

SPATIAL-TEMPORAL ANALYSIS OF NORTH ATLANTIC RIGHT WHALE AERIAL
SURVEILLANCE IN RELATION TO WHALE HABITATS AND ACTIVE FISHING
AREAS IN ATLANTIC CANADA

By

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ABSTRACT

The North Atlantic right whale (NARW) is a critically endangered migratory species found primarily along the Eastern coasts of North America. Consistent surveillance for NARW is vital to informing management measures, triggering dynamic protections, and monitoring changing population trends and distribution. Surveillance of known and potential NARW habitats is also important to ensure that protection and knowledge are adequate throughout their range. Resources for aerial surveillance in Atlantic Canada are limited, leading to a focus on areas and times of known aggregations in the southern Gulf of St. Lawrence (GSL). Although this spatial-temporal bias in effort is widely recognized, its extent and consequences have not been quantified. This project examined the spatial-temporal coverage of Canada's dedicated marine mammal surveillance program in Atlantic Canada from 2018-2021 and evaluated effort as distance surveyed (km) using GPS-recorded track line data obtained from Fisheries and Oceans Canada. We examined the amount of effort allocated across specific areas throughout Atlantic Canada relevant to NARW protection. These areas included general NARW habitats and snow crab and lobster fishing areas during their active seasons. Effort was concentrated in the southern GSL, while the migratory corridor along the Scotian Shelf and critical habitats in the Bay of Fundy and Roseway Basin lacked surveillance, along with several active fishing areas and potential future habitat. This evaluation of uneven surveillance effort provides important context for interpreting our perceived knowledge of NARW distribution in Canada and potentially encountered anthropogenic threats.

Keywords: NARW; aerial surveillance; entanglement risk; lobster fishery; snow crab fishery.

LIST OF ABBREVIATIONS

NARW: North Atlantic right whale

NFLD: Newfoundland

GSL: Gulf of St. Lawrence

BoF: Bay of Fundy

DFO: Department of Fisheries and Oceans Canada

NARWC: North Atlantic Right Whale Consortium

LFA: Lobster Fishing Area

CFA: Crab Fishing Area

GoM: Gulf of Maine

nGSL: Northern Gulf of St. Lawrence

sGSL: Southern Gulf of St. Lawrence

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1.0 CHAPTER ONE: INTRODUCTION

1.1 North Atlantic Right Whales

The North Atlantic right whale (hereafter, NARW) is a critically endangered large whale species, with less than 400 individuals remaining (New England Aquarium, 2023). The species was hunted nearly to extinction before a ban on their harvest was introduced in 1935. These whales were specifically targeted for their tendencies to swim slowly near shore and to float after death, making for easy recovery of corpses, along with the high oil content of their blubber (Langlois, 2017). Genetic diversity of the species is low (Crossman et al., 2024) and there are less than 70 reproductively active females (NOAA Fisheries, 2024a). The reproductive success of the species is calculated to be only 27% of the maximum number of calves expected each year (Frasier et al., 2023). The population has struggled to recover against a variety of anthropogenic threats, the most severe of which being entanglements in fishing gear and vessel strikes (Government of Canada, 2023). Human interaction is the main contributor to an ongoing Unusual Mortality Event concerning NARW, as designated by the United States government (NOAA Fisheries, 2024b).

1.11 Main Threats to Recovery

Approximately 85% of the NARW population has been entangled at least once, with about 60% having experienced entanglement on multiple occasions (Knowlton et al., 2012). Entanglement often leads to deterioration in body condition (Pettis et al., 2017). Entangled whales appear to have an approximately 25% lower chance of survival than non-entangled individuals (Robbins et al., 2015), and death is typically a drawn out and painful process (Myers et al., 2019). Although disentanglement by experts is possible in some cases, this activity is considered to be extremely dangerous and should be avoided (Knowlton & Kraus, 2020). Vessel strikes are another common threat to the health of this population. It is rare for NARW to survive following a ship strike (Knowlton & Kraus, 2020). Increases in vessel sizes and speeds lead to a greater risk of colliding with and killing NARW (Conn & Silber, 2013). However, vessels of all sizes are capable of inflicting lethal injuries on NARW. Even if a large ship reduces its speed, it is still highly likely that a struck whale will be killed (Kelley et al., 2021). Vessel strikes

have been the cause of death for at least 15 NARW since 2017 (NOAA Fisheries, 2024b), but as only around one third of deaths are detected, the number is likely much higher (Pace et al., 2021).

1.12 Distribution

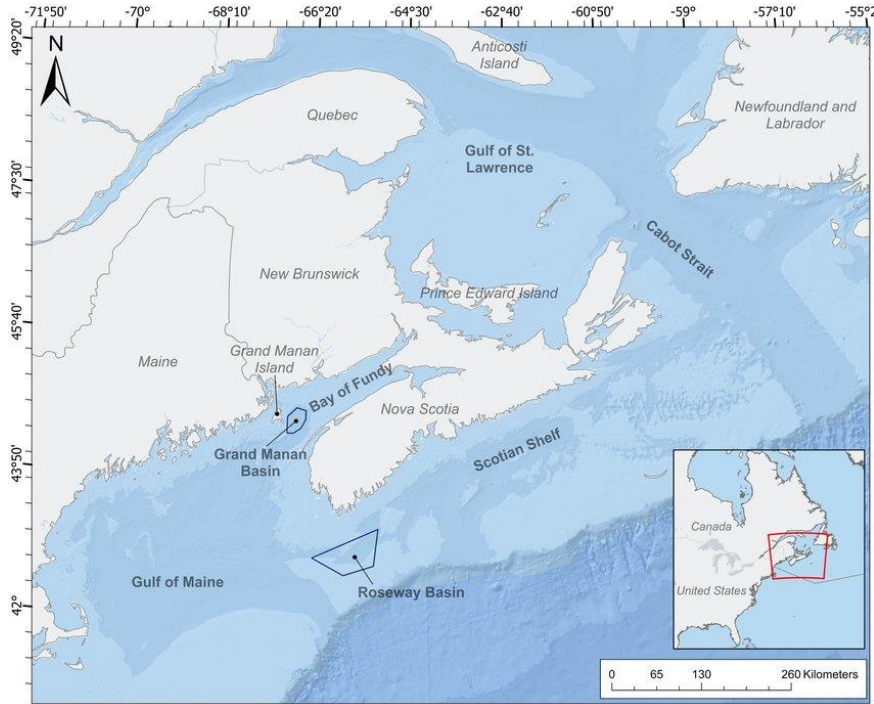


Figure 1: Map showing North Atlantic right whale critical habitats (Grand Manan and Roseway Basins) and other relevant regions in Atlantic Canada (Kadwa, 2020).

NARW are a migratory and wide-ranging species. Prior to whaling, the species' range included much of the northern Atlantic Ocean (Monsarrat et al., 2015). There is even some evidence to suggest that their range extended into the Mediterranean Sea (Rodrigues et al., 2018). The population can now be found, almost exclusively, along the eastern coast of North America from Florida to Newfoundland (NFLD) and Labrador (Davis et al., 2017). There have also been occasional sightings off the coasts of Iceland (Hamilton, 2018), Ireland (Baraniuk, 2024), and western Europe (Silva et al., 2023). The species displays dramatic habitat plasticity (Mayo et al., 2018), with high variability in the timing of use and abundance of different regions (Durette-Morin et al., 2022). However, there are consistent annual movements between northern mating and foraging areas and southern calving grounds. Much of the population spends the summer and

autumn months in Atlantic Canadian waters (Government of Canada, 2023), where drastic shifts in distribution have been observed since around 2010 (Pettis et al., 2023). Historically, a high proportion of NARW spent these months in the Grand Manan and Roseway Basins (Figure 1), both of which have been designated as critical habitats (Brown et al., 2009). Since around 2015, more whales have been detected in the Gulf of St. Lawrence (GSL) (Figure 1) (Simard et al., 2019). Many whales now gather annually in the GSL, specifically in the Shediac Valley (Fisheries and Oceans Canada, 2024b).

1.2 Protection Measures

The Canadian government has implemented several protection measures to reduce anthropogenic threats to NARW. This action was spurred by the 2017 mortality crisis in the GSL, in which 12 whales were found dead and five entangled (Daoust et al., 2018). Protection measures include vessel speed and shipping route restrictions in the GSL and seasonal and dynamic closures of fishing areas (Fisheries and Oceans Canada, 2024a). Protection measures have changed annually since implementation, but the 2024 fishery closure measures are provided for context.

If one or more NARW are detected visually or acoustically within NARW management areas, a defined area surrounding the detection is closed to non-tended fixed gear, trap and pot fishing for 15 days. If a whale is detected in the same area within the Bay of Fundy (BoF) or Roseway Basin (Figure 1) during days nine to 15 of a fishing area closure, the closure will be extended for another 15 days. A detection in days 9 to 15 of a fishing closure in the GSL (Figure 1) leads to a season long closure of applicable areas. Two surveillance flights with no NARW detections are required to re-open fisheries in the BoF, Roseway Basin and GSL. Fisheries closures in areas outside of these regions are considered on a case-by-case basis, with special consideration granted for groups of three or more NARW or a mother and calf pair.

Dynamic closures of fishing areas exclude waters less than 20 fathoms deep. This exclusion is known as the shallow water protocol. If a NARW is detected in waters between ten and 20 fathoms deep, the fishing area closure extends to the ten-fathom line. If there is a detection in waters less than ten fathoms deep, closures extend to the shoreline (Fisheries and Oceans Canada, 2024f).

In 2024, it was announced that a national plan to implement on-demand gear will also be developed (Fisheries and Oceans Canada, 2024a). On-demand gear reduces the number of vertical fishing lines in the water column, which reduces the risk of a whale encountering a rope. Fishing gear is placed on the ocean floor with a mechanism by which fishers can recall traps to the surface (Terhune, 2018), typically by acoustic signals sent between the trap and a vessel (Frith, 2021).

1.3 Habitat Determinants

The exact habitat requirements of NARW remain a mystery (Langlois, 2017). This is to be expected, as the species is highly variable in terms of habitat preference (Mayo et al., 2018). Differences in habitat selection between demographics may be present but it is often unclear what may be driving these discrepancies (Hays et al., 2016). However, general trends in habitat suitability have been identified. A primary predictor of NARW presence appears to be abundance of the copepod *Calanus finmarchicus* (Baumgartner et al., 2003), the species' main source of prey (Baumgartner & Mate, 2003). Changes in *Calanus finmarchicus* abundances are likely responsible for the shifts in NARW distribution observed since 2010 (Davies et al., 2019). It appears that the whales are being driven away from areas of low prey abundance rather than towards high abundances (Meyer-Gutbrod et al., 2023). Foraging potential in the GSL may not be adequate for promoting successful reproduction of NARW (Gavrilchuk et al., 2021). Habitat suitability also depends on oceanographic conditions which result in the formulation of high-density patches of *Calanus finmarchicus* (Sorochan et al., 2021), as patches with less than 1300 copepods/m³ tend to be ignored (Baumgartner & Mate, 2003). In general, habitat suitability for NARW likely aligns closely with that of *Calanus finmarchicus* (Grieve et al., 2017), incorporating factors such as water temperature (Melle et al., 2014), predatory-prey dynamics (Baumgartner & Mate, 2003), and depth (Baumgartner et al., 2017).

1.4 Importance of Surveillance

Good surveillance practices are crucial for monitoring changes in the distribution of NARW, as well as for making accurate population estimates (Ganley et al., 2019). Direct observation is required to assess visual health and detect entanglements and ship

strike injuries (Pettis et al., 2023). Monitoring is also needed to trigger dynamic protection measures such as fishery area closures and vessel speed restrictions (Fisheries and Oceans Canada, 2024a). Surveying areas where NARW are not yet expected could help to prevent mortality events, such as the 2017 GSL crisis, by detecting distribution shifts and responding with management actions (Koubrak et al., 2021). Surveillance data can also be used to determine the location and size of areas to be protected (Hays et al., 2016).

1.5 History and Rationale Behind the Marine Mammal Aerial Surveillance Program

The Department of Fisheries and Oceans Canada (DFO) has been conducting scientific surveillance flights for marine mammals since at least 1995 (St. Pierre et al., 2024). Following the deaths of 12 whales in the GSL in 2017 (Daoust et al., 2018), an unprecedented effort to locate NARW through aerial monitoring began (St. Pierre et al., 2024). Although flights are still meant to collect data for other marine megafauna sightings, such as sea turtles and basking sharks (Ratelle et al., 2024), their primary objective is NARW surveillance. The flights are even known as “right whale surveys” among DFO staff. Surveillance is focused on aggregation areas in the GSL. However, there are still competing interests at play within this objective. Only one to three aircraft are available at a time to conduct surveillance flights, as DFO depends on contracts with external companies (J.F. Gosselin, personal communication, June 26, 2024). The third plane was added to the program in 2020 (St. Pierre et al., 2024). This is a severe limitation to the program, with no planes available from Atlantic Canadian companies. Additionally, two of the three planes are only available at the beginning of August. The program is responsible for monitoring for whales in closed fisheries so that they can reopen and sometimes for detecting entangled whales in coordination with rescue vessels (J.F. Gosselin, personal communication, June 26, 2024). Therefore, surveillance flights vary in their purposes, but the same basic data is collected consistently (Ratelle et al., 2024). When consistent monitoring efforts for NARW began in 2017, surveillance locations were chosen based on *Calanus finmarchicus* abundance data collected by previous vessel-based surveys in the GSL. A need for systematic surveys was identified following this season. In addition to studying NARW abundance distribution and monitoring presence near anthropogenic activities (St. Pierre et al., 2024), the program

eventually hopes to conduct habitat modelling based on surveillance data. This is given as a reason for concentrating efforts in known aggregation areas in the GSL. As the population is so small, the rationale is that data collection must be efficient so that a habitat model can be developed quickly. Efficiency is ensured by primarily conducting flights where it is known there will be whales. While there is no formal process to decide priorities for flights, during the NARW season daily calls occur between scientists, Transport Canada and fisheries management. Systematic surveillance flights can sometimes be delayed due to competing interests (J.F. Gosselin, personal communication, June 26, 2024).

1.6 Line Transect Survey Design

The most widely used technique to estimate abundances of wild animal populations is distance sampling. A variety of methods are used within this technique, which is related to complete counts of sample areas. The main advantage of distance sampling is that not every individual in a given area needs to be detected, making it less time-consuming and expensive than complete counts (Buckland, 2004). The most common form of distance sampling is line-transect surveys. Typically, in these surveys, equally spaced lines are placed randomly within a study area. One or more observers travel along these lines and record any sightings of target species along with an estimation of their distance from the track. Probability of detecting the target species decreases as distance increases. The distribution of recorded distances can be used to estimate what proportion of the individuals present were detected. In theory, calculations can be expanded to determine the abundance and density of the target species in the study area (Thomas et al., 2010).

