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Acoustic Occurrence of North Atlantic Right Whales (*Eubalaena glacialis*) from 2017-2022 off Nova Scotia, Canada

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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

The purpose of this study was to summarize the occurrence of North Atlantic right whale (NARW) upcalls on passive acoustic monitoring (PAM) datasets that have been collected by the Department of Fisheries and Oceans Canada (DFO) Maritimes Region from November 2017-September 2022. Throughout this period, acoustic data were collected from 27 sites off Nova Scotia, including multiyear data collection from the Grand Manan Basin and Roseway Basin NARW Critical Habitat areas. Confirmed acoustic presence of NARW at all recording sites analyzed as part of this study supports that NARW occur over a broad geographical range in eastern Canadian waters. On-shelf sites had higher upcall presence than slope sites, suggesting the Scotian Shelf is likely to be an important movement corridor for NARW. Upcall presence was highest in Grand Manan and Roseway Basins, indicating that these areas remain important habitats for NARW off Nova Scotia. Relatively high upcall presence in Emerald Basin indicates that this area is also commonly used by NARW. Upcalls were present in the Cabot Strait throughout summer and fall, but further data collection is required to more fully understand how NARW use this area. This study also demonstrates that NARW occur in waters off Nova Scotia throughout the year. In general, upcall presence was lowest in winter (though calls were still detected at multiple sites over multiple days in this season), increased over spring and summer, and was highest in fall. This study demonstrates the value of PAM for assessing occurrence of NARW in the region throughout the year, including during periods when weather makes visual survey efforts very challenging. PAM data not only complements visual sightings data, but in some cases provides more extensive or new information on presence of this species that could not be achieved from visual survey efforts. This information will be used to inform a revised NARW Recovery Potential Assessment (RPA), and a new assessment of NARW important habitat off eastern Canada.

INTRODUCTION

The North Atlantic right whale (NARW, *Eubalaena glacialis*), listed as endangered under the Canadian Species at Risk Act (SARA) in 2005, occurs in waters off eastern Canada (Brown et al. 2009, DFO 2014). Grand Manan Basin in the Bay of Fundy and Roseway Basin off southwestern Nova Scotia were proposed as candidate Critical Habitat areas in 2007, based on where the majority of sightings were documented, as well as the occurrence of high concentrations of their primary prey, *Calanus finmarchicus* copepods (DFO 2007, Smedbol 2007). These two areas were later identified as Critical Habitat in the recovery strategy for the species in 2009 (Brown et al. 2009, DFO 2014) and have been protected under the SARA since 2017 (Government of Canada 2017). However, changes in copepod distribution and abundance in the Bay of Fundy and Gulf of Maine regions starting in 2010 have led to increased occurrence of this species in the Gulf of St. Lawrence and decreased sightings reported in their traditional habitat areas off Nova Scotia (Davies et. al. 2019, Meyer-Gutbrod et al. 2021, 2022, Record et al. 2019). This shift in NARW distribution has also resulted in most NARW visual survey efforts in Canadian waters being directed to the Gulf of St. Lawrence region, with more limited field studies occurring in and around their designated Critical Habitats off Nova Scotia (DFO 2019, 2020). Regardless of where they occur, visual survey efforts (aerial and vessel-based) off eastern Canada are largely limited to spring, summer, and early fall, due to poor weather and sea state conditions during other times of the year that decrease visibility and make surveys logistically challenging. Visual surveys are also limited to daylight hours, and generally only provide relatively brief periods (hours-weeks) of coverage of an area within a given field season.

Passive acoustic monitoring (PAM) offers an alternative method of studying NARW occurrence throughout the year. NARW produce several different types of calls, including “upcalls”: approximately 0.2-3.0 s calls often beginning around 50 Hz and increasing (sweeping up) to about 340 Hz (Matthews and Parks 2021). Upcalls are thought to be contact calls, allowing a group of individuals to remain in contact with one another acoustically even when outside visual detection range. They are made by both sexes, all age groups, in all habitats, and are distinctive to this genus (Matthews and Parks 2021). Because upcalls are a universal call type made by all members of the population throughout their distributional range and during all times of the year, presence of these calls is not thought to be biased towards a specific sex or time of year and they have been the target signal used in most NARW PAM studies focused on assessing species presence over time, including patterns in seasonal occurrence (e.g., Davis et al. 2017, 2023, Durette-Morin et al. 2022).

Acoustic presence of NARW based on upcall presence has been assessed off eastern Canada in previous studies (e.g., Mellinger 2007, Davis et al. 2017, Simard et al. 2019, Durette-Morin et al. 2022, Wingfield et. al., 2024). These studies generally showed that NARW upcalls were present in Nova Scotia waters throughout the year, with the greatest call presence tending to occur in the July to December period (Mellinger 2007, Davis et al. 2017, Durette-Morin et al. 2022). Upcalls occurred more commonly in the Bay of Fundy and at sites on the Scotian Shelf, as compared to sites in deeper waters along the Scotian Slope (Davis et al. 2017, Durette-Morin et al. 2022). Acoustic occurrence of NARW in the southern Gulf of St. Lawrence persisted from June to January, with peak occurrence between August and October (Simard et al. 2019).

These previous studies included analysis of PAM datasets collected by Department of Fisheries and Oceans Canada (DFO) Maritimes Region off Nova Scotia: data collected from 2012-2014 were included in the Davis et al. (2017) study, and data collected from 2015-2017 were included in the Durette-Morin et al. (2022) study. The DFO Maritimes Region has continued to collect PAM data in waters off Nova Scotia since 2017, expanding data collection efforts to more areas, including in the Grand Manan Basin and Roseway Basin Critical Habitats. The purpose of this study is to summarize the acoustic presence of NARW in the PAM datasets that have been collected from 2017-2022, to inform a revised NARW Recovery Potential Assessment (RPA) and a new assessment of NARW important habitat off eastern Canada.

METHODS

DATA COLLECTION

Underwater acoustic recordings analyzed in this study were collected by DFO Maritimes Region from bottom-mounted PAM moorings deployed throughout waters off Nova Scotia from November 2017 to September 2022. These included 56 mooring deployments at 27 recording sites (Figure 1, Table 1). Not all sites were sampled in every year throughout the study period, and recording durations varied from just over one month to over one year. Because of uneven sampling at individual sites, the 27 sites were binned into eight geographic “areas” to allow for assessment of patterns in call occurrence over seasonal and monthly time scales. The eight areas chosen were based on potential importance to NARW, such as feeding habitats and/or migratory corridors, as well as geographical context: Bay of Fundy (BoF) including Grand Manan Basin, Gulf of Maine (GoM), Western Scotian Shelf (SHELF-W) including Roseway Basin, Central Scotian Shelf (SHELF-C), Eastern Scotian Shelf (SHELF-E), Cabot Strait (CABOT), Western Scotian Slope (SLOPE-W), and Eastern Scotian Slope (SLOPE-E) (Figure 1). These data were collected by several research projects and programs within DFO Maritimes Region, with varying program priorities and objectives, and using multiple types of recording systems (Table 1).

All but four of the deployments were conducted using Autonomous Multichannel Acoustic Recorders (AMARs; JASCO Applied Sciences). Each AMAR system was equipped with one or more broadband omnidirectional hydrophones (either M36-100 series hydrophones or M20-105 acoustic pressure sensors; Geospectrum Technologies Inc., or HTI-92WB or HTI-99-UHF hydrophones; High Tech Inc.), that could effectively record frequencies from 1-2 Hz to at least 3 kHz. Both G3 and newer G4 AMAR models were used (Table 1). Four AMAR deployments used systems with two or four hydrophones arranged in a small (< 2 m) array that collected data on two (2CH) or four channels (4CH) simultaneously. Three AMAR deployments collected data using a 10 or 44 m eight-element hydrophone vertical line array (VLA) that recorded data simultaneously on eight channels. For these multichannel deployments, recordings from the channel with the highest recording quality within a deployment were analyzed in this study. Four AMAR deployments were conducted using an M20 low frequency particle motion sensor (Geospectrum Technologies Inc.) that simultaneously recorded acoustic pressure from an omnidirectional hydrophone sensor on one channel and 3D particle motion data from three orthogonal accelerometer-based particle motion sensors on three separate channels. For these deployments, only the omnidirectional hydrophone data were analyzed.

SoundTrap recorders (Ocean Instruments), both an ST500 and ST600 model, were used for two of the deployments. PORPOISE recorders (Turbulent Research) were also used for two of the deployments. All of these systems were equipped with a single omnidirectional hydrophone capable of sampling up to 384 kHz. The gain was manually set to 30 dB for the PORPOISE recorders.

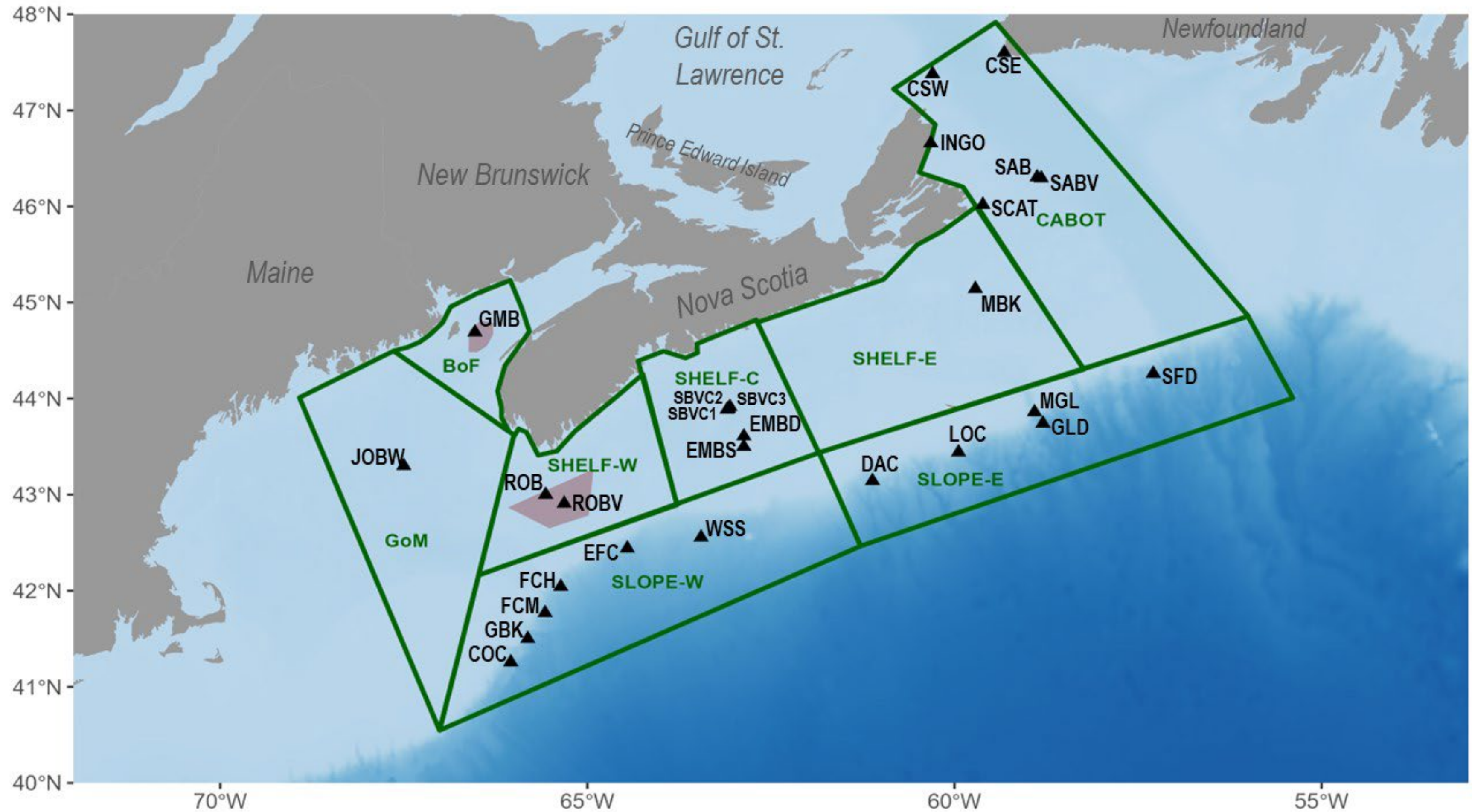

Figure 1. Map of DFO Maritimes Region's 2017-2022 passive acoustic monitoring mooring deployment sites included in this study (black triangles). Geographic areas considered in this study are also shown (green lines): Bay of Fundy (BoF), Gulf of Maine (GoM), Western Scotian Shelf (SHELF-W), Central Scotian Shelf (SHELF-C), Eastern Scotian Shelf (SHELF-E), Cabot Strait (CABOT), Western Scotian Slope (SLOPE-W), Eastern Scotian Slope (SLOPE-E). The reddish-grey polygons are the NARW Grand Manan Basin and Roseway Basin Critical Habitats.

Table 1. Summary of recorder deployments included in this study. Area indicates the geographic area defined in this study in which the recorders were deployed: Bay of Fundy (BoF), Gulf of Maine (GoM), Western Scotian Shelf (SHELF-W), Central Scotian Shelf (SHELF-C), Eastern Scotian Shelf (SHELF-E), Cabot Strait (CABOT), Western Scotian Slope (SLOPE-W), Eastern Scotian Slope (SLOPE-E). Height above seafloor indicates the approximate height of the hydrophone sensor above the seafloor for each deployment based on the mooring configuration. The actual height of the sensor throughout the deployment may vary based on the precise bottom location of the mooring and currents in the area. Recording dates indicate the start and end dates of complete recording days and recording days represents the number of complete recording days, excluding days the recorder was deployed and recovered, or shut off for other reasons. Recording schedule indicates the duration and sampling rate of the recordings included in the analysis, while duty cycle indicates how often the recordings were collected. Recorder type indicates the make and model of the acoustic recording system used in the deployment. 2CH, 4CH, and VLA denote systems equipped with a hydrophone array. Program indicates the research projects and programs from which the data were collected: Cetacean Research and Monitoring Program (CRMP), the Ocean Protection Plan Marine Environmental Quality projects led by either Oceans and Ecosystems Science Division (OPP-MEQ OESD) or Marine Planning and Conservation (OPP-MEQ MPC), the Whale Detection and Collision Avoidance (WDCA) Initiative and the Benthic Ecology Lab (BEL).

