the eastern Jacques-Cartier Strait from dynamic shipping section D to the Strait of Belle Isle and beyond for all years. Increased visual surveillance is required to determine NARW presence in this and other potential high-risk areas.

E.2. What is the likelihood of NARW being entangled in snow crab fishing gear in the southern GSL?

The probability of entanglement depends on the distribution and intensity of fishing activity, as well as the density, distribution, and behaviour of NARW. Absolute entanglement probabilities have not been definitely quantified in the southern GSL at this time. However, the co-occurrence of NARW and fishing activities in the southern GSL is high and entangled NARW have been discovered over the past three years (2016-2018), either in the GSL or elsewhere, carrying gear attributed to Canadian snow crab fisheries. There were at least two known entanglements in 2016, seven in 2017 and at least three in 2018. Since 2016, at least five NARW are considered to have died after being entangled in snow-grab gear.

Simulation models using the predicted movements of NARW and the locations of snow crab fishing gear from 2015-2017, identified areas of high potential encounters between NARW and snow-crab fishing gear in the southwestern GSL. These included the Shediac Valley, Orphan Bank and Orphan Trough. The majority of simulated potential encounters would have occurred within the static fisheries closure box that was implemented in 2018.

Sources of Uncertainty

Our understanding of the distribution and persistence of NARW in Canadian waters is limited by the amount of survey effort that has been completed. Limited monitoring occurred in a number of areas, and for most areas there is only a short time series of monitoring. This limits our ability to provide scientific advice for management decisions. Consistent efforts over multiple years will be required to determine whale abundance, distribution, timing and the various factors influencing interannual variation in habitat use in Canadian waters.

There are a number of uncertainties associated with our ability to detect NARW acoustically. These include our lack of understanding of the factors that influence calling rates (e.g., sex, age, group size, behaviour, etc.), as well as detection range that varies with ambient noise, environmental conditions and the characteristics of the whale calls. These uncertainties affect our ability to determine if whales may be present, but not acoustically active, and to estimate numbers of animals from acoustic detections.

Estimates of NARW can be obtained from visual and photographic surveys. However, sightings of whales at the surface must be corrected for both perception (i.e., whales that are present but missed by observers) and availability (whales present below the surface) biases. Our ability to sight whales varies among monitoring platforms, observers and environmental conditions. As well, the proportion of time NARW spend at the surface and at various depths is poorly known and will be influenced by group size, behavioural state (e.g., feeding vs migrating, individuals vs surface active groups) and demographic variation in whale presence. Gaining improved knowledge of diving and surfacing behaviour of NARW is necessary to improve our ability to quantify detection rates from survey platforms and estimate risk from fishing gear and vessels.

Estimating the risk of entanglements requires accurate, precise and timely data on fishing effort. Uncertainties in fishing effort, inconsistencies in the reporting of gear positions in logbooks and the lack of information on the timing of gear deployments present an important challenge in precisely identifying the probability of NARW entanglement in fishing gear

The areas identified as suitable NARW habitat should be considered as minimal given the limitations in the spatial and temporal resolution of biological sampling. Vertical modelling of *Calanus* and spatial sampling effort are limited and do not include all Canadian waters. Near bottom sampling is lacking which may impact estimates of *Calanus* density and the spatial resolution of the modelling. There are also limited data on the diet composition of NARW which will impact the way in which we model suitable habitat.

The identification of suitable habitat for NARW relies upon long term data on prey availability and whale distribution. However, given the significant changes seen in our ecosystems over the past decade and expected in the future, it is essential to maintain and build multi-year time series to account for variability in animal behaviour and environmental conditions under current ecosystem conditions.

OTHER CONSIDERATIONS

Given the changing Calanus abundances and distributions, there is no certainty that NARW distribution in Canadian Atlantic waters in 2019 will reflect that of 2018 or 2017. We do not yet know how important, or persistent, the currently identified aggregation areas are going to be with respect to future NARW habitat use.

Monitoring and evaluating compliance are a crucial component of any management initiative. As such, information is required to evaluate the effectiveness of management measures, including understanding potential reasons why implemented measures may not be working (such as lack of compliance). Thus, it is important that a compliance monitoring plan be developed and implemented for any mandatory management measures put in place to protect NARW.

