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Interim Summary of North Atlantic Right and Blue Whale Calls Detected Recently in Newfoundland and Labrador

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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 recent increase of North Atlantic right whales (*Eubalaena glacialis*; NARW) in Canadian waters, and the mortalities some have suffered here, there has been increased effort to detect and monitor the location of these whales, and ascertain how their habitat use patterns have changed. At the same time, Fisheries and Oceans Canada (DFO) is continuing research efforts with other *Species at Risk Act* (SARA)-listed species, such as blue whales (*Balaenoptera musculus*; BW). Automated detection and classification (DCS) of the vocalizations of NARW and BW is an essential tool to process the large volume of acoustic recording data gathered by the DFO to monitor these calling whales.

DFO Newfoundland and Labrador (NL) Region recently implemented Baumgartner's Low Frequency Detection and Classification System (LFDCS) to perform automated detection and classification of baleen whales on acoustic data we have been collecting since 2010. In this study we used LFDCS to detect NARW and BW, and JASCO's PamLab DCS to search for BW calls. LFDCS performed well with NARW and BW call detection, but generated many false NARW positives within the context of smeared seismic airgun sounds or pervasive calling humpback whales. For BW, LFDCS performed better relative to NARW in the number of calls detected, but suffered more false negatives than for the NARW detection task.

Although confounded by effects of high ambient noise, few moorings over the large study area, and similar humpback whale calls, possible and confirmed NARW upcalls and gunshots were detected occasionally on the Newfoundland south coast and in Placentia Bay. In addition, DFO NL's sightings database contains 18 records (29 whales) for NARW between 1932 and 2019, with 13 since 2001. Male NARW "Mogul" was observed feeding nearshore in 12 m of water on the NL north coast in September 2019, after being sighted off western France earlier in July 2019, and Iceland in the summer of 2018.

The confirmed and possible acoustic detections of NARW around Newfoundland and Labrador since at least 2015, and the rare but repeated visual sightings of this species in the region, corroborates that NARW are a component of the marine megafauna here – particularly in Placentia Bay.

BW are also sighted infrequently, but across many parts of the Newfoundland and Labrador shelves in nearshore and offshore locations. In particular, BW calls were detected on the south coast (although not in Placentia Bay), and offshore in the northern Flemish Pass.

INTRODUCTION

Passive acoustic monitoring (PAM) provides a powerful tool to detect and identify marine mammal species underwater, and is used currently in many baleen whale seasonal occurrence studies (e.g., Baumgartner et al. 2018; Mellinger et al. 2007a; Van Parijs et al. 2009; Verfuß et al. 2007). While acoustic monitoring can collect data continuously, in remote locations, and in periods of darkness and weather conditions that would limit visual detection, PAM studies must deal with a large and complex mixture of the sounds of target species of interest, other marine wildlife, anthropogenic activities, environmental processes, and noise produced by the recording system itself.

To process large amounts of acoustic data for the presence of species-specific sounds, use of an automated detection and classification system (DCS) are becoming more common and requires significantly less time than manual (visual/aural) searching by a trained expert, assuming the DCS is acceptably accurate. A variety of DCS approaches have been developed for analyzing marine mammal sounds, including low frequency detectors for the North Atlantic right whale (*Eubalaena glacialis*; NARW) and blue whales (*Balaenoptera musculus*; BW)(e.g., Davis et al. 2017). These detectors can work since NARW generate a distinctive vocal repertoire (Mellinger et al. 2007b). BW also produce several species-specific tonal call types in the North Atlantic (e.g., Berchok et al. 2006; Mellinger and Clark 2003).

Researchers in Fisheries and Oceans Canada (DFO) Newfoundland and Labrador (NL) Region have been deploying autonomous acoustic recorders on fixed moorings at locations from the Labrador coast to the Laurentian Channel south of Newfoundland, and in nearshore and deep-water offshore sites since 2010. We have recently implemented the Baumgartner Low Frequency Detection and Classification System (LFDCS) system (Baumgartner and Mussoline 2011) to speed processing of acoustic data for large whale detection in-house.

For NARW, analyzed calls consisted of a variety of upsweep calls ranging from long, short, steep, and check upsweeps. Gunshot calls and moans were also observed opportunistically; however, LFDCS in its current form does not have the capability to detect gunshot calls. Additionally a false negative analysis on the acoustic data was performed to verify the percent of potential missed calls by LFDCS for NARW. The call library used in this study consists of NARW calls from the North-eastern United States. It is speculated that upcalls from areas further north may sound slightly different and thus this study helps us to compare LFDCS performance on different populations of NARW. BW calls analyzed consisted of A, B, and AB tonal calls detected using the LFDCS program and further manual review by experienced analysts. Arch D calls were also observed opportunistically however LFDCS in its current form does not have a call library for this type of BW call. Furthermore, a false negative analysis was conducted for some of the acoustics data for BW to determine what percentage of A, B, and AB calls were being overlooked by LFDCS.

In this paper we report recent results from this on-going acoustic program, with confirmed detections of *Species at Risk Act (*SARA)-listed NARW and BW at multiple locations in NL, and describe the performance of the LFDCS used to process our data in a high ambient noise context. Some of the acoustic analysis for NL sites was described in (Durette-Morin et al. 2022); this paper is an interim report as additional analysis is being completed on the NL datasets to provide a more thorough understanding of when we hear these two species at our various recording sites.

