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North Atlantic Right Whales in Newfoundland and Labrador Waters, Based on Calls and Opportunistic Sightings

J.W. Lawson, G.L. Sheppard, S. Comeau, and A.J. Murphy

Fisheries and Oceans Canada
Northwest Atlantic Fisheries Centre
80 East White Hills Road
St. John’s, NL A1C 5X1

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Foreword

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

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ABSTRACT

With the increase of North Atlantic Right Whale (NARW) detections in Canadian waters, and the mortalities some have suffered here, there has been increased effort to detect and monitor the location and abundance of these whales, and ascertain how their habitat use patterns have changed. Automated detection and classification (DCS) of the underwater vocalizations of NARW is an essential tool to process the large volume of acoustic recording data gathered by Fisheries and Oceans Canada (DFO) to monitor these calling whales.

DFO in Newfoundland and Labrador Region (referred to as NL hereafter) implemented an updated version of Baumgartner's Low Frequency Detection and Classification System (LFDCS) to perform automated DCS of baleen whale vocalizations using acoustic data collected since 2009 from 69 successful deployments and nearly 150,000 h of recording time. In this study we used LFDCS to detect NARW presence, a task that it generally performed well, but in some offshore areas it generated false NARW detections within the context of smeared seismic airgun sounds or pervasive calling Humpback Whales.

Although confounded by effects of high ambient noise, the small number of moorings over the large study area, and occasional Humpback Whale calls, confirmed NARW upcalls were detected occasionally off the Labrador coast, the south and east coasts of Newfoundland, along the margin of the Laurentian Channel, and in offshore areas. Most NARW upcalls were detected in the summer (Jun-Aug) or fall (Sep-Nov). Analysis of a subset of audio from 20 moorings across the study area found no NARW calls missed by LFDCS. However, on rare occasions during data validation, other more irregular NARW calls were sometimes missed by both our NL23 LFDCS library and the older Gom9 library when the LFDCS settings were not generalized sufficiently. Using seismically-contaminated acoustic recordings from the Grand Banks, differences between the Gom9 and NL23 libraries in precision and F1 (the harmonic mean of precision and recall) were marginal in the limited testing we conducted after creating the NL23 library. Nonetheless, improvements incorporated into our NL23 detector library streamlined data analysis and confirmed the presence of NARW in Newfoundland and Labrador waters.

In addition, DFO NL's opportunistic sightings database contains 29 records (totalling 44 whales) of free-swimming NARW between 2002 and 2023, with sightings made in almost all years. Recent sightings, with several matched to the New England Aquarium NARW catalogue, included a few individuals feeding in relatively shallow water not far from shore in Newfoundland.

The confirmed and possible acoustic detections of NARW around Newfoundland and Labrador since at least 2009, and the sightings of this species in the region (particularly in recent years), corroborates that NARW are an occasional component of the marine megafauna in these waters.

INTRODUCTION

Passive acoustic monitoring (PAM) provides a powerful tool to detect and identify vocalizing marine mammals underwater (Kowarski and Moors-Murphy 2020; Lawson et al. 2025), and is used in many studies of baleen whale occurrence (e.g., Baumgartner et al. 2018; Macklin et al. 2024; Mellinger et al. 2007a; Van Parijs et al. 2009; Verfuß et al. 2007). To process large amounts of recorded acoustic data for the presence of species-specific sounds, the use of an automated detection and classification system (DCS) requires significantly less time than full manual (visual/aural) processing by a trained expert, assuming the DCS is acceptably accurate. A variety of DCS approaches have been developed for analysing marine mammal sounds, including low frequency detectors for calls produced by the North Atlantic Right Whale (NARW; *Eubalaena glacialis*) (e.g., Davis et al. 2017). These detectors can work well since NARW generate a distinctive vocal repertoire (Mellinger et al. 2007b); Matthews and Parks 2021).

For the acoustic detection of NARW in Newfoundland and Labrador (NL) waters, analysed calls consist of a variety of upsweep vocalizations (upcalls) including long, short, steep, and check upsweeps (e.g., Parks et al. 2011; Root-Gutteridge et al. 2018). The upsweep is a contact call used throughout the NARW range, produced by all ages and both sexes, and is therefore the most reliable call to use for determining NARW presence. Gunshot calls and tonal moans are also observed opportunistically (Parks et al. 2005), however, Baumgartner's Low Frequency Detection and Classification System (LFDCS) is not currently capable of automatically detecting gunshot calls.

Since 2009, researchers with Fisheries and Oceans Canada (DFO) have been deploying passive acoustic recorders on fixed moorings at a variety of locations in the waters around NL, ranging from the northern Labrador coast to the Laurentian Channel south of Newfoundland, and including both nearshore and offshore sites (Figure 1).

Here we summarize confirmed acoustic detections of NARW in NL waters for 2009–23 and describe the performance of the modified LFDCS library used to process recordings in a high ambient noise context. Some of the acoustic analyses presented here were previously described (e.g., Durette-Morin et al. 2022; Lawson et al. 2025); however, those analyses included only a small subset of the deployment locations summarized here, from a narrower time period (2015–17). In addition, we summarize the opportunistic visual sightings of NARW in NL waters for 2002–23.

METHODS

PASSIVE ACOUSTIC RECORDERS

Between May 2009 and December 2023, passive acoustic recorders were deployed for varying durations around NL to monitor for the presence of vocalizing cetaceans and provide data for underwater noise assessments (Figure 1, Table 1, Figures A1–A5). Deployment locations changed over this period, but included locations in nearshore and offshore Labrador (LAB), east coast NL (NLE), the Laurentian Channel (NLLC), offshore NL (NLO) and south coast NL (Placentia Bay, NLSP) (Figure 1, Table 1).

Several different types of passive acoustic recorders were used (Table 1, Table 2): the Autonomous Underwater Recorder for Acoustic Listening (AURAL M2, M3 and µAURAL; Multi-Electronique Inc., QC, Canada), the Autonomous Multichannel Acoustic Recorder (AMAR G4 Shallow and Ultradeep; JASCO Research Limited, NS, Canada), and the SoundTrap recorder (ST500 and ST600 HF; Ocean Instruments New Zealand, Auckland, New Zealand). All recorder types were able to collect acoustic data in the frequency range that encompasses NARW calls (Table 2).

AURAL

AURAL recorders were deployed at hydrophone depths ranging from 2–157 m using ocean bottom mounts where the recorder either sat directly on the sea floor or was suspended in the water column (Table 1). The M2 model was the most commonly used AURAL recorder of the three types. Both the M2 and M3 models sampled the 16 dB pre-amplified acoustic signal with 16-bit resolution and sampling rates of 32 kHz for 15 or 30 min per hr. These recorders could sample for more than a year. The receiving sensitivity of the HTI 96-MIN (High Tech Inc., Gulfport, MS) hydrophone on the AURAL is -164 + 1 dB re 1V µPa-1 over the <4-kHz bandwidth used in this study. Several deployments used the µAURAL (Table 1), which had a short recording duration, but sampled at a frequency of 96 kHz.

AMAR

AMAR (G4) recorders were deployed at hydrophone depths ranging from 38–1,664 m, using bottom mounts where the recorder either sat directly on the sea floor (deployments <200 m) or was suspended in the water column (deployments >200 m, Table 1). AMARs either had standard PVC for deployments <200 m or Ultradeep (UD) housings for deployments >200 m. The AMAR deployments recorded continuously, alternating between relatively lower (64–128 kHz; usually 14 min) and higher frequency (512 kHz; usually 1 min) sampling rates during a 60 min cycle time. The AMARs were equipped with GTI M36-V35-100 omnidirectional hydrophones (GeoSpectrum, Inc., −165 ± 3 dB re 1 V/µPa sensitivity). The low-frequency recording channel had a 24-bit resolution with a nominal ceiling of 164 dB re 1 µPa. The high-frequency recording channel had a 16-bit resolution with a nominal ceiling of 171 dB re 1 µPa.

SoundTrap

SoundTrap recorders were deployed at hydrophone depths ranging from 79–129 m (Table 1), using bottom anchors with the recorder suspended in the water column. The SoundTraps were equipped with GTI M36-V35-100 omnidirectional hydrophones (GeoSpectrum, Inc., −165 ± 3 dB re 1 V/µPa sensitivity). The low-frequency recording channel had a 24-bit resolution with a nominal ceiling of 164 dB re 1 µPa. The high-frequency recording channel has 16-bit resolution with a nominal ceiling of 171 dB re 1 µPa. Initial SoundTrap deployments recorded continuously, at a fixed sampling rate set in the range between 64–128 kHz. Beginning in 2022, in order to prolong recording duration at a single mooring, we deployed paired SoundTraps, with one recording continuously for the first half of the deployment, and the second starting its recording when the first was complete. Beginning in the spring of 2023, we deployed moorings where each of a pair of SoundTrap recorders was set to record on different half hours; for example, SoundTrap 1 recorded on the hr (12:00) for 30 min, and SoundTrap 2 recorded on the half hr (12:30) for 30 min. By doing this, we sought to achieve continuous recording for the deployment (i.e., if one recorder failed we still had data samples for all hours of the deployment).

ACOUSTIC SAMPLING EFFORT

For this report, acoustic recordings collected between August 2009 and November 2023 from 69 passive acoustic recorder deployments (Table 1; Figures A1–A5) were analysed for the presence of NARW upcalls. Recorder data collection durations varied from 2 to 580 days (Table 1). Most of the recorders were duty-cycled, with recordings ranging from 10 min/h to 34 min/h, while some single and paired recorders collected data continuously.