Area	Site Code	Latitude (decimal degrees)	Longitude (decimal degrees)	Bottom Depth (m)	Height Above Seafloor (m)	Recording Dates (yyyy-mm-dd)	# Days	Recording Schedule	Duty Cycle (min)	Recorder Type	Program
BoF	GMB	44.691	-66.530	180	< 1	2018-09-21 – 2019-04-08	386	680 s at 8 kHz	20	AMAR G4	OPP-MEQ OESD
						2019-04-01 – 2019-10-19	132	680 s at 16 kHz	15	AMAR G3	OPP-MEQ OESD
						2020-09-01 – 2021-04-11	220	1020 s at 16 kHz	20	AMAR G3	OPP-MEQ OESD
						2021-04-11 – 2021-08-23	199	1020 s at 16 kHz	20	AMAR G3	OPP-MEQ OESD
						2021-08-23 – 2022-09-15	197	1020 s at 16 kHz	30	AMAR G3	OPP-MEQ OESD
GoM	JOBW	43.300	-67.500	195	22	2019-04-09 – 2019-10-07	179	720 s at 256 kHz	15	AMAR G4	OPP-MEQ OESD
					18	2019-10-07 – 2020-09-01	328	340 s at 16 kHz	15	AMAR G3	OPP-MEQ OESD
					8	2020-09-01 – 2021-08-22	353	636 s at 64 kHz	30	AMAR G4	OPP-MEQ OESD
SHELF-W	ROB	43.000	-65.568	160	20	2018-04-30 – 2018-09-16	137	680 s at 8 kHz	20	AMAR G3	OPP-MEQ OESD
					7	2018-09-16 – 2019-08-15	331	380 s at 32 kHz	15	AMAR G4	OPP-MEQ OESD
					18	2019-10-07 – 2020-02-03	117	370 s at 256 kHz	15	AMAR G4	OPP-MEQ OESD
					18	2020-08-31 – 2021-08-19	351	340 s at 16 kHz	15	AMAR G3	OPP-MEQ OESD
	ROBV	42.909	-65.315	154	22	2020-08-31 – 2020-12-20	109	430 s at 64 kHz	20	AMAR G4 (VLA)	OPP-MEQ OESD

Area	Site Code	Latitude (decimal degrees)	Longitude (decimal degrees)	Bottom Depth (m)	Height Above Seafloor (m)	Recording Dates (yyyy-mm-dd)	# Days	Recording Schedule	Duty Cycle (min)	Recorder Type	Program
					28	2021-04-10 – 2021-08-19	129	720 s at 32 kHz	20	AMAR G4 (4CH)	OPP-MEQ OESD
					28	2021-08-19 – 2022-06-29	312	350 s at 32 kHz	20	AMAR G4 (VLA)	OPP-MEQ OESD
SHELF-C	SBVC1	43.887	-63.096	152	< 2	2021-09-12 – 2022-05-12	240	312 s at 96 kHz	15	SoundTrap ST500	BEL
	SBVC2	43.896	-63.079	151	< 2	2021-09-12 – 2022-05-12	240	312 s at 96 kHz	15	SoundTrap ST600	BEL
	SBVC3	43.914	-63.057	221	< 2	2021-09-12 – 2022-05-12	240	560 s at 64 kHz	15	AMAR G4 (4CH)	BEL
	EMBD	43.608	-62.869	200	27	2021-08-26 – 2022-09-13	381	600 s at 64 kHz	15	AMAR G4	OPP-MEQ OESD
	EMBS	43.500	-62.869	115	20	2018-05-01 – 2018-09-23	143	680 s at 8 kHz	20	AMAR G3	OPP-MEQ OESD
					7	2018-09-23 – 2019-06-28	276	380 s at 32 kHz	15	AMAR G4	OPP-MEQ OESD
					18	2019-10-06 – 2020-09-07	335	340 s at 16 kHz	15	AMAR G3	OPP-MEQ OESD
					18	2020-09-07 – 2021-08-26	351	340 s at 16 kHz	15	AMAR G3	OPP-MEQ OESD
SHELF-E	MBK	45.143	-59.715	113	8	2021-09-02 – 2022-09-14	375	370 s at 256 kHz	15	AMAR G4	CRMP
CABOT	SCAT	46.018	-59.613	52	< 1	2019-11-15 – 2020-03-28	132	1740 s at 24 kHz	29	PORPOISE	OPP-MEQ MPC
	SAB	46.305	-58.875	310	6	2017-12-04 – 2018-01-09	34	290 s at 32 kHz	8	AMAR G4	CRMP
					21	2018-09-29 – 2019-10-03	367	680 s at 8 kHz	20	AMAR G3	CRMP
					27	2021-09-01 – 2022-10-03	395	340 s at 16 kHz	15	AMAR G3	CRMP
	SABV	46.295	-58.817	333	224	2019-06-02 – 2019-08-15	72	1190 s at 4 kHz	30	AMAR G4 (VLA)	OPP-MEQ OESD
	INGO	46.659	-60.323	56	< 1	2019-11-15 – 2020-03-13	117	1740 s at 24 kHz	29	PORPOISE	OPP-MEQ MPCP
	CSW	47.379	-60.299	120	20	2020-09-04 – 2021-01-24	140	300 s at 8 kHz	6.67	AMAR G4 (M20)	WDCA
					28	2021-05-29 – 2022-03-06	279	380 s at 8 kHz	10	AMAR G4 (M20)	WDCA
	CSE	47.600	-59.322	200	20	2020-09-04 – 2021-01-24	140	300 s at 8 kHz	6.67	AMAR G4 (M20)	WDCA

Area	Site Code	Latitude (decimal degrees)	Longitude (decimal degrees)	Bottom Depth (m)	Height Above Seafloor (m)	Recording Dates (yyyy-mm-dd)	# Days	Recording Schedule	Duty Cycle (min)	Recorder Type	Program
					28	2021-05-30 – 2021-11-29	181	380 s at 8 kHz	10	AMAR G4 (M20)	WDCA
SLOPE-W	COC	41.257	-66.043	1490	8	2020-09-02 – 2021-08-21	351	370 s at 256 kHz	15	AMAR G4	CRMP
					8	2021-08-21 – 2022-09-02	375	370 s at 256 kHz	15	AMAR G4	CRMP
	GBK	41.502	-65.811	1480	8	2019-10-08 – 2020-09-02	328	370 s at 256 kHz	15	AMAR G4	CRMP
					8	2020-09-21 – 2021-08-21	237	370 s at 256 kHz	15	AMAR G4	CRMP
	FCM	41.770	-65.576	1432	7	2021-08-21 – 2022-09-12	385	360 s at 256 kHz	30	AMAR G4 (2CH)	CRMP
	FCH	42.043	-65.362	1300	21	2018-09-17 – 2019-10-08	384	680 s at 8 kHz	20	AMAR G3	CRMP
					8	2019-10-08 – 2020-09-02	328	370 s at 256 kHz	15	AMAR G4	CRMP
					8	2020-09-02 – 2021-08-21	351	360 s at 256 kHz	30	AMAR G4 (2CH)	CRMP
	EFC	42.442	-64.455	1505	27	2021-08-20 – 2022-08-13	356	370 s at 256 kHz	15	AMAR G4	CRMP
	WSS	42.556	-63.451	1490	21	2019-10-08 – 2020-09-07	333	340 s at 16 kHz	15	AMAR G3	CRMP
					8	2020-09-07 – 2021-08-21	346	370 s at 256 kHz	15	AMAR G4	CRMP
SLOPE-E	DAC	43.144	-61.117	1400	4	2017-11-29 – 2018-09-26	299	680 s at 8 kHz	20	AMAR G3	CRMP
					7	2018-09-24 – 2019-09-11	350	380 s at 32 kHz	15	AMAR G4	CRMP
	LOC	43.442	-59.944	1400	4	2017-11-29 – 2018-09-26	299	680 s at 8 kHz	20	AMAR G3	CRMP
					7	2018-09-26 – 2019-08-26	332	380 s at 32 kHz	15	AMAR G4	CRMP
	MGL	43.860	-58.910	1360	50	2017-12-01 – 2018-09-27	298	680 s at 8 kHz	20	AMAR G3	CRMP
					50	2018-09-27 – 2019-10-13	374	680 s at 8 kHz	20	AMAR G3	CRMP
					50	2019-10-13 – 2020-09-05	326	370 s at 256 kHz	15	AMAR G4	CRMP
					50	2021-08-29 – 2022-10-01	396	340 s at 16 kHz	15	AMAR G3	CRMP
	GLD	43.742	-58.795	2500	6	2017-11-30 – 2018-01-07	36	780 s at 16 kHz	8	AMAR G4	CRMP
	SFD	44.260	-57.292	1460	21	2020-09-05 – 2021-08-31	358	370 s at 256 kHz	15	AMAR G4	CRMP
					8	2021-08-31 – 2022-09-12	375	370 s at 256 kHz	15	AMAR G4	CRMP

For all deployments, the recorders were moored to the seafloor throughout the recording period, though mooring design varied by research program and site. The AMAR moorings were typically configured to have the AMAR and attached hydrophone(s) suspended 4-50 m above the seafloor via a cable and floatation (or in the case of the 44 m VLA deployed at the SABV site in 2019, approximately 224 m above the seafloor; Table 1). The deployments conducted at the GMB site were an exception to this due to the high currents in the Bay of Fundy region. At this site, the AMARs were deployed in a small lander platform encapsulated by an aerodynamic flow shield to reduce potential flow noise, with the hydrophone placed much closer to the seabed (< 1 m from the seafloor). For the PORPOISE deployments at the SCAT and INGO sites, the recorders were mounted inside a modified lobster trap with the hydrophone < 1 m above the seabed (for more information about the mooring configuration used at these coastal sites see: Wingfield et al. 2022a). For the deployments conducted in SBVC1, SBVC2 and SBVC3, the AMAR or SoundTraps were directly attached to a large lander with the hydrophones sitting < 2 m above the seafloor. Additional information about these lander deployments can be found in De Clippele et al. 2022.

Data were generally collected throughout deployments using recording schedules that cycled between low and/or high frequency recordings and a sleep (off) period, with the exception of the two PORPOISE deployments at SCAT and INGO, during which recordings were continuous (no sleep period). The recordings used in this study were collected at a sampling rate of either 4, 8, 16, 24, 32, 64 or 256 kHz, and varied in length between 300 and 1740 s (5-29 min) repeated every 6.67, 8, 10, 15, 20 or 29 minutes (Table 1). Partial recording days were removed from the datasets (recordings collected from a single deployment) before subsequent processing steps.

DATA PROCESSING

All raw PAM data were processed using the Low Frequency Detection and Classification System (LFDCS; Baumgartner and Mussoline 2011, Woods Hole Oceanographic Institute). This detector-classifier system was designed to automatically detect baleen whale calls, including NARW upcalls, in PAM datasets. LFDCS down-samples recordings to a 2 kHz sampling rate, creates a spectrogram that excludes continuous and/or broadband noise, overlays a pitch track on remaining sounds, and then uses discriminant function analysis to classify the pitch track to a species based on libraries of known species calls (Baumgartner and Mussoline 2011). Although the LFDCS NARW upcall library (gom7) does not contain examples from Canadian waters, it has successfully been used to assess NARW upcall presence on datasets collected off eastern Canada in previous studies, including for all previous analyses of DFO-Maritimes recordings for NARW presence (Davis et al. 2017, Durette-Morin et al. 2022).

VALIDATION OF DETECTIONS

Due to similarities between NARW upcalls and other baleen whale calls (particularly humpback whale upsweeping calls) and some types of background noise (such as distant seismic airgun signals), LFDCS may classify some other types of signals present on the recordings as NARW upcalls, an error referred to as false positives or false alarms. To remove these false positives, following the methods of previously published studies (Davis et al. 2017, Durette-Morin et al. 2022), all LFDCS NARW upcall detections with a Mahalanobis distance (m-dist) ≤ 3 were manually validated to confirm that the automated detections were true NARW upcalls. Detections with an m-dist > 3.0 were not considered further, as they were more likely to be false positives (Baumgartner and Mussoline 2011).

Manual validation of NARW upcall detections consisted of visual/aural inspection of spectrograms and associated audio recordings by trained human analysts. The analysts classified each detection as one of the following:

- Correct – call characteristics of the detection matched those of NARW upcalls, other NARW calls may be present on the recording, no other confounding signals (such as humpback whale calls) were present on the recording, analyst was confident in species identification
- Unknown – call characteristics of the detection match or appear to match those of NARW upcalls, but due to low signal-to-noise ratio/poor quality of the received call, the presence of overlapping background noise, or the presence of other confounding signals (such as humpback whale calls) on the recording, the analyst was not confident in species identification
- Incorrect – detection was determined not to be a NARW upcall (the detection may have been caused by noise or a call made by another species such as humpback whale calls)

Only detections classified as correct were considered to be confirmed NARW upcalls, and were used in subsequent analyses. Any detections classified as unknown or incorrect were removed from further analyses.

DETECTOR PERFORMANCE

Because all false positives were removed during the validation step, this human-in-the-loop analysis approach resulted in a dataset with 100% true positives. However, another common detector error occurs when the target signal is present but not detected – referred to as false negatives or missed calls. The rate of missed calls was not assessed in this study due to analyst time constraints. Davis et al. (2017) evaluated LFDCS detector performance at the daily level by examining a subset of full days of recordings for three sites in the United States of America (USA), and reported that upcalls were missed on 31% of days and that these days generally had low numbers of calls. Durette-Morin et al. (2022), who also analyzed data from AMAR recorders throughout eastern Canadian waters, subsampled 825 hours of recordings with no NARW upcall detections to evaluate missed call rates, and found that no files containing NARW upcalls were missed by LFDCS for 66 of the 67 AMAR datasets included in their study. For one AMAR dataset, upcalls were found to be present on two consecutive days but LFDCS missed the upcalls that occurred on one of those days (note that this evaluation does not represent a thorough assessment of missed days with upcalls).

While the proportion of days with missed upcalls in the current analysis is unknown, many of these datasets have also been extensively analyzed for calls from other baleen whale species (including blue, fin, sei, humpback and minke whales calls). NARW upcalls were rarely detected when examining recordings for these other low frequency calls. Across all deployments, only four additional days with NARW upcalls were identified during the analysis for other species. This suggests that very few days with NARW upcalls present were missed.

ASSESSMENT OF PRESENCE

Validated upcall detections were used to assess minimum daily acoustic presence of NARW. Daily presence was defined as any day with one or more confirmed (correct) upcalls present. Figures showing the number of days per week throughout the entire recording period for each recording site are provided in Appendix A (Figures A1-A8).

To examine spatial trends in daily presence, the total number and proportion of recording days with confirmed NARW upcalls present were calculated for each area and site.

To examine seasonal trends in daily presence, the percentage of recording days with NARW upcalls present at a given site within a given season (all years combined) were calculated. Seasons were defined in this study based on meteorological temperate seasons for the Northwest Atlantic, as well as general patterns observed in upcall occurrence over time: winter

(December-February), spring (March-May), summer (June-August), and fall (September-November).

Monthly trends in daily presence were examined by determining the percentage of recording days with NARW upcalls present within each area for each month. For this analysis, all sites within an area were combined, and in cases where multiple years of data were collected the average percentage of days per month with NARW upcalls present were calculated.

Finally, variability in acoustic persistence (the number of consecutive days with NARW upcalls present; Davis et. al. 2023) over seasons was examined via histograms. Seasonal persistence was examined for all sites/areas combined, and for the BoF and SHELF-W areas specifically, since they include recording sites within NARW Critical Habitat. Periods of NARW upcall presence at a given site were described as “regularly occurring” if upcalls were present at least three days a week for two consecutive weeks, “sporadic” if upcalls were present for one or two days a week for two consecutive weeks, or “rare” if upcalls were present on only one day during non-consecutive weeks. These definitions follow Durette-Morin et al. 2022, although their term “persistent” was changed to “regularly occurring” in this current study.

RESULTS

SPATIAL TRENDS IN DAILY PRESENCE

A total of 15,179 recording days were collected from multiple sites over the five-year period of this study. Recording effort varied by area and site, with individual deployment durations ranging from 34 to 396 days (Table 1), and total effort in an area ranging from 375 to 3,795 days (Table 2).

A total of 1,829 NARW upcalls were confirmed to be present on 234 recording days, representing 1.5% of the total number of recording days (Table 2). The percent of recording days with upcalls present ranged from 0.1 to 4.9% within each area, and 0 to 5.2% within each site (Table 2). Generally, on-shelf areas had a higher upcall presence than slope areas, with the highest values observed in BoF (upcalls present on 4.9% of recording days) and SHELF-W (4.6% of days). The lowest upcall presence was observed in SLOPE-W and SLOPE-E (< 1% in both cases). At the site level, upcall presence was greatest at EMBD (upcalls present on 5.2% of recording days), followed by GMB and ROBV (4.9% each), ROB (4.4%) and INGO (4.3%). The lowest presence was generally observed at the deep-water slope sites (all < 0.5%), as well as at SAB (0.1%) and SABV (0%) (Table 2).

Table 2. Recording effort (number of recording days), number of confirmed North Atlantic Right Whale (NARW) upcalls, and number and percentage of recording days with confirmed NARW upcalls present overall and by season for each site and area: Bay of Fundy (BoF), Gulf of Maine (GoM), Western Scotian Shelf (SHELF-W), Central Scotian Shelf (SHELF-C), Eastern Scotian Shelf (SHELF-E), Cabot Strait (CABOT), Western Scotian Slope (SLOPE-W), Eastern Scotian Slope (SLOPE-E). For a given season, the percent of recording days with upcalls present was calculated based on the available recording effort within that season, which varied across recording sites (see Appendix A). NA indicates no recording effort for a particular season.