METHODS

AUTONOMOUS ACOUSTIC RECORDERS

Between 2010 and 2019, passive acoustic recorders were deployed in areas of interest to monitor cetacean presence and provide data for underwater noise assessments that included coastal Labrador, offshore Newfoundland (Flemish Pass, southeastern Grand Banks), Placentia Bay, and the Laurentian Channel (Figure 1). Two types of bottom-mounted passive acoustic recorders were deployed (Table 1):

1. Autonomous Underwater Recorder for Acoustic Listening (AURAL, model M2, Multi-Electronique Inc., Rimouski, QC, Canada);
2. Autonomous Multichannel Acoustic Recorder (AMAR, JASCO Research Limited, NS, Canada).

For this report, recordings collected from late 2016 to 2019 period from AURAL and AMAR deployments were analyzed for the presence of NARW and BW calls (Tables 2 and 4) (recordings from previous/other deployments are not included here as they have not been analyzed with LFDCS, but extend back to 2010)(see for instance Durette-Morin et al. 2019). Recorder data collection durations varied from 49 to 232 days, and at hydrophone depths from 57 to 1,090 m (Table 2). Most of the recorders were duty-cycled, with recordings ranging from 13 min/hr to 34 min/hr, while some recorders collected data continuously. The recorders were deployed as single units either directly on the sea bottom or suspended in the water column using subsurface floats.

All four recorder types were able to collect acoustic data in the frequency range (0 to 2 kHz) used by the LFDCS to detect and characterize the calls of NARW and BW (see below).

AURAL

AURAL M2 recorders were deployed 42–157 m off bottom using oceanographic moorings. The AURALs sampled the 16 dB pre-amplified acoustic signal with 16-bit resolution and sampling rates of 32 kHz for 15 or 30 min per h. 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.

AMAR

AMARs were deployed ~42–157 m off bottom using an oceanographic mooring. The Flemish Pass AMAR had a deep-water housing and was deployed at a hydrophone depth of 1,083 m. Other AMARs were equipped with shallow water housing and were deployed at depths ranging from 100–120 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 has 16-bit resolution with a nominal ceiling of 171 dB re 1 µPa.

ACOUSTIC SAMPLING EFFORT

Recorders deployed on the northern margin of the Laurentian Channel, as part of Marine Protected Area (MPA) monitoring, provide data for a large portion of the study period described in this report (Figure 1). A Burgeo Bank recorder was lost in 2018, but the earlier and later deployments provided data for processing by the JASCO DCS for BW, such as in Figure 2. In Placentia Bay we increased our deployment efforts since 2017 in support of the OPP-MEQ program, with an increase from one to three locations used consistently (West Merasheen Island, Red Island and just off the town of Burin on the southwest (SW) side of Placentia Bay; Figure 1). In spring of 2018 we initiated an eight-month deployment of an AMAR recorder in deep waters at the northern end of Flemish Pass as this is an area we know has a high occupancy rate by various cetacean species.

AUTOMATED NARW AND BLUE WHALE CALL DETECTORS

Low Frequency Detection and Classification System (LFDCS)

The LFDCS automated baleen whale detector-classifier (Baumgartner and Mussoline 2011) classifies sounds from these whale species based on measures derived from basic signal features. The software suite is run within Apple's UNIX-based operating system and its scripts are linked with IDL software (Harris Geospatial Solutions, Inc., Broomfield, CO).

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 range produced for NARW and BW. The decimated audio produced by the low-pass ≤2 kHz filter was then run through a second filtration process capable of detecting and further magnifying the low frequency tonal calls of BW.

LFDCS then creates 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 (see Davis et al. 2017). After tracing contour lines, or "pitch tracks", through tonal sounds, the program uses multivariate discriminant analysis to classify the pitch tracks into call types. Calls were classified based on a user-developed call library; our library included five North Atlantic baleen whale species: NARW, BW, fin (*B. physalus*), sei (*B. borealis*), and humpback whales (*Megaptera novaeangliae*), from whales recorded in Northeastern United State waters. DFO researchers will supply new whale call samples from Canadian waters to improve the diversity in the library. Here, we focused on the detections classified as NARW and BW calls. For NARW we searched for the low-frequency modulated upsweep known as the upcall. The upcall is a contact call used throughout the NARW range, produced by all ages and both sex classes, and is; therefore, the most reliable call to use for determining right whale presence. For BW we focused on A, B, and AB tonal calls which are common among different populations of BW with variation and often found in repeated sequences (Mellinger and Clark 2003).

The underlying LFDCS call library used in this analysis is described in Baumgartner and Mussoline (2011), and was expanded and improved by other researchers to include a wider variety of examples of NARW upcalls in an effort to increase detection probability. Each NARW detection was assigned a Mahalanobis distance value (MD), 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 indicates a closer match to the assigned call type. All NARW upcall detections with a MD less than or equal to 3.0 were manually screened by experienced analysts to determine which were correctly classified (see next section). For BW tonal calls a MD of less than or equal to 5.0 was used. We chose the values of 3.0 for NARW and 5.0 for BW to mimic other studies such as Davis et al. (2017). Additionally, we did not increase the threshold above that of Davis et al. in order to make the data more manageable to process and to classify correct or incorrect detections of NARW and BW. We also included a false negative analysis in our study to further evaluate the LFDCS detector performance at these thresholds for the current call library.

JASCO's Multispecies Detector (PamLab)

We used JASCO's multispecies detector (PamLab) on some of our data to determine the presence of BW vocalizations in the acoustic data (JASCO Applied Sciences, Dartmouth, NS; see description in Delarue et al. 2018). In this report we present results of the PamLab detector (Figure 2) for blue whale calls as many of these data have been manually validated by an experienced acoustician (G. Renaud).