Prior to the 2018 NARW season in Atlantic Canada, DFO created 15 surveillance strata in potential foraging areas. From 2018 to 2022, a spacing of five nautical miles (9.26km) was used between survey lines in the BoF and GSL, and a zigzag pattern was used in strata off NFLD and Labrador (St. Pierre et al., 2024). Due to the lack of available planes, the Scotian Shelf and NFLD and Labrador are surveyed in alternating years (J.F. Gosselin, personal communication, June 26, 2024). NARW migrate along the Scotian Shelf. Migration can make it more difficult to detect whales, as they typically travel at high speeds and spend less time at the surface (Guirado et al., 2019). Sightings around

NFLD and Labrador are rare but acoustic detections of NARW confirm their presence in the area (DFO, 2020).

All surveillance flights have two or three observers in each plane, with either one person per side or two on the right side and one on the left. When a NARW is spotted, the plane breaks off of the transect line to circle the detection position for 20 minutes, known as a closing procedure (St. Pierre et al., 2024). This length of time was chosen based on the maximum dive time observed in a previous study by Baumgartner & Mate, with the logic being that any whale present in the area would surface at some point during this interval (J.F. Gosselin, personal communication, June 26, 2024). In this study, dives of up to around 16 and a half minutes were recorded for tagged NARW in the BoF and Roseway Basin (Baumgartner & Mate, 2003).

1.7 Aerial Surveillance Challenges

Surveillance can be difficult for migratory species such as NARW, especially as the population size is so small (St. Pierre et al., 2024). Difficulty is enhanced by lengthy dive times (Durette-Morin et al., 2022) and their black colouration blending in with surrounding water. Additionally, NARW lack a dorsal fin, which makes detection easier in other cetacean species (Government of Canada, 2023). A challenge across conservation is inadequate financial resources, or in the case of surveillance a lack of assets such as planes or aerial observers (J.F. Gosselin, personal communication, June 26, 2024). Bad weather can lead to lack of visibility or inability to conduct flights for safety reasons, making the surveillance season unpredictable. Furthermore, aerial surveillance can only be conducted during the day and depends on observer experience and effective protocols (Ratelle et al., 2024).

1.8 Marine Management Problem

Aerial surveillance for NARW in Atlantic Canada has been criticized for being minimal (Durette-Morin et al., 2022) and for focusing on already known aggregation areas (Oleson et al., 2020). It is also argued that migratory corridors are lacking surveillance, and therefore protection (WWF Canada, 2022). Additionally, if potential unknown and future habitats are not adequately monitored, distribution shifts may go undetected, leading to injuries and mortalities in unprotected waters (Davies & Brilliant,

2019). It is recognized that the majority of NARW aerial surveillance activity is concentrated in the southern GSL (St. Pierre et al., 2024). However, the extent of this bias has not been quantified. Our study examined the spatial coverage and intensity of the DFO marine mammal aerial surveillance program in Atlantic Canada in relation to general NARW habitats and active lobster and snow crab fishing areas. We chose to focus on the general habitats to determine if data collection is biased in terms of habitat type and location, and the fishing areas as they pose risk of entanglement to NARW. We also calculated the total distance surveyed within the shallow water exemption lines of 10 and 20 fathoms.

1.9 Research Questions

Where and when is DFO NARW aerial surveillance concentrated relative to NARW habitats and active lobster and snow crab fishing areas?

How did total distance surveyed vary from 2018-2021?

What is the total distance surveyed in the shallow water exemption protocol areas?

How can the allocation of aerial surveillance be changed to provide higher coverage and intensity in neglected areas?

2.0 CHAPTER TWO: BACKGROUND

2.1 Availability and Perception Biases

There are two common biases considered to be inherent to aerial surveillance (St. Pierre et al., 2024). One factor to be recognized and corrected for is availability bias, which refers to the amount of time animals are visible to observers. Detectability of NARW may vary based on diving time and frequency, along with oceanographic and weather conditions (Ganley et al., 2019). Availability bias for NARW is difficult to determine, as data on diving times is limited and may vary between demographics. For example, one study showed that pregnant females or those accompanied by calves tend to spend more time at the surface than other whales (Baumgartner & Mate, 2003). Diving patterns are strongly correlated with vertical distribution of *Calanus finmarchicus*, which can change seasonally and with diel migrations (Winn et al., 1995). Different availability bias correction factors are calculated for different months of NARW aerial surveillance in Atlantic Canada to account for seasonal variation in diving times. These factors are based on ratios of NARW seen from systematic track lines compared to those seen during closing procedures (St. Pierre et al., 2024).

The other primary bias in aerial surveillance is that of perception. Perception bias refers to missing detections of animals that are potentially visible during surveys due to observer error (Marsh & Sinclair, 1989). This can occur due to distance between observers and animals, height above animals, aircraft speed (Caughley, 1974), visibility conditions, and observer inexperience (Ratelle, 2024). A correction factor for perception bias was calculated using differences between observer sightings of NARW over six years of survey flights in Atlantic Canada (St. Pierre et al., 2024).

Although both of these biases are difficult to calculate and highly variable, it is important to include them in assessments of abundance and distribution based on systematic aerial surveys. Without incorporating availability and perception biases, animal counts will be underestimated, and management measures may be affected (St. Pierre et al., 2024). Our study focused only on the spatial and temporal aspect of NARW aerial surveillance, not on effectiveness of detecting whales, but it is important to consider these biases when designing surveillance programs.

2.2 Other Modes of Surveillance

Multiple methods besides surveillance flights are employed to detect NARW. The most traditional of these techniques is vessel-based surveillance. Vessels cover less ground and offer a smaller field of vision than planes but allow for more direct data collection. From a boat, it is possible to collect biological samples and take close-up photos of whales, which can help to monitor the health of populations (Wood, 2021). Another emerging surveillance method is the use of drones to detect whales. However, this method typically needs to be used in conjunction with vessel-based surveys, as drones have limited independency (Coutinho & Boukerche, 2021). Drones may be more suitable for purposes other than surveillance, such as collecting blow samples in a non-intrusive fashion (O'Mahoney et al., 2024).

Passive acoustic monitoring (PAM) is a common monitoring measure as well. PAM receivers can be stationary (e.g. attached to a buoy) or attached to autonomous gliders (UNB Newsroom, 2024). Advantages of PAM include the abilities to detect whales in remote locations, in darkness and in poor weather conditions (Durette-Morin et al., 2022). One disadvantage is that whales must be actively vocalizing to be detected. Their calls must also be distinct so as to not be confused with other species (Parks et al., 2011). The transmission of sound waves can be affected by variation in environmental conditions and in animal behaviour (Durette-Morin et al., 2019).

Satellite imagery is an emerging, novel method for detecting whales. It is impossible for visual and acoustic surveys to cover the entire range of NARW (Hodul et al., 2023). Very-high resolution satellite imagery could potentially be used to provide ocean-wide monitoring for whales (Höschle et al., 2021). Individual NARW have already been identified at the species level through satellite imagery. This is possible as NARW are the only species with distinctive callosity markings within their range, which are clearly visible to satellite cameras (Hodul et al., 2023). DFO is implementing satellite imagery as a surveillance method in collaboration with Transport Canada and the Canadian Space Agency. Although real-time detection is not yet occurring, it is likely to be possible in the near future (CFIM, 2023).

Finally, it is possible for NARW to be tagged in order to track their movements. Tags which are inserted under the skin are not currently used, as although they are longer-

lived, they can cause infection to already vulnerable animals (Wood, 2021). However, shorter term but non-invasive tags can be used. Tags are attached to whales by suction cups, which can be applied by a long pole from a vessel. More recently, drones have been used to drop suction cup tags onto whales from above (McPherson, 2023). This technique allows for tags to be applied with more precision and from a safer distance, which minimizes the risks of disturbance to the animal and harm to humans. Drones can also be deployed from vessels that are too large to approach NARW with but are more suited to rough weather conditions (NOAA Fisheries, 2023).

2.3 Other Surveillance Organizations

Several organizations besides DFO conduct NARW monitoring activities but vary in their purposes. Transport Canada conducts surveillance flights for NARW in GSL shipping lanes (Transport Canada, 2024) and researchers from the National Oceanic and Atmospheric Administration (NOAA) visit from the United States whenever possible to conduct flights as well. However, the primary purpose of NOAA flights is to complete photo-identification work. Therefore, these flights focus only on the southern GSL in order to document as many whales as possible. Vessel-based surveys and research are conducted frequently within the NARW season by organizations such as Dalhousie University, the Canadian Whale Institute, the New England Aquarium (Ratelle et al., 2024) and the University of New Brunswick (UNB, 2019). Several organizations use acoustic detections to locate NARW as well, but these detections are not considered in DFO Science aerial surveillance design (J.F. Gosselin, personal communication, June 26, 2024).

3.0 CHAPTER THREE: METHODS

3.1 Study Area

3.11 NARW Habitat Use

Five categories of NARW habitats in Atlantic Canada were defined based on behavioural observations from NARW Consortium (NARWC) sightings data (Right Whale Consortium 2021), and from a literature scan. Google Scholar was used to find publications on NARW habitat use and timing. Any information on NARW habitat use which included a geographical location and/or had an associated time of year was collected and compiled. Areas where the primary associated behaviours were transitory (i.e., movement in a region within a season), social, or foraging were identified using the NARW sightings data, including the expected timing (months) of primary usage. The migratory corridor and potential future habitat were identified through the literature scan and sightings lacking an associated behaviour. Habitat areas were further categorized based on region (i.e., GSL, BoF). After ground truthing the behavioural observations of NARW with the results of the literature scan, habitat polygons were drawn which encompassed all NARW sightings in Canadian waters using ArcGIS Pro v3.3.2 (ESRI, 2024; Right Whale Consortium, 2021).

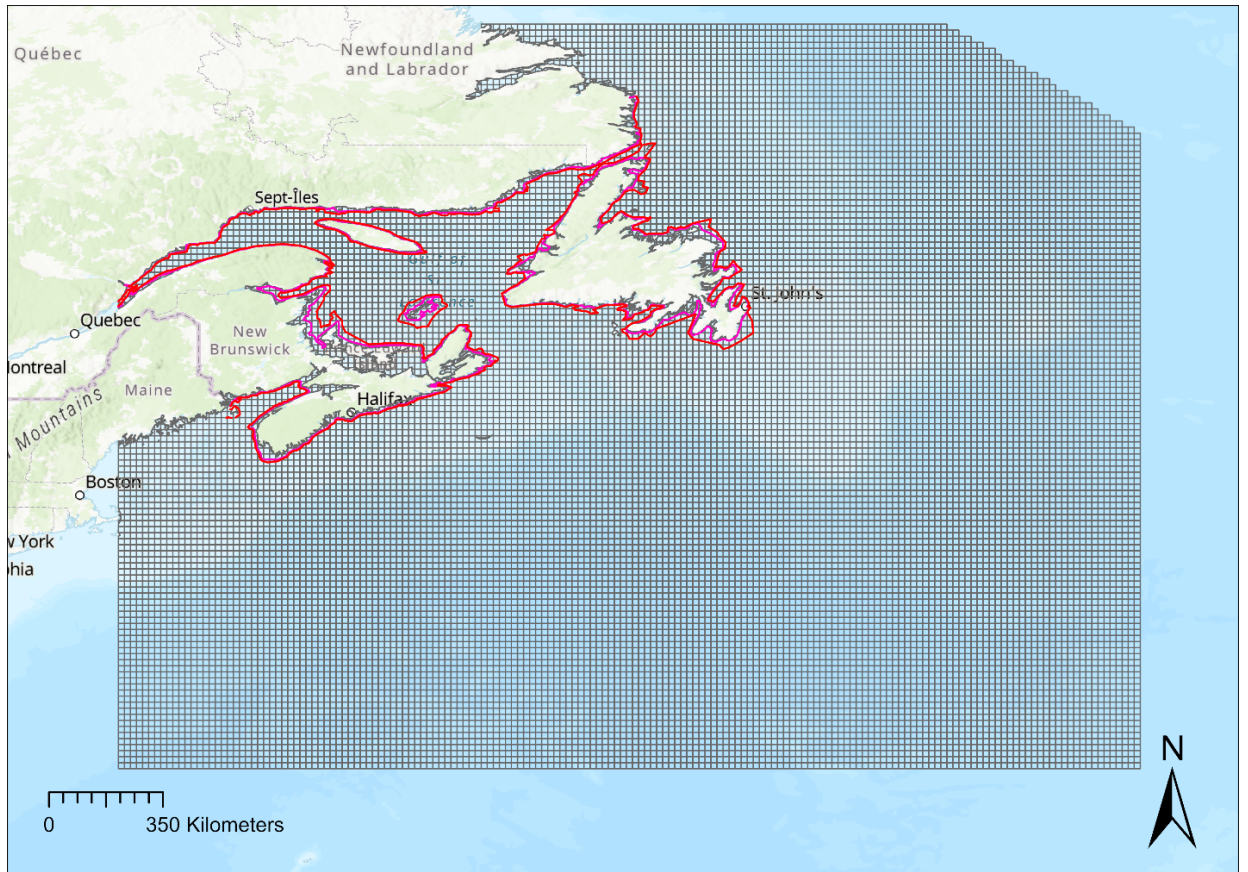


Figure 2: Map showing the Department of Fisheries and Oceans Canada’s 10-minute North Atlantic right whale management grid cells and shallow water protocol lines. The 10-fathom line is shown in pink and the 20-fathom line is shown in red.

The 10-minute (approximate 220-240km²) NARW management grid cells and shallow water protocol exemption lines (10 and 20 fathoms) were obtained from DFO Gulf Region (Figure 2) and overlaid with the habitat polygons. These divided the habitats into the grid cells used to manage the NARW fisheries closures and were used as the spatial scale of analysis.

3.12 Fisheries Management Area

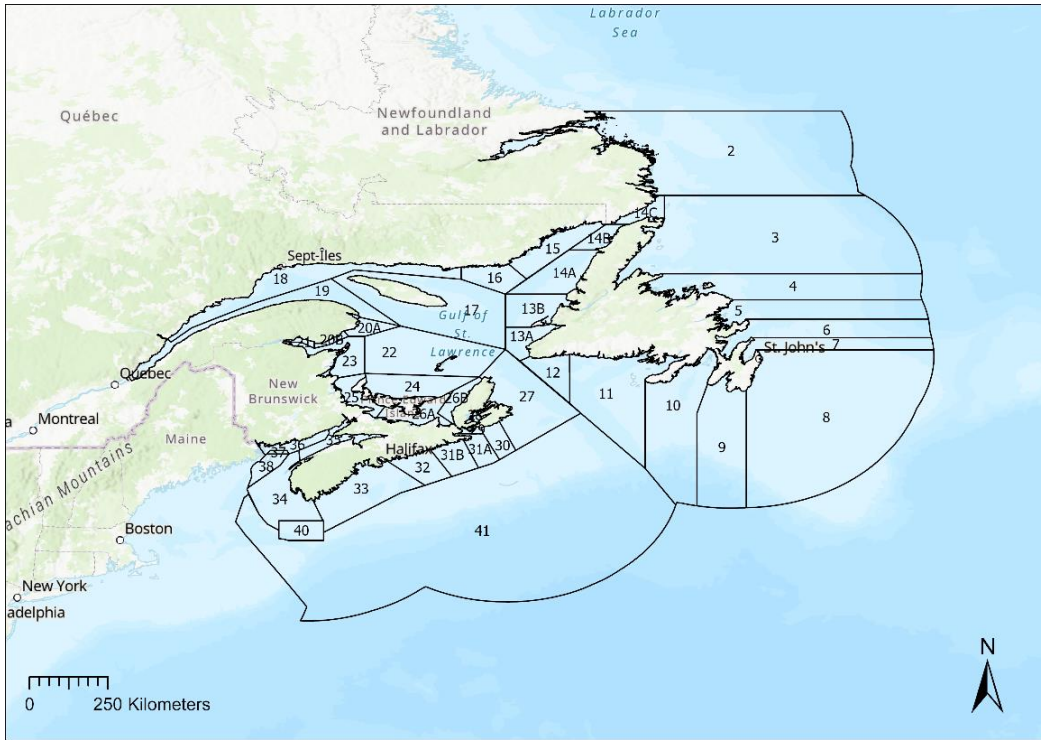


Figure 3: Map of Lobster Fishing Areas in Atlantic Canada (DFO).