Area	Site Code	Number recording days	Total number confirmed upcalls	Number recording days with upcalls present (% recording days within specified time period with upcalls present)				
				All	Winter (Dec – Feb)	Spring (Mar – May)	Summer (Jun – Aug)	Fall (Sep – Nov)
BoF	GMB	1139	1077	56 (4.9)	0	4 (1.4)	4 (1.5)	48 (15.3)
GoM	JOBW	863	125	22 (2.5)	2 (1.1)	12 (5.1)	1 (0.4)	7 (3.9)
SHELF-W	ROB	940	112	41 (4.4)	8 (3.3)	5 (2.3)	6 (2.4)	22 (9.4)
	ROBV	553	200	27 (4.9)	1 (0.9)	7 (4.9)	8 (6.7)	11 (6)
	ALL	1493	312	68 (4.6)	9 (2.5)	12 (3.4)	14 (3.8)	33 (7.9)
SHELF-C	SBVC1	241	12	5 (2.1)	0	0	NA	5 (6.3)
	SBVC2	241	9	4 (1.7)	1 (1.1)	0	NA	3 (3.8)
	SBVC3	241	23	5 (2.1)	0	0	NA	5 (6.3)
	EMBD	382	96	20 (5.2)	4 (4.4)	2 (2.2)	4 (4.1)	10 (9.7)
	EMBS	1109	14	9 (0.8)	1 (0.4)	3 (1)	3 (1)	2 (0.9)
	ALL	2214	154	43 (1.9)	6 (1)	5 (0.8)	7 (1.8)	25 (4.3)
SHELF-E	MBK	376	31	10 (2.7)	2 (2.2)	4 (4.3)	1 (1.1)	3 (2.9)
CABOT	SCAT	133	4	2 (1.5)	2 (2.2)	0	NA	0
	SAB	799	14	1 (0.1)	0	0	0	1 (0.5)
	SABV	73	0	0 (0)	NA	NA	0	NA
	INGO	118	43	5 (4.2)	3 (3.3)	0	NA	2 (13.3)
	CSE	323	27	8 (2.5)	0	0	2 (2.2)	6 (3.4)
	CSW	421	21	8 (1.9)	1 (0.7)	0	1 (1.1)	6 (3.4)
	ALL	1867	109	24 (1.3)	6 (1)	0	3 (0.7)	15 (2.5)
SLOPE-W	COC	728	3	1 (0.1)	0	1 (0.5)	0	0
	GBK	583	3	3 (0.5)	1 (0.6)	0	2 (1.2)	0
	FCM	386	0	0 (0)	0	0	0	0
	FCH	1066	2	1 (0.1)	0	0	1 (0.4)	0
	EFC	357	1	1 (0.3)	0	0	0	1 (1.1)
	WSS	681	0	0 (0)	0	0	0	0
	ALL	3801	9	6 (0.2)	1 (0.1)	1 (0.1)	3 (0.3)	1 (0.1)
SLOPE-E	DAC	651	1	1 (0.2)	0	1 (0.5)	0	0
	LOC	633	4	1 (0.2)	0	1 (0.5)	0	0
	MGL	1397	7	3 (0.2)	0	0	3 (0.8)	0
	GLD	37	0	0 (0)	0	NA	NA	NA
	SFD	735	0	0 (0)	0	0	0	0
	ALL	3453	12	5 (0.1)	0	2 (0.2)	3 (0.3)	0
ALL COMBINED		**15206**	**1829**	**234 (1.5)**	**26 (0.6)**	**40 (1.1)**	**36 (1.0)**	**132 (3.5)**

SEASONAL TRENDS IN DAILY PRESENCE

NARW upcalls occurred off Nova Scotia throughout the year. While upcall presence was lowest in winter (0.6% of recording days with upcalls), they were still present during this time of year at multiple sites, often for multiple days (Table 2). Winter call presence was generally confined to GoM, SHELF-W, SHELF-C, SHELF-E, and the sites on the western side of the CABOT area (Figure 2). Presence increased over spring and summer (1.1% and 1.0% of recording days with upcalls present; Table 2), with upcalls mostly occurring at sites in BoF, GoM, SHELF-W, SHELF-C and SHELF-E (Figure 2). While upcalls were present in the CABOT area in summer, no upcalls were found in this area in spring (Figure 2). Presence was highest in the fall (3.5% of recording days with upcalls; Table 2), with upcalls occurring at every site throughout BoF, GoM, SHELF-W, SHELF-C, and SHELF-E, and at all but one site in CABOT (Figure 2). Upcall presence was generally much lower in SLOPE-W and SLOPE-E (Figure 2).

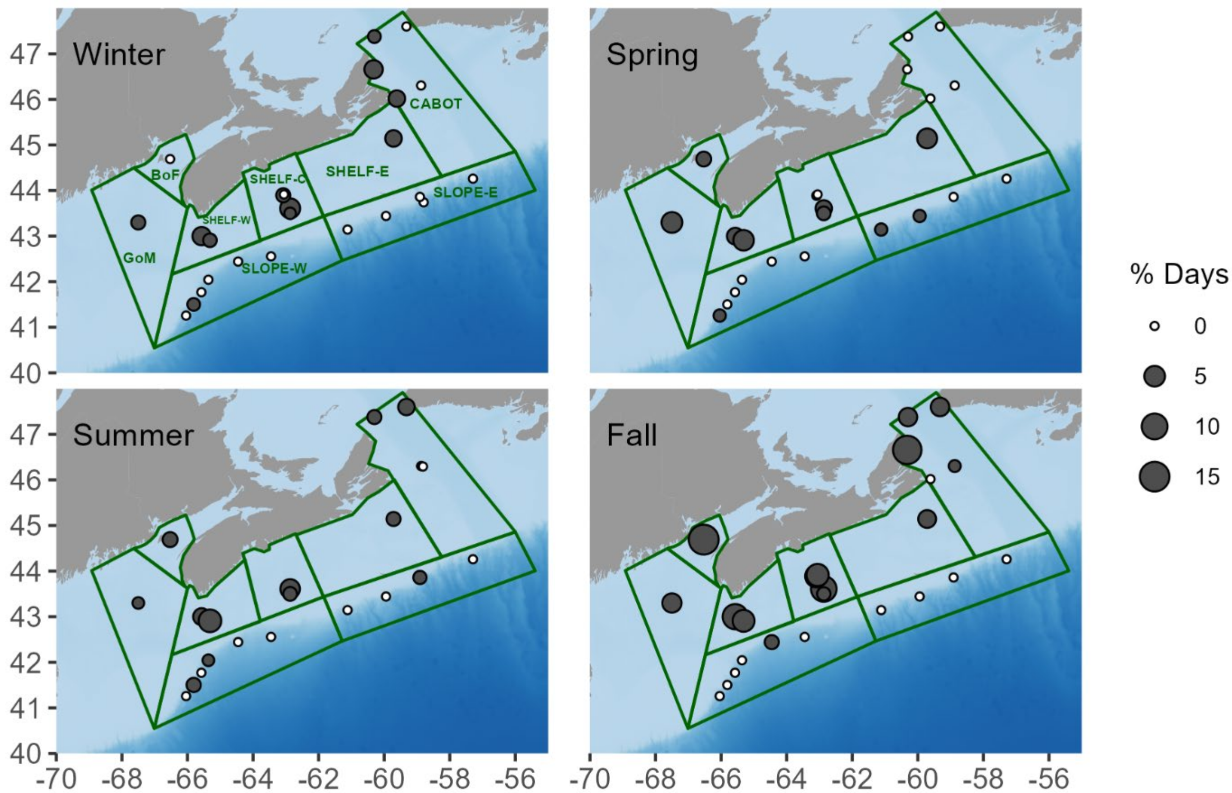

Figure 2. Percentage of recording days in winter (December-February), spring (March-May), summer (June-August) and fall (September-November) with confirmed North Atlantic right whale (NARW) upcalls present at each of the 27 recording sites (indicated by circles), all years combined. Geographic areas considered in this study are indicated in green: Bay of Fundy (BoF), Gulf of Maine (GoM), Western Scotian Shelf (SHELF-W), Central Scotian Shelf (SHELF-C), Eastern Scotian Shelf (SHELF-E), Cabot Strait (CABOT), Western Scotian Slope (SLOPE-W), Eastern Scotian Slope (SLOPE-E).

MONTHLY TRENDS IN DAILY PRESENCE

Examination of NARW upcall presence within each area by month provides further detail on potential occurrence and movement patterns throughout the region (Figure 3). Upcalls were present almost every month of the year within BoF, GoM, SHELF-W, SHELF-C and SHELF-E, with a small increase in upcall presence during the April-June period, and a larger peak occurring in the September-November period. Upcalls were present in the July-December period in CABOT, with a peak occurring in October. Again, upcalls only occasionally occurred within SLOPE-W and SLOPE-E.

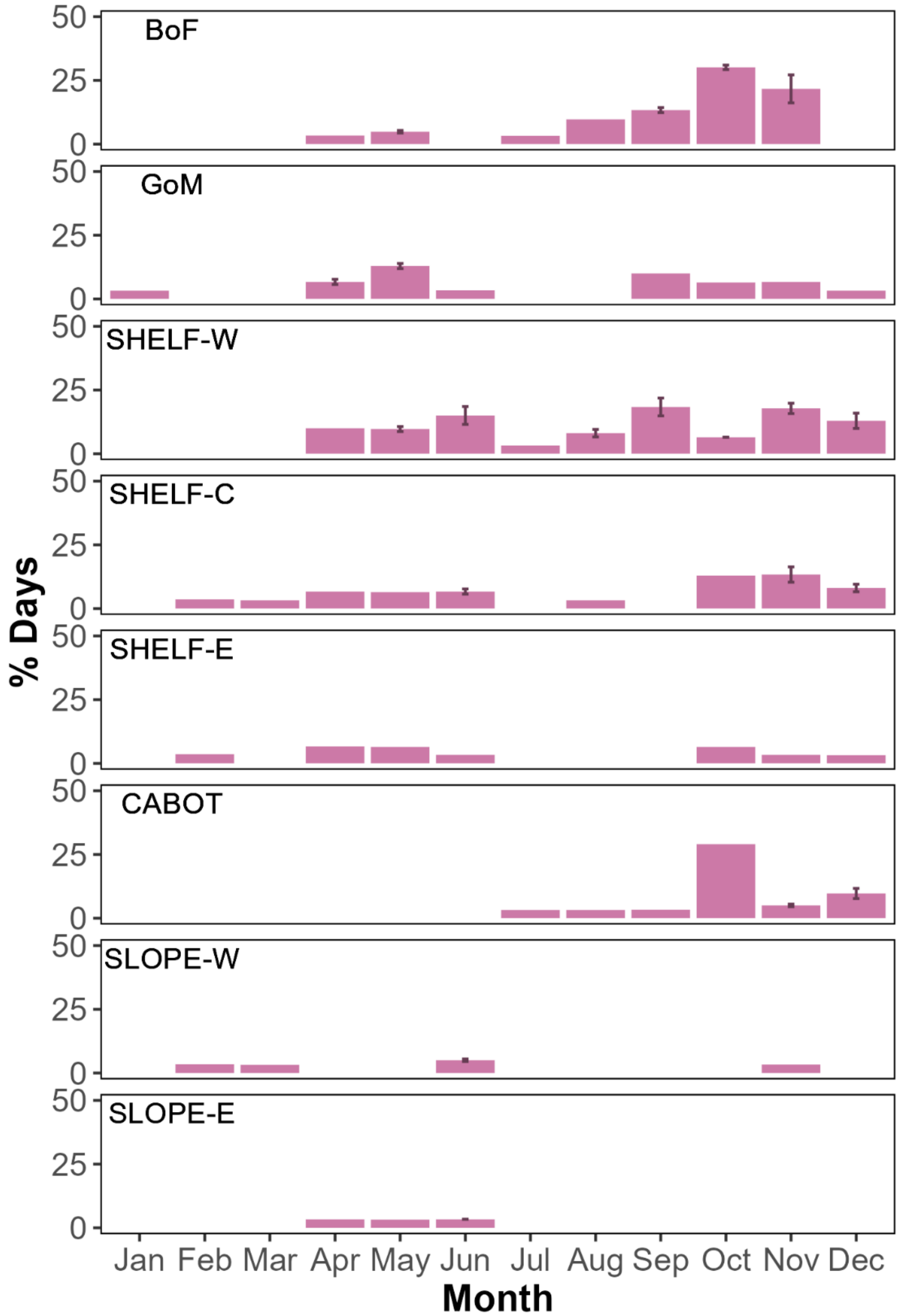

Figure 3. Percentage of recording days within each month with confirmed North Atlantic right whale (NARW) upcalls present within each area: Bay of Fundy (BoF), Gulf of Maine (GoM), Western Scotian Shelf (SHELF-W), Central Scotian Shelf (SHELF-C), Eastern Scotian Shelf (SHELF-E), Cabot Strait (CABOT), Western Scotian Slope (SLOPE-W), Eastern Scotian Slope (SLOPE-E). All sites within an area were combined, and in cases where multiple years of data were collected the average percentage of days/month with NARW upcalls present were calculated (error bars = standard error).

SEASONAL ACOUSTIC PERSISTENCE

In this study, NARW upcalls generally only persisted within an area for up to four consecutive days (Figure 4). During winter and spring, in most cases upcalls only occurred for one or two days in a row. This was also true of summer, though there were some cases where upcalls were present up to four consecutive days. In fall, upcalls commonly occurred for two or three consecutive days, and sometimes up to four consecutive days. This general trend holds true for the BoF and SHELF-W areas individually, with more consecutive days with upcalls present in fall (and also in the summer for SHELF-W) than during winter or spring.

In the BoF, no upcalls were detected December through March, upcalls tended to be rare April through July, sporadic in September, and regularly occurring in October and November (Figure A1). In SHELF-W, no upcalls were detected January through March, and were generally rare or sporadic April through December, with the exception of June in 2022 which had regularly occurring upcalls at ROBV (Figure A3). Periods of upcall presence were generally rare or sporadic throughout the year at sites in the GoM, SHELF-C, SHELF-E and CABOT areas (Figures A2, A4, A5 and A6), and were rare at all sites in SLOPE-E and SLOPE-W (Figures A7 and A8).

DISCUSSION

BROADSCALE DISTRIBUTION

The overall daily occurrence of NARW upcalls throughout the region was low (upcalls present on 1.5% of all recording days, or 0-5% of days within a given area), but this is not atypical of NARW throughout their broader range. Davis et al. (2017) assessed NARW acoustic occurrence on recordings collected during the period of 2004 to 2014 from 324 recorders deployed from Bermuda to the Davis Strait (though mainly concentrated off eastern USA), and reported 7% of the 35,600 recording days examined had confirmed NARW upcalls. Durette-Morin et al. (2022) examined NARW upcall presence on 80 acoustic recorder deployments conducted off eastern Canada (from the Bay of Fundy to Labrador) during the period of 2015 to 2017, and reported upcalls present on 3% of 18,400 recording days.

There remain many knowledge gaps in our understanding of NARW acoustic behaviour and calling rates, including rates of upcall production during different behavioural states. Generally, call rate has been shown to vary with behavioural state, with higher call rates observed when socializing at the surface or travelling than when foraging or resting (Matthews and Parks 2021). Call rates also generally increase with group size, though this relationship depends on group composition (Matthews and Parks 2021). Calling rates and upcall production have been shown to vary greatly among individuals within the same area; for example, Parks et al. (2011) report call rates that varied between 0 and 333 calls/h based on data collected from 46 acoustic tag attachments on 35 individuals in the Bay of Fundy over multiple years (2000, 2001, 2002 and 2005). Only 14 of these tag deployments had more than two calls produced by the tagged individual, and individual calling rates in these cases varied between 0.2-16.2 calls/h. Individuals often produced no or very few calls when logging, foraging or travelling, while the highest call rates were observed when whales were socializing in surface active groups. Periods of silence ranged from 0.35 to 14.1 h, with a mean of 2.9 h (± 2.8 h standard deviation). Only 15 of the 35 individuals tagged produced upcalls, with only 264 upcalls found on the 167.8 hours of recordings analyzed (Parks et al. 2011).

