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Acoustic Monitoring Along Canada's East Coast: August 2015 to July 2017

Surveillance acoustique le long de la côte est du Canada : août 2015 à juillet 2017

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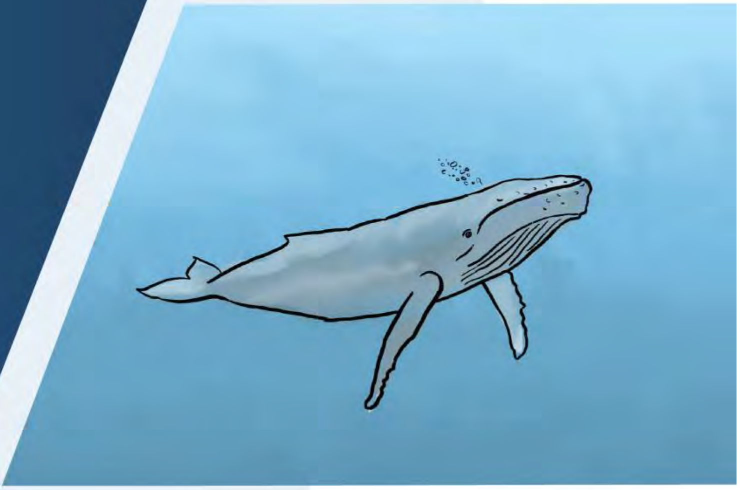
Acoustic Monitoring Along Canada's East Coast

August 2015 to July 2017



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Executive Summary

This report is part of the Environmental Studies Research Fund Project 2014-02S final deliverables. The overall project objectives were to provide new results that will inform future environmental assessments of human activities on Canada's East Coast. The project was broken into two major programs:
1) measurement of the existing soundscape and the presence of vocalizing marine life; and
2) understanding the effects of the acoustic footprint of seismic surveys in the study area. Measurements of the soundscape were made continuously at 20 sites from Labrador to Nova Scotia over a two year period. To study of the effects of seismic sound, computer-based acoustic propagation modeling was performed that was validated by field measurements

This acoustic monitoring study is one of three reports delivered under 2014-02S. (Delarue et al. 2018) contains the modeled acoustic footprints for hypothetical seismic surveys conducted near each of the monitoring locations and provides the radii to at which the sound levels exceed the (NMFS 2018) exposure thresholds for acoustic injury (temporary or permanent hearing threshold shifts). The modeling analysis compared the results from modeling a generic sand bottom with a bottom whose geo-acoustic properties were obtained by measuring the attenuation of a single airgun's propagation loss. This experiment was performed in the summer of 2016 while the 2015-2016 acoustic recorders were replaced for the second year of recording. The determination of the geo-acoustic parameters is documented in Chapter 1 of Warner and MacGillivray (2018). The modeling study concluded that use of local bottom properties is important for obtaining accurate propagation loss values and therefore realistic radii for possible acoustic injury and disturbance to marine life.

Another component of the program was validation of a source model (AASM, JASCO Applied Sciences) for seismic airgun arrays that is able to predict particle motion in the first 100 m near the array. It is well known that all crustaceans and most fish do not sense acoustic pressure, rather they sense acceleration of the water due to sound. The acceleration of the water can be directly predicted from the pressure, except very close to the source and near the surface and seabed. Therefore accurate modeling of acceleration is important for predicting the effects of seismic sound on fish and crustaceans. The model was validated using the 'Svien Vaage' measurements made by the Joint Industry Program of the oil and gas industry at a Fjord in Norway in 2010 which were never properly analyzed before this program. The results showed that the source model accurately predicts the particle-motion component of the sound field (see Chapter 2 of Warner and MacGillivray 2018). The best agreement between the measurements and models is at frequencies below 300 Hz, which are the frequencies that contain the most sound energy and are also frequencies at which fish and crustaceans are most sensitive.

Direct measurements of particle motion from a single airgun were attempted during the 2016 sea cruise when measurements for the geoacoustic properties of the seabed were performed. The data were of limited value because the airgun did not get close enough to the recorders to generate the particle motion effects of interest. Through a literature review and theoretical analysis it was determined that a full airgun array needs to be within ~50 m of the seabed to generate the interface waves of concern. Single airguns are unlikely to cause these effects in most situations. The lessons learned from the 2016 experiment were applied for the fall of 2016 acoustic measurements of crab exposures to seismic sound. A detailed report on particle motion is contained in the report for that project (2014-01S).

The acoustic monitoring program deployed twenty marine acoustic recorders off Canada's east coast between August 2015 and July 2017. The recording protocol was selected to monitor marine mammal acoustic occurrence and characterize the underwater soundscapes of selected areas. The monitored locations ranged from the Scotian Shelf to the southern Labrador shelf through the Grand Banks of Newfoundland. The choice of monitored locations represents a balance between areas of potential interest for oil and gas development and less-sampled locations that were known or presumed to be important to marine mammals. The original acoustic data recordings from this study are available to other researchers on request (~75 TB of data).

The underwater soundscape and its noise contributors were quantified. Drilling platforms contributed significantly to the local soundscape of targeted areas and were measurable for extended periods to ranges of at least 15 km at the seabed in deep water and 35 km in shallow water. Seismic survey sound was detected over wide areas, particularly north of the Flemish Pass. Vessels were detected at all stations, with the highest vessel sound levels measured at stations near shipping lanes or near active drilling platforms. The man-made sounds reduced or prevented the detection of calls of some marine mammal species over substantial time periods. This effect, known as acoustic masking, would also reduce the ability of marine animals to use biologically-important sounds, such as sounds used for communicating and for detecting prey and predators. The effects of anthropogenic noise on the listening spaces (Hannay et al, in press) of marine mammals should be considered more thoroughly in future analysis of these or similar data.

Sounds from up to twenty-three species of marine mammals were identified acoustically in the data. This included up to six species of the *Delphininae* subfamily (small dolphins). Species richness was consistently higher at deep stations along the continental slope than at nearshore stations or at stations on the continental shelf. Stations in the southern parts of the study area maintained high species richness throughout the year, whereas northern stations saw a decline in winter and spring.

The study provided unprecedented insight into the occurrence of beaked whales off Eastern Canada and highlighted areas of potential significance to species that overlap with anthropogenic activities. The year-round presence of Cuvier's and Sowerby's beaked whales south of the Grand Banks and northern bottlenose whales north of the Flemish Pass and off southern Labrador, represents valuable new information. The year-round presence of sperm whales in the Flemish Pass area contrasts with the seasonal decline in detection rates observed throughout the study area in winter and highlights the area's potential importance for this species. In general, areas near the northern and southern entrance of the Flemish Pass recorded among the highest and most persistent species diversity. These areas, particularly north of the Flemish Pass, are also the subject of the most intense oil and gas exploration programs. More thorough investigations of the potential effects of nearby sound from oil and gas development on these marine animals are warranted.

The acoustic signals of several pinniped and baleen whale species varied seasonally. Bearded, grey, and harp seal acoustic detections were associated with male sound production during the breeding season, when these species are most vocally active. Baleen whales showed pronounced seasonal variations in acoustic occurrence, which was attributed to the seasonality of their vocal behaviour, migratory movements, or both. Blue whales occurred nearly year-round in the Cabot Strait, and into January at most stations. In winter, they were common at deep offshore stations east of the Grand Banks. Sustained fin whale acoustic signals from September to March at most stations (excluding those with seasonal ice cover) indicates that this species does not migrate seasonally out of Canadian waters, as is traditionally believed. In summer and fall, sei whales regularly occurred at deep stations ranging from the Flemish Pass to southern Labrador. The spatio-temporal overlap of sei whale acoustic detections with oil and gas exploration activities warrants further research.

Delphinid acoustic signals were the most commonly recorded signals, reflecting the large combined population size of these species, this highly vocal behaviour and the size of their combined range, which covers the entire study area. Their distribution is concentrated around the southern recording locations in winter and spring. Harbour porpoise detections showed pronounced seasonal variations, retracting to stations around Nova Scotia in winter and spring, but peaking in summer at the northern stations. Signals similar to harbour porpoise clicks but recorded at stations where signal characteristics and depth are incompatible with valid detections, were tentatively assigned to *Kogia* species (dwarf and pygmy sperm whales).

This study contributes important new information on the occurrence of marine mammals and characterized the underwater soundscape within a large area of eastern Canadian waters. It identifies existing data and knowledge gaps about the occurrence of several species and lays the foundation for future research required to investigate factors driving the distributions of marine mammals. Our findings suggest that there is potential for noise effects of anthropogenic activities on marine mammals in areas of overlap, primarily in the form of communication masking or habitat displacement. The effects of long-lasting noise exposures (e.g. chronic stress, Rolland et al. 2012) are poorly understood in marine mammals and deserve attention given the anticipated development oil and gas activities in areas such as the Flemish Pass. The drilling activities planned for the Flemish Pass in 2018 and beyond should be considered as an opportunity for in depth investigation of the effects of human activity on a highly productive deep-water environment with little previous activity except fishing.

Titre: **Surveillance acoustique le long de la côte est du Canada : D’août 2015 à juillet 2017**

Sommaire

Ce rapport est le premier de trois rapports finals du projet du Fonds pour l’étude de l’environnement 2014-02S. Les objectifs généraux du projet visaient à fournir de nouveaux résultats afin d’informer les évaluations environnementales futures des activités humaines sur la côte est du Canada. Le projet était divisé en deux grands programmes : 1) Mesure de l’environnement acoustique actuel et de la présence de vie marine qui contribue au paysage sonore et 2) comprendre les effets de l’empreinte acoustique des relevés sismiques dans la zone d’étude. Les mesures de l’environnement acoustique se sont effectuées de façon continue à vingt sites situés entre le Labrador et la Nouvelle-Écosse au cours d’une période de deux ans. Pour étudier les effets des bruits sismiques, un modèle informatisé de la propagation sonore a été réalisé et il a été validé avec des mesures prises sur le terrain.

L’étude sur la surveillance acoustique est un des trois rapports présentés dans le cadre de l’étude 2014-02S. L’étude (Delarue et al. 2018) comporte les empreintes acoustiques modélisées des relevés sismiques hypothétiques menés à proximité de chacun des sites de surveillance et indique le rayon où les niveaux acoustiques excèdent les seuils d’exposition (NMFS 2018) susceptibles d’endommager l’ouïe (variations temporaires ou permanents du seuil auditif). L’étude a comparé les résultats de modélisation d’un plancher océanique sablonneux avec un plancher dont les propriétés géoacoustiques ont été obtenues en mesurant l’atténuation de l’affaiblissement de propagation d’un canon à air unique. L’expérience a été réalisée au cours de l’été 2016 alors que les capteurs acoustiques 2015-2016 étaient remplacés en vue de la deuxième année d’enregistrement. Les calculs des paramètres géoacoustiques sont documentés au chapitre 1 de Warner et MacGillivay (2018). L’étude de modélisation a démontré l’importance de tenir compte des propriétés du plancher océanique pour obtenir des valeurs d’affaiblissement de propagation précises et donc, des valeurs de rayons réalistes en ce qui concerne la perte de l’ouïe et la perturbation de la vie marine.

Une autre composante du programme consistait en la validation d’un modèle source (AASM, JASCO Applied Sciences) pour une batterie de canons à air comprimé, qui peut prédire le mouvement des particules à une distance de moins de 100 m des canons à air comprimé. Il est bien connu que tous les crustacés et la plupart des poissons ne perçoivent pas la pression acoustique, mais qu’ils perçoivent plutôt l’accélération de l’eau attribuable au son. L’accélération de l’eau peut être calculée directement à partir de la pression, sauf très près de la source et près de la surface et du plancher océanique. Par conséquent, il est important de modéliser l’accélération de façon précise afin de prédire les effets des bruits sismiques sur les poissons et les crustacés. Le modèle a été validé à l’aide des mesures de « Svein Vaage », prises par le programme conjoint de l’industrie du pétrole et du gaz dans un fjord de la Norvège en 2010. Ces données n’avaient jamais été analysées adéquatement avant ce programme. Les résultats ont démontré que le modèle source prédisait avec précision la composante de mouvement des particules du champ sonore (consulter le chapitre 2 de Warner et MacGillivray 2018). Les mesures et les modèles présentent la meilleure concordance à des fréquences inférieures à 300 Hz. Ce sont les fréquences qui contiennent le plus d’énergie sonore et auxquelles les poissons et les crustacés sont les plus sensibles.

La prise de mesures directes du mouvement des particules produites par un seul canon à air comprimé a été tentée au cours de la croisière en mer en 2016, alors que nous prenions des mesures servant à établir les propriétés géoacoustiques du plancher océanique. Les données se sont avérées d’une valeur limitée puisque le canon à air ne s’est pas assez approché des

capteurs pour générer des effets de mouvement des particules utiles. Par suite d'un examen de la littérature et d'une analyse théorique, nous avons déterminé qu'une batterie de canons à air doit être à moins de 50 m du plancher océanique pour générer les ondes d'interface qui représentent une inquiétude. Dans la plupart des cas, il est peu probable que des canons à air uniques produisent ces effets. Les leçons retenues de l'expérience de 2016 ont été appliquées aux mesures acoustiques de l'automne 2016 sur l'exposition des crabes à des bruits sismiques. Le rapport de ce projet (ESRF 2014-01S) comporte un rapport détaillé sur le mouvement des particules.

Le programme de surveillance acoustique a déployé vingt capteurs acoustiques sur la côte est du Canada entre août 2015 et juillet 2017. Le protocole d'enregistrement sélectionné visait à surveiller les activités sonores des mammifères marins et à caractériser l'environnement acoustique sous-marin des zones sélectionnées. Les zones contrôlées se situaient entre la plate-forme néo-écossaise et le plateau continental sud du Labrador, en passant par les Grands Bancs de Terre-Neuve. Les choix de zones contrôlées constituent un équilibre entre les zones d'intérêt potentiel pour l'exploitation du pétrole et du gaz et les zones moins bien étudiées qui sont connues ou présumées importantes pour les mammifères marins. Les données acoustiques enregistrées au début de cette étude sont à la disposition de d'autres chercheurs sur demande (environ 75 To de données).

L'environnement acoustique sous-marin et les éléments qui produisent du bruit ont été quantifiés. Les plates-formes de forage ont contribué considérablement à l'environnement acoustique local des zones ciblées et étaient mesurables sur de longues périodes et à des distances d'au moins 15 km au raz du plancher océanique en eau profonde, et jusqu'à 35 km en eau peu profonde. Les bruits des relevés sismiques ont été détectés sur de vastes étendues, particulièrement au nord de la passe Flamande. Des navires ont été détectés à toutes les stations, et les stations près des routes maritimes ou des plates-formes de forage en opération ont affiché les niveaux sonores les plus élevés. Les bruits anthropogéniques ont réduit ou empêché la détection des bruits de certaines espèces de mammifères marins au cours de longues périodes. Cet effet, connu sous le nom de masquage acoustique, réduirait également la capacité d'utiliser des bruits biologiques importants chez les animaux marins, comme les bruits utilisés pour communiquer et pour détecter des proies et des prédateurs. Il serait préférable de tenir compte, de façon plus approfondie, des effets des bruits anthropogéniques de mammifères marins sur le milieu d'écoute (Hannay et al, sous presse) au cours des analyses futures de ces données ou de données semblables.

Des bruits produits par vingt-trois espèces de mammifères marins ont été identifiés sur le plan acoustique dans les données, dont près de 6 espèces de la sous-famille des *Delphininae* (petits dauphins). La diversité des espèces était toujours plus élevée au large de la pente continentale qu'aux stations littorales ou qu'à celles situées sur le plateau continental. Les stations situées dans les régions sud de la zone d'étude maintenaient une diversité des espèces élevée toute l'année, alors que celle des stations nordiques déclinait en hiver et au printemps.

L'étude a fourni un aperçu sans précédent des activités des baleines à bec au large de la côte est du Canada et de régions ciblées en raison de leur importance potentielle pour l'espèce et du fait qu'elles se produisent au même endroit que des activités anthropogéniques. La présence à longueur d'année des baleines à bec de Cuvier et de Sowerby au sud des Grands Bancs et des baleines à bec au nord de la passe Flamande et au large du sud du Labrador constitue de l'information nouvelle et précieuse. La présence à longueur d'année de cachalots dans la région de la passe Flamande contraste avec le déclin saisonnier des taux de détection observés dans l'ensemble de la zone d'étude en hiver et souligne l'importance potentielle de la zone pour ces espèces. En général, les zones à proximité des entrées nord et sud de la passe Flamande ont enregistré la diversité des espèces la plus grande et la plus constante. Ces zones, particulièrement au nord de la passe Flamande, font également l'objet des programmes d'exploration pétrolière et gazière les plus intenses. Des études approfondies sur les effets potentiels des bruits produits par l'exploitation du pétrole et du gaz sur ces animaux marins sont nécessaires.

Les signaux acoustiques de nombreuses espèces de pinnipèdes et de baleines à fanons variaient selon la saison. Les détections acoustiques des phoques barbus, des phoques gris et phoques du Groenland ont été associées à la production de sons par les mâles pendant la période de reproduction, la période où ces espèces produisent le plus de son. L'activité sonore des baleines à fanons a démontré des variations saisonnières prononcées qui ont été attribuées au cycle saisonnier de leur comportement sonore, de leurs mouvements migratoires ou des deux. L'activité sonore des rorquals bleus a été décelée presque toute l'année dans le détroit de Cabot et jusqu'en janvier à la plupart des stations. En hiver, ils étaient fréquemment détectés aux stations en mer profonde des Grands Bancs. La présence continue, de septembre à mars, des signaux acoustiques du rorqual commun à la plupart des stations (sans compter celles comportant une couche de glace saisonnière) indique que l'espèce ne quitte pas les eaux canadiennes de façon saisonnière, contrairement à ce que nous pensions. En été et à l'automne, la présence du rorqual boréal a été régulièrement détectée aux stations en mer, de la passe Flamande au sud du Labrador. La concordance spatio-temporelle des détections acoustiques du rorqual boréal et des activités d'exploration du pétrole et du gaz justifie une étude approfondie.

Les signaux acoustiques des delphinidés se sont avérés les signaux enregistrés les plus communs, ce qui est représentatif de la forte population combinée de ces espèces, de leur comportement hautement vocal et de la taille de leur portée qui couvre l'entière zone d'étude. En hiver et au printemps, leur répartition se situe surtout autour des zones méridionales d'enregistrement. La détection de marsouins communs a démontré des variations saisonnières prononcées qui affluaient vers les stations situées au large de la Nouvelle-Écosse en hiver et au printemps, mais qui atteignaient ses plus hauts niveaux au large des stations nordiques en été. Des signaux semblables aux clics des marsouins communs, mais enregistrés aux stations où les caractéristiques et la profondeur des signaux sont incompatibles avec les détections valides, ont été provisoirement attribués à l'espèce des Kogia (cachalots nains et pygmées).

Cette étude fournit des renseignements nouveaux et importants sur les activités des mammifères marins et a caractérisé l'environnement acoustique sous-marin sur une vaste étendue des eaux de l'est du Canada. Elle dresse la liste des données actuelles et du manque de connaissances liés aux activités de plusieurs espèces et établit les fondements pour des recherches futures qui sont essentielles à l'étude des principaux facteurs de répartition des mammifères marins. Nos résultats laissent à penser qu'il est possible que les bruits d'activités anthropogéniques aient des répercussions sur les mammifères marins dans les régions où on retrouve les deux, principalement sous forme de masquage des communications ou de déplacement de l'habitat. Les effets liés à l'exposition de longue durée au bruit (ex. stress chronique, Rolland et al. 2012) sont peu connus chez les mammifères marins et mérite notre attention étant donnée le développement prévu des activités pétrolières et gazières dans des régions comme la passe Flamande. Les activités de forage prévues à la passe Flamande en 2018 et au cours des prochaines années doivent servir d'occasions de réaliser des études approfondies sur les effets des activités humaines sur un milieu marin en eau profonde très productif qui présentait, auparavant, peu d'activités, autres que la pêche.

1. Introduction

The Canadian Atlantic seaboard is home to a wealth of marine life, and it is the site of diverse human activities including fishing, maritime shipping, and oil and gas exploration and production activities. To varying degrees, these anthropogenic activities contribute to the soundscape of the surrounding waters. The Canadian Atlantic Exclusive Economic Zone (EEZ) has seen relatively few dedicated acoustic monitoring efforts, except for ongoing acoustic monitoring in Marine Protected Areas such as the Gully Canyon (Whitehead 2013, Kowarski et al. 2015). Some monitoring has also occurred at several sites in the Gulf of St. Lawrence or south of Newfoundland (J. Lawson, personal communication). In 2015, the Environmental Studies Research Fund (ESRF) funded a two year program aimed at describing the underwater soundscape, the occurrence of marine mammals off the Canadian Atlantic coast, as well as the potential effects of seismic surveys on the soundscape and marine life. The study area includes shallow and deep monitoring sites, and extends from Dawson Canyon off Halifax, NS, to Nain Bank on the Labrador shelf (Figure 1). Recording locations were chosen to balance the three main project objectives:

- To monitor areas of interest to the oil and gas industry
- To document marine mammal occurrence in areas of known or potential high density that remain undersampled, particularly in winter
- To characterize transmission losses and the particle-motion component of seismic airgun signals as well as sub-bottom geoacoustic properties in the study area.

To avoid duplicating effort the choice of monitoring station locations also accounted for other ongoing acoustic monitoring programs, therefore recorders were not placed in the Gulf of St Lawrence, Gully Marine Protected Area, Bay of Fundy, or Roseway and Emerald Basins. Data from these areas were included in this analysis when such data was available from collaborators.

Here we present the results of the analysis focusing on the biological (marine mammal), anthropogenic (seismic surveys, oil and gas production activities and shipping), and environmental contributors to the underwater soundscape.

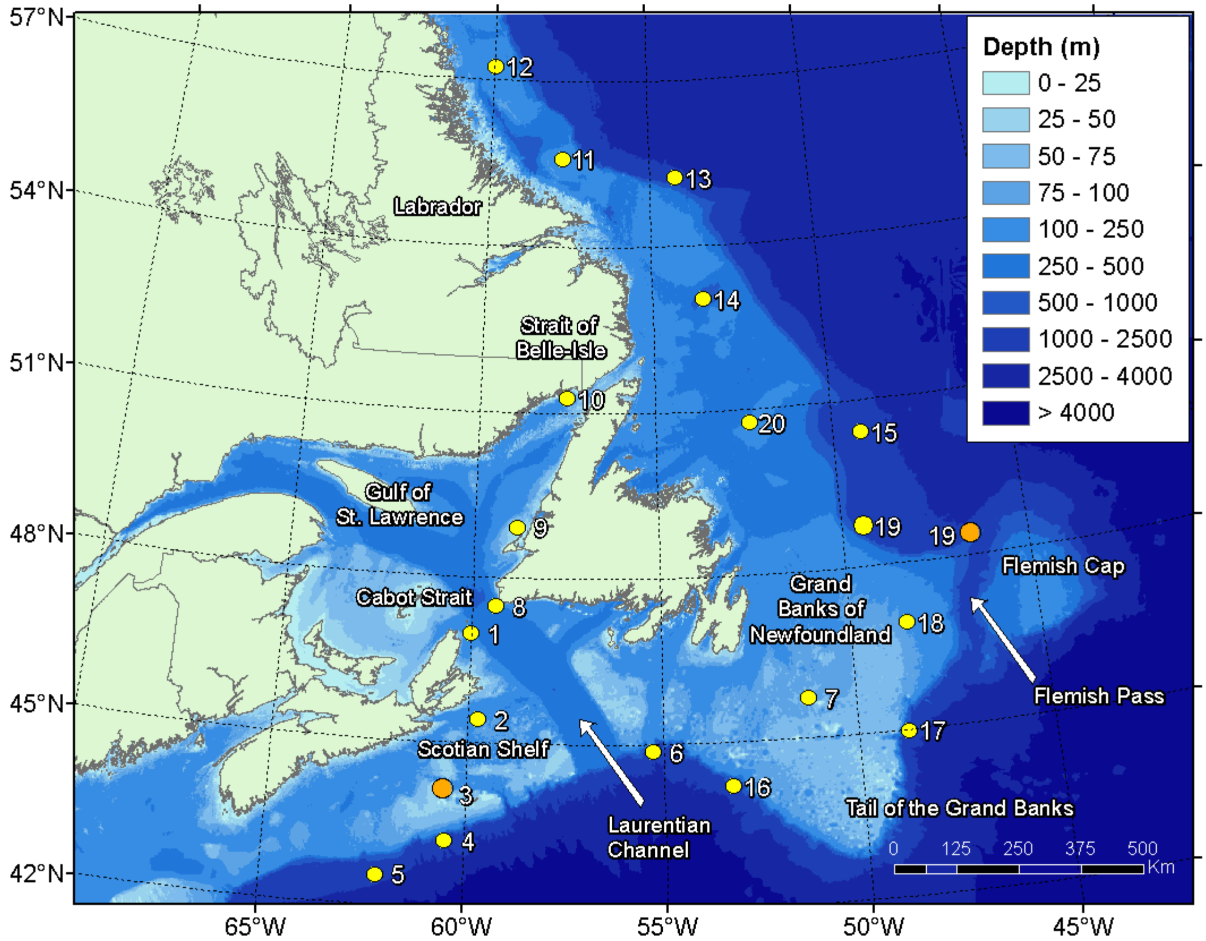

Figure 1. Map of locations of the acoustic recorders (yellow dots) off the Canadian East coast from August 2015 to July 2017. The two orange dots indicate a change in location between 2015–16 and 2016–17. The recorders at stn 3 in 2015-16 and stn 7 in 2016-17 were not recovered.

1.1. Soniferous Marine Life and Acoustic Monitoring

Passive acoustic monitoring relies on the monitored species to produce detectable sound. Several marine taxa produce sounds. With few exceptions (e.g., snapping shrimp; see Au and Banks 1998), crustaceans are not believed to actively produce sound and have not been acoustically monitored. Many fish species produce sound during the breeding season or when engaged in agonistic behaviours (Amorim 2006). Several species of gadids (cod family), such as Northern cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*), form spawning aggregations that have been detected acoustically (Nordeide and Kjellsby 1999, Hawkins et al. 2002). The acoustic monitoring of fish is hindered by a limited understanding of their acoustic repertoire and behaviour. Nevertheless, the stereotypical nature of acoustic signals produced by some species have led to the development of dedicated acoustic detectors (e.g., cod; see Urazghildiiev and Van Parijs 2016). These detectors allow for a more systematic analysis of acoustic data for fish occurrence. Irrespective of species identity, fish choruses can raise ambient noise levels and therefore influence local soundscapes (Erbe et al. 2015).

The biological focus of this study was on marine mammals. Twenty-five cetacean and seven pinniped species may be found in the study area (Table 1). The presence of certain species, such as humpback whales (Kowarski et al. 2015), pilot whales (Sergeant 1962), and other delphinids (Sergeant and Fisher 1957), is well documented in at least part of the study area (Hammill et al. 2001, Lawson and Gosselin

2009, Whitehead 2013). However, records of some species are scarce, particularly for deep-diving cetaceans occurring in waters off the continental shelf. The presence of pygmy sperm whales (*Kogia breviceps*) is known only from strandings (Measures et al. 2004). Blainville's beaked whales (*Mesoplodon densirostris)* have stranded in Nova Scotia (Mead 1989) and were observed once near the Gully Canyon (DFO 2016). The presence of True's beaked whales (*M. mirus*) is known from two recent strandings in Atlantic Canada[1]. Cuvier's beaked whales (*Ziphius cavirostris*) were visually sighted once in the Gully Canyon (Whitehead 2013). Gervais' beaked whales (*M. europaeus*) may occur in the study area based on habitat characteristics, but they have not been sighted or recorded. A bowhead whale sighted in the Bay of Fundy in 2012 is believed to have been a vagrant individual[2]. The northernmost recorder in this study was expected to be at the southern edge of the range of bowhead whale's Eastern Arctic population, so detections of this species were expected to be rare or absent. This study seeks to document the occurrence of both well-described and little-known marine mammals in eastern Canadian waters.

Marine mammals are the main biological contributors to the underwater soundscape. For instance, fin whale songs can raise noise levels in the 18–25 Hz band by 15 dB for extended durations (Simon et al. 2010). Marine mammals, cetaceans in particular, rely almost exclusively on sound for navigating, foraging, breeding, and communicating (Clark 1990, Edds-Walton 1997, Tyack and Clark 2000). Although species differ widely in their vocal behaviour, most can be reasonably expected to produce sounds on a regular basis. Passive acoustic monitoring is therefore increasingly preferred as a cost-effective and efficient survey method. Seasonal and sex- or age-biased differences in sound production, as well as signal frequency, source level, and directionality all influence the applicability and success rate of acoustic monitoring, and its effectiveness must be considered separately for each species.

Knowledge of the acoustic signals of the marine mammals expected in the study area varies across species. These sounds can be split into two broad categories: Tonal signals, including baleen whale moans and delphinid whistles, and echolocation clicks produced by all odontocetes mainly for foraging and navigating. While the signals of most species have been described to some extent, these descriptions are not always sufficient for reliable, systematic identification, let alone to design automated detectors to process large datasets (Table 2). For instance, while the whistles of species in the subfamily *Delphininae* (small dolphins) in the area have all been described, the overlap in their spectral characteristics complicates their identification by both analysts and automated detectors (Ding et al. 1995, Gannier et al. 2010). The echolocation clicks of three of the six beaked whale species are well-described and reliably detected. True's beaked whale clicks have been recorded recently, but their full description is not yet available for detector development. Detector development for the clicks of Gervais and Blainville's beaked whales was hindered by a lack of access to recordings containing the signals of these species. In some cases, a general understanding of the spectral features of signals combined with knowledge of habitat preference and signal propagation allowed us to make inferences about the occurrence of a species (e.g., *Kogia* sp.). In most cases, baleen whale signals can be reliably identified to the species level, although, seasonal variation in the types of vocalizations produced results in seasonal differences in our ability to detect these species acoustically. For example, the tonal signals produced by blue, fin, and sei whales tend to show lots of similarities in late spring and summer, but they are markedly different from September to April. These issues are considered and discussed on a case-by-case basis.

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[1] https://baleinesendirect.org/en/extremely-rare-beaked-whale-species-stranded-in-magdalen-islands/

[2] http://rightwhales.neaq.org/2012/08/11-bowhead-whale-in-bay-of-fundy.html

Table 1. List of cetacean and pinniped species known to occur (or possibly occur) in the study area and their Committee on the Status of Endangered Wildlife in Canada (COSEWIC) and Species at Risk Act (SARA) status.

Species name	Scientific name	COSEWIC status	SARA status
Baleen whales			
Minke whale	*Balaenoptera acutorostrata*	Not at risk	Not listed
Sei whale	*Balaenoptera borealis*	Data deficient	Not listed
Blue whale	*Balaenoptera musculus*	Endangered	Endangered
Fin whale	*Balaenoptera physalus*	Special concern	Special concern
Humpback whale	*Megaptera novaeangliae*	Not at risk	Special concern
North Atlantic right whale	*Eubalaena glacialis*	Endangered	Endangered
Bowhead whale	*Balaena mysticetus*	Special concern	Endangered
Toothed whales			
Short-beaked common dolphin	*Delphinus delphis*	Not at risk	Not listed
Striped dolphin	*Stenella coeruleoalba*	Not at risk	Not listed
White-beaked dolphin	*Lagenorhynchus albirostris*	Not at risk	Not listed
White-sided dolphin	*Lagenorhynchus acutus*	Not at risk	Not listed
Bottlenose dolphin	*Tursiops truncatus*	Not at risk	Not listed
Risso's dolphin	*Grampus griseus*	Not at risk	Not listed
Killer whale	*Orcinus orca*	Special concern	Not listed
Beluga whale	*Delphinapterus leucas*	Endangered[1]	Threatened[1]
Long-finned pilot whale	*Globicephala melas*	Not at risk	Not listed
Harbour porpoise	*Phocoena*	Special concern	Threatened
Pygmy sperm whale	*Kogia breviceps*	Not at risk	Not listed
Sperm whale	*Physeter macrocephalus*	Not at risk	Not listed
Cuvier's beaked whale	*Ziphius cavirostris*	Not at risk	Not listed
Sowerby's beaked whale	*Mesoplodon bidens*	Special concern	Special concern
Northern bottlenose whale	*Hyperoodon ampullatus*	Endangered[2]	Endangered[2]
Blainville's beaked whale	*Mesoplodon densirostris*	Not at risk	Not listed
Gervais beaked whale	*Mesoplodon europaeus*	Not assessed	Not listed
True's beaked whale	*Mesoplodon mirus*	Not at risk	Not listed
Pinnipeds			
Grey seal	*Halichoerus grypus*	Not at risk	Not listed
Ringed seal	*Phoca hispida*	Not at risk	Not listed
Hooded seal	*Cystophora cristata*	Not at risk	Not listed
Bearded seal	*Erignathus barbatus*	Not assessed	Not listed
Harp seal	*Phoca groenlandica*	Not at risk	Not listed
Harbour seal	*Phoca vitulina*	Not at risk	Not listed
Atlantic walrus	*Odobenus rosmarus*	Special concern	Not listed

[1] Status of the Gulf of St. Lawrence population

[2] Status of the Scotian shelf population

Table 2. Acoustic signals used for identification and automated detection of the species expected off the Canadian east coast, and supporting references. 'NA' indicates that no automated detector was available for a species.

Species name	Signal used for identification	Signal for automated detections	Reference
Minke whale	Pulse train	N/A	(Risch et al. 2013)
Sei whale	Tonal downsweeps	Tonal downsweeps	(Baumgartner et al. 2008)
Blue whale	A-B vocalizations, tonal downsweeps	A-B vocalizations	(Mellinger and Clark 2003, Berchok et al. 2006)
Fin whale	20-Hz pulse, tonal downsweeps	20-Hz pulse	(Watkins 1981, Watkins et al. 1987)
Humpback whale	Moans, grunts	Moans	(Dunlop et al. 2008, Kowarski et al. 2018)
North Atlantic right whale	Tonal upsweeps, gunshots	Upsweeps	(Parks et al. 2005, Parks and Tyack 2005)
Bowhead whale	Moans	N/A	(Clark and Johnson 1984, Delarue et al. 2009a)
Small dolphins[1]	Whistles	Whistles >6k Hz	(Steiner 1981, Rendell et al. 1999, Oswald et al. 2003)
Killer whale[2]	Whistles, pulsed vocalizations	Tonal signals <6 kHz	(Ford 1989, Deecke et al. 2005)
Beluga whale	Whistles	Whistles	(Karlsen et al. 2002, Garland et al. 2015)
Long-finned pilot whale[2]	Whistles, pulsed vocalizations	Tonal signals <6 kHz	(Nemiroff and Whitehead 2009)
Harbour porpoise	Clicks	Clicks	(Au et al. 1999)
Pygmy sperm whale	Clicks	Clicks	(Marten 2000)
Sperm whale	Clicks	Clicks	(Mohl et al. 2000, Mohl et al. 2003)
Cuvier's beaked whale	Clicks	Clicks	(Zimmer et al. 2005a)
Sowerby's beaked whale	Clicks	Clicks	(Cholewiak et al. 2013)
Northern bottlenose whale	Clicks	Clicks	(Hooker and Whitehead 2002, Wahlberg et al. 2012)
Blainville's beaked whale	Clicks	NA	(Madsen et al. 2005, Johnson et al. 2006)
Gervais beaked whale	Clicks	NA	(Gillespie et al. 2009)
True's beaked whale	Clicks	NA	Annamaria Izzy, personal communication
Grey seal	Grunts, moans	NA	(Asselin et al. 1993)
Ringed seal	Grunts, yelp, barks	NA	(Stirling 1973, Jones et al. 2011)
Hooded seal	Unknown	NA	(Ballard and Kovacs 1995)
Bearded seal	Trills	Trills	(Risch et al. 2007)
Harp seal	Grunts, yelp, barks	NA	(Terhune 1994)
Harbour seal	Roar	NA	(Van Parijs and Kovacs 2002)
Atlantic walrus	Grunts, knock, bells	NA	(Stirling et al. 1987, Mouy et al. 2011)

[1] See Table 1 for dolphin species likely to be detected by the dolphin whistle detector

[2] This detector does not distinguish between killer whale and pilot whale vocalizations.

1.2. Ambient Sound Levels

The ambient, or background, sound levels that create the ocean soundscape are comprised of many natural and anthropogenic sources (Figure 2). The main environmental sources of sound are wind, precipitation, and sea ice. Wind-generated noise in the ocean is well-described (e.g., Wenz 1962, Ross 1976), and surf noise is known to be an important contributor to near-shore soundscapes (Deane 2000). In polar regions, sea ice can produce loud sounds that are often the main contributor of acoustic energy in the local soundscape, particularly during ice formation and break up. Precipitation is a frequent noise source, with contributions typically concentrated at frequencies above 500 Hz. At low frequencies (<100 Hz), earthquakes and other geological events contribute to the soundscape (Figure 2).

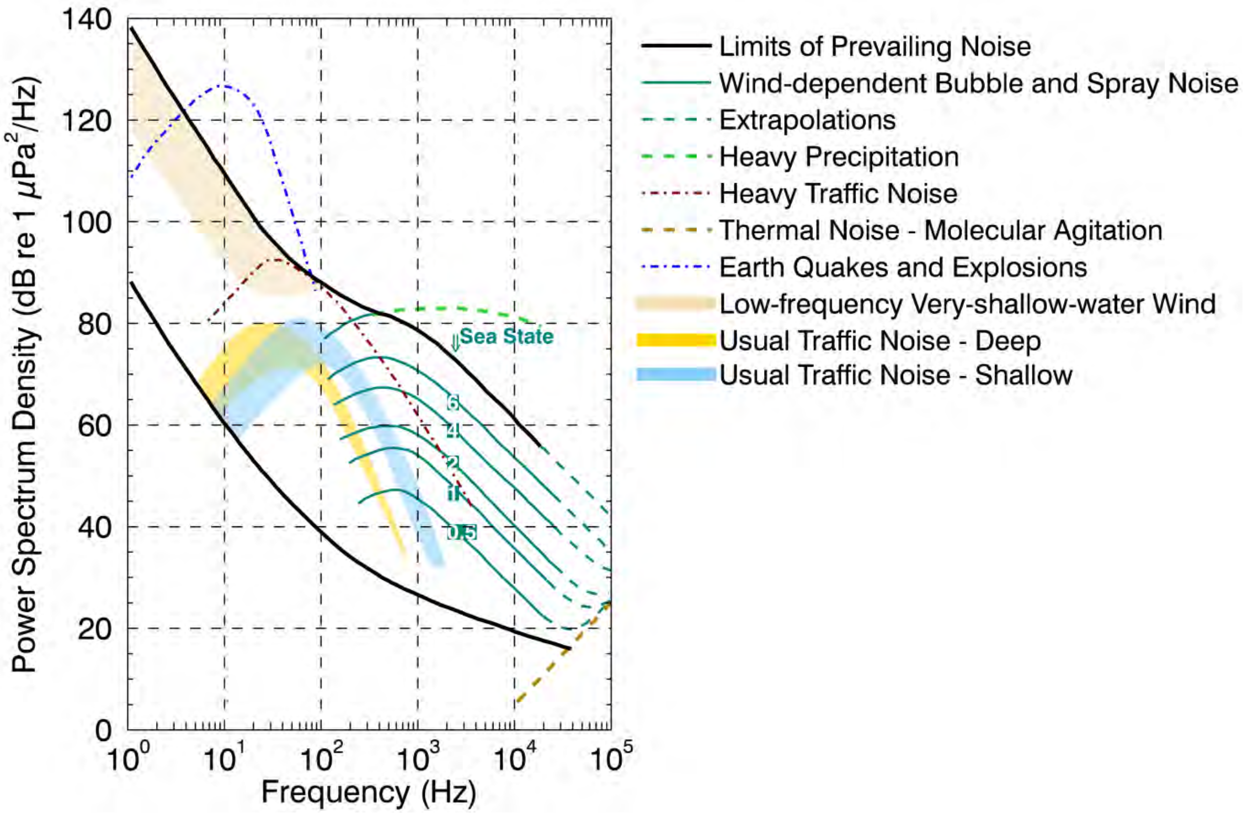


Figure 2. Wenz curves (NRC 2003), adapted from (Wenz 1962), describing pressure spectral density levels of marine ambient noise from weather, wind, geologic activity, and commercial shipping.

1.3. Anthropogenic Contributors to the Soundscape

Anthropogenic (human-generated) sound can be a by-product of vessel operations, such as engine noise radiating through vessel hulls and cavitating propulsion systems, or a product of active acoustic data collection with seismic surveys, military sonar, and depth sounding as the main contributors. The contribution of anthropogenic sources to the ocean soundscape has increased steadily over the past several decades. This increase is largely driven by greater maritime shipping and oil and gas exploration globally (Hildebrand 2009). The extent of seismic survey sounds has increased significantly following the expansion of oil and gas exploration into deep water, and seismic sounds can now be detected across ocean basins (Nieukirk et al. 2004). The main anthropogenic contributors to ambient noise off Eastern Canada were vessels (including fishing vessels) and seismic surveys. Localized sound sources from the Hibernia oil and gas production platform and the Shell Cheshire well drilling campaign (2015–16) were also captured in this data set by nearby recording stations.

1.3.1. Vessel Traffic

There are several major shipping lanes in study area, most notably those along the Laurentian Channel associated with the St. Lawrence Seaway. Vessel fan out after leaving the Gulf of St. Lawrence, resulting in consistent traffic on the Scotian shelf and in areas south of Newfoundland. A few isolated areas of denser vessel traffic off the coast indicate the location of oil and natural gas extraction platforms and the associated transit of support vessels, as well as areas targeted by seismic surveys and potential fishing hotspots (Figure 3).

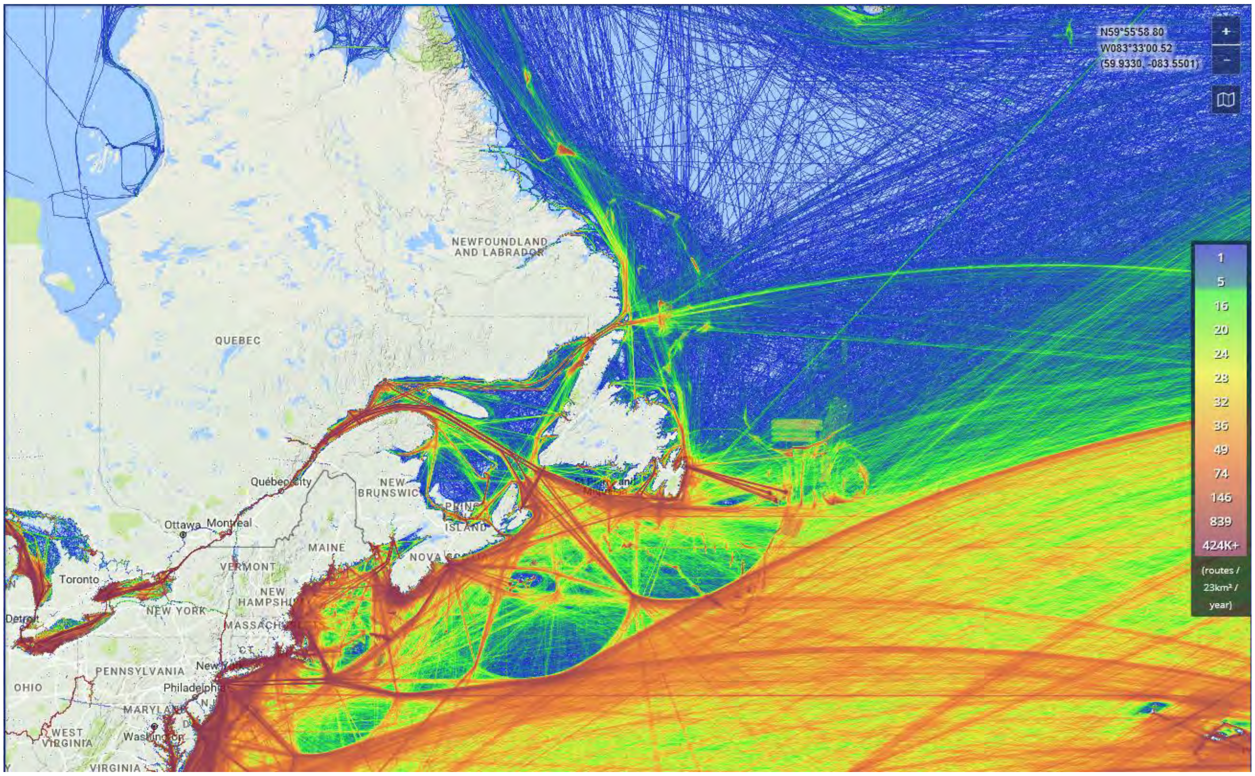


Figure 3. Vessel traffic off the US and Canadian east coast for 2016 and 2017 (source: marinetraffic.com; accessed 2 May 2018).

1.3.2. Fishing Activities

Waters within the Canadian EEZ support a multitude of fisheries, including otter and shrimp trawling, gillnetting, longlining, and fixed gear (pots). Owing to the collapse of the groundfish fisheries in the 1990s, the focus of fisheries has shifted to crustaceans, with lobster and snow crab now dominating the landings. Figure 4 presents the distribution of effort for pot fisheries between 2008-2011 (see Appendix A for other fisheries). While the compilation period does not overlap with the study period, the distribution of fishing effort has remained relatively stable (Mardi Gullage, personal communication). Despite their geographical spread, most fisheries are seasonal and localized and their impact on the soundscape is likely to be similarly restricted.

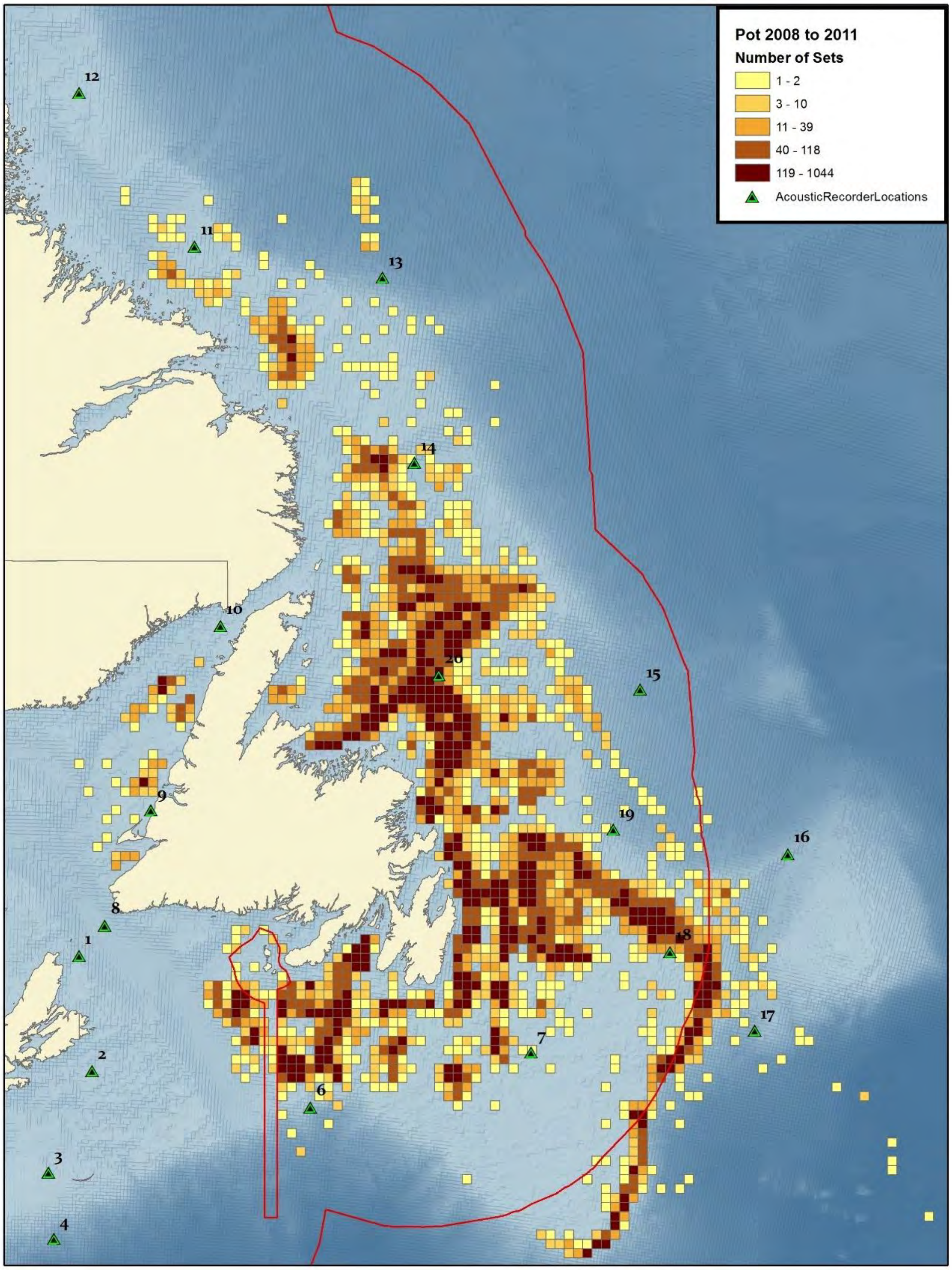


Figure 4. Fishing effort (2008–2011) for pots in areas under the jurisdiction of DFO Newfoundland-Labrador. The acoustic recorders are displayed as green triangles.

1.3.3. Seismic Surveys and Oil and Gas Extraction

Seismic exploration has a long history on Canada's east coast. Increasing in the 1960s, success in both Nova Scotia and Newfoundland in the 1970s and 1980s resulted in an exploration peak in 1983. The next wave of seismic exploration began in 1995 and continued into the 2000s, as 3-D work focused on the Scotian Shelf. In recent years ,TGS, Petroleum Geo-Services (PGS), Nalcor Energy, and, to a lesser extent, Shell and BP have undertaken extensive surveys from Nova Scotia to Labrador (Table 3). Figure 5 shows the spatial coverage of the seismic surveys conducted off eastern Canada until 2015. There were no seismic surveys conducted in 2015–2017 in areas under the jurisdiction of the Canada Nova Scotia Offshore Petroleum Board (CNSOPB). Despite decades of seismic exploration, the sound propagation modelling and acoustic characterization of seismic survey sounds along the east coast of Canada remains limited and is one of the main objectives of this study. Figure 6 depicts the close proximity of several acoustic recorders to areas of interest to the oil and gas industry in support of this objective.

Table 3. Geoscientific programs with fieldwork authorized during in 2015, 2016 and 2017.(Source: CNLOPB 2016).