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SOURCES OF INFORMATION

This Science Advisory Report is from the National Marine Peer Review Committee (NMMPRC) 2018 Meeting I: Review of North Atlantic right whale occurrence and risk of interactions with fishing gear and collision with vessels, held November 26-30, 2018, in Montreal, Quebec. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

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APPENDIX 1.

Data collected, scientific and technical advantages and disadvantages of technologies that are currently being used for detecting and monitoring NARW. New and emerging technologies that may prove to be valuable for supporting research and monitoring in the future are not included but should continue to be tested and developed.

Method	Information Collected	Advantages	Disadvantages
On-water platforms			
Vessel-based field studies/surveys	Photo identification of species, individual identification, health and scar assessment, life history	Mobility is vessel dependent Dedicated MMOs	Limited coverage area
(information collected, strengths, and limitations vary with vessel size and objectives)	Biopsies that can be used for genetics; blubber samples for diet and contaminants; Entanglement documentation	Potentially high encounter rate Entanglement response support Quantified observer effort	Generally coastal or shelf based (range dependent on vessel size)
	Faecal samples for stress and reproductive hormone analyses, and health assessment	Near real-time information	Weather limited
		Daylight operations for whale surveys and whale data collection, oceanographic sampling can occur at night	No collection of data on whales during night
	Plankton and hydrographic sampling (stratified and integrated) possible		Opportunistic /preferential sampling
			Availability bias, but may be lower than aircraft depending upon survey methods
Aerial platforms			
TC aircraft (Dash 7 and 8)	Presence of NARW in shipping lanes	Camera system (Identification and photo ID, precise locations)	Weather limited
	Photographic identification (camera)	Multispectral imaging	Sampling coverage not designed for density estimation

Method	Information Collected	Advantages	Disadvantages
	Entanglement documentation	Longer flight time than Twin Otter, shorter than Cessna	No abundance indices
		Quantified observer effort	Daylight operations
			limited ability to fly slow
		Entanglement response support	
		Near real-time information transmission	Availability bias higher than vessels
			Limited data on species other than NARW
C&P aircraft and surveillance method (King Air)	Presence of NARW in fishing areas	Opportunistic sightings of whales as part of the surveillance of fisheries	Difficult to quantify observer effort
			Not flown under specific abundance survey design
			No abundance estimates
	Photographic identification (camera)	Support of fisheries management needs	Weather limited
		Additional detection	Daylight operations
		Camera system (Identification and photo ID)	No dedicated MMOs (NARW observation may require confirmation later by MMO using pictures)
	Entanglement documentation	Near real-time information transmission	More limited field of view than other aircraft
		Entanglement response support	
		Large number of flights and available aircraft	Limited flight time (although offset by higher airspeed for

Method	Information Collected	Advantages	Disadvantages
			long distance capability) low wing, small windows, exhaust interferes with visibility Availability bias higher than vessels or slower aircraft
DFO Science aircraft and survey method (Twin Otter, Cessna Skymaster, Partenavia P-68)	Density and abundance indices	Estimates of total abundance of multiple species (NARW and others to address US MMPA) Large spatial coverage	Variance associated with abundance estimates may be high for rare species
	Distribution of densities over a large spatial scale	Systematic effort sampling strategy, better than other platforms Both line transect and photographic strip transect surveys	Daylight operations
	Photographic identification (camera)	Near real-time information Provide data on multiple species	Weather limited
	Entanglement response support possible	Data on fishing gear presence, debris, vessels Photographic capabilities allow for identification of multiple species and data validation; photo-id of individual NARW	Flight time effort temporally and spatially limited relative to acoustics Visual survey estimates available reasonably soon but photographic

Method	Information Collected	Advantages	Disadvantages
			surveys take considerable time to analyze.
		Quantified observer effort	Availability bias likely higher than vessels, although may be similar if circle-back used
			Dependent on a pre-defined survey design (less flexible to support day-to-day management operations)
NOAA aircraft and NARW search methods (Twin Otter)	Identification of individual NARW	Photo identification focus	Weather limited
	Abundance estimates using counts + mark/recapture	Focus monitoring of aggregation	Daylight operations
	Residency	Quantified observer effort	Flight time effort temporally limited relative to acoustics
	Individual movements of NARW	Monitoring NARW in southwestern GSL	Availability bias higher than vessels survey, but may be lower than DFO Science aircraft for NARW
			NARW estimate negatively biased for total whales in Canada, uncertainty likely under-estimated
			Limited to NARW; data on other marine species not collected