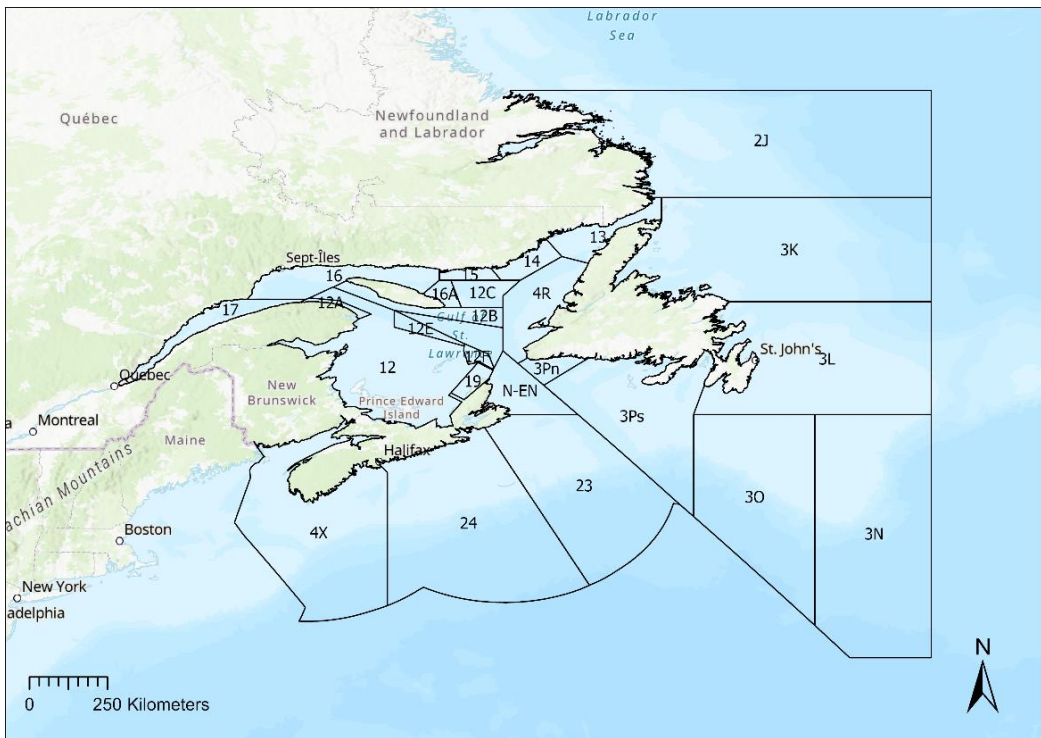


Figure 4: Map of Crab Fishing Areas in Atlantic Canada (DFO).

Table 1: Regions and active seasons of Lobster Fishing Areas in Atlantic Canada (Fisheries and Oceans Canada- Quebec Region, 2024; Fisheries and Oceans Canada- Gulf Region, 2021a; Fisheries and Oceans Canada- Maritimes Region 2023a; Fisheries and Oceans Canada- Maritimes Region 2023b; DFO, 2023a; DFO, 2018; Justice Laws Website, 1985; Fisheries and Oceans Canada- Newfoundland and Labrador Region, 2021).

LFA	Region	Active Season
2	NFLD & Labrador	April-July
3	NFLD & Labrador	May-July
4	NFLD & Labrador	May-July
5	NFLD & Labrador	May-July
6	NFLD & Labrador	April-July
7	NFLD & Labrador	May-July
8	NFLD & Labrador	May-July
9	NFLD & Labrador	May-July
10	NFLD & Labrador	May-July
11	NFLD & Labrador	April-July
12	NFLD & Labrador	April-June
13A	NFLD & Labrador	April-June
13B	NFLD & Labrador	April-July
14A	NFLD & Labrador	May-July
14B	NFLD & Labrador	May-July
14C	NFLD & Labrador	May-July
15	Quebec	May-August
16	Quebec	May-August
17	Quebec	April-July
18	Quebec	April-August
19	Quebec	April-July
20A	Quebec	April-July
20B	Quebec	April-July
21	Quebec	May-July
22	Quebec	May-July
23	Gulf	April-July
24	Gulf	April-July
25	Gulf	August-October
26A	Gulf	April-July
26B	Gulf	April-July
27	Maritimes	May-July
29	Maritimes	April-June
30	Maritimes	May-July
31A	Maritimes	April-June
31B	Maritimes	April-June
32	Maritimes	April-June
33	Maritimes	November-May
34	Maritimes	November-May
35	Maritimes	October-December, February-July
36	Maritimes	November-January, March-June
37	Maritimes	November-January
38	Maritimes	November-June

LFA	Region	Active Season
40	Maritimes	NA
41	Maritimes	January-December

Table 2: Regions and active seasons of Crab Fishing Areas in Atlantic Canada (Fisheries and Oceans Canada, 2024c; Fisheries and Oceans Canada- Quebec Region, 2024; Fisheries and Oceans Canada, 2024d; Fisheries and Oceans Canada- Newfoundland and Labrador Region, 2024; Fisheries and Oceans Canada- Gulf Region, 2021b; Fisheries and Oceans Canada, 2024e; Fisheries and Oceans Canada, 2016).

CFA	Region	Active Season
2J	NFLD & Labrador	June-August
3K	NFLD & Labrador	April-July
3L	NFLD & Labrador	April-July
3N	NFLD & Labrador	April-July
3O	NFLD & Labrador	April-July
3Pn	NFLD & Labrador	April-June
3Ps	NFLD & Labrador	April-July
4R	NFLD & Labrador	April-June
4X	Maritimes	November-March
12	Gulf	April-June
12A	Gulf	April-June
12B	Gulf	April-June
12C	Gulf	April-June
12E	Gulf	April-June
12F	Gulf	April-June
13	Gulf	May-August
14	Gulf	April-August
15	Gulf	April-July
16	Quebec	April-July
16A	Quebec	April-July
17	Quebec	March-June
19	Gulf	July-September
23	Maritimes	March-August
24	Maritimes	March-August
N-ENS	Maritimes	April-May, July-August

Lobster and snow crab fishery area (LFA and CFA, respectively) management boundaries for Atlantic Canada (Maritimes, Gulf, Quebec and NFLD and Labrador DFO regions) were obtained from DFO (Figures 3 and 4). These areas were plotted in ArcGIS Pro v.3.3.2 (ESRI 2024) and overlaid with the NARW management grid cells and shallow water exemption protocol lines (Figure 2). The active fishing seasons for each LFA (Fisheries and Oceans Canada- Quebec Region, 2024; Fisheries and Oceans Canada- Gulf Region, 2021a; Fisheries and Oceans Canada- Maritimes Region 2023a; Fisheries and Oceans Canada- Maritimes Region 2023b; DFO, 2023a; DFO, 2018; Justice Laws

Website, 1985; Fisheries and Oceans Canada- Newfoundland and Labrador Region, 2021) and CFA (Fisheries and Oceans Canada, 2024c; Fisheries and Oceans Canada- Quebec Region, 2024; Fisheries and Oceans Canada, 2024d; Fisheries and Oceans Canada- Newfoundland and Labrador Region, 2024; Fisheries and Oceans Canada- Gulf Region, 2021b; Fisheries and Oceans Canada, 2024e; Fisheries and Oceans Canada, 2016) (Tables 1 and 2) were defined by month, rather than day (e.g., April 15 became April, second Tuesday of November became November), to simplify comparison of surveillance activity with the active fishing areas.

A final management area was defined including only the management grid cells and shallow water areas (Figure 2), without delineation by NARW habitat or fishing area, providing a fourth measure of comparison.

3.2 Aerial Surveillance Track Line Data

GPS-recorded track line data was received from DFO Gulf Region for all scientific aerial surveillance flights from 2018-2021 (St. Pierre et al., 2024). Data included the aircraft position (latitude and longitude), date and time of the recorded position, elevation (m), time since last position (s), bearing (degrees), distance from last position (m), speed (km/h) and platform (name of aircraft). The position and speed of the aircrafts were recorded every two seconds during the flights (St. Pierre et al., 2024). Using the platform and date, each unique flight was given a flight ID number and each sequential data point was given an order ID number in R v.4.3.1 (R Core Team, 2023).

It was assumed that all track lines were on effort if over water and travelling at speeds between 20km/h and 250km/h. These limits were defined after mapping and visually inspecting the data, as planes appeared to be transiting to transect lines when travelling at speeds over 250km/h. This upper limit provides a buffer on the target speed of 185km/h for aerial surveys from 2018-2022 (St. Pierre et al., 2024). Data points over land or outside of this speed range were removed and not considered in further analysis.

Using the Point to Line tool in ArcGIS Pro v3.3.2 (ESRI, 2024), a continuous line for each flight was created using the flight and order ID numbers. The track lines were then clipped into corresponding management grid cells using the Intersect tool. This step provided distances (km) surveyed by each flight in each grid cell. These distances were divided by associated average speeds per grid cell (km/h) to calculate the time (h) spent

on effort per flight in each grid cell. The total distance (km) and time (h) spent on effort in each grid cell, management area and shallow water area was calculated by month and year (R Core Team, 2023).

3.3 Distance/ Time Correlation

The total time and distance surveyed between 2018-2021 were merged into one dataset, then a Spearman's rank correlation test was run for the two variables (R Core Team, 2023). This was to determine if only one of the variables could be used moving forward.

3.4 Open and Closed Seasons

The distances surveyed in each management area were divided into open and closed seasons based on the previously mentioned fishing area active seasons (Tables 1 and 2) and the expected months of NARW occurrence in each habitat polygon (R Core Team, 2023). As fishing is relevant to surveillance only when an area is active, all distances surveyed in the closed seasons were removed for the LFA and CFA analyses. The "closed" season distances were maintained for the NARW habitat analysis as these seasons were more subjective and surveillance is still important to determine distribution when whales are not expected to be aggregating.

3.5 Standardized Distance

It was decided to use km/km^2 as a measure of surveillance in the NARW habitats and fishing areas to make comparisons possible between different areas regardless of their size. To determine which areas were receiving more or less surveillance relative to their size, the distance surveyed (km) in each habitat and fishing area was divided by the associated area (km^2) of the habitat, LFA or CFA.

3.6 Data Visualization

Maps were created with the DFO management grid cells colour-coded according to how much surveillance they received (km). Low versus high density effort bins were determined using Jenks natural breaks (R Core Team, 2023). This method aims to minimize variation within groups so that values within a group are as similar to each other as possible, while maximizing variation between groups (Ahmad, 2019). Finally,

tables were created associating expected whale occurrence, derived from the NARW habitats, with LFA and CFA active seasons (Tables 1 and 2). These tables acted as analysis tools for indicating which active fishing seasons aligned spatially and temporally with expected occurrence of NARW.

4.0 CHAPTER FOUR: RESULTS

4.1 NARW Habitats

4.1.1 Literature Scan Results

NARW occupy an expansive range throughout the entire year (Davis et al., 2017), with remarkable habitat plasticity displayed (Mayo et al., 2018). NARW typically migrate along the Scotian Shelf between southern waters in the winter and northern waters in the summer (Brillant et al., 2015). In the past, NARW were known to aggregate in the BoF, especially in the Grand Manan Basin, and in the Roseway Basin (Brown et al., 2009). These areas were designated as critical habitats and used for foraging, among other purposes such as socializing and breeding. A transitory corridor was identified between the mouth of the BoF and the Jordan Basin (Baumgartner & Mate, 2005). NARW have been shown to be highly transitory when in the Gulf of Maine (GoM) and surrounding areas and tend to move between locations several times annually (Brillant et al., 2015).

Currently, most NARW in Atlantic Canada are detected in the GSL (Fisheries and Oceans Canada, 2024b). Within the GSL, the most suitable habitat conditions for resting and pregnant or lactating NARW have been identified in the southern GSL (Gavrilchuk et al., 2021). NARW detections tend to be concentrated in the western GSL in May and June before a broader dispersal within the gulf occurs between July and September. Sightings have been highest in July and August (Crowe et al., 2021). NARW tend to move several times between regions while in their northern habitats (Brillant et al., 2015). Individual NARW have been seen in both the southern and northern GSL within one season (Crowe et al., 2021), indicating that the Laurentian Channel is a transitory area. Whales of different age classes and sex are regularly detected in the GSL, indicating that it does not serve a purpose for a specific demographic (Cole et al., 2020). NARW have been observed foraging and socializing in the gulf (NOAA Fisheries, 2021).

NARW detections near NFLD and Labrador are rare but whales are occasionally seen in these areas (Ayers, 2021). As climate change progresses, NARW prey distribution will likely shift northward (Ross et al., 2021). It is important to monitor potential unknown and future habitats such as NFLD and Labrador (Oleson et al., 2020).

4.12 NARWC Sightings Data and Habitat Definition

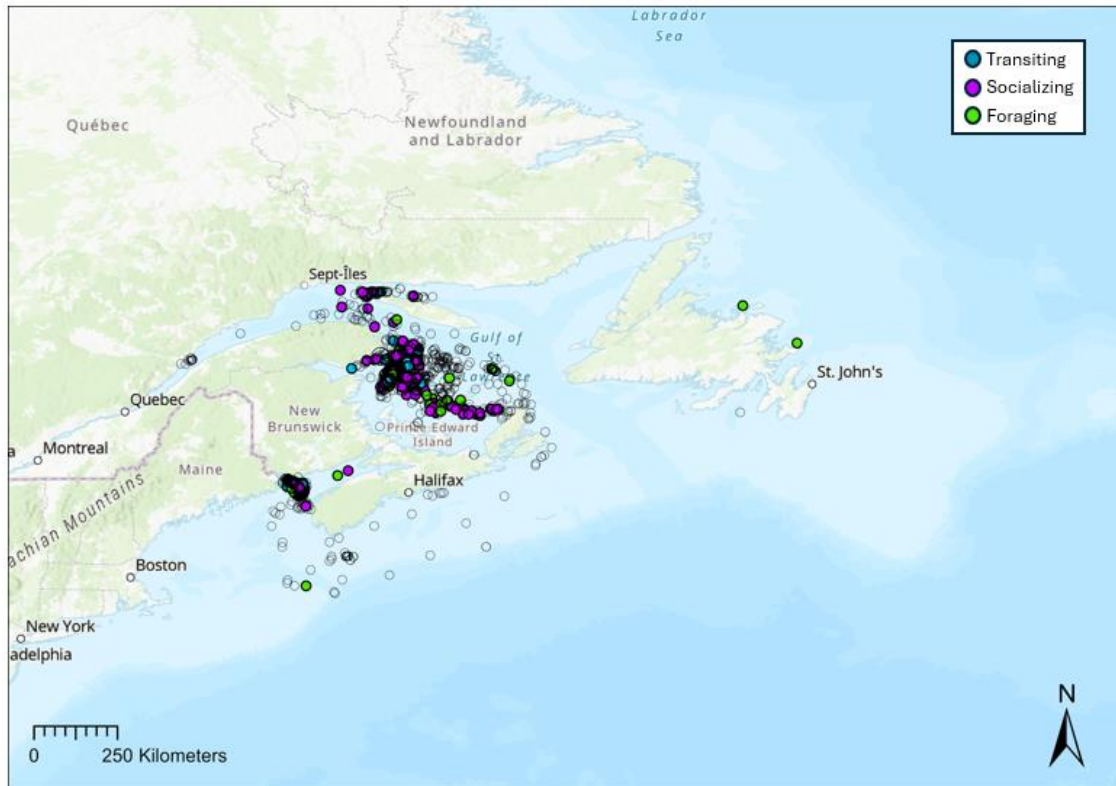


Figure 5: North Atlantic right whale sightings in Canadian waters from 2015-2021 colour-coded by primary associated behaviour (Right Whale Consortium, 2021). Whale sightings without an associated behaviour are outlined only.