Survey type	Area	Start	End	Survey coverage
2015				
Seabed Survey	Flemish Pass	2 Jun 2015	21 Jun 2015	2672 km
3-D Seismic	Northeast Newfoundland Slope	7 Jun 2015	21 Oct 2015	5293 km^2
4D Seismic	Hibernia	10 Jun 2015	26 Aug 2015	757 km^2
2-D Seismic	South and Southeast Newfoundland	2 Jul 2015	25 Oct 2015	14404 km
3-D Seismic	East Newfoundland	16 Jul 2015	26 Oct 2015	4987 km^2
2-D Seismic	Southern Labrador and northeast Newfoundland	24 Jul 2015	5 Oct 2015	9951 km
2-D Seismic	East and Northeast Newfoundland	11 Aug 2015	7 Nov 2015	2483 km
2016				
3-D Seismic	Flemish Pass Basin	19 May 2016	17 Oct 2016	10890.1 km^2
2-D Seismic	Northeast Newfoundland Slope	26 May 2016	9 Nov 2016	17220.9 km
2-D Seismic	South Grand Banks	3 Jun 2016	10 Nov 2016	16570.5 km
2-D Seismic	South Labrador Sea	11 Jul 2016	14 Nov 2016	7087.7 km
3-D Seismic	Northeast Newfoundland Slope	5 Aug 2016	28 Sep 2016	1908.1 km^2
2017				
2-D Seismic	South Labrador to southeast Newfoundland	17 May 2017	30 Oct 2017	21200 km
3-D Seismic	East and southeast Newfoundland	1 Jun 2017	8 Oct 2017	38004 km^2
Geohazards Survey	Hibernia	21 Sep 2017	12 Oct 2017	2551 km

In addition to the seismic exploration programs, other contributors to the soundscape included several active oil and gas production platforms in the study area: five on the eastern edge of the Grand Banks associated with Jeanne d'Arc basin (e.g., Hibernia) and two east of Sable Island on the Scotian shelf. There were also five active exploratory drilling platforms on the eastern Grand Banks and one on the edge of the Scotian Shelf during the 2015–17 period.

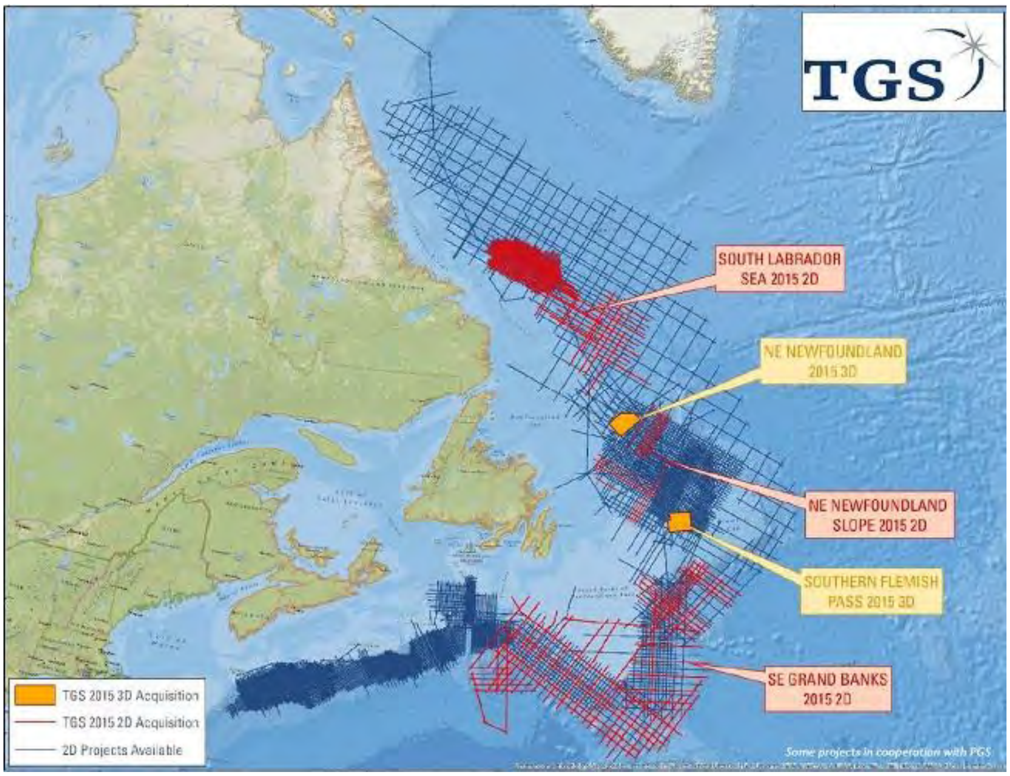


Figure 5. Seismic surveys completed by TGS and PGS as of 2015 and previously available 2-D seismic data in eastern Canadian waters. (Source: Larsen and Ashby 2015; accessed 14 Nov 2016).

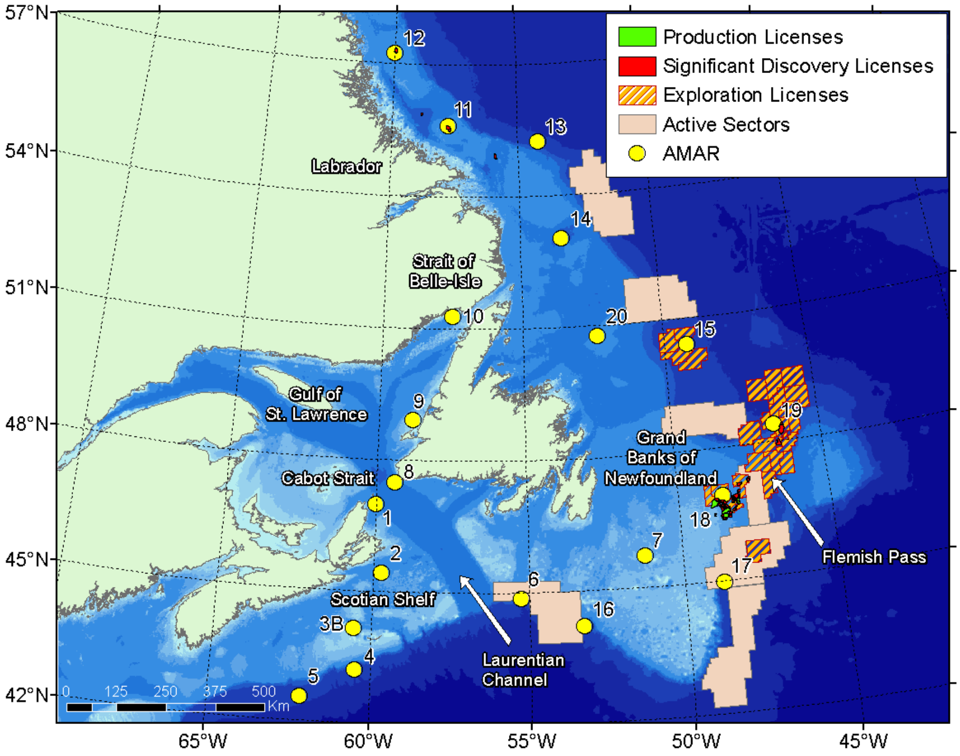


Figure 6. Areas of interest to the oil and gas industry under the jurisdiction of the CNLOPB, in relation to the location of acoustic recorders in this study.

2. Methods

2.1. Data Collection

2.1.1. Acoustic Recorders

Underwater sound was recorded with Autonomous Multichannel Acoustic Recorders (AMARs, JASCO) (Figure 7). In 2015–16, each AMAR was fitted with an HTI-99 omnidirectional hydrophone (HTI, Inc., −165 ± 3 dB re 1 V/µPa sensitivity). The low-frequency recording channel had 24-bit resolution with a nominal ceiling of 165 dB re 1 µPa. The high-frequency recording channel had 16-bit resolution with a nominal ceiling of 173 dB re 1 µPa. In 2016–17, each AMAR was fitted with a GTI M36-V35-100 omnidirectional hydrophone (GeoSpectrum, Inc., −165 ± 3 dB re 1 V/µPa sensitivity). The low-frequency recording channel had 24-bit resolution with a nominal ceiling of 164 dB re 1 µPa. The high-frequency recording channel had 16-bit resolution with a nominal ceiling of 171 dB re 1 µPa.

The AMAR hydrophones were protected by a hydrophone cage, which was covered with a cloth shroud to minimize non-acoustic noise caused by water flow past the hydrophone. The AMARs operated on a duty cycle. They recorded at 8,000 samples per second (for a recording bandwidth of 10 Hz to 4 kHz) during 11 min 18 s and at 250,000 samples per second (for a recording bandwidth of 10 Hz to 125 kHz) during 1 min 4 s, for a total cycle of 20 min. All acoustic data were stored on 1,792 GB of internal solid-state flash memory.

Six recorders, located at stn 1, 2, 7, 9, 10, and 18 were serviced in the fall 2015. All recorders operated as expected. Details about the mooring designs and calibration procedure can be found in Appendix B.

Figure 7. Mooring set up prior to deployment.

2.1.2. Deployment Locations

AMARs were deployed at 20 locations (Figure 1) between 3 Aug 2015 and 23 Jul 2016 (Table 4; 2015–16) and between 8 Jul 2016 and 23 Jul 2017 (Table 5; 2016–17). Nineteen instruments were retrieved in each year (stn 3 of 2015–16 and stn 7 of 2016–17 were not retrieved). The AMAR at stn 3 in 2015–16 was in very shallow water(~30 m), and the loss was attributed to the recorder being displaced or buried in the sandy bottom by large waves during winter storms. The 2016–17 stn 7 AMAR was similarly shallow (<80 m), and the loss was attributed to possible snagging in fishing gear. Several unsuccessful attempts were made to locate the lost AMARs, including pinging the acoustic transponders on their mooring, searching with side-scan and multi-beam sonars. The 2016–17 deployment of stn 3 was moved to a deeper nearby location. The AMAR deployed at stn 10 in 2015–16 broke its mooring on 5 Jul 2016, 5 days before the field team visited the site for retrieval. The recorder and mooring components were later retrieved by local fishermen on the south side of the Strait of Belle-Isle and returned to JASCO. Stn 19 was moved to the Sackville Spur area, north of the Flemish Pass, for the second year of the program to provide year-round coverage in an area where northern bottlenose whales were repeatedly sighted in recent summers (Laura Feyrer, personal communication).

Eighteen of the nineteen AMARs retrieved in each year recorded as planned from deployment until retrieval, with average recording durations of 335 days in the first year and 363 days in the second year. The AMAR at stn 9 in 2015–16 stopped recording on 26 Apr 2016 after 255 days of operation. In 2016–17, the AMAR at stn 9 did not produce usable data due to a hydrophone issue. Overall, system performance was good and a very large dataset was acquired.

Table 4. ESRF study 2015–16: Operation period, location, and depth of the AMARs deployed.

Station	Latitude	Longitude	Depth (m)	Deployment	Retrieval	Duration (days)
1	46.99134	−60.02403	186	17 Aug 2015	8 Jul 2016	327
2	45.42599	−59.76398	126	18 Aug 2015	21 Jul 2016	339
4	43.21702	−60.49943	1830	19 Aug 2015	22 Jul 2016	339
5	42.54760	−62.17624	2002	19 Aug 2015	23 Jul 2016	340
6	44.85309	−55.27108	1802	22 Aug 2015	20 Jul 2016	334
7	45.70082	−51.23315	78	23 Aug 2015	19 Jul 2016	332
8	47.49307	−59.41325	428	16 Aug 2015	8 Jul 2016	328
9	48.92733	−58.87786	44	16 Aug 2015	26 Apr 2016	255
10	51.26912	−57.53759	121	3 Aug 2015	5 Jul 2016	338
11	55.60300	−57.75040	158	9 Aug 2015	13 Jul 2016	340
12	57.25273	−60.00175	143	10 Aug 2015	13 Jul 2016	339
13	55.22797	−54.19047	1750	8 Aug 2015	11 Jul 2016	339
14	53.01567	−53.46022	582	4 Aug 2015	14 Jul 2016	346
15	50.41327	−49.19638	2000	14 Aug 2015	16 Jul 2016	338
16	44.19230	−53.27441	1602	23 Aug 2015	20 Jul 2016	333
17	44.97141	−48.73373	1282	24 Aug 2015	18 Jul 2016	330
18	46.90877	−48.50418	111	25 Aug 2015	18 Jul 2016	329
19	48.72873	−49.38087	1282	25 Aug 2015	17 Jul 2016	328
20	50.75232	−52.33602	237	13 Aug 2015	15 Jul 2016	338

Table 5. ESRF study 2016–17: Operation period, location, and depth of the AMARs deployed.

Station	Latitude	Longitude	Depth (m)	Deployment	Retrieval	Duration (days)
1	46.98697	−60.0209	175	8 Jul 2016	10 Jul 2017	367
2	45.43153	−59.7725	120	21 Jul 2016	9 Jul 2017	353
3	44.14955	−60.596	72	22 Jul 2016	8 Jul 2017	351
4	43.216	−60.5017	1558	22 Jul 2016	8 Jul 2017	351
5	42.54767	−62.1769	1831	23 Jul 2016	8 Jul 2017	350
6	44.8521	−55.2707	1790	20 Jul 2016	23 Jul 2017	368
8	47.49302	−59.4124	420	8 Jul 2016	10 Jul 2017	367
9	48.9274	−58.8774	43	9 Jul 2016	10 Jul 2017	366[1]
10	51.27692	−57.5349	110	10 Jul 2016	11 Jul 2017	366
11	55.60505	−57.7488	150	14 Jul 2016	14 Jul 2017	365
12	57.24852	−60.0079	142	13 Jul 2016	14 Jul 2017	366
13	55.22788	−54.1901	1700	12 Jul 2016	15 Jul 2017	368
14	53.02073	−53.4605	551	15 Jul 2016	16 Jul 2017	366
15	50.41112	−49.1959	1993	16 Jul 2016	18 Jul 2017	367
16	44.19273	−53.2748	1608	20 Jul 2016	22 Jul 2017	367
17	44.96777	−48.7336	1273	19 Jul 2016	21 Jul 2017	367
18	46.9118	−48.5012	214	18 Jul 2016	20 Jul 2017	367
19	48.3802	−46.5254	1547	17 Jul 2016	19 Jul 2017	367
20	50.75857	−52.3303	236	16 Jul 2016	18 Jul 2017	367

[1] Corrupt data, no analysis performed

2.2. Automated Data Analysis

Approximately 40 TB of acoustic data were collected during the study. These data are available at no-cost by request to We used a specialized computing platform capable of processing acoustic data hundreds of times faster than real-time. The system performed automated analysis of total ocean noise and sounds from vessels, seismic surveys, and (possible) marine mammal vocalizations. Appendix C outlines the stages of the automated analysis.

We also classified the dominant sound source in each minute of data as “Vessel”, “Seismic”, or “Ambient”. To minimize the influence of anthropogenic sources on ambient sound level estimates, we defined ambient levels from individual minutes of data that did not have an anthropogenic detection within one hour on either side of that minute. This results in more accurate estimates of daily sound exposure levels (SEL) from each source class, cumulative distribution functions of sound pressure levels, and exceedance spectra.

2.2.1. Total Ocean Noise and Time Series Analysis

Ambient noise levels at each station were examined to document the local baseline underwater sound conditions. In Section 3.1, ambient noise levels are presented as:

- Statistical distribution of SPL in each 1/3-octave-band. The boxes of the statistical distributions indicate the first (L_{25}), second (L_{50}), and third (L_{75}) quartiles. The whiskers indicate the maximum and minimum range of the data. The solid line indicates the mean sound pressure level (SPL), or L_{mean}, in each 1/3-octave.
- Spectral density level percentiles: Histograms of each frequency bin per 1 min of data. The L_{eq}, L_5, L_{25}, L_{50}, L_{75}, and L_{95} percentiles are plotted. The L_5 percentile curve is the frequency-dependent level exceeded by 5% of the 1 min averages. Equivalently, 95% of the 1 min spectral levels are above the 95th percentile curve.
- Broadband and approximate-decade-band sound pressure levels (SPL) over time for these frequency bands: 10 Hz to 4 kHz, 10–100 Hz, 100 Hz to 1 kHz, and 1–4 kHz.
- Spectrograms: Ambient noise at each station was analyzed by Hamming-windowed fast Fourier transforms (FFTs), with 1 Hz resolution and 50% window overlap. The 120 FFTs performed with these settings are averaged to yield 1 min average spectra.
- Daily sound exposure levels (SEL): Computed for the total received sound energy and the detected shipping energy. The SEL is the linear sum of the 1 min SEL. For shipping, the 1 min SEL values are the linear 1 min squared SPL values multiplied by the duration, 60 s. For seismic survey pulses, the 1 min SEL is the linear sum of the per-pulse SEL.

The 50th percentile (median of 1 min spectral averages) can be compared to the well-known Wenz ambient noise curves (Figure 2), which show the variability of ambient spectral levels off the US Pacific coast as a function of frequency of measurements for a range of weather, vessel traffic, and geologic conditions. The Wenz curve levels are generalized and are used for approximate comparisons only.

The 1 min averaged, 1 Hz spectral density levels are summed over the 1/3-octave and decade bands to calculate the 1 min averaged broadband levels (dB re 1 µPa). They are presented with the density levels. Table F-1 lists the 1/3-octave-band frequencies.

Table F-2 lists the decade-band frequencies. Weather and ice coverage conditions throughout the deployment periods were also gathered to inform the discussion on the factors driving noise levels and influencing marine mammal detections.

Detailed description of acoustic metrics and third-octave band analysis can be found in Appendix D.

2.2.2. Vessel Noise Detection

Vessels are detected in two steps:

1. Constant, narrowband tones produced by a vessel's propulsion system and other rotating machinery (Arveson and Vendittis 2000) are detected. These sounds are also referred to as tonals. We detect the tonals as lines in a 0.125 Hz resolution spectrogram of the data.
2. The root-mean-square sound pressure levels (SPL) are assessed for each minute in the 40–315 Hz frequency band, which commonly contains most sound energy produced by mid-sized to large vessels. Background estimates of the shipping band SPL and broadband SPL are then compared to their median values over the 12 h window, centred on the current time.

Vessel detections are defined by three criteria:

- The SPL in the shipping band is at least 3 dB above the median.
- At least 5 shipping tonals (0.125 Hz bandwidth) are present.
- The SPL in the shipping band is within 8 dB of the broadband SPL (Figure 8).

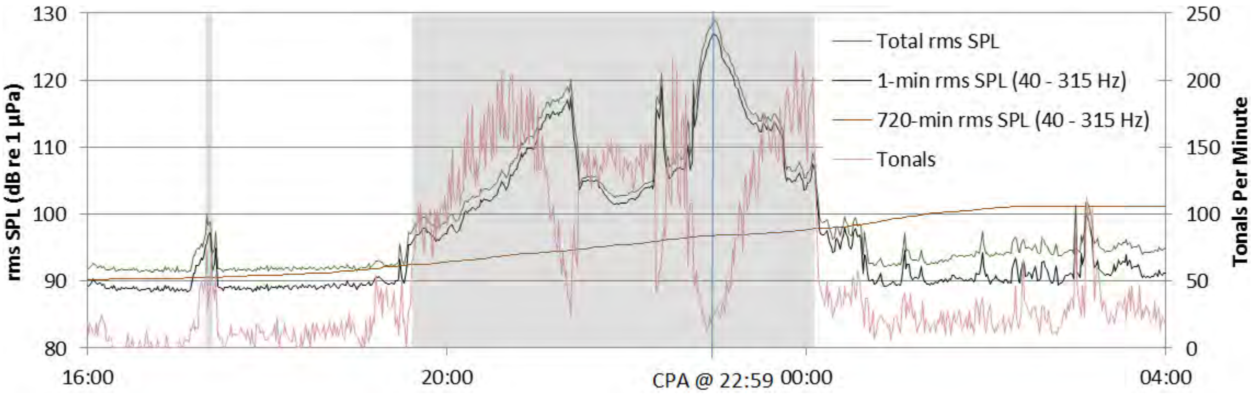


Figure 8. Example of broadband and 40–315 Hz band SPL, as well as the number of tonals detected per minute as a ship approached a recorder, stopped, and then departed. The shaded area is the period of shipping detection. Fewer tonals are detected at the ship's closest point of approach (CPA) at 22:59 because of masking by broadband cavitation noise and due to Doppler shift that affects the tone frequencies.

2.2.3. Seismic Survey Event Detection

Seismic pulse sequences are detected using correlated spectrogram contours. We calculate spectrograms using a 300 s long window with 4 Hz frequency resolution and a 0.05 s time resolution (Reisz window). All frequency bins are normalized by their medians over window the 300 s window. The detection threshold is three times the median value at each frequency. Contours are created by joining the time-frequency bins above threshold in the 7–1000 Hz band using a 5 × 5 bin kernel. Contours 0.2–6 s in duration with a bandwidth of at least 60 Hz are retained for further analysis.

An "event" time series is created by summing the normalized value of the frequency bins in each time step that contained detected contours. The event time series is auto-correlated to look for repeated events. The correlated data space is normalized by its median and a detection threshold of 3 is applied. Peaks larger than their two nearest neighbours are identified and the peaks list is searched for entries with a set repetition interval. The allowed spacing between the minimum and maximum time peaks is 4.8 to 65 s, which captures the normal range of seismic pulse periods. Where at least six regularly spaced peaks occur, the original event time series is searched for all peaks that match the repetition period within a tolerance of 0.25 s. The duration of the 90% SPL window of each peak is determined from the originally sampled time series, and pulses more than 3 s long are rejected.

2.2.4. Marine Mammal Detection Overview

We used a combination of automated detectors and manual review by experienced analysts to determine the presence of sounds produced by marine mammals. First, automated detectors identified acoustic signals potentially produced by odontocetes, mysticetes, and pinnipeds (Appendix E.1 and E.2). We manually reviewed (validated) detections within a sample of the dataset, critically reviewed the results of each detector, and restricted the detectors' output where necessary to provide the most accurate description of marine mammal presence (Appendix E.3). Where detector results were found to be unreliable, only the validated results are presented. Finally, for the few species of interest that no effective detector was available for, additional manual review of selected data was completed as is described at the species level.

In this report, the term detector is used to describe automated algorithms that combine detection and classification steps. A detection refers to an acoustic signal that has been flagged as a sound of interest based on spectral features and subsequently classified based on similarities to several templates in a library.

2.2.4.1. Click Detection

Odontocete clicks are high-frequency impulses ranging from 5 to over 150 kHz (Au et al. 1999, Mohl et al. 2000). We applied an automated click detector to the 250 kilosamples per second (ksps) data (audio bandwidth up to 125 kHz for ~1 min of every 20 min) to identify clicks from sperm whales, beaked whales, porpoises, and delphinids. This detector is based on zero-crossings in the acoustic time series. Zero-crossings are the rapid oscillations of a click's pressure waveform above and below the signal's normal level (e.g. Figure 116). Zero-crossing-based features of detected events are then compared templates of known clicks for classification (see Appendix E.1 for details).

2.2.4.2. Tonal Signal Detection

Tonal signals are narrowband, often frequency-modulated, signals produced by many species across a range of taxa. Examples include the moans of baleen whales and whistles of delphinids. The signals of some pinniped species, such as the trills of bearded seals, also have tonal components. Baleen whale, pilot whale, and pinniped tonal acoustic signals range predominantly between 15 Hz and 4 kHz (Berchok et al. 2006, Risch et al. 2007), thus detectors for these species were applied to the 8 ksps data (audio bandwidth up to 4 kHz for ~11 min every 20 min). In contrast, the detector for small dolphin tonal acoustic signals was applied to the high frequency data as these whistles can reach 20 kHz (Steiner 1981). The tonal signal detector identifies continuous contours of elevated energy and classifies them against a library of marine mammal signals (see Appendix E.2 for details).

2.2.4.3. Validation of Automated Detectors

We develop and test automated detectors with example data files that contain a range of vocalization types and background noise conditions. However, test files cannot cover the full range of possible vocalization types and noise conditions. Therefore, a selection of files was manually validated to check each detector's performance for a specific location and timeframe to determine how best to refine the detector results and when to entirely rely on manually validated results to accurately represent marine mammal occurrence Details of the file selection and validation process can be found in Appendix E.3.

To determine the performance of each detector and any necessary thresholds, the automated and validated results (excluding files where an analyst indicated uncertainty in species occurrence) were fed to a maximum likelihood estimation algorithm that maximizes the probability of detection and minimizes the number of false alarms using the 'F-score' (see Appendix E.3.2 for details). It also estimates the precision (P) and recall (R) of the detector. P represents the proportion of files with detections that are true positives. A P of 0.9 means that 90% of the files with detections truly contain the targeted signal, but does not indicate whether all files containing acoustic signals from the species were identified. R represents the proportion of files containing the signal of interest that were identified by the detector. An R of 0.8 means that 80% of files known to contain a target signal had automated detections, but says nothing about how many files with detections were incorrect. An F-score is a combined measure of P and R where an F-score of 1 indicates perfect performance–all events are detected with no false alarms.

The algorithm determines a detector threshold for each species, at every station, for both years, that maximizes the F-score. The resulting thresholds, Ps, and Rs are presented in Section 3.4.1 and in further detail in Appendix F.

Only detections associated with a P greater than or equal to 0.75 were considered. When $P < 0.75$, only the validated results were used to describe the acoustic occurrence of a species.

The occurrence of each species (both validated and automated, or validated only where appropriate) was plotted using JASCO's Ark software as time series showing presence/absence by hour over each day for the two recording periods. Marine mammal occurrence is also presented as spatial plots for each station and recording year. The spatial plots depict mean hourly detection counts (MHDC) or presence/absence over the whole recording period or selected sub-periods if justified by temporal patterns of acoustic detections revealed by the detection time series.

2.2.4.4. Species Diversity

To evaluate the relative importance of each station to the marine mammal community and to highlight areas with higher species diversity, we compiled the manual and automated detections of all species. Results were summarized to show the number of species acoustically present by station and month. The monthly integration period limits the bias against the effort limitations of manual review. Indeed, the automated detectors scanned every single sound file, whereas analysts manually review less than one file per day for each station. Species counts were also computed for four time periods when all recorders were active and shown as bubble plots to assess spatial and seasonal variations in species diversity across the study area. Delphinid click detections were excluded to avoid duplicate records with tonal call detections of killer whales, pilot whales, and dolphins.

3. Results

3.1. Ambient Noise by Station

Ambient noise results and detailed discussions are presented here for seven stations (of the 20 stations) representing deep and shallow sites, distributed over the study area: deep stations (stn 4, 5, 15, and 19) and shallow stations (stn 1, 12, and 18) as shown in Figure 9. Several contributors to ambient noise are discussed: weather; mammals, shipping, and oil and gas activity. Noise measurements for all other stations are presented in Appendix F.

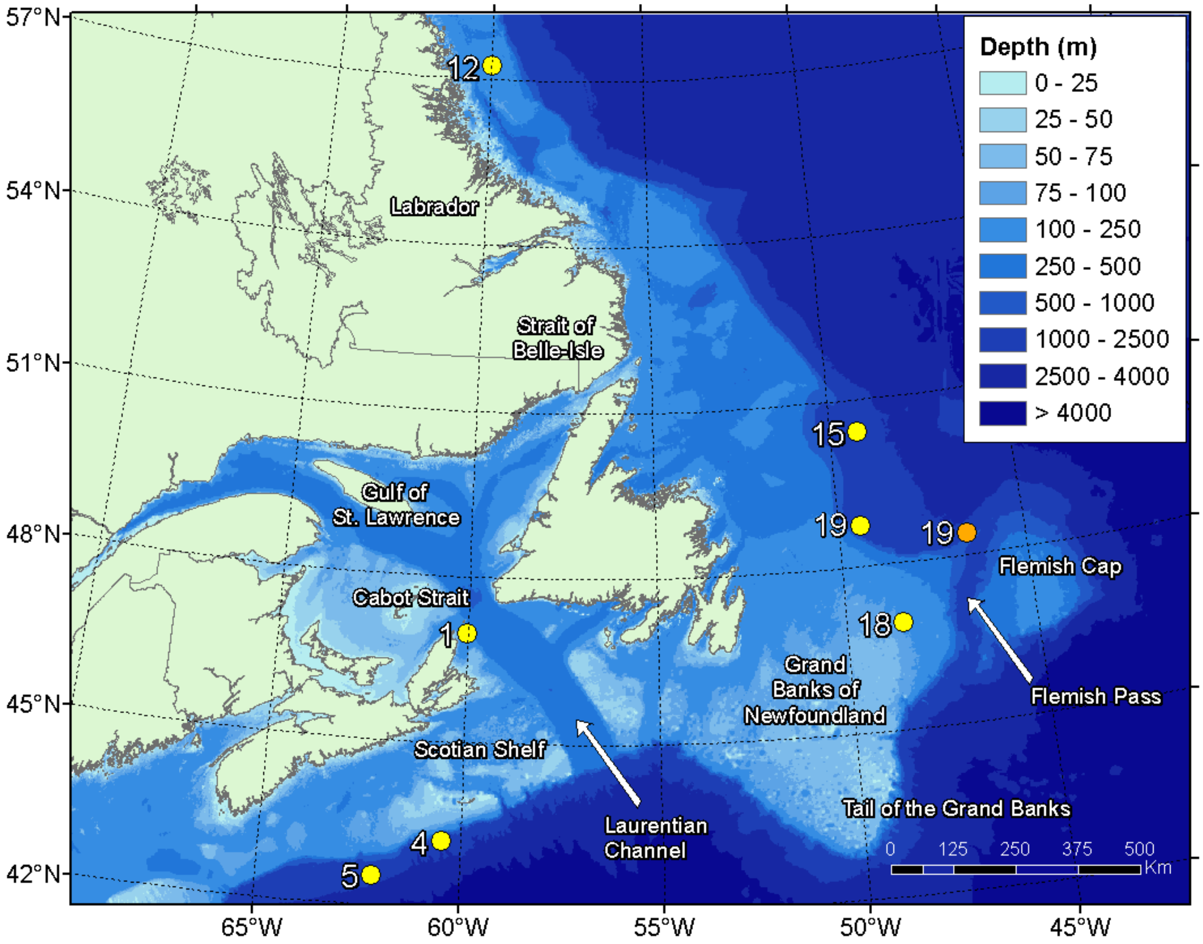


Figure 9. Map of study area and stations where detailed ambient noise characteristics are provided in the discussion. The orange dot represents the location of stn 19 in 2016–17 (see section 3.1.3 for details).

3.1.1. Station 12

Stn 12 was located off the coast of Labrador at a depth of ~140 m. It was the northernmost recorder in the study. The maximum and minimum broadband SPL (1-minute average) measured in 2015–16 were 137.7 and 80.7 dB re 1 µPa, respectively. The maximum and minimum broadband SPL measured in 2016–17 were 147.9 and 84.9 dB re 1 µPa, respectively (Figure 10). There was flow noise occurring periodically throughout the recordings in both years, with peaks at 18 and 31 Hz in 2015–16 and 27 Hz in 2016–17 (Figures 10 and 11). These peaks are not indicative of ambient noise in the area.

Noise associated with seismic surveys was the main contributor, up to about 200 Hz, to the local soundscape from August to late October 2015. In 2016, seismic noise was present until late August, but the associated sound levels were lower than in 2015 (Figure 12). Vessel noise dominated the soundscape below 500 Hz in November and December 2015, possibly from fishing activity in the area (Figure 4). Noise levels in the 1–4 kHz frequency band increased from November to January and is associated with an increase in wind speeds in winter.

The Labrador shelf is covered by sea ice in winter and spring. Sea ice formed at stn 12 in December 2015 and was mostly broken up by June 2016 (Figure 13). Sea ice growth on the Labrador shelf occurred slightly later during the next winter (Jan 2017) but disappeared on a similar timeframe (Figure 14). Sea ice formation was associated with localized, high-intensity ice-cracking impulses (Figure 10, bottom). Scattering at the rough under-ice surface highly attenuates sound propagation under ice at frequencies above 200 Hz (Greene and Buck 1964, Diachok 1976, Roth et al. 2012). This phenomenon caused low sound levels above 200 Hz for most of the ice-covered period (Figure 10). Bearded seal vocalizations were a major contributor to the ambient noise levels from April to June 2016. These vocalizations range from about 200 to 2000 Hz and are apparent in Figure 10.

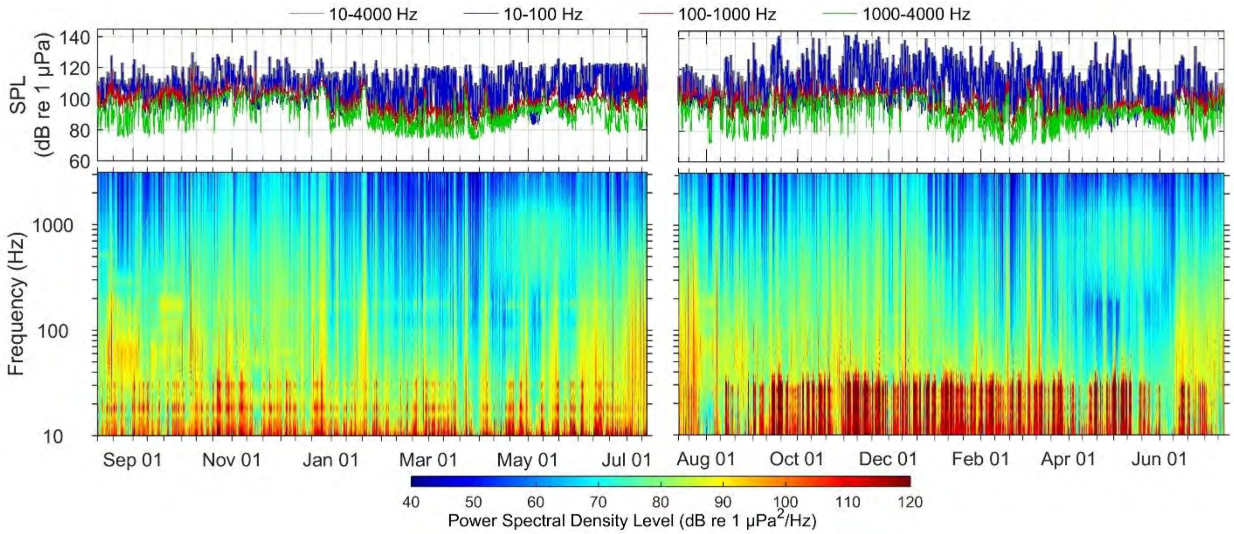


Figure 10. Stn 12 (left) 2015–16, (right) 2016–17: In-band SPL and spectrogram of underwater sound.

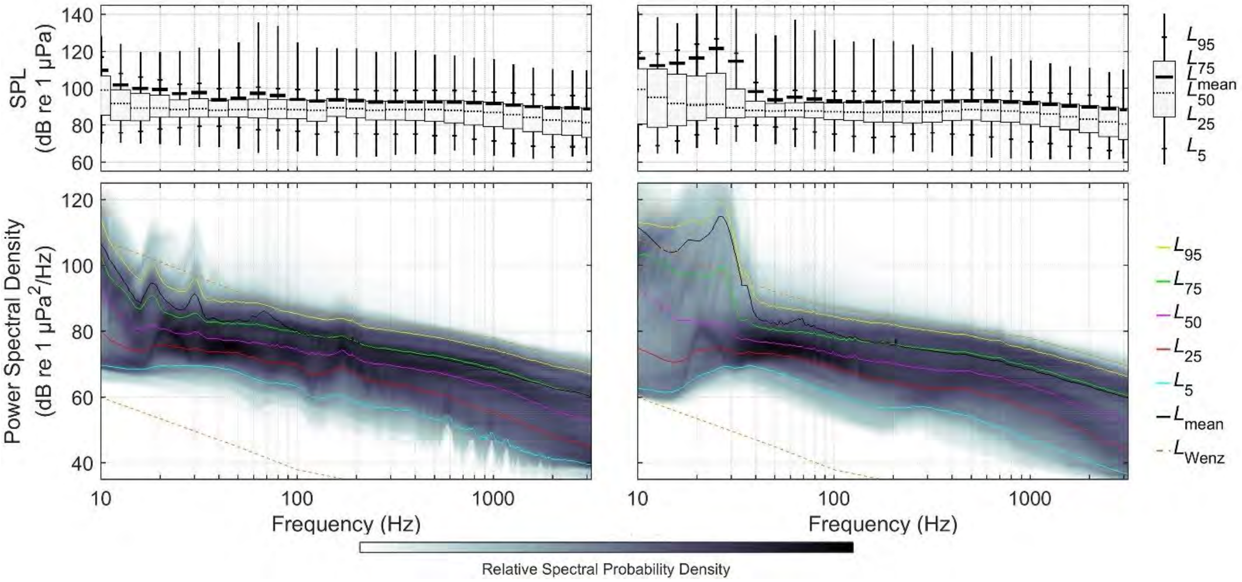


Figure 11. Stn 12 2015–16 (left), 2016–17 (right): Exceedance percentiles and mean of 1/3-octave-band SPL and exceedance percentiles and probability density (grayscale) of 1-min PSD levels compared to the limits of prevailing noise (Wenz 1962).

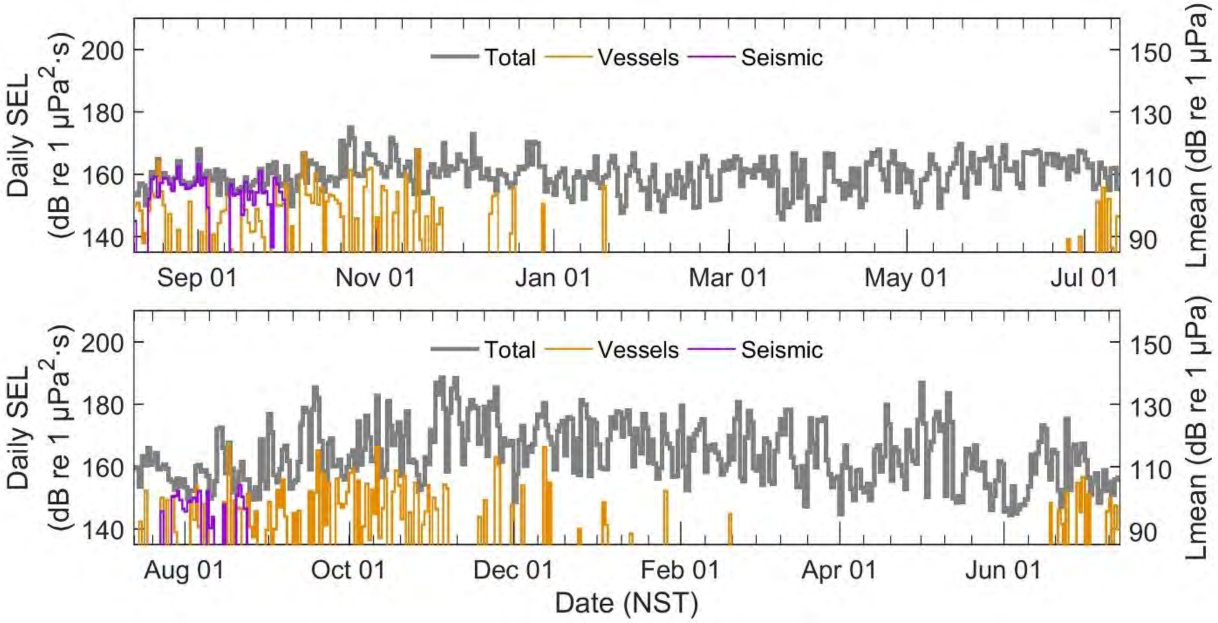


Figure 12. Stn 12 (top) 2015–16, (bottom) 2016–17:Total, vessel, and seismic-associated daily SEL and equivalent continuous noise levels (L_{eq}).

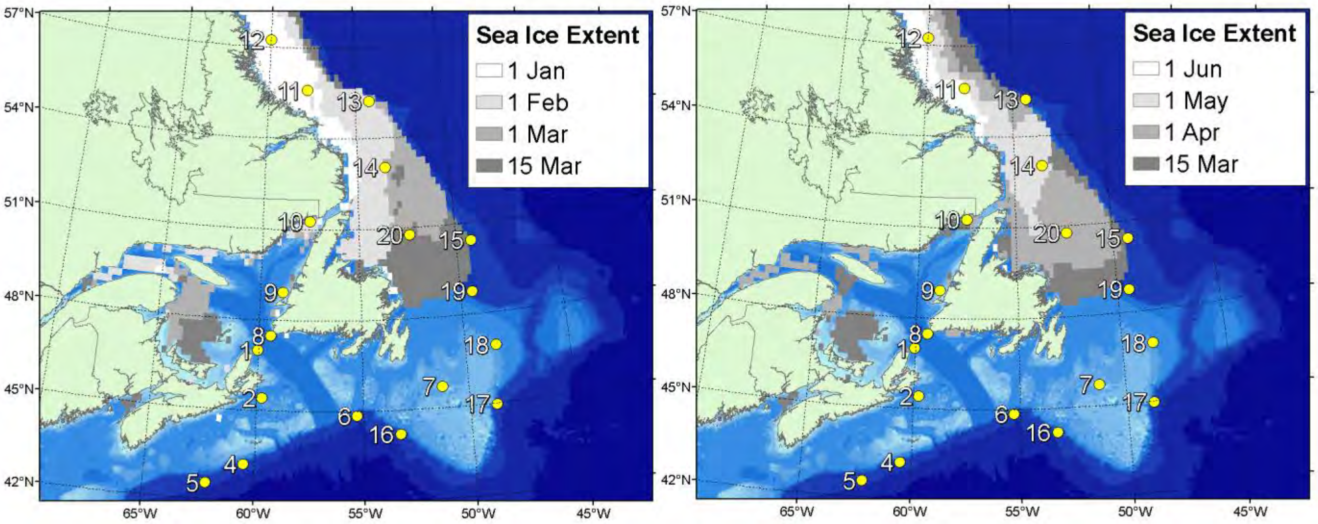


Figure 13. Sea Ice extent during the growth (left) and decline (right) of the ice pack from January to June 2016. Copyright 2017 EUMETSAT.

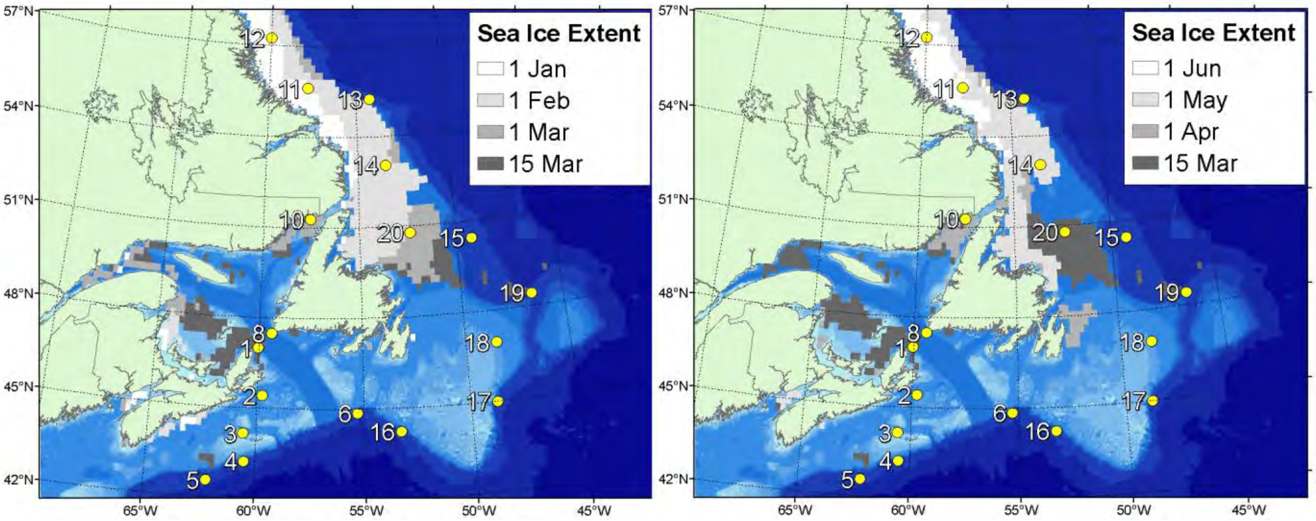


Figure 14. Sea Ice extent during the growth (left) and decline (right) of the ice pack from January to June 2017. Copyright 2017 EUMETSAT.

3.1.2. Station 15

Stn 15 was located off the northeastern coast Newfoundland at a depth of ~2000 m. The maximum and minimum broadband SPL (1-minute average) measured in 2015–16 were 137.6 and 87.9 dB re 1 µPa, respectively (Figure 15). The maximum and minimum broadband SPL measured in 2016–17 were 144.3 and 91.1 dB re 1 µPa, respectively. The soundscape at this station was strongly dominated by seismic survey sounds in the summer and fall as is apparent in the spectrogram. Seismic survey sounds raised the SPL below 300 Hz to exceed the expected limits of prevailing noise (Figure 16) for the L_5 percentile curve, or for 95% of the time. Seismic survey activity occurred from August to early November in 2015, from late May to October 2016, and from late June to July 2017 (Figure 17). The maximum sound levels were measured during a period of seismic survey activity.

Fin whale 20 Hz notes were the main biological contributors to the soundscape between September and March (Figure 15). These notes raised the noise levels by at least 10 dB when present (Figure 16). The narrowband nulls in the spectrograms throughout the recording at 1650 and 2000 Hz are due to destructive interference from reflections off the AMAR UD pressure case used at this and other deep locations.

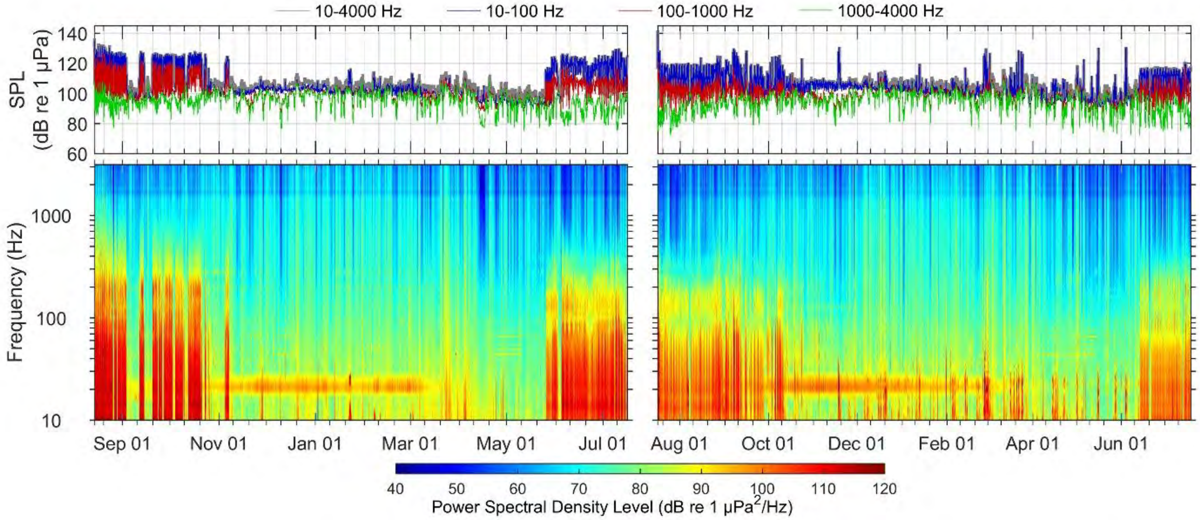


Figure 15. Stn 15 (left) 2015–16, (right) 2016–17: In-band SPL and spectrogram of underwater sound.

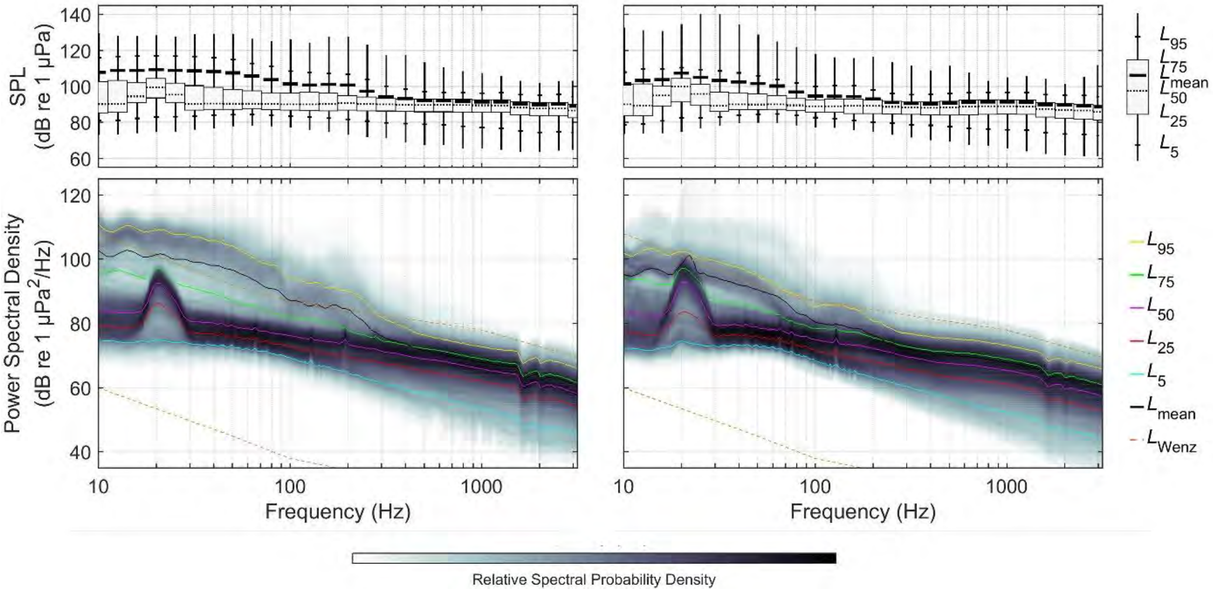


Figure 16. Stn 15 2015–16 (left), 2016–17 (right): Exceedance percentiles and mean of 1/3-octave-band SPL and exceedance percentiles and probability density (grayscale) of 1-min PSD levels compared to the limits of prevailing noise (Wenz 1962).