Method	Information Collected	Advantages	Disadvantages
	Entanglement documentation	Entanglement response support Near real-time information	Distributional bias (searching areas expected to contain NARW), extremely limited spatial coverage (by design) compared to other aerial platforms
Acoustic devices			
Near real-time acoustic gliders (e.g., Slocum Gliders equipped with PAM packages, processed data uplinked to shore)	Minimum call presence in area (within hours; more thorough validation upon retrieval)	Near real-time call presence	Small spatial coverage relative to aircraft and vessels
		Not weather/visibility limited	Dependent on NARW calling
			Presence only, unable to determine number or density of whales
(archival PAM packages exist for gliders which save data for download after retrieval - an option for DFO Alseamar Gliders		Larger spatial coverage relative to moored acoustic systems	Variable detection performance (effective radius)
		Can be used to assess multi-species presence	Collision risk, especially in traffic lanes
		Background noise measures over the water column	Limited by environmental conditions (e.g., ice, currents), noise/anthropogenic noise
		Ability to re-analyse recovered data	
			Need to uplink and send data to shore
		As for all acoustic approaches, automated detector performance may be a consideration in some areas	Uncertain position of calling animal, lack of directionality

Method	Information Collected	Advantages	Disadvantages
			Small temporal coverage relative to archival systems
Near real-time moored buoys (processed data uplinked to shore via satellite/cell phone signal or other technology)	Minimum call presence in area (within hours; more thorough validation upon retrieval)	Near real-time call presence	Small spatial coverage relative to vessels and aircraft
	Could be deployed for shorter periods for presence over shorter time scales (e.g., days, weeks)	Can be used to assess multi-species presence	Dependent on NARW calling
		Continuous long-term presence (months-year)	Presence only, number of calling whales unknown.
		Not limited by weather/visibility	Limited by environmental conditions (e.g., ice), noise/anthropogenic noise
		Larger temporal coverage relative to acoustic glider systems	Static location
		Background noise measures over the water column	Used in ice-free season
		Near-constant performance	
		Directionality and localization of detections may be possible in future	Data transmission limited by surface time, signal length/reception capabilities of satellite
Near real-time cabled systems (raw or processed data directly uplinked to shore)	Minimum call presence in area (within hours)	Near real-time call presence	Small spatial coverage relative to vessels and aircraft
	Continuous long-term presence (months-year)	Can be used to assess multi-species presence	Dependent on NARW calling
			Presence only, number of calling whales unknown

Method	Information Collected	Advantages	Disadvantages
	Can be networked or repositioned	Not limited by weather/visibility	Limited by environmental conditions, noise/anthropogenic noise
		Larger temporal coverage relative to acoustic glider systems	
		Directionality and localization of detections may be possible in future	
		Background noise measures over long periods and broad frequencies	
		Raw data directly fed to shore	
		Powered through shore (no need for battery changeout)	
Drifting buoys (e.g., sonobuoys, drifters, wave gliders; in some cases processed data available in near real-time and uplink to shore; other cases require retrieval for data download)	Minimum call presence in area (within hours-weeks; more thorough validation upon retrieval)	Potentially call presence over relatively short temporal scales	Small spatial coverage relative to vessels and aircraft
		Can be used to assess multi-species presence	Cannot control direction/area surveyed
		Not limited by weather/visibility	Dependent on NARW calling (presence only, number of calling whales unknown)
		Low power, can potentially be deployed for longer than gliders	Limited by environmental conditions (e.g., ice,), noise/anthropogenic noise

Method	Information Collected	Advantages	Disadvantages
		As for all acoustic approaches, automated detector performance may be a consideration in some areas	Uncertain position of calling animal, lack of directionality
			In most cases, need to retrieve to download and process data
Moored archival single hydrophones (e.g., AURALs, AMARs, other systems; raw data available for download upon retrieval)	Minimum call presence in area (within months-years)	Call presence over long temporal scales (months-years)	Small spatial coverage relative to vessels, aircraft and gliders
	Could be deployed for shorter periods for presence over shorter time scales (e.g., weeks)	Can be used to assess multi-species presence	Dependent on NARW calling (presence only, number of calling whales unknown)
		Not limited by weather/visibility	Limited by environmental conditions (e.g., storms), noise/anthropogenic noise
		Extensive temporal coverage by deploying multiple units	Uncertain position of calling animal, lack of directionality
		Background noise measures over long periods and broad range of frequencies	Not real-time, need to retrieve to download and process data
		As for all acoustic approaches, automated detector performance may be a consideration in some areas	Large datasets result in data storage issues and long delay between retrieval of data and analysis results
Moored archival horizontal/vertical arrays	Minimum call presence in area (within weeks-months but possibly over longer time frames)	Call presence over short-moderate temporal scales (weeks-months)	Small spatial coverage relative to vessels and aircraft and gliders