Passive acoustic recorders were deployed on the Labrador Shelf (LAB; 2013–14, 2020–23) and along the northern margin of the Laurentian Channel (NLLC; 2014–23) in support of potential future (LAB) and current (NLLC) Marine Protected Areas (Figure 1, Figures A1 and A3. On the south coast of NL, deployments efforts were focused in Placentia Bay (NLSP) with greater effort from 2017 onward in support of DFO's Ocean Protection Plan - Marine Environmental Quality (OPP-MEQ) program (Figure 1, Figure A5). The number of offshore deployments in deep waters off the edge of Newfoundland Shelf (NLO) were increased from 2018 onward, with long-term deployments at the northern end of Flemish Pass (NLO03) tail of the Grand Banks (NLO04) and east of Bonavista Bay (NLO05) (Figure 1, Figure A4) as these were areas known to have high occupancy rates by various cetacean species. The number of deployment locations on the northeast coast of NL (NLE) was increased from one to four in 2022 (Figure 1, Figure A2) in support of long term monitoring and a potential future Marine Protected Area (MPA) under the Marine Conservation Target (MCT) program.

AUTOMATED NARW WHALE CALL DETECTION USING LFDCS

We implemented the Baumgartner LFDCS system (Baumgartner and Mussoline 2011) to speed processing of acoustic data for the detection of large baleen whale calls in the recordings recovered from our deployments. The LFDCS automated baleen whale call detector-classifier (Baumgartner and Mussoline 2011) classifies sounds from large baleen whale species based on measures derived from basic signal features, such as slope of call frequency upsweep (for further details refer to Baumgartner and Mussoline 2011; Davis et al. 2017). The software suite was run within Apple's UNIX-based operating system and its scripts were linked with IDL software (Harris Geospatial Solutions, Inc., Broomfield, CO), and a custom call feature library (either the Gom9 library or our NL23 library, see below).

The audio .wav format recordings were first low-pass filtered and decimated to ≤2 kHz for analytical consistency across recordings, and to remove the processing overhead for frequencies beyond the relevant range for NARW (and other baleen whale) calls.

LFDCS then created conditioned spectrograms using short-time Fourier transformations with a data frame of 512 samples and 75% overlap resulting in a time step of 64 ms and frequency resolution of 3.9 Hz (Baumgartner and Mussoline 2011). After tracing contour lines, or "pitch tracks", through tonal sounds, the program uses multivariate discriminant analysis to classify the pitch tracks into call types. Previously, calls were classified by LFDCS based on a default underlying call library. The LFDCS default call library (Gom09) included calls from five north Atlantic baleen whale species: NARW, blue whale (*Balaenoptera musculus*), fin whale (*B. physalus*), sei whale (*B. borealis*), and humpback whale (*Megaptera novaeangliae*), primarily from vocalizations recorded in the NE U.S. and on the eastern Scotian Shelf. In this study, we focused on the detections classified as NARW calls; we searched for the low-frequency modulated upsweep known as the upcall. Since LFDCS is not designed to detect broad band sounds like the NARW gunshot calls, the few gunshot calls found on the recordings from the deployments in this study were identified during the manual data validation process.

In an effort to increase detection probability, we modified the default Gom09 LFDCS library to include a wider variety of exemplars of NARW upcalls from Atlantic Canada, and renamed the library "NL23". To improve the diversity in the NL23 library we added 53 new NARW upcall samples from NL waters. In addition, we eliminated 13 of the New England NARW upcalls from the library as outliers (see below). The NARW calls added to the library included long, short, steep, and check upsweeps (see, for example Matthews and Parks 2021; Parks et al. 2011). The NARW exemplars from NL waters were added from recordings made at locations on the northern margin of the Laurentian Channel (NLLC05, NLC06), in Placentia Bay on the south coast (NLSP03), and offshore (NLO03, NLO05) (Figure 1). Each NARW detection is assigned a

Mahalanobis Distance (MD) value, which measures the deviation of a detection from the assigned library archetypical call type (see Baumgartner and Mussoline (2011) for a more complete description). A lower MD value indicates a closer match to the assigned call type. If the call characteristics are too dissimilar from the mean archetype in the LFDCS library it will be flagged as an outlier and it can then be selected for elimination from the dataset in order to fine tune the LFDCS library for each specific call type (see the LFDCS reference guide NOAA technical memorandum NMFS-NE-295 for further explanation of outliers). This occurred during our additions of the 53 NARW calls from NL waters whereby some New England NARW upcalls were considered by LFDCS to be outliers relative to the NL NARW calls, as a result of the calls being too dissimilar from the mean call archetype as defined by seven features described in the LFDCS reference manual (Baumgartner and Mussoline 2011). Additionally, due to the relatively noisy underwater soundscape of NL in the summer, with multiple ongoing seismic exploration programs, the Gom09 LFDCS library falsely classified a large number of duration-smeared seismic airgun shots as NARW upcalls (i.e., false positives). We incorporated a new "call" type, using 122 exemplars of smeared[1] seismic airgun shots, into the NL23 library to reduce the occurrence of these false classifications. After re-running LFDCS analyses using the NL23 library on six of our acoustic mooring records which contained background seismic noise there was, on average, a 50% reduction in the number of false positives. This did not lower system recall (see Table 4), but did significantly reduce data processing time.

Per deployment, NARW autodetections ranged in number from 0 to 34,000, and all autodetections were validated with the Gom9 library, except for one deployment in the offshore (NLO03d; Flemish Pass) which was validated with the NL23 call library. Calls for NLO03d were manually validated for the period April to mid-July 2019 with Gom9; beyond this date seismic interference became inordinate and caused too many false detections to validate effectively. Once our new NL23 library was developed, we manually validated the entire deployment record for NLO03d as there was a significant reduction in NARW autodetections when using the NL23 library (see below).

MANUAL VALIDATION OF AUTOMATED DETECTIONS

NARW Call Validation

Similar to previous studies (e.g., Davis et al. 2017, Durette-Morin et al. 2022), all NARW upcall detections with a MD less than or equal to 3.0 were visually and aurally inspected by experienced analysts to determine which were classified correctly (see below). We chose MD values of 3.0 for NARW to match other studies, such as Davis et al. (2017) and Durette-Morin et al. (2022). Signals detected that exceeded this MD threshold had a much greater probability of being incorrect as these calls had greater deviation from the archetypical call type.

The high degree of variability in NARW upcalls and the overlap with other species' vocalizations, such as the upsweeps produced by humpback whales, necessitated additional manual validation of the LFDCS detections. The manual validation process required the analyst to classify each pitch track detected by the LFDCS as "correct", "incorrect", or "unknown". If LFDCS autodetected NARW pitch tracks as NARW that were made by non-biological sources such as vessels or seismic pulses, or if they were determined to be calls made by another whale species, the NARW detections were classified as "incorrect". Calls marked as "unknown"

[1] In this context, the duration of the seismic impulse increases as it propagates over a distance of tens of kilometers, resulting in a signal with amplitude rises and falls that resemble smoother NARW up- and downsweeps, rather than the original, brief spike signal shape near the seismic source.

indicated that there was a biological source, and possibly a NARW, producing the sound with the possibility of a NARW upcall. Detections classified as “unknown” were reviewed a second time in Raven Pro 1.6 software to further exclude false positive detections (such as another type of biological or anthropogenic noise). This allowed for greater manipulation of the .wav file such as changing spectrogram parameters, increasing speed, and visually examining the surrounding soundscape. After the second review the remaining “unknown” detections were then considered “possible NARW calls” and copies were forwarded to a highly experienced acoustician (G. Davis or J. Wilder) at the National Oceanic and Atmospheric Administration (NOAA) for further review. These acousticians classified these calls as “correct”, “possible”, or “incorrect” as a NARW call. Calls that were considered “possible” by all analysts were recorded as “possible” in our dataset (see Figures A1-A5) but were not included in further analyses. Calls originally classified as “possible” or “unknown”, but ruled as “incorrect” by at least one analyst, were reassigned as “incorrect”.

False Negative Analysis

In order to test the efficacy of the LFDCS Gom9 call library for detecting NARW upcalls in NL waters we conducted a false negative analysis on approximately 1% of 35,000 hours of audio data recorded from a subset of 20 moorings deployed around NL over the entire study period (Table 3). This analysis provides an improved understanding of LFDCS performance for NARW detection, with one measure being the proportion of NARW calls missed. One percent of audio data was chosen for this analysis following the false negative protocols of similar studies such as Buchan et al. (2010), and given the time constraints of our study. For each deployment at least one hour of raw audio per week was selected randomly to be reviewed further. Each selected hour of audio was uploaded into Raven Pro and scanned visually and acoustically for missed NARW upcalls. When the analyst discovered a candidate call they would cross reference with the manual validation data to ascertain if the upcall was detected by LFDCS as well, and if it was autodetected by the LFDCS Gom9 library. For NARW upcalls, 347 hours of raw audio was reviewed for false negatives (Table 3). Due to the low numbers of correct NARW detections in some contexts, for each positive NARW detection classified as correct, one hour before and one hour after each confirmed upcall was also analysed manually in Raven Pro to search for possible missed upcalls. This equalled 11 hours of additional false negative analysis bringing the total to 358 hours of audio reviewed for possible missed NARW upcalls in a subset of 20 acoustic moorings.

To ascertain if our NL23 library was (1) missing NARW upcalls and (2) capturing a similar level of NARW upcalls as the Gom9 library, we manually scanned the audio recordings for missed NARW upcalls (“false negatives”) on approximately one month of recording duration for each of six acoustic moorings with high levels of seismic airgun noise interference. We did this by scanning approximately 5 min before and after each NARW detection that the NL23 library detected in the month where we had the most detections for each of the six moorings with seismic interference. We then also scanned forward and backward for that same month on each mooring for the NARW detections that the Gom9 library detected to see if the NL23 library was detecting the same or more NARW upcalls compared to Gom9. If potential upcalls were discovered, both the NL23 and Gom9 manual validation sheets were cross-referenced to see if the calls were detected by either library and to what category they were classified. We found that, (1) the NL23 library was not missing any of the NARW upcalls that the Gom9 library was detecting and (2) the NL23 library had many fewer false positives than the Gom9 library due to the addition of the seismic exemplars to the NL23 library (Table 4).