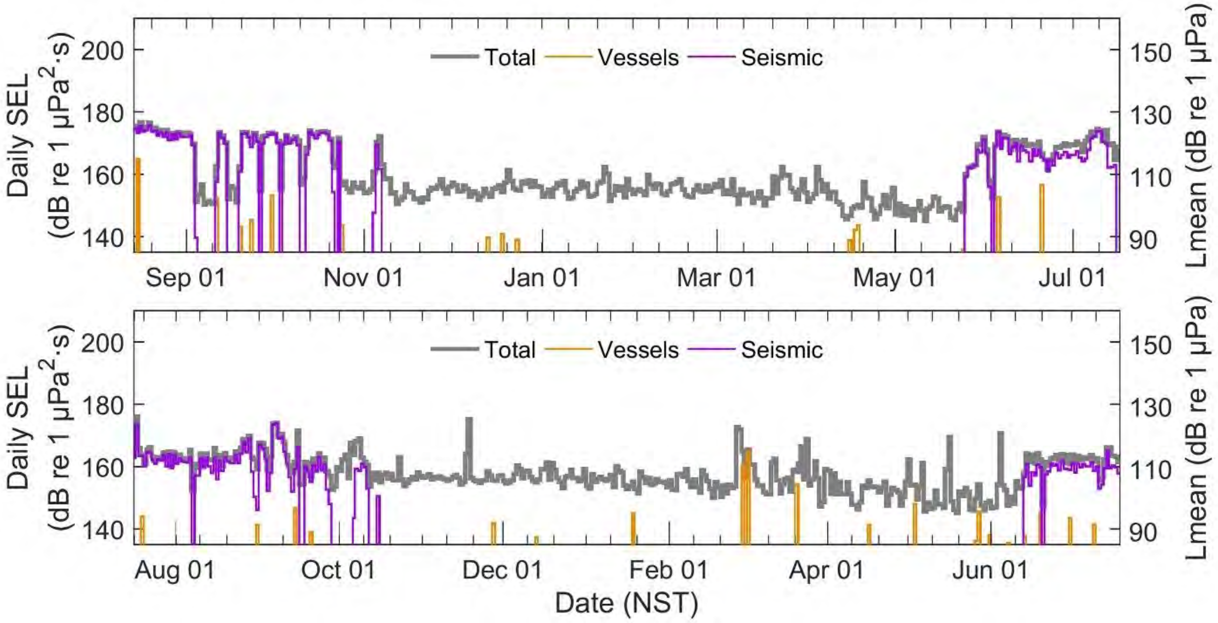


Figure 17. Stn 15 top (2015–16), (bottom) 2016–17:Total, vessel, and seismic-associated daily SEL and equivalent continuous noise levels (L_{eq}).

3.1.3. Station 19

Stn 19 was located off the northeastern coast Newfoundland at slightly different locations in 2015–16 and 2016–2017 (210 km east of 2015-16 location). In 2015–16, the location was chosen to monitor anticipated oil and gas activity development and to assess transmission losses off the northeast Grand Banks (see Table 4 for location details). The change in location for 2016–17 was motivated by repeated summer sightings of northern bottlenose whales in the Sackville Spur area (Laura Feyrer, personal communication). It also brought the recorder closer to the site of a 3-D seismic survey conducted in the northern Flemish Pass.

The maximum and minimum broadband SPL measured in 2015–16 were 139.5 and 90.6 dB re 1 µPa, respectively (Figure 18). The maximum and minimum broadband SPL measured in 2016–17 were 157.6 and 95.5 dB re 1 µPa, respectively. The two main soundscape features at this station in both years were seismic survey activity from July to October and fin whale vocalizations from September through March, (Figure 18). In 2015–16, the recorder was relatively far from the site of seismic surveys, so airgun sounds were identifiable but did not often raise SPL above the limits of prevailing noise. In 2016–17, the adjusted station location was closer to a 3-D seismic survey, which frequently raised the SPL below 300 Hz to exceed the expected limits of prevailing noise (Figure 19). However, environmental and mooring noise at this location also regularly exceeded the limits of prevailing noise. The higher sound levels measured in 2016–17, particularly in winter and spring, are largely attributed to flow-induced mooring noise, suggesting stronger currents at the second location. We also interpret the higher vessel detections in winter and spring during the second year as false vessel detections triggered by tonals caused by mooring cable vibrations. The 20-Hz peak attributed to fin whales was masked to some extent by the contribution of flow noise, which has a slightly more broadband signature.

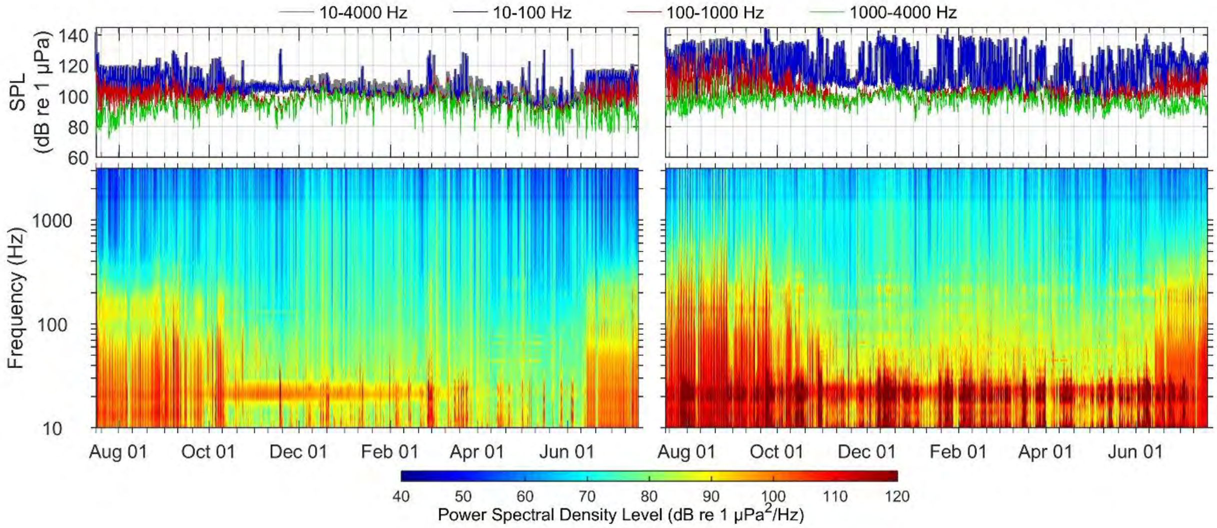


Figure 18. Stn 19 (left) 2015–16, (right) 2016–17: In-band SPL and spectrogram of underwater sound.

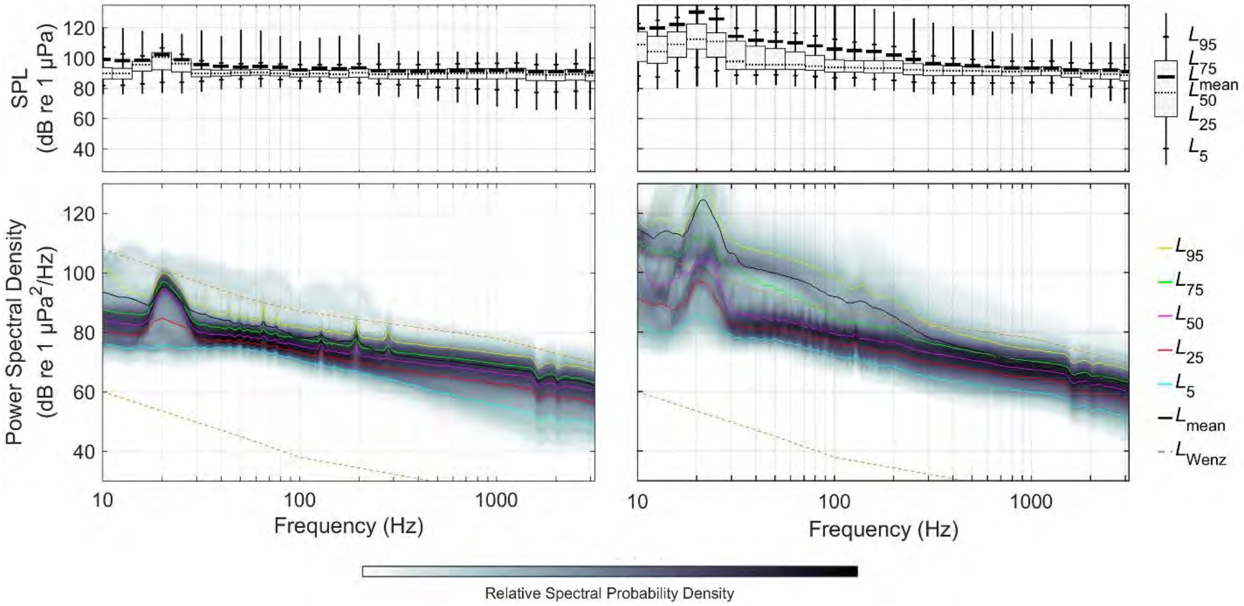


Figure 19. Stn 19 2015–16 (left), 2016–17 (right): Exceedance percentiles and mean of 1/3-octave-band SPL and exceedance percentiles and probability density (grayscale) of 1-min PSD levels compared to the limits of prevailing noise (Wenz 1962).

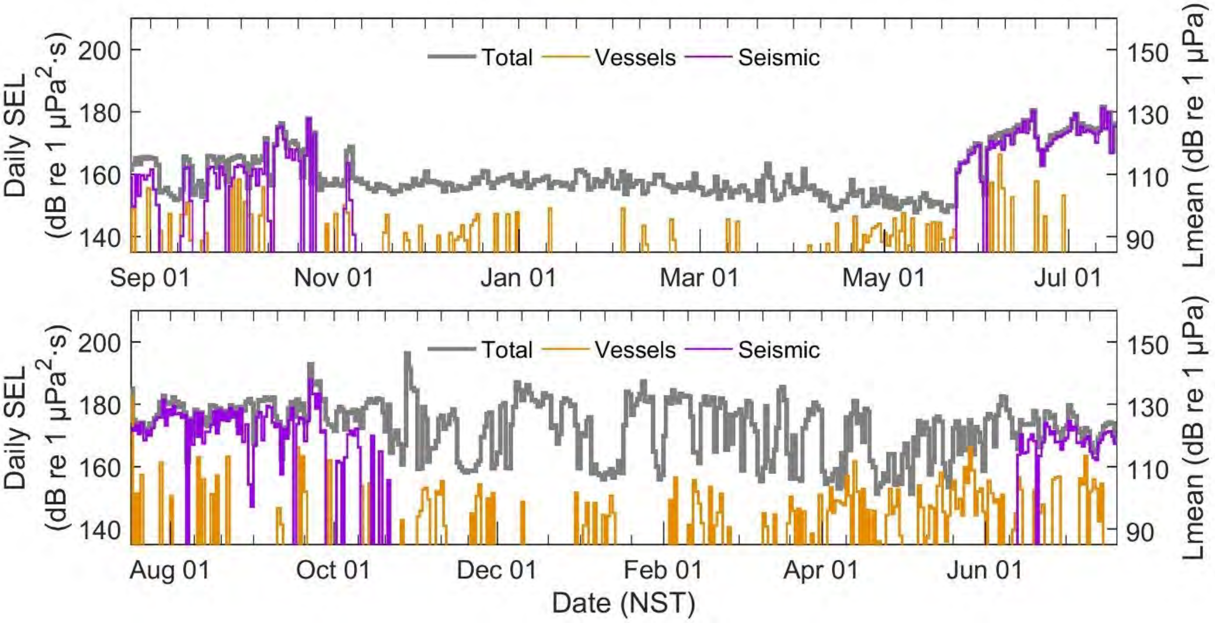


Figure 20. Stn 19 (top) 2015–16, (bottom) 2016–17:Total, vessel, and seismic-associated daily SEL and equivalent continuous noise levels (L_{eq}).

3.1.4. Station 18

Stn 18 was located ~300 km east of St. John's, NL, at a depth of 110 m. The Hibernia oil platform is located 17 km from the deployment location. The maximum and minimum broadband SPL measured in 2015–16 were 142.8 and 104.7 dB re 1 µPa, respectively, and 144.4 and 104.1 dB re 1 µPa in 2016–17.

Fin whale 20 Hz vocalizations were present from September to March (Figure 21) in both years. They are visible as a slight bump in the PSD at 20 Hz (Figure 22). Vessel traffic in the area occurred over the entire period (Figure 23). It is worth noting the similarity of the PSD levels in both years, which is best explained by the continuous presence of a stationary source (Hibernia) operating in a consistent manner over time.

Vertical lines on the spectrogram (Figure 21, bottom) from 30–300 Hz indicate vessels travelling near the recorder and most likely represent support vessels associated with the Hibernia platform. The 200 Hz tone throughout the recording period was likely associated with machinery on the platform, since it was constant over the study period. In the first year's deployment, distant seismic noise was also detected in October 2015 and in June and July 2016 (Figure 23). In the second year, seismic survey sounds were detected from the end of July to November 2016 and again in June and July 2017 (Figure 23).

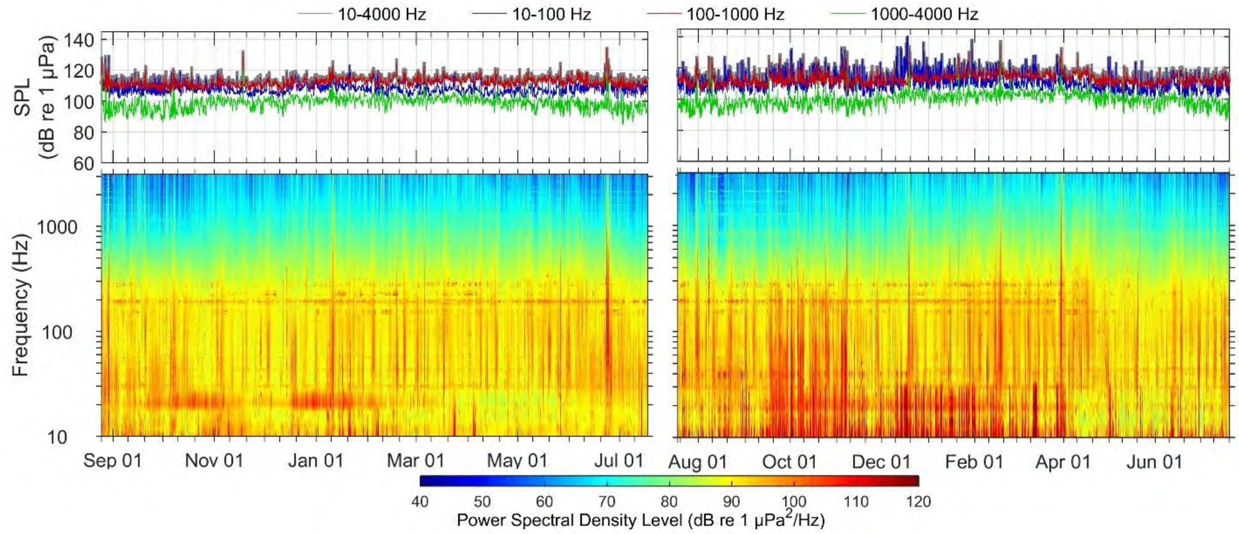


Figure 21. Stn 18 (left) 2015–16, (right) 2016–17: In-band SPL and spectrogram of underwater sound.

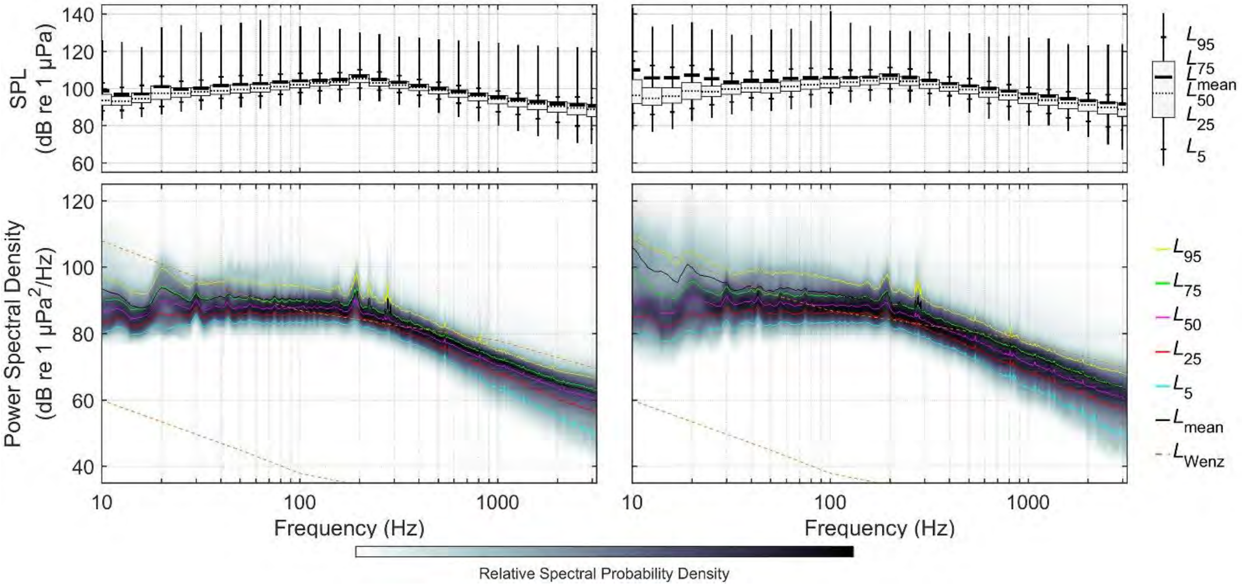


Figure 22. Stn 18 2015–16 (left), 2016–17 (right): Exceedance percentiles and mean of 1/3-octave-band SPL and exceedance percentiles and probability density (grayscale) of 1-min PSD levels compared to the limits of prevailing noise (Wenz 1962).

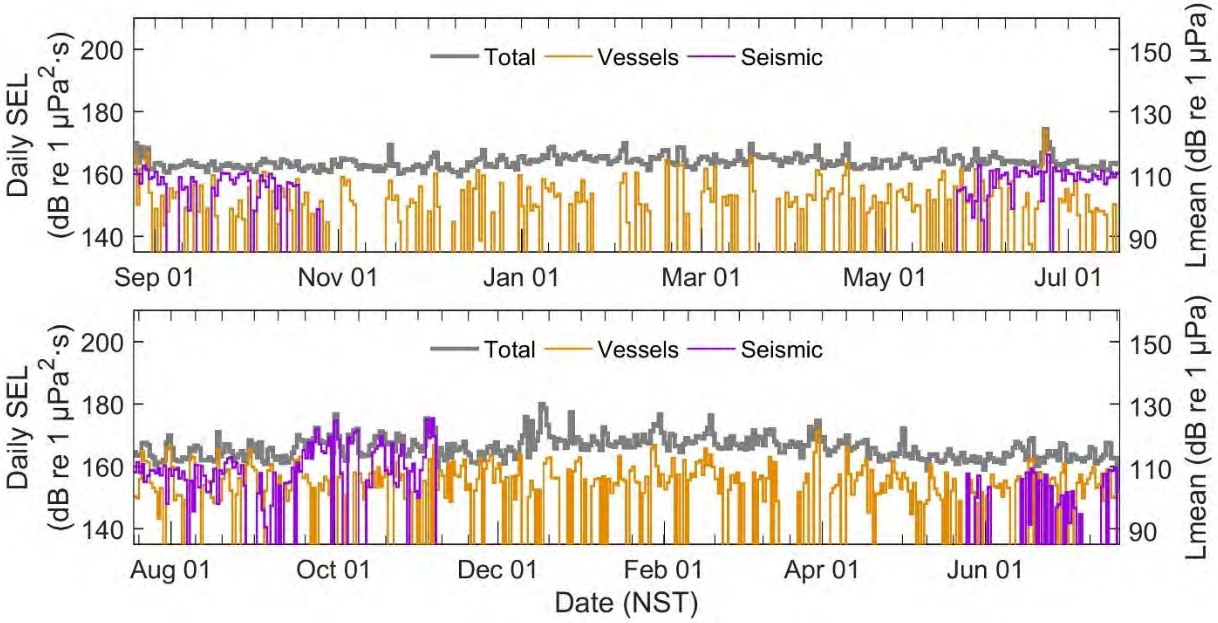


Figure 23. Stn 18 (top) 2015–16, (bottom) 2016–17:Total, vessel, and seismic-associated daily SEL and equivalent continuous noise levels (L_{eq}).

3.1.5. Station 1

Stn 1 was located north of Cape Breton, NS, on the edge of the Laurentian Channel and St. Lawrence Seaway at a depth of 180 m. The maximum and minimum broadband SPL measured in 2015–16 were 144.8 and 91.1 dB re 1 µPa, respectively (Figure 24). In 2016–17, the maximum and minimum broadband SPL measured were 157.1 and 91.4 dB re 1 µPa, respectively (Figure 24). The L_{95} percentile exceeded the limits of prevailing noise (Figure 25) below 200 Hz in both years. This was due to nearby vessel traffic (Figure 26). This recorder was located near the shipping lane that exits the St. Lawrence estuary (Figure 3). One shipping lane passes by the recorder, en route to and from Sydney, NS. There is also regular ferry service between Sydney, NS, and Port-aux-Basques, NL, that may have contributed to the sound levels, even though the ferry lane was ~25 km from the recorder. Fin whale 20 Hz notes were present from October to March in both years as indicated by manual identification, but they are difficult to see in the spectrogram (Figure 24). The contribution of fin whale vocalizations to the soundscape is detectable in the PSD plots in 2015–16, but not in 2016–17 (Figure 25). The latter appears to be due to more elevated background noise that is not vessel-related, but significant under 30 Hz, where all the fin whale vocalization energy occurs.

Vessel noise drove total daily SELs almost entirely in 2015–16, except for some periods in winter and spring where elevated environmental noise during storms was also a factor. In 2016–17, the larger difference between total and vessel-only daily SEL is presumed to have been driven by a higher flow-induced mooring noise.

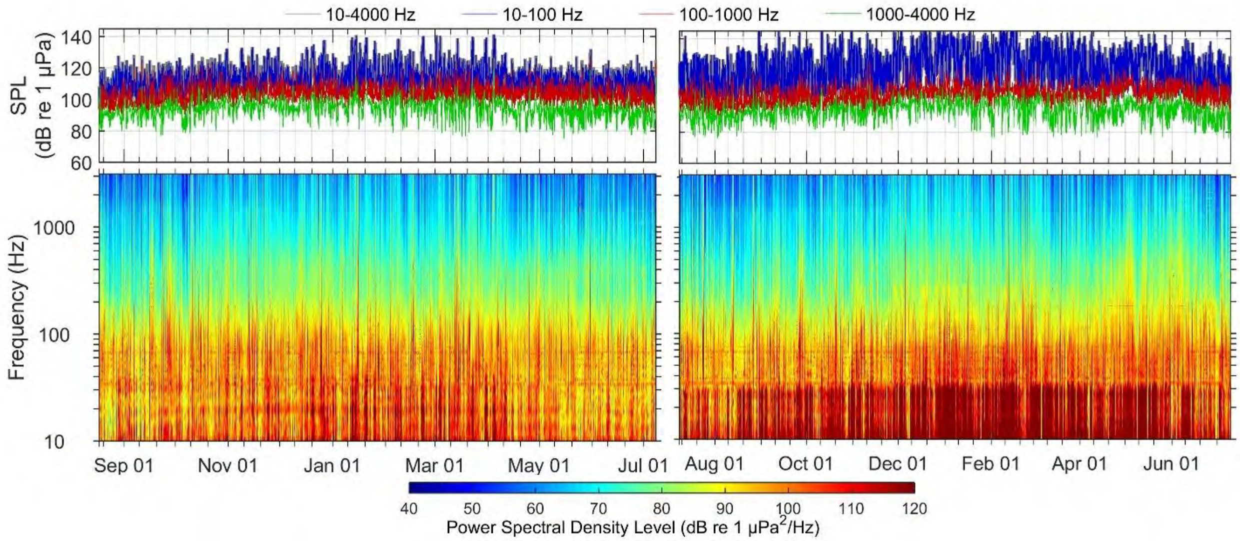


Figure 24. Stn 1 (left) 2015–16, (right) 2016–17: In-band SPL and spectrogram of underwater sound.

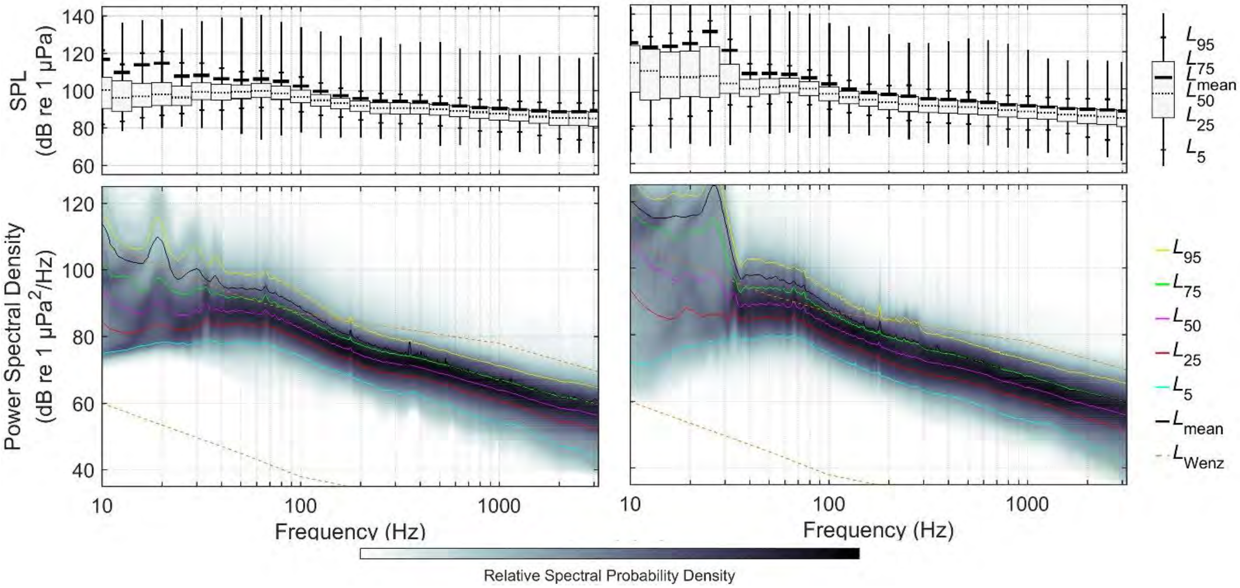


Figure 25. Stn 1 2015–16 (left), 2016–17 (right): Exceedance percentiles and mean of 1/3-octave-band SPL and exceedance percentiles and probability density (grayscale) of 1-min PSD levels compared to the limits of prevailing noise (Wenz 1962).

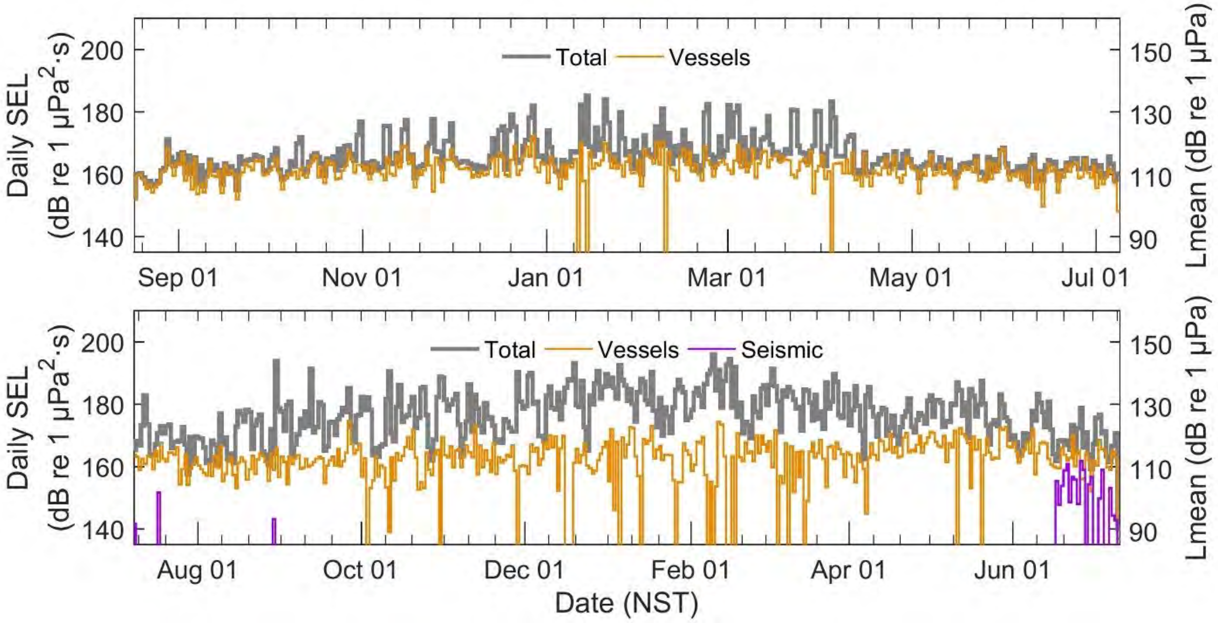


Figure 26. Stn 1 (top) 2015–16, (bottom) 2016–17:Total, vessel, and seismic-associated daily SEL and equivalent continuous noise levels (L_{eq}).

3.1.6. Station 4

Stn 4 was located southeast of Halifax, NS, just off the Scotian Shelf at a depth of 2000 m. The maximum and minimum broadband SPL measured in 2015–16 were 133.2 and 91.2 dB re 1 µPa, respectively (Figure 27). The maximum and minimum broadband SPL measured in 2016–17 were 133.8 and 91.7 dB re 1 µPa, respectively (Figure 27). The peak on 15 Jul 2016 was due to what appeared to be a geological event. Fin whale 20 Hz notes are visible in the spectrogram from late September to March, and also as a bump in the PSD plot (Figure 28).

The SEL plot (Figure 29) shows that vessel noise contributed regularly to the overall soundscape but did not dominate the total SEL. Seismic activity was detected in September 2015, and June and July 2016, with limited contribution to the total daily SEL. This station was one of the quietest, and it is a good representation of ambient noise in deep waters off the Scotian Shelf. Deep stations off Newfoundland (e.g. 13, 15, 17) had generally higher noise levels below 100 Hz, possibly due greater amount of anthropogenic activities. Noise levels were more widespread above 100 Hz but had similar median levels.

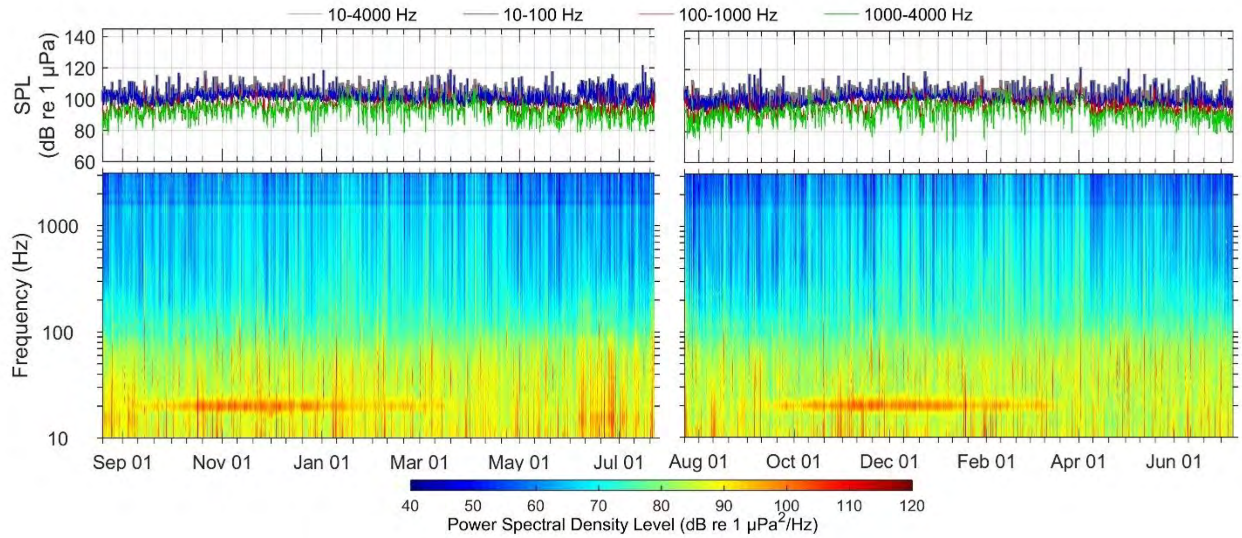


Figure 27. Stn 4 (left) 2015–16, (right) 2016–17: In-band SPL and spectrogram of underwater sound.

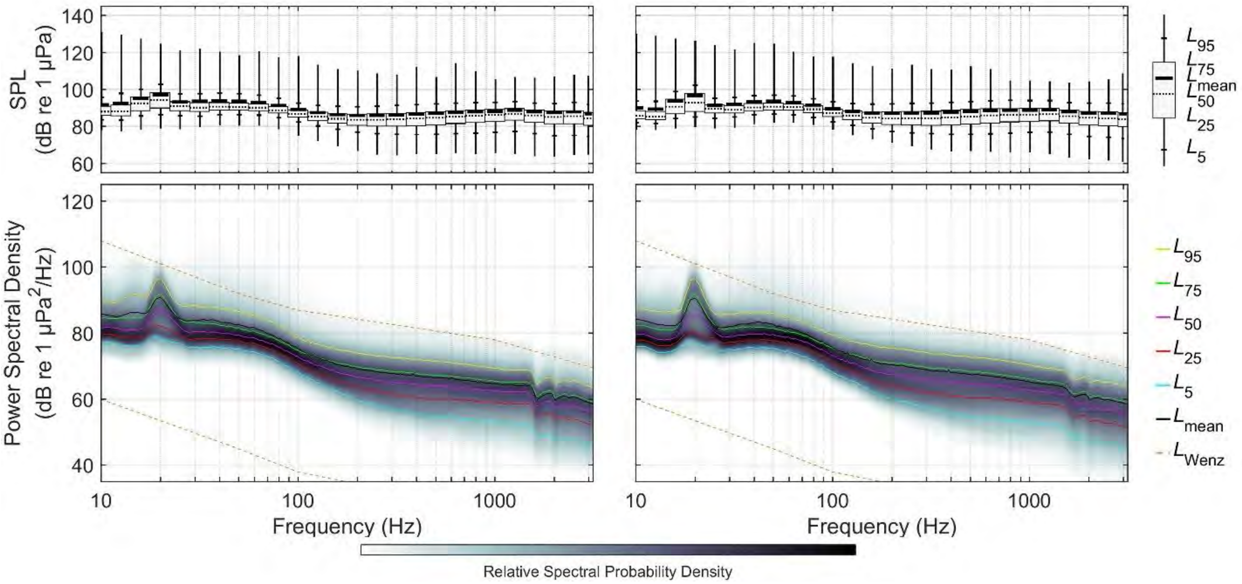


Figure 28. Stn 4 2015–16 (left), 2016–17 (right): Exceedance percentiles and mean of 1/3-octave-band SPL and exceedance percentiles and probability density (grayscale) of 1-min PSD levels compared to the limits of prevailing noise (Wenz 1962).

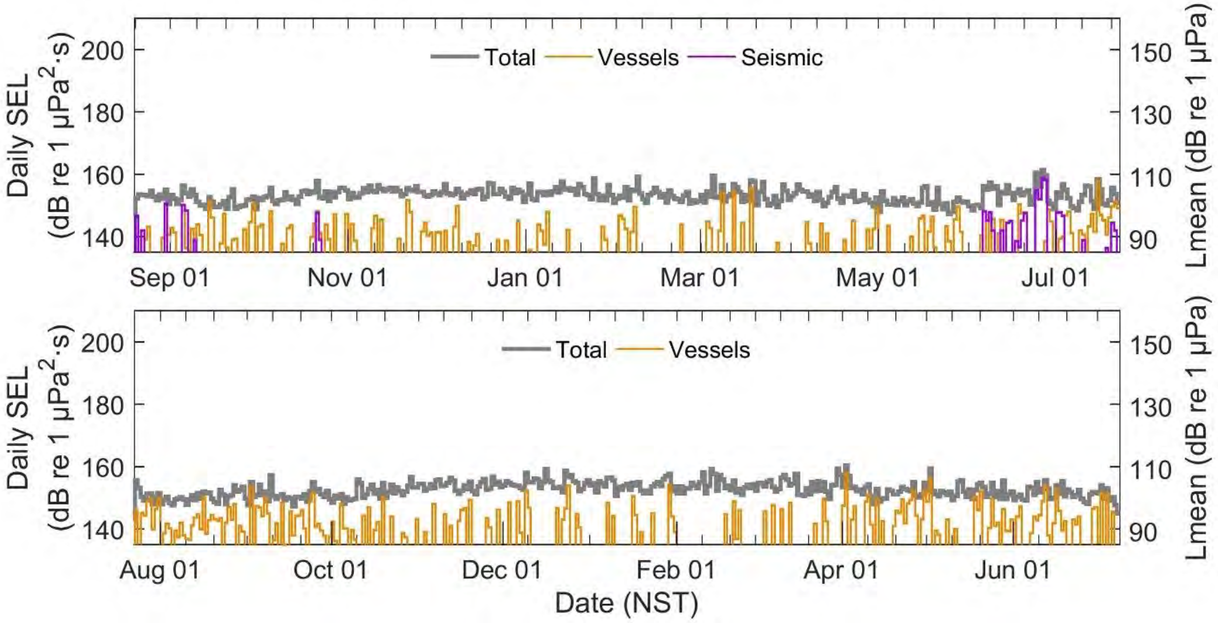


Figure 29. Stn 4 (top) 2015–16, (bottom) 2016–17:Total, vessel, and seismic-associated daily SEL and equivalent continuous noise levels (L_{eq}).

3.1.7. Station 5

Stn 5 was located south of Halifax, NS, just off the Scotian Shelf at a water depth of 2000 m. The maximum and minimum broadband SPL measured in 2015–16 were 141.2 and 90.6 dB re 1 µPa, respectively (Figure 30). The maximum and minimum broadband SPL measured in 2016–17 were 150.9 and 94.3 dB re 1 µPa, respectively (Figure 30). Fin whale 20 Hz notes are visible in the spectrogram from mid-September to April, increasing the PSD at 20 Hz (Figure 31). The SEL plot (Figure 32) indicates that vessel traffic was present throughout the recording period.

Shell Canada Limited conducted exploratory drilling at the Cheshire well site, ~13 km southwest of stn 5, using the Mobile Offshore Drilling Unit (MODU) Stena IceMAX and several support vessels, from October 2015 to September 2016. The operations were suspended in spring 2016 following the loss of the riser pipe during a storm. The sounds from the IceMAX and the support vessels at the Cheshire well site are audible in the data at stn 5. The increase from 50–1000 Hz is visible in the spectrogram (Figure 30) and the PSD plot (Figure 31). We believe the sudden drop in sound levels below 1000 Hz in early March 2016 was associated with IceMAX operational issues, which did not return to normal operations until late May 2016. When the Cheshire well site recommenced operations the daily SEL increase by nearly 10 dB (Figure 32).

Without the contribution of the nearby MODU and support vessels, the soundscape at stn 5 was very similar to that of stn 4 (110 km away), and also representative of the much of the continental slope off the Scotian Shelf. Sound levels were, however, slightly elevated relative to those at stn 4, possibly as a result of their respective proximity to distant marine traffic routes.

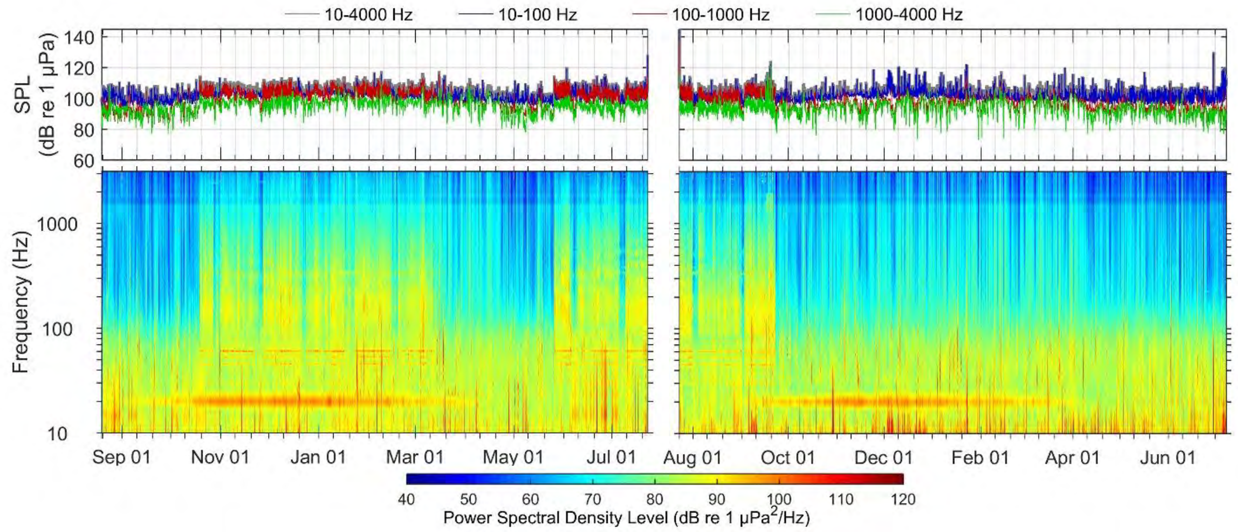


Figure 30. Stn 5 (left) 2015–16, (right) 2016–17: In-band SPL and spectrogram of underwater sound.

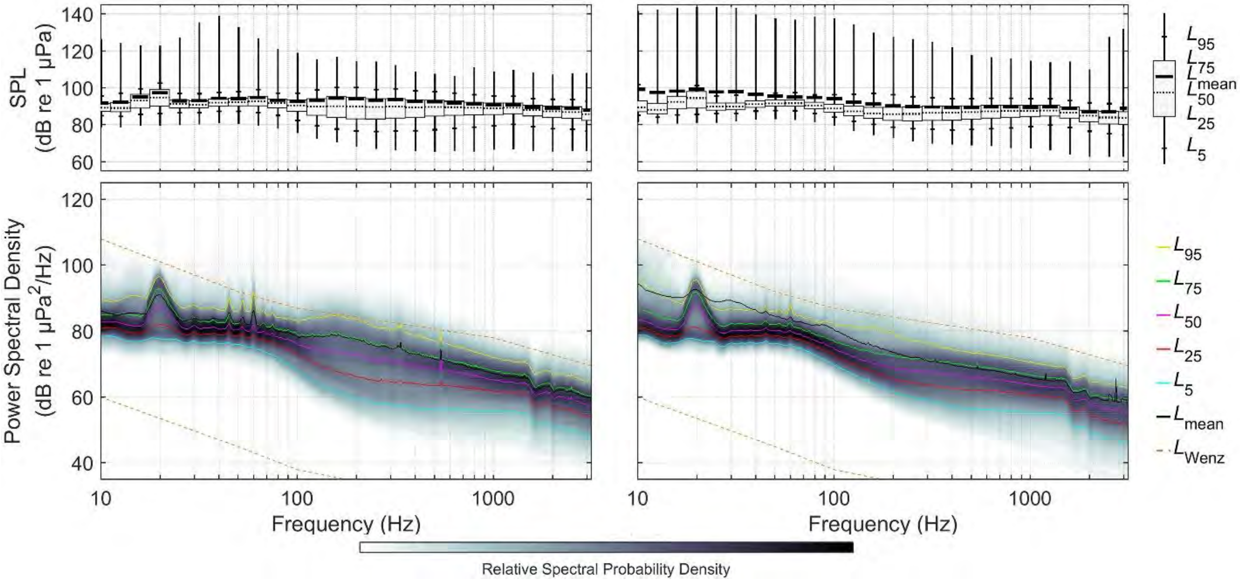


Figure 31. Stn 5 2015–16 (left), 2016–17 (right): Exceedance percentiles and mean of 1/3-octave-band SPL and exceedance percentiles and probability density (grayscale) of 1-min PSD levels compared to the limits of prevailing noise (Wenz 1962).

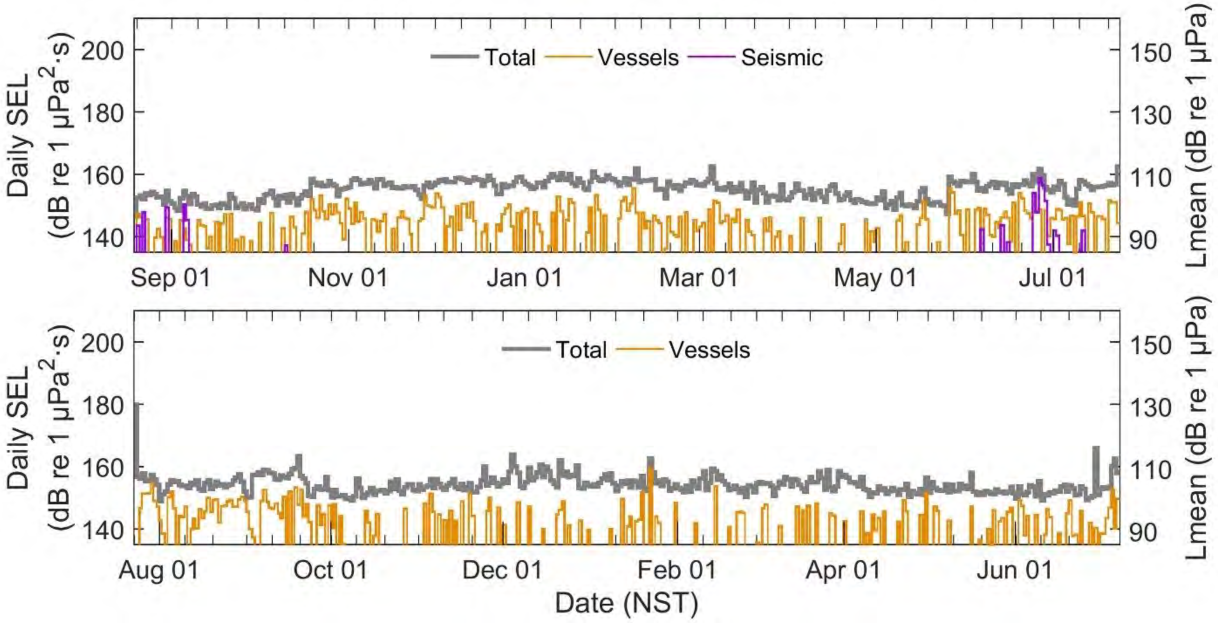


Figure 32. Stn 5 (top) 2015–16, (bottom) 2016–17:Total, vessel, and seismic-associated daily SEL and equivalent continuous noise levels (L_{eq}).

3.2. Vessel Detections

Vessels were detected using the automated detection algorithm described in Section 2.2.2. Vessel detections denote closest points of approach (CPA) to the recorder, by hour. Detections are shown for a sample of representative stations across the study area (Figure 33). Stn 1 and 18 had the most vessel detections, followed by stn 5 and 6. Stn 15 had the least detections (Figure 33). At stn 1, vessel transit through the St Lawrence Seaway shipping lanes as well as daily crossings by the Newfoundland-Cape Breton ferry contributed to the large number of detections. At stn 12 off Nain Labrador vessel passage ceased during the ice-covered season, as expected. The sustained detections at stn 18 reflect the presence of support vessels near Hibernia. The denser periods of detections at stn 5 are associated with the exploratory drilling program by Shell. Detections at stn 15 are most likely representative of seismic vessels and distant traffic. Although not affected by sea ice, the remoteness of this station explains the absence of detections in winter months.

A sample spectrogram of a vessel passing stn 18 (Figure 34) illustrates the Lloyd's mirror, or bathtub pattern, as a vessel passes by the recorder. This pattern is caused by constructive and destructive interference between direct and reflected paths of sound.

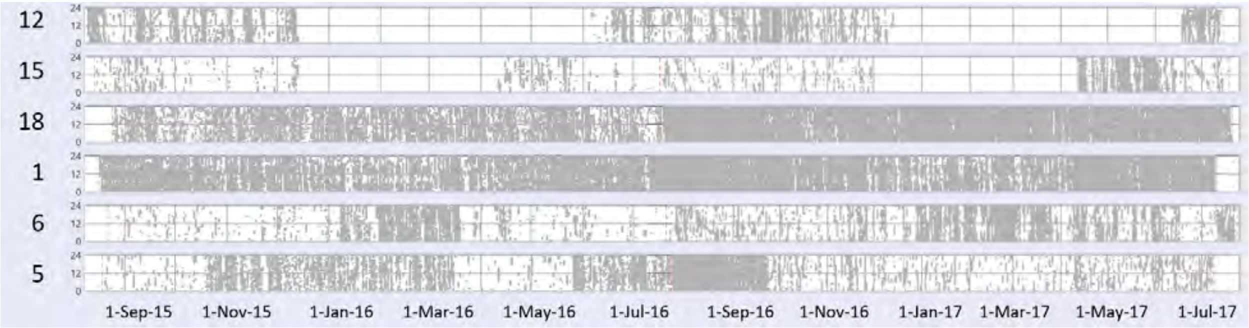


Figure 33. Vessel detections each hour (vertical axis) compared to date (horizontal axis) at six stations (stn 1, 4, 5, 12, 15, and 18) from 10 Aug 2016 to 23 Jul 2016. The grey areas indicate hours of darkness. Vertical dashed lines indicate AMAR deployment and retrieval dates.

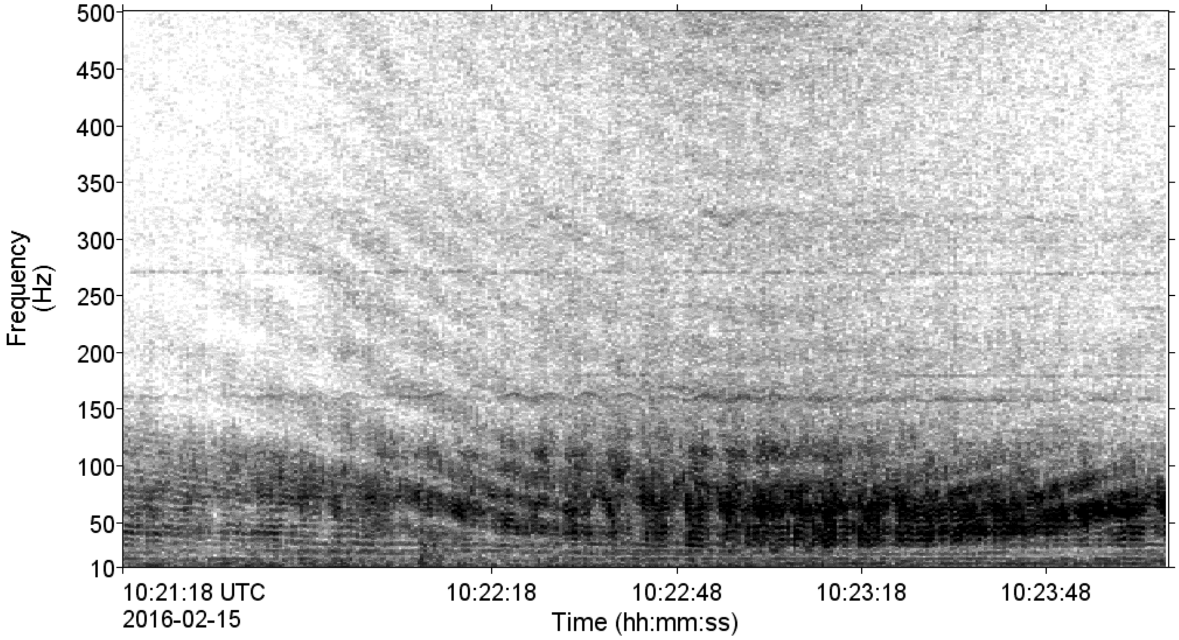


Figure 34. Spectrogram of a vessel passing stn 18, 15 Feb 2016 (0.12 Hz frequency resolution, 1 s time window, 0.5 s time step, Hamming window).