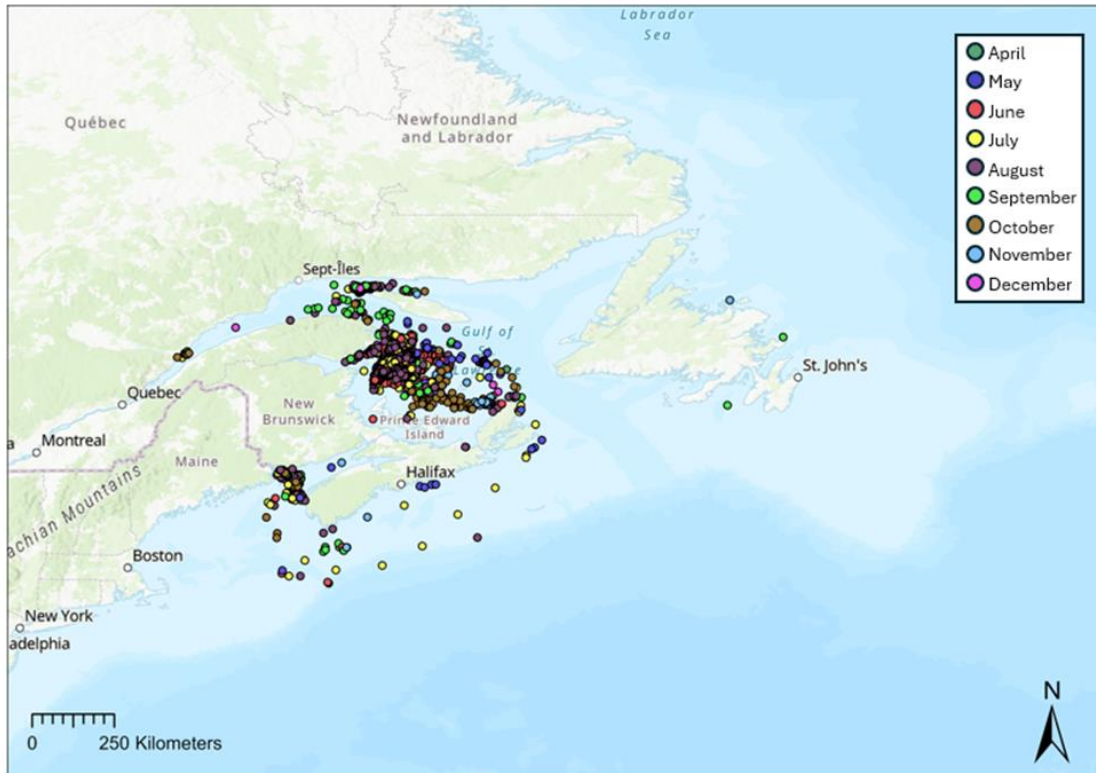


Figure 6: North Atlantic right whale sightings in Canadian waters from 2015-2021 colour-coded by month (Right Whale Consortium, 2021).

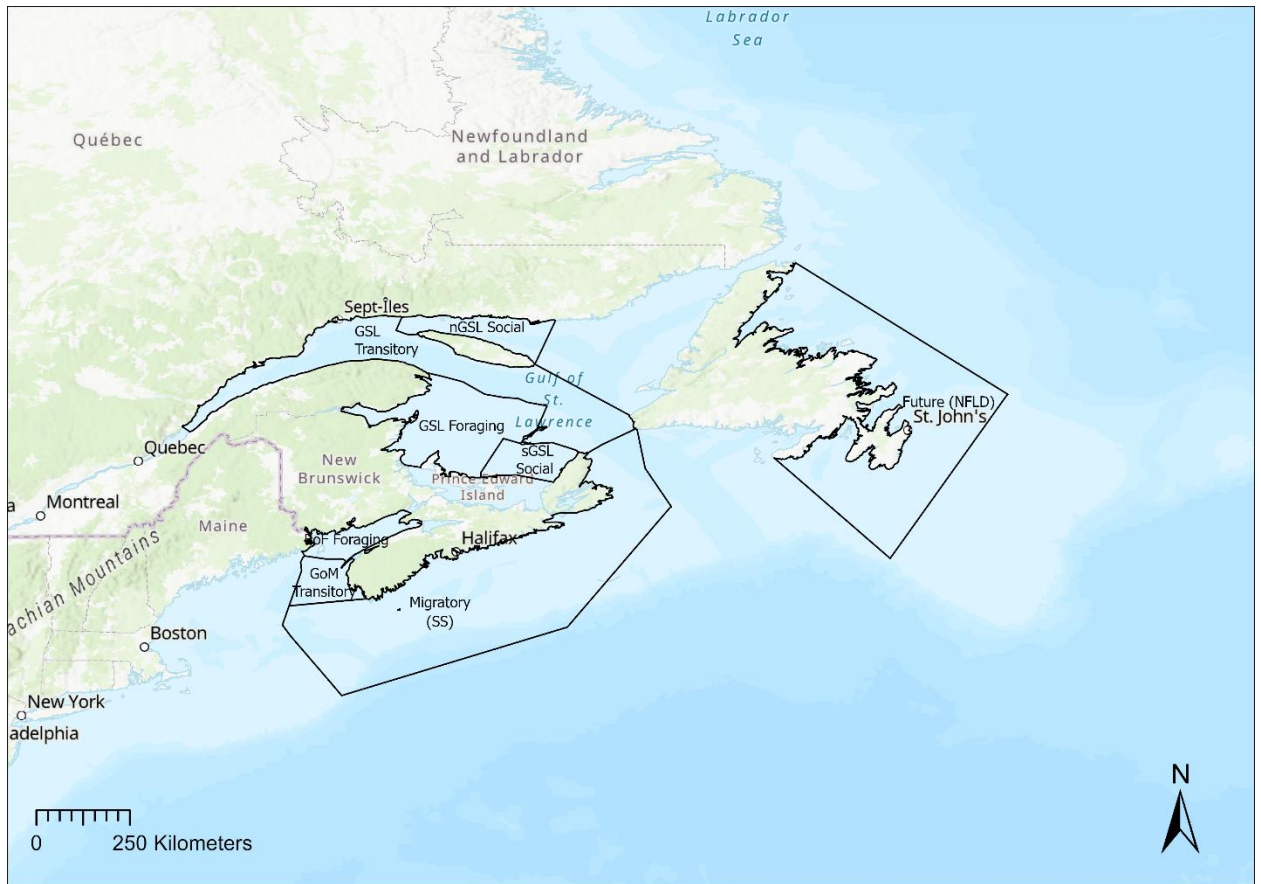


Figure 7: General North Atlantic right whale habitats derived from a literature scan and North Atlantic right whale sightings in Canadian waters from 2015-2021 (Right Whale Consortium, 2021).

Table 3: Months when North Atlantic right whales are expected in general habitats derived from a literature scan and North Atlantic right whale sightings in Canadian waters from 2015-2021 (Right Whale Consortium, 2021).

General NARW Habitat Name	Months When Whales Expected
GSL Foraging	May-August
BoF Foraging	July-September
sGSL Social	October-November
nGSL Social	August-November
Migratory (SS)	May-September
GSL Transitory	May-September
GoM Transitory	June-October
Future (NFLD)	September-November

From the NARWC sightings data (Right Whale Consortium, 2021) (Figures 5 and 6) and literature scan, eight habitats were defined (Figure 7). Each habitat had different months of expected whale occurrence (Table 3). Two foraging habitats were identified,

one in the BoF and one in the GSL. Transitory habitats were defined in the GoM and GSL. Two social habitats were identified in the northern (nGSL) and southern (sGSL) GSL, along with a migratory corridor along the Scotian Shelf (SS). Waters around NFLD and Labrador were defined as a potential future habitat.

4.2 Expected NARW Occurrence in Active Fishing Areas

Table 4: Regions and active seasons of Lobster Fishing Areas in Atlantic Canada with expected months of NARW occurrence (Fisheries and Oceans Canada- Quebec Region, 2024; Fisheries and Oceans Canada- Gulf Region, 2021; Fisheries and Oceans Canada- Maritimes Region 2023a; Fisheries and Oceans Canada- Maritimes Region 2023b; DFO, 2023a; DFO, 2018; Justice Laws Website, 1985; Fisheries and Oceans Canada- Newfoundland and Labrador Region, 2021).

LFA	Region	Active Season	Months When Whales Expected
2	NFLD & Labrador	April-July	September-November
3	NFLD & Labrador	May-July	September-November
4	NFLD & Labrador	May-July	September-November
5	NFLD & Labrador	May-July	September- November
6	NFLD & Labrador	April-July	September-November
7	NFLD & Labrador	May-July	September-November
8	NFLD & Labrador	May-July	September-November
9	NFLD & Labrador	May-July	September-November
10	NFLD & Labrador	May-July	September-November
11	NFLD & Labrador	April-July	NA
12	NFLD & Labrador	April-June	May-September
13A	NFLD & Labrador	April-June	May-September
13B	NFLD & Labrador	April-July	NA
14A	NFLD & Labrador	May-July	NA
14B	NFLD & Labrador	May-July	NA
14C	NFLD & Labrador	May-July	NA
15	Quebec	May-August	NA
16	Quebec	May-August	May-September
17	Quebec	April-July	August-November
18	Quebec	April-August	May-November
19	Quebec	April-July	May-September
20A	Quebec	April-July	May-August
20B	Quebec	April-July	May-August
21	Quebec	May-July	May-August
22	Quebec	May-July	May-November
23	Gulf	April-July	May-August
24	Gulf	April-July	May-November
25	Gulf	August-October	May-August
26A	Gulf	April-July	October-November
26B	Gulf	April-July	October-November
27	Maritimes	May-July	May-September
29	Maritimes	April-June	May-September
30	Maritimes	May-July	May-September

LFA	Region	Active Season	Months When Whales Expected
31A	Maritimes	April-June	May-September
31B	Maritimes	April-June	May-September
32	Maritimes	April-June	May-September
33	Maritimes	November-May	May-September
34	Maritimes	November-May	May-October
35	Maritimes	October-December, February-July	July-September
36	Maritimes	November-January, March-June	July-September
37	Maritimes	November-January	July-September
38	Maritimes	November-June	June-October
40	Maritimes	NA	May-September
41	Maritimes	January-December	May-September

Table 5: Regions and active seasons of Crab Fishing Areas in Atlantic Canada with expected months of NARW occurrence (Fisheries and Oceans Canada, 2024c; Fisheries and Oceans Canada- Quebec Region, 2024; Fisheries and Oceans Canada, 2024d; Fisheries and Oceans Canada- Newfoundland and Labrador Region, 2024; Fisheries and Oceans Canada- Gulf Region, 2021b; Fisheries and Oceans Canada, 2024e; Fisheries and Oceans Canada, 2016).

CFA	Region	Active Season	Months When Whales Expected
2J	NFLD & Labrador	June-August	NA
3K	NFLD & Labrador	April-July	September-November
3L	NFLD & Labrador	April-July	September-November
3N	NFLD & Labrador	April-July	NA
3O	NFLD & Labrador	April-July	September-November
3Pn	NFLD & Labrador	April-June	May-September
3Ps	NFLD & Labrador	April-July	September-November
4R	NFLD & Labrador	April-June	May-September
4X	Maritimes	November-March	May-October
12	Gulf	April-June	May-November
12A	Gulf	April-June	May-September
12B	Gulf	April-June	May-September
12C	Gulf	April-June	August-November
12E	Gulf	April-June	May-September
12F	Gulf	April-June	May-September
13	Gulf	May-August	NA
14	Gulf	April-August	NA
15	Gulf	April-July	August-November
16	Quebec	April-July	May-November
16A	Quebec	April-July	August-November
17	Quebec	March-June	May-September
19	GSL	July-September	May-October
23	Maritimes	March-August	May-September
24	Maritimes	March-August	May-September
N-ENS	Maritimes	April-May, July-August	May-September

Tables were created showing when NARW were expected in each LFA and CFA (Tables 4 and 5) to act as analysis tools. Expected occurrence of NARW in each fishing area was determined by overlaying the general NARW habitats (Figure 7) onto the LFA and CFA maps (Figures 3 and 4) to visualize where these areas overlap. The expected months of NARW occurrence in each general habitat were ascribed to any overlapping fishing areas. If a fishing area overlapped with multiple habitats, the expected months of NARW presence of those habitats were combined.

4.3 Distance/ Time Correlation

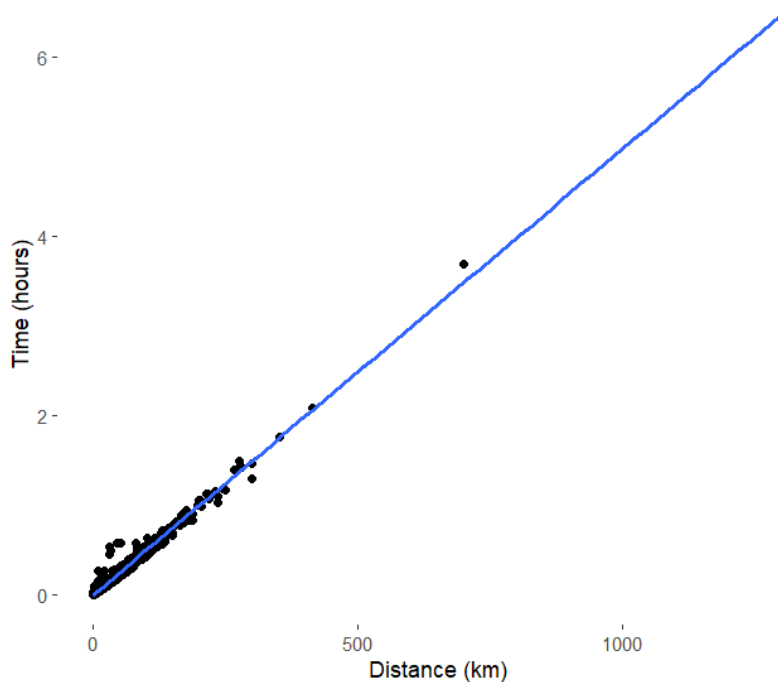


Figure 8: Spearman's rank correlation test between time and distance surveyed for NARW by the Department of Fisheries and Oceans Canada Marine Mammal Surveillance Program from 2018-2021 (correlation coefficient: 0.99, p-value: 2.2e-16).