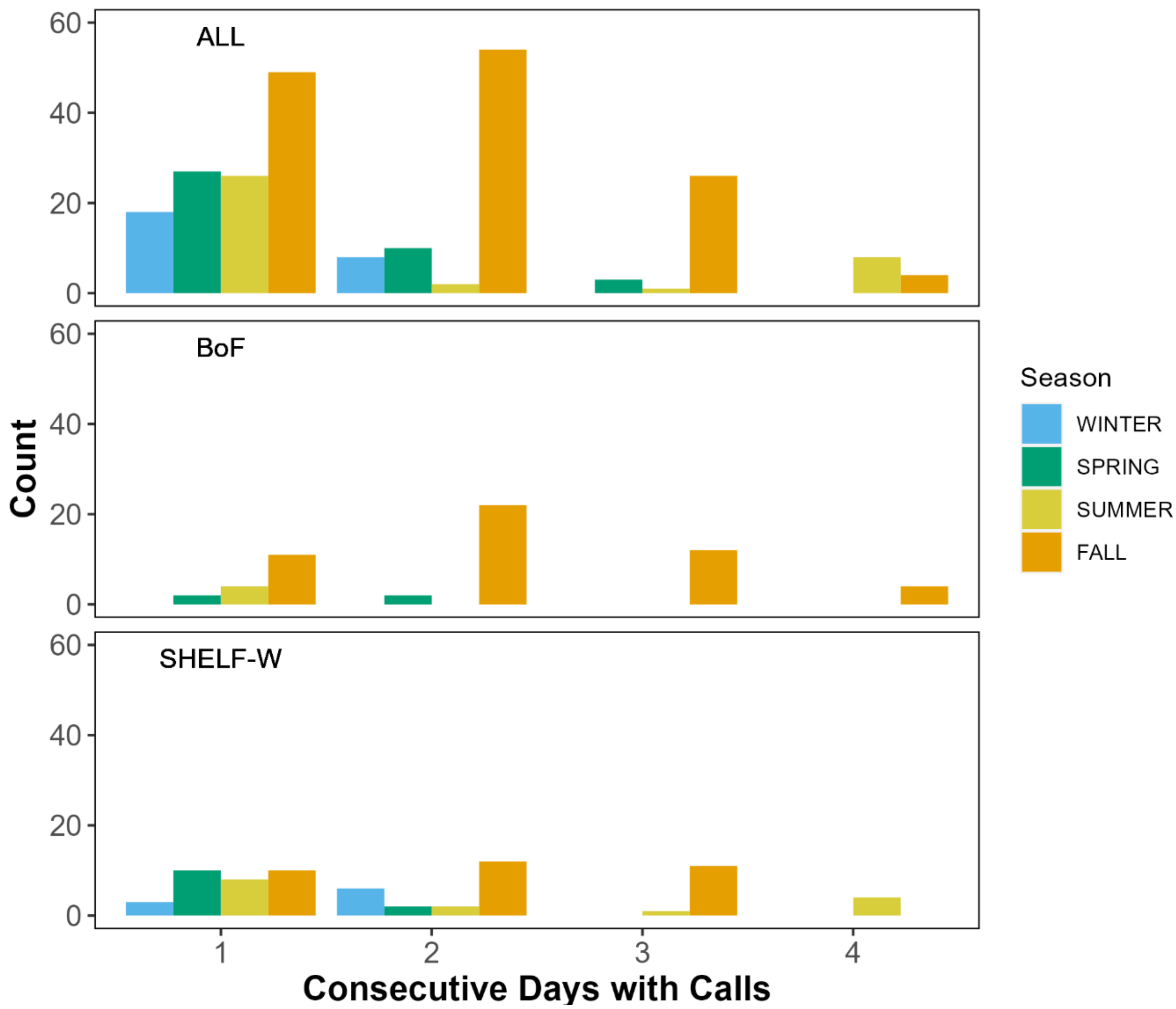

Figure 4. Histograms showing the number of consecutive days with confirmed North Atlantic right whale upcalls present by season (Winter = December-February, Spring = March-May, Summer = June-August and Fall = September-November) for all sites/areas combined (ALL), Bay of Fundy (BoF) and Western Scotian Shelf (SHELF-W).

Considering the large extent of the distribution and range of this very small whale population, the detection range of recorders generally being limited to tens of kilometres (though this depends on a number of factors including local environmental conditions and background noise, in addition to calling behaviour of the animals – such as the source level and depth at which calls are produced), incomplete temporal coverage by the datasets (many recordings were duty-cycled and not continuous), and the variable calling behaviour of the animals (generally having relatively low calling rates often with long periods of silence; Parks et al 2011), relatively low daily acoustic occurrence overall is not surprising. Rather, even low rates of acoustic occurrence, particularly if reoccurring over multiple years, suggests areas of potential importance for this species. With confirmed acoustic presence of NARW at all recording areas, this study supports previous PAM findings that NARW occur over a broad geographical range in eastern Canadian waters. Most of the Nova Scotia datasets included in the Davis et al. (2017) study (from Roseway Basin, Emerald Basin, and several shelf-edge sites), and all of the Nova Scotia datasets included in the Durette-Morin et al. (2022) study (some data from the Bay of

Fundy, several sites from the Scotian Shelf, and some shelf-edge sites) had at least one day with NARW upcalls present on them.

SEASONALITY AND MOVEMENT

NARW are generally considered a migratory species that mainly occur in eastern Canadian waters in summer and fall to feed, and migrate to coastal waters off the southeastern USA in winter to give birth (DFO 2014). This study shows that NARW occur off Nova Scotia year-round, including in all winter months, complementing previous findings for this region (Davis et al. 2017, Durette-Morin et al. 2022). Though daily upcall presence was lowest in winter, NARW upcalls occurred at 11 of the 27 recording sites, spread over six of the eight areas, showing a relatively broad distribution throughout the Gulf of Maine, Scotian Shelf and Cabot Strait in winter. It has long been recognized that not all individuals migrate to the southern calving grounds in winter (e.g., Gaskin 1991), and although less data is available on winter habitats outside of this area, Davis et al. (2017) show broadscale acoustic occurrence throughout the winter along the entire eastern seaboard of the USA and off Nova Scotia, demonstrating the expansive winter habitat of this species.

Call presence increased in spring, occurring at more sites spread over seven areas, and continued to increase throughout summer, with upcalls found at more sites in all eight areas. Increasing call presence in spring and summer off eastern Canada supports the idea of increased movement into eastern Canadian waters during this period (as previously suggested by Davis et al. 2017), which also corresponds to decreased acoustic presence of NARW observed in the more southern regions of their range off the USA (from waters off Florida to New York) during summer months (Davis et al. 2017), and increased acoustic presence observed in the Gulf of St. Lawrence (Simard et al. 2019).

Call presence peaked in the fall, with the highest daily upcall presence occurring in all of the geographic areas considered in this study except the two slope areas. Similarly, Davis et al. (2017) and Durette-Morin (2022) also observed the highest presence at Nova Scotia sites in the September to November period. NARW acoustic presence in the Gulf of St. Lawrence was highest in the August to October period, though call presence tended to decrease in this region starting in mid-September (Simard et al. 2019). Visual surveys have indicated that NARW are present in the Gulf of St. Lawrence region throughout the period these surveys occur, from at least May to December, with the highest numbers of sighting events occurring in July and August when most survey effort tends to occur (Crowe et. al. 2021, DFO 2020). Abundance estimates based on systematic surveys in the southern Gulf of St. Lawrence for November 2017 and September/October 2018 show that there were still relatively high numbers of NARW in this region during fall (DFO 2020). However, increased acoustic presence in the fall coupled with increased persistence of upcalls over multiple consecutive days off Nova Scotia (and the regular occurrence of calls in the Bay of Fundy) supports increased movement into Nova Scotia waters from the Gulf of St. Lawrence or other areas during this time of year.

Seasonal changes in upcall detection or presence could indicate changes in use of a given site (more animals moving into or out of an area), or a shift in calling behaviour of the whales (seasonal changes in the rate of upcall production). There are no available data on how NARW call production rates may vary throughout the year, and it is not known if upcall production rates change. There is some evidence that increases in NARW call rates are correlated to the number of individuals present; for example, Durette-Morin et al. (2019) demonstrated a positive relationship between call counts and the relative abundance of NARW over multiple years in Roseway Basin during the August to September period. However, Franklin et. al. (2022) compared concurrent visual and acoustic observations of NARW over multiple years in the Gulf of St. Lawrence and concluded that call rates were too variable to reliably predict density of animals. Rather, increases in NARW call rates from the June to August period were more predictive of behavioural state (increases in observed social behaviour), also observed by Durette-Morin et al. (2019), rather than the number of whales present (Franklin et al. 2022). While the minimum call presence reported in our study cannot be used to determine either the number of animals present or their behavioural state, it does demonstrate seasonal changes in the occurrence of upcalls in waters off Nova Scotia that correspond with broader movement patterns reported in other studies.

Sightings data for NARW off Nova Scotia in recent years are limited with only 152 NARW sighting events documented in Nova Scotia waters between November 2017 and September 2022 from various sources (see Appendix B). All sightings occurred between May and November, with some sightings in spring, increasing number of sightings over summer, and the highest number of sightings occurring in fall: May (12% of sightings), June (13%), July (13%), August (18%), September (36%), October (6%), November (2%). These data are highly biased by when and where visual survey efforts have occurred off Nova Scotia and no corrections for observation effort have been made, thus these sightings also only represent minimum presence. However, the sightings generally support the observed trends in acoustic occurrence in this region.

SHELF VS SLOPE WATERS

Despite significant recording effort along the Scotian Slope since 2005, NARW upcalls are rarely detected suggesting that these deep water sites are not regularly used by NARW (Davis et al. 2017, Durette-Morin et al. 2022). NARW tend to produce upcalls near the surface, as evidenced by data collected from acoustic tags placed on NARW in the Bay of Fundy, which showed that upcalls were produced at depths between 0 to 109 m with a median calling depth of 2 m (Parks et al. 2011). The surface calling behaviour of NARW may limit the range to which upcalls can be detected on our deep slope recorders, which were deployed at depths of approximately 1300-2500 m. At these sites, the recorders likely have a greater detection range out into deeper off-shelf waters than on-shelf waters due to the slope bathymetry. A deep-water sound channel that persists throughout the year occurs around 600–750 m depth (referred to as the SOFAR channel)[1]; and during times of the year when the surface water warms (late spring to early fall), a thermocline develops around 100-200 m (Drinkwater and Gilbert 2004), creating a second sound channel. Both of these sound channels affects the propagation of sounds produced near the surface into deeper water. Sound propagation at these sites may also be affected by occasional warm water incursions of the Gulf Stream into these off-shelf areas (Li et al. 2015). Though detection range modelling was not completed for this study, these sites tended to have relatively low background noise levels compared to on-shelf or other shallower water or more coastal sites, and other baleen whale calls that occur in the same frequency range as NARW upcalls are regularly heard on deep-water slope recordings (e.g., Kowarski et al. 2017, Macklin 2022, Wingfield et al. 2022b). This suggests that if NARW were regularly producing upcalls in these areas, they would be detected. Further, very few visual sightings of NARW have been reported around the Scotian Shelf edge (see Appendix B), even in areas where there have been significant cetacean-focused field studies, such as the Gully (e.g., Whitehead 2013).

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[1] Global Ocean Physical Multi Year product. E.U. Copernicus Marine Service Information (CMEMS). Marine Data Store (MDS). DOI:10.48670/moi-00021 (Accessed on 18 Oct 2024)

These results support greater use of the on-shelf areas by NARW, as opposed to deeper shelf-edge/slope areas (SLOPE-W, SLOPE-E). The Scotian Shelf is likely to be part of the movement corridor for NARW in general, though higher acoustic presence (and persistence of upcalls over multiple days at least in SHELF-W), particularly in fall, suggests that these areas (SHELF-W, SHELF-C, SHELF-E) may support habitat functions beyond movement. Understanding if and how NARW may be using even deeper waters beyond the slope is outside the scope of this study.

OCCURRENCE IN EXISTING CRITICAL HABITATS

Overall daily acoustic occurrence of NARW was highest in the BoF and SHELF-W areas. The Grand Manan and Roseway Basin sites had some of the highest rates of upcall presence observed in this study. This suggests that these Critical Habitats remain important to NARW despite the decreased number of visual sightings that have been reported in these areas in recent years (e.g., DFO 2019, 2020).

In the Grand Manan Basin Critical Habitat (the GMB site/BoF area), no upcalls were detected from December to March, and upcall presence remained low in spring and summer, but increased in the fall (September-to November) when the highest persistence was documented. In the fall, GMB had the highest upcall presence of any of the sites in any season, and was the only area and season where upcalls were considered to be regularly occurring. PAM data previously collected from within and near the Grand Manan Basin Critical Habitat in the 2004 to 2010 period showed frequent occurrence of NARW upcalls in summer and highest upcall presence in fall (Davis et al. 2017). PAM data collected from August 2015 to April 2016 within and near the Grand Manan Basin Critical Habitat showed sporadic NARW acoustic presence throughout the fall months, with upcalls also occurring in December and on one day in January (Durette-Morin et al. 2022).

The bottom-mounted recorders used in this study are expected to have a detection range on the order of tens of kilometres. As a result, it is possible that some of the upcalls detected within Grand Manan Basin occurred outside the Critical Habitat boundaries. While detection range modelling for the various monitoring sites was not completed as part of this study, it would provide insight into the extent of the area being monitored at this location. Other PAM efforts in this area in the 2015-2022 period demonstrate that NARW in the outer Bay of Fundy are not restricted to Grand Manan Basin Critical Habitat, and acoustic presence has also been documented in more coastal areas north of the Critical Habitat boundaries (see Appendix D). Upcalls were detected on one day (in June 2020) during an approximately two-month acoustic recorder deployment northwest of Grand Manan island near Lubec, Maine, conducted by NOAA’s Northeast Fisheries Science Center[2]. Sightings that have been reported in the Bay of Fundy further support that NARW occur outside the boundaries of the Critical Habitat. Between November 2017 and September 2022, a total of 152 NARW sightings were reported by various sources in Nova Scotia waters, from the Bay of Fundy to the Cabot Strait. Of these, 63% of them were in the Bay of Fundy area, the majority of which were reported northwest of the Grand Manan Basin Critical Habitat (Appendix B). Most of these sightings were reported in summer and early fall, corresponding to when most cetacean search effort occurs in this area. NARW sightings data collected from vessel-based NARW monitoring surveys in the outer Bay of Fundy

[2] Passive Acoustic Cetacean Map (PACM). 2024. Woods Hole (MA): NOAA Northeast Fisheries Science Center v1.1.10 [September 27 2024].

from 1987 through 2016 showed evidence of NARW occurrence increasing in the Owen Basin and The Wolves area northwest of the Critical Habitat (Davies et al. 2019).

The high acoustic presence and persistence of NARW in late fall, including November in Grand Manan Basin coincide with the opening of lobster fisheries in the Bay of Fundy. This suggests the importance of increased real-time surveillance efforts in the fall to effectively implement the dynamic fisheries management measures, such as temporary fisheries closures, aimed at decreasing the risk of entanglements. The outer Bay of Fundy is also an area of high vessel traffic, and the existing NARW Critical Habitat partly overlaps the TSS leading to and from the Port of Saint John, New Brunswick (NB). It also intersects several ferry transit routes, including one that regularly operates between Grand Manan island and mainland NB north of the island, passing through the areas where recent NARW sightings have been reported. Additionally, the area is frequented by traffic associated with fishing, ecotourism, and recreational activities. Continued regular occurrence of NARW in this area highlights the ongoing need for mitigation measures to reduce potential vessel strikes. This includes reinforcing the recommendation to decrease vessel speed to < 10.0 knots when transiting through this area between June and December as outlined in the annual Notices to Mariners (see Section A2-5) and monitoring compliance with this recommendation.

There was consistent relatively high NARW upcall presence within the Roseway Basin Critical Habitat (ROB and ROBV sites/SHELF-W area) year round, with the lowest presence observed in winter (and no upcalls detected in the January to March period). Upcall presence increased throughout spring and summer, and peaked in fall, where upcalls were present on > 6% of recording days at each site. Similar trends in acoustic presence have been reported in past NARW PAM studies. Mellinger et al. (2007) collected PAM data from Roseway Basin from July 2004 to August 2005 and recorded upcalls in Roseway Basin from June to December, with peak presence observed in the August to October period, and no upcalls detected in the December to May period. Durette-Morin et al. (2022) also reported high NARW upcall presence in Roseway Basin in the 2015-2017 period, with upcalls regularly detected from June to December.

Acoustic data collected using Slocum gliders deployed within the Roseway Basin area over shorter time frames (days-months)further support the presence of NARW during fall from November 2017 to September 2022. NARW upcalls were heard on four of nine glider deployments in and around Roseway Basin, totalling 18 days with confirmed NARW upcalls across September, October and November, though not all of the acoustic detections occurred within the Critical Habitat boundaries (see Appendix C). As with Grand Manan Basin, it is possible that some of the upcalls detected within Roseway Basin during ROB and ROBV deployments occurred outside the boundaries of the Critical Habitat, although this was not verified with detection range modelling.

While only eight NARW sightings have been reported in the Roseway Basin Critical Habitat from November 2017-September 2022 (Appendix B; three occurred in late May/early June, four in August/September and one in mid-November; though these are biased by when/where search effort occurs), the 68 days with confirmed upcalls reported in this study, along with additional upcall detections from glider deployments, (Appendix C) suggest continued use of this Critical Habitat throughout most of the year, particularly in fall when the highest acoustic presence and persistence was observed. This also suggests that with the limited visual survey effort that occurs in the Roseway Basin Critical Habitat, PAM provides essential information on the occurrence and persistence of NARWs in this area.

Increased real-time surveillance efforts are needed in this area for effective implementation of dynamic fisheries management measures (temporary closures) aimed at decreasing entanglement risk. Additionally, the NARW Roseway Basin Critical Habitat remains a seasonal

International Maritime Organization recommendatory Area To Be Avoided (ATBA) from June 1 – December 31 each year. It is also recommended as a vessel slow-down area, with a speed limit of less than 10.0 knots for vessels transiting through this area between June and December as outlined in the annual Notices to Mariners Section A2-5. Compliance with the ATBA and recommended vessel slow-down speeds should continue to be monitored and reinforced in this area.