3.3. Seismic Survey Sounds

Seismic survey sounds were detected using the automated detection algorithm described in Section 2.2.3 and are shown for a sample of representative stations (Figure 35). Stn 15, where seismic noise was the main contributor to total SEL (Figure 17), had the most seismic detections overall (Figure 35), followed by stn 18. Stn 5 and 6 were farther from active survey areas, and therefore had few detections.

The length of the seismic survey detection period east and northeast of the Grand Banks is noteworthy. For instance, stn 15 and 18 (and other stations in the same general area such as stn 19 and 20) experienced elevated noise levels due to seismic survey activity for up to five continuous months (Figure 35). Also worth noting is that two (and up to three) distinct surveys were occasionally detected (Figure 36). The bathymetry of the Orphan Basin (north of the Flemish Pass) is presumably responsible for the multi-pulse patterns systematically observed at stn 15 and 19 (Figure 37). The reverberations of the initial airgun pulse often continued until the next pulse, ~ 10 s later, and often retained a significant amount of acoustic energy. This deserves attention both for modelling the propagation of seismic survey sounds as well as for evaluating the effects to noise on marine life in this area. This multi-pulse pattern was not observed at shallower stations on the continental shelf (Figure 36).

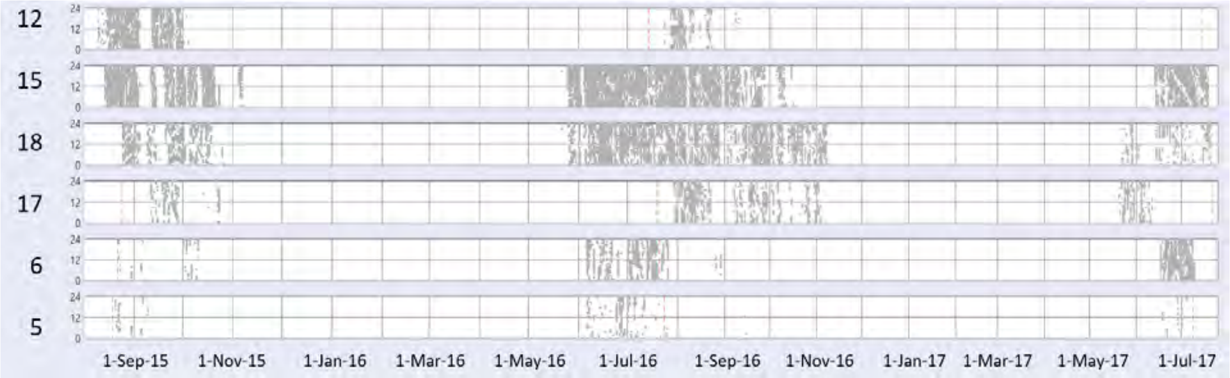


Figure 35. Seismic detections each hour (vertical axis) versus date (horizontal axis) at six stations (stn 1, 4, 5, 12, 15, and 18) from 10 Aug 2016 to 23 Jul 2016. The grey areas indicate hours of darkness. Vertical dashed lines indicate AMAR deployment and retrieval dates.

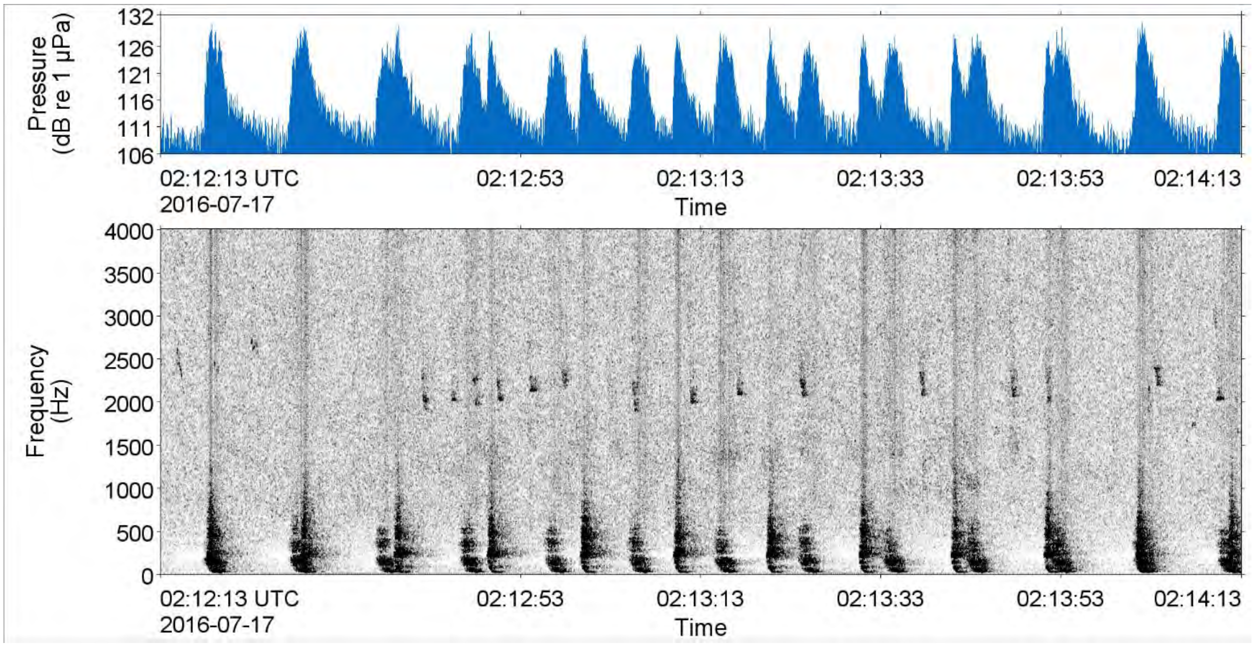


Figure 36. (Top) Pressure signature and (bottom) spectrogram of seismic pulses from two airgun arrays, at stn 20 on 17 Jul 2016 (1.95 Hz frequency resolution, 0.128 s frame size, 0.032 s time step, and Hamming window).

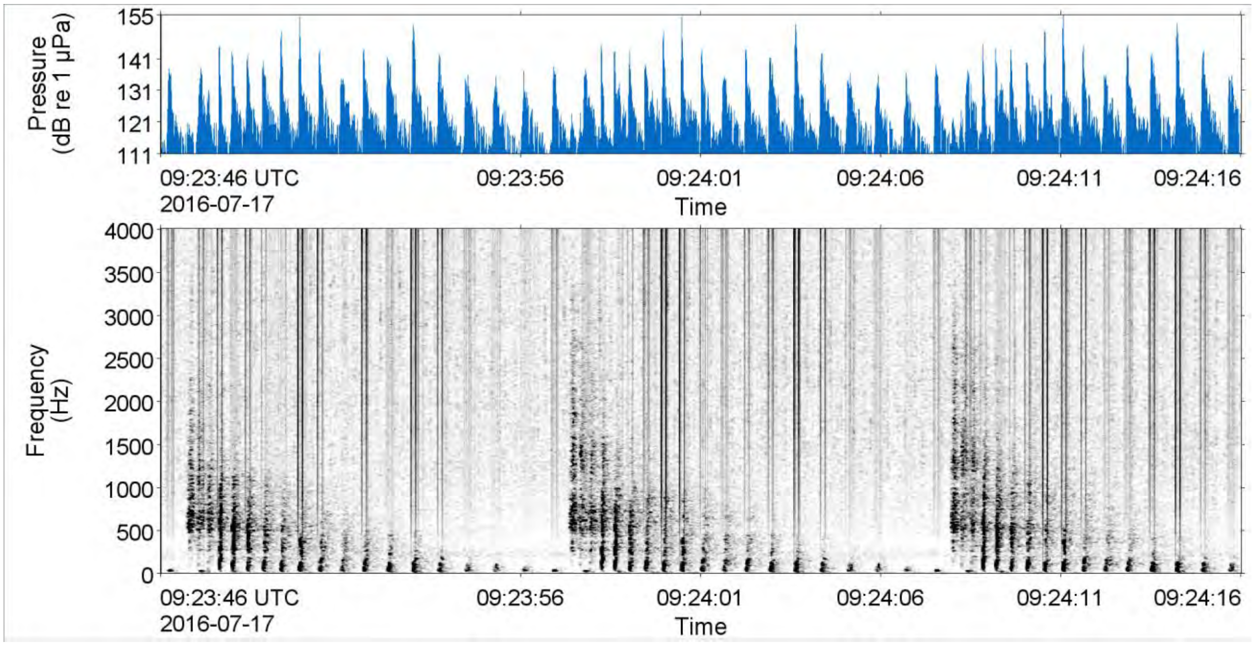


Figure 37. (Top) Pressure signature and (bottom) spectrogram of seismic pulses from an airgun array, at stn 15 on 17 Jul 2016 (1.95 Hz frequency resolution, 0.128 s frame size, 0.032 s time step, and Hamming window).

3.4. Marine Mammals

The acoustic presence of marine mammals was identified automatically by JASCO's detectors (Section 2.2.4.3) and validated via the manual review of 0.5% of the low- and high-frequency datasets, which represents ~9000 sound files, or 74 hr worth of 1-min 250 ksps sound files and 825 hr worth of 11-min 8 ksps sound files (Appendix G). Detectors and analysts found acoustic signals of blue, fin, humpback, minke, North Atlantic right, sei, long-finned pilot, and killer whales, as well as sounds of walruses and bearded, harp, and grey seals. In addition to these species, the high-frequency acoustic recordings contained signals of Cuvier's and Sowerby's beaked, northern bottlenose, and sperm whales, as well as harbour porpoise and several dolphin species. Other suspected species include *Kogia* sp (most likely pygmy sperm whale *K. simus*) and at least one unidentified species of Mesoplodon (most likely Gervais' or True's beaked whale).

3.4.1. Detector Performance

Detector performance varied across species, call types, and stations (Figure 38). Detectors targeting stereotyped acoustic signals or those that are unique in spectral content, such as fin whale 20-Hz notes and Sowerby's beaked whale clicks, outperformed detectors aimed at finding acoustic signals with greater inter-specific overlap in spectral content, such as the broadband moans of sei, fin, humpback and blue whales. The latter, more generic detectors, generally required higher thresholds (Figure 38).

Detector precision was generally high, with most species scoring above our precision threshold of 0.75 at all stations in both years (Appendix G, Figure 38). Notable exceptions include Cuvier's beaked whale, humpback whale, and sperm whale detections in 2016–17. The lower the precision values, the higher the proportion of non-target signals included in the results. Inter-annual differences in detector performance may reflect different distribution of the target species (or species with conflicting signals) relative to the recorder yielding different SNR, call quality, and therefore distinctiveness.

Detector recall values were comparatively much lower than precision (Appendix G, Figure 38). This is partly by design because the detection count threshold is based on maximizing the F-score, which is itself biased towards precision (see Appendix E.3.2).

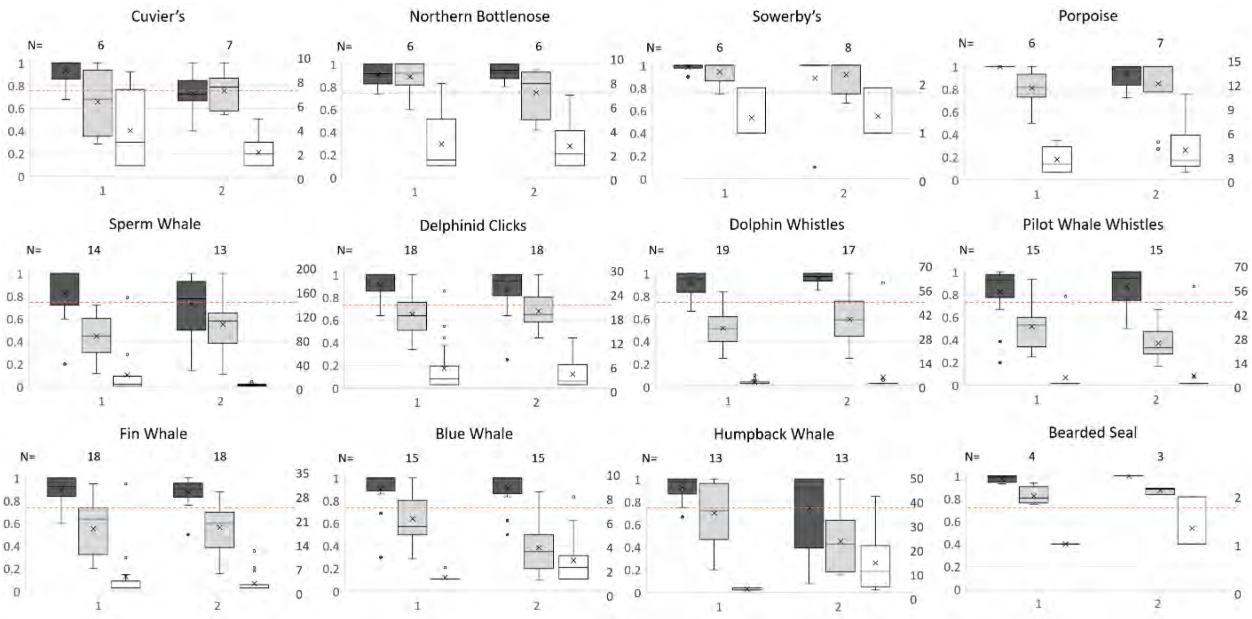


Figure 38. Box-and-whisker plots of the precision (dark grey; left axis), recall (light grey; left axis), and threshold (white; right axis) of the automated detectors for each species across the stations they were detected (N is number of stations) for recording year 1 (1) and year 2 (2). The red dashed line indicate the minimum precision (0.75) required for automated detections to be considered.

A low recall translates into missing detections. The detector could miss an entire string of detections because of low SNR or individual detections within a detection bout. The actual effect of a low recall is likely a combination of these scenarios, although the relative contribution of each will depend on species, season, and interfering sound sources at each location. The long duration of the study required duty-cycled recordings with a total cycle time of 20 min. For most species, the duration of a detection event is often greater than the cycle time, despite significant seasonal variations. Baleen whales produce songs continuously over extended periods during fall, winter, and early spring. They are far less loquacious the rest of the year (Watkins et al. 2000, Stafford et al. 2007). Delphinid and sperm whale acoustic signals can also be reasonably expected to be heard over several consecutive recording cycles when present. There is more uncertainty about the typical length of detection events for beaked whales, especially *Mesoplodon* sp., and it has been suggested that duty cycle and cycle duration have an effect on the percentage of acoustic signals detected (Stanistreet et al. 2016). Ultimately, the objectives of this study were not to describe the fine-scale patterns of occurrence of each species, but rather to document general trends throughout the area. In this regard, we believe that the results presented in this report closely represent the acoustic occurrence of species during periods of vocal activity. Detectors with low recall values yield results that underestimate hourly occurrence, but they can be expected to be accurate on a daily to weekly basis. Detectors with high recall values yield results that are likely accurate on an hourly to daily basis.

Detector results, refined to incorporate the classification threshold and exclude stations and timeframes where manual validation did not confirm species presence (Appendix G), are presented in the following results sections for odontocetes (Section 3.4.2), mysticetes (Section 3.4.3), and pinnipeds (Section 3.4.4).

The acoustic signals of some species were not accurately captured by any of the automatic detectors used in this study. Further, the ability of some detectors were affected by seasonal changes in the type of acoustic signals produced by a species. This may be the result of overlap between signals of different species, the lack of overlap between a species signal and the detectors' templates, or similarity with noise sources that resulted in excessively high numbers of false detections. The affected species included grey and harp seals, and sei (too many false positives triggered by seismic airgun pulses), minke (no detector), killer (inability to distinguish from pilot whale detections), and North Atlantic right whales (overlap with humpback whale vocalizations, resulting in large numbers of false positives). The spring and early summer acoustic occurrence of fin and blue whales is also underestimated because the signals produced at this time of year were not appropriately captured by our detectors. Where applicable, manual detections obtained during the validation process are presented to describe minimum baseline occurrence. It is important to remember that while these results likely reflect true large scale spatial and temporal trends in species presence, they are surely an underrepresentation of the true acoustic occurrence of most species. The presence of hooded seals, though likely, could not be confirmed due to the limited description of their vocalizations in the literature. Walrus vocalizations were detected once opportunistically.

3.4.2. Odontocetes

3.4.2.1. *Beaked Whales*

3.4.2.1.1. Northern Bottlenose Whales

Clicks classified as northern bottlenose whales had a centroid frequency between 25 and 30 kHz and a smooth upswept contour (Figures 39 and 40) (Hooker and Whitehead 2002, Wahlberg et al. 2012). Northern bottlenose whale clicks were detected throughout the year at six stations (stn 6, 13, 15, 16, 17, and 19; Figures 41 and 42). Despite being located closest to the Gully Canyon resident population (Gowans et al. 2000), clicks were only identified at stn 4 manually at the end of the first deployment in July 2016.

These six stations were located in deep water along the continental slope or within submarine canyons. Northern bottlenose whale acoustic occurrence was highest at stn 13 and 19, with nearly daily detections throughout the study period. Despite the change in location of stn 19 between years, no noticeable change in detection rates or pattern of occurrence was observed. The temporal pattern of detection at stn 16 was similar in both years, with limited detections from August to February and more consistent detections throughout the rest of the year. Stn 6 shared a similar trend with stn 16, except that detections persisted between August 2016 and February 2017. Detections at stn 15 did not show any obvious temporal trends but were generally more sporadic than at stn 13 and 19 (Figures 41 and 42). Higher mean hourly detection counts at stn 13 and 19 suggest that these areas may be used more regularly by greater number of animals, and/or that animals detected there produce more detectable clicks per unit time (e.g., closer proximity to the recorder of animals foraging rather than transiting).

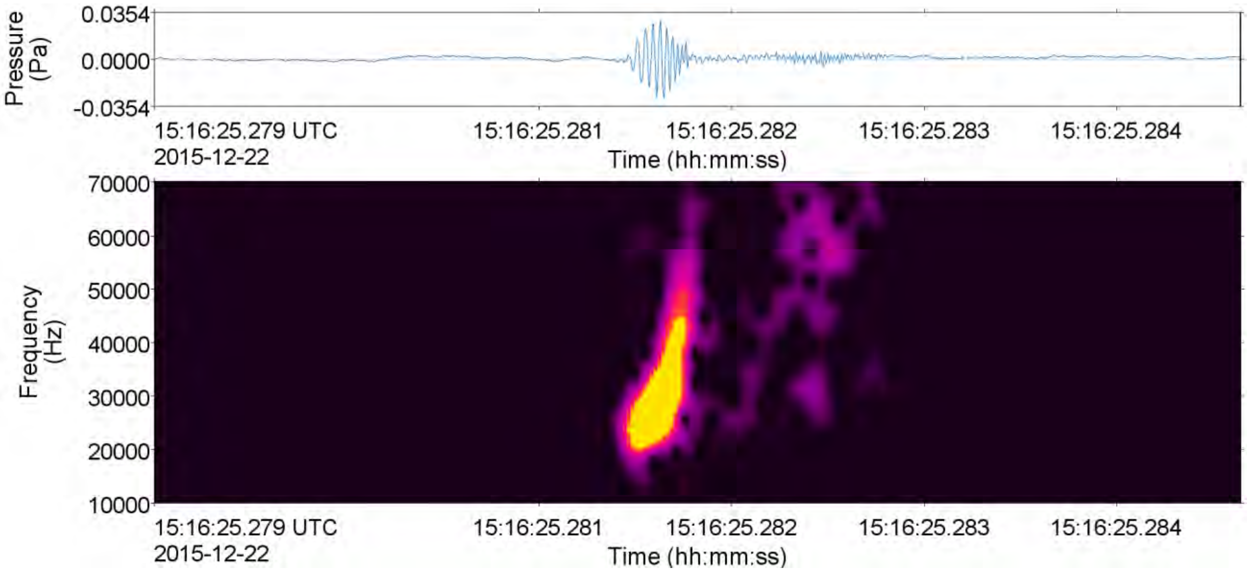


Figure 39. Spectrogram of a northern bottlenose whale click recorded at stn 19 on 22 Dec 2015 (512 Hz frequency resolution, 0.26 ms time window, 0.02 ms time step, Hamming window).

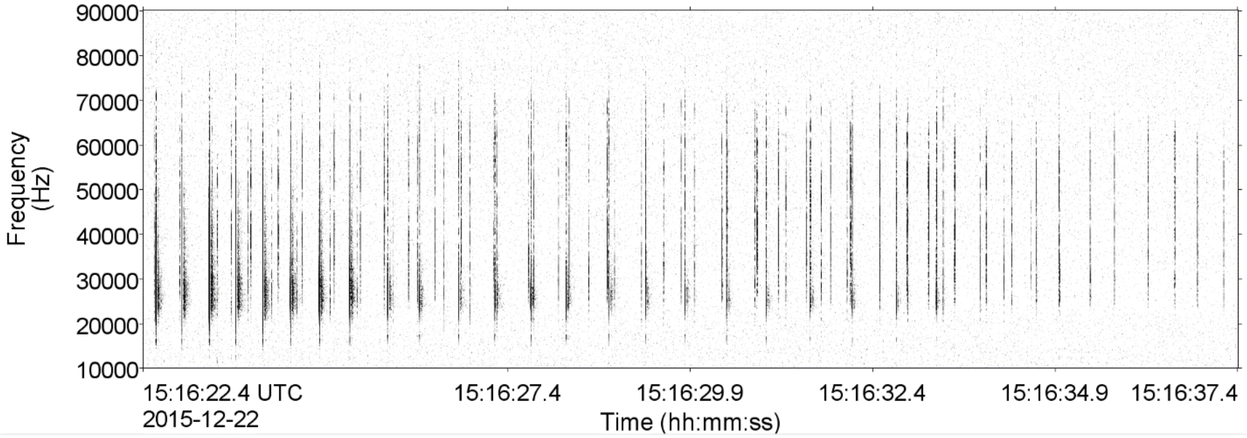


Figure 40. Spectrogram of northern bottlenose whale click trains recorded at stn 16 on 3 Nov 2015 (64 Hz frequency resolution, 0.01 s time window, 0.005 s time step, Hamming window). The window length is 15 s.

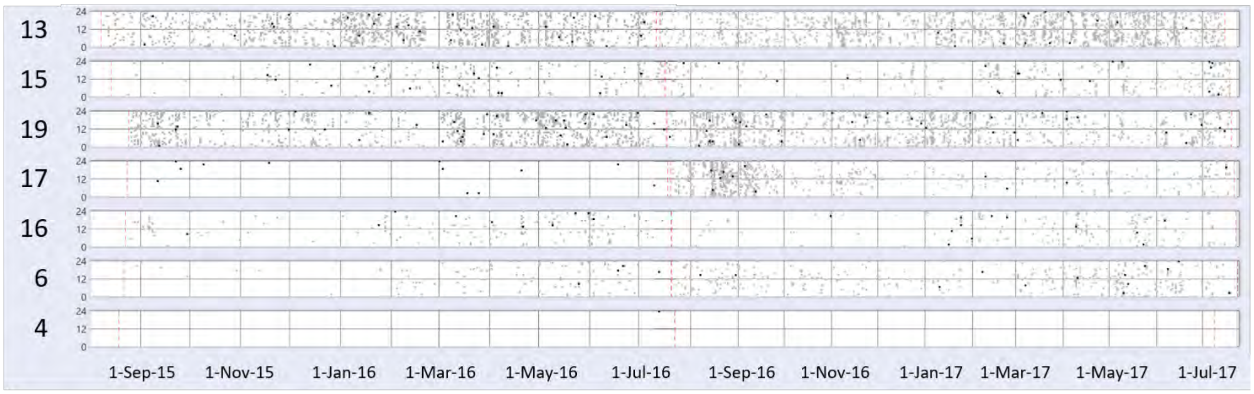


Figure 41. Daily and hourly occurrence of northern bottlenose whale clicks recorded at stn 4, 6, 13, 15–17, and 19 from 3 Aug 2015 to 23 Jul 2017. Stations are ordered from (top) north to (bottom) south. Grey dots indicate automated detections. Black dots indicate manually validated results. The red dashed lines indicate AMAR deployment and retrieval dates. Stn 7 in 2015–16 and stn 4 in 2015–16 and 2016–17 do not have automated detections displayed, as they were found to be unreliable at these locations/times.

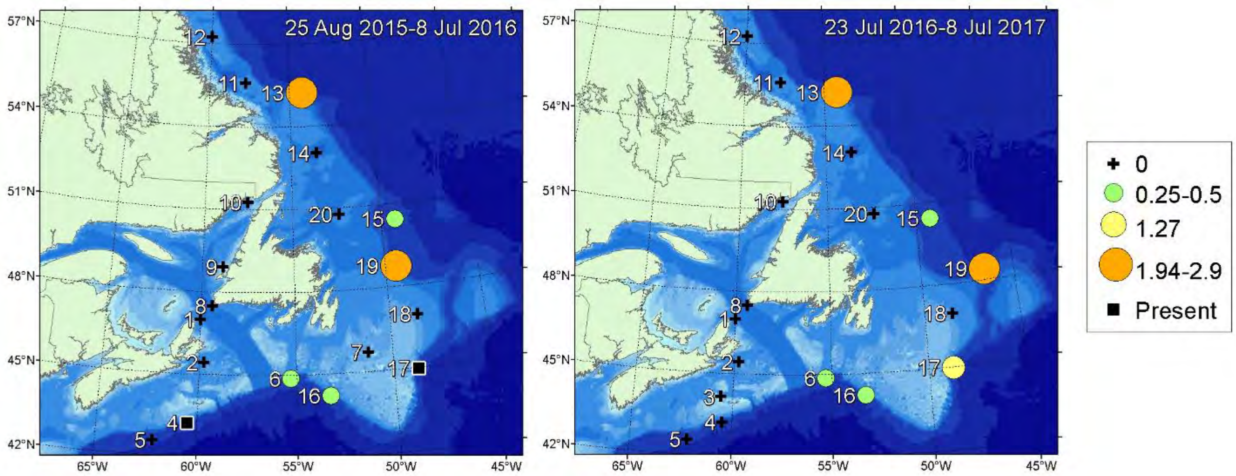


Figure 42. Northern bottlenose whale clicks: Mean hourly detection count (MHDC) at stations where acoustic data were recorded in 2015–16 (left) and 2016–17 (right). The black square indicates stations where the species was manually identified but the detector accuracy was below the accepted P of 0.75 or unevaluated due to a lack of validated automated detections.

3.4.2.1.2. Cuvier's Beaked Whales

The Cuvier's beaked whale clicks recorded in this study were identified on the basis of descriptions by several authors in different areas of the world (Zimmer et al. 2005b, Baumann-Pickering et al. 2013). The detected clicks had a centroid frequency ~40 kHz and often a characteristic C-shaped contour (Figures 43 and 44). These whales occurred at seven stations (stn 4–6, 15–17, and 19) and were most common along the edge of the Scotian Shelf (stn 4 and 5). Detections occurred year-round at stn 5 in both years and at stn 4 in the second year, where they were otherwise sparse from August 2015 to March 2016. Stn 6 and 16 were characterized by sporadic automated or manual detections throughout the year. One can note the similarity in temporal detection patterns in 2015–16 between stn 4 and 6. Cuvier's beaked whale occurrence at stn 15 and 17 was concentrated almost exclusively from April to July. The species was never confirmed at stn19 in 2015–16, but their signals were identified three times manually in 2016–17 (Figures 45 and 46).

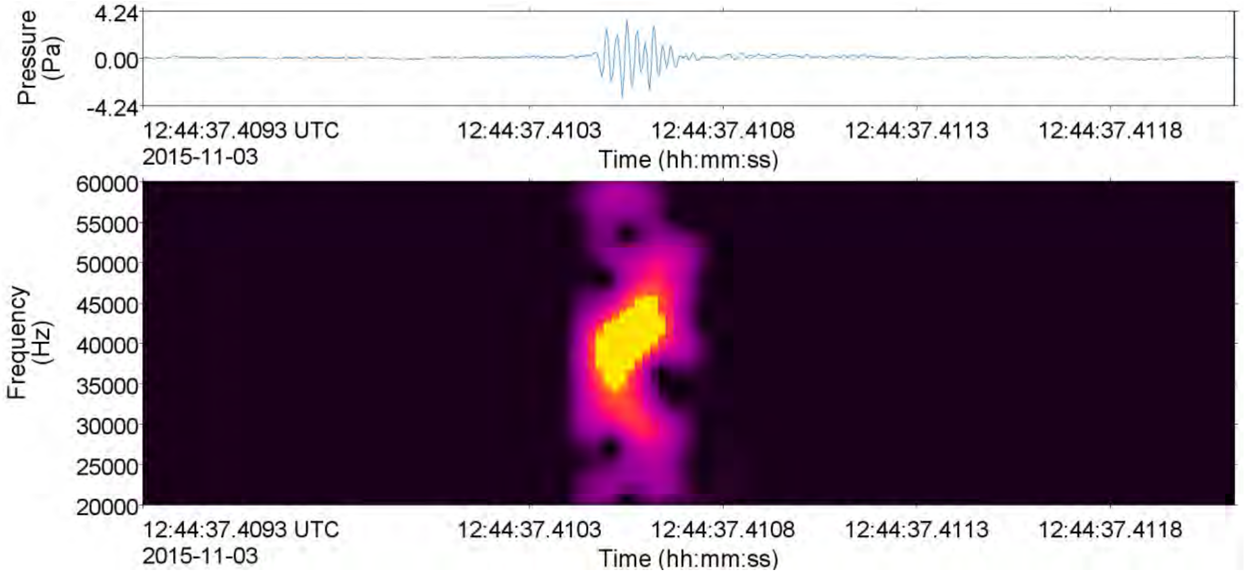


Figure 43. Spectrogram of a Cuvier's beaked whale click recorded at stn 16 on 3 Nov 2015 (512 Hz frequency resolution, 0.26 ms time window, 0.02 ms time step, Hamming window).

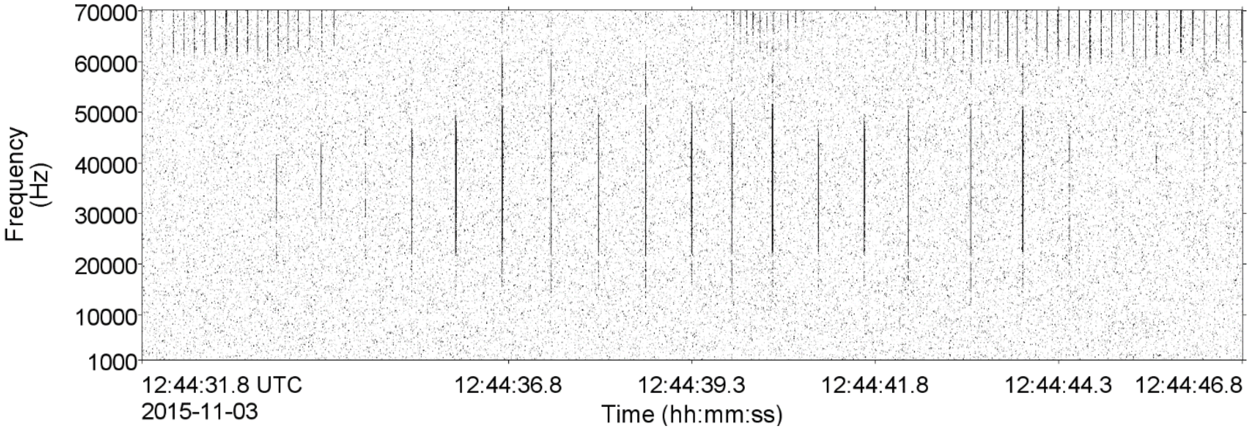


Figure 44. Spectrogram of Cuvier's beaked whale click trains recorded at stn 16 on 3 Nov 2015 (64 Hz frequency resolution, 0.01 s time window, 0.005 s time step, Hamming window). The window length is 15 s. Sowerby's beaked whale clicks are visible above 60 kHz.

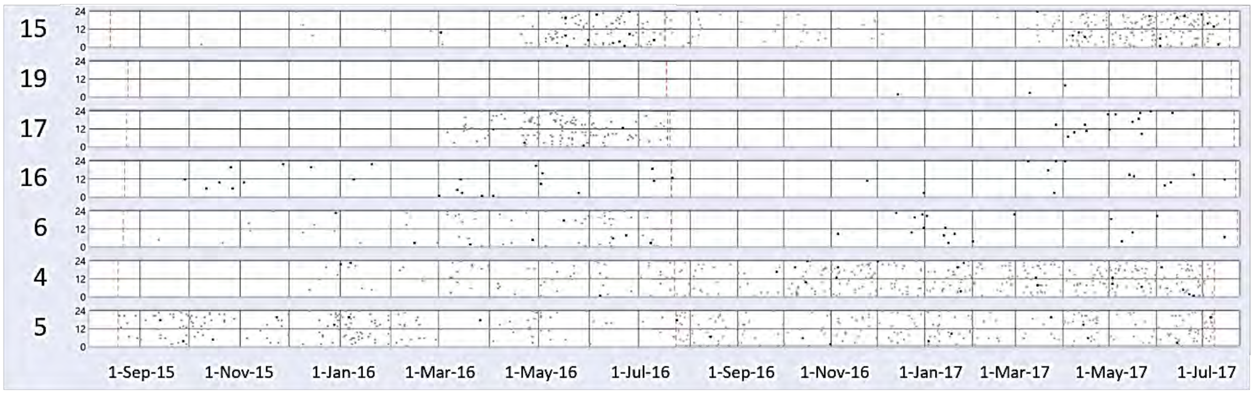


Figure 45. Daily and hourly occurrence of Cuvier's beaked whale clicks recorded at stn 4–6, 15–17, and 19 from 3 Aug 2015 to 23 Jul 2017. Stations are ordered from (top) northeast to (bottom) southwest. Grey dots indicate automated detections. Black dots indicate manually validated results. The red dashed lines indicate AMAR deployment and retrieval dates. Manually identified signals are shown if the detector's precision was below 0.75 (Stn 19, 17 in 2016–17, 16, and 6 in 2016–17).

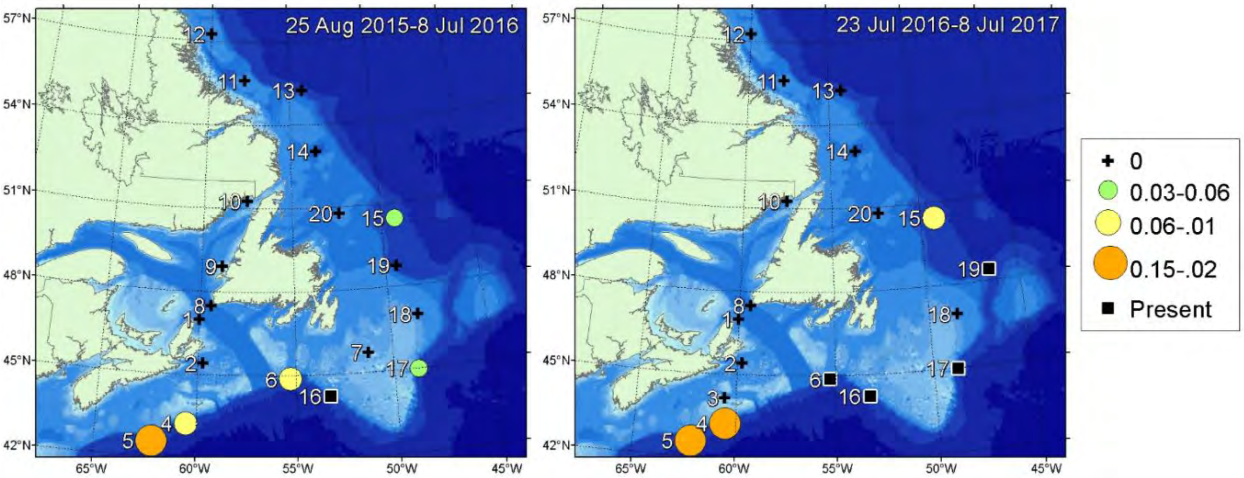


Figure 46. Cuvier's beaked whale clicks: Mean hourly detection count (MHDC) at stations where acoustic data were recorded in 2015–16 (left) and 2016–17 (right). The black square indicates stations where the species was manually identified but the detector accuracy was below the accepted P of 0.75 or unevaluated due to a lack of validated automated detections.

3.4.2.1.3. Sowerby's Beaked Whales

Sowerby's beaked whale clicks were identified as those labelled "high clicks" in Cholewiack et al. (2013). These clicks had a frequency-modulated slope that peaked in frequency near 67 kHz, which placed them above the frequency bands of other species' clicks (Figures 47 and 48). Sowerby's beaked whales were automatically detected and manually validated at six stations (stn 4–6 and 15–17) in both years. They were also manually identified once in the Cabot Strait at stn 8 in November 2016. They were detected throughout the year off the Scotian shelf and south of the Grand Banks. It is worth highlighting the markedly lower number of detections at stn 5 than stn 4, despite their being deployed in a similar area with similar depth (2000 versus 1800 m). Sowerby's beaked whale acoustic signals were absent at stn 19 during the first year, but detected in all except winter months at the 2016–17 location. Detections at stn 15 were sporadic and comparable in timing to those at stn 19.

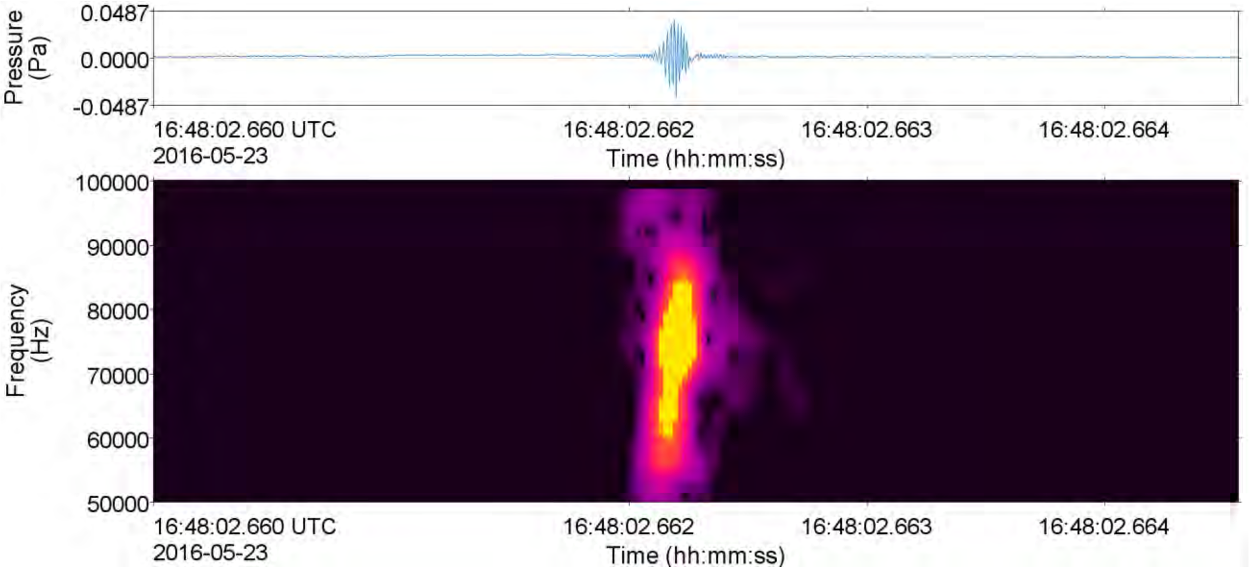


Figure 47. Spectrogram of a Sowerby's beaked whale click recorded at stn 17 on 23 May 2016 (512 Hz frequency resolution, 0.26 ms time window, 0.02 ms time step, Hamming window).

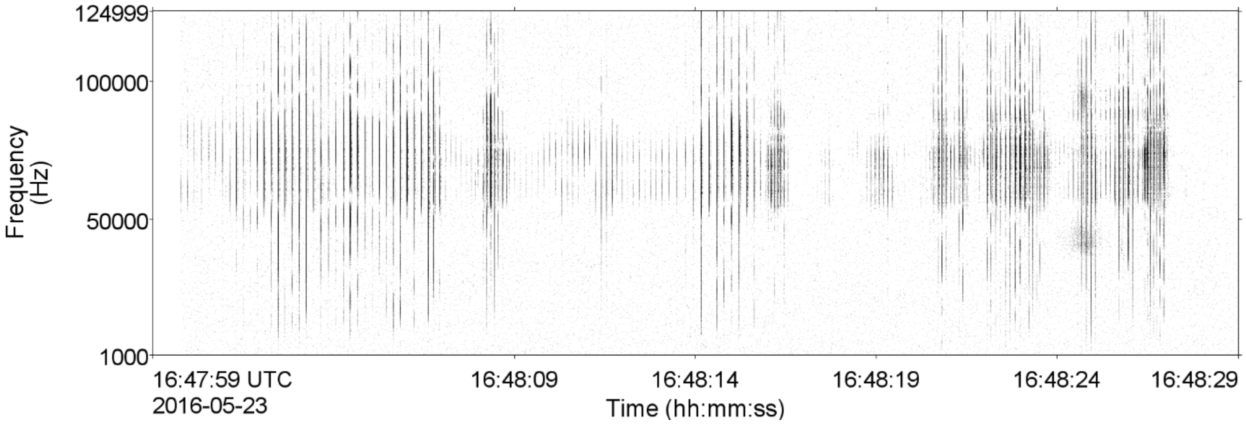


Figure 48. Spectrogram of Sowerby's beaked whale click trains recorded at stn 17 on 23 May 2016 (64 Hz frequency resolution, 0.01 s time window, 0.005 s time step, Hamming window). The window length is 30 s.

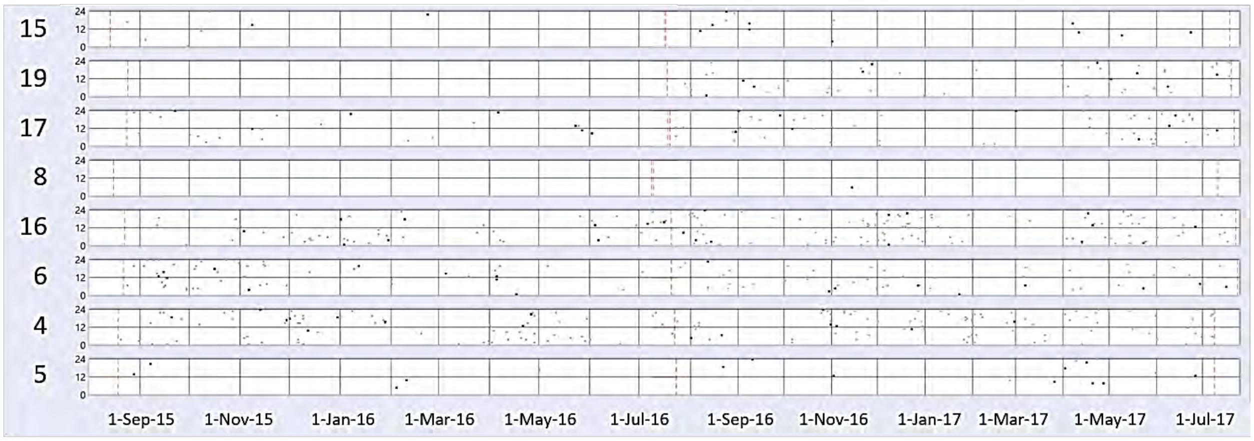


Figure 49. Daily and hourly occurrence of Sowerby's beaked whale clicks recorded at stn 4–6 and 15–17 from 3 Aug 2015 to 23 Jul 2017. Stations are ordered from (top) north to (bottom) south. Grey dots indicate automated detections. Black dots indicate manually validated results. The red dashed lines indicate AMAR deployment and retrieval dates. Manually identified signals are shown if the detector's precision was below 0.75 (Stn 8).

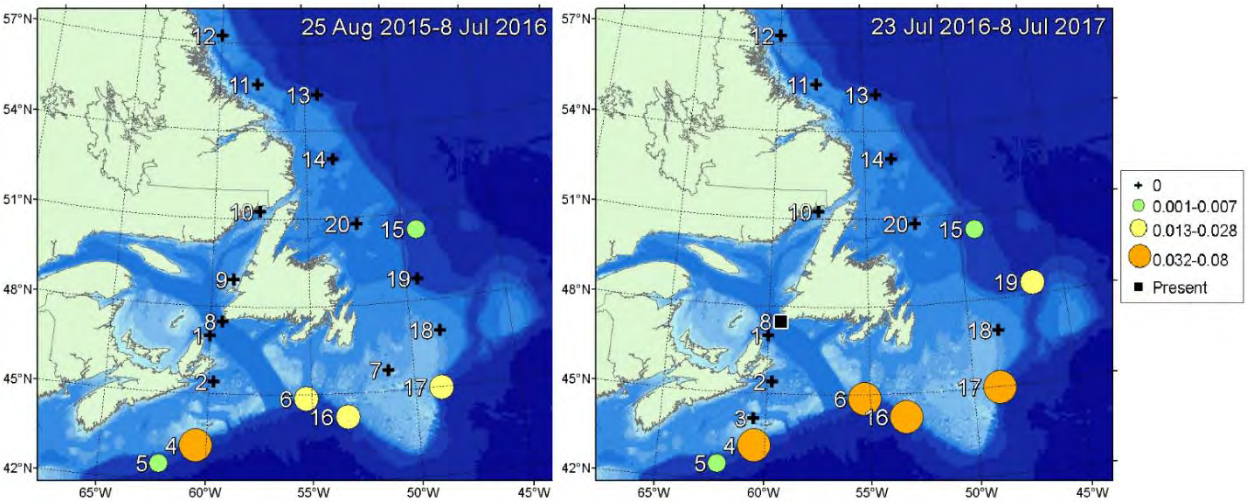


Figure 50. Sowerby's beaked whale clicks: Mean hourly detection count (MHDC) at stations where acoustic data were recorded in 2015–16 (left) and 2016–17 (right). The black square indicates stations where the species was manually identified but the detector accuracy was below the accepted P of 0.75 or unevaluated due to a lack of validated automated detections.

3.4.2.2. *Delphinids*

Unlike most other odontocetes that are only known to produce clicks, delphinids produce both impulsive (click) and tonal (whistle) sounds that show less species-level specificity than other marine mammal signals and are therefore more difficult to distinguish acoustically. Here, we present results of three species groups that could be confidently distinguished based on tonal signals: killer whales, whose stereotyped vocalizations have a low-frequency component's fundamental frequency below 1kHz (Filatova et al. 2015); pilot whales, whose tonal vocalizations' low frequency can be as low as 1.5 kHz and main energy around 3–5 kHz; and unidentified small dolphins, whose whistles' acoustic energy is concentrated above 5–6 kHz (Steiner 1981, Rendell et al. 1999). Because of the overlap in spectral features of tonal signals from the different dolphin species expected in the study area (Steiner 1981) and the expected but unquantified variability of these signals around the few described vocalization types, we were unable to distinguish dolphin vocalizations by species in most cases. Exceptions included stepped whistles (Figure 51) that we suspect were produced by white-sided dolphins.

Delphinid clicks show even less species-specificity than tonal signals, partially because of their directionality and the associated degradation of their spectral features when recorded at increasing angles away from the longitudinal axis of the vocalizing animal. Delphinid click detections are presented following the dolphin whistle detections.

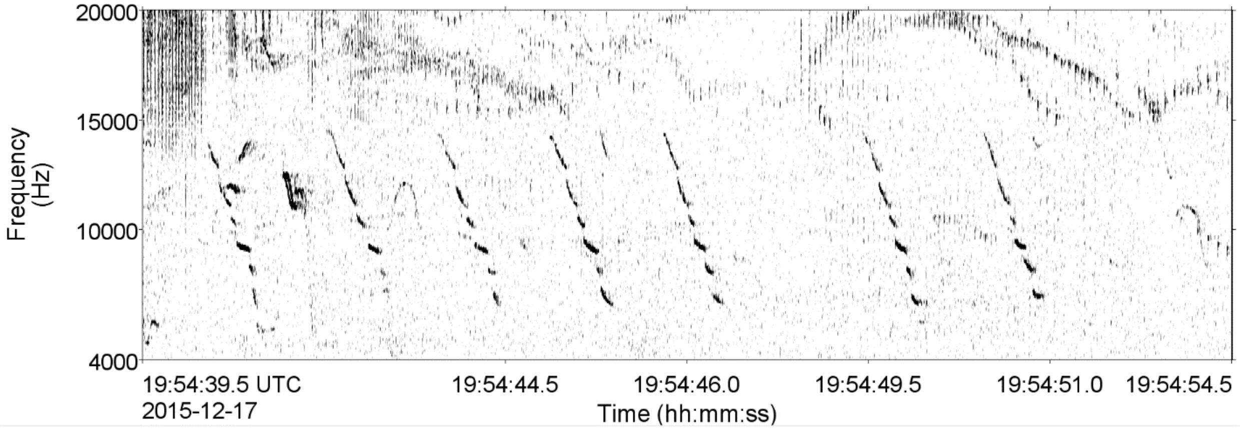


Figure 51. Spectrogram of white-sided dolphin whistles recorded at stn 2 on 17 Dec 2015 (64 Hz frequency resolution, 0.01 s time window, 0.005 s time step, Hamming window).

3.4.2.2.1. Killer Whales

Killer whale acoustic signals (Figure 52) were rare in these data. Killer whale vocalizations cannot be reliably distinguished from pilot whale vocalizations that are detected by the same detector since the signals of both species are within the same frequency range and are similar in structure. In addition, pilot whales are far more common in the study area than killer whales. We, therefore, relied on validated results to describe the acoustic occurrence for killer whales.

Killer whale acoustic signals were observed at 10 stations over the course of both years (Figure 53), mostly in summer and fall, although killer whale vocalizations were recorded on 13 and 14 Apr 2016 at stn 6 and 7. The species was never identified more than twice per year at any station except at stn 10 and 11 in the fall during the first deployment. Stn 6 and 18 were the only stations where killer whales were detected in both years.