The Spearman's rank correlation test indicated that distance and time surveyed are highly correlated, with a p-value below 0.05 (Figure 8). Distance (km) was used as the measurement for surveillance moving forward as no extra calculations had been performed to obtain these values. To calculate time, distance (km) in each NARW management grid cell had been divided by associated average speeds.

4.4 Overall Surveillance

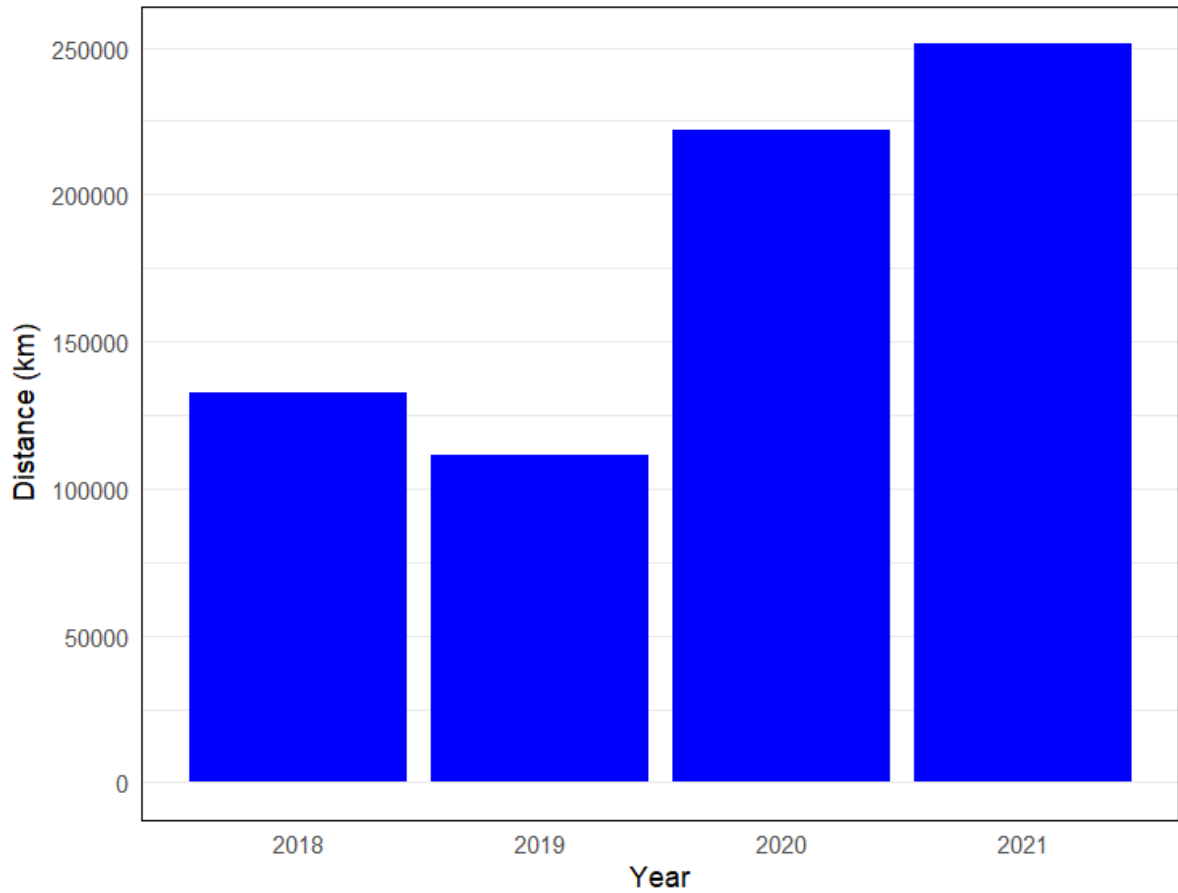


Figure 9: Total distances (km) of North Atlantic right whale aerial surveillance flights conducted by the Department of Fisheries and Oceans Canada Marine Mammal Surveillance Program from 2018-2021.

Total distance surveyed was summed for each year from 2018-2021 (Figure 9). The least distance was covered in 2019 (111,462km), followed closely by 2018 (132,490km). There was a major increase in surveillance in 2020 (222,096km), with the greatest distance covered in 2021 (251,516km).

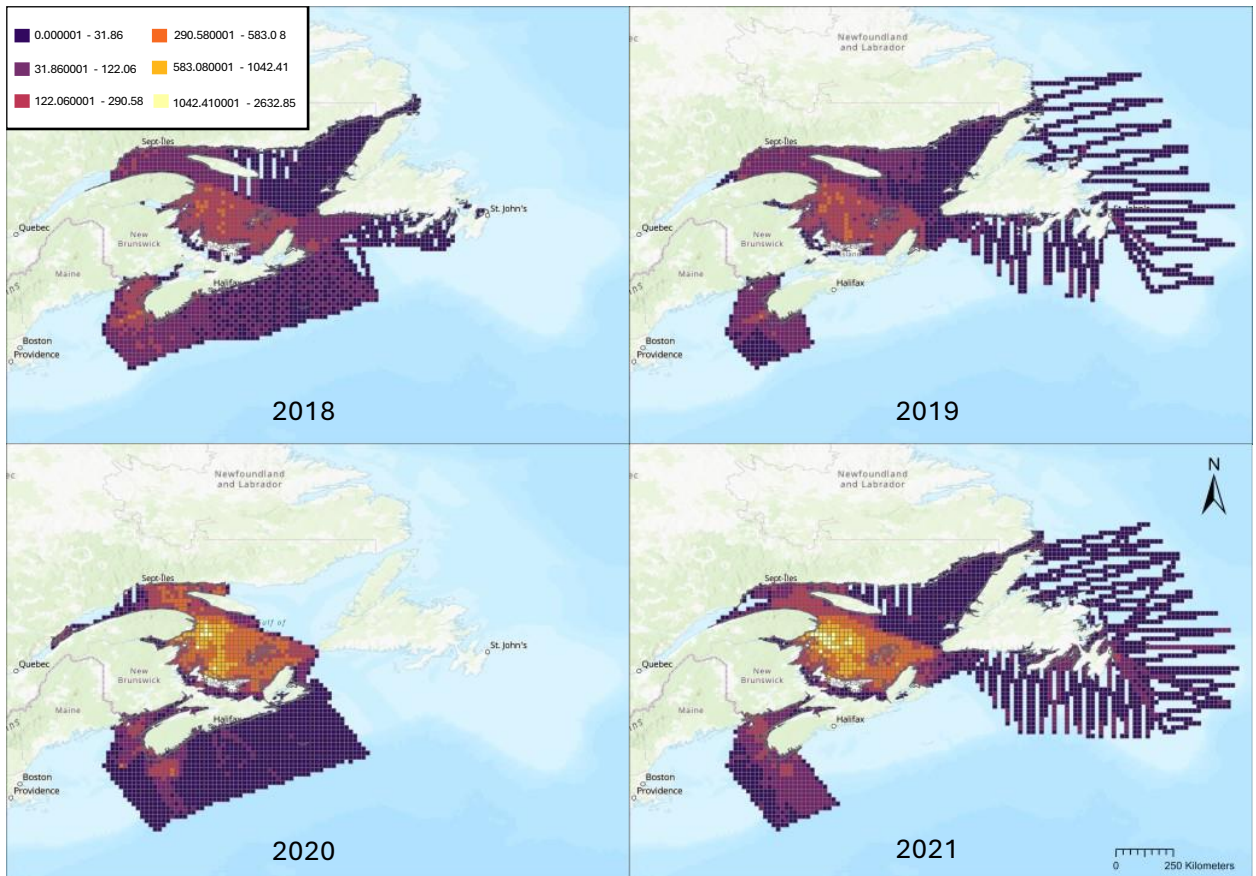


Figure 10: Maps showing coverage and intensity of North Atlantic right whale aerial surveillance flights by the Department of Fisheries and Oceans Canada Marine Mammal Surveillance Program from 2018-2021. Cool colours indicate low effort (km) while warmer colours indicate high effort.

Although total distance surveyed varied greatly over the four years, the highest intensity of surveillance was consistently found in the southern GSL (Figure 10). The Scotian Shelf was surveyed in 2018 and 2020, while the waters around NFLD and Labrador were surveyed in 2019 and 2021. There was more coverage around NFLD and Labrador in 2018 than in 2020, but these years show similar patterns in surveillance. Coverage and relative intensity were similar in 2019 and 2021 as well.

4.5 Surveillance in Shallow Water Protocol Areas

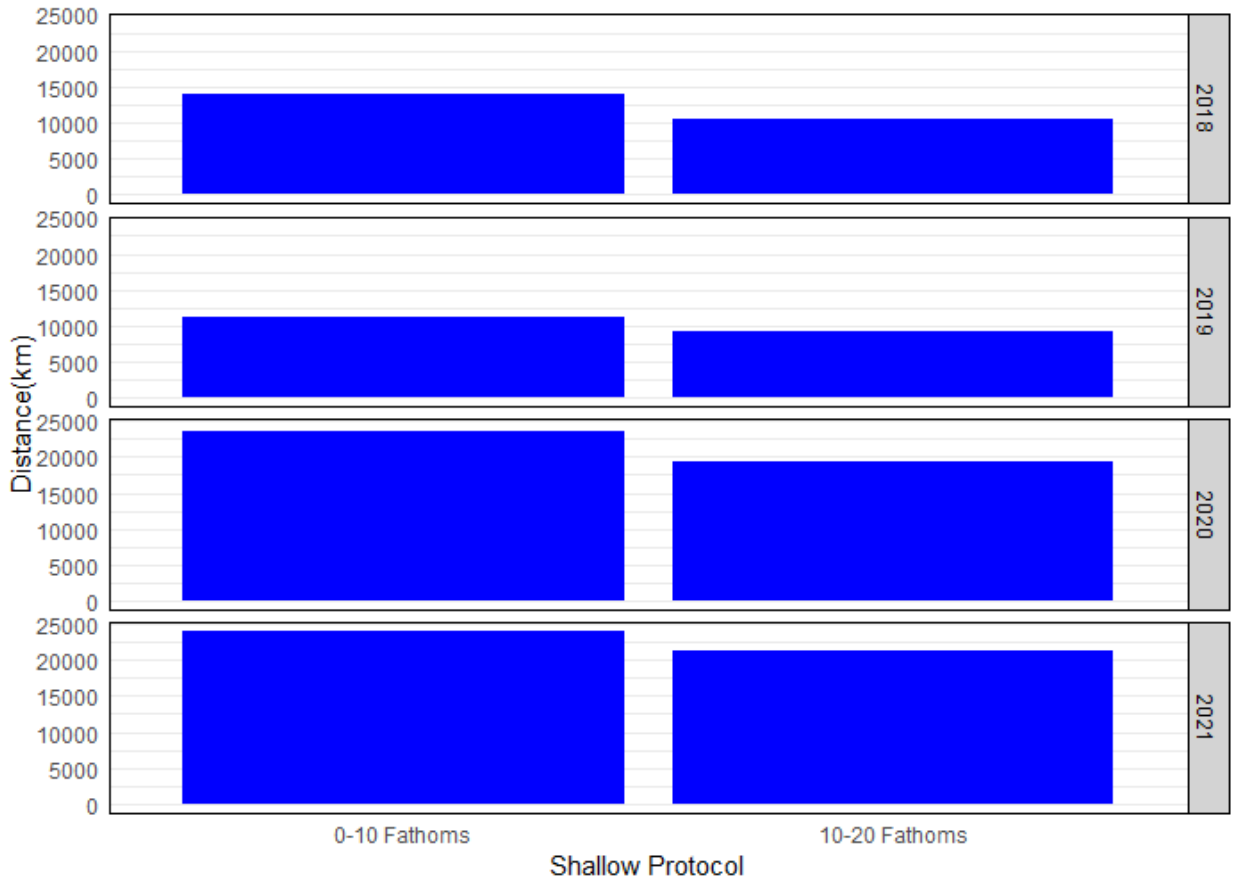


Figure 11: Total distance surveyed (km) by the Department of Fisheries and Oceans Canada Marine Mammal Surveillance Program in shallow protocol areas from 2018-2021.

In every year, there was slightly more distance surveyed in the 0-10 fathoms area than in the 10-20 fathoms area (Figure 11). Similar distances were surveyed in each area in 2020 and 2021 despite 2021 having the most surveillance overall (Figure 9).

4.6 Surveillance in NARW Habitats

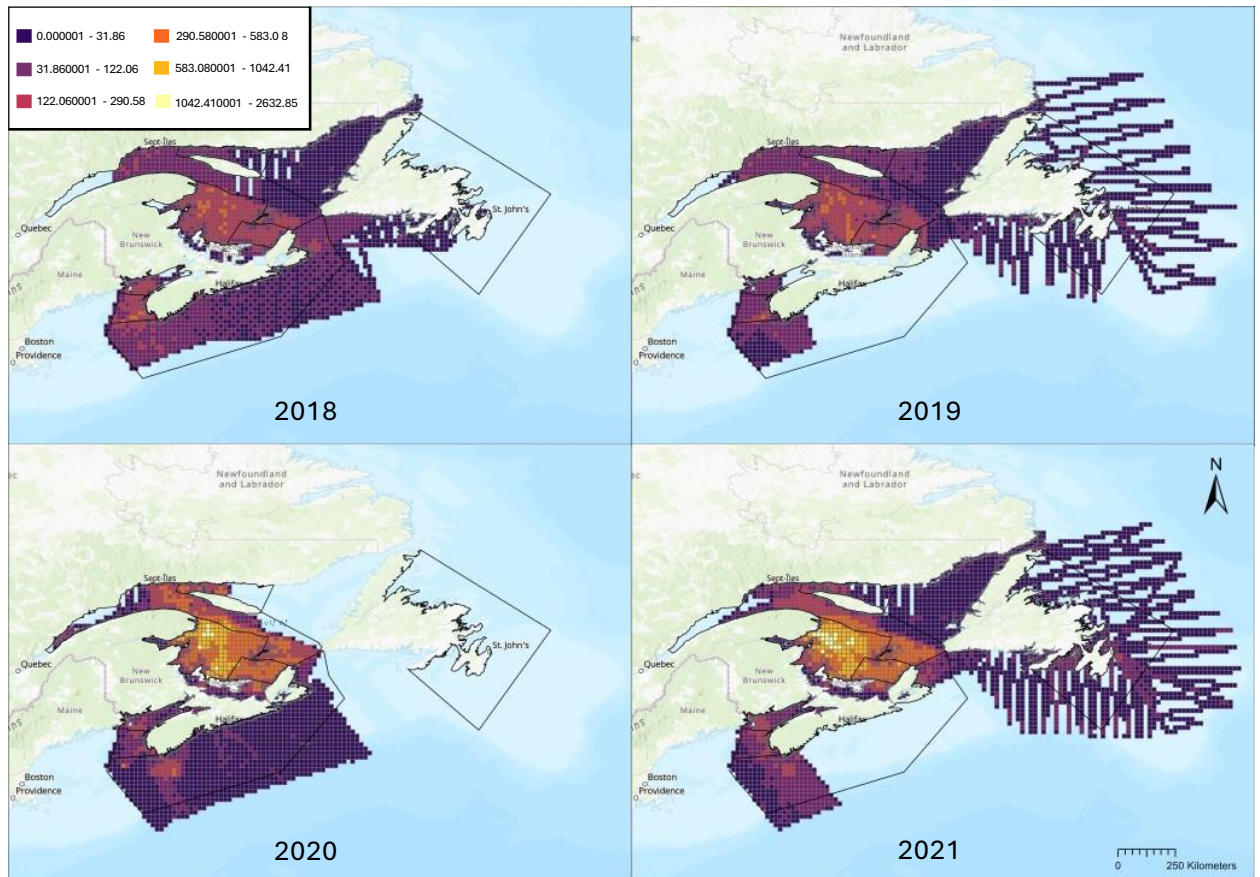


Figure 12: Maps showing coverage and intensity of North Atlantic right whale aerial surveillance flights by the Department of Fisheries and Oceans Canada Marine Mammal Surveillance Program from 2018-2021 in relation to general North Atlantic right whale habitats. Cool colours indicate low effort (km) while warmer colours indicate high effort.