OCCURRENCE IN THE CABOT STRAIT AREA

The Cabot Strait is assumed to be the primary migration route for NARW entering and leaving the Gulf of St. Lawrence. However, very few sightings of NARW have been documented in this area (e.g., see Appendix B), likely related to highly limited visual survey efforts occurring in the area (DFO 2019, 2020). Use of this area and the timing of movements into and out of the Gulf of St. Lawrence thus remain uncertain (DFO 2019).

Acoustic presence of NARW within the Cabot Strait and surrounding region (SCAT, SAB, SABV, INGO, CSW and CSE sites/CABOT area) was relatively low overall, with upcalls occasionally detected from July to December, and upcall presence greatest in fall (October). Similar trends were reported by Durette-Morin et al. (2022), with inconsistent acoustic presence from late May to mid-December, and less than 1% of recordings days with upcalls present in this area. There were two days in October 2021 and one day in November 2021 with NARW upcalls reported from deployments of Slocum gliders equipped with PAM packages (see Appendix C). Notably, the inshore INGO site had the highest acoustic presence outside of the sites within the current Critical Habitat areas, particularly in fall, despite limited data collection from this site, which only covered the late fall and winter period of a single year (mid-November to early March). The limited number of NARW sightings reported in this area between 2017-2022 were reported near the Cape Breton coastline, although these data are not corrected for observation effort. Further data collection from coastal sites in this area would allow for a more thorough investigation of how NARW are utilizing the shallow waters near the shoreline.

While there have been visual and acoustic detections of NARW in the Gulf of St. Lawrence in late April/early May (DFO 2019, 2020, Simard et al. 2019), the low number of confirmed upcalls in spring suggests that PAM recorders are missing individuals transiting this area on their way into the Gulf. The same is likely true for NARW leaving the Gulf in the fall. This could be due to a number of different reasons including: our limited recording effort at these sites during the study period; recorder locations being located outside their main transit routes; high noise levels in the area masking calls or greatly reducing detection range of the recorders given the proximity to major shipping routes and high amounts of vessel traffic; behaviour of the whales and a general lack of upcall production when NARW are travelling through this area. A more thorough assessment of ambient and anthropogenic noise levels, detection range modelling, and probability of detection are needed to better interpret the results from this area. Additionally, there is evidence of lower call rates when NARW are travelling (Parks et al. 2011). In the Gulf of St. Lawrence call rates were observed to be lower earlier in summer (June) compared to later in season (August) despite high numbers of NARW present throughout this period. This decrease in call rates was attributed to increased social behaviour later in the summer (Franklin et al. 2022).

OCCURRENCE IN OTHER AREAS

Emerald Basin, located on the central Scotian Shelf and east of Roseway Basin, particularly the EMBD site, had relatively high NARW acoustic presence throughout the year, with a notable peak in the fall. During this period, NARW upcalls were present nearly 10% of the recording days. Mellinger et. al. (2007) also documented frequent acoustic occurrence of NARW from

June to December in Emerald Basin on recordings collected from this area from July 2004 to August 2005; however, a higher call presence was documented in Roseway Basin during this same period in this earlier study. Durette-Morin et al. (2022) report rare to sporadic presence of NARW calls in Emerald Basin throughout the year (with upcalls detected in every month except March) in the 2015-2017 period, with peak presence occurring August to October. The Emerald Basin recording station monitored by Durette-Morin et al. (2022) corresponds to the EMBD site in this current study, and acoustic occurrence at EMBD in 2015-2017 and 2021-2022 was generally much higher with upcalls present on approximately 5-6% of recording days, compared to the nearby EMBS site (approximately 12 km away) where upcalls present on < 1% of recording days. This suggests a higher occurrence of NARW within the deep basin rather than along the southern edge or adjacent to the basin, and further highlights how specific recorder location can impact results. Few NARW sightings were reported in the SHELF-C area from 2017-2022 (Appendix B), likely due to limited search effort in and around this area; however, of the sightings that were reported, most occurred near the coast during spring. Expanding data collection efforts in shallow coastal waters could provide a clearer understanding of how frequently NARWs occur close to shore.

There was occasional NARW acoustic presence at the JOBW site in the GoM area throughout the year, located near Jordon Basin. Peak upcall presence was observed in spring, with a second smaller peak observed in fall. Extensive PAM efforts have been conducted in the broader Gulf of Maine area, particularly in USA waters between 2004-2012, which demonstrate acoustic occurrence of NARW year round. Peaks in daily call presence were observed in July-August and December-February, with a decline in acoustic occurrence documented during 2011-2014 compared to 2004-2010(Davis et al. 2017). Since 2020, PAM efforts in the broader Gulf of Maine have expanded to include additional sites in Canadian waters (e.g., see “All Deployments” on NOAA’s Passive Acoustic Cetacean Map). Analysis of these data for NARW upcall presence are currently underway and will provide further insights into NARW occurrence throughout the broader Gulf of Maine

Similar to JOBW, there was occasional acoustic occurrence in single site (MBK) in the SHELF-E area, located in Misaine Bank. Peak upcall presence was observed in the spring, with a smaller peak in the fall. While Davis et al. (2017) did not present data from this area, Durette-Morin et al. (2022) found rare to sporadic upcalls at their recording station near Misaine Bank (approximately 30 km away from the MBK site), with confirmed upcall presence on 5% of recording days. They also had another recording station in the eastern Scotian Shelf area that had upcalls on 6% of recording days (Durette-Morin et al. 2022). Few NARW sightings have occurred in this area in the 2017-2022 period (Figure B1), but there has also been relatively little visual survey effort throughout the eastern Scotian Shelf. The results presented for this area come from a single year of deployment at a single site; further data collection is needed to better understand occurrence of NARW throughout the broader eastern Scotian Shelf area.

INTERPRETATION OF PASSIVE ACOUSTIC MONITORING RESULTS

There are several limitations and considerations when using PAM data to assess trends in cetacean occurrence. Firstly, it is likely that the results presented in this document underestimate the daily presence of NARW. The datasets were not continuous recordings so upcalls may have occurred during times the systems were not recording. NARW could also be present and calling outside the range of the recorder, or may be present and producing other sounds such as gunshots, moans, or groans, or may be present but not calling. Furthermore, this study did not assess the performance of LFDCS, particularly the rate of missed upcalls. Detector performance, including missed call rate, generally varies with signal-to-noise ratio, which is impacted by background noise and local environmental conditions, and may change with site, season, presence of other species, presence of human activities, or other factors. While false positives were removed from the datasets analyzed in this study, missed calls were not assessed. Given the generally low occurrence of NARW upcalls in these datasets, a systematic analysis to identify additional upcalls potentially missed by the detector would require a significant time investment, as it would require manually reviewing a large portion of the data. However, such an analysis may not identify missed upcalls and therefore provide additional information on the rate of false negatives. The missed call rates associated with the analysis methods used in this study are expected to be low, especially when scaling results up to the level of daily presence. It is likely that some days with upcalls were not detected (Davis et al. 2017), especially since call occurrences were infrequent at some recording sites. Therefore, the results presented in this document should be interpreted as representing the minimum NARW presence within a given area and time period.

The area monitored by the recording systems (i.e., the range to which NARW upcalls can be detected) is generally assumed to extend from a few to tens of kilometres around a recording site (e.g., Johnson et al. 2020, Simard et al. 2019, Gervaise et. al. 2021). However, the actual detection range will vary depending on factors such as the type of recording system used, hydrophone sensitivity, mooring configuration, as well as with background noise and local environmental conditions, which can change seasonally, or daily. The detection range also depends on the source levels of the calls produced by the whale, which can vary within and among individuals, and likely also with the context that the call is being produced. Therefore, the detection range likely varies over space and time. Although detection range modelling has not been completed for the sites/datasets presented in this study, consideration should be given to the potential variability in detection range within and between sites over time when interpreting the results.

The number of NARW upcalls detected, and the number or proportion of days with calls present, may not correspond to the number of individuals within an area or during a certain time of year, or with a particular behavioural state such as foraging, breeding and travelling. With single omnidirectional hydrophones it is not possible to count or track individual calling animals. Additionally, gaps in the knowledge of NARW calling behaviour throughout this region prevent the correlation of the number of calls or call presence with specific behaviours. The results presented in this document should therefore only be interpreted as evidence of the presence or persistence of calling animals.

CONCLUSIONS AND FUTURE RECOMMENDATIONS

This study highlights the value of PAM for assessing the occurrence of NARW in the region throughout the year, including during periods when weather makes visual survey efforts very challenging or not feasible. PAM data not only complements visual sightings data, but in some cases provides more extensive or new information on presence of this species that could not be achieved from visual survey efforts.

The results from this PAM study show that:

- NARW are present in Nova Scotia waters throughout the year
- Acoustic presence and persistence of upcalls in this region was greatest in fall (September-November)
- Acoustic presence was greater in shallower water of the on-shelf areas as compared to deeper slope waters, suggesting that NARW migrate to/from the Gulf of St. Lawrence and other areas along the Scotian Shelf rather than along the Scotian Slope

- Relatively high acoustic presence and persistence in Grand Manan Basin and Roseway Basin support that these areas remain Critical Habitat for NARW
- Acoustic presence was also relatively high in Emerald Basin, suggesting that NARW commonly occur in the central Scotian Shelf area
- Upcalls were present in the Cabot Strait from July to December (with a peak in October), but further studies are required to fully understand how NARW use this area
- Additional data from the Gulf of Maine is needed to fully understand how NARW use this area (extensive data collection and analysis is currently underway)
- Given the highly limited PAM and visual survey data collection on the eastern Scotian Shelf , further studies are also required to better understand how NARW use this area

PAM technologies are fast advancing and in addition to the archival PAM systems used in this study to collect data from sites of interest over long temporal periods, near real-time PAM systems have been tested (Theriault et al. 2020) and/or are actively collecting marine mammal acoustic occurrence data off eastern Canada (e.g., Appendix C, Gervaise et al. 2021, Indeck et al. 2024). This includes DFO Maritimes Region's Whale Acoustic Slocum Program, which has been conducting deployments of Slocum gliders equipped with smart hydrophones to provide information on the acoustic occurrence of baleen whales within Emerald and Roseway basins and the southern Gulf of St. Lawrence in near real-time since 2023. While real-time PAM is a useful tool for understanding current species occurrence in an area and supporting implementation of dynamic management measures, it can also be challenging to implement. It often requires additional infrastructure and resources compared to archival PAM systems such as smart recorders with onboard data processing capabilities, running cables to land-based stations or to the surface to allow for data transmissions, efficient data transmission systems, and dedicated acoustic analysts to review incoming data promptly. Archival PAM systems continue to be a valuable and commonly used method for collecting long time series data on NARW occurrence throughout their range.

Future archival PAM studies off Nova Scotia should continue to monitor the existing Critical Habitats in Grand Manan Basin and Roseway Basin, as well as areas adjacent to current Critical Habitat boundaries that appear to be regularly used by NARW (such as to the northwest of Grand Manan Basin and east of Roseway Basin), to increase understanding of the full extent of the habitat important to NARW. Efforts are currently underway to expand monitoring effort near the Cabot Strait area. This increased coverage will provide more information on occurrence and use in this important movement corridor. Consideration should also be given to expanding PAM efforts to additional areas of the Scotian Shelf that have had more limited PAM and/or survey efforts in the past, including in shallower coastal waters, to fill in knowledge gaps.

Additionally, it is recommended that noise assessment and detection range modelling be conducted to better understand detection probability at the recording sites, particularly in areas with high management significance such as the Cabot Strait. This area includes a major shipping route that generates high amounts of low frequency noise that may mask NARW calls, and also poses a vessel strike risk to individuals passing through the area. Understanding detectability via PAM is required to implement effective management measures such as vessel slow-downs.

Future PAM studies should also consider including other calls produced by NARW. In addition to upcalls, NARW also produce gunshots, moans, and other call types throughout their range (Matthews and Parks 2021). These other call types may be produced even in the absence of upcalls (Durette-Morin et al. 2019, Franklin et al. 2022), and incorporating their occurrence into PAM studies could provide a more complete picture of NARW habitat use and behavioural state, though developing reliable detector-classifiers for these other call types will require significant effort.

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APPENDIX A – WEEKLY UPCALL PRESENCE

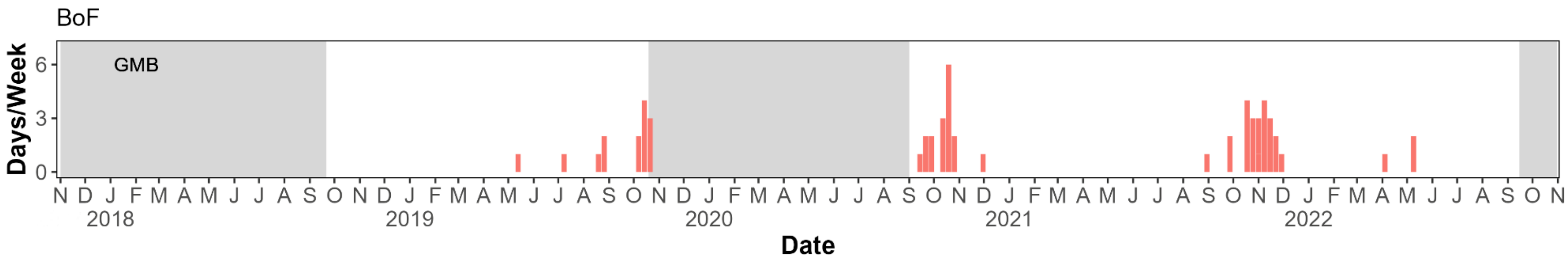

Figure A1. Number of days/week with confirmed NARW upcalls present (orange bars) at with the Bay of Fundy (BoF) area recording site throughout the study period (November 2017-September 2022). Grey shading represents periods with no recording effort.

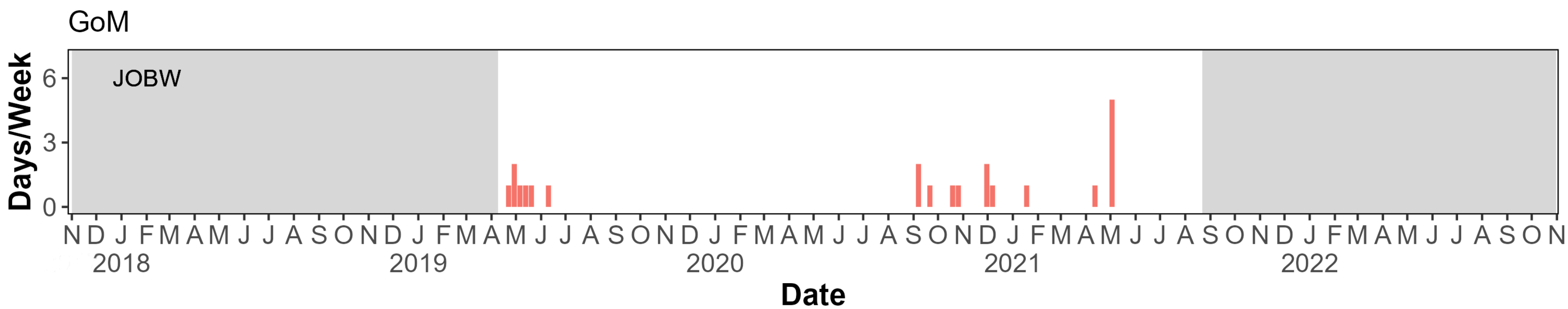

Figure A2. Number of days/week with confirmed NARW upcalls present (orange bars) at with the Gulf of Maine (GoM) area recording sites throughout the study period (November 2017-September 2022). Grey shading represents periods with no recording effort.

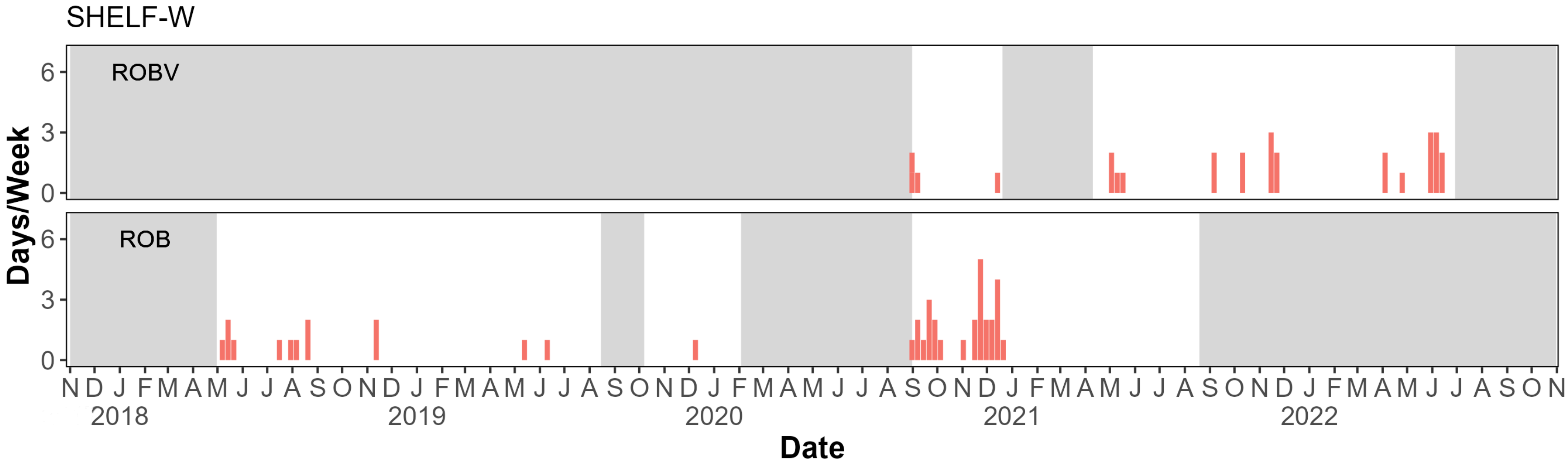

Figure A3. Number of days/week with confirmed NARW upcalls present (orange bars) at with the Western Scotian Shelf (SHELF-W) area recording sites throughout the study period (November 2017-September 2022). Grey shading represents periods with no recording effort.