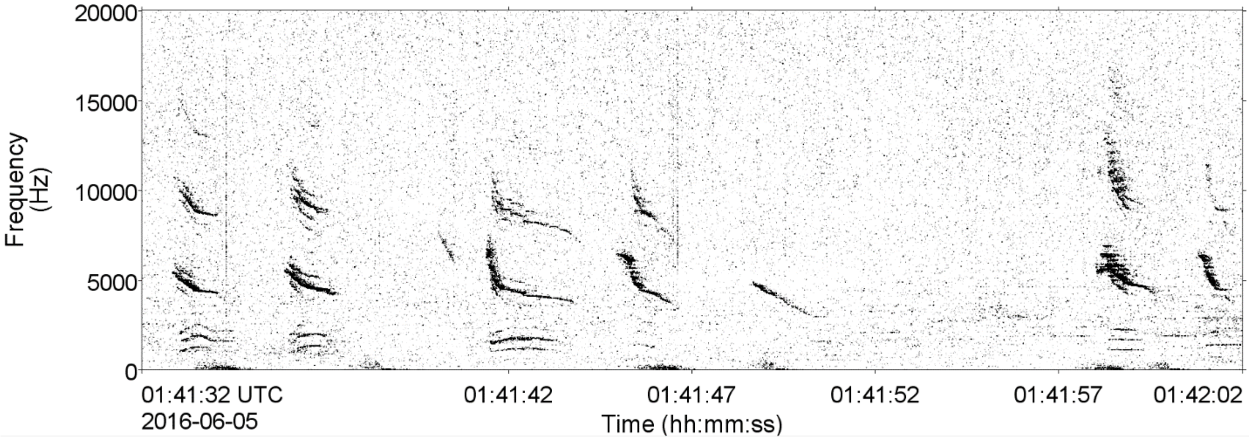


Figure 52. Spectrogram of killer whale vocalizations recorded at stn 18 on 5 Jun 2016 (4 Hz frequency resolution, 0.05 s time window, 0.01 s time step, Hamming window).

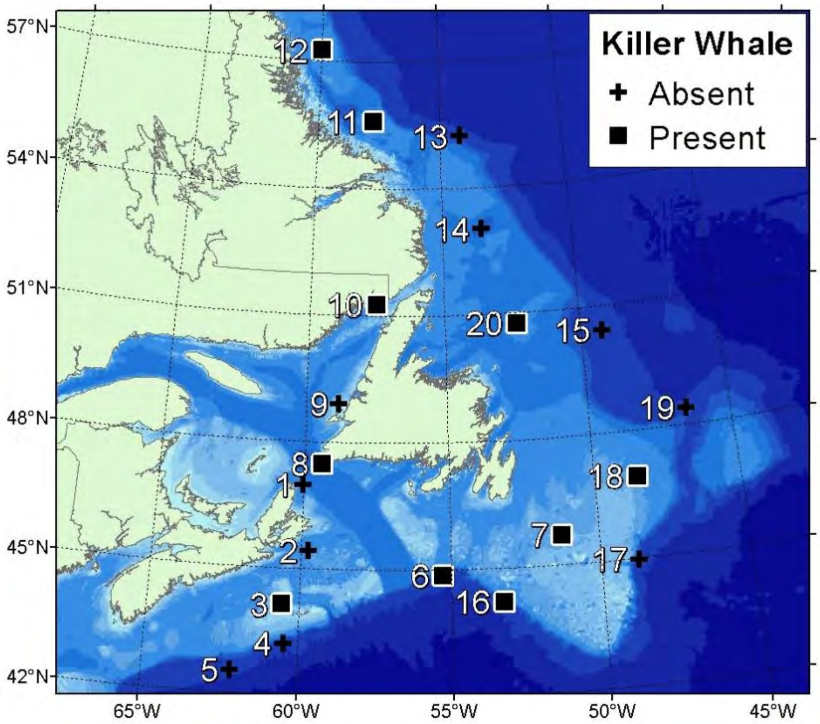


Figure 53. Locations of killer whale vocalizations manually identified between August 2015 and July 2017.

3.4.2.2.2. Pilot Whales

Pilot whale whistles (Figure 54) occurred in at least one of the two years at all stations except stn 10 (Figures 55 and 56). The detector's results were generally below threshold at most on-shelf stations. Where applicable, detections at these stations revealed that pilot whale do occur on the continental shelf. For instance, a strong detection period was observed at stn 2 in May and June of both years. Pilot whale acoustic occurrence was nevertheless more common at deep stations. It varied seasonally at all stations and was generally consistent from May to November. Vocalizations were typically absent in winter and spring at stations affected by sea ice and, more generally, those north of the Flemish Pass. Stations south of the Grand Banks and off Scotian shelf saw pilot whale signals persist through the winter and spring, though at lower levels (Figures 55 and 56). Detection rates were generally higher during the second year of the study.

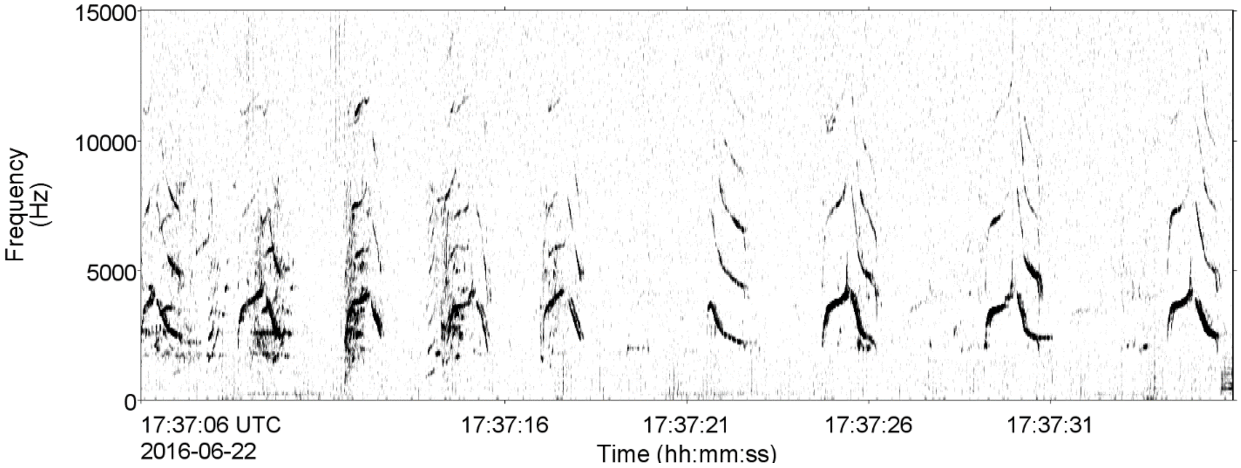


Figure 54. Spectrogram of pilot whale whistles recorded at stn 13 on 22 Jun 2016 (64 Hz frequency resolution, 0.01 s time window, 0.005 s time step, Hamming window).

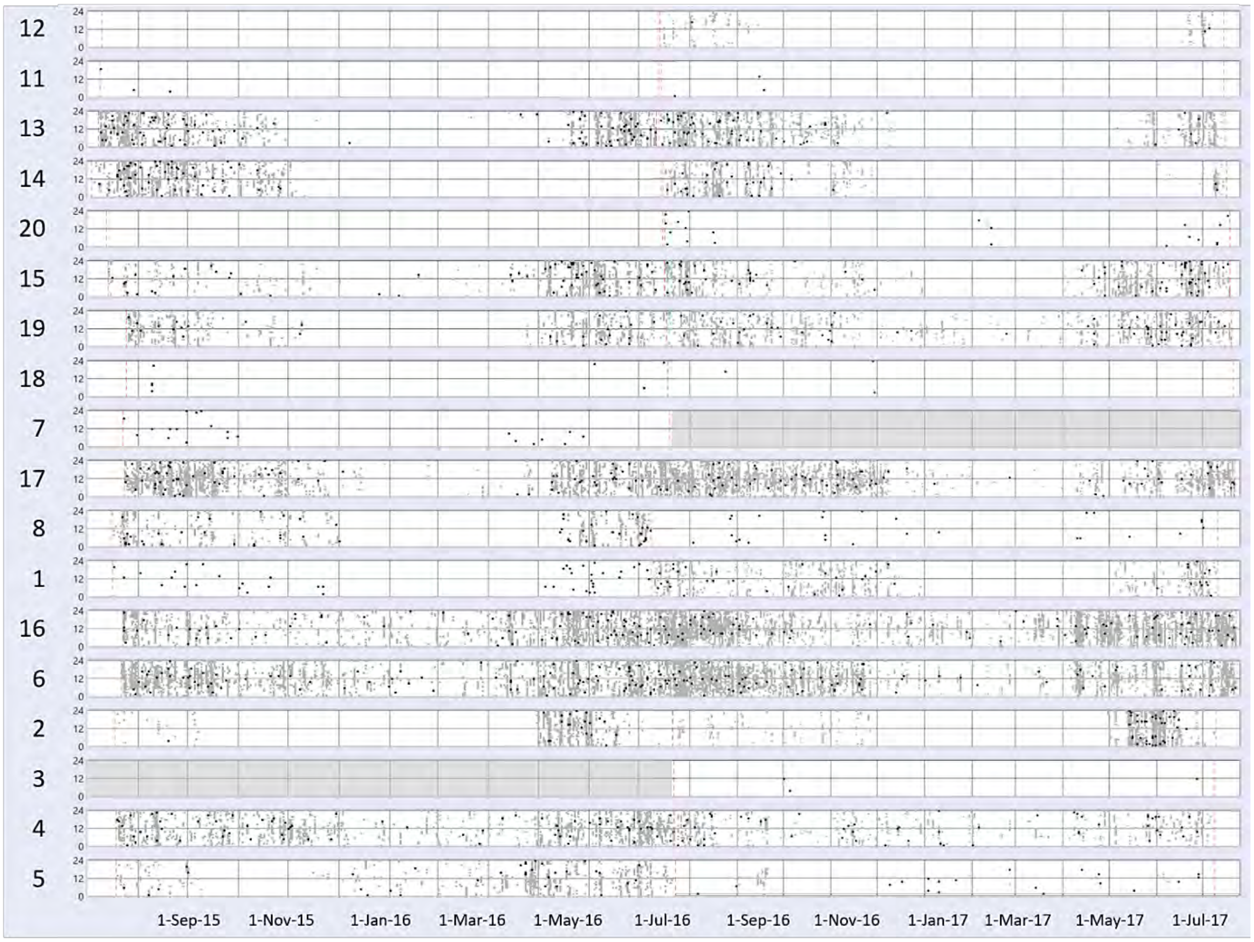


Figure 55. Daily and hourly occurrence of pilot whale whistles recorded at stn 1, 2, 4–9, and 11–20 from 3 Aug 2015 to 23 Jul 2017. Stations are ordered from (top) north to (bottom) south. Grey dots indicate automated detections. Black dots indicate manually validated results. The red dashed lines indicate AMAR deployment and retrieval dates. Manually identified signals are shown if the detector's precision was below 0.75 (Stn 12 in 2015–16, 11, 20, 18 in 2016–17, 7, 8 in 2016–17, 1 in 2015–16, and 3).

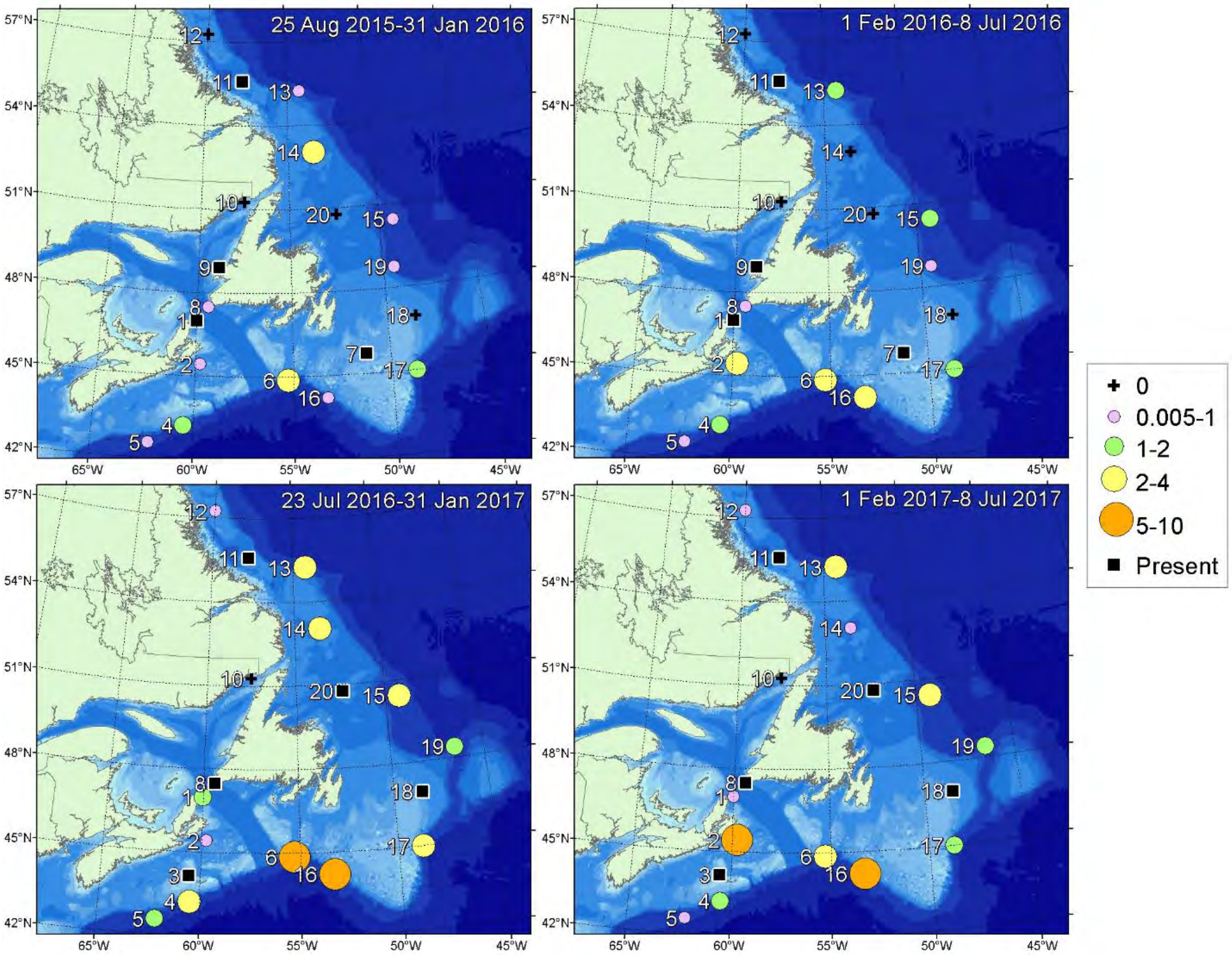


Figure 56. Pilot whale tonal signals: Mean hourly detection count (MHDC) at stations where acoustic data were recorded in 2015–16 (left) and 2016–17 (right). The black square indicates stations where the species was manually identified but the detector accuracy was below the accepted P of 0.75 or unevaluated due to a lack of validated automated detections.

3.4.2.2.3. Small Dolphins (Delphininae subfamily)

Small dolphin whistles (Figure 57) and delphinid clicks (Figures 58 and 59) occurred at all stations and showed similar spatio-temporal patterns (Figures 60 and 61), which suggests that small dolphin species, rather than killer or pilot whales, contributed a large proportion of the observed clicks. Whistle and click seasonal variations were observed at all stations (Figures 60 and 61). A winter and spring decline occurred at all stations but was increasingly obvious at on-shelf stations (e.g., stn 2) and northern stations affected by sea ice (e.g., stn 10, 14, and 20). Stn 11 and 12 generally had low levels of detections. Detections patterns were consistent across both years for both whistles and clicks. However, whistle detections rates were higher during the second year, while click detection rates were higher during the first year (Figures 62 and 63). The rapid increase in detections at stn 19 in July 2016 can be attributed to the change in location. Stn 17 and 19, on the southern and northern end of the Flemish Pass, consistently had the highest detection rates for both clicks and whistles with a pronounced peak from July to November. Stations along the Scotian shelf and southern Grand Banks (stn 4–6, 16) also had relatively high detection rates, but detections were less concentrated in summer and fall.

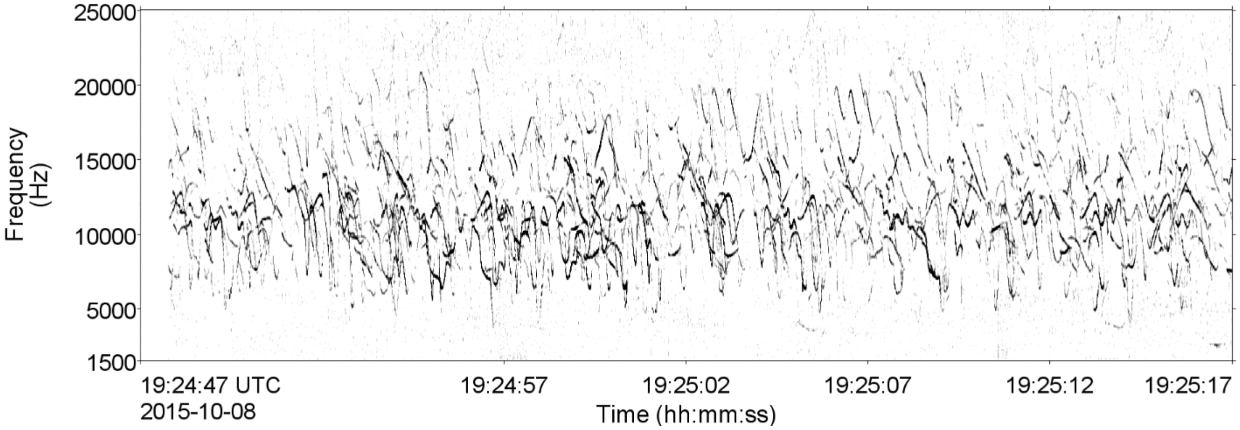


Figure 57. Spectrogram of unidentified dolphin whistles recorded at stn 14 on 8 Oct 2015 (64 Hz frequency resolution, 0.01 s time window, 0.005 s time step, Hamming window).

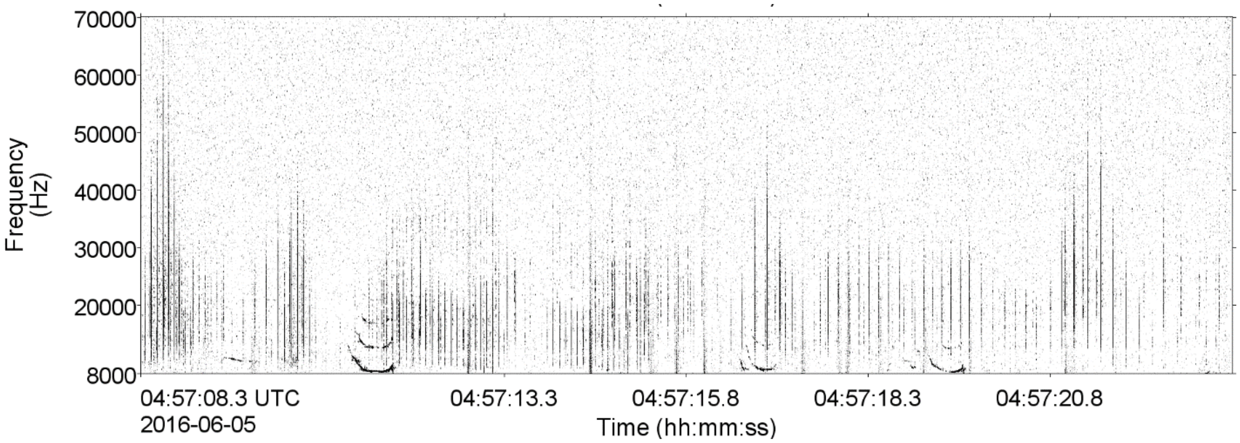


Figure 58. Spectrogram of unidentified dolphin click trains recorded at stn 19 on 5 Jun 2016 (64 Hz frequency resolution, 0.01 s time window, 0.005 s time step, Hamming window). The window length is 15 s.

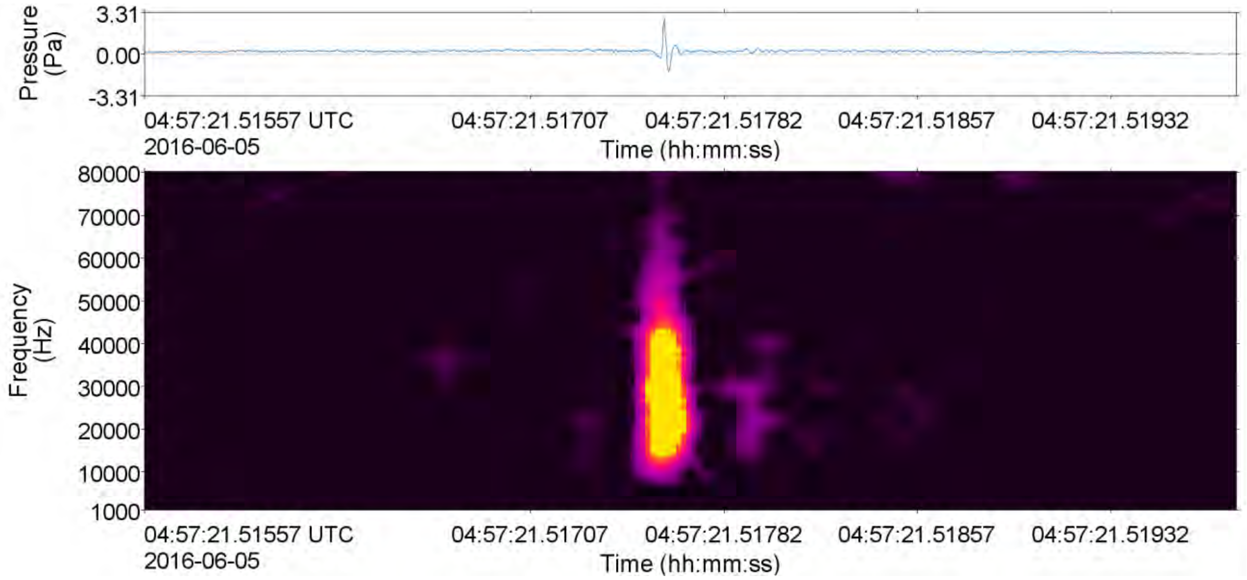


Figure 59. Spectrogram of unidentified dolphin click recorded at stn 19 on 5 Jun 2016 (512 Hz frequency resolution, 0.26 ms time window, 0.02 ms time step, Hamming window).

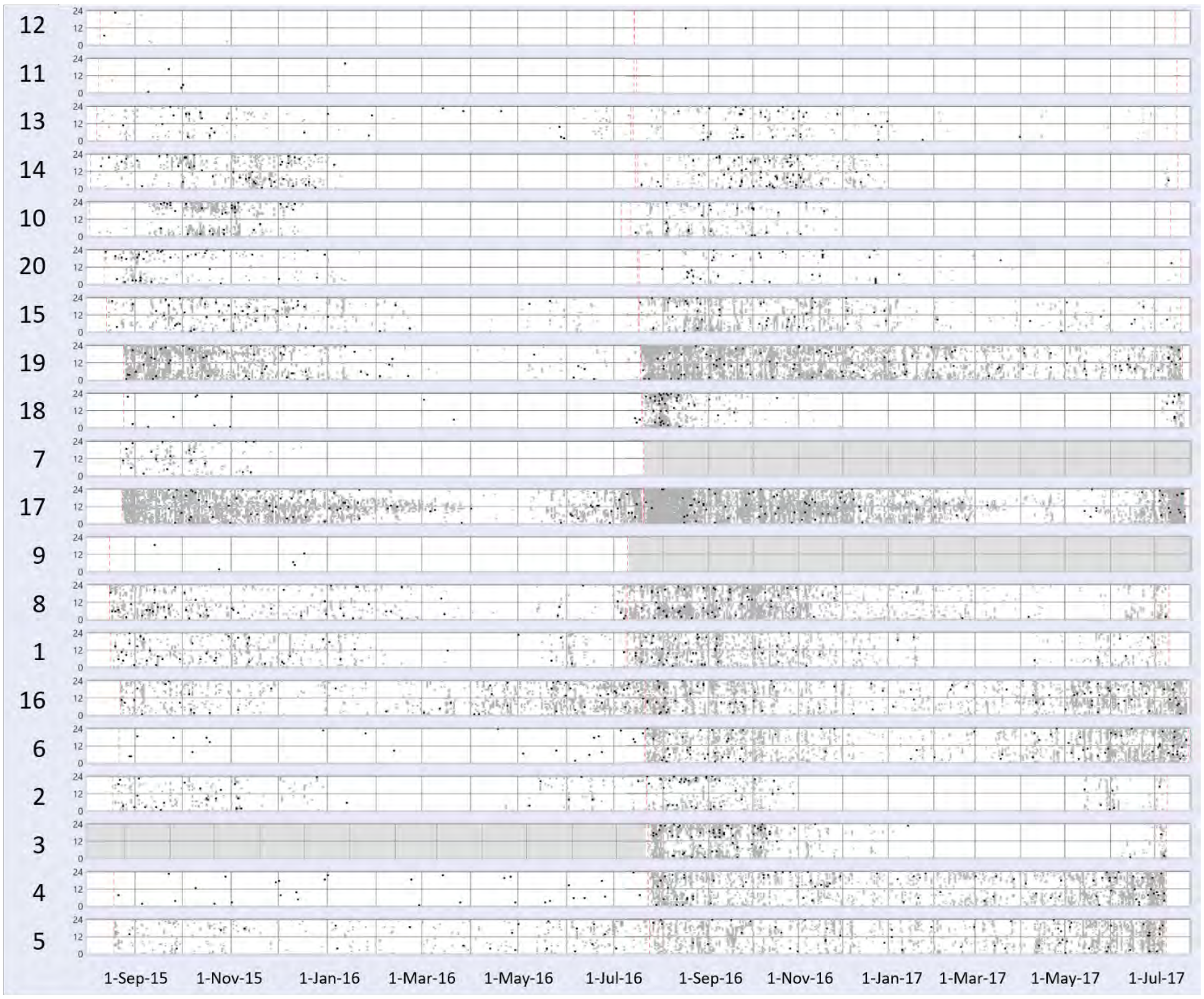


Figure 60. Daily and hourly occurrence of dolphin whistles recorded at all stations from 3 Aug 2015 to 23 Jul 2017. Stations are ordered from (top) north to (bottom) south. Grey dots indicate automated detections. Black dots indicate manually validated results. The red dashed lines indicate AMAR deployment and retrieval dates. Manually identified signals are shown if the detector's precision was below 0.75 (Stn 11 in 2016–17, 18 in 2015–16, 6 in 2015–16, and 4 in 2015–16).

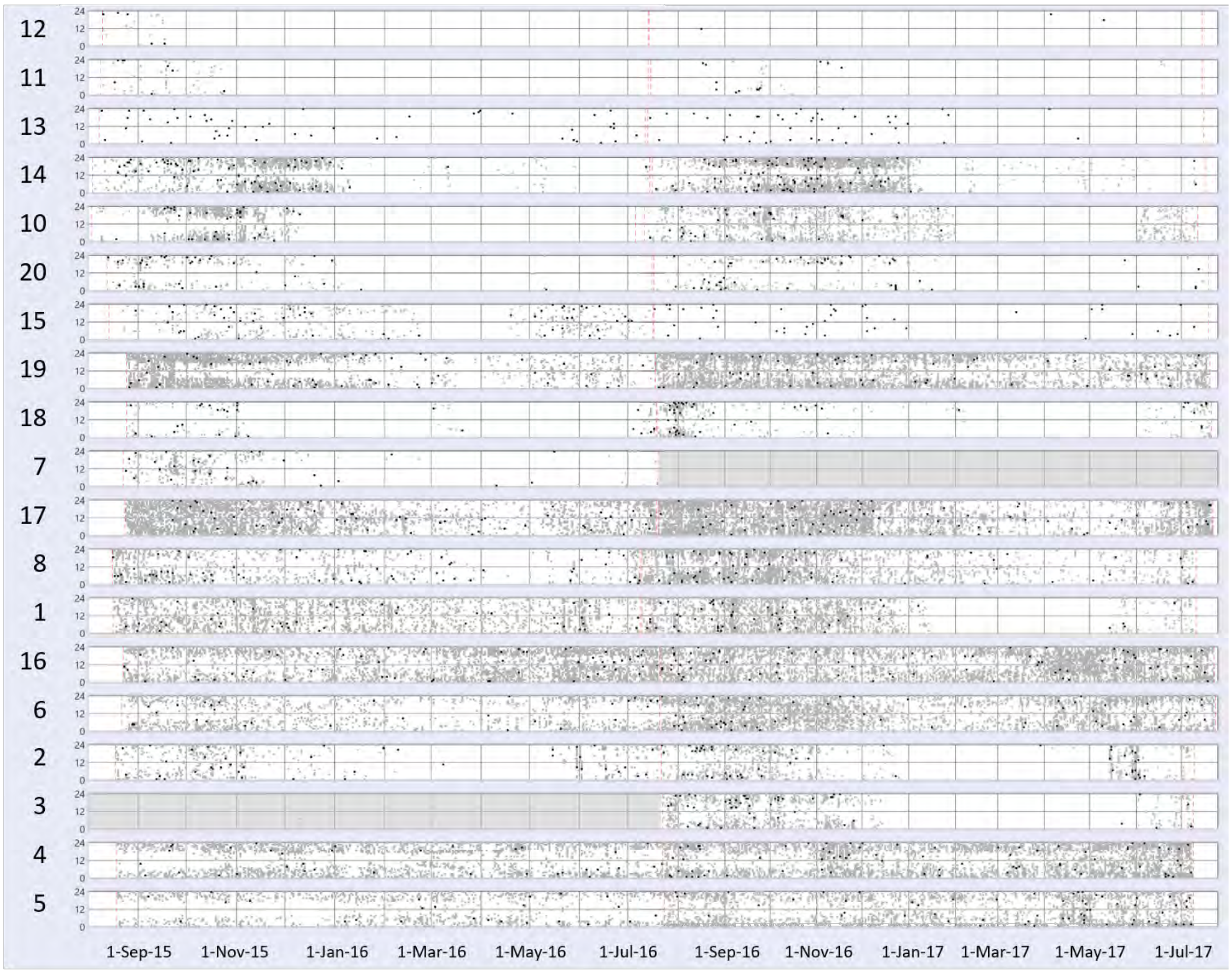


Figure 61. Daily and hourly occurrence of delphinid click detections recorded at all stations from 3 Aug 2015 to 23 Jul 2017. Stations are ordered from (top) north to (bottom) south. Grey dots indicate automated detections. Black dots indicate manually validated results. The red dashed lines indicate AMAR deployment and retrieval dates. Manually identified signals are shown if the detector's precision was below 0.75 (Stn 13).

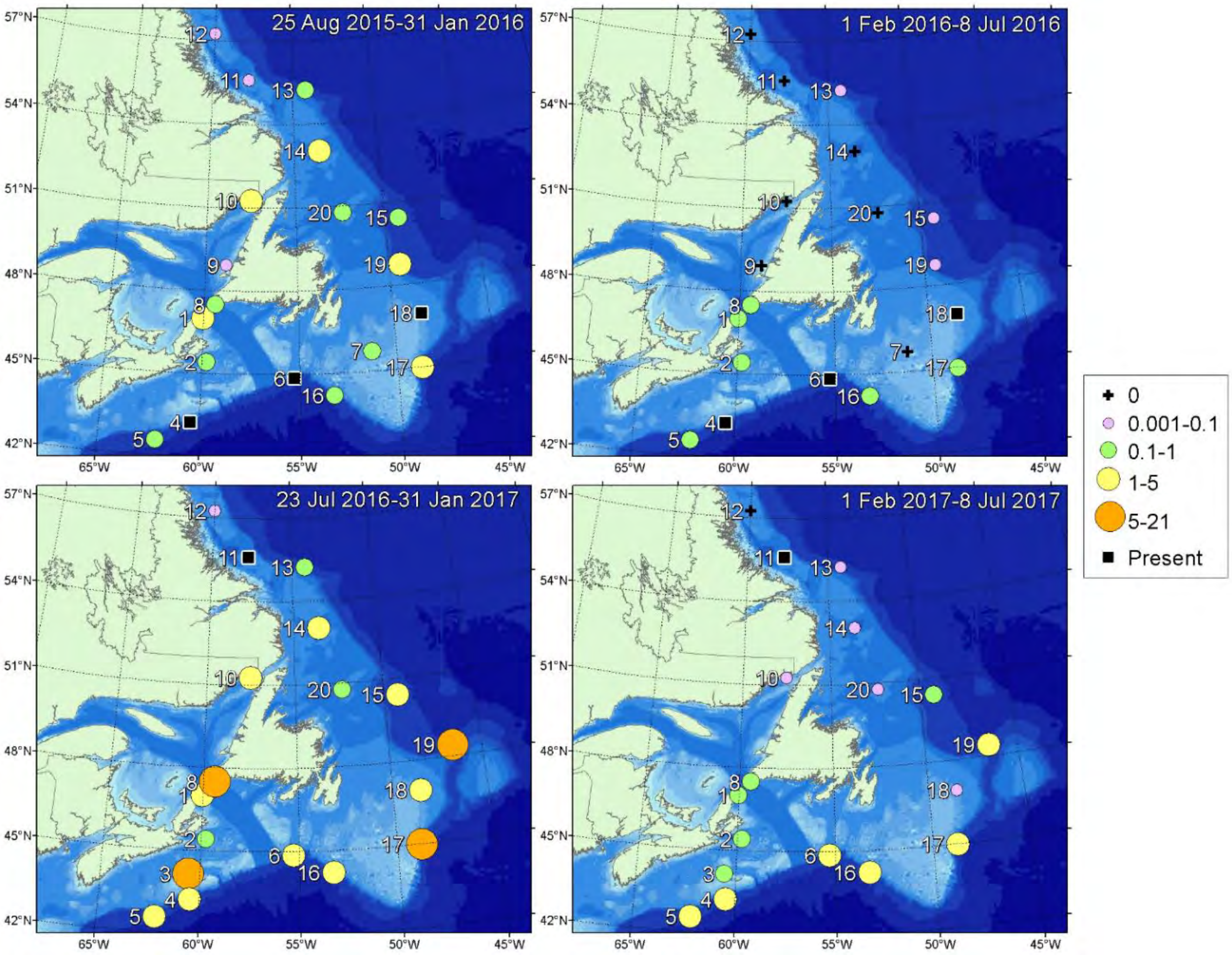


Figure 62. Dolphin whistles: Mean hourly detection count (MHDC) at stations where acoustic data were recorded in 2015–16 (left) and 2016–17 (right). The black square indicates stations where the species was manually identified but the detector accuracy was below the accepted P of 0.75 or unevaluated due to a lack of validated automated detections.

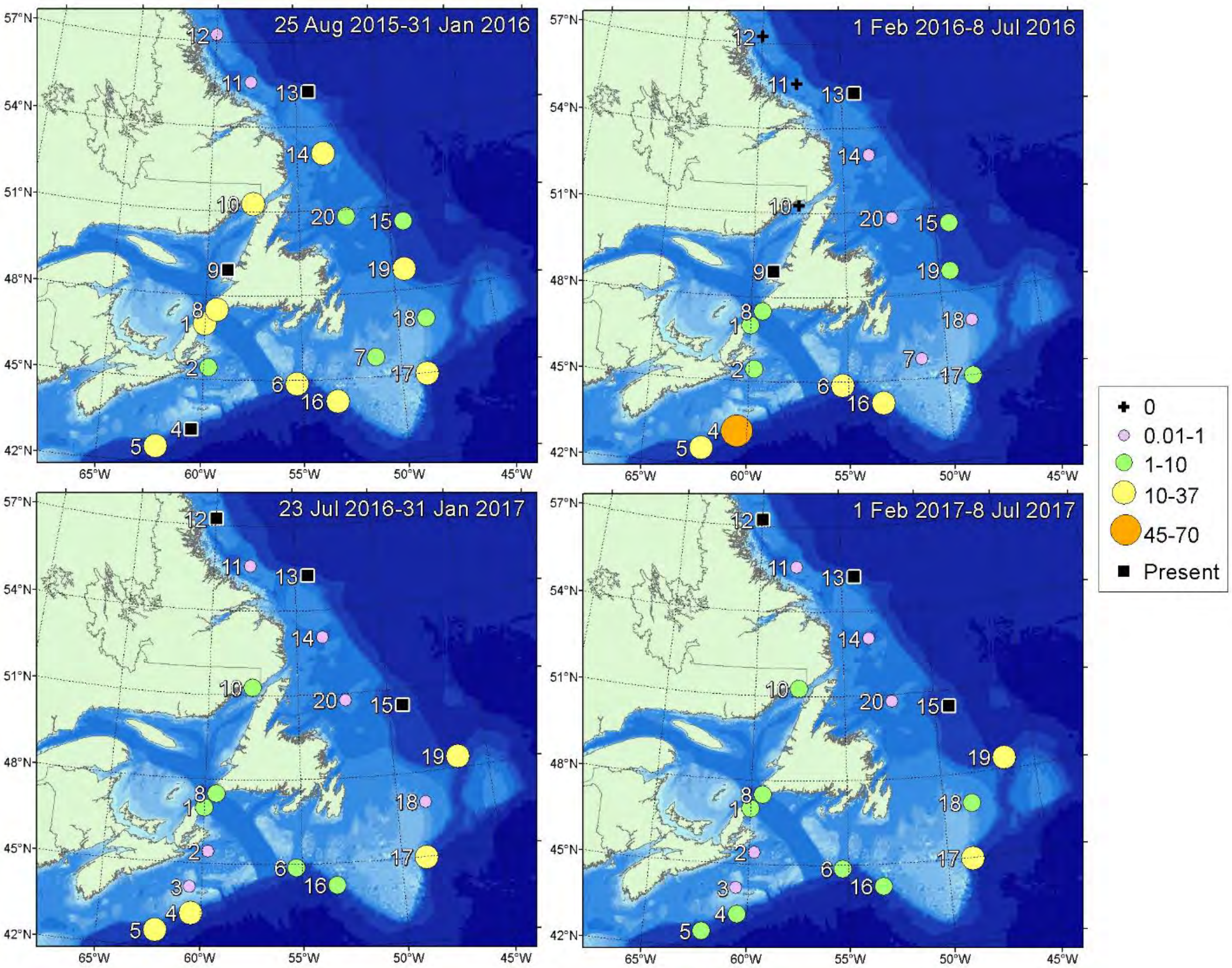


Figure 63. Delphinid clicks: Mean hourly detection count (MHDC) at stations where acoustic data were recorded between 15 Jul 2016 and 31 Jan 2017 (left) and 1 Feb and 15 Jul 2017 (right). Stations where the detector output was below the precision threshold of 0.75 are displayed as black squares.

3.4.2.2.4. Harbour Porpoise

Harbour porpoise clicks have a peak frequency near 125 kHz and no frequency modulated slope (Au et al. 1999) (Figures 64 and 65). In the study area, the only other species whose clicks share similar spectral characteristics is the pygmy sperm whale (*Kogia breviceps*) (Marten 2000, Madsen et al. 2005). Harbour porpoise clicks have short propagation range due to the high frequency of their clicks. The maximum estimated (horizontal) active space, under a favourable scenario with a sound channel, is 1.1 km (DeRuiter et al. 2010). The maximum dive depth recorded for this species is 132 m off in the shallow North Sea (Teilmann et al. 2007) but up to 410 m in deep waters off Greenland (Nielsen et al. 2018). Because of the depth of most off-shelf recorders (>1250 m), it was highly unlikely that porpoise clicks could be detected at these stations. Porpoise-like signals detected at deep stations have therefore been tentatively assigned to *Kogia* sp.

Porpoise clicks occurred at 11 stations (Figure 66). A seasonal shift from coastal northern stations in summer and fall to coastal in winter and spring was observed in both years (Figure 66). Stn 10 had the highest detection rates in summer and fall in both years, while stn 1 and 2 north and east of Cape Breton, as well as stn 3 on the outer Scotian shelf, had the highest detection rates from winter to early summer (Figure 67). Detections also occurred at low level throughout the year at offshore, on-shelf stations of the Grand Banks (stn 7 and 18).

Clicks tentatively attributed to pygmy sperm whales were detected at stn 4, 5, 6, and 16 (Figure 68). A noteworthy cluster of detections occurred in the spring 2017 at stn 4 and 5.

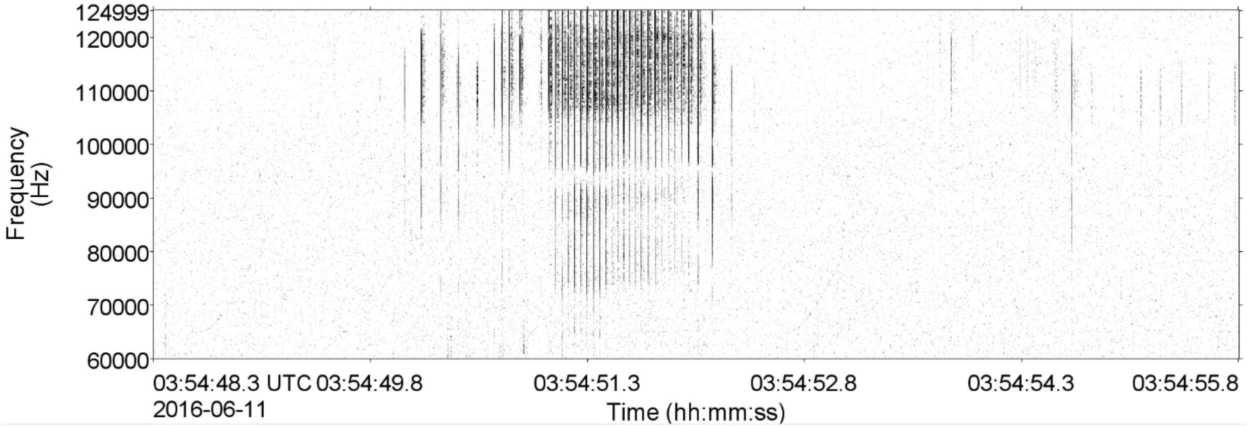


Figure 64. Spectrogram of harbour porpoise clicks recorded at stn 2 on 11 Jun 2016 (64 Hz frequency resolution, 0.01 s time window, 0.005 s time step, Hamming window).

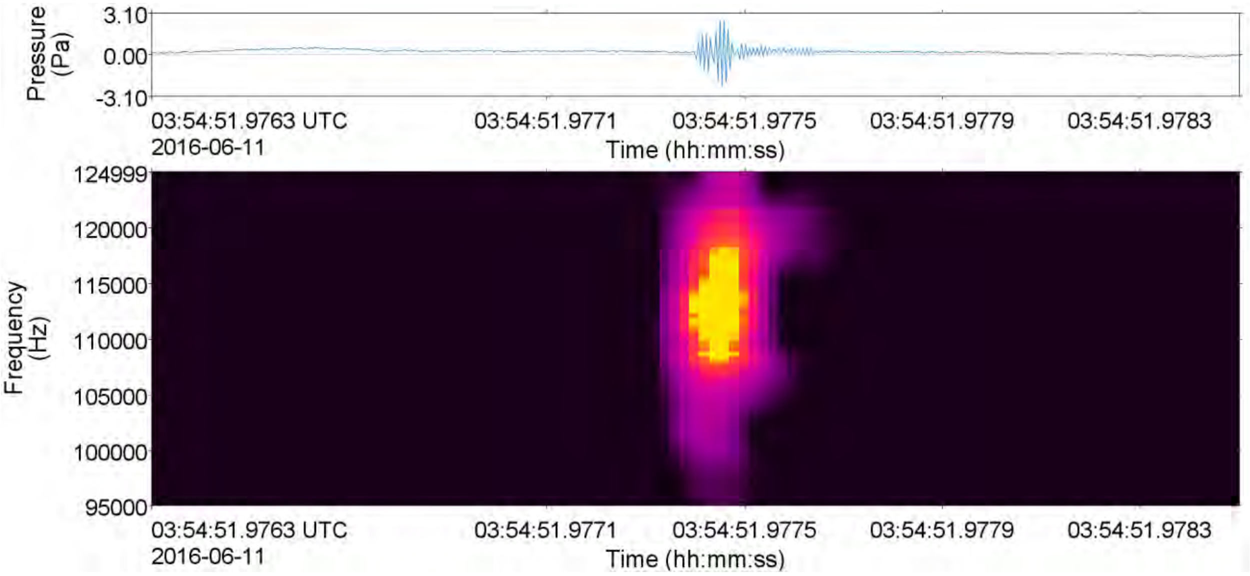


Figure 65. Spectrogram of a harbour porpoise click recorded at stn 2 on 11 Jun 2016 (512 Hz frequency resolution, 0.26 ms time window, 0.02 ms time step, Hamming window).

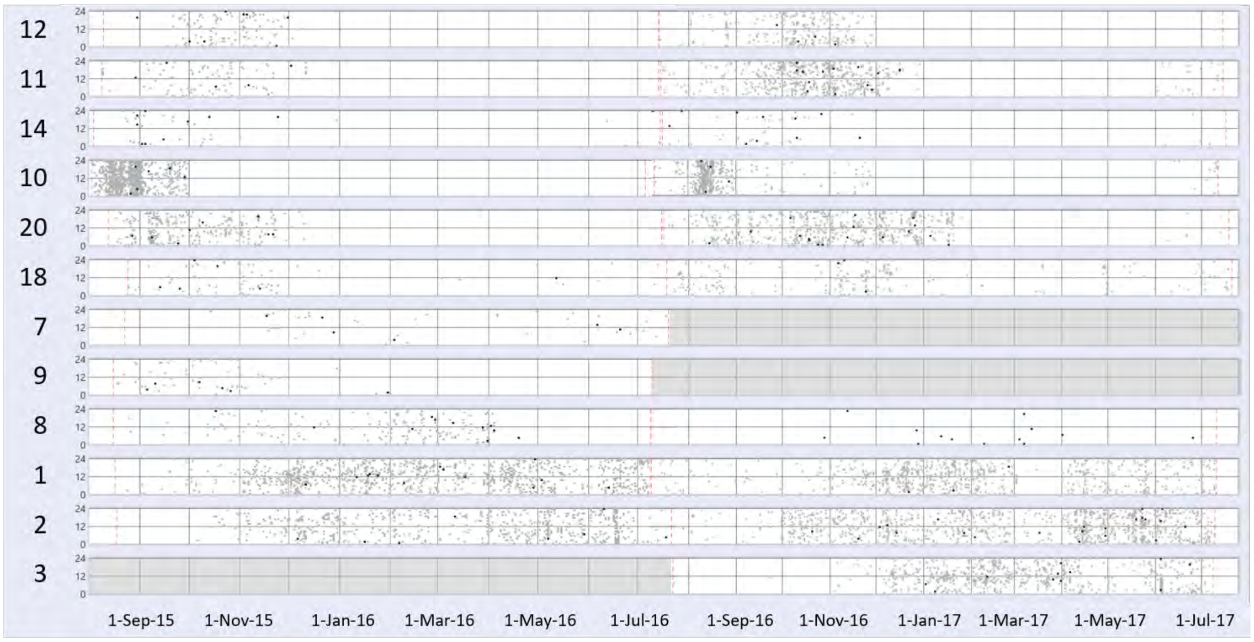


Figure 66. Daily and hourly occurrence of harbour porpoise clicks recorded at stn 1, 2, 4, 7–12, 14, 16, 18, and 20 from 3 Aug 2015 to 23 Jul 2016. Stations are ordered from (top) north to (bottom) south. Grey dots indicate automated detections. Black dots indicate manually validated results. The red dashed lines indicate AMAR deployment and retrieval dates. Manually identified signals are shown if the detector's precision was below 0.75 (Stn 8 in 2016–17).

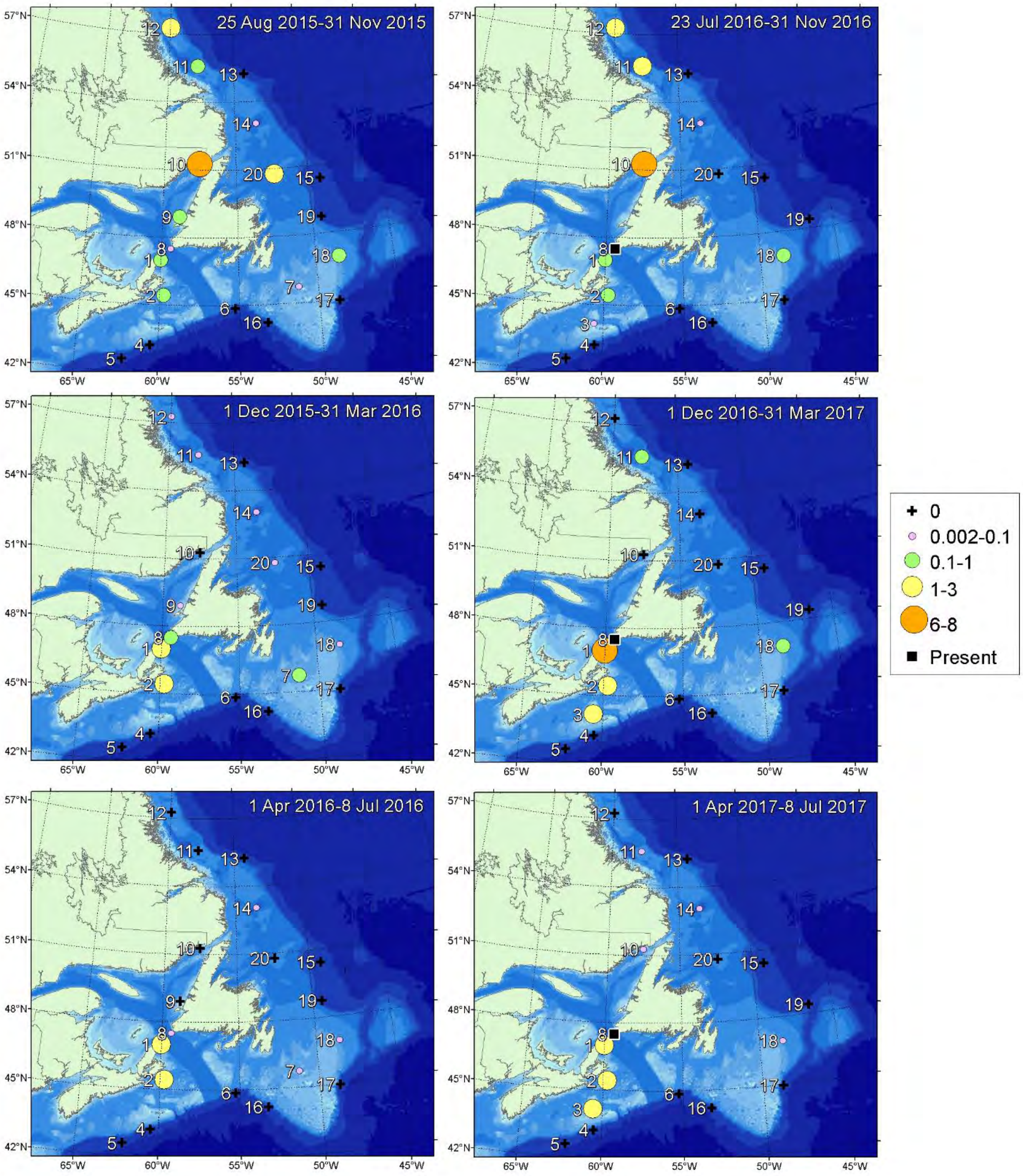


Figure 67. Harbour porpoise clicks: Mean hourly detection count (MHDC) at stations where acoustic data were recorded in 2015–16 (left) and 2016–17 (right). The black square indicates stations where the species was manually identified but the detector accuracy was below the accepted P of 0.75 or unevaluated due to a lack of validated automated detections.