Aside from the large reduction in the number of false positive NARW calls flagged by LFDCS using the updated NL23 library, and the resulting decrease in manual validation effort, the differences in precision and F1 were marginal in the limited testing we conducted after creating the NL23 library (Table 4). These two measures are lower for both the Gom9 (precision = 0.00064) and NL23 (precision = 0.00034) libraries than have been reported for LFDCS tests using data from Roseway and Emerald Basins (see Tables 2 and 3 in Lawson et al. 2025), where there was no acoustic contamination by seismic exploration. We plan a more structured false negative analysis of LFDCS performance with the Gom9 and NL23 libraries to ascertain if the performance of the latter is similar to Gom9 across a broader range of contexts, and thus limiting the NL23 library's advantage to reduced data processing time.

OPPORTUNISTIC SIGHTINGS OF NARW

Opportunistic sightings of live, free-swimming NARW in NL waters between 2002–23 were extracted from DFO NL's opportunistic cetacean sightings database. Sightings originated from DFO platforms, commercial and recreational vessels, and the general public from shore locations. Only confirmed (using imagery or experienced observers) or highly probable (using credible or multiple observers in good sighting conditions) sighting records were extracted.

RESULTS

ACOUSTIC RECORDING EFFORT

Between August 2009 and November 2023 a total of 82 passive acoustic recorders were deployed around NL (Figures A1–A5). Data from 13 acoustic moorings were lost due to fishing activity, release failures, or recorder malfunctions (Figures A1–A5). There was a total of 69 successful recorder deployments and recoveries for a total of 11,891 recording days (Figure 1, Table 1).

Data from 92% of the 69 acoustic moorings were run through LFDCS and manually validated for NARW, excluding some older Aural deployments and µAural deployments. Eleven percent of the earlier deployments from 2009–14 were processed using JASCO's proprietary DCS software and manually validated by a contracted acoustician.

ACOUSTIC DETECTIONS OF NARW

There were a large number of autodetections of NARW calls made by the LFDCS systems Gom9 library, particularly for NLO03 (Flemish Pass), where LFDCS marked over 34,000 events as possible upcalls. However, after the NL23 library was created, there was a 50% reduction in the number of possible events for this mooring location, which allowed us to manually validate the data. In total, 100 upcalls across 13 mooring locations were confirmed as NARW upcalls (Figure 1, Table 1, Table 5, Figures A1–A5). Across all deployments, the number of days in a recording period with confirmed upcalls ranged from 0–2 (Table 1). For deployments with confirmed NARW upcalls, the percentage of days in the recording period which contained confirmed NARW upcalls ranged from 0.44–2.70% (Table 1). A total of 18 days with confirmed NARW upcalls were identified across all seasons (Table 5) although detection days occurred more frequently in summer (6) and fall (8). In addition, there were 17 days with "possible" NARW upcalls identified across 12 mooring locations, also mostly in summer and fall (Figures A1–A5).

LFDCS PERFORMANCE WITH NARW UPCALLS

Analysis of 358 hours of audio and a random sample of raw audio from 1% of all audio recorded on a subset of 20 acoustic moorings, revealed no false negatives for NARW upcalls when using the Gom9 library. This indicates that LFDCS is detecting the majority of true NARW upcalls from our acoustic deployments. However, LFDCS produced a significant amount of false positive detections prior to manual review. For example, using LFDCS with the Gom9 call library at an MD of 3.0 on one of the Laurentian Channel deployments (NLLC01b, Burgeo Bank) resulted in 5,012 NARW upcall autodetections; however, after manual review of all detections only three of these were confirmed as NARW upcalls. The rest were eliminated as anthropogenic noise or biological noise from other species. Similar results occurred for other moorings, with noisier mooring locations inducing more false autodetections by LFDCS than quieter ones.

All NARW upcalls detected by the Gom9 library were also positively detected by the NL23 library; however, there were a small number of irregular NARW upcalls with a MD greater than 3.0 that both our NL23 and the Gom9 libraries missed. These upcalls were discovered during the analysis for false negatives from the NL23 library by scanning data adjacent to the autodetections and cross referencing the Gom9 library manual validation sheets. Overall, using our NL23 library reduced the amount of false positives by 50% on average and thus reduced processing time, likely due to the addition of the duration-smeared seismic airgun shots to the call library. The number of false positive identifications may be further reduced by the addition of more NARW upcalls recorded in NL waters (such as the missed upcalls identified here).

The largest impact of using the NL23 call library was the reduction in the number of false detections at acoustic moorings subject to various levels of seismic interference. For one of the deployments in the Flemish Pass (NLO03d), total LFDCS autodetections declined from 34,781 to 16,574 when using the NL23 library. For other acoustic moorings subject to interference from seismic surveys, we saw similar autodetection reductions of approximately 50%. To check that the new NL23 library was not causing upcalls to be misclassified, we performed a false negative analysis and cross referenced where the Gom9 library had picked up correct NARW upcalls, and ascertained if the NL23 library also detected them. We found that the NL23 library was not missing any NARW upcalls that the Gom9 library had detected (Table 4).

We did find two calls on one of our offshore Bonavista deployments (NLO05b) that were missed by both LFDCS libraries, but these calls were irregularly shaped, had MD values above 3.0, and would have been captured if the MD had been set to 5.0 on the LFDCS detector. Due to close proximity to other upcalls that were captured by both libraries these unusual calls were quickly spotted during manual validation. Overall, the addition of the 122 duration-smeared seismic airgun shot exemplars to the library yielded the greatest improvement to the speed of our acoustics analyses by reducing false detections by approximately 50% in mooring areas subject to higher levels of seismic interference. The addition of 53 new NARW upcall samples recorded in NL waters may also have contributed to the improved performance of the library, but testing with more exemplars recorded in NL waters (such as the upcalls with MD >3.0 manually identified above) is needed to better compare the Gom9 and NL23 libraries based on possible varying geographic characteristics of upcalls.

OPPORTUNISTIC SIGHTINGS OF NARW

Between August 2002 and November 2023, there were 29 NARW sighting records (44 whales total) in NL waters, with NARW being sighted in almost all years since 2002 (Figure 2, Table 6). The majority (17) of the opportunistic sightings events occurred during the fall months (Table 6). As is typical of opportunistic sightings, the predominantly nearshore distribution of NARW sightings in NL waters (Figure 2) is likely a reflection of higher observer presence in coastal waters.

There have been no sightings of NARW in NL waters during any of DFO’s large-scale aerial survey efforts (2002–03, 2007, 2016, 2018–19, 2021, 2023).

Only a small proportion of the NARW opportunistically sighted in NL waters were photographed, allowing them to be matched to individuals in the photoidentification catalogue maintained by the New England Aquarium (Table 6). In September 2019, EgNo 3845 (“Mogul”), was observed surface skim feeding very close to shore in 12 m of water on the NL east coast after being previously sighted off western France in July 2019, and Iceland in the summer of 2018. In June 2022, the 2021 calf of EgNo 1145 was observed among a pod of pilot whales off the south coast of NL. In November 2022, EgNo 3545 (brother of “Mogul”), was photographed swimming very close to shore near St. John’s, NL. In November 2023, EgNo 4308 ("Freckles”), last seen in 2022 in the NE U.S., and never previously identified in Canadian waters, was seen skim feeding within a few hundred meters of shore on the NL east coast.

DISCUSSION

EFFORT

With the loss of data from 13 deployments, and changes to deployment locations over the study period (Figure 1, Table 1), few locations were monitored consistently over the 15 year study period (Table 1, Figures A1–A5). In addition, given that the effective detection range of the acoustic recorders for NARW upcalls is estimated to be 5–15 km (Davis et al. 2017), the volume of NL waters monitored acoustically for NARW presence is relatively small.

Given the acoustic and visual detections of NARW in offshore waters and along the north coast (Tables 1 and 2, Figures 1 and 2), we have deployed additional acoustic moorings at the tail of the Grand Banks, and at offshore locations in northern Newfoundland and southern Labrador in recent years. While logistically much more difficult to deploy and retrieve, deepwater acoustic moorings in this study have and likely will continue to provide data to detect NARW presence in offshore waters, where it has been postulated that a portion of the NARW population resides during winter (Davis et al. 2017; Kraus and Rolland 2007; Silber et al. 2023).

NARW ACOUSTIC DETECTIONS

NARW were detected infrequently across all acoustic mooring sites in NL waters (Table 1), which is likely related to several factors. Our confirmed NARW acoustic detections are an indication of minimum NARW presence; however, there are several reasons why we may be underestimating overall NARW presence from acoustic monitoring. For instance, given the relatively high ambient underwater noise levels associated with almost all of the NL sites, the detection range for NARW upcalls may be lower than the 5–15 km estimated by Davies et al. (2017) (see Future Research, below). This, combined with the overall rarity of this species and our limited knowledge of their calling behaviour outside the Gulf of St. Lawrence and traditional feeding grounds, might explain why NARW acoustic detections are rare around NL. Corroborative evidence of their uncommon presence is that since 2002, there have been only 29 sightings of 44 NARW in waters around NL (Figure 2, Table 6). This was despite large-scale stratified aerial surveys that included NL waters in 2002–03, 2007, 2016, 2018–19, 2021, and 2023 (see St-Pierre et al. 2024). We might not see NARW in these large-scale surveys if, for example, it is harder to detect lone individuals as usually reported in NL waters. It is also possible that lone NARW have a lower calling rate and thus would be less likely to be recorded.

The relatively greater number of NARW detections in recent years is likely a product of more acoustic and visual monitoring effort, public outreach and awareness, and the implementation of more capable acoustic technology to detect these whales. Also, this increase coincides with more NARW moving into the Gulf of St. Lawrence to feed over the last decade and points to a potential more common use of northern habitat areas.

Given the small number of days with confirmed NARW detections (Table 1, Table 5), it is not possible to establish spatial or seasonal patterns for NARW in NL waters. One point of consistency was Placentia Bay on the south coast (NLSP). NARW vocalizations have been detected at several sites within the bay including St. Brides (NLSP01), Arnolds Cove (NLSP02), and Red Island (NLSP03; Figure 1, Table 5). Additional ‘possible’ NARW detections have occurred at the Merasheen Island (NLSP04), Burin (NLSP05), and Ship Cove mooring locations (Figure A5).