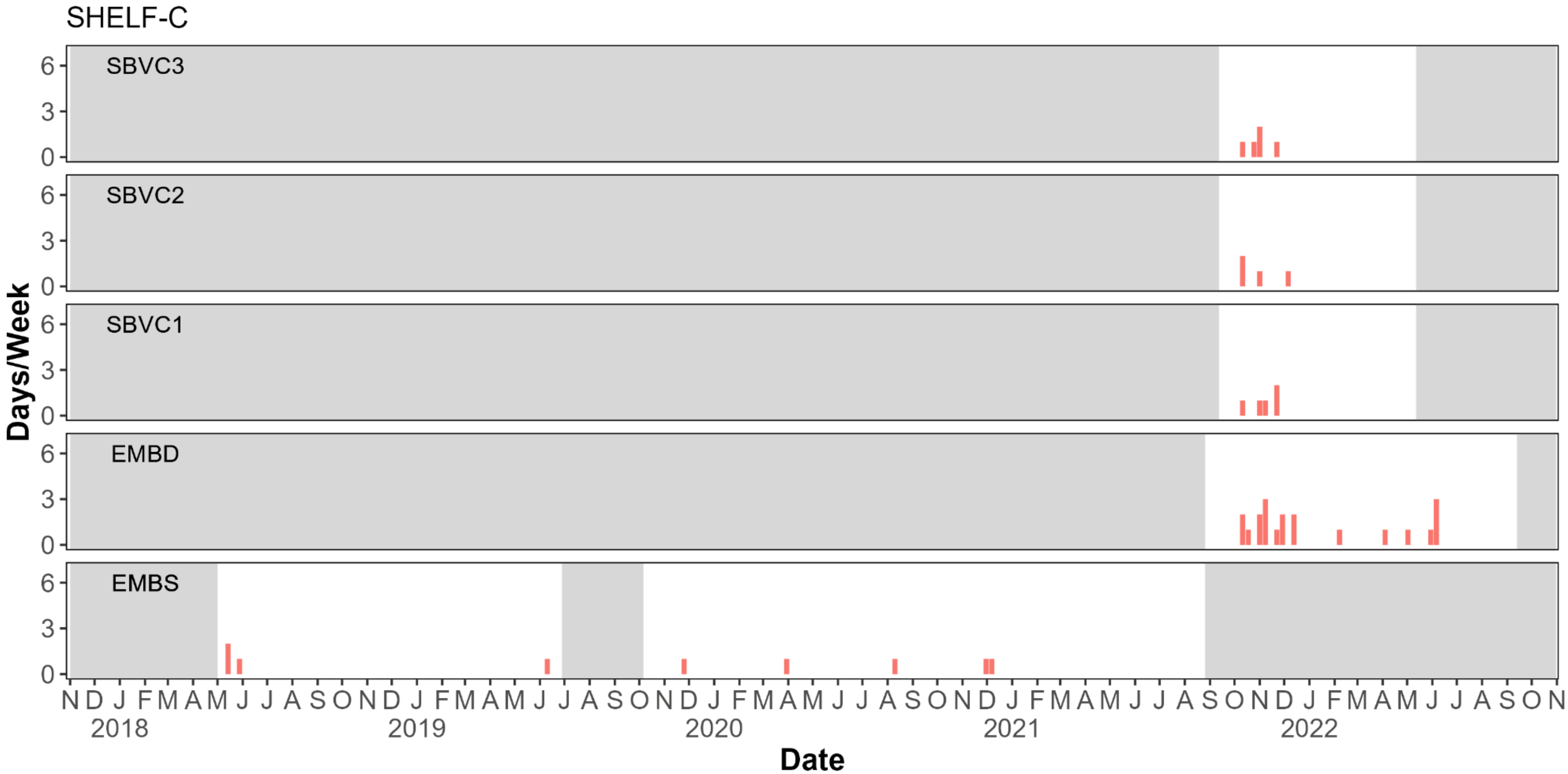

Figure A4. Number of days/week with confirmed NARW upcalls present (orange bars) at with the Central Scotian Shelf (SHELF-C) area recording sites throughout the study period (November 2017-September 2022). Grey shading represents periods with no recording effort.

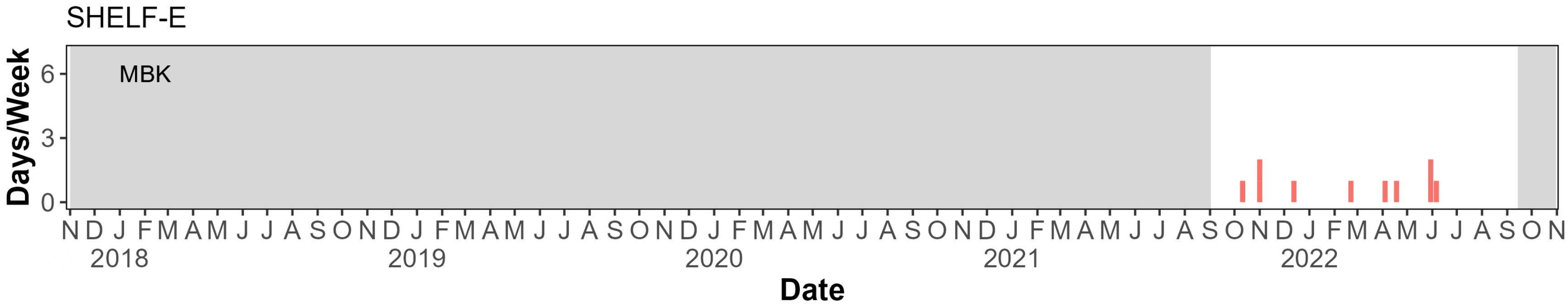

Figure A5. Number of days/week with confirmed NARW upcalls present (orange bars) at with the Eastern Scotian Shelf (SHELF-E) area recording sites throughout the study period (November 2017-September 2022). Grey shading represents periods with no recording effort.

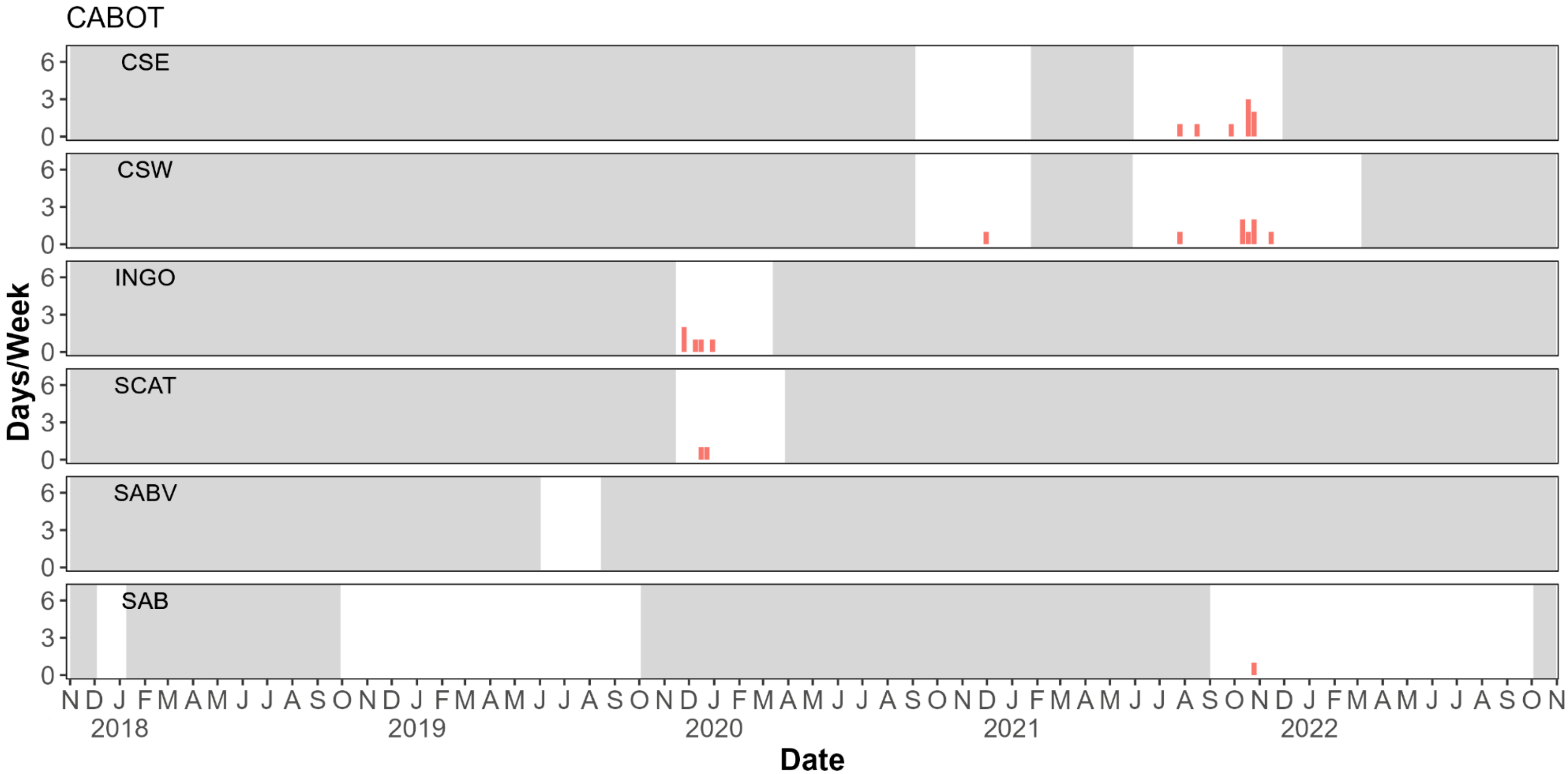

Figure A6. Number of days/week with confirmed NARW upcalls present (orange bars) at with the Cabot Strait (CABOT) area recording sites throughout the study period (November 2017-September 2022). Grey shading represents periods with no recording effort.

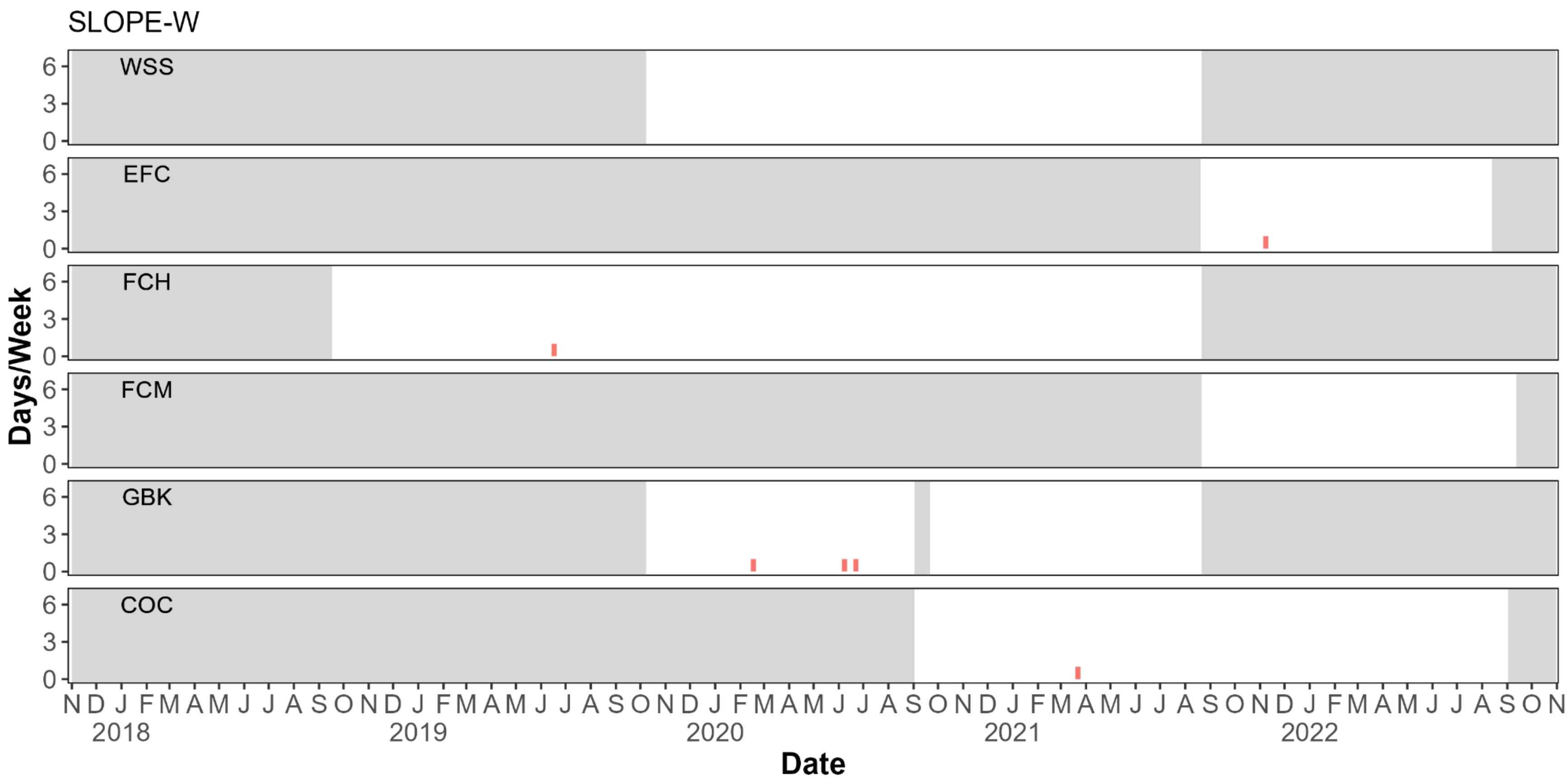

Figure A7. Number of days/week with confirmed NARW upcalls present (orange bars) at with the Western Scotian Slope (SLOPE-W) area recording sites throughout the study period (November 2017-September 2022). Grey shading represents periods with no recording effort.