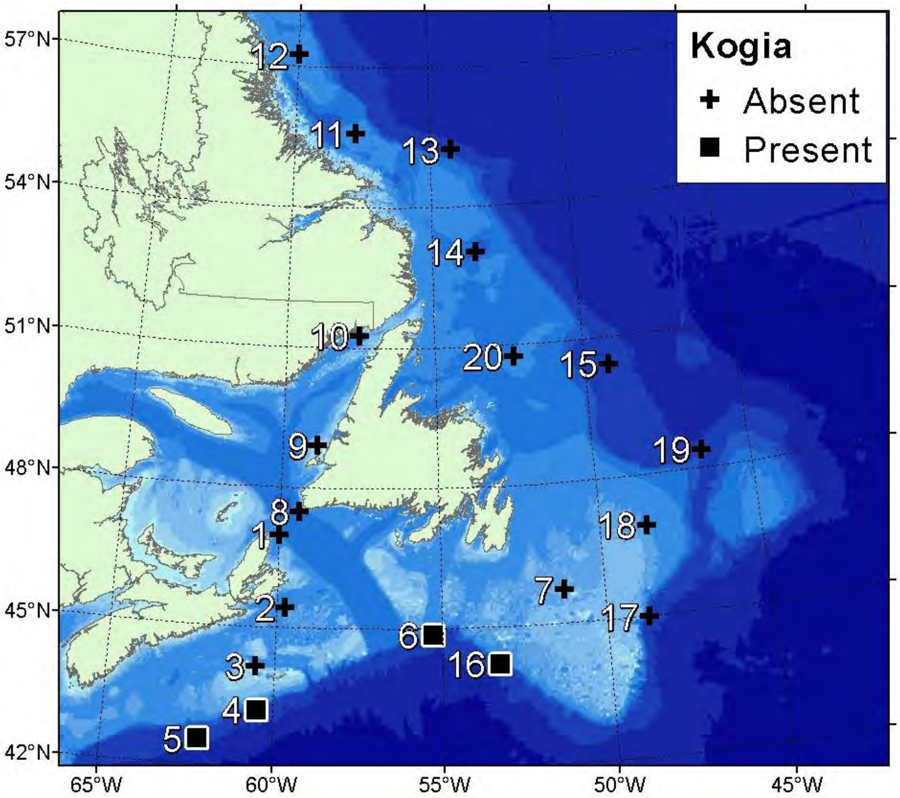


Figure 68. Locations where Kogia clicks were tentatively identified between August 2015 and July 2017.

3.4.2.3. *Sperm Whales*

Sperm whale clicks (Figure 69) occurred at 15 stations (Figures 70 and 71). Most stations were deep, off-shelf stations. Exceptions included detections on the southern Labrador shelf (stn 11 and 12) and northern Grand Banks (stn 14, 18, and 20). Stn 1 and 8 were also relatively shallow, but they were on the edge of the 400–500 m deep Laurentian Channel.

At the deep stations where clicks were most consistently recorded, a seasonal decline in detections was generally observed, except at stn 17 (both years) and stn 19 (second year) (Figure 70). These two stations had the highest detection rates (Figure 70), suggesting that the Flemish Pass and adjacent waters may be an important area for this species.

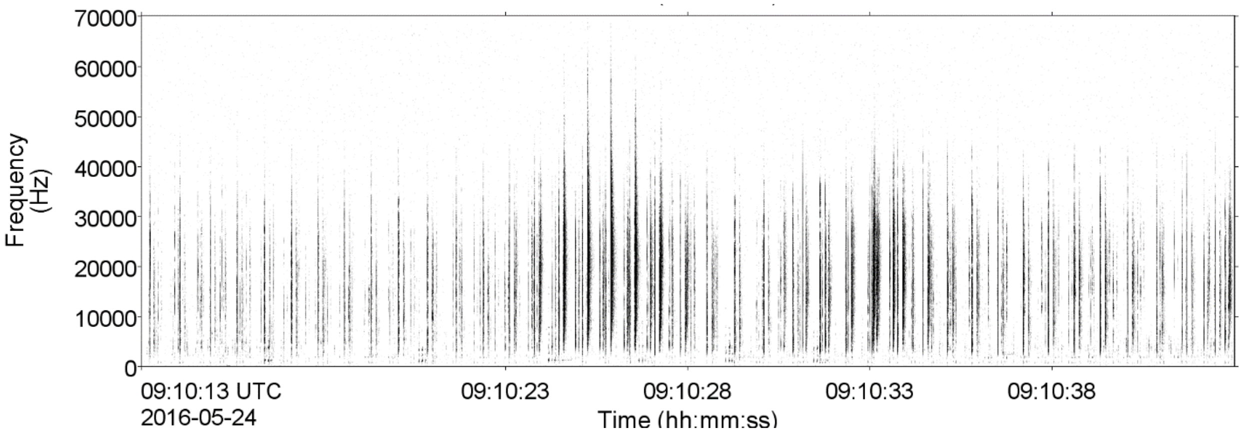


Figure 69. Spectrogram of sperm whale clicks recorded at stn 8 on 24 May 2016 (64 Hz frequency resolution, 0.01 s time window, 0.005 s time step, Hamming window).

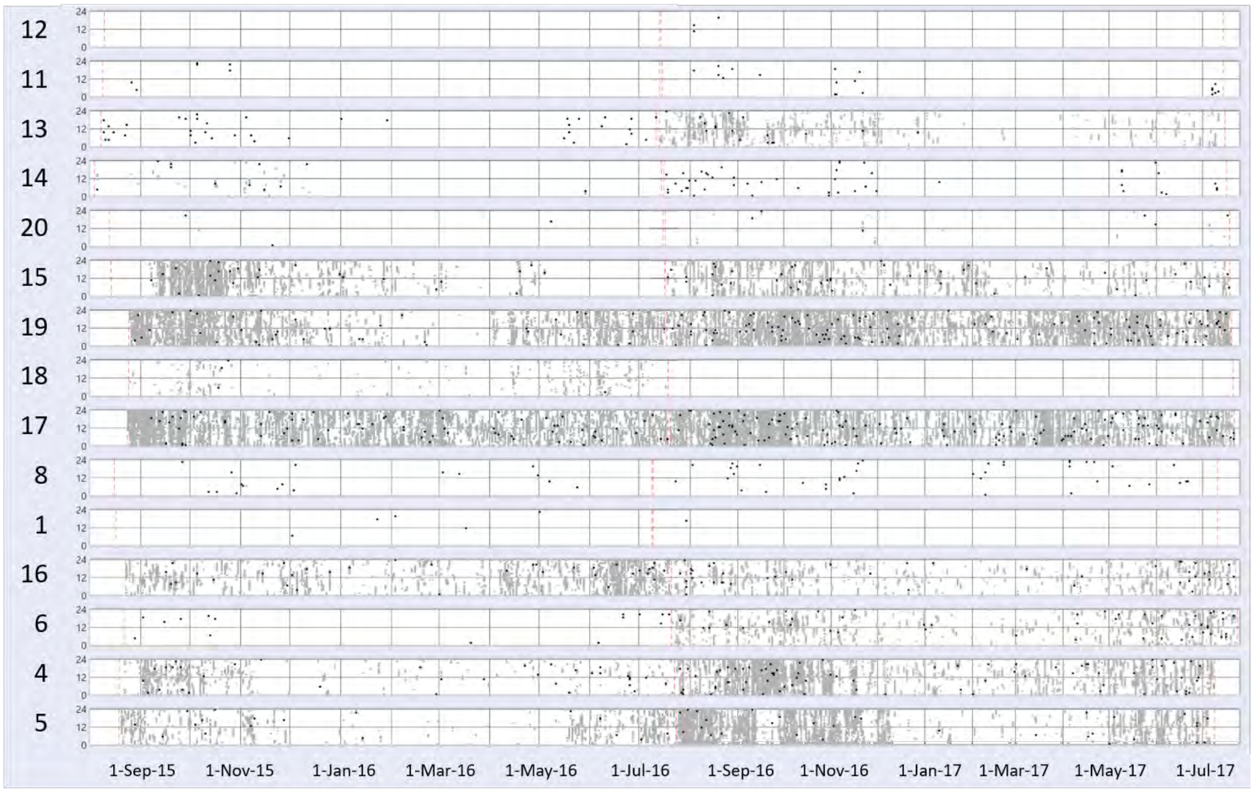


Figure 70. Daily and hourly occurrence of sperm whale clicks recorded at stn 1, 4–6, 8, and 11–20 from 3 Aug 2015 to 23 Jul 2016. Stations are ordered from (top) north to (bottom) south. Grey dots indicate automated detections. Black dots indicate manually validated results. The red dashed lines indicate AMAR deployment and retrieval dates. Manually identified signals are shown if the detector's precision was below 0.75 (Stn 12, 11, 13 in 2015–16, 14 in 2016–17, 18 in 2016–17, 8 in 2016–17, 1, and 6 in 2015–16).

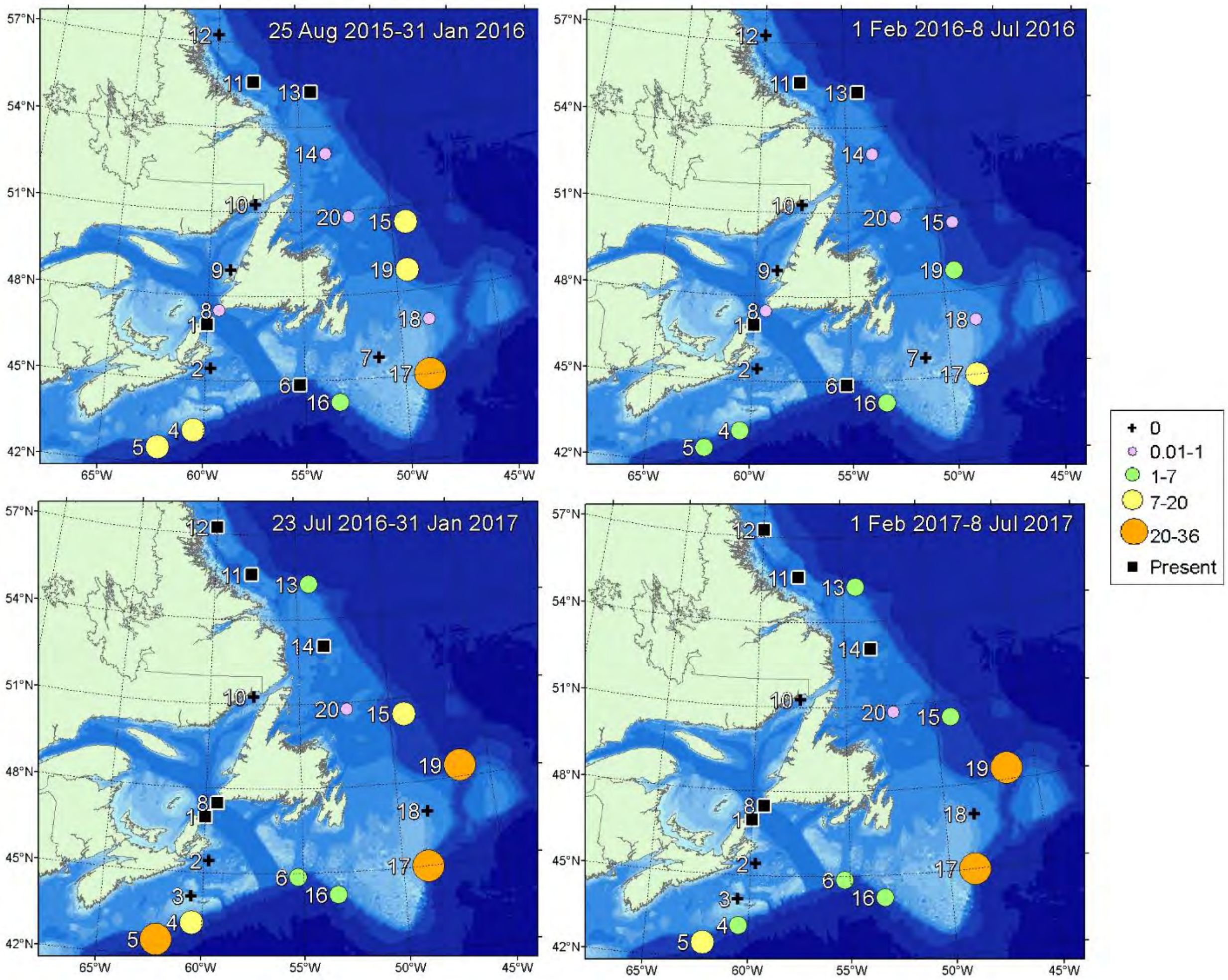


Figure 71. Sperm whale clicks: Mean hourly detection count (MHDC) at stations where acoustic data were recorded in 2015–16 (left) and 2016–17 (right). The black square indicates stations where the species was manually identified but the detector accuracy was below the accepted P of 0.75 or unevaluated due to a lack of validated automated detections.

3.4.3. Mysticetes

3.4.3.1. *Blue Whales*

The detector was configured to find blue whale infrasonic A-B vocalizations (Figure 72) (Mellinger and Clark 2000), which are produced by blue whales from late summer to early spring. Blue whale audible downsweeps (Figure 73) (Berchok et al. 2006) show substantial overlap in spectral characteristics with sei whale vocalizations (mostly, but fin whale vocalizations as well to some extent) and were not consistently identified by the detector. Only manually validated results of these vocalizations were considered. Because the downsweeps occur predominantly in spring and summer when infrasonic moans are absent or rare, the inability to detect these vocalizations automatically hinders the evaluation of acoustic occurrence of blue whale during this period.

Blue whale vocalizations occurred at all stations except stn 9, 10, and 12 (Figure 74), generally from August to January. However, they continued into February at stn 17 in both years and into March in the Cabot Strait (stn 1 and 8), as well as off the Scotian shelf (stn 4 and 5) in the second year. In both years, stations on the southern end of the Grand Banks (stn 6 and 16) had the highest detection rates, seconded by those in or near the Laurentian Channel (stn 1, 2, and 8) (Figure 75).

Deep offshore stations in the northern part of the study area had low monthly detection rates. However, a band of energy at 17 Hz attributed to blue whale A-B vocalizations is visible in long-term spectrograms (Figures 76 and 77), suggesting that the occurrence of this species may be underestimated in these areas. The detector was configured with a threshold high enough to restrict the number of false alarms caused by other long tonal signals, such as those produced by vessels. Faint, distant, acoustic signals were generally missed (see low recall values, particularly in the second year). The detection range of blue whale vocalizations for other deep oceanic areas has been estimated at over 200 km (Sirovic et al. 2007, Stafford et al. 2007). Therefore, it is likely that many of the signals contributing to the visible energy band were produced by animals that were not in the immediate vicinity of the recorders.

Because A-B vocalizations occurred past January at several stations, the lack of vocalizations in February and March can be safely interpreted as an absence of blue whales. Manual identified audible downsweeps (Figure 73) (Berchok et al. 2006) in the spring and summer in the Cabot Strait area highlight the year-round occurrence of the species.

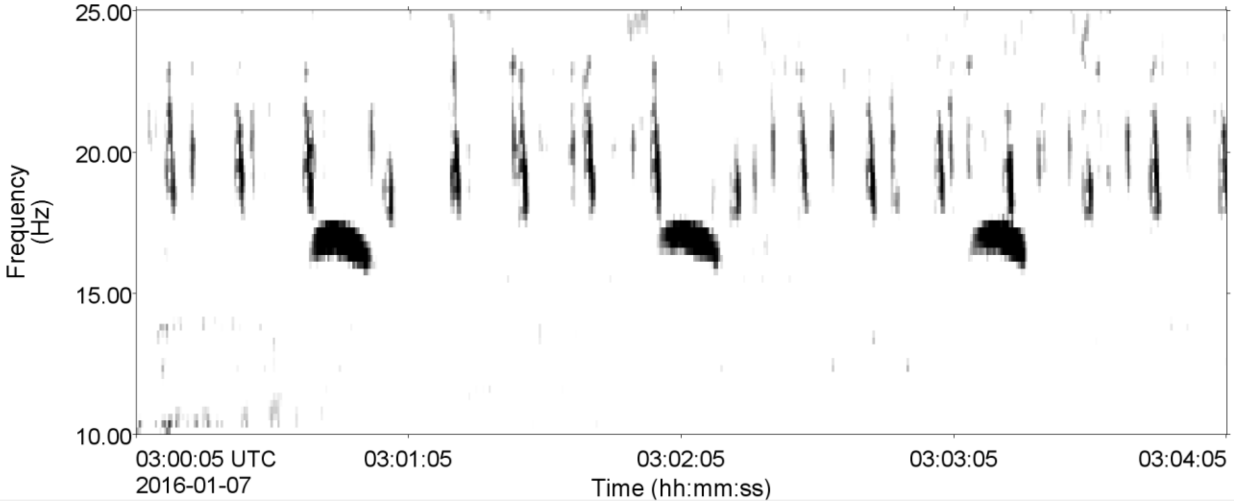


Figure 72. Spectrogram of blue whale infrasonic A-B vocalizations recorded at stn 1 on 7 Jan 2016 (0.4 Hz frequency resolution, 2 s time window, 0.5 s time step, Hamming window).

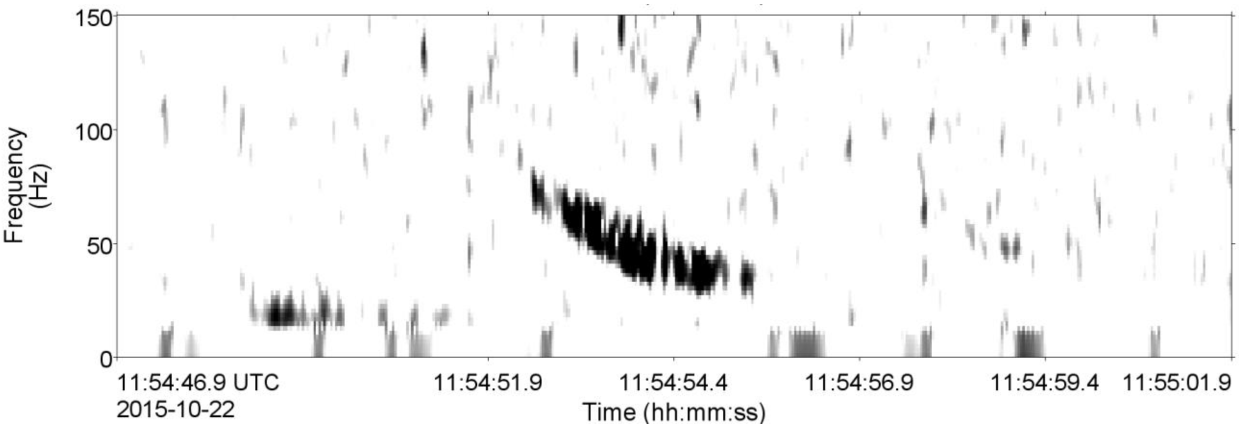


Figure 73. Spectrogram of blue whale D vocalization recorded at stn 2 on 22 Oct 2015 (2 Hz frequency resolution, 0.128 s time window, 0.032 s time step, Hamming window).

Figure 74. Daily and hourly occurrence of blue whale infrasonic vocalizations recorded at all stations (except stn 9–12) from 3 Aug 2015 to 23 Jul 2016. Stations are ordered from (top) north to (bottom) south. Grey dots indicate automated detections. Black dots indicate manually validated results. The red dashed lines indicate AMAR deployment and retrieval dates. Manually identified signals are shown if the detector's precision was below 0.75 (Stn 11 in 2015–16, 13 in 2015–16, 20 in 2016–17, 18 in 2016–17, and 1 in 2015–16).

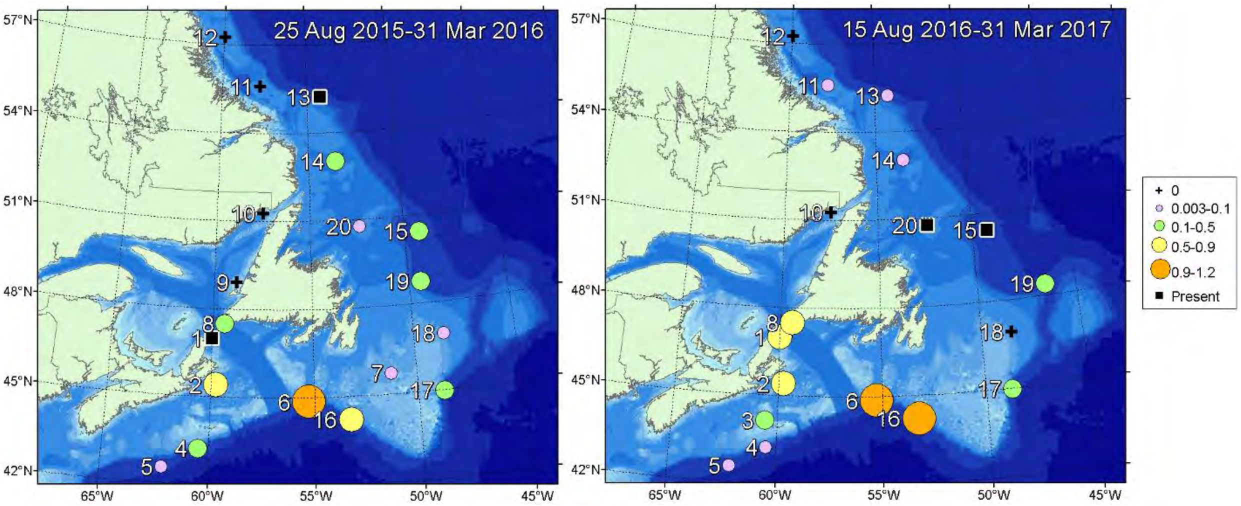
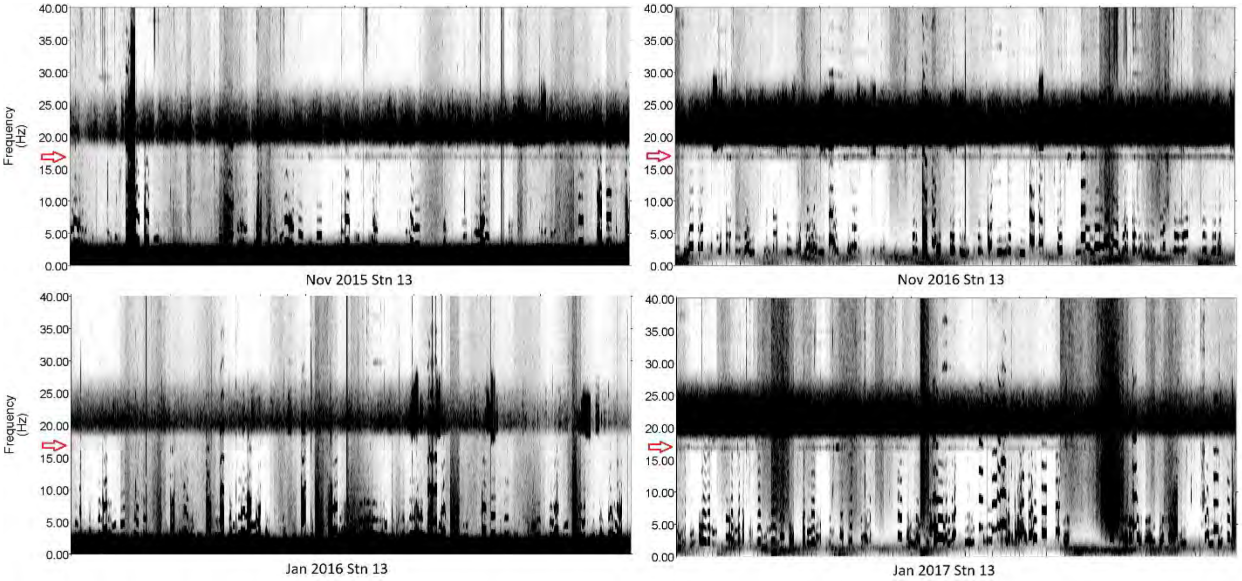


Figure 75. Blue whale A-B vocalizations: Mean hourly detection count (MHDC) at stations where acoustic data were recorded in 2015–16 (left) and 2016–17 (right). The black square indicates stations where the species was manually identified but the detector accuracy was below the accepted P of 0.75 or unevaluated due to a lack of validated automated detections.



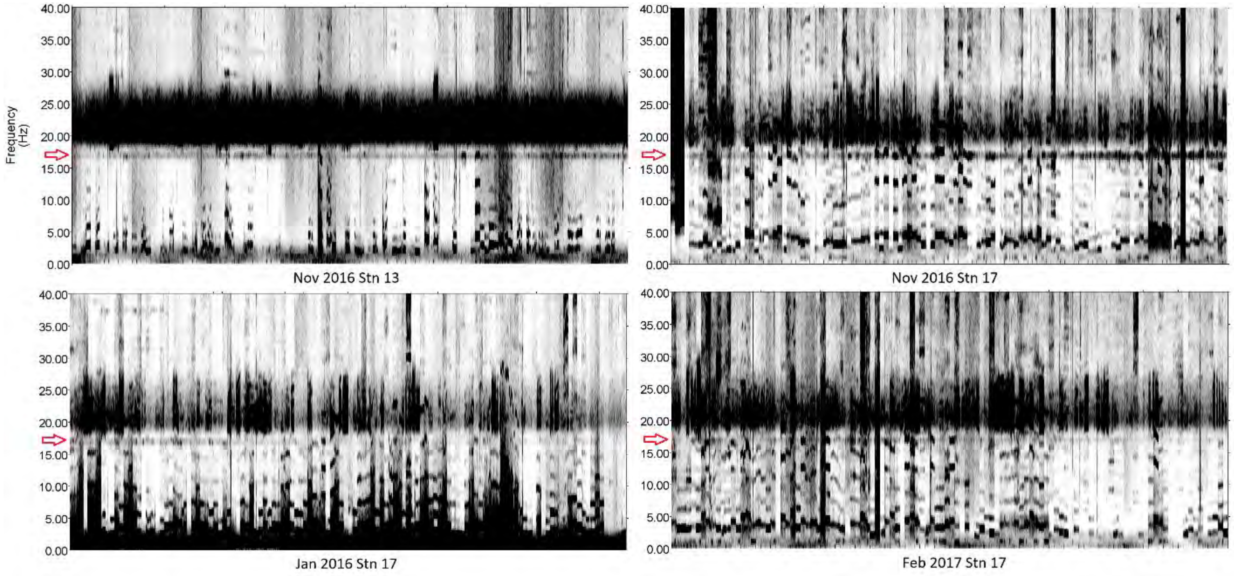
Nov 2015 Stn 13

Nov 2016 Stn 13

Jan 2016 Stn 13

Jan 2017 Stn 13

Figure 76. Monthly spectrograms for data recorded at stn 13 in Nov 2015 and 2016 and Jan 2016 and 2017 (0.4 Hz frequency resolution, 2 s time window, 0.5 s time step, Hamming window). The arrow shows the 17-Hz band of energy associated with blue whale vocalizations.



Nov 2016 Stn 13

Nov 2016 Stn 17

Jan 2016 Stn 17

Feb 2017 Stn 17

Figure 77. Monthly spectrograms for data recorded at stn 17 in Nov 2015 and 2016 and Jan 2016 and Feb 2017 (0.4 Hz frequency resolution, 2 s time window, 0.5 s time step, Hamming window). The arrow shows the 17-Hz band of energy associated with blue whale vocalizations.

3.4.3.2. *Fin Whales*

Fin whale 20-Hz vocalizations (Figure 78) occurred at all stations except stn 9. The detector accuracy was above threshold at all but three station-year pairs (Figure 79). Most detections occurred between August and April, which coincided with the period associated with song production (Watkins et al. 1987). 20-Hz signal production typically occurs year-round although vocalization rates are substantially lower between May and July, when other vocalizations types that are reliably detected automatically tend to be more common (Watkins 1981). Detections extended into May and beyond at some stations (e.g., stn 6, 17, and 19), but summer detections were often excluded from May onward due to the increasing proportion of false detections caused by increasing anthropogenic signals (mostly seismic airgun signals) in relation to decreasing detection rates (Figure 79). At stations where fin whale vocalizations truly occurred in the spring and early summer, detections were sporadic, which reflects a change in vocalization rate rather than a change in occurrence.

Mean hourly detection counts suggest a prevalence of fin whales at outer shelf stations (stn 3, 7, and 18). Stations off Labrador and on or off the northern Grand Banks had the lowest number of detections (Figure 80); however, these numbers have to be put into perspective. The bump in spectral density levels around 20 Hz associated with fin whale song notes varied substantially between stations. For instance, the deviation between PSD levels at 20 Hz compared to 15 Hz in December 2015 was 25 dB re 1 µPa^2/Hz at stn 14 and 10.8 dB re 1 µPa^2/Hz at stn 7 (Figure 81). In contrast, the number of automated detections (above threshold) at these stations during that month was 2708 and 90871, respectively. Figure 82 illustrates typical detector output at these stations. Individual acoustic signals were distinct and numerous at stn 7, and the detector identified most of them. In contrast, individual acoustic signals were engulfed in a band of noise associated with fin whale songs at stn 14, resulting in a poor performance of the detector and a high detection count threshold (see Appendix G.1). Therefore, it is likely that the acoustic occurrence of fin whales on and off the northern and northeastern sections of the Grand Banks is underestimated by Figure 80 and may in fact be larger than at stations farther south.

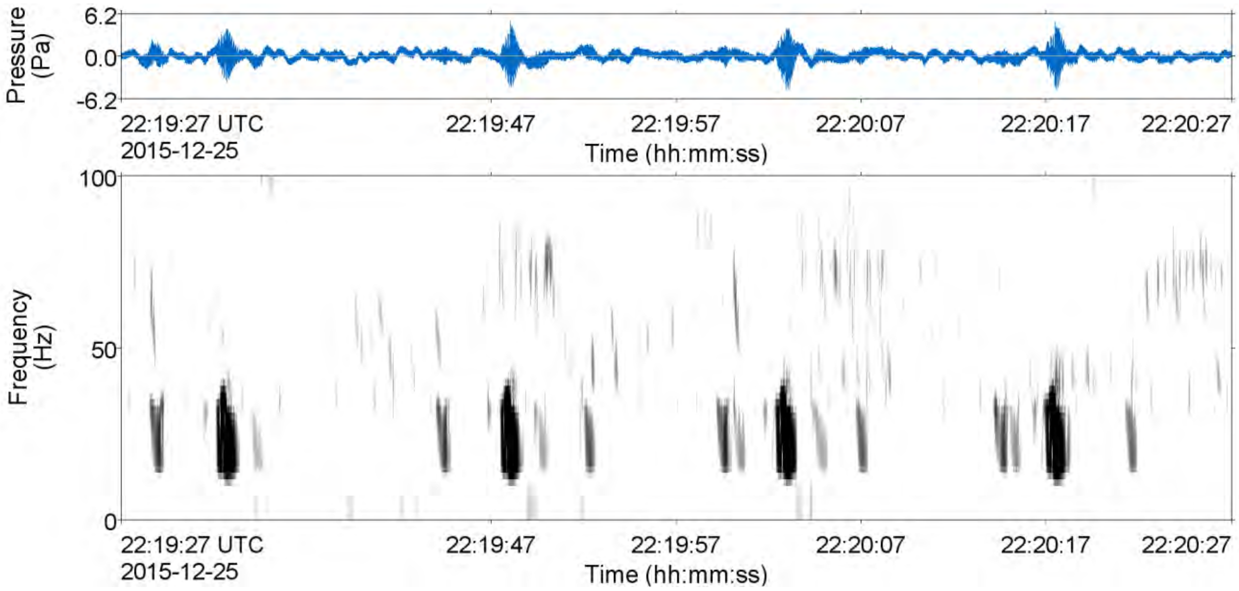


Figure 78. Spectrogram of fin whale 20 Hz notes recorded at stn 7 on 25 Dec 2015 (2 Hz frequency resolution, 0.128 s time window, 0.032 s time step, Hamming window).

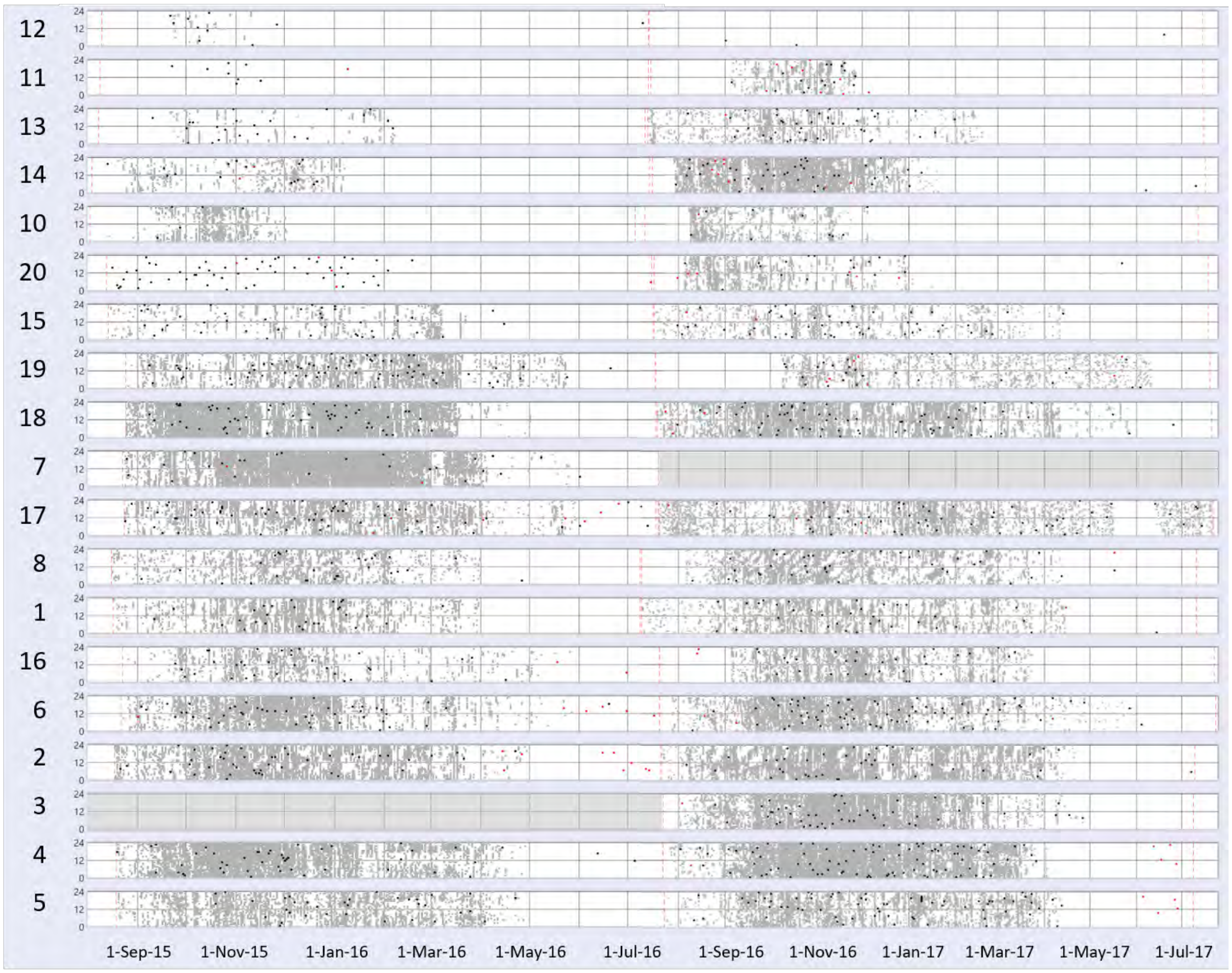


Figure 79. Daily and hourly occurrence of fin whale 20-Hz vocalizations recorded at all stations (except stn 9) from 3 Aug 2015 to 23 Jul 2016. Stations are ordered from (top) north to (bottom) south. Grey dots indicate automated detections. Black dots indicate manually validated results. The red dashed lines indicate AMAR deployment and retrieval dates. Manually identified signals are shown if the detector's precision was below 0.75 (Stn 12 in 2016–17, 11 in 2015–16, and 20 in 2015–16).

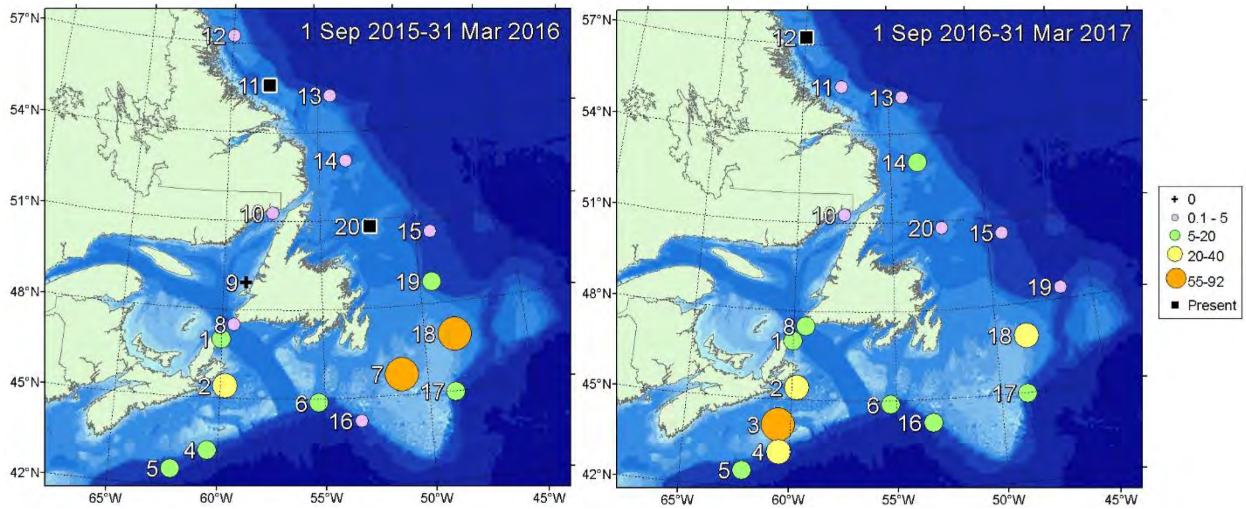


Figure 80. Fin whale 20-Hz vocalizations: Mean hourly detection count (MHDC) at stations where acoustic data were recorded in 2015–16 (left) and 2016–17 (right). The black square indicates stations where the species was manually identified but the detector accuracy was below the accepted P of 0.75 or unevaluated due to a lack of validated automated detections.

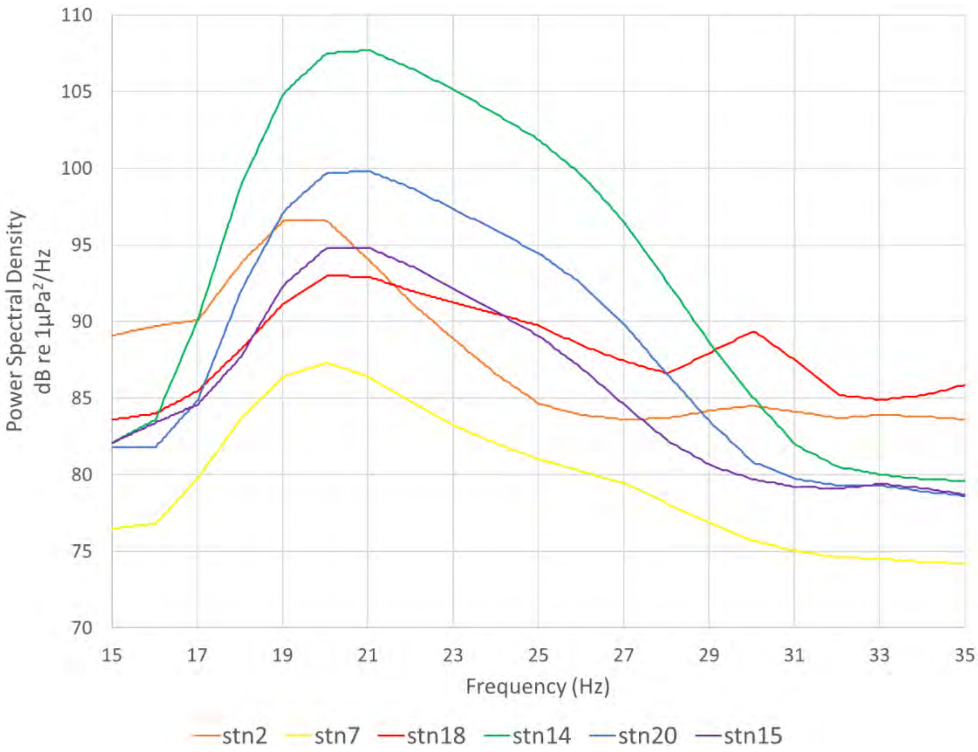


Figure 81. 50th percentile of the power spectral density levels between 15 and 35 Hz for December 2015 at selected stations.

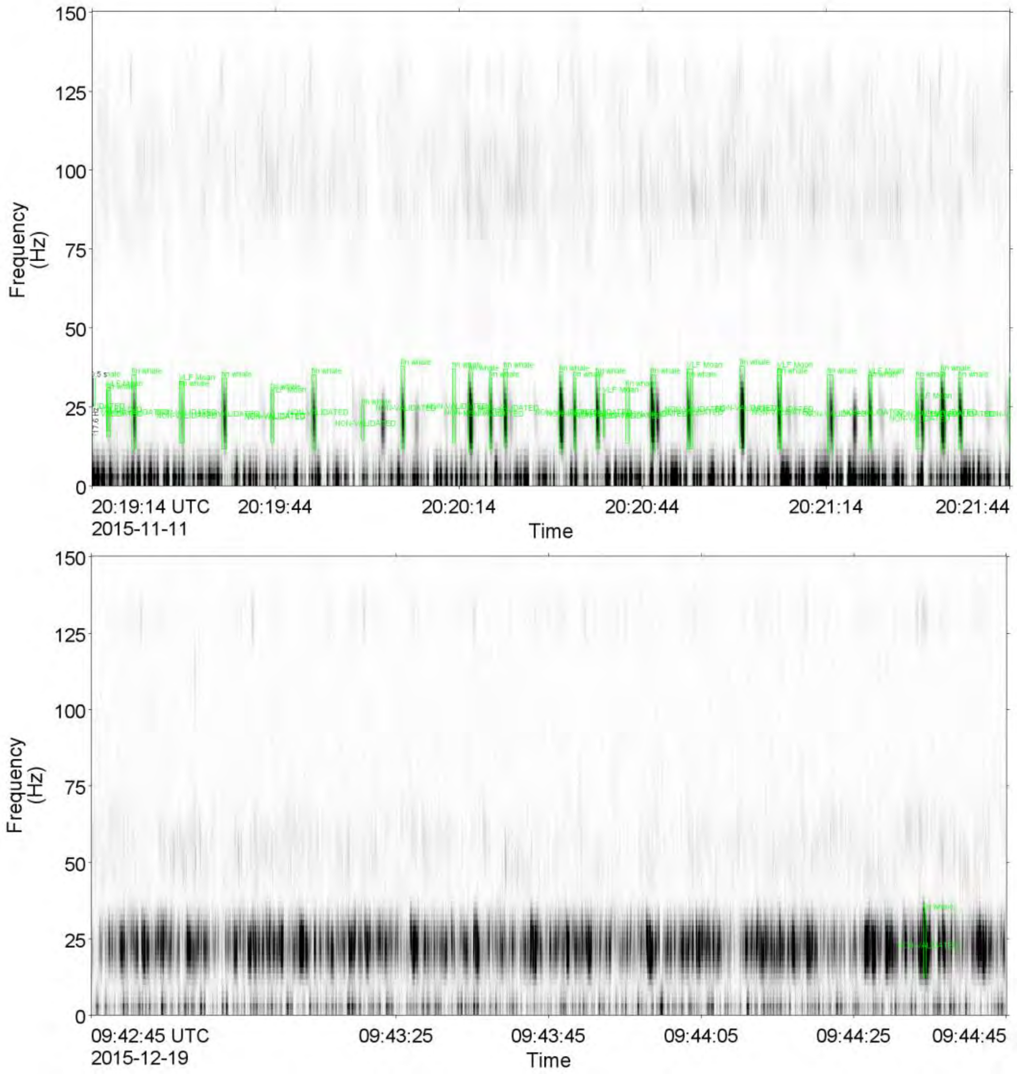


Figure 82. Fin whale detector output in 120-sec windows recorded at stn 7 on 11 Nov 2015 (top) and stn 14 on 19 Dec 2015 (2 Hz frequency resolution, 0.128 s time window, 0.032 s time step, Hamming window, no spectrogram normalization).

3.4.3.3. *Humpback Whales*

Most humpback whale vocalizations in fall and winter were hierarchical songs (Figure 83) (Payne and McVay 1971), while vocalizations at the beginning and end of the recording period were less sequenced and included a diversity of moans and non-tonal calls, typical of humpback whale repertoire on their feeding ground (e.g., Thompson et al. 1986).

Humpback whales occurred at all stations except stn 9 (Figure 84). Acoustic occurrence was highly seasonal throughout the study area for this species. In the fall and early winter, all stations recorded humpback whale vocalizations, with detections highest at stn 10, 7, and 14 (Figure 85). In the spring and early summer humpback whale vocalizations occurred only at the more southerly stations on the Scotian shelf and along southern Grand Banks, as well as in the Cabot Strait and Strait of Belle-Isle. Spring detections were highest at stn 1, 2, and 7 (Figure 85). Where detections occurred in fall and spring, the gap in detections usually lasted 2–3 months, with the exception of stn 7 where detections decreased but never completely ceased. Several deep offshore stations (stn 4 in 2016–17, 17, 19) had humpback whale signals only between December and February (Figure 84).

It is important to note that the abrupt beginning and cessation of humpback vocalization detections in some instances in Figure 84 is the result of the removal of detections during periods when the detector was confounded by noise or signals from other species (Appendix G). This includes the exclusion of summer detections from stn 4 to 6, 10–12, 14, 15, and 17–20 when the detector was falsely triggered by noise associated with seismic activity and no humpback whale vocalizations were manually validated (Appendix G). Also, winter detections were removed at stn 10 to 12 when bearded seal trills falsely triggered the detector.

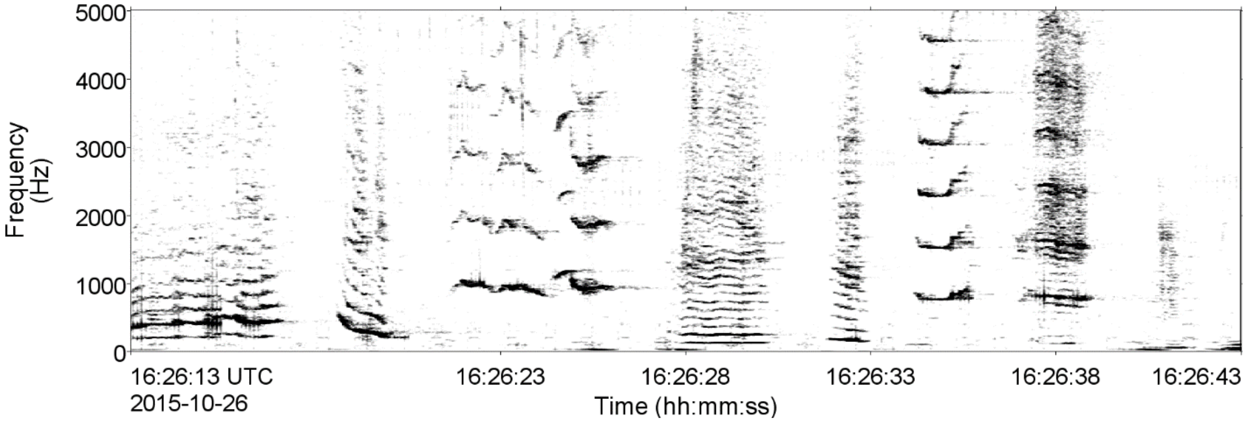


Figure 83. Spectrogram of humpback whale vocalizations (song) recorded at stn 7 on 26 Oct 2015 (2 Hz frequency resolution, 0.128 s time window, 0.032 s time step, Hamming window).