The PamLab detectors for baleen whales were applied to the 8 kHz sampled data (audio bandwidth up to 4 kHz for approximately 11 min every 20 min). The tonal signal detector identifies continuous contours of elevated energy and classifies them against a library of marine mammal signals (see Appendix E.2 of Delarue et al. 2018 for details). BW tonal acoustic signals were defined using multiple call characteristics (Table 3).

MANUAL VALIDATION OF AUTOMATED DETECTIONS

NARW Call Validation

The high degree of variability in NARW upcalls and the overlap with other species' vocalizations, such as upsweeps produced by humpback whales, necessitated additional manual validation of the LFDCS and PamLab detections. Summaries of NARW autodetections found within each deployment were exported following the LFDCS filtration process. Per deployment NARW autodetections ranged from 0 to 21,000 and all autodetections were manually validated, except for MMNL051 Flemish Pass. Calls for MMNL051 were manually validated for the period April to mid-July 2019; however, past this date seismic interference became too great and caused too many false detections to validate effectively. However no correct autodetections were discovered prior to July 2019 for MMNL051. 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 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, they were classified as "incorrect". Calls marked as "unknown" indicated that there was a biological source creating sound with the possibility of a NARW upcall. Detections classified as "unknown" were reviewed a second time in Raven pro 1.6 to further exclude false positive detections (such as another type of biological or anthropogenic noise). The remaining "unknown" detections were then considered "possible NARW calls" and copies were forwarded to other experienced acousticians at National Oceanic and Atmospheric Administration (NOAA) (G. Davis) and the Bedford Institute of Oceanography (BIO) for further review. These acousticians classified these calls as "correct", "possible", or "incorrect" as a NARW. Calls that were considered "possible" by all analysts were left as "unknown" in our dataset, whereas a call originally classified as "possible" but ruled as "incorrect" was reassigned to "incorrect".

BW Call Validation

Due to the low frequency of BW calls and high levels of anthropogenic noise in the recordings, all LFDCS BW auto detections required manual validation. Summaries of BW autodetections found within each deployment were exported following the LFDCS filtration process. Across all moorings there was a total of 30,724 BW detections of A, B, and AB tonal calls predominantly in the 15–40 Hz range. All detections were reviewed and classified as "incorrect" or "unknown" by both inspecting them visually and aurally at 10X playback speed. Unknown detections were presumed to be correct based on analyst experience and review/cross referencing calls with peer-reviewed articles (e.g., Berchok et al. 2006; Mellinger and Clark 2003; Romagosa et al. 2020). Calls that analysts were not fully confident of were played back in Raven Pro. This allowed analysts to visually and aurally play the sound back at various speeds and isolate the call from surrounding noise to confirm the call source.

False Negative Analysis

In order to test the efficacy of the LFDCS call library at detecting NARW upcalls and BW tonal calls we conducted a false negative analysis on almost 1% of 32,296 hr of audio data recorded for the study period; this analysis allows for a better understanding of LFDCS performance to indicate when there is or isn't a biological call of interest, and what percent of NARW and BW calls may be missed by the LFDCS autodetector. For each deployment one hr of raw audio per week was selected at random to be reviewed further in Raven Pro. The analyst would then retrieve the LFDCS manual validation timestamp's for correct and incorrect calls on each mooring. Each hr of audio was then uploaded into Raven Pro and scanned visually and acoustically for potentially missed NARW and BW calls. When the analyst was scanning the raw audio and discovered a candidate call they would cross reference the manual validation data to ascertain if it was detected by LFDCS and if it was classified as "incorrect", "unknown", or "correct". The analyst would scan each sample hr in the frequency range of typical NARW upcalls (0–1,000 Hz) and then again in the range of BW tonal calls (0–300 Hz). For NARW calls, 317 hr of raw audio was reviewed for false negatives in Raven Pro (not including MMNL051). For BW calls, 350 hr of raw audio was reviewed in Raven Pro (including MMNL051). Due to the low numbers of correct NARW detections compared to BW detections, for each positive NARW detection one hr before and one hr after each correct call was analyzed in Raven Pro to search for false negatives. This equaled 11 hr of additional false negative analysis bringing the total to 328 hr of audio reviewed for NARW. The same was not done for BW because there was 9,811 positive BW detections.

RESULTS

EFFORT

During the sampling period several moorings were lost, likely due to fishing activity and recorder/release malfunctions (see below). There were a total of 19 moorings deployed and 32,296 hr of audio recorded in the study period. The longest sampling periods were from Red Island (18 mo continuous sampling with no malfunctions) (Table 2). Data from all 19 moorings were run through LFDCS and manually validated for NARW and BW. Additionally two moorings, one off of the town of Burgeo (Figure 2) and one off Saglek Bank, were only analyzed using JASCO's PamLab detector.

NARW DETECTIONS

There were a large number of detections of NARW by the LFDCS system, particularly in the Flemish Pass, where LFDCS flagged over 20,000 events as possible calls; however, all such events in the Flemish Pass were determined to be false. All autodetections from the 19 moorings were manually validated (except for MMNL051) and possible detections were sent to other experienced LFDCS users at NOAA for review (G. Davis). In total 33 calls were confirmed as correct NARW upcalls with the majority of them being from moorings around Red Island and four calls from Port Aux Basques. Additionally we had 14 "possible" NARW calls in West Merasheen Island, Burin, St. Pierre Bank, and Rose Blanche. There was also one "possible" gunshot call identified opportunistically off West Merasheen Island in August 2018; however, it is unconfirmed due to the lack of concurrent upcalls and thus not included in Table 2. The confirmed NARW vocalizations were detected in spring, summer, and fall. For the deployments with "possible" NARW detections, they have been reviewed by DFO NL Region staff and experienced acousticians at NOAA or BIO, and all agreed it is possible that the calls were NARW. Analysis of 328 hr of audio, a random sample of raw audio from 1% of all audio recorded, revealed no false negatives. This indicates that LFDCS is detecting the majority of true NARW upcalls from our mooring deployments. For accuracy of the detector LFDCS produced a significant amount of false positive detections prior to manual review. Using LFDCS with our current call library, at a Mdist of 3.0, suggested 59,540 NARW detections, but with only 33 of these being correct NARW calls and 14 “possible”. The rest were eliminated as anthropogenic noise or biological noise from another species. There is also a possibility of missed NARW detections due to the malfunction or loss of AURAL recorders (Table 2).