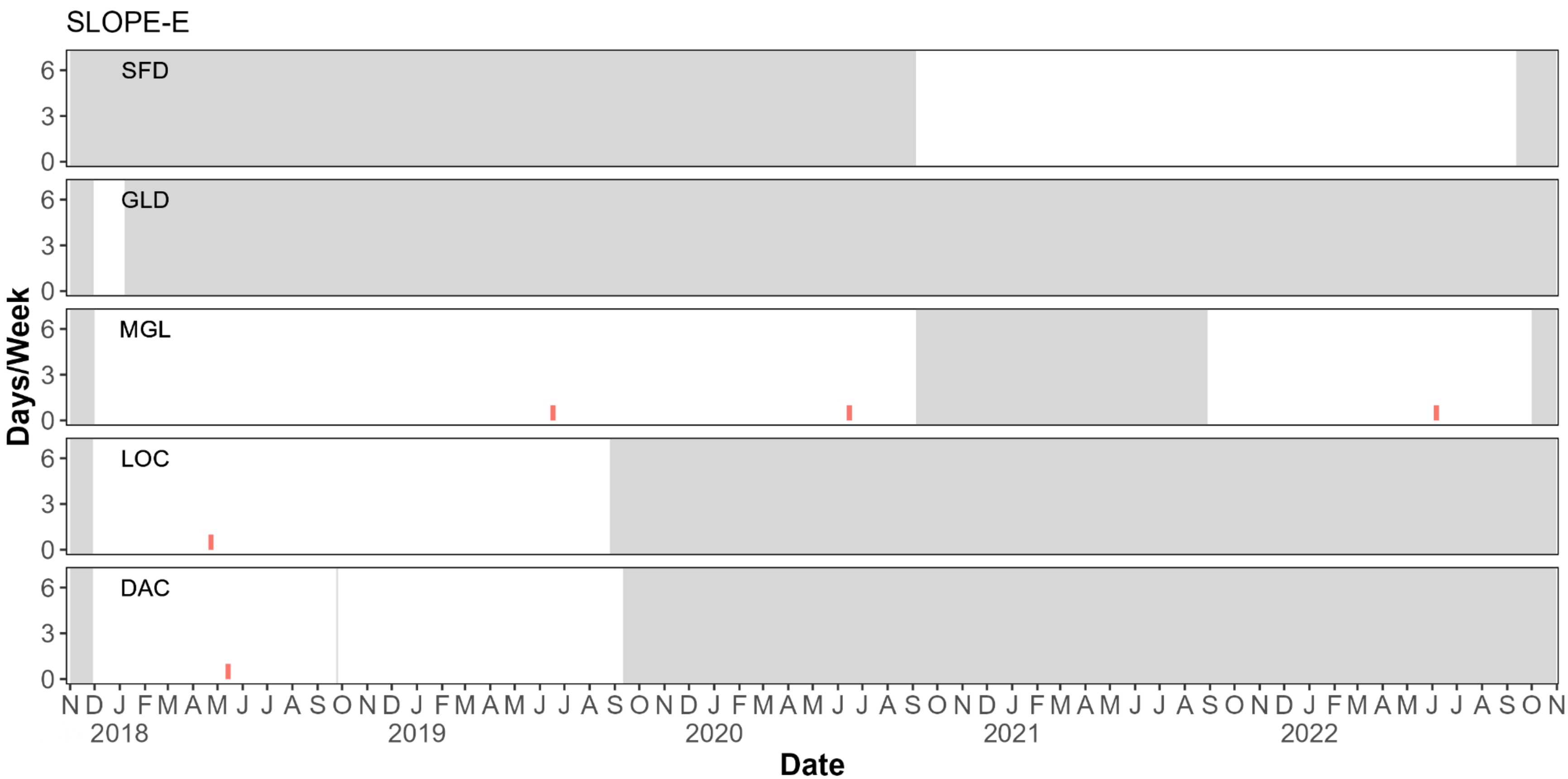

Figure A8. Number of days/week with confirmed NARW upcalls present (orange bars) at with the Eastern Scotian Slope (SLOPE-E) area recording sites throughout the study period (November 2017-September 2022). Grey shading represents periods with no recording effort.

APPENDIX B – NON-ACOUSTIC DATA ON NARW OCCURANCE

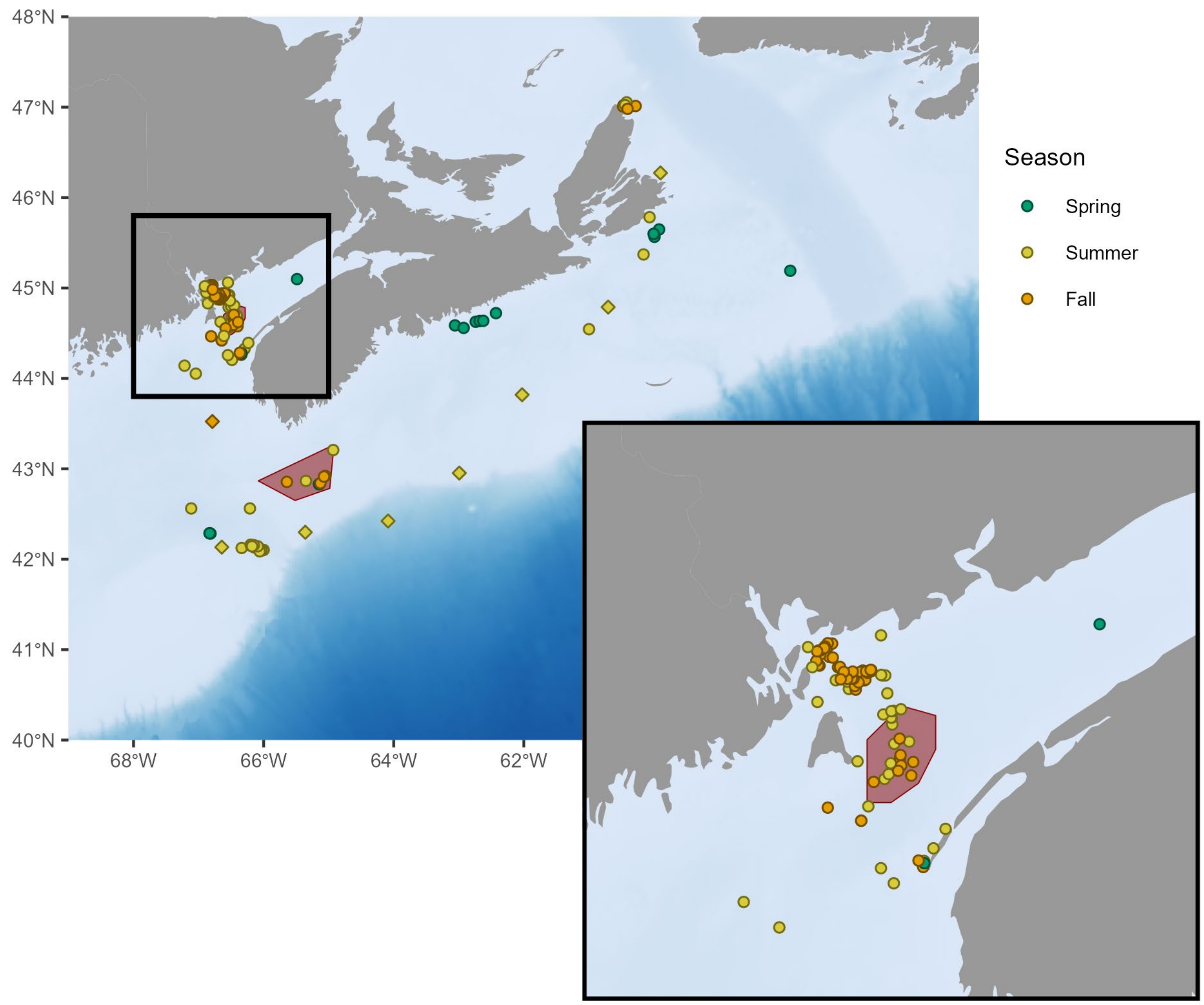

Figure B1. NARW sightings (indicated by circles), and in some cases satellite tag positions (indicated by diamonds), (n = 152) for each season (Spring = March-May, Summer = June-August and Fall = September-November) in eastern Canadian waters reported to DFO from various sources/contributors in Canada and the USA for the period of November 1 2017 to September 30 2022 (data points obtained the [DFO's Whales Insight interactive mapping tool]() with permission from contributors). Note that there were no sightings reported in Winter (December-February), and the line of points from Cape Breton to the western Scotian Slope in summer are daily satellite tag positions of one animal; other satellite tag data points may also exist but are not clearly indicated within the dataset. A zoomed in view of the sightings in the Bay of Fundy region (black box; n = 95 sighting events) is provided on the bottom right panel. Red shaded polygons show NARW Critical Habitats. Caveats associated with these sighting data include: maps and data are preliminary and subject to change; survey effort has not been quantified thus a lack of detections does not represent a lack of species present in a particular area; misalignment of some datasets may occur due to the methods used to produce the original mapping products; while every reasonable effort has been made to ensure that the data is correct, DFO does not warrant or guarantee the accuracy, completeness, or currency of the data for any specific use.

APPENDIX C – NARW UPCALLS FROM SLOCUM GLIDER DEPLOYMENTS

Information provided by Kim Davies, University of New Brunswick

OVERVIEW

The data described in this document were collected through multiple research and monitoring projects, which had various objectives, though in all cases assessment of NARW acoustic occurrence was a priority. The intent of many of these glider deployments off eastern Canada were to monitor areas of biological and/or management interest for NARW presence in near-real-time through determining presence of upcalls.

Only a subset of the available glider data collected from eastern Canada is presented here, specifically; data collected using Slocum gliders (Teledyne-Webb Research) equipped with a digital acoustic monitoring instrument (DMON; Johnson and Hurst, 2007) PAM package for near real-time monitoring deployed off Nova Scotia (including on the Scotian Shelf and in the Cabot Strait) between November 2017 to September 2022 (to match the time period covered by this current study). Data collected using these same PAM gliders prior to November 2017 were included in the NARW acoustic occurrence study conducted by Durette-Morin et al. (2022). Data is not presented for deployments that occurred outside our study area (e.g., in the Gulf of St. Lawrence).

All data presented here are accessible on WHOI's Robots4Whales website.

METHODS

Slocum gliders were equipped with DMON acoustic recorders, which are capable of collecting, storing and processing acoustic data in real-time (Johnson and Hurst, 2007). LFDCS was implemented on the DMON to detect and classify potential whale calls (including NARW upcalls) via their pitch tracks (Baumgartner and Mussoline 2011). Information on the detected calls (such as the number of each call type) and their associated pitch tracks were relayed to a shore-based computer in near real-time via satellite transmissions (Baumgartner et al. 2013). Gliders were deployed for weeks-months at a time, and all transmitted NARW upcall detections were manually validated by experienced acoustic analysts following a standard protocol (Baumgartner et al. 2020) in near real-time. The results presented here summarize only the confirmed “definite” NARW upcalls present in each near real-time dataset. The protocol results in a 0 % false positive rate for NARW in near real-time (Baumgartner et al. 2019).

RESULTS

NARW upcalls were present on five of the nine Western Scotian Shelf deployments, all of which took place in and around Roseway Basin (Table C1). The proportion of recording days with upcalls present ranged from 2-39%, the majority of which (but not all) occurred when the glider was within the boundaries of the Roseway Basin Critical Habitat (Figure C1). No confirmed upcalls were present on the single Central Scotian Shelf deployment, while there were two days (2%) with NARW upcalls present on one of the two Cabot Strait deployments (Table C1, Figure C1).

Table C1. Summary of deployments between November 2017-Sepetmber 2022 of Slocum gliders (G1, G2 or G3 models used) equipped with DMON/LFDCS PAM packages conducted off Nova Scotia and confirmed NARW upcall presence (information summarized from WHOI's Robots4Whales website).

Deployment name	Deployment dates (yyyy-mm-dd)	Number recording days (includes partial days)	Number days with confirmed upcalls (% recording days with upcalls present in brackets)	Dates of confirmed upcalls (yyyy-mm-dd)
Western Scotian Shelf Principle Investigators: Kim Davies, Chris Taggart, Hansen Johnson, Richard Davis (Dalhousie University), Moira Brown (New England Aquarium/Canadian Whale Institute), and Mark Baumgartner (WHOI)				
Roseway Basin, Canada, December 2017	2017-12-16 – 2018-01-03	19	1 (5.3)	2017-12-18
Roseway Basin, Canada, August 2018	2018-08-15 – 2018-09-07	24	0	NA
Roseway Basin, Canada, September 2018	2018-09-18 – 2018-09-22	5	0	NA
Roseway Basin, Canada, November 2018	2018-11-01 – 2018-11-20	20	0	NA
Roseway Basin, Canada, August 2019	2019-08-28 – 2019-09-25	29	0	NA
Roseway Basin, Canada, September 2019	2019-09-25 – 2019-11-15	52	1 (1.9)	2019-10-14
Roseway Basin, Canada, September 2020	2020-09-05 – 2020-10-02	28	11 (39.3)	2020-09-10, 11, 13, 14, 15, 16, 24, 26, 27, 28, 29
Roseway Basin, Canada, October 2020	2020-10-15 – 2020-11-25	40	5 (12.5)	2020-11-12, 13, 15, 16, 19
Roseway Basin, Canada, October 2021	2021-10-19 – 2021-12-08	51	1 (1.9)	2021-11-21
Central Scotian Shelf Principle Investigators: Kim Davies, Chris Taggart, Hansen Johnson (Dalhousie University) and Mark Baumgartner (WHOI)				
Halifax Line, Scotian Shelf, Canada, March 2019	2019-03-19 – 2019-03-27	15	0	NA
Cabot Strait[3] Principle Investigators: Kim Davies (University of New Brunswick)				
Cabot Strait, Canada, July 2021	2021-07-19 – 2021-11-03	108	2 (1.9)	2021-10-19, 20

[3] The glider deployments in Cabot Strait partially occurred outside of the area defined as CABOT in this study.

Deployment name	Deployment dates (yyyy-mm-dd)	Number recording days (includes partial days)	Number days with confirmed upcalls (% recording days with upcalls present in brackets)	Dates of confirmed upcalls (yyyy-mm-dd)
Cabot Strait, Gulf of St. Lawrence, Canada, April 2022	2022-04-21 – 2022-07-05	76	0	NA

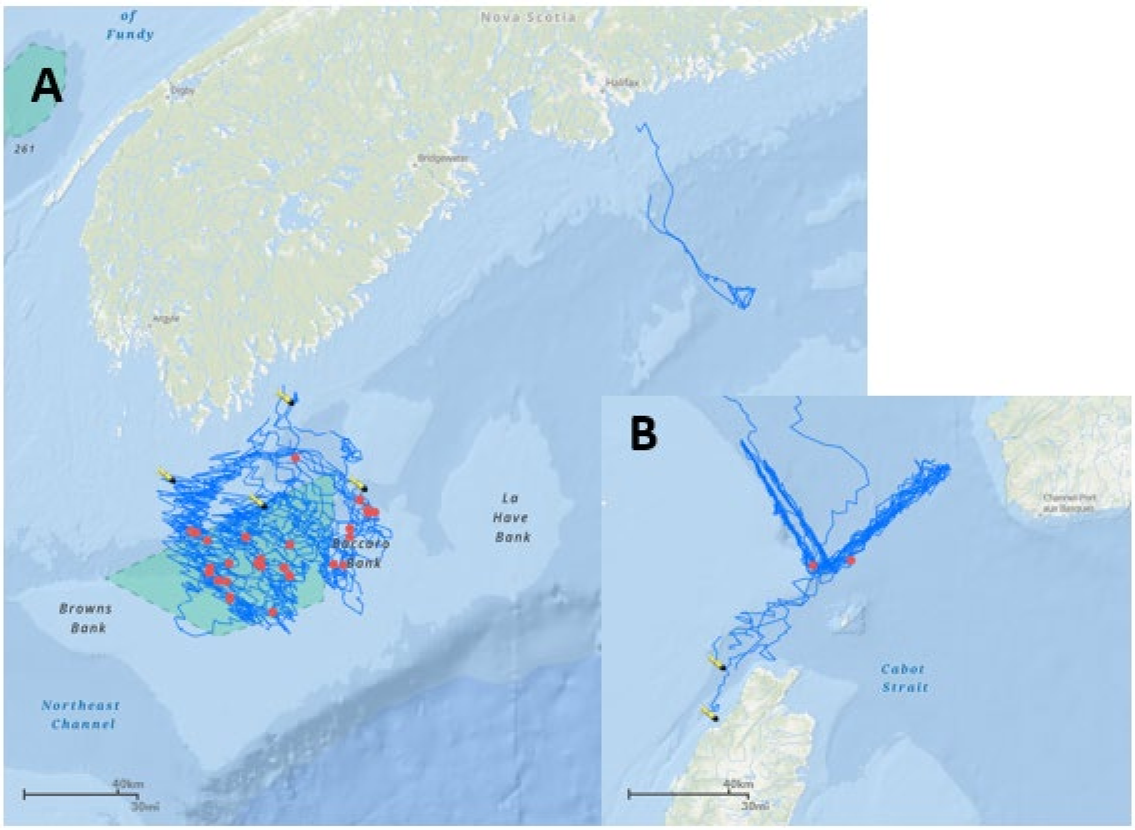

Figure C1. Confirmed NARW upcalls (red circles) from recordings collected during Slocum glider deployments (track lines shown in blue) between November 2017-Sepetmber 2022 off western and central Scotian Shelf (panel A) and in the Cabot Strait (panel B). The green polygon in Panel A is the NARW Roseway Basin Critical Habitat, These screen shots were taken from the Whales Insight interactive mapping tool taken on January 30 2024: https://gisp.dfo-mpo.gc.ca/apps/WhaleInsight).

ACKNOWLEDGEMENTS

Funding for these deployments was provided by Transport Canada, the Marine Environmental Observation, Prediction and Response Network, Ocean Tracking Network, NSERC, Fisheries and Oceans Canada (DFO), the World Wildlife Federation (WWF), and Canadian Steamship Lines (CSL). The gliders were expertly prepared, deployed and piloted by the CEOTR glider team at Dalhousie University. Hansen Johnson, Mark Baumgartner, Chris Taggart, Katherine Indeck and Kim Davies co-led the research with help from analysts Delphine Durette-Morin and Allison Richardson.