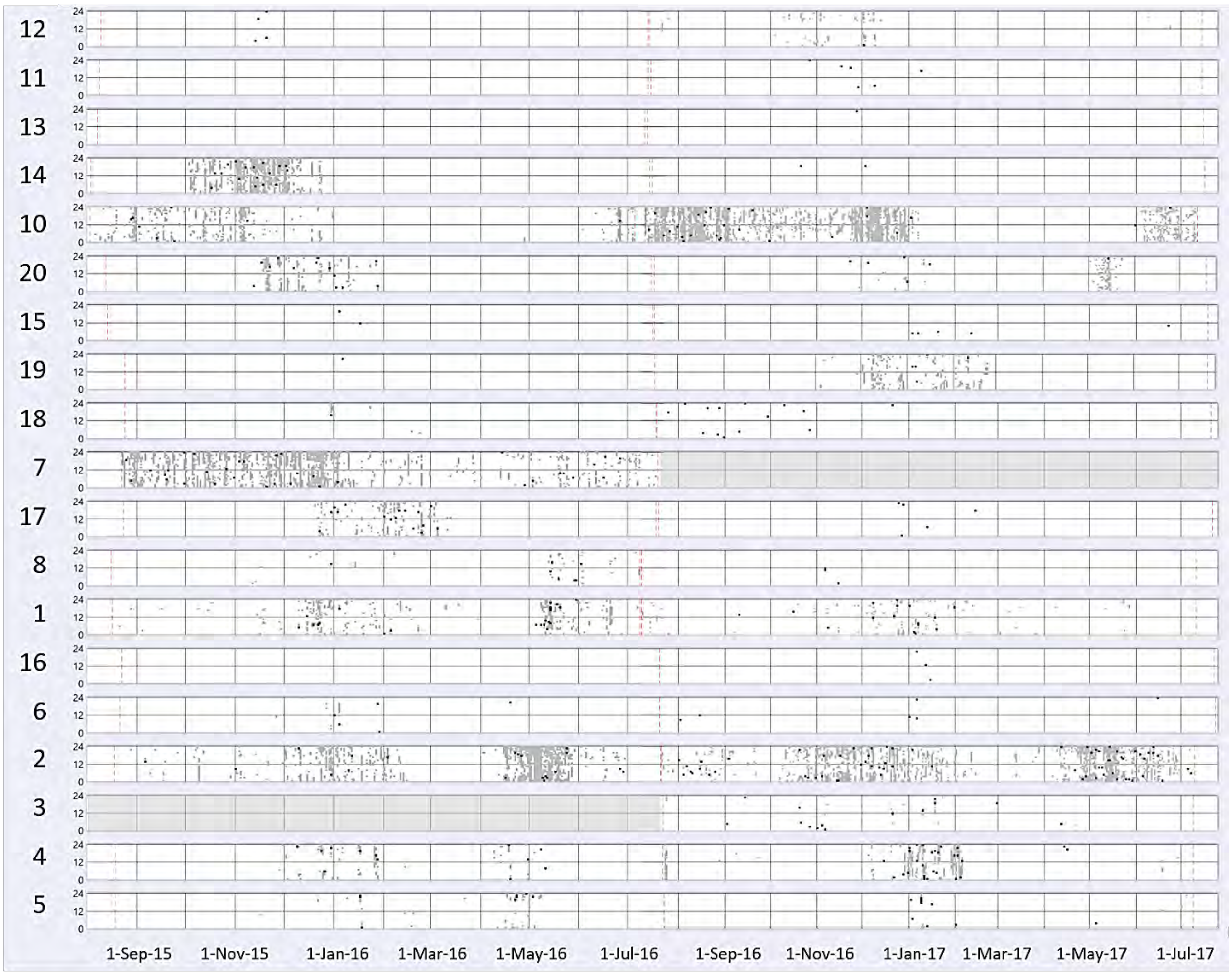


Figure 84. Daily and hourly occurrence of humpback whale song notes recorded at all stations (except stn 9 and 13) from 3 Aug 2015 to 23 Jul 2016. Stations are ordered from (top) north to (bottom) south. Grey dots indicate automated detections. Black dots indicate manually validated results. The red dashed lines indicate AMAR deployment and retrieval dates. Manually identified signals are shown if the detector's precision was below 0.75 (Stn 12 in 2015–16, 11, 13, 14 in 2016–17, 15, 19 in 2015–16, 18, 17 in 2016–17, 8 in 2016–17, 16, and 6 in 2016–17).

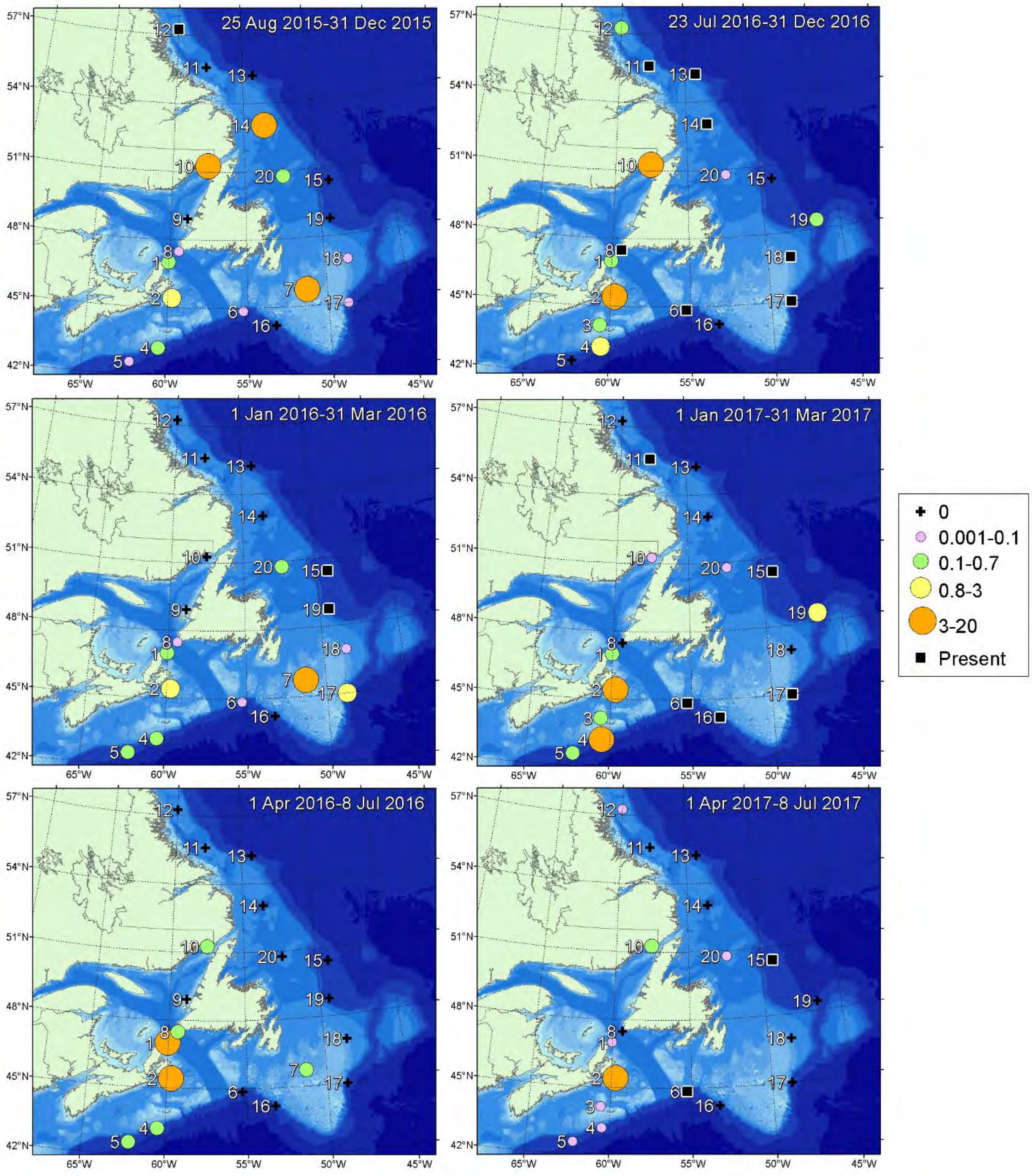


Figure 85. Humpback whale moans: Mean hourly detection count (MHDC) at stations where acoustic data were recorded in 2015–16 (left) and 2016–17 (right). The black square indicates stations where the species was manually identified but the detector accuracy was below the accepted P of 0.75 or unevaluated due to a lack of validated automated detections.

3.4.3.4. *Minke Whales*

Minke whale pulse trains (Figure 86) were manually identified in 2015–16 at stn 2 between 20 Aug and 22 Oct 2015. In 2016–17, the species occurred at stn 1, 2, 3, 5, and 16 from late July to mid-December (Figure 87). The species was rarely identified at all stations except for stn 3, where minke whales were acoustically present consistently until mid-November. These results underestimate the acoustic occurrence of the species in eastern Canadian waters as pulse trains were not automatically detected and the detections presented here are based on the manual review of 0.5% of the acoustic data. However, results from the manual review provide a representative picture of the distribution of vocally active minke whales (Figure 87).

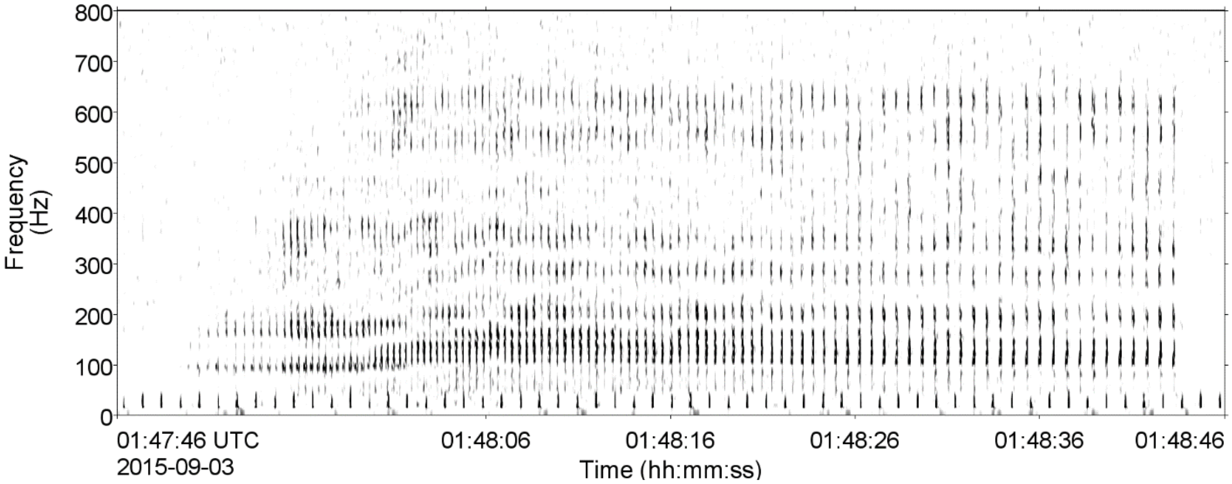


Figure 86. Spectrogram of a minke whale pulse train recorded at stn 2 on 3 Sep 2016 (2 Hz frequency resolution, 0.128 s time window, 0.032 s time step, Hamming window). The window length is 60 s.

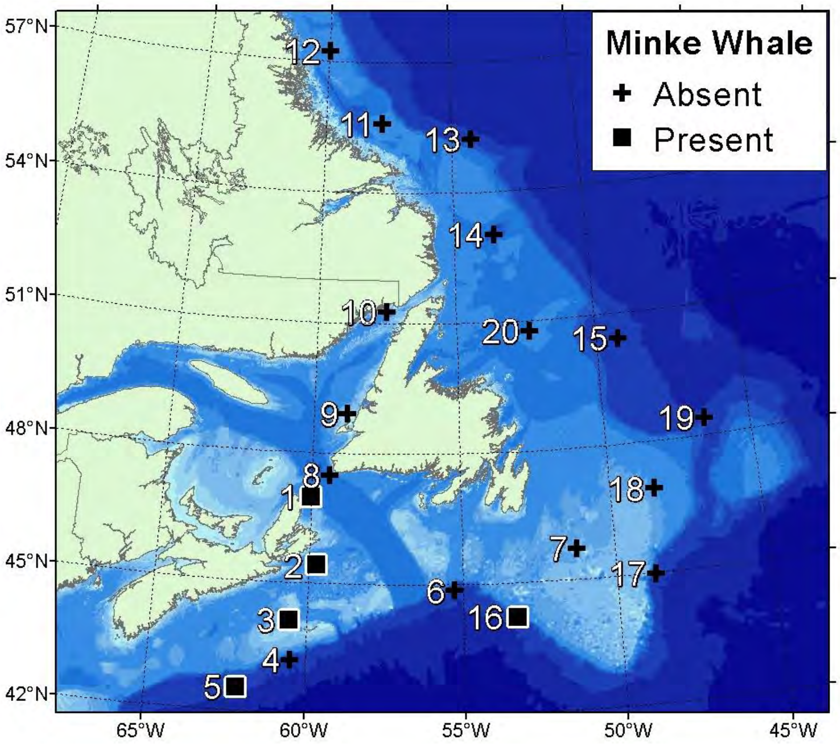


Figure 87. Locations of minke whale pulse trains manual detections between August 2015 and July 2017.

3.4.3.5. *North Atlantic Right Whales*

The right whale detector was configured to identify upcalls (Figure 88) (Clark 1982). Upcalls are frequency-modulated moans that increase in frequency from 100 to 400 Hz over ~1 s (Clark 1982). These moans are similar to some of the moans of humpback whales, whose relative abundance in the dataset resulted in a poor precision of the right whale detector. To ensure an accurate representation of right whale occurrence, we performed additional manual review of data recorded where and when right whale presence was expected, based on the current knowledge of the species' seasonal distribution. We reviewed 1 min of every 11-min sound file (corresponding to 3 min per hour, or 9% of the recorded data) recorded at the following stations and periods: mid-August to 31 Oct 2015 at stn 1, 2, 8, and 10; 1 Jun to 31 Oct 2016 at stn 1 and 2; and 1 Jun to mid-July 2017 at stn 1 and 2. All manually identified right whale signals occurred from late August to late November and only at stn 1 and 2, with the exception of a single detection at stn 6 in late November 2016. Possible right whale vocalizations also occurred at stn 8, 10, and 15 (Figure 89).

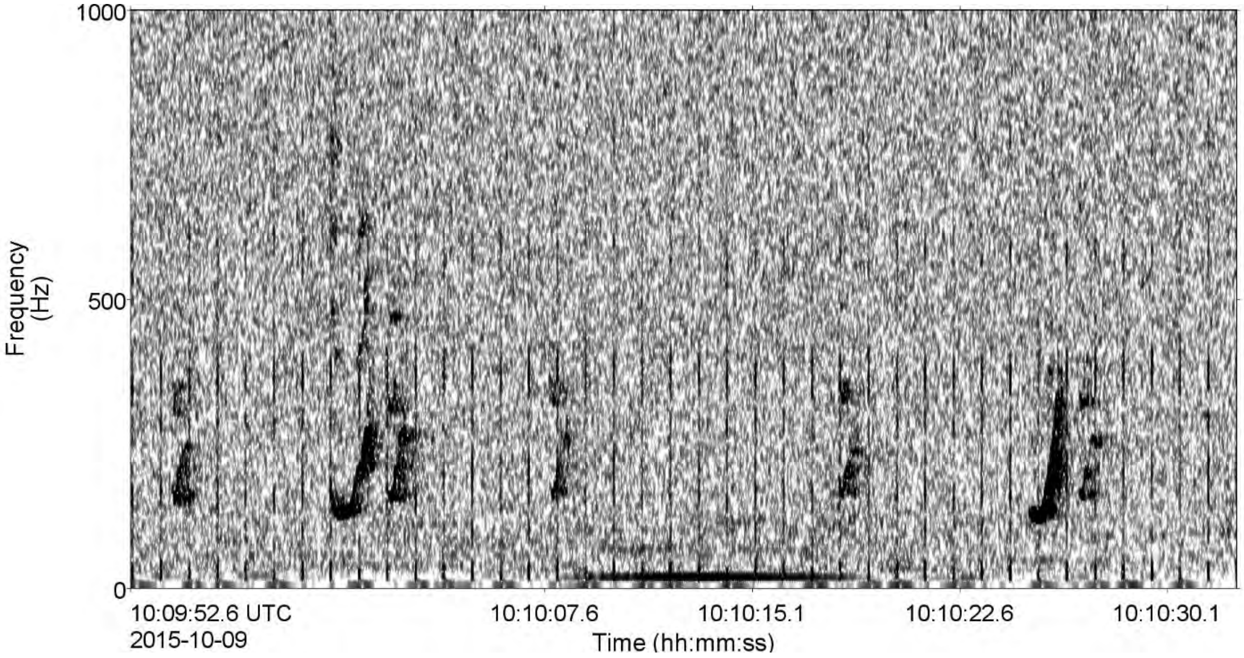


Figure 88. Spectrogram of right whale upcalls recorded at stn 2 on 9 Oct 2015 (2 Hz frequency resolution, 0.128 s time window, 0.032 s time step, Hamming window).

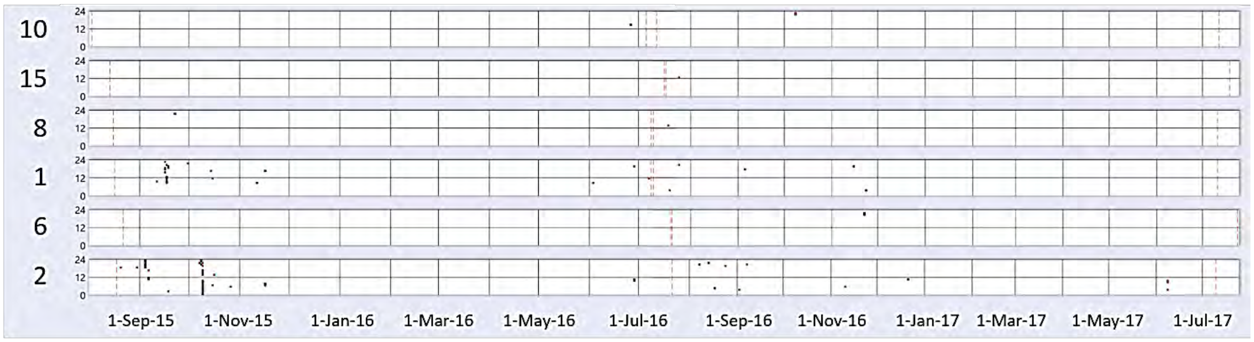


Figure 89. Daily and hourly occurrence of right whale vocalizations manually identified at stn 1 and 2 from 3 Aug to 31 Nov 2015. Stations are ordered from (top) north to (bottom) south. Black dots indicate confirmed right whale acoustic signals. Red dots indicate potential right whale acoustic signals. The red dashed lines indicate AMAR deployment and retrieval dates

3.4.3.6. *Sei Whales*

Low-frequency sei whale downsweeps typically last ~1–2 s, decreasing from ~90–40 Hz (Figure 90) (Baumgartner et al. 2008). They occur in singles, pairs (Figure 90), and triplets. The sei whale detector was systematically triggered by airgun pulses, as well as fin and blue whale broadband downsweeps. These confounding signals were far more numerous than sei whale vocalizations, making the detector's results unusable. Vocalizations were therefore identified by analysts during the manual review process. In addition, we performed a more thorough review of data for stations and periods of interest. One 11-min sound file per hour was reviewed for stn 13 and 15 between mid-August and 30 Nov 2015, 1 May and 30 Nov 2016, and 1 May to mid-July 2017; and also for mid-Aug 2015 to mid-July 2017 at stn 5 (Figure 91).

Sei whale vocalizations occurred at 14 stations (stn 2, 4–7, 13, 15–17, 19, and 20) (Figure 91). In the fall, the species occurred primarily at offshore stations off Labrador (stn 13) and the eastern Grand Banks (stn 15, 17, 19, and 20) (Figure 91). Sei whale vocalizations ceased in late November to early December throughout the area, except at stn 4 and 5 where they continued sporadically in winter. Sei whale manual detections resumed in May at stn 13, 15, and other offshore stations (Figure 91). We believe that a more systematic review of data would reveal similar trends at other stations, particularly stn 16, 17, and 19. With the exception of stn 2, the relative absence of sei whale signals at on-shelf stations suggests a preference of sei whales for deep water of the continental slope.

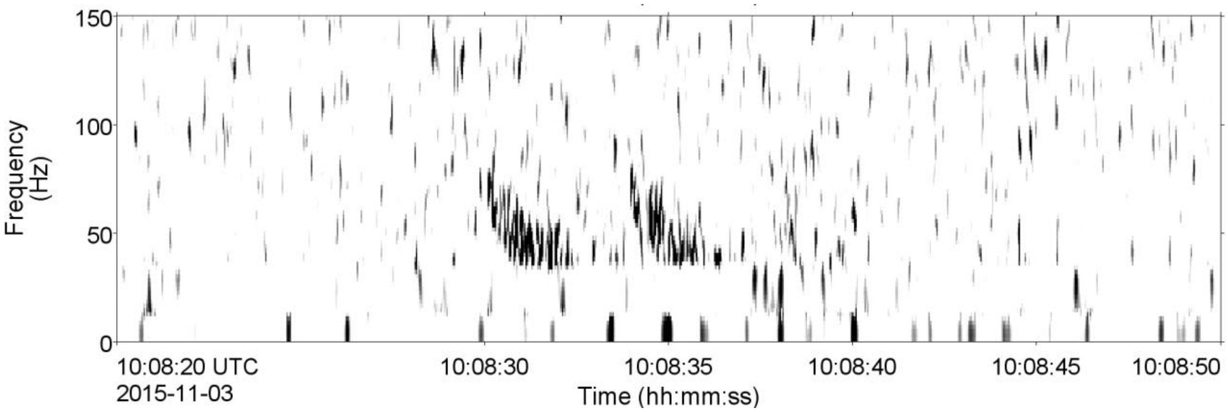


Figure 90. Spectrogram of a sei whale paired downsweep recorded at stn 20 on 3 Nov 2015 (1 Hz frequency resolution, 0.1 s time window, 0.01 s time step, Hamming window).

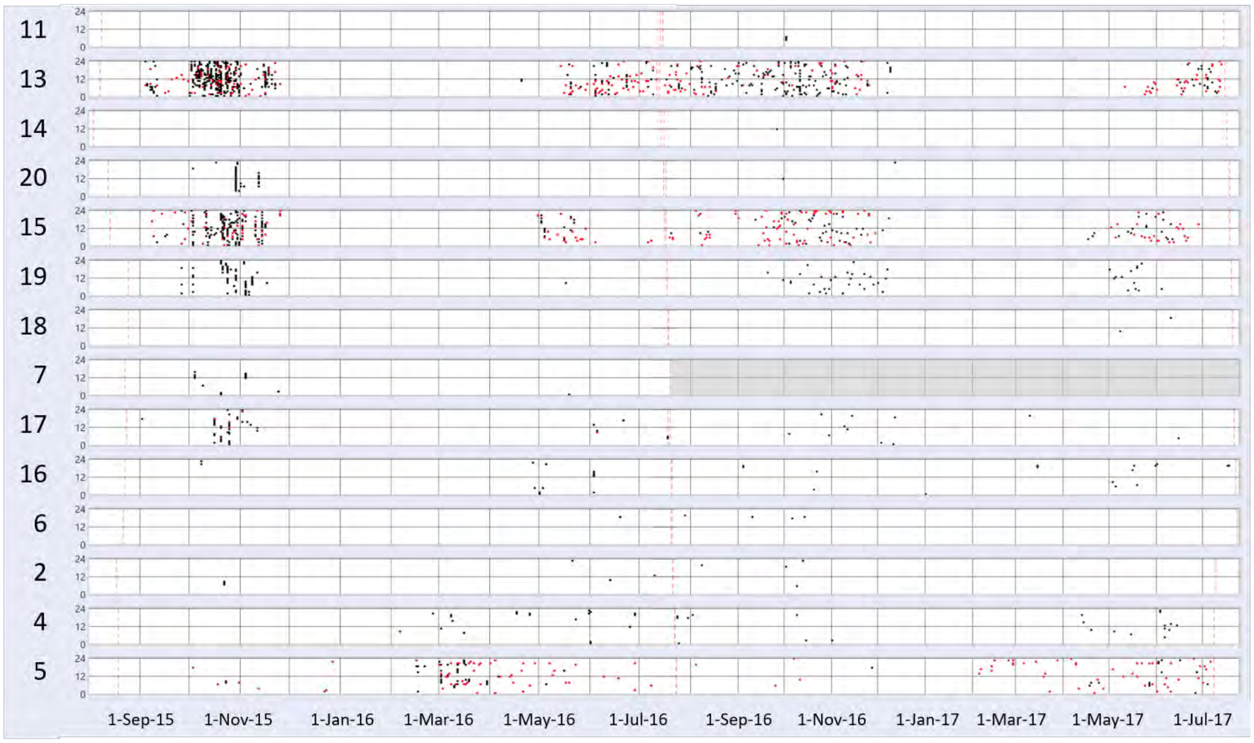


Figure 91. Daily and hourly occurrence of sei whale vocalizations manually detected at stn 2, 4–7, 13, 15–17, 19, and 20 from 3 Aug to 31 Nov 2015. Stations are ordered from (top) north to (bottom) south. Black dots indicate sei whale signals identified during detector validation and red dots indicate sei whale signals identified during additional manual analysis specifically aimed at this species.

3.4.4. Pinnipeds

3.4.4.1. *Atlantic Walruses*

Atlantic walrus vocalizations were identified once on 9 Mar 2016 at stn 12, the northernmost recording location. The vocalizations consisted of knock sequences and bells (Mouy et al. 2012) (Figure 92). This single event is consistent with the low expected occurrence of the species in the study area, stn 12 lying at the southern edge of this species' range in the north Atlantic.

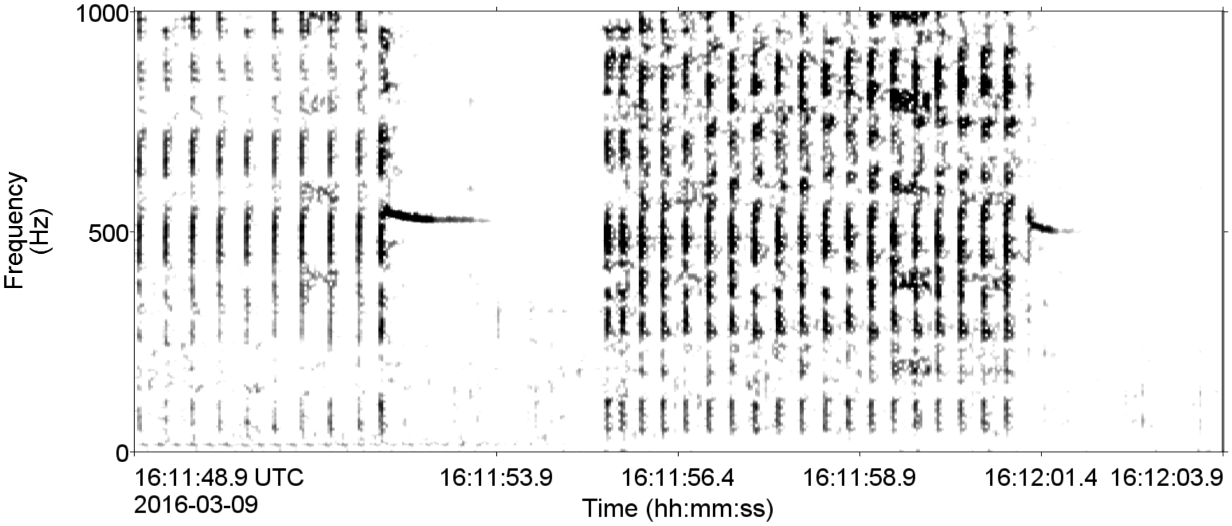


Figure 92 Spectrogram of walrus vocalizations recorded at stn 12 on 9 Mar 2016. (2 Hz frequency resolution, 0.128 s time window, 0.032 s time step, Hamming window). The window length is 30 s.

3.4.4.2. *Bearded Seals*

Bearded seal trills (Figure 93) were detected in winter and spring 2016 and 2017 at the northernmost inshore stations during periods of ice cover (Figures 94 and 95). In both years, detections at stn 10–12 began gradually in late December/early January and increased until trills occurred nearly continuously in the spring. Vocalizations ceased at stn 11 and 12 in early June 2016 and 2017. At the more southern stn 10, vocalizations ceased earlier (17 Apr 2016 and 6 May 2017), with a second pulse of vocalizations in 2017 from 22 May to 4 Jun (Figure 94). Detections at stn 14 were restricted to a short event in April 2016 (Figure 94). Diel vocalization patterns were apparent only during the first half of the detection period at stn 10, 11, and 12 in 2016 and 2017, with vocalizations occurring primarily during hours of darkness (Figure 94).

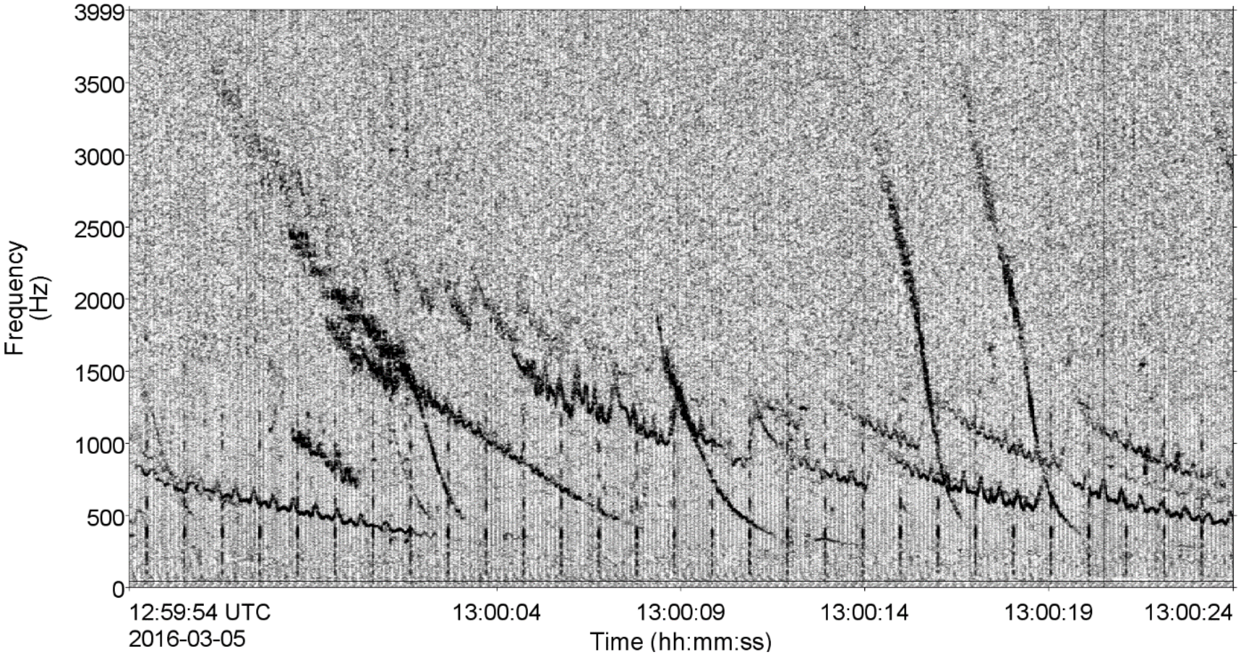


Figure 93. Spectrogram of bearded seal vocalizations recorded at stn 10 on 5 Mar 2016. (2 Hz frequency resolution, 0.128 ms time window, 0.032 ms time step, Hamming window). The window length is 30 s.

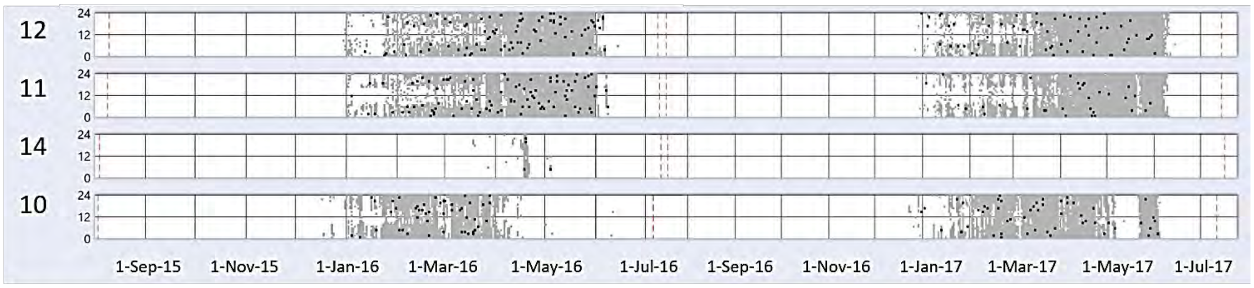


Figure 94. Daily and hourly occurrence of bearded seal vocalizations recorded at stn 10–12 and 14 from Aug 2015 to Jul 2017. Stations are ordered from (top) north to (bottom) south. Grey dots indicate automated detections. Black dots indicate manually validated results. The red dashed lines indicate AMAR deployment and retrieval dates.

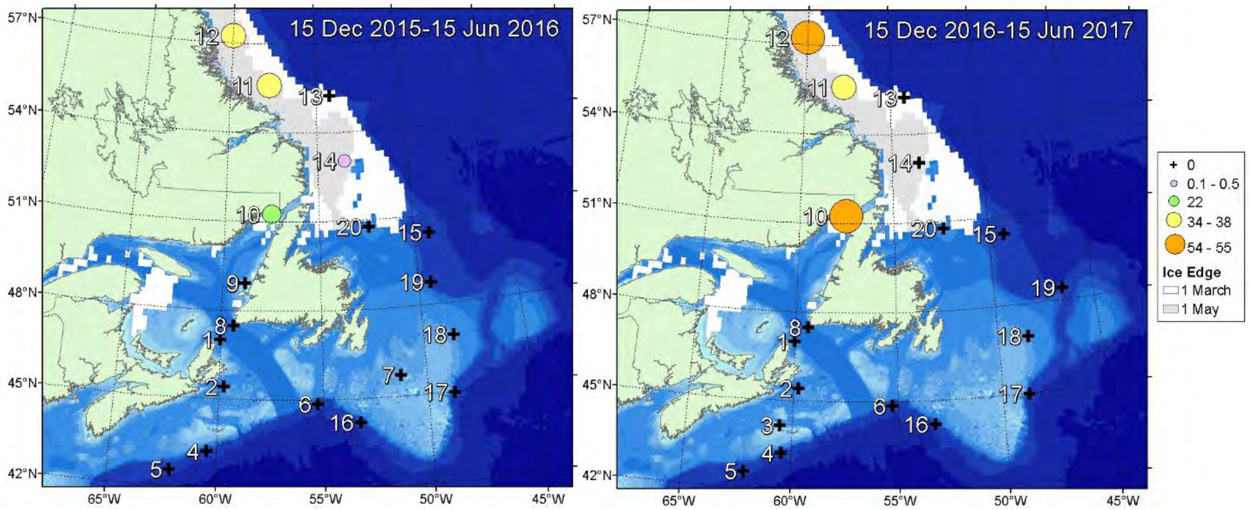


Figure 95. Bearded seal trills: Mean hourly detection count (MHDC) at stations where acoustic data were recorded in 2015–16 (left) and 2016–17 (right). The black square indicates stations where the species was manually identified but the detector accuracy was below the accepted P of 0.75 or unevaluated due to a lack of validated automated detections.

3.4.4.3. *Grey Seals*

While no detectors effectively identified grey seal acoustic signals, winter vocalizations were identified during manual validation at stn 1, 2, and 9 in 2016 and stn 1–3 in 2017 (Figure 96). Most occurred from December to February of both years (Figure 96), which coincides with the grey seal mating season. Grey seal vocalizations were amplitude-modulated growls lasting ~2 s and fundamental frequencies below 100 Hz (Figure 97) (Asselin et al. 1993).

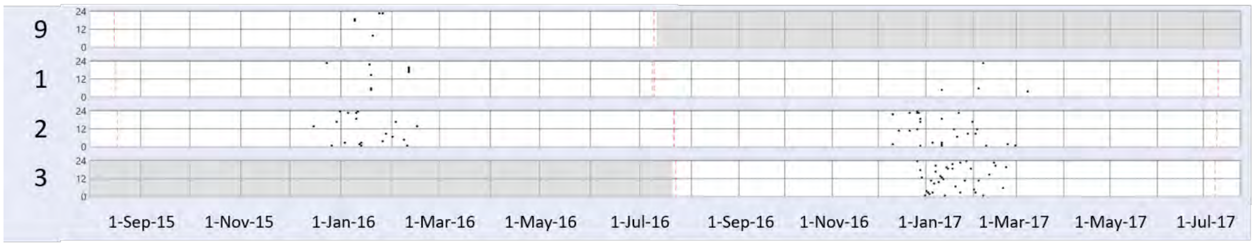


Figure 96. Daily and hourly occurrence of grey seal vocalizations manually detected at stn 1–3 and 9 from Aug 2015 to Jul 2017. Stations are ordered from (top) north to (bottom) south. Grey dots indicate automated detections. Black dots indicate manually validated results. The red dashed lines indicate AMAR deployment and retrieval dates.

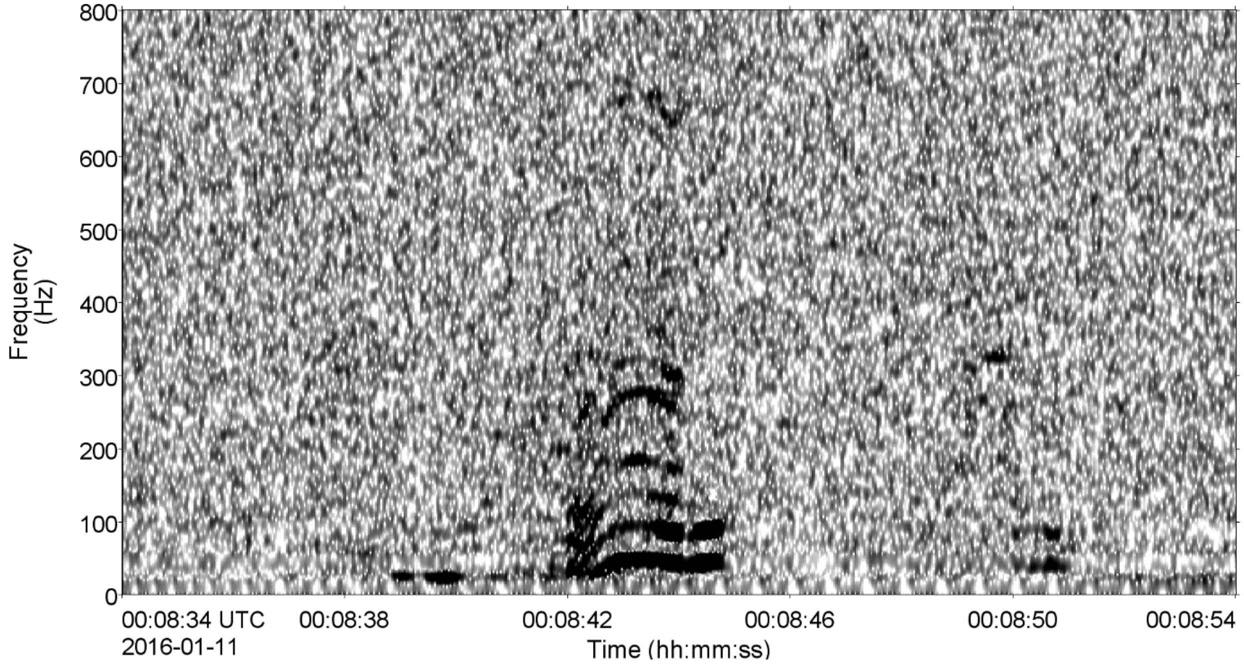


Figure 97. Spectrogram of a grey seal vocalization recorded at stn 2 on11 Jan 2016 (1 Hz frequency resolution, 0.128 s time window, 0.032 s time step, Hamming window). The window length is 20 s.

3.4.4.4. *Harp Seals*

Harp seal vocalizations were identified manually at nine stations. Six were located along the northeastern margin of the Grand Banks and off Labrador (stn 11–14, and 18–20), one was in the Strait of Belle-Isle (stn 10), and one was in the Lawrencian Channel (stn 1)(Figure 98). Most harp seal vocalizations occurred at stn 10, 14, and 20. They were largely concentrated in February and March, although vocalizations occurred at stn 10 as early as November in 2016 (Figure 99). Acoustic signals classified as harp seals were highly diverse (Moors and Terhune 2005). A sample is shown in Figure 99.

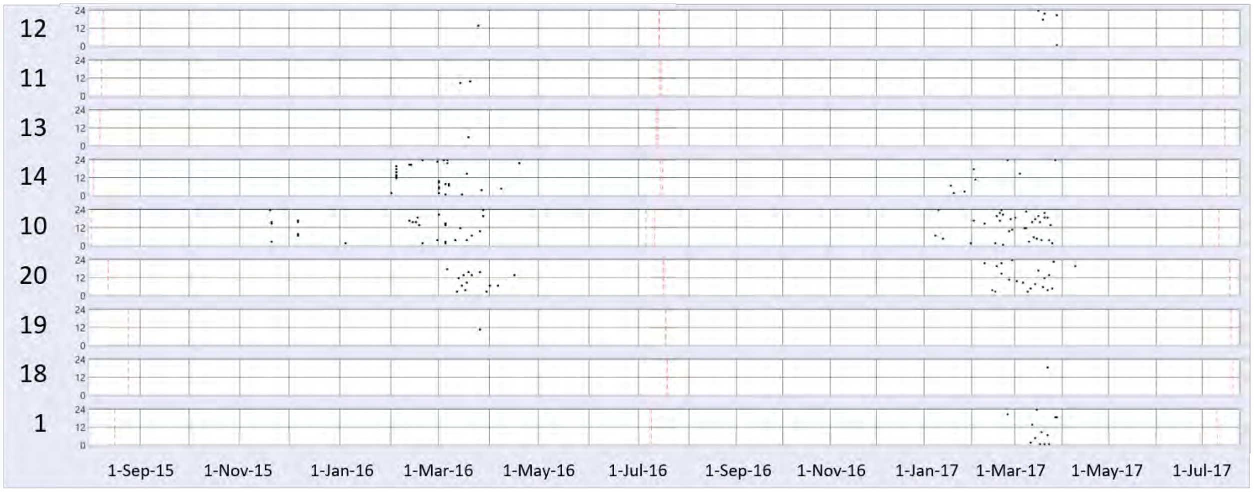


Figure 98. Daily and hourly occurrence of harp seal vocalizations manually detected at stn 1, 10–14, and 18–20 from Aug 2015 to Jul 2017. Stations are ordered from (top) north to (bottom) south. Grey dots indicate automated detections. Black dots indicate manually validated results. The red dashed lines indicate AMAR deployment and retrieval dates.

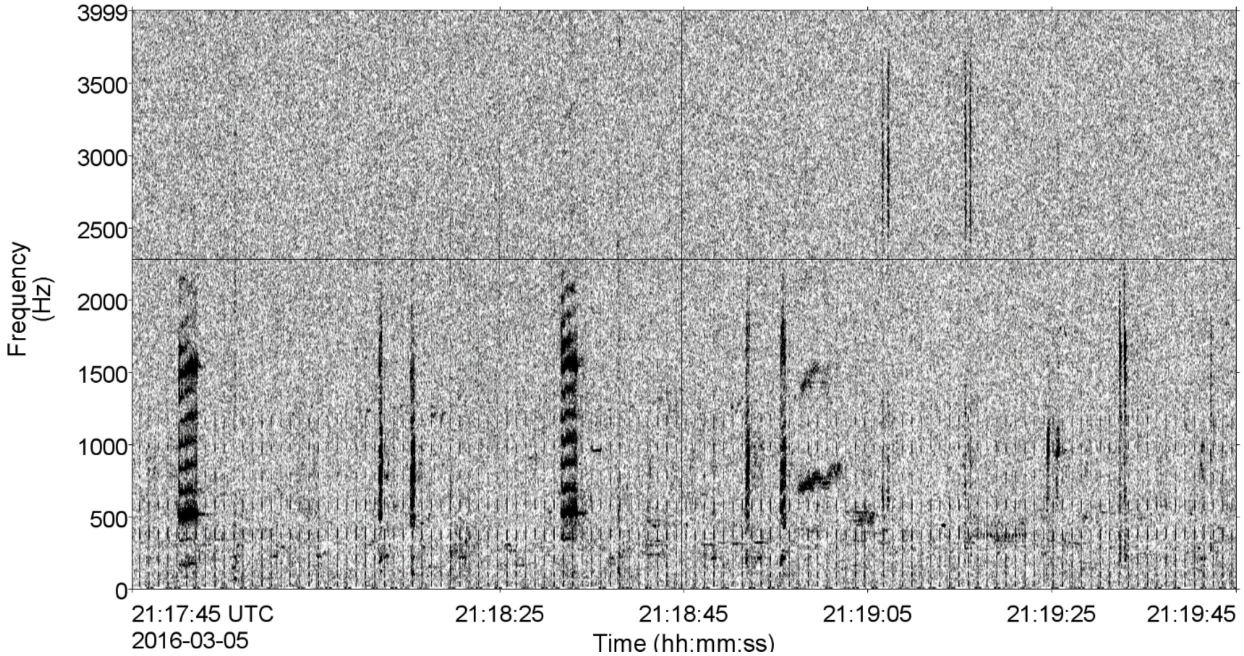


Figure 99. Spectrogram of harp seal vocalizations recorded at stn 14 on 5 Mar 2016. (2 Hz frequency resolution, 0.128 s time window, 0.032 s time step, Hamming window). The window length is 120 s.

3.4.5. Species Diversity

The chosen index of species diversity (monthly species count) revealed several patterns. Diversity was consistently higher at deep stations along the continental slope (Figures 100 and 101; Tables 6 and 7). In addition, species diversity remained relatively consistent throughout the year at these stations while a clear decrease at the northern and inshore stations occurred in winter and spring, tied to the presence of sea ice. The highest monthly species counts were recorded at stn 16 in September and stn 15 in October during year 1 (n = 9); and in December at stn 19 (n = 10) during year 2. Species counts were slightly higher during year 2.

The species count provided here represents minimum estimates. All the *delphininae* species potentially included under the dolphin whistle detections counted as 1, but the number of species of this taxa in Canadian waters decreases with increasing latitude. Similarly, the pygmy sperm whale and one or two unidentified species of beaked whales were not included. Preliminary results indicate that their occurrence is restricted to deep stations off the Scotian shelf and southern Grand Banks. Therefore, the latitudinal gradient in species diversity is presumably steeper than depicted here.

It is worth noting that all areas with consistently high species diversity, such as the extremities of the Flemish Pass, the southern Grand Banks, the Orphan Basin (stn 15), and the continental slope off the Scotian shelf are currently being actively targeted by the oil and gas industry (see Figure 6).

Table 6. Number of acoustically detected species by month and station in 2015–16 (arranged from northern stations at top to southern stations at bottom). August 2015 and July 2016 include recording days between 25–31 Aug and 1–8 Jul, respectively. Both automated and manual detections were included, but duplicate detections of the same species for each month were excluded. Delphinid click detections were excluded to avoid duplicate detections with dolphin, killer whale or pilot whale tonal signal detections. Months with the highest and second highest counts of detected species are shown as green cells.

Station	Aug 2015	Sep 2015	Oct 2015	Nov 2015	Dec 2015	Jan 2016	Feb 2016	Mar 2016	Apr 2016	May 2016	Jun 2016	Jul 2016	Mean
12	2	4	4	3	2	1	1	3	1	2	1	0	2.0
11	3	5	5	2	1	3	1	2	1	1	1	0	2.1
13	3	6	7	7	4	5	3	4	3	5	5	5	4.8
14	6	5	6	6	7	2	1	2	2	2	1	1	3.4
10	4	4	4	3	4	2	2	2	2		1	1	2.6
20	4	6	5	7	4	4	1	1	1	1	1	1	3.0
15	5	8	9	7	7	8	7	5	6	6	4	3	6.3
19	6	6	7	7	6	6	4	5	5	7	5	3	5.6
9	0	3	2	0	1	2	0	0	0	N/A	N/A	N/A	0.9
8	5	6	6	7	7	6	5	5	4	5	3	3	5.2
1	3	7	6	6	7	6	6	6	1	5	4	4	5.1
18	4	6	5	4	5	5	3	4	3	3	4	3	4.1
17	6	7	7	7	7	7	7	8	7	7	8	5	6.9
7	4	6	7	5	5	4	4	2	5	4	3	2	4.3
16	6	9	8	8	8	8	6	7	7	8	8	5	7.3
6	7	8	8	7	8	8	6	6	8	7	8	6	7.3
2	5	5	7	6	6	6	5	2	5	4	5	4	5.0
4	5	7	6	7	8	7	7	7	8	7	8	5	6.8
5	6	6	6	6	7	7	8	7	7	7	5	4	6.3

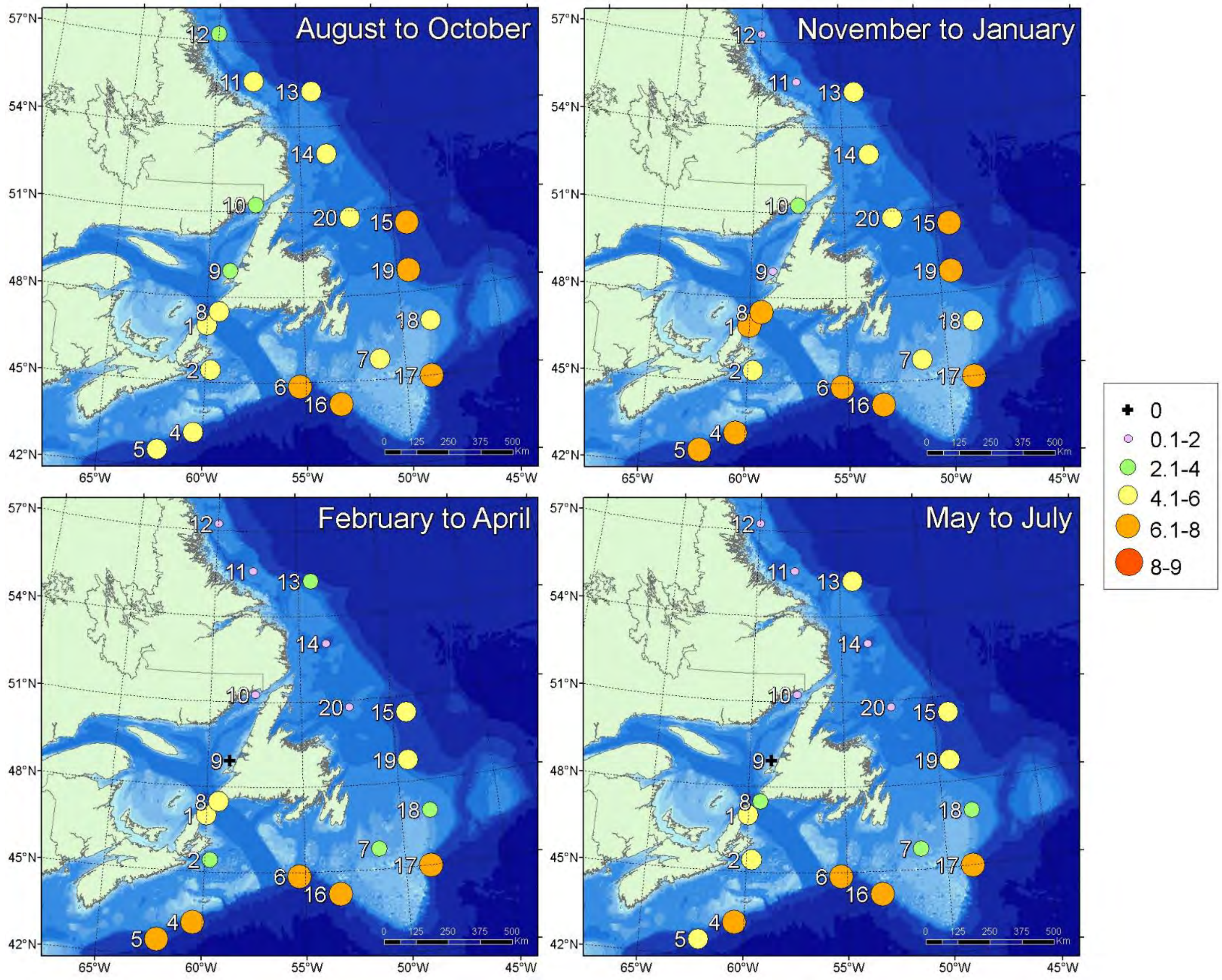


Figure 100. Mean monthly count of manually and automatically detected species by station and periods in 2015–16. Recordings in August were restricted to 25–31 Aug 2015. Recordings in July were restricted to 1–8 July 2016. The AMAR at stn 9 was inactive during the last period. Delphinid click detections were excluded to avoid duplicate detections with dolphin, killer whale or pilot whale tonal call detections.