BLUE WHALE DETECTIONS

Relative to NARW, BW vocalizations were detected much more often in NL waters, using JASCO’s PamLab software. The Saglek Bank (Labrador) AMAR had only one validated BW call in November 2018. Vessel noise dominated at 18 Hz, thereby potentially mimicking blue whale tonal AB calls, so many of the BW autodetections on the Cote Saglek Bank deployment were false positives. Vessel noise was a particular issue for the Placentia Bay recordings where few of JASCO’s autodetections were true BW when validated manually. At Merasheen Island, nine BW autodetections in September and October 2017 were false. The same was true for the Burin site on the southwest side of Placentia Bay where 16 BW autodetections from August to November 2018 were not correct BW tonal calls. Results were much different on the south coast of Newfoundland, where there were many BW AB and arch calls detected. At the southern end of Burgeo Bank, 231 AURAL recorder acoustic files were classed as containing BW tonal calls from August 2017 to April 2018 (Figure 2). Of these 221 (95.7%) contained correct AB calls from BW. Opportunistically, 17 D arch calls produced by BW were also observed from August to February, with a peak in December, with six observations. All of these BW calls were detected despite significant vessel noise. There were correct BW detections present in the Port aux Basques and Flemish Pass deployments, but many other JASCO autodetections have not yet been validated.

Nineteen of the same moorings from the NARW analysis were also analyzed with LFDCS and manually validated for BW detections. The mooring omitted for the NARW analysis, MMNL051 Flemish Pass, was included in these BW validations because detections were much more manageable to validate and there were frequent BW calls observed in years prior. LFDCS searched for A, B, and AB calls, with a resulting majority being classified as B calls. However most of these B calls were actually AB calls with which LFDCS had not detected the “A” portion of the call. Of the 32,296 hr of audio analyzed, LFDCS produced 30,724 detections, and of those a high proportion relative to NARW (9,811, 32%) were correct BW tonal calls.

A large amount of anthropogenic noise, from seismic shooting and large vessel traffic, masked frequencies between 15–20 Hz, and this caused many false autodetections. There were many more correct BW detections than NARW. The most frequent locations where we had repeated positive BW calls were from our Port aux Basques and Flemish Pass moorings, with the highest number of calls from the months of October to December. For example, the month with the highest number of BW calls was November 2018 when there were 2,364 detections in the Flemish Pass. For moorings in and around Placentia Bay there were far fewer detections, with rare detections from moorings closer to the southern mouth of the bay (St. Pierre Bank) and few for moorings further inside the Bay. Additionally BW arch calls were observed opportunistically in data from our mooring in Rose Blanche in February 2019.

In regards to detector performance, 350 hr of audio was reviewed manually for potential missed BW calls compared to those autodetected by LFDCS. LFDCS only detected 4–28% of BW tonal calls. Frequently LFDCS would trace one AB tonal call but then fail to trace 4–5 contiguous calls. Thus LFDCS is able to detect calling BW in most samples, but not detect every tonal call that is present even with Mdist set to 5.0. The number of BW call detections reported in this study should be considered underestimates.

DISCUSSION

EFFORT

With the loss of several moorings, few sampling locations were monitored continuously during this study. The loss of a mooring on Burgeo Bank off the Newfoundland south coast was a noteworthy occurrence given the high rate of BW detections there before and after that period.

However, even with long periods of continuous monitoring in Port aux Basques (16 mo) and Red Island (16 mo)(Table 2), there were few NARW calls confirmed overall.

Given the acoustic and visual detections of NARW off the province's offshore and north coast (e.g., Figure 1), and habitat modelling for NARW that suggested that the shelf break on the tail of the Grand Banks was favourable, we intend to deploy further acoustic moorings at the tail of the Grand Banks and off Cape Bonavista.

NARW DETECTIONS

In this study, NARW were detected rarely at DFO's Newfoundland and Labrador mooring sites. Given the relatively high ambient noise levels associated with almost all of these sites, the detection range for NARW upcalls will likely be low (see Future Research, below). This, combined with the rarity of these whales and our limited knowledge of their distribution outside the Gulf of St. Lawrence and traditional feeding grounds, might explain why NARW acoustic detections are rare in Newfoundland and Labrador. Further evidence of their uncommon presence is that since 1932 there have been 18 sightings of 29 NARW in waters around Newfoundland (Figure 1), with most (13) occurring since 2001. And this was despite two large-scale aerial surveys in Atlantic Canadian waters in 2007 and 2016. However the larger number of sightings in recent years is likely a product of more effort and the implementation of more capable acoustic technology to detect whales and confirm sightings.