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APPENDIX D – EASTERN CHARLOTTE WATERWAYS PAM MOORING DATA

Information provided by Kirsti Mrazek and Kalen Mawer, Eastern Charlotte Waterways

GENERAL PROJECT DESCRIPTION

The data presented in this report are part of a larger effort to assess spatiotemporal occurrence of marine mammal calls on passive acoustic monitoring (PAM) datasets collected by Eastern Charlotte Waterways (ECW) from the outer Bay of Fundy between 2015 and 2022. PAM data collection efforts were initially focused on understanding the underwater soundscape in the region, with special emphasis on anthropogenic noise associated with vessel traffic in and around the Port of Saint John, and analysis of communication space loss in endangered North Atlantic Right Whales (NARW). The PAM datasets collected for these noise measurement studies also provide information on the presence of NARW (and other species) in the region.

METHODS

Data Collection

Acoustic data were collected opportunistically between May 2015 to October 2022 across five coastal sites in the outer Bay of Fundy including: Dipper Harbor (DH), Grand Manan (GM), Port Saint John (SJ), Southern Wolves (SW), and a site adjacent to the Traffic Separation Scheme (TSS) (Figure C1). Water depth at these sites varied between 25-94 m (Table C1). A single Ocean Sonics icListenHF hydrophone coupled with an ISO-17208-1-compliant 3-channel vertical hydrophone array were moored to the seafloor to collect data at these sites. Recordings were made at sampling rates that varied between 32 and 512 kHz, for 2 or 5 minutes every 10 or 20 minutes. Deployment durations varied from weeks to months, and the number of deployments conducted varied between sites. Deployment and recording details are provided in Table C1. No monitoring was completed in 2018 due to the project structure and funding constraints.

Data Processing

JASCO Applied Sciences was contracted to process the acoustic data collected using their suite of contour-based automated detectors (Lawrence and Delarue 2022, Lawrence 2023) to detect potential marine mammal calls for species likely to be found in the Bay of Fundy. This included a NARW upcall detector. A 2 or 5-minute spectrogram image was generated for each recording file that had an upcall detection.

Validation of Detections

For each recording file with one or more NARW upcall detections, the corresponding 2 or 5-min spectrogram image was examined visually by a trained analyst (K. Mrazek) to verify the presence of NARW upcalls on the file. Acoustic recordings were also aurally examined using the acoustic analysis software PAMlab (JASCO Applied Sciences) as needed (such as if there was any uncertainty in call identity) to confirm upcall presence. If the analyst was uncertain about the identity of a call, the spectrogram and corresponding audio file was sent to an acoustic analyst at JASCO or DFO for further validation.

Humpback whale and NARW vocalizations can look and sound similar, making it difficult to distinguish between the species, especially in areas where they often co-occur such as in the Bay of Fundy. A protocol was developed specifically to discern between these two species if there was uncertainty in the detected call origin. In these cases of uncertainty, five files before and after the file containing the detected upcall were examined for the presence of other humpback whale or NARW calls (such as additional upcalls or gunshot calls in the case of NARW) to assist in identifying the source of the detected upcall. If other humpback whale calls were present, and NARW calls were absent, the file was marked as having a humpback whale call present; if other NARW calls were present and humpback whale calls were absent, the file was marked as having a NARW upcall present. If no other calls were present, or there were presumed calls from both species in the surrounding files, the file was marked as 'unknown baleen whale' and left out of subsequent analyses.

Files marked as having one or more confirmed upcalls were used to determine the number of days with NARW upcalls present for each site. Weekly summaries beginning at the earliest deployment date out of all sites and extending to the last deployment date for all sites were then used to determine the number of days per week with confirmed upcalls present.

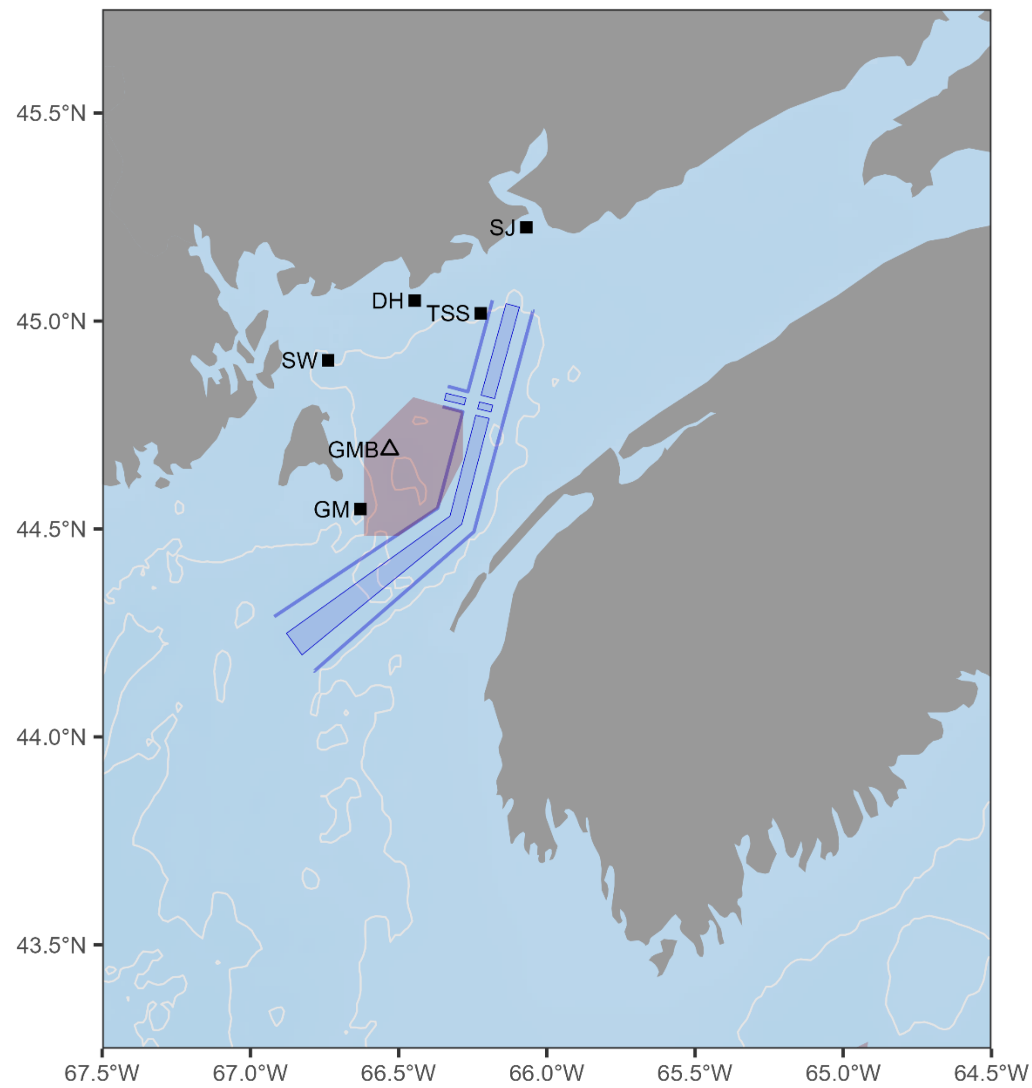

Figure D1. Five recording sites in the outer Bay of Fundy indicated by black squares: Dipper Harbor (DH), Grand Manan (GM), Port Saint John (SJ), Southern Wolves (SW), and a site adjacent to the Traffic Separation Scheme (TSS). The DFO Grand Manan Basin recording site (GMB) is indicated by the triangle. The red polygon is the NARW Grand Manan Critical Habitat and the Bay of Fundy Traffic Separation Scheme is shown in blue.

Table D1. Deployment information for each recording dataset across the five sites: Dipper Harbor (DH), Grand Manan (GM), Port Saint John (SJ), Southern Wolves (SW), and a site adjacent to the Traffic Separation Scheme (TSS). Depth indicates the bottom depth at each site. Recording dates indicates the start and end dates of the deployment. Recording schedule indicates the duration and sampling rate of the recordings, while duty cycle indicates how often the recordings are were collected.

Site	Latitude (decimal degrees)	Longitude (decimal degrees)	Depth (m)	Recording Dates (yyyy-mm-dd)	Recording Schedule	Duty Cycle (min)
DH	45.0490	-66.4455	36	2015-06-19 – 2015-07-29	120 s at 32 kHz	10
				2015-07-29 – 2015-09-13	120 s at 32 kHz	10
				2015-09-18 – 2015-11-01	120 s at 32 kHz	10
				2016-06-02 – 2016-07-16	120 s at 32 kHz	10
				2017-06-21 – 2017-08-02	120 s at 32 kHz	10
				2017-08-02 – 2017-09-13	120 s at 32 kHz	10
				2019-05-09 – 2019-06-03	300 s at 512 kHz	20
				2019-07-18 – 2019-08-10	300 s at 64 kHz	20
				2019-09-12 – 2019-10-06	300 s at 32 kHz	20
GM	44.5477	-66.6287	85	2016-06-06 – 2016-07-20	120 s at 32 kHz	10
				2017-06-27 – 2017-08-12	120 s at 32 kHz	10
				2017-08-29 – 2017-10-09	120 s at 32 kHz	10
				2017-10-11 – 2017-11-24	120 s at 32 kHz	10
				2019-06-11 – 2019-07-07	300 s at 64 kHz	20
				2019-08-01 – 2019-08-24	300 s at 32 kHz	20
				2019-10-03 – 2019-10-25	300 s at 32 kHz	20
				2020-07-22 – 2020-09-09	300 s at 32 kHz	20
				2020-09-09 – 2020-09-14	300 s at 32 kHz	20
SJ	45.2250	-66.0693	25	2016-11-03 – 2016-12-18	120 s at 32 kHz	10
				2017-01-26 – 2017-03-11	120 s at 32 kHz	10
				2017-03-13 – 2017-05-04	120 s at 32 kHz	10
				2017-05-24 – 2017-07-11	120 s at 32 kHz	10
				2017-08-30 – 2017-10-15	120 s at 32 kHz	10
				2019-04-08 – 2019-05-27[4]	300 s at 512 kHz	20
				2019-06-26 – 2019-07-22	300 s at 64 kHz	20
				2019-10-21 – 2019-11-08	120 s at 32 kHz	20
				2020-01-28 – 2020-03-01	300 s at 32 kHz	20
				2020-03-12 – 2020-04-11	120 s at 32 kHz	10
SW	44.9056	-66.7376	94	2015-05-27 – 2015-06-25	120 s at 32 kHz	10
				2015-07-06 – 2015-07-30	120 s at 32 kHz	10
				2015-08-05 – 2015-09-16	120 s at 32 kHz	10
				2015-09-18 – 2015-10-28	120 s at 32 kHz	10
TSS	45.0186	-66.2227	90	2021-10-07 – 2021-11-03	300 s at 32 kHz	20

[4] This recording period was covered by two different recorders deployed at the same site that overlapped in time for a couple of days. One recorder was deployed from 2019-04-08 to 2019-05-04, while the second recorder was deployed from 2019-05-03 to 2019-05-27.

Site	Latitude (decimal degrees)	Longitude (decimal degrees)	Depth (m)	Recording Dates (yyyy-mm-dd)	Recording Schedule	Duty Cycle (min)
				2022-08-10 – 2022-09-08	300 s at 32 kHz	20
				2022-09-13 – 2022-10-17	300 s at 32 kHz	20

RESULTS

NARW upcalls were present at four of the five sites (Table C2, Figure C2). Though only a partial year of recordings were collected at SW, this site had the greatest proportion of days with upcalls present, with more upcalls found in the September to November period than the June to August period. Upcalls also occurred on a relatively high proportion of recording days at TSS, through recording effort was also limited at this site with two short summer/fall deployments. The GM site, which is relatively close to but not within the NARW Critical Habitat boundary (Figure D1), also had a relatively high proportion of recording days with upcalls present on them. Some upcalls were present at the very shallow (only 36 m deep) DH site, although a lower proportion of recording days had upcalls present compared to most other sites. No confirmed upcalls were found at the SJ site.

Table D2. Recording effort (number of recording days) and daily occurrence of confirmed NARW upcalls at each site: Dipper Harbor (DH), Grand Manan (GM), Port Saint John (SJ), Southern Wolves (SW), and a site adjacent to the Traffic Separation Scheme (TSS). Recording days represents the number of complete recording days, excluding days the recorder was deployed and recovered.

Site	Number recording days	Number recording days with upcalls present (% recording days with upcalls present in brackets)
DH	319	4 (1.3)
GM	301	11 (3.7)
SJ	380	0
SW	131	8 (6.1)
TSS	87	4 (4.5)

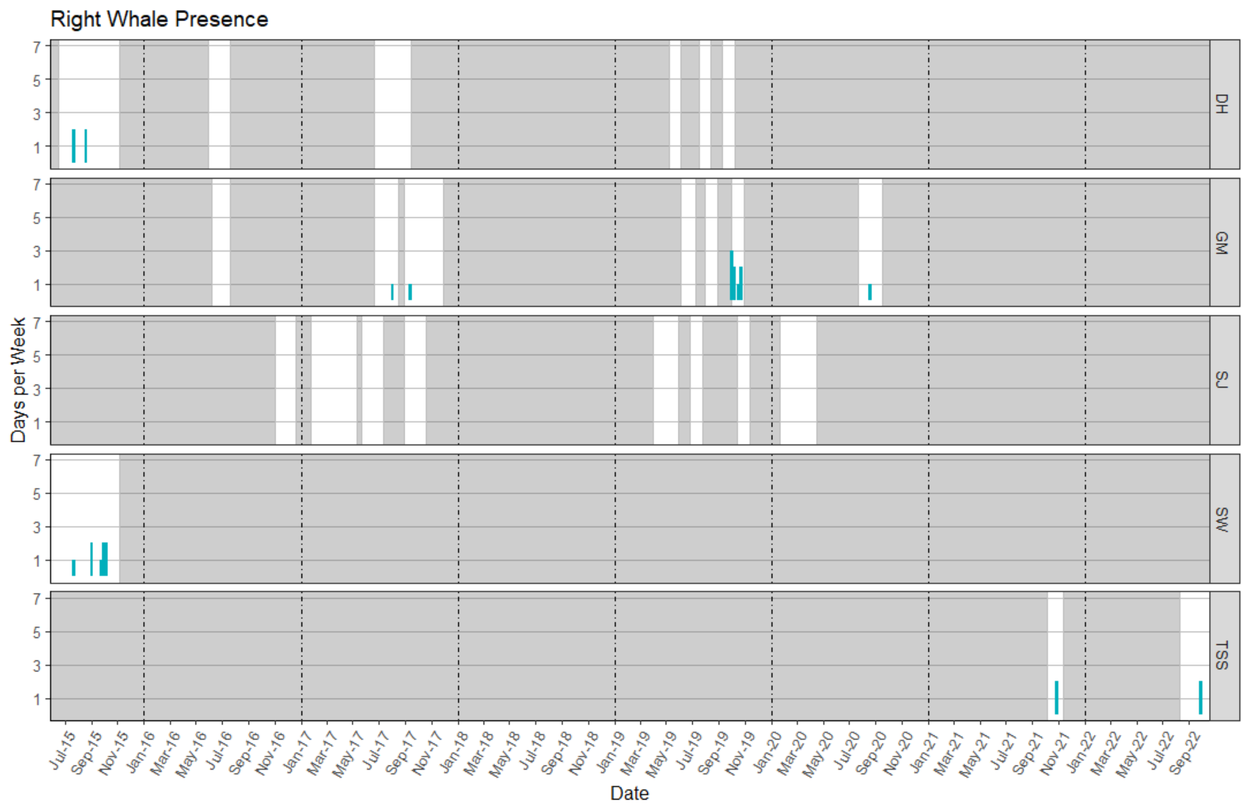

Figure D2. Weekly acoustic presence of NARW from five sites in the Bay of Fundy, sampled between May 2015 and October 2022 at five sites: Dipper Harbor (DH), Grand Manan (GM), Port Saint John (SJ), Southern Wolves (SW), and a site adjacent to the Traffic Separation Scheme (TSS). Grey areas represent time periods with no sampling effort.

ACKNOWLEDGEMENTS

ECW would like to thank The Gulf of Maine Initiative, the Environmental Trust Fund, The NB Department of Agriculture Aquaculture and Fisheries, and Fisheries and Oceans Canada for funding projects that supported PAM data collection and analysis in recent years; this continued support has resulted in a wealth of important information specific to our region. More information about these efforts can be found on Eastern Charlotte Waterways website.

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