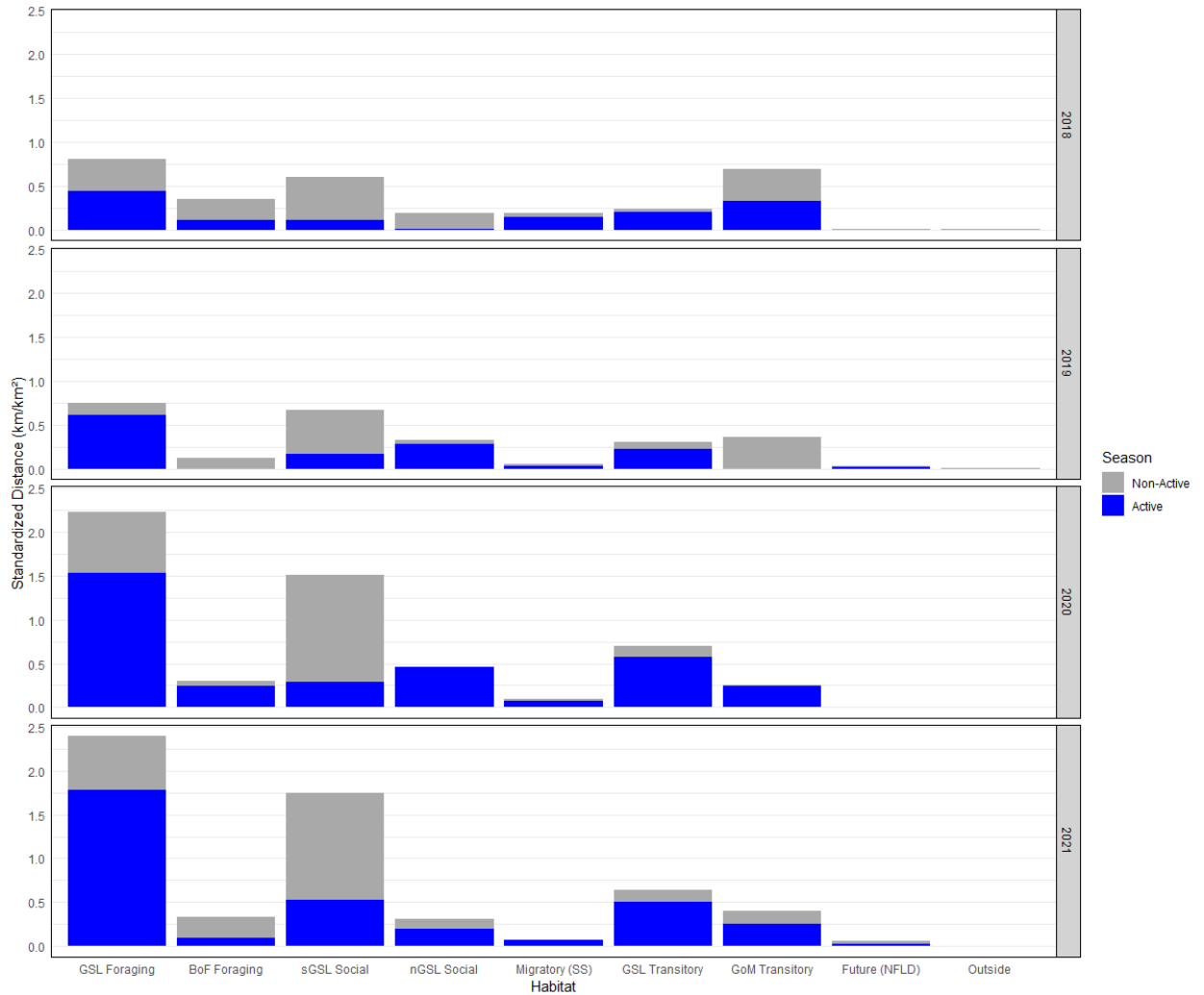


Figure 13: Standardized distance (km/km²) surveyed in the active and non-active seasons of general NARW habitats by the Department of Fisheries and Oceans Canada Marine Mammal Surveillance Program from 2018-2021. Active season refers to months when NARW are expected in each habitat while the non-active season is outside of these months.

There appears to have been a more even spread in NARW habitat surveillance coverage and intensity in 2018 and 2019 than in 2020 and 2021 (Figures 12 and 13). In terms of standardized distance (km/km²), surveillance focused more on the GSL Foraging, mostly in the active season, and sGSL Social habitats in the latter two years. The Foraging habitat in the BoF received a similar amount of surveillance in all years except for 2019, when less surveillance was received and all within the non-active season. The GoM Transitory habitat received more surveillance than the GSL Transitory habitat in 2018. The two Transitory habitats then received similar surveillance in 2019

before the GSL habitat was surveyed more in 2020 and 2021. Most of the surveillance in the Transitory habitats was within the active season, aside from in the GoM in 2018 and 2019. The nGSL Social habitat was surveyed similarly intensively throughout the four years, with the most surveillance received in 2020. The Migratory habitat along the Scotian Shelf received relatively more surveillance in 2018 than in other years but was surveyed very little comparatively in all other years. Potential Future habitat around NFLD and Labrador received minimal surveillance in all years and there was only a small distance covered outside of the defined habitats in 2018 and 2019. Overall, the habitats in the GSL were focused on most in terms of surveillance intensity.

4.7 Surveillance in Active LFAs

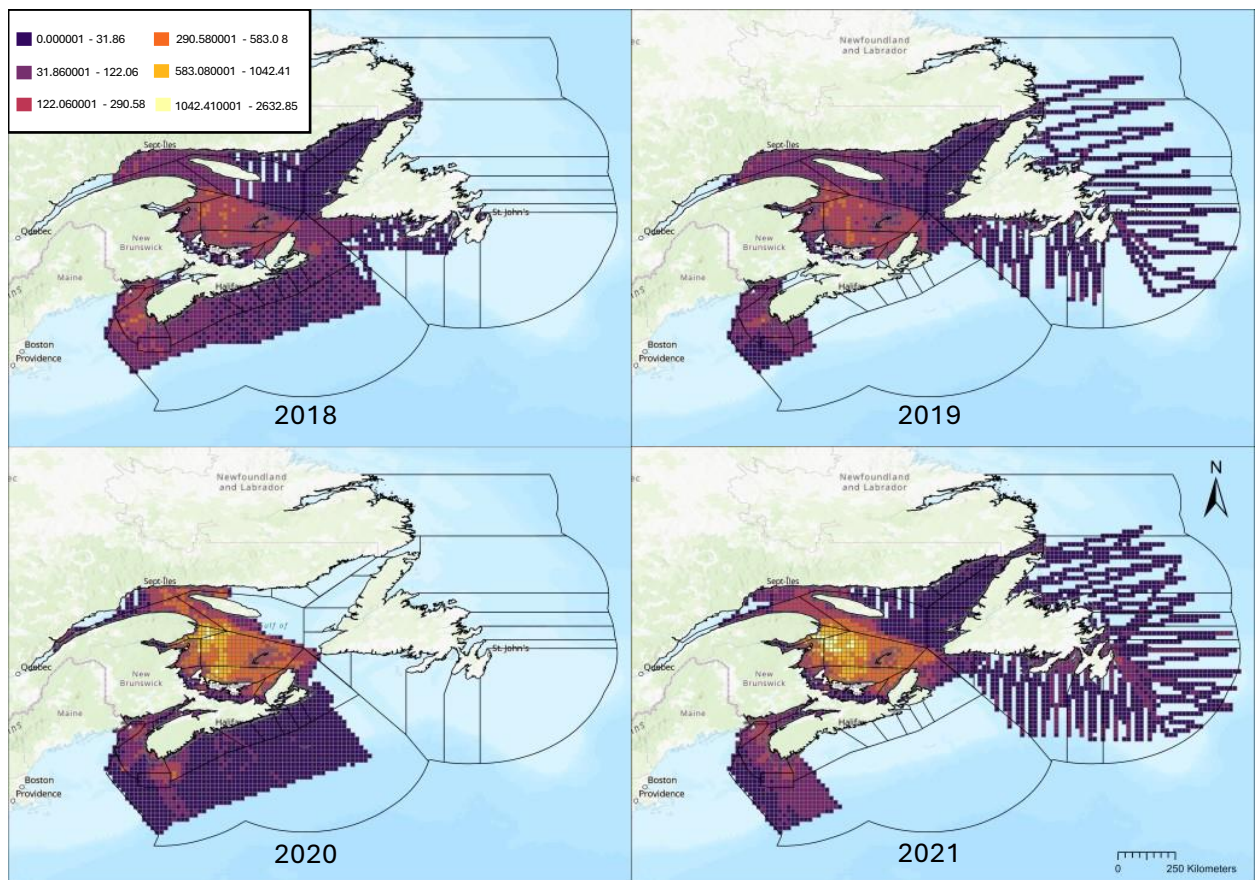


Figure 14: Maps showing coverage and intensity of North Atlantic right whale aerial surveillance flights by the Department of Fisheries and Oceans Canada Marine Mammal Surveillance Program from 2018-2021 in relation to Lobster Fishing Areas. Cool colours indicate low effort (km) while warmer colours indicate high effort.

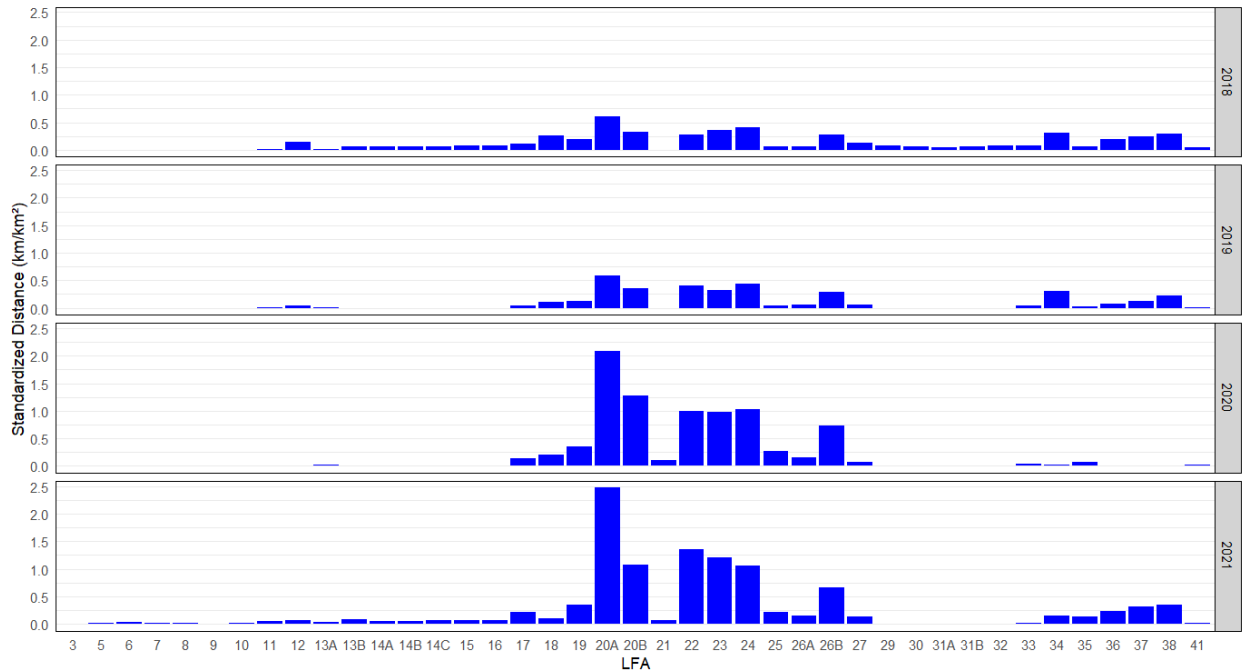


Figure 15: Standardized distance (km/km²) surveyed in the active seasons of Lobster Fishing Areas by the Department of Fisheries and Oceans Canada Marine Mammal Surveillance Program from 2018-2021.

There seems to have been more even coverage and surveillance intensity of LFAs in 2018 than in the following three years (Figures 14 & 15). Figure 14 shows total surveillance in relation to LFAs, rather than only distance surveyed within active seasons, but is provided for visualization purposes. In all years, there was a focus on LFAs 17 to 27, aside from LFA 21 which is a small area in the Chaleur Bay, in terms of standardized distance (km/km²) (Figure 15). These areas are all found in or around the GSL. LFAs 3 to 10 were minimally surveyed in all years, with the most surveillance occurring in 2021. These LFAs are located around NFLD and Labrador. LFAs 11 to 16, found in NFLD and Labrador and the northern GSL, received little surveillance but were surveyed more in 2018 and 2021. LFAs 17 to 27 received little surveillance but were surveyed more in 2018 and 2021. LFAs 29 to 33 received minimal surveillance in all years, with the most distance covered in 2018. These areas are found along the Scotian Shelf in the migratory corridor. LFAs 34 to 38 received a similar pattern of surveillance in 2018, 2019 and 2021. In 2020, there was minimal surveillance in these areas. These LFAs are found in and around the BoF and GoM. LFA 41 received little surveillance in all years and is an offshore fishery along the Scotian Shelf.