Given the small number of confirmed detections it is not possible to determine spatial or seasonal patterns for NARW in Newfoundland and Labrador waters at this time. One point of consistency has been Red Island, Placentia Bay (Figure 1). In addition to the 2017 and 2019 confirmed detections, Red Island has been the site of possible NARW vocalizations in 2018 as well (plus three NARW sightings in the bay). Additional possible NARW detections have also occurred at the West Merasheen Island (NW of Red Island) and Burin (SW of Red Island in Placentia Bay) moorings in 2017 and 2018 (Table 2). When we did have confirmed NARW calls the most in one month (28 events) occurred off Red Island in 2017. As well, our search for false negatives did not discover missed calls contiguous with the few confirmed calls. The four confirmed NARW calls in December of 2017 off Port Aux Basques is interesting since it is assumed that most NARW migrate back south for the winter by this time.

JASCO also deployed multiple offshore AMAR recorders in Atlantic Canada, although they manually validated a much smaller proportion of their positive DCS cases than this study (Delarue et al. 2018). Similar to results from our recordings, JASCO's acoustic detections of NARW from 2015–17 were rare relative to those of other cetacean species. A single confirmed NARW was detected at Whale Bank off the Newfoundland south coast (SE of DFO's St. Pierre Bank mooring) in late November 2016. Possible right whale vocalizations were also recorded by

JASCO at Port aux Basques (nearby DFO NL's mooring) in July and September, and Orphan Basin (NNW of DFO's Flemish Pass mooring) in July (Figure 1).

It is possible that the distribution of NARW is changing; DFO's monitoring efforts have detected a larger number of NARW in the Gulf of St. Lawrence in recent years (such as with acoustics, see Simard et al. 2019), and a passive acoustic monitoring study detected right whale calls in an offshore area off southern Greenland where they used to be hunted (Mellinger et al. 2011). In September 2019 a male right whale, Mogul, was imaged feeding in less than 15 m of water close to shore on the NE coast of Newfoundland (Figure 1); the New England Aquarium later confirmed that this NARW had been seen feeding off NE U.S. in the spring, SW France earlier in July, and in Iceland in the summer of 2018.

The confirmed and possible acoustic detections of NARW around NL since at least 2015, and the rare but repeated visual sightings of this species in the region, corroborates that NARW are an occasional component of the marine megafauna in our waters with most frequent visits likely occurring in Placentia Bay and near the South Coast. However, future monitoring efforts could lead to discovering similar occasional or repeated presence in other areas of the province.

BLUE WHALE DETECTIONS

The acoustics data analyzed in this study demonstrate that blue whales are distributed broadly in the waters of NL, more commonly detected than north Atlantic right whales, but far less common than humpback or fin whales (e.g., Lawson and Gosselin 2009). With a relatively high source amplitude and infrasonic frequency, BW calls would normally propagate 10s to 100s of kilometres. However, all mooring locations were exposed to high levels of shipping noise (particularly in Placentia Bay and Cabot Strait) and, in the case of the mid-Labrador, St. Pierre Bank, and Flemish Pass moorings, multiple concurrent seismic programmes (e.g., four seismic projects in each of 2018 and 2019). This likely masked an unknown number of the BW calls.

Nonetheless, BW were heard from mid Labrador to Port aux Basques, and as far offshore as the Flemish Pass. Of particular interest is the data from the Newfoundland south coast (based on the JASCO PamLab detector), where BW were heard frequently from late summer through to the following spring at decreasing rates (Figure 2). This, reinforced by sightings and habitat modelling results, supports the supposition that BW occur through the winter outside the Gulf, off southern Newfoundland, before an unknown proportion of them move into the Gulf to feed in the spring (for a recent review see Moors-Murphy et al. 2019).

For the analysis of BW calls using the LFDCS detector we saw similar levels of AB calls at our mooring sites to results from the JASCO detector. We observed that many AB calls did not have harmonics and this matches similar findings for North Atlantic BW populations reported by Mellinger and Clark (2003). Although we set up LFDCS to detect AB tonal calls, BW arch D calls were also observed opportunistically off Rose Blanche during February of 2017. The summaries we present are based on AB calls as we have not completed the analyses for arch calls. Given that arch calls are associated with certain BW behaviour (made by both sexes and are thought to be related to foraging), it would be useful to eventually investigate both types of calls to assess BW presence throughout year and evaluate their behaviour while here (see Moors-Murphy et al. 2019).

LFDCS PERFORMANCE WITH NARW UPCALLS AND BW TONAL CALLS

The LFDCS performed well in that it processed our acoustic datasets much quicker than a manual validator. As expected, the performance of LFDCS was compromised by the low SNR at most of our recorder sites, and in the case of NARW, the similarity with common humpback whale tonal calls.

Davis et al. (2017) determined that the rate of missed 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. To date our data supports this conclusion of a precautionary detector with the settings we have employed. Our false negative analysis, during which we reviewed 328 hr of raw audio (approximately 1% of all audio recorded), did not reveal any missed upcalls. Even in the 11 hr of audio that consisted of one hr samples before and after each confirmed upcall we did not find any false negatives, as was the case for Davis et al. (2017). On our study area LFDCS did however produce a large number of false positives which required significant manual validation. Specifically, too many false positives to validate in a reasonable time frame for our mooring in the Flemish Pass in 2019 which recorded high levels of seismic activity. This may be remedied by editing our current LFDCS call library so that it is better adapted for the common sound sources in NL waters.