The confirmed NARW upcalls detected in December off Port Aux Basques (NLLC06), in late October off northern Labrador (Saglek Bank, LAB05), and along the east coast of NL in November (NLE03, NLE04), along with the opportunistic sightings along the NE coast in November (Figure 2, Table 6), accords with literature that NARW have a broad distribution in the winter and not all individuals move to southern calving grounds (see Davis et al. 2017; Durette-Morin et al. 2022).

A passive acoustic monitoring study in 2007–08 detected more than 2,000 NARW upcalls, from multiple whales, during July to November in an offshore area of southeastern Greenland where NARW used to be hunted (Mellinger et al. 2011). Given those records, it was not surprising that we detected some NARW upcalls in moorings offshore of northern Labrador as these whales might be migrating northwards through Labrador waters each spring, then southwards in the fall. Whether the NARW that are detected in southeastern Greenland pass near northern Labrador, or the NARW detected in northern Labrador are different whales, is unknown. Despite considerable survey effort in the Gulf of St. Lawrence and further south, many individual NARW are not commonly seen during the summer, and the winter distribution of a large portion of the NARW population is unknown (Hayes et al. 2023; Meyer-Gutbrod et al. 2022).

The distribution of NARW is changing. DFO’s monitoring efforts have detected a larger number of NARW in the Gulf of St. Lawrence since 2015 (such as with acoustics, see Simard et al. 2019). In the NL region we have collected visual records of known NARW, based on the New England Aquarium catalogue, which had not been identified in the area previously (Table 6).

The confirmed (Figure 1, Table 5) and possible (Figures A1–A5) acoustic detections of NARW around Newfoundland and Labrador since at least 2009, and the rare visual sightings of this species in the region (Figure 2, Table 6), substantiates the conclusion that NARW are an occasional component of the marine megafauna in NL waters. With changes in our acoustic monitoring locations, we expect to discover similar occasional NARW presence in other areas of the region.

LFDCS PERFORMANCE WITH NARW UPCALLS

Although LFDCS performed well in that it processed our underwater acoustic datasets much more quickly than a manual validator, its performance was compromised by the low signal-to-noise ratio (SNR) at some of our recorder sites, and in the case of NARW upcalls, their similarity with common humpback whale tonal calls and temporally smeared seismic airgun shots.

Davis et al. (2017) determined that the rate of missed days with upcall detections using LFDCS was low (25%), and while this rate depended on the characteristics of individual deployments, such as ambient and anthropogenic background noise at the site, the resulting detections provided a satisfactory indication of the broad-scale distribution of NARW. So far, our analyses support this conclusion of a precautionary detector with the settings we have employed. Our false negative analysis of the Gom9 library, during which we reviewed 358 hours of raw audio (approximately 1% of all audio recorded on a subset of 20 moorings), did not reveal any missed upcalls. Even in the review of 11 hours of audio that consisted of one hour samples before and after each confirmed upcall we did not find any missed NARW upcalls, as was the case for Davis et al. (2017). In our study area the Gom9 LFDCS library produced a large number of false positives which would require significant manual validation. This was remedied somewhat by further editing the LFDCS call library (now "NL23") so that it is better adapted to operate within the context of NARW calls in offshore NL waters (e.g., Table 4), and the common anthropogenic sound sources there, such as seismic exploration and vessel transits.

FUTURE RESEARCH

Maximum detection ranges for NARW vocalizations can vary considerably depending on recording equipment, mooring location, ambient noise, environmental conditions (e.g., seasonal presence of the thermocline), and the calling behaviour of the animals (including variability in source levels of the calls, the call types produced and the behavioural context). Davies et al. (2017) estimated a detection range of 5 to 15 km for NARW, while Gervais et al. (2019) estimated a median detection range for NARW, in the Cabot Strait, of approximately 10 km. For Newfoundland waters, particularly during the summer and early fall, areas such as the Flemish Pass are exposed to noise from vessel transits and wide-ranging and concurrent seismic programs (see Delarue et al. 2018; and a list of seismic activities in NL waters at Canada-Newfoundland and Labrador Offshore Petrolem Board) and, as a result, the detection range for NARW upcalls in these areas could be even less than those estimated in the above studies. By deploying more acoustic moorings across the NL region we increase our chances of detecting NARW upcalls.

However, the many LFDCS false positive autodetections in the low SNR regimes in areas like the NL offshore (Flemish Pass, Tail of the Grand Banks), Placentia Bay, and the Cabot Strait likely cannot be reduced with changes to mooring configuration or placement. It is unclear if adding more moorings at closer spacing for areas like the Cabot Strait would allow for more NARW detections since they may not be vocalizing as they migrate through this area or their calls may be significantly masked by noise from transiting vessels (Cominelli et al. 2020). Given that adding exemplars of confirmed NARW upcalls from NL waters and smeared seismic airgun shots to the call library facilitated a reduction in false detections relative to the default Gom9 library, we intend to try to improve the library further by adding more NARW upcall and seismic pulse exemplars from NL waters and conducting further testing of the NL23 library. In all likelihood, we will still have to manually validate LFDCS data with larger contextual subsamples around each autodetection to rule out humpback and seismic sounds, so processing time will be longer than for quieter sites such as east Greenland (Mellinger et al. 2011). We intend to continue to deploy moorings in Placentia Bay to better understand why we are collecting recurring acoustic detections there, despite few visual detections. As well, we will deploy more moorings in other theorized preferred habitats for NARW around NL. A planned sound propagation study will be undertaken with the aim of modelling and measuring the detection range of NARW calls at many of these sites.

Increased visual monitoring effort, via systematic or opportunistic platforms, would be beneficial in areas where these whales have been sighted recently in NL. As well, public outreach should continue in an effort to increase reporting of NARW sightings and collection of imagery suitable to individual identification.

CONCLUSIONS

- Updating the LFDCS library with exemplars of NARW upcalls recorded in NL waters and smeared seismic airgun shots improved its performance significantly, with fewer false positives and much reduced processing time.

- Confirmed NARW upcalls were detected rarely near the NL south coast, in Placentia Bay, near the NL southwest coast, and offshore in the northern Flemish Pass and Tail of the Grand Banks, and offshore of the Labrador coast.
- The highest number of confirmed NARW calls in one day occurred at Red Island, Placentia Bay (NLSP03). Multiple occurrences have been documented at this location over different years, despite the fact that visual detections of NARW were no more likely there than elsewhere around the island.
- DFO NL's opportunistic sightings database contains 29 records (totalling 44 whales) for NARW between 2002 and 2023, with sightings made in almost all years. Recent sightings included a few feeding in relatively shallow water not far from shore.
- The nearshore distribution of NARW sightings in this region is likely a function of higher observer presence in nearshore areas, although several NARW have been sighted far offshore in recent years.
- The confirmed and possible acoustic detections of NARW around NL since at least 2009, and the sightings of this species in the region (particularly in recent years), corroborates that NARW are an occasional component of the marine megafauna in these waters.

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TABLES

Table 1. Details of passive acoustic recorder deployments in the waters off Newfoundland and Labrador between May 2009 and December 2023. Start/End indicate the beginning and end of the acoustic recording for each deployment, respectively. Days, the number of recording days. C, number of confirmed NARW upcalls detected on each recording. ND, number of days in the recording period with confirmed NARW upcalls. PD, percentage of days in the recording period which contained confirmed NARW upcalls.

Labrador (LAB)

Location Code	Site Name	Deploy Code	Recorder Type	Lat	Long	Depth (m)	Start	End	Days	C	ND	PD
LAB01	Nain	LAB01	AURAL M2	56.27576	-59.08252	64	1-Aug-2014	28-Nov-2014	119	-	0	-
LAB02	Emily Harbour	LAB02a	AURAL M2	54.82900	-56.40090	42	19-Oct-2013	1-Mar-2014	133	-	0	-
		LAB02b	AURAL M2	54.82897	-56.40162	72	1-Aug-2014	4-Dec-2014	125	-	0	-
LAB03	Hatton Basin	LAB03a	AMAR UD G4	60.46056	-61.26194	508	1-Oct-2017	30-Aug-2018	333	-	0	-
		LAB03b	AMAR UD G4	60.47298	-61.26753	487	1-Sep-2020	7-Aug-2021	340	-	0	-
		LAB03c	SoundTrap	60.47230	-61.25993	514	20-Sep-2022	26-Jul-2023	309	-	0	-
LAB04	Makkovik	LAB04	SoundTrap	55.41948	-58.81792	447	25-Aug-2020	16-Jun-2021	295	-	0	-
LAB05	Saglek Bank	LAB05	AMAR UD G4	59.37490	-60.30957	450	23-Jul-2021	20-Sep-2022	424	1	1	0.24

NL - East Coast (NLE)

Location Code	Site Name	Deploy Code	Recorder Type	Lat	Long	Depth (m)	Start	End	Days	C	ND	PD
NLE01	Witless Bay	NLE01a	AURAL M2	47.18065	-52.78083	89	29-May-2019	1-Sep-2019	95	-	0	-
		NLE01b	AURAL M2	47.18025	-52.78032	84	27-Nov-2019	16-Dec-2019	19	-	0	-
		NLE01c	AURAL M2	47.17930	-52.78182	85	20-Jul-2020	4-Nov-2020	107	-	0	-
		NLE01d	AURAL M3	47.16418	-52.80800	91	7-Dec-2022	24-Jul-2023	229	-	0	-
NLE02	Inshore Bonavista	NLE02a	SoundTrap STD500	48.64300	-52.85533	88	28-Apr-2022	31-Dec-2022	247	-	0	-
		NLE02b	AURAL M3	48.64015	-52.85968	108	7-Dec-2022	4-Jul-2023	209	1	1	0.48
NLE03	Eastport Duck Islands	NLE03	SoundTrap ST600HF	48.76341	-53.59093	126	30-Jun-2023	17-Nov-2023	140	18	1	0.71

NLE04	Eastport Round Island	NLE04	SoundTrap ST600HF	48.61628	-53.57873	115	30-Jun-2023	17-Nov-2023	140	2	2	1.43