4.8 Surveillance in Active CFAs

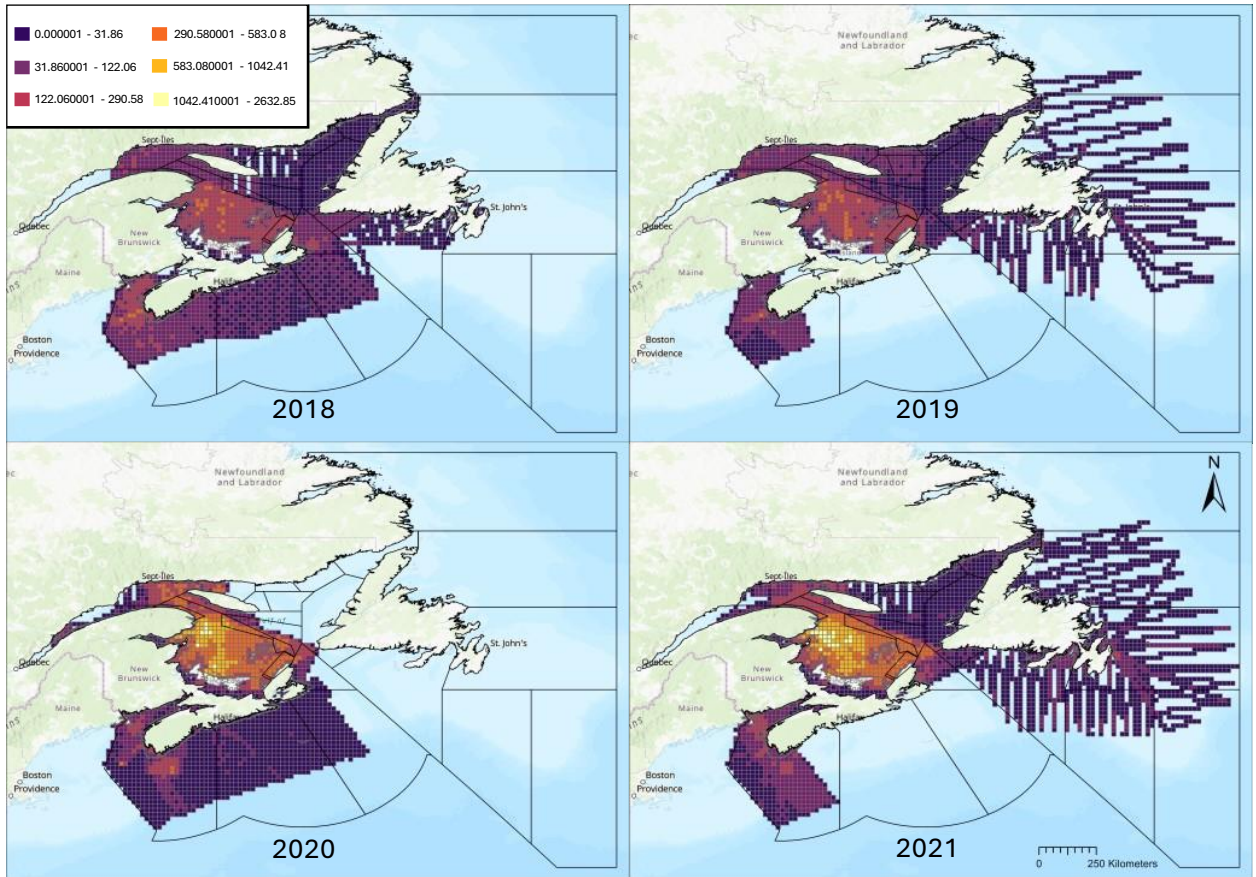


Figure 16: Maps showing coverage and intensity of North Atlantic right whale aerial surveillance flights by the Department of Fisheries and Oceans Canada Marine Mammal Surveillance Program from 2018-2021 in relation to Atlantic Canadian Crab Fishing Areas.

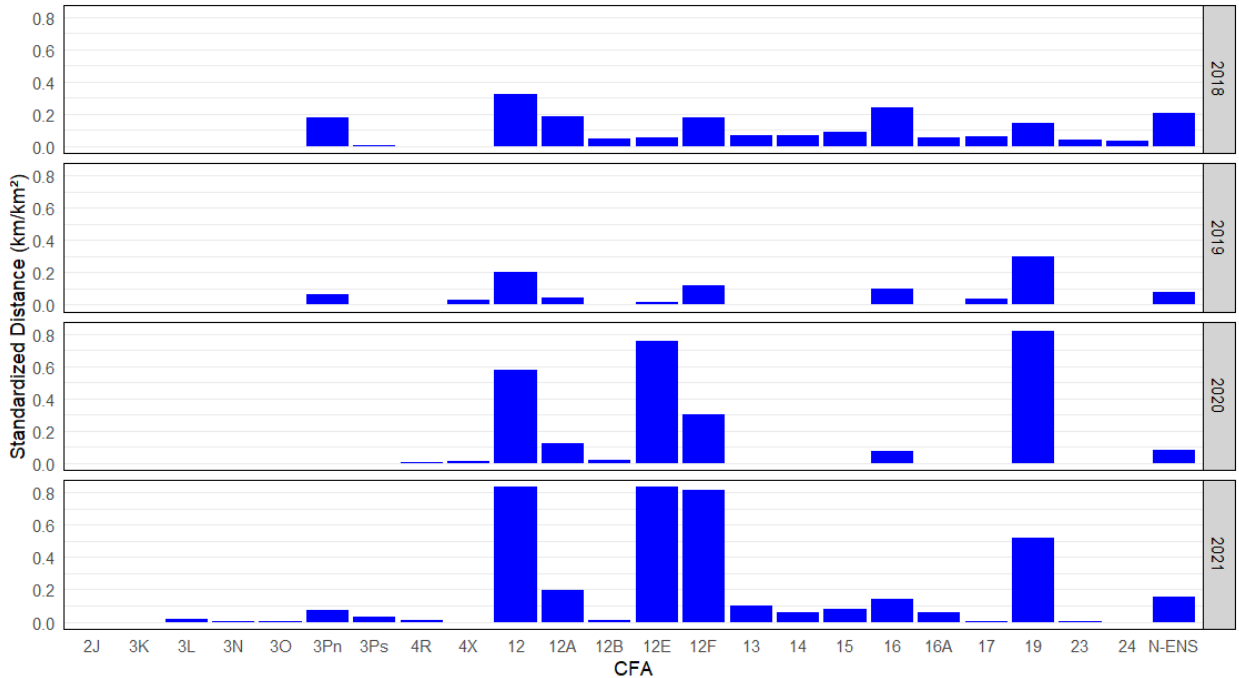


Figure 17: Standardized distance (km/km^2) surveyed in the active seasons of Crab Fishing Areas by the Department of Fisheries and Oceans Canada Marine Mammal Surveillance Program from 2018-2021.

Similar to the LFAs, the most even coverage and intensity of CFA surveillance occurred in 2018 (Figures 16 and 17). Again, Figure 16 shows total surveillance in relation to CFAs, rather than only distance surveyed within active seasons, but is useful for visualization. In 2019, less CFAs received surveillance than in the other years, in terms of standardized distance (km/km^2) (Figure 17). In 2020 and 2021, surveillance focused primarily on CFAs 12, 12E, 12F and 19. These CFAs are located in the southern GSL. CFAs 2J to 3O received little surveillance in all four years. These CFAs are located around eastern NFLD and Labrador. CFAs 3Pn and N-ENS are found in the Cabot Strait, the entrance to the GSL. These CFAs received some surveillance in all years, aside from 3Pn in 2020. CFAs 3Ps and 4R received no or little surveillance in all years and are located near NFLD. CFA 4X received little surveillance. This CFA is comprised of the BoF and GoM, along with a section of the migratory corridor along the Scotian Shelf. CFAs 12A and 12B were surveyed similarly in 2018, 2020 and 2021, with the least surveillance occurring in 2019. CFA 12A received more surveillance than 12B in all years. These two CFAs are found around the Laurentian Channel and the northern GSL.

CFAs 13 to 16A received similar surveillance in 2018 and 2021 and in 2019 and 2020. In 2018 and 2021, all five CFAs received surveillance. In 2019 and 2020, out of the five CFAs, only CFA 16 received surveillance. CFA 16 takes up much of the northern GSL. CFAs 13, 14, 15 and 16A are located in the northern GSL and around NFLD and Labrador. CFA 17 received little to no surveillance in all years and is found mainly in the St. Lawrence Estuary. CFAs 23 and 24 received little to no surveillance in all years as well, with the most surveillance occurring in 2018.

5.0 CHAPTER FIVE: DISCUSSION

5.1 Overall Surveillance

Total distance surveyed varied greatly between years from 2018 to 2021 (Figure 9). There was a major increase in surveillance in 2020, which can be attributed to impacts of the COVID-19 pandemic. Researchers from the United States were unable to cross the border into Canada to conduct fieldwork/monitoring in 2020 and 2021, leading DFO to increase surveillance in these years to compensate (Morin, 2020). Additionally, only two planes were available for aerial surveillance prior to 2020. A third plane may have helped to substantially increase the distance covered in 2020 and 2021 (St. Pierre et al., 2024).

As expected (St. Pierre et al., 2024), surveillance was most intense in the southern GSL in all years and alternated annually between the Scotian Shelf and NFLD and Labrador. Coverage was slightly more extensive in 2018 than in 2020, although these two years were similar in their geographic scope (Figure 10). This may have been because the NARW aerial surveillance program was relatively new in 2018. As time passed, more emphasis may have been placed on the southern GSL than other regions.

5.2 Surveillance in Shallow Water Protocol Areas

In each year, slightly more distance was surveyed in the 0 to 10 fathoms shallow protocol area than in the 10 to 20 fathoms area (Figure 11). Around 18-19% of total distance surveyed occurred in the shallow water areas in all four years of the study (Figures 9 and 11). These areas were defined to prevent shallow water fisheries from having to shut down in the event of NARW sightings triggering closures, with the assumption being that NARW tend to spend time in deeper waters when in Atlantic Canada (Fisheries and Oceans Canada, 2022a). However, there have been many incidents in which NARW were observed close to shore in this region. Surveillance flights identified two whales swimming in shallow waters near the Magdalen Islands in 2021 (St. Pierre et al., 2024). In 2023, fishers, scientists and fisheries managers agreed that NARW were being detected more often than usual in shallow waters (Withers, 2023). In May of 2024, a NARW was seen in the Saint John Harbour only a few metres from the shoreline (MacRae, 2024). The next month, another whale was reported swimming near the shore by Peggy's Cove (Murphy, 2024). It is possible that low surveillance effort is

contributing to the assumption that NARW do not often spend time in shallow waters, resulting in a confirmation bias scenario.

The majority of lobster fishing in Atlantic Canada occurs in waters less than 20 fathoms deep (Fisheries and Oceans Canada, 2022a). Although lobster fishing gear has not yet been identified as the definite cause of a NARW death (Withers, 2022), a NARW named Argo was found entangled in gear from LFA 33 in early 2023 (Fisheries and Oceans Canada, 2023). It is also possible that lobster fishing gear has resulted in the deaths of NARW that have not been recorded, as many deaths are not detected by humans (Pace et al., 2021). Additionally, the majority of retrieved gear is not identified, meaning more gear from entanglements could have originated from lobster fisheries (Fisheries and Oceans Canada, 2024g). It is clear that NARW will occasionally spend time in shallow waters in Atlantic Canada and encounter associated fisheries. Therefore, it is important to monitor these areas to ensure protection throughout their range.

5.3 Surveillance in NARW Habitats

It is important to recognize that the NARW habitats we defined should not be perceived as universal or static in terms of location (Figure 7) or times of expected whale occurrence (Table 3). As previously mentioned, NARW move within and between regions often and display high variation in habitat usage (Brillant et al., 2015; Mayo et al., 2018). General habitat polygons have been used in previous studies (e.g. Meyer-Gutbrod et al., 2023; Crowe et al., 2021; Kreuser & Meyer-Gutbrod, 2023) and in our case are helpful to determine the level of surveillance in different habitat types and locations. The NARWC sightings data we used to define these habitats (Right Whale Consortium, 2021), along with the literature scan, may also be biased due to previous uneven surveillance effort.

Throughout the years of our study, NARW habitat surveillance coverage went from broader to focused on the GSL Foraging and sGSL Socializing habitats (Figure 12). Intensity was greatest in these two habitats in all years except 2018, when the GoM Transitory habitat received similar surveillance. Most of the surveillance in the GSL Foraging habitat was within the active season we defined, while more of the surveillance in the sGSL Socializing habitat was in the non-active season (Figure 13). It is possible that the active season we identified for this habitat was shorter than it should have been and that the DFO science team is aware of usage in this area throughout more of the year.

It is understandable that DFO is focusing resources on the southern GSL habitats, as the largest aggregations of NARW are now found in these areas (Fisheries and Oceans Canada, 2024b) and a lack of available planes limits the geographic scope of surveys (St. Pierre et al., 2024). Since 2017, around 130 individual NARW have been seen each summer in the GSL (New England Aquarium, 2024). Although this number represents approximately a third of the total population (Cole et al., 2020), this leaves many whales unaccounted for. For a critically endangered population, it is important that as many individuals as possible be monitored and protected. Undetected distribution shifts have already led to many NARW deaths and injuries in unprotected waters (Koubrak et al., 2021). If surveillance is too focused in one area, this could lead to another mass mortality event should the population drastically change movement patterns again.

The Foraging habitat in the BoF received minimal surveillance compared to the GSL (Figure 13). Although there have been recent drastic distribution shifts away from this area (Davies et al., 2019), NARW are still present in the region (St. Pierre et al., 2024). The Grand Manan Basin critical habitat is also contained within the BoF (Figure 1). It is always possible that NARW will return to this area in greater numbers, which occurred in the fall of 2024 when many sightings were reported (Ogrysko, 2024). This resurgence in NARW sightings in the BoF highlights the region's continued importance to the population. Based on our literature scan and the Right Whale Consortium sightings (2021), we had designated July-September as the active season for the BoF Foraging habitat (Table 3). The sightings in the BoF in 2024 have been later in the year than our expected months of whale occurrence. This demonstrates the difficulty of defining NARW habitat usage and timing and emphasizes that surveillance should occur regardless of expected whale presence.

The GoM Transitory habitat received some surveillance in all four years. The proportion of surveillance in the active and non-active seasons varied each year, meaning timing of surveillance was inconsistent (Figure 13). The GoM is one of the fastest warming bodies of water in the world (Pershing et al., 2015), and habitat suitability for NARW is expected to decrease as climate change progresses (Ross et al., 2021). Distribution patterns within the GoM may change rapidly, meaning the region should be surveyed consistently. This important transitory habitat between critical habitats (Figure

1) should be well monitored. The Transitory habitat in the GSL received increasing surveillance over the years of our study. Sections of the Laurentian Channel are encompassed in this habitat, a major shipping corridor posing risk of ship strikes to NARW (Crowe et al., 2021). Consistent surveillance in this habitat should continue.

The Social habitat in the nGSL received some surveillance in each year. Other than in 2018, most of the surveillance was in the active season (Figure 13). Although more whales are found in the southern GSL than in the northern GSL, this habitat may become more important as climate change progresses, causing further distribution shifts (Meyer-Gutbrod et al., 2021). NARW are already detected often in the northern GSL (Crowe et al., 2021) and should be monitored for to increase knowledge of the species and ensure protection.

The Migratory habitat along the Scotian Shelf received minimal surveillance in all years of our study, with the most occurring in 2018. Most of the surveillance in this habitat was within the active season (Figure 13). Concerns have been expressed that the migratory corridor of NARW is not well-monitored (WWF Canada, 2022), which are validated by our results. NARW face threats as a result of heavy industry and fishing as they migrate along the eastern seaboard of North America (Koubrak et al., 2021). It is important that surveillance helps to protect NARW as they move throughout their range, especially when mass movements are occurring between northern and southern habitats.