Over 350 hr of raw audio was analysed for Blue Whale false negatives representing one hr per recorded week for each mooring and approximately 1% of all audio records. Upon comparing the number of detected calls in the sampled hours to the number of missed calls we found that LFDCS was able to autodetect between 4–28% of all BW calls (Table 5). This range represents only the moorings in the study that had over 50 confirmed BW calls in the sampled audio hours analysed in the false negative analysis. Moorings in Placentia Bay either had so few BW calls or none at all that they did not give a good indication of the true performance of the detector for BW. Frequently while validating LFDCS detections LFDCS would trace one AB call but then there would be occasionally up to 4–5 very clear AB calls adjacent that it would miss. Additionally, LFDCS was much better at tracing the B portion of calls or tracing the entire AB call and classifying it as just a B call. Thus it seems that LFDCS is good at detecting when BW are calling near the mooring but not as capable at classifying every tonal call. This could be due to North Atlantic BW calls possibly being slightly different than the those in our call library and thus limiting the LFDCS match rate. Alternately, the relatively high level of anthropogenic noise is masking many calls.

FUTURE RESEARCH

Maximum detection ranges for NARW vocalizations can vary considerably depending on recording equipment, location, ambient noise, and environmental conditions, as well as call type and behavioural context. Davies et al. (2017) estimated detections ranged from 8 km to 16 km for NARW, while Gervais et al. (2019) estimated a median detection range for NARW, in Cabot Strait, of approximately 10 km. While BW calls are louder and can be detected at greater distances (Stafford et al. 1998), they too can be masked by high amplitude shipping and seismic noise. For Newfoundland waters, particularly during the summer and early fall, areas such as the Flemish Pass are exposed to noise from wide-ranging and concurrent seismic programs, and the detection range for NARW and BW could be even less. The many LFDCS false positive autodetections in the low SNR regimes offshore, in Placentia Bay, and in the Cabot Strait likely cannot be reduced in the future with changes to mooring configuration or placement. It is unclear if adding more moorings at closer spacing for areas like the Cabot Strait would detect more NARW detections since they may not vocalizing as they migrate through this area or their calls are masked significantly (Cominelli et al. 2020). We will investigate whether changing the analysis settings for LFDCS could reduce the proportion of false call triggering yet maintain acceptably low levels of false negatives. We will also add more Newfoundland exemplars of confirmed NARW and BW detections to the call library in order to detect more call occurrences than when using the current detector. Doing this may slightly improve the rate of NARW call detection since the false negative analysis demonstrated that the detector seems to identify most upcalls. However, for BW adding in better examples of regional A, B, and AB calls may significantly improve LFDCS's ability to detect tonal calls in this study area. We will also add a new "call" type for seismic shots to the library since it was apparent that LFDCS mis-classified many time-smeared seismic shots as NARW upcalls. 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 for quieter sites such as east Greenland (Mellinger et al. 2011). We intend to analyse more of our previous data with LFDCS as most of these have been analysed using PamLab for a variety of species (although few have yet been manually validated for NARW). We also continue to deploy moorings in Placentia Bay to better understand why we are seeing recurring detections there. As well, we will deploy more moorings in other theorized preferred habitats for NARW around NL. Given that recent modelling efforts have suggested that the tail of the Grand Banks could represent a preferred habitat for NARW, we will deploy an AMAR there in Fall 2019. In all cases we intend to continue this deployment pattern, with an additional pair of recorders on the Newfoundland north coast and the tail of the Grand Banks where habitat models suggest we might expect NARW. A new graduate project will model and measure the detection range of NARW and BW calls at these sites using a sound propagation study.

CONCLUSIONS

- LFDCS detected NARW upcalls, but generated many false positives within the context of smeared seismic airgun sounds or calling humpback whales.
- Confirmed and possible NARW upcalls (and gunshots) were detected rarely on the Newfoundland south coast, in Placentia Bay, and offshore in the northern Flemish Pass. All three Placentia Bay recording sites had confirmed/possible NARW vocalizations recently, and in the case of Red Island had the most confirmed and consistent calls by NARW.
- DFO NL's sightings database contains 18 records (29 whales) for NARW between 1932 and 2019; only five records occur before 1991, and 13 since 2001. A known male NARW was observed feeding nearshore in 12 m of water on the NL NE coast in September 2019.
- The confirmed and possible acoustic detections of NARW around NL since at least 2015, and the rare but repeated sightings of this species in the region, corroborates that NARW are an occasional component of the marine megafauna in these waters.
- BW are also sighted rarely, but across many parts of the NL shelves in nearshore and offshore locations. In particular, 9,611 BW calls were detected on the south coast (although not in Placentia Bay), and offshore in the northern Flemish Pass.
- While BW detections by LFDCS were more common than NARW, LFDCS also suffered far more missed BW detections then NARW, with only 4–28% of BW tonal calls being detected.
- BW detections occurred most frequently in the Fall far offshore and on the south coast of Newfoundland from September to January, and were usually AB calls.

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validations of blue and right whale calls while under contract to DFO. C. Evers (DFO Maritimes) and D. Durette-Morin (Dalhousie University) also reviewed selected autodetections. Dr. D. Coté (DFO NL) provided us with acoustic data from an AMAR deployed on a hydrographic mooring near the upper Labrador Shelf.

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TABLES

Table 1. Autonomous acoustic receivers deployed in Newfoundland and Labrador to collect NARW and BW calls, and other sounds, since 2010.

Acoustic Receiver Type	Max Depth Rating (m)	Recording Duration	Storage Volume	Sensors	Useable Freq Range (kHz)
AURAL M2 (128 D Cells)	300	1+ year	1 TB	Hydrophone, Temperature, Pressure	10–16.4
µAURAL (rechargeable)	100	70+ hrs	64 GB	Hydrophone, Temperature	2–48
AMAR Shallow	350+	330 days	10 TB	Hydrophone, Pressure	2–256
AMAR Deep	5,000	330 days	10 TB	Hydrophone, Pressure	2–256

Table 2. Acoustic recorder effort to collect NARW calls in Newfoundland and Labrador since late 2016 (grey shaded cells). After manual validation, green cells contain counts of confirmed NARW upcalls, yellow cells possible NARW upcalls, red cells indicate recorder malfunction, and cells with / indicate positive/possible upcalls.