NL - Laurentian Channel (NLLC)

Location Code	Site Name	Deploy Code	Recorder Type	Lat	Long	Depth (m)	Start	End	Days	C	ND	PD
NLLC01	Burgeo Bank	NLLC01a	AURAL M2	46.96967	-57.97250	50	9-Sep-2014	27-May-2015	260	-	0	-
		NLLC01b	AURAL M2	46.96967	-57.97250	59	12-Aug-2015	11-Apr-2016	243	3	2	0.82
		NLLC01c	AURAL M2	46.97480	-57.95900	91	21-Aug-2017	3-Apr-2018	225	-	0	-
		NLLC01d	AURAL M2	46.97965	-57.96585	98	15-Jul-2019	1-Aug-2019	17	-	0	-
		NLLC01e	AURAL M3	46.98035	-57.96418	10	25-Jul-2020	23-Nov-2020	121	-	0	-
NLLC02	Rose Blanche Bank - Offshore	NLLC02a	AURAL M2	47.47233	-58.77567	128	15-Nov-2016	21-Aug-2017	279	-	0	-
		NLLC02b	AURAL M2	47.44933	-58.82800	126	1-Dec-2017	18-Jun-2018	199	-	0	-
NLLC03	St. Pierre Bank - Deep	NLLC03	AURAL M2	45.88083	-56.99800	50	27-Jan-2016	29-Jan-2016	2	-	0	-
NLLC04	St. Pierre Bank - Shallow	NLLC04a	AURAL M2	46.48217	-57.37833	60	12-Aug-2015	14-Jul-2016	337	-	0	-
		NLLC04b	AURAL M2	46.49055	-57.37147	93	20-Jul-2018	9-Dec-2018[1]	32	-	0	-
		NLLC04c	AURAL M2	46.49182	-57.37003	88	15-Jul-2019	29-Nov-2019[2]	20	-	0	-
		NLLC04d	AURAL M3	46.48998	-57.36895	88	25-Jul-2020	28-Mar-2021	246	-	0	-
NLLC05	Rose Blanche Bank - Nearshore	NLLC05a	AURAL M2	47.57100	-58.77767	72	15-Nov-2016	11-Jun-2017	208	-	0	-
		NLLC05b	AURAL M2 µAURAL	47.57100	-58.77767	72	21-Aug-2017	1-Dec-2017	102	-	0	-
		NLLC05c	AMAR PVC G4	47.56668	-58.76953	91	27-Jul-2020	23-Jul-2021	361	4	1	0.28
NLLC06	Port aux Basques	NLLC06a	AURAL M2 µAURAL	47.52010	-59.02495	124	20-Aug-2017	1-Dec-2017	103	-	0	-
		NLLC06b	AURAL M2	47.52013	-59.02500	121	1-Dec-2017	11-Jan-2018	41	4	1	2.44
		NLLC06c	AURAL M2	47.52010	-59.02523	128	20-Jul-2018	7-Mar-2019	230	-	0	-

[1] recording was not continuous over this period, as no acoustic data were collected between 1-Aug-2018 and 19-Nov-2018.
[2] recording was not continuous over this period, as no acoustic data were collected between 1-Aug-2019 and 29-Nov-2019.

NL - Offshore (NLO)

Location Code	Site Name	Deploy Code	Recorder Type	Lat	Long	Depth (m)	Start	End	Days	C	ND	PD
NLO01	Carson Canyon	NLO01	AURAL M2	45.57040	-48.70830	81	5-Aug-2009	11-Feb-2010	190	-	0	-
NLO02	Lilly Canyon	NLO02	AURAL M2	44.50250	-49.07380	76	5-Aug-2009	11-Feb-2010	190	-	0	-
NLO03	Flemish Pass	NLO03a	AMAR UD G4	46.99730	-47.05762	1,060	20-Apr-2018	6-Jul-2018	77	-	0	-
		NLO03b	AMAR UD G4	46.99820	47.05850	1,068	19-Jul-2018	6-Dec-2018	140	-	0	-
		NLO03c	AMAR UD G4	47.00017	-47.05150	1,083	14-Apr-2019	11-Dec-2019	241	-	0	-
		NLO03d	AMAR UD G4	46.99940	-47.05669	1,118	6-Dec-2019	16-Jul-2020	223	-	0	-
		NLO03e	AMAR UD G4	46.99800	-47.05833	1,078	17-Jul-2020	2-Jun-2021	320	1	1	0.31
NLO04	Tail of the Grand Banks	NLO04a	AMAR UD G4	42.75425	-49.81192	1,664	25-Nov-2019	18-Jan-2020	54	-	0	-
		NLO04b	AMAR UD G4	42.75437	-49.81307	1,657	11-Sep-2020	14-Apr-2022	580	1	1	0.17
NLO05	Bonavista	NLO05a	AMAR UD G4	49.76604	-49.63970	1,100	29-Nov-2020	5-Jul-2021	218	-	0	-
		NLO05b	AMAR UD G4	49.79801	-49.66153	1,125	29-Apr-2022	28-Oct-2022	182	2	1	0.55
		NLO05c	AMAR UD G4	49.79846	-49.66210	1,109	28-Oct-2022	23-Jul-2023	268	-	0	-

NL - South Coast - Placentia Bay (NLSP)

Location Code	Site Name	Deploy Code	Recorder Type	Lat	Long	Depth (m)	Start	End	Days	C	ND	PD
NLSP01	St. Brides	NLSP01a	AURAL M2	46.98100	-54.28400	63	13-Aug-2009	30-Nov-2009	109	-	0	-
		NLSP01b	AMAR PVC G4	46.95737	-54.28809	80	8-May-2021	2-Feb-2022	270	1	1	0.37
NLSP02	Arnold's Cove	NLSP02	AURAL M2 µAURAL	47.77124	-54.04253	96	26-Jun-2017	2-Aug-2017	37	5	1	2.70
NLSP03	Red Island	NLSP03a	AURAL M2 µAURAL	47.34244	-54.16725	96	26-Jun-2017	2-Aug-2017	37	28	1	2.70
		NLSP03b	AURAL M2	47.34330	-54.18382	57	23-Jun-2018	11-Nov-2018	141	-	0	-
		NLSP03c	AMAR PVC G4	47.34128	-54.16820	100	10-Nov-2018	11-Jun-2019	213	1	1	0.47
		NLSP03d	AMAR PVC G4	47.34182	-54.17613	100	12-Jun-2019	4-Nov-2019	145	-	0	-
		NLSP03e	AMAR PVC G4	47.34105	-54.17262	100	4-Nov-2019	1-Apr-2020	149	28	2	1.34
		NLSP03f	AMAR PVC G4	47.33978	-54.17178	100	22-Jul-2020	9-Nov-2020	110	-	0	-

Location Code	Site Name	Deploy Code	Recorder Type	Lat	Long	Depth (m)	Start	End	Days	C	ND	PD
		NLSP03g	AMAR PVC G4	47.33787	-54.16817	100	23-Nov-2021	6-May-2022	164	-	0	-
		NLSP03h	AMAR PVC G4	47.33857	-54.16562	97	6-May-2022	7-Oct-2022	154	-	0	-
NLSP04	Merasheen Island	NLSP04a	AURAL M2	47.65120	-54.22010	120	1-Sep-2017	13-Nov-2017	73	-	0	-
		NLSP04b	AMAR PVC G4	47.58828	-54.34967	100	8-Aug-2018	8-Nov-2018	92	-	0	-
		NLSP04c	AURAL M2	47.58833	-54.34758	110	13-Jun-2019	15-Oct-2019	124	-	0	-
NLSP05	Burin	NLSP05a	AMAR PVC G4	47.09283	-55.03005	120	6-Aug-2018	8-Nov-2018	94	-	0	-
		NLSP05b	AMAR PVC G4	46.93156	-55.19415	65	15-Jun-2019	1-Nov-2019	139	-	0	-
		NLSP05c	AURAL M2	46.93176	-55.19588	73	11-May-2021	3-Sep-2021	115	-	0	-
NLSP06	Ship Cove	NLSP06a	AMAR PVC G4	47.07903	-54.14082	38	25-Nov-2019	3-Jun-2020	191	-	0	-
		NLSP06b	AMAR PVC G4	47.08001	-54.14397	40	1-Aug-2020	8-Nov-2020	99	-	0	-
NLSP07	Hollets Island	NLSP07	AURAL M2	47.65448	-54.16913	40	23-Jul-2020	10-Nov-2020	110	-	0	-
NLSP08	Jude Island	NLSP08	AURAL M2	47.17602	-54.74792	100	23-Jul-2020	24-Aug-2020	32	-	0	-
NLSP09	Mouth of Placentia Bay	NLSP09a	AMAR UD G4	46.91350	-54.67530	200	22-Nov-2021	8-May-2022	167	-	0	-
		NLSP09b	AMAR UD G4	46.91325	-54.67539	200	8-May-2022	7-Oct-2022	152	-	0	-

Table 2. Specifications of the different types of passive acoustic recorders deployed in the waters off Newfoundland and Labrador between May 2009 and November 2023.

Receiver Type	Max Depth Rating (m)	Max Recording Duration	Storage Volume	Useable Freq. Range (kHz)
µAURAL	100	70+ hours	64 GB	0.1–48.0
AURAL M2	300	1+ year	1 TB	0.1–16.4
AURAL M3	1,200	1+ year	5 TB	0.1–32.0
AMAR PVC G4	250	330 days	10 TB	0.1–256.0
AMAR UD G4	6,700	330 days	10 TB	0.1–256.0
SoundTrap STD500	500	180 days	1 TB	0.1–150.0
SoundTrap ST600 HF	500	150 days	2 TB	0.2–192.0

Table 3. Passive acoustic recorder deployments (n=20) used for false negative analyses. One hour per week of each deployment was randomly sampled and manually analysed for NARW false negative detections.