The potential future habitat near NFLD and Labrador was surveyed minimally throughout the years of our study, with no surveillance occurring in this area in 2020 (Figures 12 and 13). Although sightings in this region are now relatively rare (Ayers, 2021), NARW were historically found in abundance off the coasts of NFLD (Monsarrat et al., 2016). Monitoring potential habitats where NARW are not currently expected in high numbers is a proactive response that could be taken to avoid mortality events caused by undetected distribution shifts, such as that of 2017 (Davies & Brilliant, 2019).

One of the stated objectives of the NARW aerial surveillance program is to develop a habitat model for predicting where NARW presence may occur. This is given as a reason for focusing effort in the southern GSL, as data can be collected for many individuals in a short period of time (J.F. Gosselin, personal communication, June 26, 2024). However, this model would theoretically only encompass one habitat type. It is

important to determine the conditions preferred by NARW for other purposes, such as migration, as well. Extreme habitat plasticity has been observed for NARW (Mayo et al., 2018), meaning whales will likely continue to display variation in preferences and range. As the NARW population is small and their habitat preferences are broad, a habitat model will likely overpredict NARW presence. Suitable habitat identified by a model may be more widespread than areas that are actually occupied (Keller et al., 2012). Therefore, a habitat model might not be the best use of resources when the situation is so dire, and protection should be ensured for as many whales as possible. Wide coverage and consistency in surveillance is one way to potentially help the species recover against anthropogenic threats.

5.4 Surveillance in Active LFAs

Risk of entanglement in active LFAs occurs as a result of fishing gear and NARW presence co-occurrence (Bisack & Magnusson, 2021). Table 4 is used as a tool to estimate this co-occurrence. However, it is again important to recognize that the timings of expected whale occurrence that we identified in each LFA should not be regarded as absolute. Due to high variation in NARW habitat usage, it is always possible for whales to be present in active LFAs. This analysis provides a starting point for determining adequacy of surveillance in active LFAs.

Similar to the NARW habitats, surveillance appeared to have covered a broader range of active LFAs in 2018 before focusing more on the southern GSL in the following years (Figures 14 and 15). LFAs 17 to 27 received the highest intensity of surveillance over our study period, aside from LFA 21 in the Chaleur Bay (Figure 15). Out of these LFAs, only three had no expected NARW occurrence in their active season: 17, 26A and 26B. The overlap in active seasons of the remaining LFAs and expected occurrence of NARW fell in the spring and summer from May to August (Table 4). The fishing effort in LFA 18 is relatively low but has been steadily increasing (DFO, 2024), posing risk of entanglement to NARW. LFAs 19 to 21 are found in the Gaspé, with 87% of active licenses held by fishers in LFAs 20A and 20B (Fisheries and Oceans Canada, 2018a). LFA 20A received the highest intensity of surveillance in all four years of our study (Figure 15), which is positive as it is an active fishery with expected co-occurrence of fishing and NARW presence (Table 4). LFA 22 is found near the Magdalen Islands. This

area has the highest recorded landings in the Quebec region (Fisheries and Oceans Canada, 2018b). Landings in the Gulf region LFAs (23 to 26B) are currently high compared to historical levels (Fisheries and Oceans Canada- Gulf Region, 2021a). LFAs 23 and 24 received relatively high surveillance intensity in all four years of our study, while LFA 25 had less (Figure 15). LFAs 26A and 26B did not have expected co-occurrence of fishing and NARW presence according to our NARW habitat active seasons (Table 4). LFA 26A received little surveillance while 26B received more (Figure 15). LFA 26A is located south of Prince Edward Island, where NARW sightings are rare. LFA 27 has the third highest number of licenses in the Maritimes region (Fisheries and Oceans Canada, 2023a). and is located near the Cabot Strait where NARW are thought to enter and leave the GSL (Simard et al., 2019). This area should be surveyed often, especially during the expected times of NARW migrations.

LFAs 3 to 10, located near NFLD and Labrador, were minimally surveyed in their active seasons in all years of our study (Figure 15). The active seasons of these LFAs do not overlap with expected NARW occurrence (Table 4). However, it is always possible that the species will move into these areas unexpectedly in the future. A lack of NARW detections in the region could be related to lack of surveillance, meaning our times of expected whale occurrence are inaccurate. These LFAs are relatively inactive when compared to the remainder of the NFLD and Labrador LFAs (Fisheries and Oceans Canada- Newfoundland and Labrador Region, 2021). Overall, entanglement in these LFAs appears to not pose an immediate threat, but all areas should be monitored consistently in case the situation changes.

LFAs 11 to 16 are found in NFLD and Labrador and in the northern GSL. These areas were surveyed minimally in their active season throughout our study but the most surveillance occurred in 2018 and 2021 (Figure 15). Approximately half of all lobster harvested in NFLD and Labrador is caught in LFA 11 (Fisheries and Oceans Canada- Newfoundland and Labrador Region, 2021). However, no NARW are ever expected in this area (Table 4). LFAs 12 to 14C are relatively active in the NFLD and Labrador region (Fisheries and Oceans Canada- Newfoundland and Labrador Region, 2021). The active seasons of LFAs 12 and 13A do not overlap with expected NARW occurrence, while NARW are never expected in LFAs 13B to 14C (Table 4). The fishing effort

deployed in LFAs 15 and 16 is low but gradually increasing (DFO, 2024). NARW are never expected in LFA 15 but expected occurrence overlaps with all months in the active season of LFA 16 (Table 4). Surveillance in LFA 16 may not be adequate for protection.

LFAs 29 to 33 are found along the NARW migratory corridor and were surveyed minimally in all years of our study. The most surveillance occurred in 2018 (Figure 15). The active seasons of all of these LFAs overlap with expected occurrence of NARW, mostly throughout the late spring and early summer. The active season of LFA 33 only overlaps with expected NARW occurrence in May (Table 4) but this LFA is one of the largest lobster fisheries in Canada (Rankin, 2024). Due to the expected co-occurrence of NARW and productive lobster fisheries, it is clear that this region needs more surveillance in order to increase NARW protection as they migrate between northern and southern habitats.

LFAs 34 to 38 are located in the BoF and GoM and received some surveillance in every year of our study. The least surveillance occurred in 2020 (Figure 15). As with LFA 33, the active season of LFA 34 overlaps with NARW occurrence only in May (Table 4) but the fishery is extremely productive (Rankin, 2024). The active seasons of LFAs 35 and 38 overlap for one month each with expected NARW occurrence (Table 4). Harvesting in LFA 35 has increased dramatically over the past 15 years (DFO, 2023b) and disproportionate risk of NARW entanglement has previously been attributed to LFA 38 (Brillant et al., 2017). There are also no fishery closure regulations in place for part of LFA 38, as there are disputes between Canada and the United States over sovereignty in the area (Edwards, 2024). The active seasons of LFAs 36 and 37 do not overlap with expected NARW occurrence (Table 4), but these LFAs are in the BoF which has seen increased abundance of NARW in an unexpected time (Ogrysko, 2024). Surveillance in these LFAs is likely inadequate for NARW protection.

LFA 41, an offshore fishery along the Scotian Shelf, received little surveillance over the course of our study (Figure 15). This fishery is open year-round and is the only LFA that operates on a Total Allowable Catch (Howse, 2024). Only one vessel currently operates in this LFA (Clearwater, n.d.), but the area could still pose risk of entanglement to NARW as they migrate along the Scotian Shelf and should be monitored consistently.

5.5 Surveillance in Active CFAs

The same disclaimer as the LFAs regarding definition of NARW habitat locations and timings of expected whale occurrence is relevant to the active CFA analysis.

Surveillance coverage within the active seasons of CFAs was most broad in 2018 (Figures 16 and 17). The most intense surveillance occurred in the southern GSL CFAs (12, 12E, 12F, and 19) in 2020 and 2021 (Figure 17). The recent distribution shift of NARW into the southern GSL has resulted in extended overlap of whale aggregations with snow crab fishing, leading to heightened risk of entanglement (Cole et al., 2021). The active seasons of CFAs 12, 12E and 12F overlap with expected NARW occurrence in May and June, while the overlap in CFA 19 spans from July to September (Table 5). CFA 12 is the largest snow crab fishery in the GSL in terms of area, number of harvesters and landings (Landry et al., 2024). Around one fifth of snow crab landings in Canada come from the four southern GSL CFAs (Fisheries and Oceans Canada- Gulf Region, 2021b). However, fishers have begun attempting to catch their quota early in the active season, prior to the arrival of NARW in the GSL, to avoid dynamic closures (Russell, 2024). Consistent surveillance should continue in these CFAs to ensure NARW protection. Although early fishing may help to avoid entanglement, it is possible that movement patterns will shift again and result in earlier arrival of NARW.

CFAs 2J to 3O, located in NFLD and Labrador, received little surveillance in their active seasons over the course of our study (Figure 17). NARW were never expected in CFAs 2J and 3N, and no overlap between the active seasons of CFAs 3K, 3L and 3O and expected NARW presence occurred (Table 5). Snow crab quotas in NFLD and Labrador have increased in recent years and the fishery is one of the most lucrative in the province (Fisheries and Oceans Canada, 2022b). Although there does not appear to be immediate risk of NARW entanglement in these CFAs, distribution may shift more towards NFLD and Labrador as climate change progresses and the GSL continues to warm (Gavrilchuk et al., 2021). It is important that these areas receive proactive surveillance.

CFAs 3Pn and N-ENS, located in the Cabot Strait, received some surveillance in their active seasons. The only instance of no surveillance occurred in 2019 in CFA 3Pn (Figure 17). The active season of CFA 3Pn overlaps with expected NARW presence in May and June, while the overlap of CFA N-ENS occurs in May, July and August (Table

5). This presents risk of entanglement to NARW as they migrate in and out of the GSL (Simard et al., 2019). Consistent surveillance in these CFAs could help protect detected NARW by triggering dynamic fishery closures.

CFAs 3Ps and 4R, located on the coasts of NFLD, were surveyed minimally in two years each and not at all in the others (Figure 17). There is no overlap in the active season of CFA 3Ps and expected NARW presence. However, NARW are expected in the active season of CFA 4R in May and June (Table 5). Both of these CFAs have small quotas when compared to other NFLD and Labrador region CFAs (Fisheries and Oceans Canada, 2019) but still pose risk of entanglement to NARW.

CFA 4X was surveyed minimally over the course of our study (Figure 17). This CFA is located in the BoF and GoM, along with part of the migratory corridor along the Scotian Shelf. There is no predicted overlap in the active season of CFA 4X and NARW occurrence in the region (Table 5). However, the active season begins in November. In November of 2024, NARW were detected in the BoF (Edwards, 2024), again demonstrating the difficulty of defining NARW habitat use and the importance of surveying in areas where whale presence is not expected.

CFAs 12A and 12B received some surveillance in each year, aside from 2019 when CFA 12B was not surveyed (Figure 17). These CFAs are located around the Laurentian Channel and the northern GSL and both of their active seasons overlap with expected NARW presence in May and June (Table 5). Although surveillance is focused on the southern GSL, NARW also occupy northern areas of the gulf (Crowe et al., 2021). Risk of entanglement is present in the northern GSL and Laurentian Channel, meaning these areas should be surveyed consistently, especially in the active seasons of fishery areas.

CFAs 13 to 16A all received some surveillance in 2018 and 2021, while only CFA 16 was surveyed in 2019 and 2020 (Figure 17). These CFAs are located throughout the northern GSL and Strait of Belle Isle. No whales are ever expected in CFAs 13 and 14, while no overlaps between the active seasons of CFA 15 and 16A and NARW presence are expected. The active season of CFA 16 overlaps with expected NARW occurrence between May to July (Table 5). Considering limited resources, it is understandable that, out of these five CFAs, CFA 16 is surveyed the most. However, all active fishing areas

should be monitored for NARW, as distribution can be unpredictable (Davies & Brilliant, 2019).

CFA 17 extends well into the St. Lawrence Estuary and received little to no surveillance from 2018-2022 (Figure 17). There is an expected overlap in the active season of CFA 17 and NARW presence in May and June (Table 5). Multiple entangled NARW were detected in the St. Lawrence Estuary in summer of 2024 (MacKinnon, 2024; Nguyen, 2024). This area is likely inadequately surveyed considering the apparent risk of entanglement in the region.

CFAs 23 and 24 received no or minimal surveillance in all years of our study (Figure 17). These CFAs are located along the Scotian Shelf migratory corridor and both of their active seasons overlap with expected NARW occurrence from May to August (Table 5). Around 60% of snow crab vessels in the Maritimes region fish in CFAs 23 and 24 (Fisheries and Oceans Canada, 2016). This further emphasizes that NARW lack protection as they move between southern and northern habitats.

5.6 Conclusions

Aerial surveillance for NARW is crucial to detecting distribution shifts, making population estimates, assessing population health and triggering dynamic protection measures. The DFO marine mammal surveillance program focuses on the southern GSL in order to detect large aggregation of whales, given the lack of resources available to the program. However, this comes at the expense of minimal monitoring along the Scotian Shelf migratory corridor and in the BOF and GoM, along with potential future habitats. Surveillance is also lacking in some fishing areas throughout their active seasons, posing threat of entanglement to NARW. Surveillance effort could be re-allocated for better representation of habitat types and locations and active fishery areas in coverage and intensity. Increased surveillance could help to supplement knowledge of and mitigate anthropogenic threats to this critically endangered species.

5.7 Recommendations

Re-allocate surveillance effort to improve monitoring along the migratory corridor:

Our results validate concerns that the Scotian Shelf migratory corridor is lacking surveillance and therefore NARW knowledge and protection. The high coverage and

intensity of surveillance in the southern GSL could be re-distributed to better monitor whales as they migrate along the heavily fished and industrialized Scotian Shelf. The objective of developing a habitat model using data collected in the southern GSL may be less effective in ensuring protection for NARW than a more widespread aerial surveillance program. Surveillance of the migratory corridor should align with times of mass NARW movements and active fishing whenever possible.

Increase surveillance in historic and potential future habitats: Surveillance is lacking in areas around the BoF, GoM and NFLD and Labrador. Although NARW aggregations presently occur most frequently in the southern GSL, sudden and undetected shifts in distribution have caused mass mortality events in the past. The return of NARW in greater numbers to the BoF in fall of 2024 demonstrates that their movement patterns can be unpredictable, meaning monitoring should occur in areas not currently expected to have high abundance of whales. As the NARW population is so low, surveillance should cover as much of the range of this wide-ranging species as possible.

Align surveillance with active fishing seasons: Risk of NARW entanglement occurs when the presence of fishing gear and whales overlaps spatially and temporally. When decisions have to be made regarding prioritization of areas to be surveyed, aligning monitoring with the active seasons of fisheries could help to protect NARW. Although occurrence of NARW can be unpredictable, when resources are limited priority should be given to areas where whale aggregations are expected in the active seasons of fishing areas.

Increase funding to the DFO marine mammal surveillance program: DFO staff have to make difficult decisions regarding NARW surveillance priorities given competing interests and a lack of resources. More financial resources should be allocated to the marine mammal surveillance program, along with assets such as planes and trained observers.

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