Method	Information Collected	Advantages	Disadvantages
		Can be used to assess multi-species presence Potentially direction/location of calling animal	Dependent on NARW calling (presence only, number of total calling whales unknown)
	Potentially estimate of numbers of calling animals	Not limited by weather/visibility	Limited by environmental conditions, noise/anthropogenic noise
		Larger temporal coverage relative to acoustic glider systems depending upon number of units	
		Potential ability to localize, track, and count animals (depending on setup)	Not real-time, need to retrieve to download and process data
		Background noise measures over long periods and broad range of frequencies	Large datasets result in long delay between retrieval of data and analysis results
Tagging			
Satellite tagging	Precise data on movement of individuals on large spatial scale	Longer deployment relative to suction cup tags (D-tags)	Invasive technology (possible infection risk)
	Dive profile, time-at-depth	No tag recovery necessary	Low sample size limits statistical robustness of results
	Assess behaviour		
		Potentially provides information on movements over large spatial scales	Deployment on NARW currently limited from days to few months
			Weather limited for deployment and retrieval
Acoustic Biologging Tags (e.g., D-TAGS)	Precise movement of individuals at a fine scale	3-D movement	Tag recovery necessary
	Dive profile, time-at-depth	Records sounds (often stereosound)	Shorter deployment time than satellite tags

Method	Information Collected	Advantages	Disadvantages
	Sound production and exposure	Suction cups less invasive relative to implantable tags (lower infection risk)	Smaller spatial scale (relative to satellite tags)
	3-D dive profile		Low sample size can limit statistical robustness of results
	Assess behaviour		Weather limited for deployment and retrieval
Drones			
Large fixed-winged drone (Unmanned Aerial Vehicle or UAV under the Canadian Aviation Regulations) (e.g., Remotely Piloted Aerial System - RPAS)	Tested use to asses presence of NARW in shipping lanes (or other areas of interest)	Repeatability of survey analysis (can analyze archived data multiple times)	Still in development to be operational
	Ultimately could be similar to other aerial platforms	Lower disturbance relative to aircraft (noise)	Some areas/airspace closed to operations
	Photographic identification (onboard camera/video)	Similar to manned aerial platforms	Ability to collect data for photo ID limited
			Requires compliance with a Special Flight Operations Certificate (SFOC), and coordination with NavCanada and airspace users to ensure safe integration of manned and unmanned aircraft in the airspace above the monitoring areas around the UAV
	Searches and surveys of areas similar to larger aircraft but generally slower	Can fly multiple consecutive missions limited only by daylight hours	Requires significant data storage capacity
			Currently, analyze of data is time consuming

Method	Information Collected	Advantages	Disadvantages
			Post-flight image processing requires further improvement
			Daylight operations; weather limitations
			Limited strip width
Small drones (including rotary-winged)	Used to collect data (photos/video) for photo identification	Onboard camera system (photo ID capabilities)	Short flying time
	Health and behaviour assessment	Portable and inexpensive	Short range relative to larger drones or aircraft
	Photogammetry (relative length and width)	Lower disturbance relative to aircraft (noise)	Weather limited (more than large aircraft)
	Blow sampling,	Can fly multiple consecutive missions limited by daylight hours	Daylight limited
	Surveys of small areas for presence		Wind limited
			May be subject to permitting and closed airspace
	Real time entanglement assessment and documentation		
Other Detection/Monitoring Tools			
Opportunistic observations	Information on species presence	Additional information on whale presence, potentially from areas with little systematic monitoring effort	Requires data validation
	Can be used in presence-only habitat suitability models	Identification and photo ID	Requires advertised reporting system (and regular monitoring of system)

Method	Information Collected	Advantages	Disadvantages
			Effort uncertain Uncertainty in sampling design Effort needed to identify duplicate sightings Uncertain if lack of report is due to absence of animals or failure to report

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