Mooring Location	2016		2017												2018												2019											
	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Port Aux Basques	-	-	-	-	-	-	-	-	-					4/3																				-	-	-	-	-
Rose Blanche											-	-	-	1							-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Flemish Pass	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-									-	-	-	-									
St. Pierre Bank	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	1																
Burin	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1				-	-	-	-	-	-							-
Marasheen Island West	-	-	-	-	-	-	-	-	-	-			1							-	-					-	-	-	-	-	-		1					-
Placentia Bay Red Island	-	-	-	-	-	-	-		28	-	-	-	-	-	-	-	-	-	-		1											1/2	1					-

Table 3. Vocalization characteristic definitions used by the JASCO DCS PamLab software to classify tonal vocalizations of NARW and BW expected in the northwest Atlantic.

Species	Vocalization	Frequency (Hz)	Duration (s)	Bandwidth (Hz)	Other detection parameters
Blue whale	Infrasonic moan	15–22	8–30	1–5	Minimum frequency <18 Hz
Right whale	Upcall	50–300	0.4–2.2	60–250	Minimum frequency <120 Hz Sweep rate 30 to 200 Hz/s

Table 4. Acoustic recorder effort to collect BW AB calls in Newfoundland and Labrador since late 2016 (grey shaded cells). After manual validation, green cells contain counts of confirmed BW calls and red cells contain months when a recorder malfunctioned.

Mooring Location	2016		2017												2018												2019											
	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Port Aux Basques	-	-	-	-	-	-	-	-	-	16	204	606	267	271	4							48	124	115	134	204	217	76	10					-	-	-	-	-
Rose Blanche	11								3	6	-	-	-	69	13	7			4		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Flemish Pass	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		7	2		347	763	939	2364	-	-	-	-					104	631	1188	635	228
St.Pierre Bank	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	13			73	15							25				39	
Burin	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1				-	-	-	-	-	-					1		-
Marasheen Island West	-	-	-	-	-	-	-	-	-	-										-	-		4			-	-	-	-	-	-			6	1	1	-	-
Placentia Bay Red Island	-	-	-	-	-	-	-			-	-	-	-	-	-	-	-	-	-																			-

Table 5. One hr per week for each deployment was sampled and analysed for false negatives in Raven Pro 1.6. Total false negatives detected from audio sampled were compared to LFDCS autodetected calls in the same hours sampled. Calls were then summed to determine the percentage of calls autodetected by LFDCS in the hours sampled. Deployments with less than 50 BW calls were omitted due to presumed low BW activity in those areas.

Mooring Name	False Negatives Detected	Calls Detected by LFDCS in Sample	Calls Detected by LFDCS + False Negatives	Percent of Calls Deteced by LFDCS
MMNL032	99	20	119	17.0
MMNL039	79	3	82	4.0
MMNL043	130	20	150	13.0
MMNL044	140	18	158	11.0
MMNL046	59	3	62	4.8
MMNL051	40	16	56	28.0