Location Code	Site Name	Deploy Code	Audio Recording Start	Audio Recording End	Total H:M of False Negative Analysis
NLLC01	**Burgeo Bank**	NLLC01d	15-Jul-2019	1-Aug-2019	7:12
NLLC02	**Rose Blanche Bank - Offshore**	NLLC02a	15-Nov-2016	21-Aug-2017	33:00
		NLLC02b	1-Dec-2017	18-Jun-2018	32:52
NLLC04	**St. Pierre Bank - Shallow**	NLLC04b	20-Jul-2018	1-Aug-2018	9:32
		NLLC04c	15-Jul-2019	1-Aug-2019	18:40
NLLC06	**Port aux Basques**	NLLC06a	20-Aug-2017	1-Dec-2017	13:00
		NLLC06b	1-Dec-2017	11-Jan-2018	7:00
		NLLC06c	20-Jul-2018	7-Mar-2019	28:36
NLO03	**Flemish Pass**	NLO03a	20-Apr-2018	6-Jul-2018	9:00
		NLO03b	19-Jul-2018	6-Dec-2018	19:36
		NLO03c	14-Apr-2019	11-Dec-2019	32:54
NLSP03	**Red Island**	NLSP03a	26-Jun-2017	2-Aug-2017	5:00
		NLSP03b	23-Jun-2018	11-Nov-2018	23:48
		NLSP03c	10-Nov-2018	11-Jun-2019	27:46
		NLSP03d	12-Jun-2019	4-Nov-2019	19:10
NLSP04	**Merasheen Island**	NLSP04a	1-Sep-2017	13-Nov-2017	10:00
		NLSP04b	8-Aug-2018	8-Nov-2018	13:04
		NLSP04c	13-Jun-2019	15-Oct-2019	16:00
NLSP05	**Burin**	NLSP05a	6-Aug-2018	8-Nov-2018	13:04
		NLSP05b	15-Jun-2019	1-Nov-2019	19:10

Table 4. Comparative performance statistics for the LFDCS libraries "Gom9" (assessed for 20 and 18 moorings) and "NL23" (assessed for six moorings) used in this study.

LFDCS Library Used To Process Data	False Negative NARW Calls	True Positive NARW Calls	False Positive NARW Calls	Recall	Precision	F1
Gom9 (20 seismically-contaminated moorings)	0	36	55,996	1.0	0.00064	0.0013
Gom9 (18 seismic-free moorings)	0	36	19,778	1.0	0.0018	0.0036
NL23 (6 seismically-contaminated moorings)	0	11	32,263	1.0	0.00034	0.00068

Table 5. Locations and dates of confirmed NARW upcall detections in the waters off Newfoundland and Labrador between May 2009 and December 2023. No. Upcalls, number of confirmed NARW upcalls detected for each location and date. Seasons: Spring (Mar/Apr/May), Summer (Jun/Jul/Aug), Fall (Sep/Oct/Nov), Winter (Dec/Jan/Feb).

Area	Location Code	Site Name	Date	No. Upcalls	Season
Labrador (LAB)	LAB05	Saglek Bank	15-Oct-2021	1	Fall
E. Coast (NLE)	NLE02	Inshore Bonavista	5-Apr-2023	1	Spring
	NLE03	Eastport - Duck Islands	10-Nov-2023	18	Fall
	NLE04	Eastport - Round Island	21-Sep-2023	1	Fall
			14-Nov-2023	1	Fall
S. Coast Placentia Bay (NLSP)	NLSP01	St. Brides	12-Jul-2021	1	Summer
	NLSP02	Arnold's Cove	14-Jul-2017	5	Summer
	NLSP03	Red Island	14-Jul-2017	28	Summer
			6-Jun-2019	1	Summer
			31-Dec-2019	12	Winter
			6-Jan-2020	16	Winter
Laurentian Channel (NLLC)	NLLC01	Burgeo Bank	16-Aug-2015	1	Summer
			23-Sep-2015	2	Fall
	NLLC05	Rose Blanche Bank - Nearshore	11-Aug-2020	4	Summer
	NLLC06	Port aux Basques	12-Dec-2017	4	Winter
Offshore (NLO)	NLO03	Flemish Pass	23-Oct-2020	1	Fall
	NLO04	Tail of the Grand Banks	4-Nov-2020	1	Fall
	NLO05	Bonavista	4-Sep-2020	2	Fall

Table 6. Opportunistic sightings of NARW in the waters off Newfoundland and Labrador between August 2002 and November 2023 (29 sightings, 44 individuals). Seasons: Spring (Mar/Apr/May), Summer (Jun/Jul/Aug), Fall (Sep/Oct/Nov), Winter (Dec/Jan/Feb).

Year	Month	Season	Sighting Confidence	Number of Individuals	Comments
2002	2	Winter	Confirmed	3	-
2003	6	Spring	Confirmed	2	-
2005	8	Summer	Confirmed	1	-
2006	9	Fall	Confirmed	1	-
2010	9	Fall	Confirmed	1	-
2012	10	Fall	Confirmed	1	-
2012	11	Fall	Confirmed	1	-
2014	8	Summer	Probable	1	-
2015	8	Summer	Confirmed	2	-
2017	9	Fall	Confirmed	1	-
2019	9	Fall	Confirmed	1	EgNo 3845 ("Mogul)
2020	6	Spring	Probable	2	-
2020	6	Spring	Probable	5	-
2020	8	Summer	Probable	2	-
2020	8	Summer	Probable	2	-
2020	9	Fall	Confirmed	1	-
2021	11	Fall	Probable	2	-
2021	11	Fall	Confirmed	1	-
2021	11	Fall	Confirmed	1	-
2021	11	Fall	Confirmed	1	-
2022	5	Spring	Confirmed	2	-
2022	6	Spring	Confirmed	2	2021 calf of EgNo 1145
2022	11	Fall	Confirmed	1	-
2022	11	Fall	Confirmed	1	EgNo 3545
2022	11	Fall	Confirmed	1	-
2022	11	Fall	Probable	1	-
2023	11	Fall	Confirmed	1	EgNo 4308 ("Freckles")
2023	11	Fall	Confirmed	1	-
2023	11	Fall	Possible	2	-

FIGURES

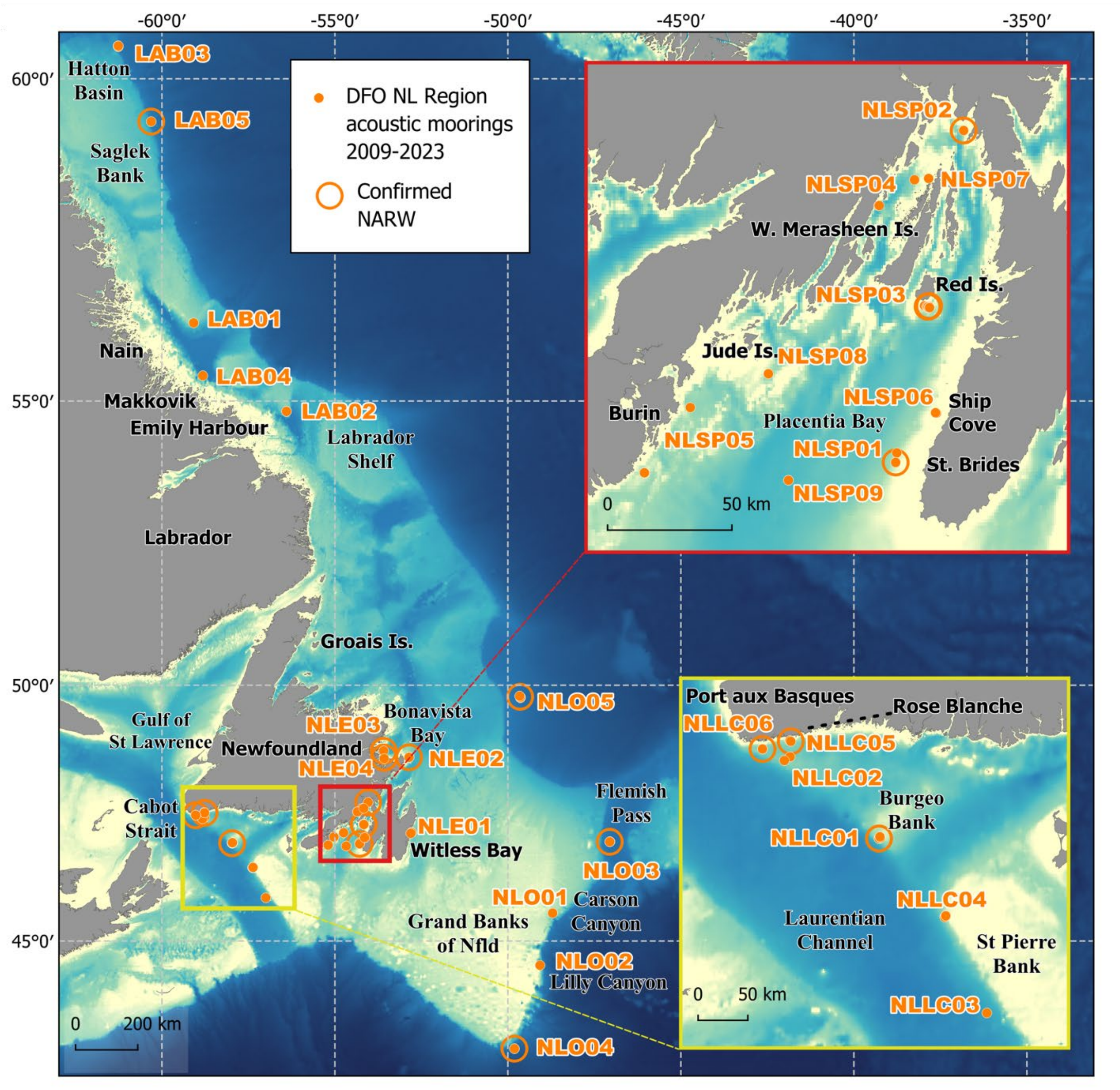

Figure 1. Locations of deployments of passive acoustic recorders in the waters off Newfoundland and Labrador between May 2009 and December 2023. Circled locations indicate confirmed detection of a NARW call. For deployment details see Table 1.