FIGURES

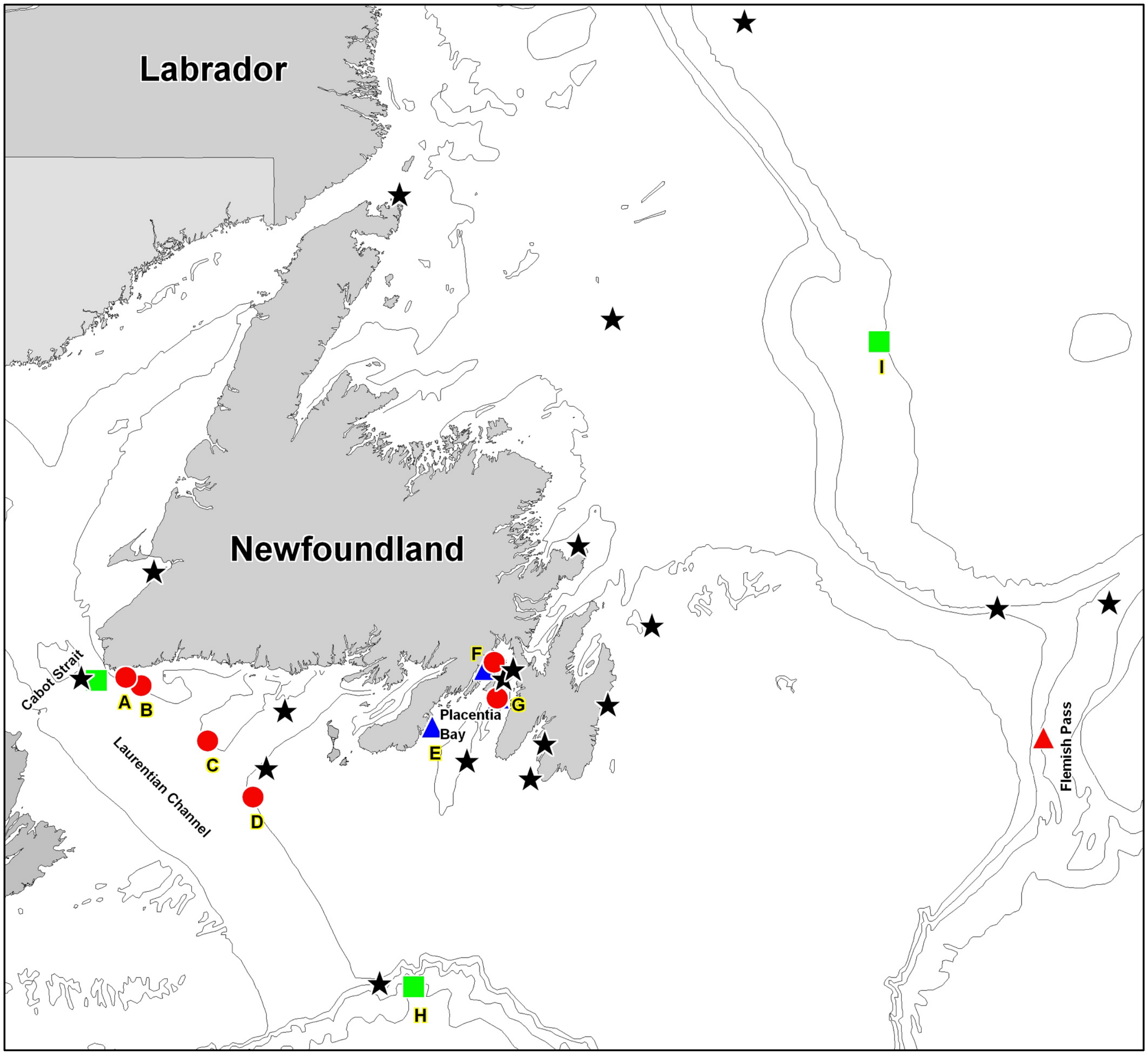

Figure 1. Deployment locations of autonomous acoustic moorings (DFO AURALs indicated by red circles; DFO AMARS indicated by blue and red triangles; JASCO AMARs indicated by green boxes) and sightings of NARW in the study area, most since 2001 (black stars, N=18). Deployment sites are indicated with letter labels (A – Port aux Basques, B – Rose Blanche Bank, C – Burgeo Bank, D – St. Pierre Bank, E – Burin, F – West Merasheen Island, G – Red Island, H – Whale Bank, and I – Orphan Basin).

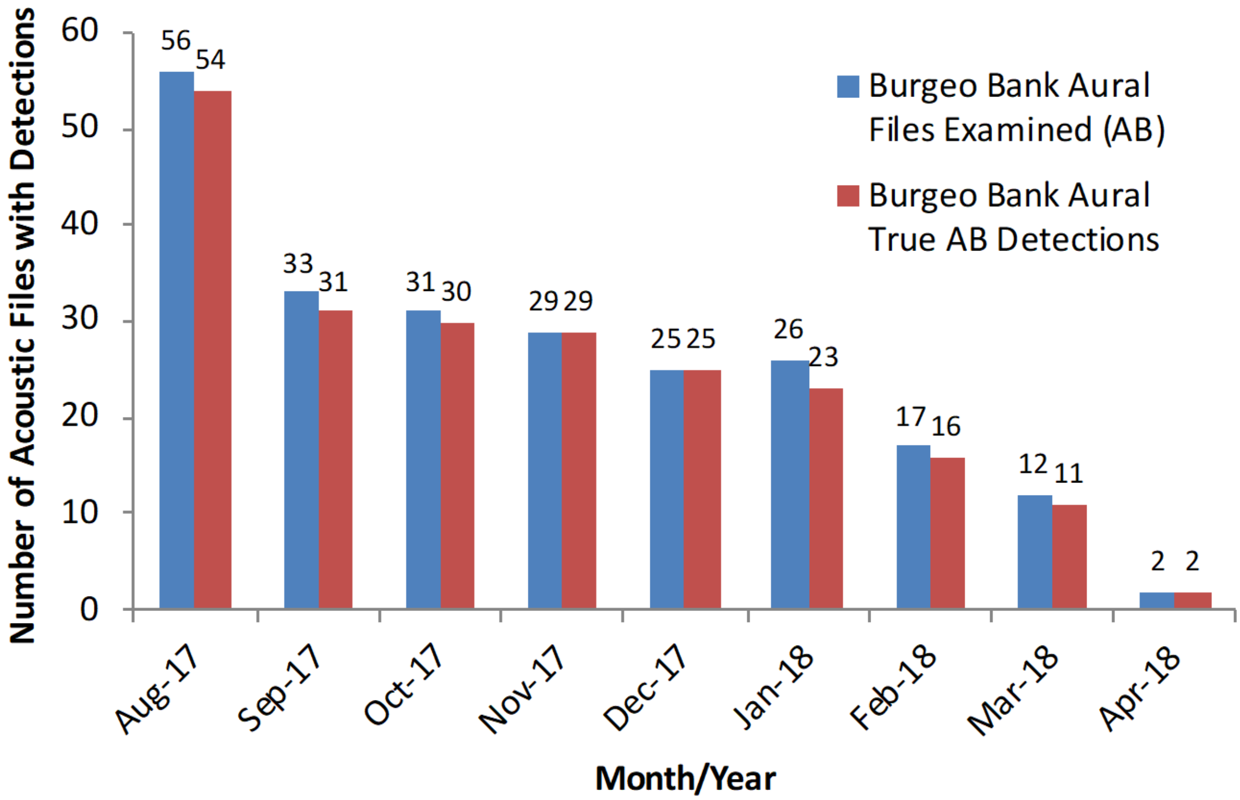

Figure 2. Number of 30-min acoustic files containing BW call detections (blue bars), as indicated by the JASCO DCS for August 2017-April 2018 at an AURAL recorder deployed on Burgeo Bank. Upon manual validation, almost all of the recordings contained true BW AB calls (red bars).