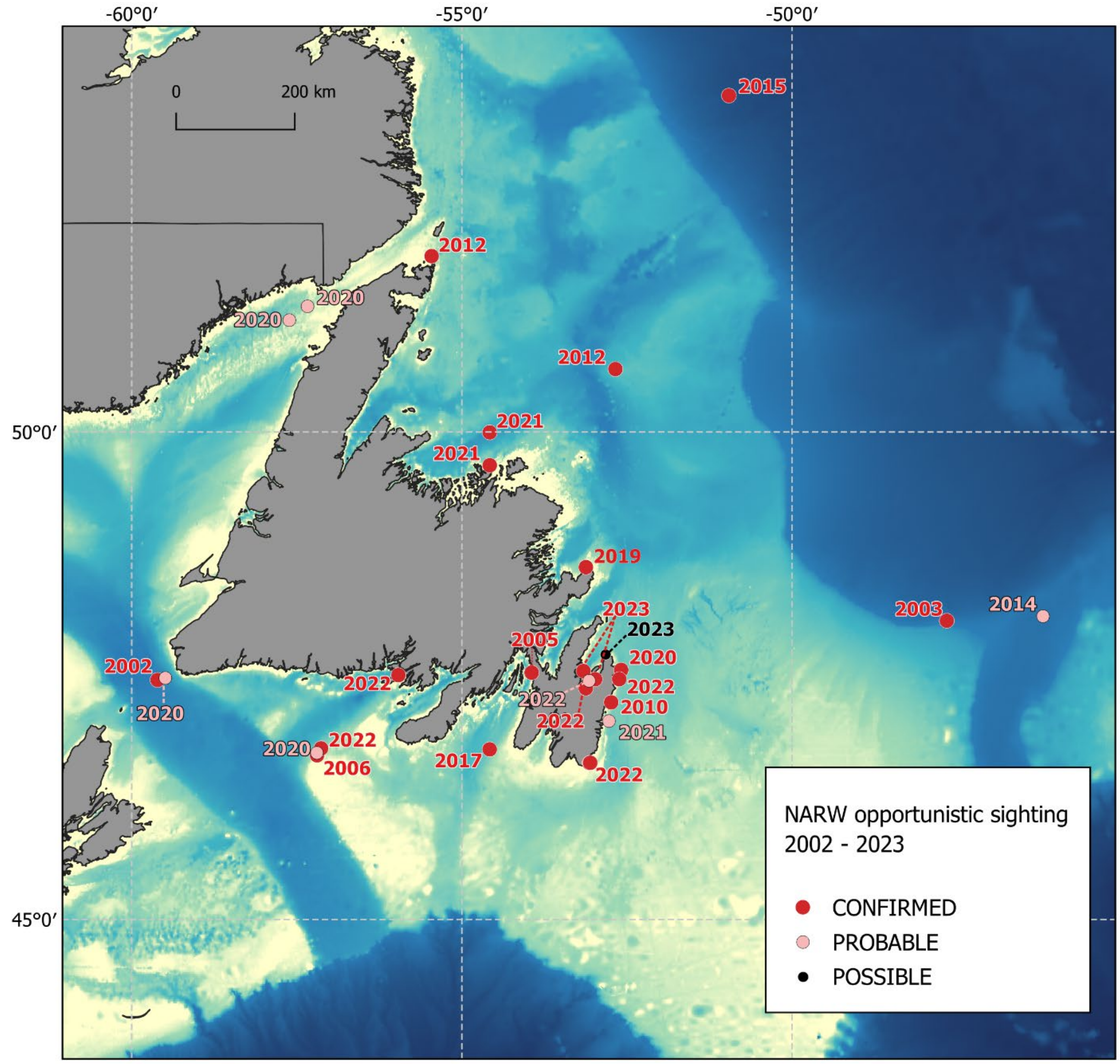

Figure 2. Locations of opportunistic sightings of NARW in the waters off Newfoundland and Labrador between August 2002 and November 2023.

APPENDIX

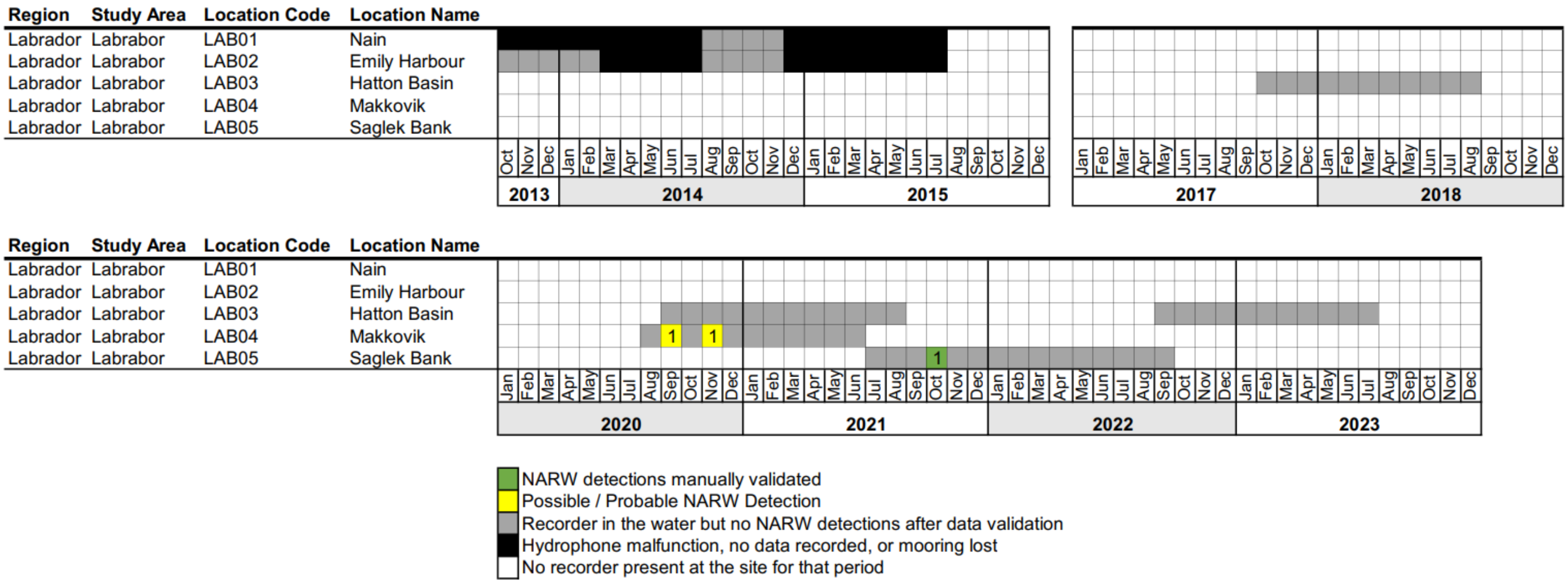

Figure A1. Passive acoustic recorder effort to detect NARW upcalls off the coast of Labrador (LAB) for 2013–23. Numbers within green and yellow cells indicate the number of days in the period that confirmed (green) or possible (yellow) NARW upcalls were detected for that location. There was no effort in this region during 2015–17.

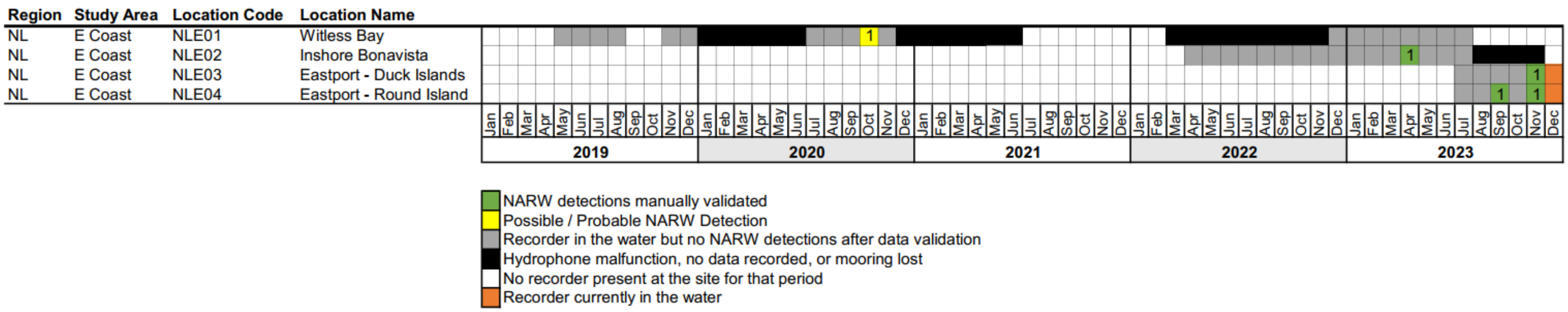

Figure A2. Passive acoustic recorder effort to detect NARW upcalls off the east coast of Newfoundland (NLE) for 2019–23. Numbers within green and yellow cells indicate the number of days in the period that confirmed (green) or possible (yellow) NARW upcalls were detected for that location.

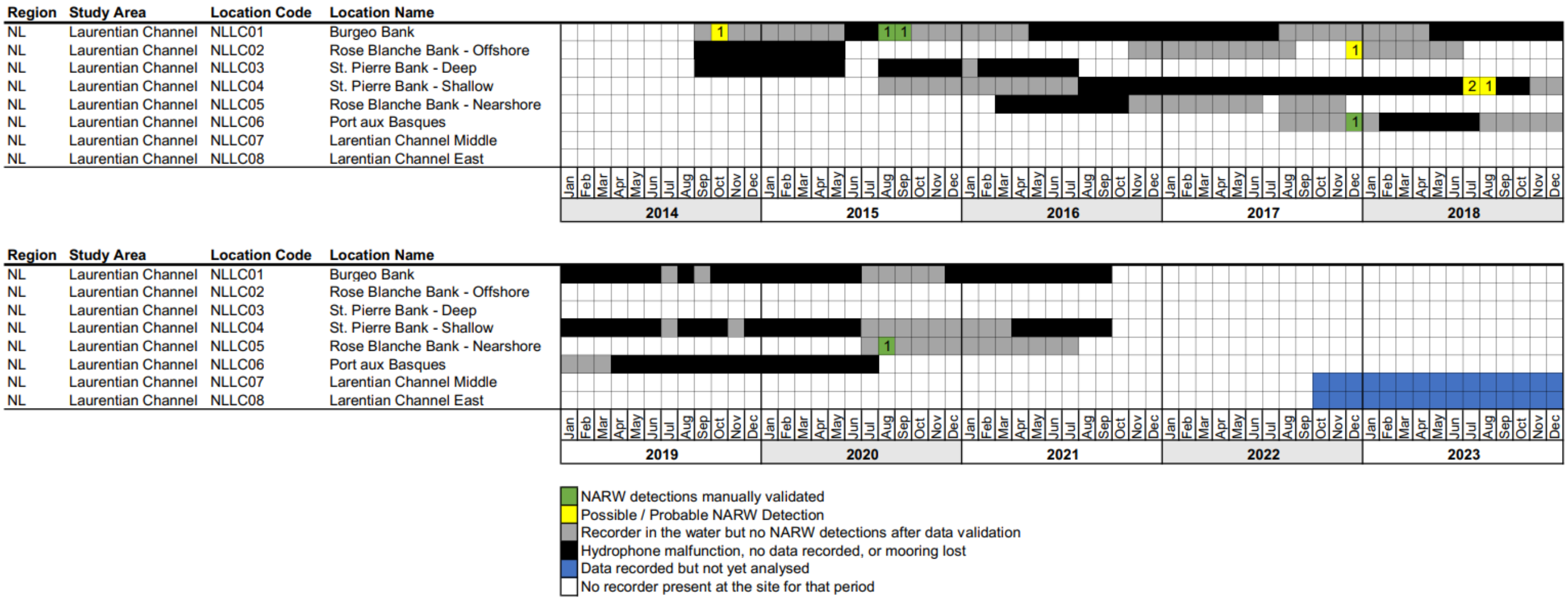

Figure A3. Passive acoustic recorder effort to detect NARW upcalls in Newfoundland waters along the margin of the Laurentian Channel (NLLC) for 2014–23. Numbers within green and yellow cells indicate the number of days in the period that confirmed (green) or possible (yellow) NARW upcalls were detected for that location.

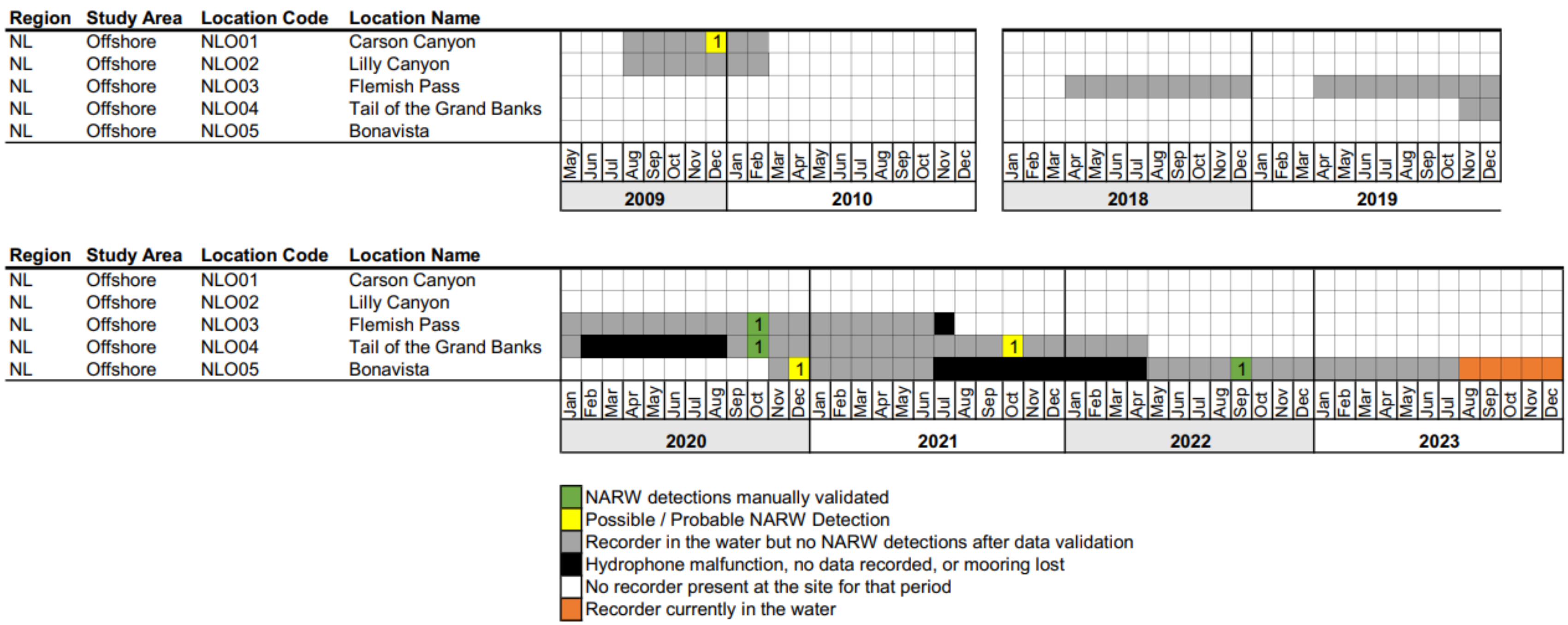

Figure A4. Passive acoustic recorder effort to detect NARW upcalls in offshore locations around Newfoundland (NLO) for 2009–23. Numbers within green and yellow cells indicate the number of days in the period that confirmed (green) or possible (yellow) NARW upcalls were detected for that location. There was no effort in offshore locations for the 2011–17 period.

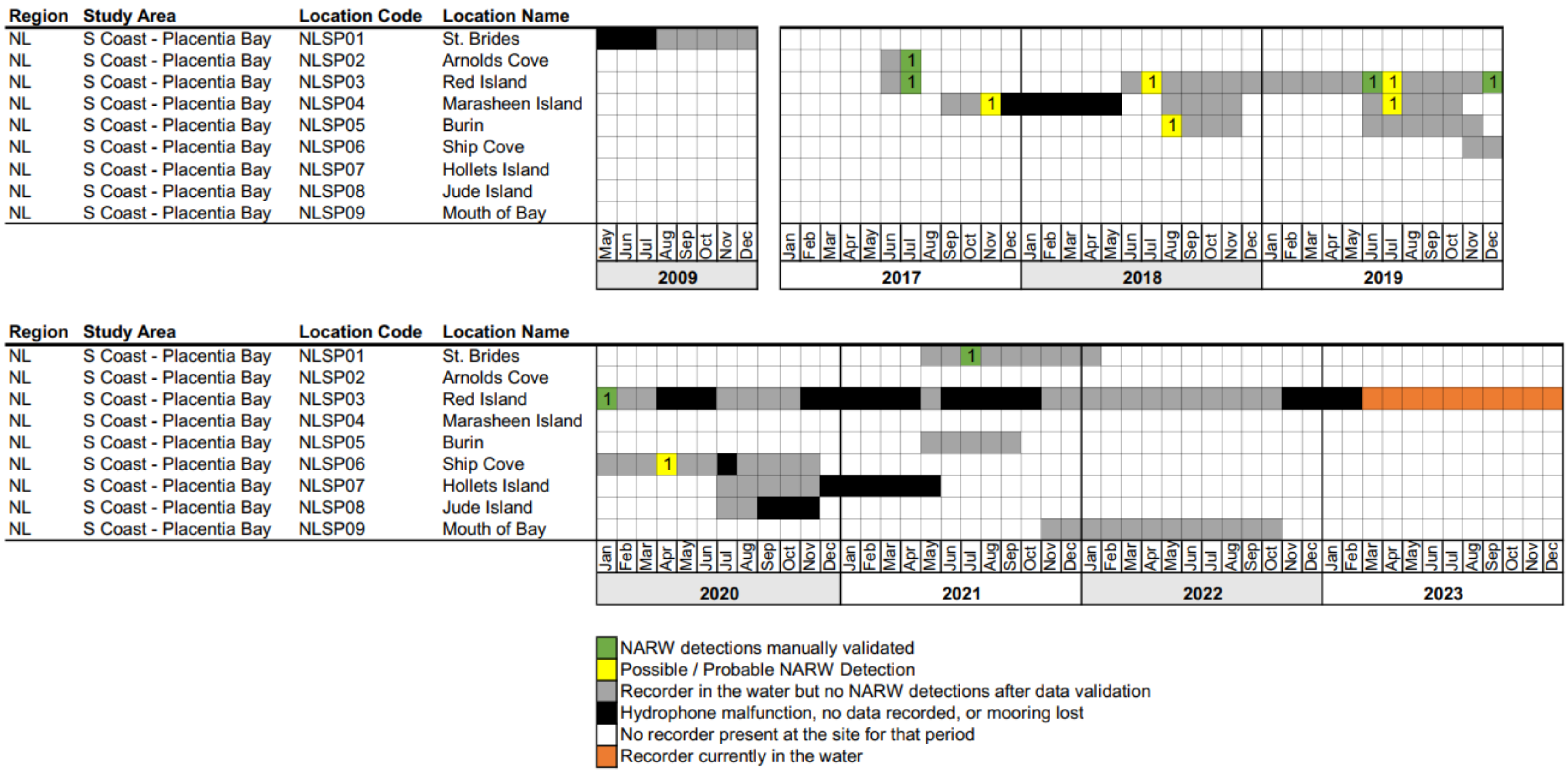

Figure A5. Passive acoustic recorder effort to detect NARW upcalls along the south coast of Newfoundland in Placentia Bay for 2009–23. Numbers within green and yellow cells indicate the number of days in the period that confirmed (green) or possible (yellow) NARW upcalls were detected for that location. There was no effort in Placentia Bay for the period 2009–16.