Table 7. Number of acoustically detected species by month and station in 2016–17. (arranged from northern stations at top to southern stations at bottom). July include recording days from 23–31 Jul 2016 and 1–8 Jul 2017. Both automated and manual detections were included, but duplicate detections of the same species were excluded. Delphinid click detections were excluded to avoid duplicate detections with dolphin, killer whale or pilot whale tonal signal detections. Months with the highest and second highest counts of detected species are shown as green cells.

Station	Aug 2016	Sep 2016	Oct 2016	Nov 2016	Dec 2016	Jan 2017	Feb 2017	Mar 2017	Apr 2017	May 2017	Jun 2017	Jul 2017	Mean
12	4	3	3	2	2	1	1	2	1	1	4	3	2.3
11	3	5	4	5	4	2	1	1	1	1	2	2	2.6
13	7	7	7	8	7	5	4	3	3	5	5	6	5.6
14	6	7	7	5	4	4	1	0	0	1	4	5	4.4
10	4	3	4	3	3	3	2	2	1	2	3	2	2.7
20	5	4	3	5	7	5	3	2	0	4	2	5	4.1
15	9	9	8	9	8	7	6	5	8	8	8	6	7.6
19	6	7	8	9	10	8	7	7	7	8	8	6	7.6
8	6	5	6	8	5	5	5	4	6	5	6	3	5.3
1	5	6	6	6	7	5	4	5	5	5	5	7	5.5
18	5	4	4	5	3	2	3	2	2	3	2	5	3.3
17	7	7	7	8	9	7	8	8	7	7	7	6	7.3
16	7	8	7	8	8	9	6	7	6	7	8	7	7.3
6	8	7	8	9	8	9	8	7	6	7	8	7	7.7
2	7	7	8	5	5	5	5	4	4	5	4	6	5.4
3	5	6	7	6	6	6	4	2	3	2	3	4	4.5
4	9	7	7	8	8	8	8	7	9	6	8	9	7.8
5	6	7	6	7	6	7	8	7	7	6	8	6	6.8

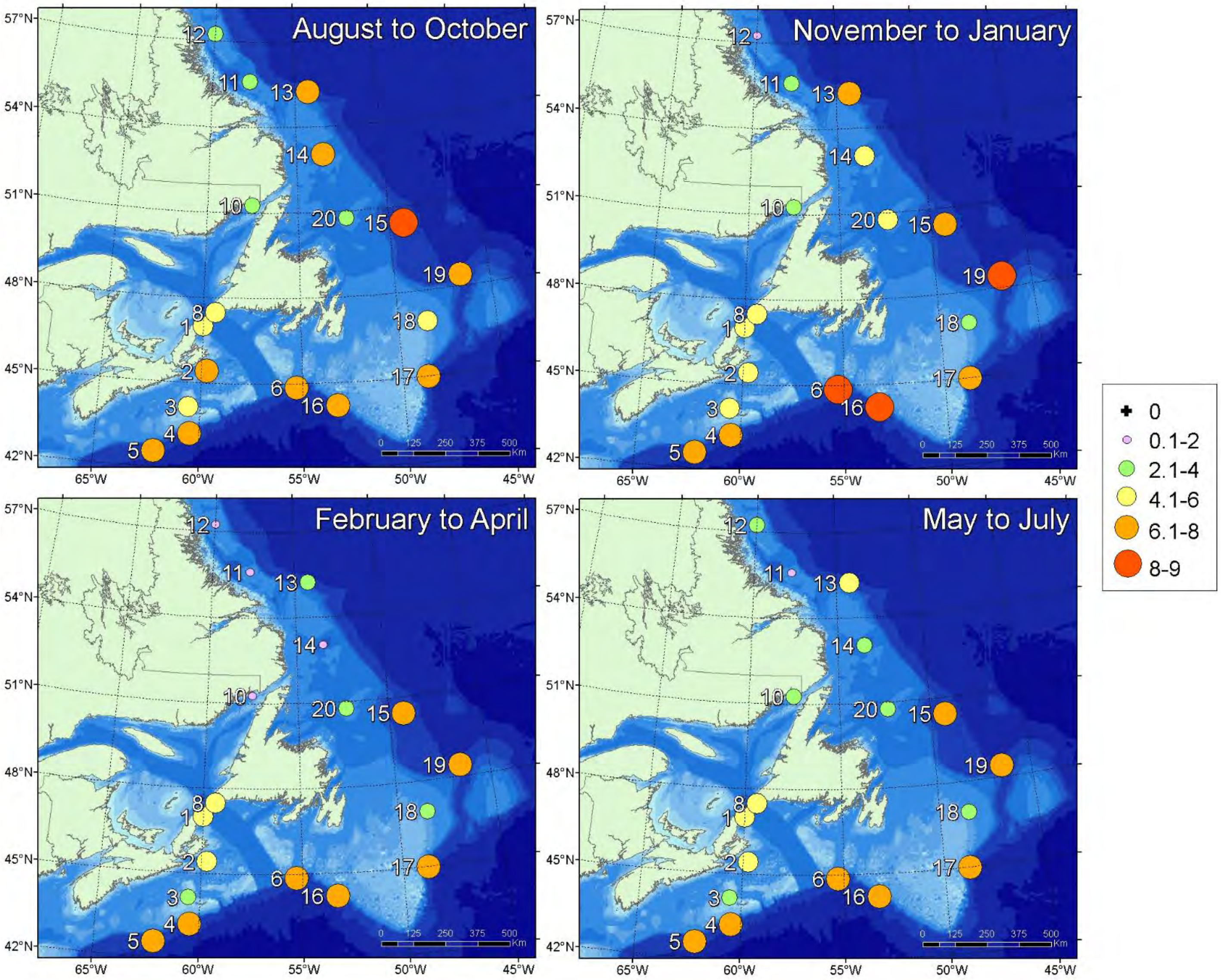


Figure 101. Mean monthly count of manually and automatically detected species by station and periods in 2015–16. July data include recording days from 23–31 Jul 2016 and 1–8 Jul 2017. Delphinid click detections were excluded to avoid duplicate detections with dolphin, killer whale or pilot whale tonal call detections.

4. Discussion and Conclusion

4.1. Ambient Noise, Vessel, and Seismic Survey Measurements

Acoustic levels in the ocean are influenced by sounds produced by wind, waves, ice-cracking events, geological seismic events, biological sources, and human activities. The acoustic levels were assessed at all stations of this study. More detailed analyses of ambient, vessel, and seismic noise were performed on data from the seven stations (deep: stn 4, 5, 15, and 19 and shallow: stn 1, 12, and 18; Section 3.1). The median (L_{50}) power spectrum density (PSD) levels for these stations are plotted together in Figure 102 to facilitate comparisons. An interesting observation is the consistency in sound levels at individual sites between both study years, with the exception of stn 1 below 30 Hz due to higher flow noise. The higher flow noise observed during the second year at stn 1 and several others cannot be assigned to a change in mooring design. Annual variations in current speed may be a factor.

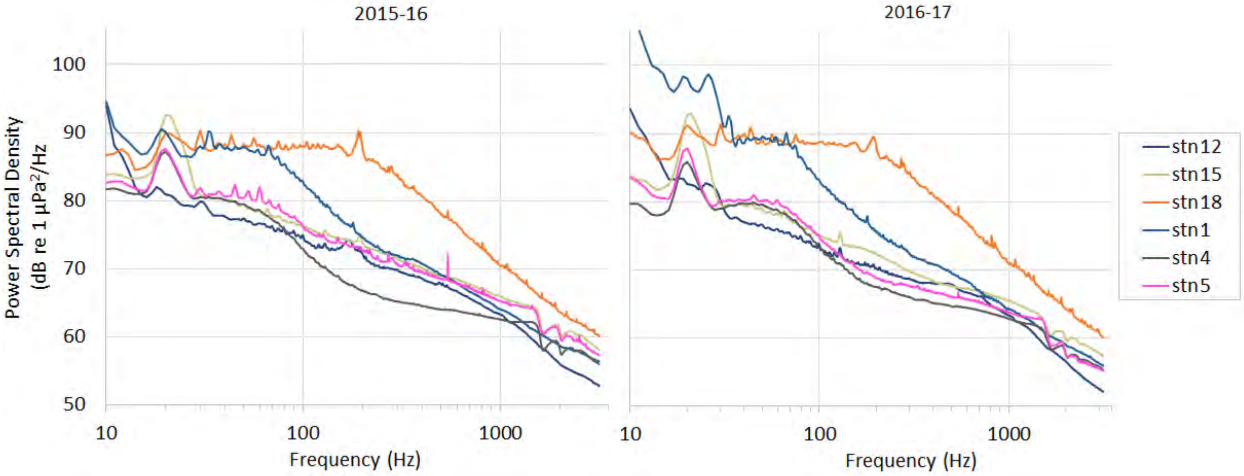


Figure 102. Median 1-min PSD levels for stn 1, 4, 5, 12, 15, and 18 in 2015–16 (left) and 2016–17 (right).

The noise contributions of vessels varied across the area, influenced by the proximity of the station to shipping lanes or to drilling platforms which are often surrounded by support vessels over extended time periods. These support vessels, as well as drill ships, are often in dynamic positioning mode, using thrusters to hold position. Dynamic positioning creates more cavitation than transiting vessels because the thruster propellers are not moving smoothly through the water, hence creating more noise. The contribution of vessels to the soundscape was most noticeable at stn 1 and 8, located near shipping lanes associated with the St. Lawrence Seaway, stn 18 located near the Hibernia platform, and to a lesser extent at stn 5 due to its proximity to the exploratory drilling occurring at the Cheshire well site during the first deployment (Figure 102). Most stations had vessel detections throughout the year, although their contribution to the total sound levels was not always significant. Exceptions include stn 12, 13, 14, 15, and 20, which saw several consecutive months with no or very few vessel detections in winter and early spring, primarily due to the presence of sea ice (Appendix F.3).

It should be noted that low-frequency (< 30 Hz) tonal sounds induced by the vibration of cables joining components of the moorings due to currents resulted in false vessel detections. This was particularly notable at some deep stations in year 2 (stn 16, 19), as well as a few shallower stations (stn 3, 11, and 20 in 2016–17; Appendix F.3). As a result, the contribution of vessels to the daily SEL may have been overestimated, and the total noise levels may have also been inflated during some periods as they include flow and mooring noise that is not acoustic in origin.

The contribution of sounds associated with seismic surveys was significant when surveys were present. This was particularly true at stn 13, 15, and 19 during fall and spring when the daily SEL increased by 20–

25 dB, relative to baseline levels, when the seismic surveys were detected. Stn 15 and 19 were near the sites of the most focused seismic exploration programs during this study. This is noteworthy as these stations otherwise experience comparatively little amount of anthropogenic activities and had the highest species diversity throughout the year. Stn 19 is also the site where northern bottlenose whales were most consistently recorded, highlighting the need for a more thorough assessment of potential effects of seismic activity on this and other species.

Regarding drilling operations, the average broadband SPL in April at stn 5, representing ambient levels in the absence of drilling and fin whale sounds, was 104.0 dB re 1 µPa. The broadband SPL from June, representing levels during drilling activity, without the presence of fin whale 20 Hz vocalizations, was 107.8 dB re 1 µPa. This suggests that the presence of the ICEMAX drillship increased the broadband ambient SPL by 3.8 dB at a distance of 13 km.

The contribution of environmental sounds to the soundscape was brought by weather events and sea ice formation and break-up at the northern stations (e.g. stn 12). Weather events are generally short-lived and did not influence the median levels despite being visible as spikes of elevated broadband noise levels on the spectrograms. Shallow stations (e.g., stn 3 and 9), which were more directly coupled to surf noise, were more strongly affected by weather events. The effects of bottom currents were visible though strum noise resulting from the vibration of cables connecting the different mooring components. This is presumably the cause of the spikes of increased noise near 18 and 35 Hz at stn 11 and 12.

The unusual L_5 PSD levels at stn 9 and 10 in 2015–16 were due to electronic noise artefacts in the recording system and were not representative of the local soundscape.

Marine mammals influenced underwater noise noticeably at some stations. Fin whale song notes (20-Hz notes in particular) are clear in the spectrograms of many stations. These notes increased daily SEL by 20 dB in November and December at stn 14. While the increase was more modest at other stations, an increase in median PSD levels near 20-Hz was observed at most stations where this species was detected. This is mainly driven by three factors: the high vocalization rates of individual singers, which produce a note every 12–15 s in the study area (Delarue et al. 2009b); the relatively large population size of fin whales in Newfoundland waters (n = 2,177; CV = 0.465; estimates uncorrected for visual survey biases (Lawson and Gosselin 2018); and high source levels of song notes (Sirovic et al. 2007). Bearded seal vocalizations were visible on the long-period spectrograms at stn 11 and 12 (Appendix F.1) and would have likely increased median PSD levels between 300 and 2000 Hz if calculated only for the period of peak acoustic activity for that species (April and May). Blue whale A-B vocalizations also appeared in monthly spectrograms (see Figure 76 and Figure 77) and can raise daily PSD levels above ambient at 17 Hz on days of sustained detections.

The median PSD levels are plotted (Figure 103) for the eight recorders in deep water off the continental shelf (Figure 1, Table 11). All of these stations recorded 20 Hz fin whale vocalizations with stn 19 having the highest peak. Stn 5, 15, and 19 show PSD peaks associated with vessel traffic between 30 and 500 Hz. Despite differences in the relative contribution of different noise contributors, the similarity in the median PSD levels between these deep stations was quite remarkable. The greatest difference between stations occurred at 196 Hz, with median PSD levels at stn 4 and 19 at 67 and 77 dB re 1 µPa^2/Hz, respectively. We believe this is the result of a tone produced at the Hibernia platform, as it can be seen more strongly at stn 18 (Figure 102) and is absent at stn 19 in the second year when that recorder was moved to a new location ~ 100 km farther from Hibernia. For most frequencies, most stations are within 5 dB re 1 µPa^2/Hz, which is noteworthy considering that they were distant by as much as 1500 km. This may reflect similar sound propagation environments for recorders located along the continental slope. Stn 19 in year 2 is an exception, but that is attributed mainly to elevated flow noise.

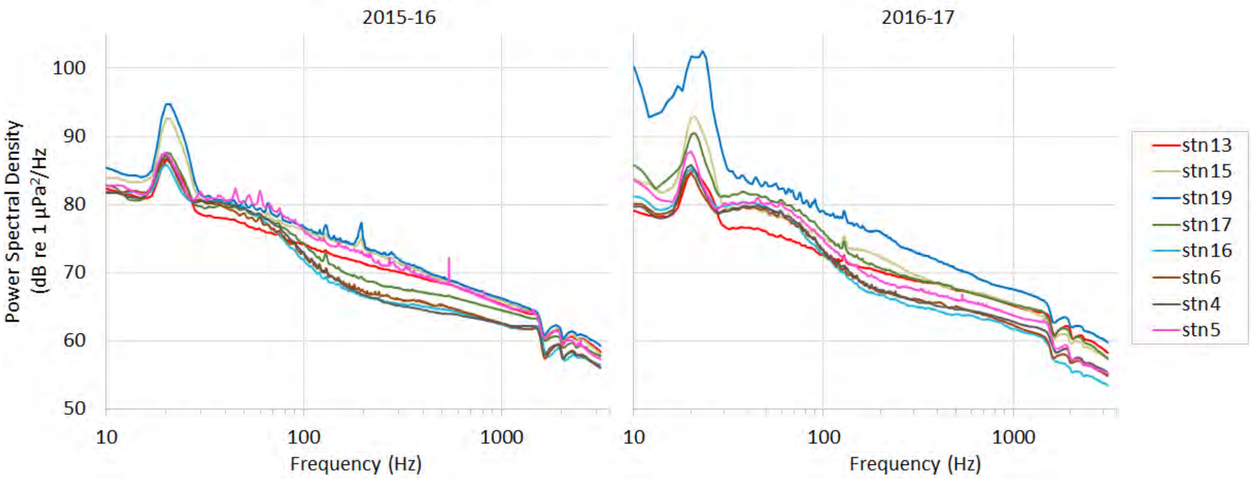


Figure 103. Median 1-min PSD levels for recorders deployed off the continental shelf: stn 4, 5, 6, 13, 14, 16, 17, and 19 in 2015–16 (left) and 2016–17 (right).

4.2. Marine Mammals

The marine mammal acoustic detection results presented in this report provide an index of acoustic occurrence for each species. Although they can be used to describe the relative abundance of a species across the study area, a number of factors influence the detectability of the targeted signals. While acoustic detection does indicate presence, an absence of detections does not necessarily indicate absence of animals; that can be due to lack of vocalizations by individuals near the acoustic recorders, masking of signals by environmental or anthropogenic noise sources, or a combination of these factors. Different sound propagation environments and between seasons will affect the detection range of a given signal over time and therefore influence the number of detected signals. Seasonal variations in calling behaviour may falsely suggest changes in occurrence. Therefore, the acoustic occurrence of each species across stations is discussed in light of environmental, anthropogenic and biological factors influencing the detectability of the targeted acoustic signals.

4.2.1. Odontocetes

4.2.1.1. *Beaked Whales*

Ziphiidae species are difficult to visually differentiate at sea. In contrast, distinct species-specific acoustic signals allow for reliable identification of many species (Baumann-Pickering et al. 2013). Here, northern bottlenose whale, Cuvier's beaked whale, and Sowerby's beaked whale acoustic signals were identified off Atlantic Canada.

Based on the measured source levels of two Ziphiid species, the estimated detection range of Ziphiids is between 2 and 7 km, depending on the species and season (JASCO, unpublished data). Therefore, the beaked whale clicks recorded at each station reflect the occurrence of species in the immediate vicinity of the recorders. The lack of persistent anthropogenic and weather-related contribution to the soundscape at the frequencies used by beaked whales indicates that masking was not a contributing factor to the detection patterns described in this report.

When comparing the acoustic occurrence across species, one needs to consider the effect of duty cycle (see Section 2.1.1) on the probability of detections. Duty cycling and cycle time appear to have limited effects on the assessment of the daily occurrence of Cuvier's beaked whales and northern bottlenose whales, but could result in an underestimation of daily occurrence for *Mesoplodon* species, including Sowerby's beaked whales (Stanistreet et al. 2016).

4.2.1.1.1. Northern Bottlenose Whales

Two northern bottlenose whale populations occur off eastern Canada (Dalebout et al. 2001): an endangered, well-studied population in the Gully and adjacent canyons (Whitehead et al. 1997, Gowans et al. 2000, Wimmer and Whitehead 2004) and a larger, unstudied population off the northeast Grand Banks, Labrador, and in the Davis Strait. The boundary between these two populations, or whether there may be more than two populations, is unclear (Dalebout et al. 2001). The current results remain inconclusive regarding the possible boundary between the two putative Canadian populations. Northern bottlenose whale detections at stations along the southern and southeastern edge of the Grand Banks occurred relatively evenly throughout the year and do not suggest a discontinuity in habitat use between the Scotian shelf and continental slope areas off Newfoundland and Labrador.

A notable finding from this study was the year-round presence of northern bottlenose whales along the shelf break, particularly north of the Flemish Cape (stn 19) and off the southern Labrador coast (stn 13). Deep stations along the Scotian Shelf, despite their proximity to the Gully Canyon resident population, had no or very few detections. Comparing our findings to those from the Gully (recorded by DFO using the same acoustic recorders during the same period) where a resident northern bottlenose whale population of known size concentrates, should allow us to assess the relative use of our sites by this species. A preliminary assessment indicates that the detection rates in the Gully Canyon were substantially higher than at stn 13 and 19, the two stations in this study with the highest number of detections (JASCO, unpublished data).

Another important finding is the pronounced overlap between northern bottlenose habitat and areas of active seismic exploration in 2015 and 2016, particularly north of the Flemish Pass, near stn 19. A better understanding of the potential effects of seismic survey sounds on high-frequency specialists such as beaked whales is required to fully assess the importance of extended exposures to seismic surveys.

4.2.1.1.2. Cuvier's Beaked Whales

The year-round acoustic occurrence of Cuvier's beaked whales along the Scotian Shelf and southern Grand Banks and their seasonal presence around the Flemish Pass and farther north is interesting, considering the scarcity of sightings and strandings in eastern Canadian waters (Whitehead 2013, NOAA Fisheries 2018). Our acoustic results either indicate a recent range expansion into Canadian waters or, more likely, reflect the limitations of other survey methods to track this species, possibly combined with a low population size. Nova Scotia is believed to be at the northern edge of the range of Cuvier's beaked whales (Macleod et al. 2005). An eastern seaboard-wide study showed acoustic detections to be most common off Cape Hatteras and decreasing in regularity farther north (Stanistreet et al. 2017). Our results were consistent with this latitudinal trend since detection rates were highest off the Scotian Shelf and decreased farther north. They also indicate that the range of the species extends north of the Flemish Cap in the northwest Atlantic.

4.2.1.1.3. Sowerby's Beaked Whales

The occurrence of Sowerby's beaked whales in the study region was expected, as they are regularly sighted in summer on the Scotian Slope (Hooker and Baird 1999, Whitehead 2013). Known as the most northerly of the *Mesoplodon* in the North Atlantic, they have been reported off Labrador in the past and occur as far north as the Norwegian Sea in the eastern Atlantic (Macleod 2000). It is therefore interesting to find Sowerby's beaked whales no farther north than Cuvier's beaked whales. In fact, the acoustic occurrence of Sowerby's beaked whales largely parallels that of Cuvier's beaked whales, with a similar negative latitudinal trend in detections. However, Cuvier's beaked whale clicks were common at the southernmost station (stn 5) whereas Sowerby's were rare, possibly due to differences in habitat suitability related to bathymetry (e.g., distance to the shelf break, continental slope gradient). It is possible that the acoustic occurrence of Sowerby's beaked whales is underestimated relative to that of Cuvier's beaked whales because of different effects of duty-cycled recordings on the detection of each species (Stanistreet et al. 2016).

4.2.1.1.4. *Other Beaked Whales*

Three other beaked whale species possibly occur in Canadian waters. Blainville's beaked whales were sighted once in the Gully (DFO, unpublished data) and stranded in Nova Scotia twice (Mead 1989). As the most common *Mesoplodon* species in eastern U.S. waters, Gervais' beaked whale range is thought to extend into Canadian waters (Jefferson et al. 2008), though they have yet to be sighted and strandings have only occurred as far north as Cape Cod (Waring et al. 2015). Two recent True's beaked whale strandings occurred in the Gulf of St. Lawrence and on the south coast of Newfoundland[1], indicating that this species can occur in Canadian waters. A more southerly distribution is usually assumed for this species, but that assumption is based on a limited number of sightings (Jefferson et al. 2008).

The echolocation signals of Blainville's and Gervais' beaked whales are relatively well described (Johnson et al. 2006, Gillespie et al. 2009). True's beaked whale signals have been recorded, but their description has yet to be published (A. Izzy, personal communication). JASCO's click detector is currently not configured to identify the signals of these three species and their presence in the study area remains uncertain. However, distinct beaked whale signals that differ from those of northern bottlenose whale, Cuvier's beaked whale, and Sowerby's beaked whale were detected manually during the detection validation process. On the basis of their spectral characteristics and inter-click interval (ICI), we suggest that Gervais' and/or True's beaked whale may also be present near several deep stations but predominantly off the Scotian Shelf and southern Grand Banks (stn 4, 5, 6, and 16). Once the detector has been developed to include these species, the data recorded during this study should be re-evaluated to assess their occurrence[3].

4.2.1.2. *Dolphins*

Dolphins were the only species group to be acoustically detected at every recorder location, likely reflecting that multiple species accounted for these detections and that their combined range covers the entire study area.

The white-beaked dolphin is the northernmost species included in this group (Mercer 1973). Their habitat is characterized by shallow depth and low water temperatures (MacLeod et al. 2007). In eastern Canadian waters, they have been observed in winter and spring off Newfoundland and in summer off Labrador (Mercer 1973, Reeves et al. 1998). They are regularly observed in summer in the Strait of Belle Isle (Kingsley and Reeves 1998). White-beaked dolphins were the most abundant dolphin species recorded in the Newfoundland-Labrador strata during the 2007 TNASS aerial surveys (Lawson and Gosselin 2011) and were the most abundant cetacean seen in all of Atlantic Canada during the 2016 NAISS survey (Lawson and Gosselin 2018). They are likely responsible for a large proportion of detections across all stations.

Atlantic white-sided dolphins are known to occur across the entire study region (Mercer 1973), with the possible exception of the northernmost station (stn 12). They are commonly recorded in the Gully submarine canyon (Gowans and Whitehead 1995) just north of stn 4 and 5. Their presence is also well known in nearshore areas, e.g., around Cape Breton (near stn 1, 2, and 8) (Kingsley and Reeves 1998) and Newfoundland (e.g., stn 8 and 10 regions; Sergeant and Fisher 1957). The northern limit of their range is presumably linked to that of white-beaked dolphins. Indeed, the parapatric summer distribution of white-beaked and white-sided dolphins observed in the Gulf of St. Lawrence (Kingsley and Reeves 1998) may apply more broadly. As white-beaked dolphins retract to the northern part of the study area, tracking the movement of colder waters, white-sided dolphin likely expand their range to the north in summer. Their abundance was second to that of white-beaked dolphins and common dolphins in the Newfoundland-Labrador and Scotian shelf-Gulf of St. Lawrence strata of the 2007 TNASS surveys, respectively (Lawson and Gosselin 2011).

Short-beaked common dolphins prefer warmer, more saline waters than Atlantic white-sided dolphins and tend to be associated with the edge of the continental shelf (Selzer and Payne 1988, Gowans and Whitehead 1995). However, areas of prey abundance often result in distribution overlaps between both

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[3] https://baleinesendirect.org/en/extremely-rare-beaked-whale-species-stranded-in-magdalen-islands/

species. Off eastern Canada, they occur mostly in summer and fall in slope waters of the Scotian Shelf and southern Newfoundland, as well as near prominent bathymetric features such as the Flemish Cape (Jefferson et al. 2009). They are generally associated with water temperatures greater than 11°C. Previous studies found that common and white-sided dolphins partition their use of the Gully Canyon temporally rather than geographically (Gowans and Whitehead 1995), which likely reflects different sea surface temperature preferences. This tendency may apply to the area as a whole. Common dolphins were by far the most common dolphins sighted in the Scotian Shelf-Gulf of St. Lawrence strata during the 2007 TNASS surveys (Lawson and Gosselin 2011).

The status of striped dolphins in Canada was reviewed by Baird et al. (1993), who concluded that Canada lies at the northern edge of their range. The majority of sighting records in eastern Canada are located in and around the Gully Canyon, usually when surface temperature exceeds 15 °C (Baird et al. 1993, Whitehead 2013). Their presence, and therefore acoustic occurrence, is expected to be limited to summer at the southern offshore stations.

Bottlenose dolphins are rare in eastern Canada. Like the common and striped dolphins, they generally prefer warmer areas. The northernmost record in the western north Atlantic is of a single individual trapped in a tributary to the Bay of Fundy in 1950 (Sergeant and Fisher 1957). The only recent records are sightings from the Gully Canyon (Hooker et al. 1999, Whitehead 2013) and one in Cape Breton (K. Kowarski, pers. comm.). Bottlenose dolphin acoustic signals may have therefore contributed a small portion of our acoustic detections at the southernmost stations (stn 4 and 5).

Risso's dolphins are similarly rare in the study area. A few sightings have occurred off the Scotian Shelf near Haldimand Canyon in summer (Whitehead 2013; JASCO unpublished data). This species inhabits deep oceanic and continental slope waters. Their relative contribution to the dolphin acoustic detections is unknown but likely limited.

The decrease in dolphin detections with increasing latitude during winter and spring reflects the southward shift in distribution by some species and a departure from the study area by others during these periods. Nevertheless, the continuous acoustic occurrence of dolphin signals off the Scotian Shelf and southern Grand Banks indicates that these areas provide suitable habitat for some species year-round. In summer, detection hot spots likely resulted from the overlap between favourable oceanographic conditions, the associated local productivity and prey availability, and the habitat preference and abundance of local species. Stations near the Flemish Pass and along the Scotian Shelf and southern Grand Banks appear to combine these conditions most consistently.

Click detections followed a distinct diel pattern at some stations (e.g., stn 4, 5, and 14) and not others (e.g., stn 1 and 8). Where a diel detection pattern was observed, detections occurred almost exclusively at night which possibly reflects the night-time foraging of dolphins that take advantage of the diel vertical migration of their prey species (Au et al. 2013). The lack of a clear diel pattern at several stations may indicate day-time foraging on other prey types.

4.2.1.3. *Killer Whales*

Killer whales occur predictably in some parts of the study area, predominantly nearshore around the eastern and northern Newfoundland coast and the southern Labrador coast (Lawson and Stevens 2013), although this may be at least partly the result of observer effort. Indeed, a group of eight killer whales was observed in the Flemish Pass (250 nmi offshore) during the acoustic recorder retrieval cruise in July 2016 on the only day with good visibility conditions. Our acoustic detections are, however, consistent with historical distribution patterns: stn 10 in the Strait of Belle-Isle yielded the highest number of detections, followed by stn 11, off the southern Labrador coast.

As expected, the number of killer whale detections was low. The killer whale population off the Canadian east coast is likely small. Lawson and Stevens (2013) identified a minimum of 67 uniquely marked killer whales, but recognized that this was an underestimate. In addition, with the exception of the recorder at stn 10, we had no recorders in nearshore areas that have yielded the most sightings to date. Finally, although the prey preferences of killer whales in eastern Canada is unknown and whether prey specialization even exists here is unclear, there is evidence that some killer whales forage on marine mammals (Lawson and Stevens 2013). Mammal-eating killer whales in the north Pacific tend to be more acoustically cryptic than their fish-eating counterparts (Barrett-Lennard et al. 1996). The acoustic foraging behaviour of killer whales off eastern Canada should therefore be considered when assessing the acoustic occurrence of that species. Our results nevertheless validated the sporadic occurrence of killer whales in offshore waters.

Killer whales produce vocalizations similar to pilot whales, and some killer whale vocalizations may indeed have been included in the pilot whale detection records. However, the spatial and temporal spread of pilot whale detections is such that an attempt at separating killer whale detections was beyond the analytical scope of this project. In addition, the spatial overlap between these two species is likely limited, pilot whales preferring deep, continental slope waters whereas killer whales seem to be more common on the continental shelf. The limited manual review effort (0.5% of the data) indicates that the acoustic detections presented in this report provide a conservative picture of their range in eastern Canadian waters.

4.2.1.4. *Pilot Whales*

The range of pilot whales extends in the western north Atlantic from the United States to Greenland (Abend and Smith 1999). Gowans and Whitehead (1995) reported them on the Scotian Slope, and (Sergeant 1962) reported them in Newfoundland waters. The 2007 TNASS surveys estimated the population size for the Scotian Shelf-Gulf of St. Lawrence strata at ~16,000 individuals (Lawson and Gosselin 2011). Pilot whales also occur consistently from summer to late fall off western Cape Breton (Nemiroff and Whitehead 2009, Kowarski et al. 2014), a preferred area that is reflected in the present results. Pilot whales are thought to migrate south toward the Carolinas in winter (Gowans and Whitehead 1995). Here, we have found that while this species does appear to move southward in winter, at least a portion of the population remains in Canadian waters in areas where access is not restricted by ice cover. Acoustic detections were more focused at stations along the continental slope, a known preferred habitat where pilot whales (Payne and Heinemann 1993) forage on long-finned squid (*Lollgo pealei*), among other species (Gannon et al. 1997, Aguilar Soto et al. 2009). The detection period observed in both years on the eastern Scotian shelf (stn 2) in the spring may also be associated with the predictable presence of their prey.

4.2.1.5. *Porpoise*

The harbour porpoise is known to occur across the entire study area (Mercer 1973, Gaskin 1992, COSEWIC 2006). They have been observed in deep water off Labrador and in the Gully Canyon (Whitehead 2013), but they generally prefer shallow coastal waters (Marubini et al. 2009). They are abundant in the Gulf of St. Lawrence and on the Scotian Shelf (Kingsley and Reeves 1998, Lawson and Gosselin 2011) and have similarly been reported around Newfoundland (Sergeant and Fisher 1957, Westgate et al. 1997). The harbour porpoise detections presented here likely include signals from two of the three sub-populations proposed by Palka et al. (1996), namely the Gulf of St. Lawrence sub-population and the eastern Newfoundland and Labrador sub-population. We noted a strong seasonal shift in the spatial distribution of detections: detections were most common at northern stations between August and November but almost exclusively restricted to waters surrounding Cape Breton for the rest of the recording period. This presumably reflects seasonal movements of individuals in response to sea ice and changes in water temperature. It also highlights the potential importance of the shelf areas around Nova Scotia for that species. However, several prime areas for harbour porpoises such as the Bay of Fundy and the Gulf of St Lawrence were not sampled during this study, so the relative importance of our recording areas relative to these remains unclear. Because of the short detection ranges for this species' acoustic signals, even small detection counts may represent high density of animals.

4.2.1.6. *Sperm Whales*

Sperm whales are widely distributed in the Atlantic Ocean, including the present study region. In eastern Canada, they prefer areas near the continental slope although they have been occasionally encountered in shallow areas of the Scotian Shelf (Whitehead et al. 1992). Sperm whales in eastern Canadian waters appear to be exclusively males, with the possible exceptions of areas near the US-Canada border (Reeves and Whitehead 1997). Females remain at lower latitudes year-round, while males migrate between higher latitudes feeding grounds in the summer and lower latitude to breed in winter (Whitehead 2002). The decline in detections observed at most stations in winter and spring may be related to this migratory behaviour. Nevertheless, detections at stn 17 continued year-long. The change in location of stn 19 in the second year to the northern entrance of the Flemish Pass could explain the disappearance of the seasonal detection pattern in 2016–17, paralleling the trend seen at stn 17. This highlights the potential importance of the Flemish Pass as a year-round habitat for sperm whales. Similar to northern bottlenose whales, it calls for an investigation into the potential effects of seismic airgun sounds on sperm whales in this area of extended spatio-temporal overlap. Studies conducted to date on the reactions of sperm whales to seismic survey sounds range from no detectable reaction to distant (>20 km) or close (<2 km) surveys (Madsen et al. 2002, Stone and Tasker 2006), to subtle changes in foraging behavior (Miller et al. 2009), with unknown effects on the long-term fitness of the whales.

4.2.2. Mysticetes

4.2.2.1. *Blue Whales*

The fall and winter acoustic detections of blue whales span from offshore Labrador (stn 13) to the southern Scotian Slope (stn 5) and almost every recorder location in between. These findings greatly expand our current understanding of the seasonal distribution of this species off eastern Canada. Besides localized, well-studied, summer concentrations, such as the Gulf of St. Lawrence (Sears and Calambokidis 2002), the distribution and movements of endangered blue whales off Atlantic Canada and in the north Atlantic in general remain poorly understood (Reeves et al. 2004). A recent satellite telemetry study revealed migratory movements from the Gulf of St. Lawrence to the mid-Atlantic region via the Scotian Shelf and the New England Seamounts (Lesage et al. 2017). All stations along the Laurentian Channel (stn 1, 2, 6, 8, and 16) had nearly continuous blue whale detections into January and these extended into March in the Cabot Strait in both years, and on the eastern Scotian shelf in the second year. While the Gulf of St. Lawrence is considered to be a prime feeding ground for that species, persistent song detections throughout the winter suggest that some individuals use these areas not only as migration corridors to and from the Gulf of St. Lawrence, but also as foraging, and potentially breeding, grounds. The Cabot Strait experiences high levels of vessel traffic and increased background noise as a result. Therefore, vocalizations of blue whales in this area may, at times, have been masked, and detections may be underestimated compared to stations less directly affected by vessel traffic such as those on the southern edge of the Grand Banks.

The sustained presence of blue whales signals at deep water stations off the eastern Grand Banks between November and February (see Section 3.4.3.1) is noteworthy. The low levels of these signals suggests distant sources, but their origin is unclear. Tagged blue whales have been shown to forage in winter at offshore seamounts off the Scotian Shelf (Lesage et al. 2017). The detections south of the Gully submarine canyon (stn 4 and 5) were sparse, which suggests that blue whales use these areas as migratory corridors (Lesage et al. 2017). The sporadic acoustic occurrence of blue whales on the Scotian Slope (stn 4 and 5) presented here is consistent with the occasional blue whale sightings by Whitehead (2013) in the Gully Canyon, despite regular survey effort. It is, however, lower than that recorded at stations deployed in the Gully and two other cayons farther east (Rubin 2016), which may reflect their greater proximity to the Laurentian Channel.

The lack of detections past January at the northern stations is likely associated with blue whales' departure from these areas. In most areas of the North Atlantic, peak song detections occur in December and January, with a sharp decline in February and March (Charif and Clark 2000, Clark and Gagnon

2002, Nieukirk et al. 2004). Our results also indicate that song production can be expected until the end of March in Canadian waters. In the Cabot Strait, the lack of song detections past March reflects a change in acoustic behaviour, namely the end of song production by males, since the occasional detections of non-song signals indicate continued presence. Because of the difficulty to detect blue whale non-song signals automatically, a systematic, manual review of acoustic data is necessary to reliably evaluate blue whale acoustic occurrence when songs are not produced (from April to August).

4.2.2.2. *Fin Whales*

Fin whales were by far the most commonly-detected mysticete. Their calling behaviour, namely the production of loud sequences of low-frequency notes (~20 Hz) repeated every 9–15 s for hours at a time (Watkins et al. 1987), translates into a high detection probability. Year-round detections indicate that fin whales remain in Canadian waters year long, only displaced from the northern parts of the study area by sea ice. The sharp decline in detections past April reflects the end of song production by males. It translates into a decline in detection probability as fin whales switch from high calling rates associated with song production to sporadic bouts of calling involving more diverse, less reliably detected broadband downsweeps (Watkins 1981).

Detection rates suggest that the outer shelf regions of the Grand Banks (stn 7 and 18) and Scotian shelf are important areas for fin whales in fall and winter. However, the increase in PSD levels at 20-Hz referenced to levels at 15 Hz provides a different picture. The largest increases (up to 25 dB) were observed at stations off the northern Grand Banks (stn 14 and 20) in year 1. In contrast, a deviation is only noticeable in the highest percentiles at stn 7, which saw the highest mean hourly detection count in year 1. This suggests that detection rates in fin whales should not be interpreted without an understanding of the amount of acoustic energy associated with fin whale notes, which is related to the number of singers and the detection range around a recorder.

4.2.2.3. *Humpback Whales*

Humpback whales were detected seasonally across almost all stations over the full north-south extent of the study. Humpback presence in northern areas was more limited than in the south, likely reflecting habitat accessibility restrictions due to sea ice in winter and spring. The reduced occurrence or absence of humpback whales in winter through early spring is consistent with a departure from the study area when the majority of animals leave their northern summer feeding grounds (Katona and Beard 1990, Smith et al. 1999) and migrate to their breeding grounds in the West Indies (Whitehead and Moore 1982, Martin et al. 1984, Palsbøll et al. 1997). The sporadic humpback acoustic presence in Canadian waters throughout the winter/spring supports previous research showing that not all individuals undertake the large-scale migration (Clapham et al. 1993, Vu et al. 2012, Stanistreet et al. 2013, Kowarski et al. 2018).

Our results highlight areas that may be important to humpback whales in eastern Canadian waters. Several stations, both inshore and offshore, showed distinct detection peaks in winter and spring, most likely representing transit by migrating animals. Others, such as in the Strait of Belle-Isle, had temporal detection patterns more consistent with use as a feeding ground. Considering all stations collectively, humpback whales were present throughout the year in at least one of the recording locations, but the occurrence of the species declines is at its lowest in February and March.

Humpback whales are typically described as having two predominant calling behaviours. The first is the song (Payne and McVay 1971) produced by males (Herman et al. 2013) on southern breeding grounds. Here, songs were observed in fall, winter, and spring, which supports emerging literature that humpbacks sing not only on the breeding grounds, but also on feeding grounds before and during migration (Clapham and Mattila 1990, Charif et al. 2001, Clark and Clapham 2004). Whether this is indicative of mating behaviour in Canadian waters is yet unknown (Stimpert et al. 2012). The second predominant humpback whale call behaviour includes the less structured calls described on summer feeding grounds that were similarly observed here in the late spring to early fall. These calls have been linked to social and feeding behaviours (Silber 1986, Dunlop et al. 2007, Stimpert et al. 2007).

4.2.2.4. *Minke Whales*

Minke whales were conspicuous by their acoustic absence in our study. This contrasts with visual survey data showing that this species is the most common baleen whale species in eastern Canadian waters (Lawson and Gosselin 2018), with corrected abundance estimates derived from the 2007 summer TNASS aerial surveys reaching 9,054 in the Newfoundland-Labrador survey strata and 16,050 in the Gulf of St. Lawrence and Scotian Shelf survey strata (Lawson and Gosselin 2011).

Between October and November minke whales leave their feeding grounds in the North Atlantic and migrate toward tropical and sub-tropical waters for the winter (Risch et al. 2014). An acoustic study tracking minke whale seasonal movements found pulse trains, the most common signal for that species in the North Atlantic, to be rare during summer, but common in fall during migration. All recorders in this study were deployed when pulse train production and detections usually start (i.e., around mid-August; Risch et al. 2013); therefore, the lack of detections, with the exception of stn 1, 2 and 3 in the fall, suggests that either minke whales were absent from the vicinity of most recorders, or that minke whales present throughout the study area in the summer and fall are not acoustically active.

Minke whales are known to occur throughout the Canadian EEZ and this species was in fact sighted repeatedly during the deployment/retrieval cruises, including in offshore waters near the Flemish Pass. Like the songs of other baleen whales, pulse trains are presumed to be a male breeding display. Minke whales display sex segregation based on latitude, with females usually found at higher latitudes (Laidre et al. 2009). In the Gulf of St. Lawrence, the minke whale sex ratio is strongly biased toward females (Christian Ramp, personal communication). Therefore, the lack of summer and fall detections could reflect sex-biased distribution and calling behaviour. Abundant pulse train detections in the Bay of Fundy and western Scotian Shelf in fall (JASCO, unpublished data) suggest that the male-female distribution boundary lies somewhere on the eastern Scotian Shelf. A better understanding of female vocal repertoire is required for acoustic monitoring to provide a viable survey method for minke whales, particularly in northern, female-biased areas. Automatic detections of pulse trains may provide additional evidence of acoustic occurrence in the study area and should be considered for further assessment of this species in eastern Canadian waters.

4.2.2.5. *North Atlantic Right Whales*

In Canadian waters, the known annual summer aggregation sites of right whales are in the Bay of Fundy, Roseway Basin, and in the Gulf of St. Lawrence, although their respective level of frequentation has varied greatly in recent years (Brown et al. 2009). None of the aforementioned summer feeding grounds were specifically targeted in the present study, though the right whale vocalizations detected around northern Nova Scotia (stn1 and 2) in late summer and fall 2015 presumably reflect seasonal movements of right whales in and out of the Gulf of St. Lawrence. Indeed, sightings in the Gulf of St. Lawrence have increased substantially in recent years. The short duration of each detection event best corresponds to travelling individuals or groups rather than consistent use of the areas surrounding the recorders.

The confirmed detection at stn 6 in late November 2016 as well as a possible detection at stn 15 suggests that a dedicated analysis of additional stations may be warranted. Indeed, the distribution of right whales is changing (Davis et al. 2017) and a number of individuals in this well-studied species are not observed at the traditional aggregation sites. A passive acoustic monitoring study detected right whale calls in an offshore area off southern Greenland where they used to be hunted (Mellinger et al. 2011). This acoustic dataset may hold detections that could be valuable to the conservation efforts aimed at North Atlantic right whales, and further examination for that purpose is recommended.

4.2.2.6. *Sei Whales*

A widely distributed mysticete, sei whales were expected to occur at least in the southern part of the study area, as the species has been reported east and south of Nova Scotia on the Scotian Slope (Thompson et al. 1979, Knowlton et al. 1991, Baumgartner and Fratantoni 2008, Whitehead 2013) and in areas of the Scotian Shelf (COSEWIC 2003). Sei whales were hunted during a short period (1967–1971) of whaling off Nova Scotia, with catches peaking in June-July and September-October (Mitchell 1974).

Sei whales are generally thought to migrate between winter southern breeding grounds and summer northern feeding grounds (Kellogg 1929, Mackintosh 1942, Mackintosh 1966, Norris 1967). We observed a clear acoustic absence in winter at stations off the northeast Grand Banks that were consistently frequented from spring to fall. Sei whales are known to frequent the Labrador Sea in summer (Kapel 1985, COSEWIC 2003). A sei whale tagged in the Azores was tracked up to a location near stn 13 in early summer (Olsen et al. 2009). Off the Scotian Shelf, sei whale acoustic signals peaked from late February to July and occurred sporadically throughout the rest of the year. Whether the generally asynchronous occurrence periods off the northeast Grand Banks and Nova Scotia are indicative of migratory movements between these areas remains unclear. A more dedicated analysis is required to answer this question.

The stock structure of sei whales in the north Atlantic is unresolved. Mitchell and Chapman (1977) suggested that sei whales in the northwest Atlantic are divided between a stock centred around Nova Scotia ranging from slope waters in the US to southern Newfoundland and another in the Labrador Sea. The geographic clustering in our detections appears consistent with this hypothesis. More recently, genetic analyses failed to identify distinct stocks in the North Atlantic, but the uncertainty in the genetic divergence estimates precludes ruling out the presence of multiple stocks (Huijser et al. 2018).

Improvements to the sei whale automated detector are required to more systematically evaluate the seasonal occurrence of sei whales in the study area. The current results are based on a limited manual review of the data and therefore should be interpreted as a minimum estimate of acoustic occurrence. The timing and location of detections off the northeast Grand Banks showed a pronounced overlap with seismic activity. This raises concerns about potential effects of noise on this species and warrants further investigation.

4.2.3. Pinnipeds

4.2.3.1. *Atlantic Walruses*

Before the arrival of Europeans, walruses occurred across eastern Canada (Wright and Museum 1989), but they are now almost exclusively found in the Arctic. The walrus vocalizations recorded off Labrador are likely associated with individuals belonging to the southernmost stock whose range includes northern Hudson Bay, Hudson Strait, southeastern Baffin Island, and Northern Labrador. This stock's range extends as far south as Okak Bay, Labrador (Born et al. 1995), just north of stn 12, where they were acoustically observed. The walrus acoustic signals recorded here correspond to male walruses' breeding display (Stirling et al. 1987).

4.2.3.2. *Bearded Seals*

In winter, the continental shelf off southern Labrador and northern Newfoundland provide suitable habitats for bearded seals that prefer ice-covered shallow regions where they have access to their benthic prey (Burns and Frost 1979) and ice flows for hauling out and pupping. Bearded seals are known to occur off Labrador and northern Newfoundland in winter and spring (Kovacs 2002); therefore, their acoustic occurrence in these areas from January to June was expected. This arctic species is capable of making large migrations (Burns and Frost 1979), moving from the Canadian high arctic in the summer and fall to areas farther south in the winter and spring.

The number of bearded seals in eastern Canadian waters, which include Hudson Bay, the Canadian Arctic Archipelago and Western Baffin Bay, is estimated at ~190,000 individuals (Cameron et al. 2010). There are no abundance estimates for the areas where detections occurred in this study, but they represent the southern limits of the range. The proportion of the population using these areas, primarily as pupping, nursing, and breeding grounds, is unknown.

Like many pinnipeds, bearded seals display a pronounced seasonality in calling rates. Calls are virtually absent in summer, progressively increase in fall and winter, and peak in spring during the breeding season (Frouin-Mouy et al. 2016). While the onset of detections can be reasonably interpreted as the arrival of bearded seals in the affected areas, the abrupt cessation of calling observed in early June is representative of bearded seal calling behaviour. It has been described in other parts of the species range (e.g., MacIntyre et al. 2015) and does not necessarily translates into an abrupt departure from the study area. Although bearded seals appear to be the least selective ice seal species in terms of the type of sea ice they require (Cameron et al. 2010), the presence of suitable ice conditions and their proximity to continental shelf areas compatible with foraging are likely the main factor driving the presence of this species in the study area.

4.2.3.3. *Grey Seals*

Grey seals in Canadian waters form a single genetic population that can be divided into three groups based on breeding site locations. As of 2010, most pups (81%) were born on Sable Island, 15% in the Gulf of St. Lawrence, and 4% along the coast of Nova Scotia. The total estimated population size is upward of 350,000 individuals and increasing (DFO 2010). We identified grey seals at stn 1, 2, 3 and 9. Seals at stn 3 were likely associated with individuals breeding on Sable Island. Those at stn 1 and 9 may be associated with animals breeding in the Gulf of St. Lawrence, while grey seals at stn 2 may breed in Nova Scotia or transit to Sable Island.

Grey seals are most vocally active during the breeding season in December and January, which coincides with our findings. They are thought to be mostly silent when not breeding (Schusterman et al. 1970, Asselin et al. 1993), with the exception of seals in areas near terrestrial haul-outs (JASCO, unpublished data). Development of an automated detector would contribute to assessing the distribution of this species during the breeding season.

4.2.3.4. *Harp Seals*

Harp seals occur in Canadian waters from fall to spring in two main areas: the southern Gulf of St. Lawrence and an area known as the Front, off southern Labrador and northern Newfoundland, where they give birth in late February or March. After forming large moulting aggregations off northeastern Newfoundland and in the northern Gulf of St. Lawrence in April and/or May, they migrate northward to the Davis Strait although some individuals may remain in Canadian waters (Sergeant 1973, DFO 2012). Our results are consistent with the presence of harp seals in the Front during the breeding season. Harp seal acoustic signals occurred almost exclusively in February and March, except in the Strait of Belle-Isle, where isolated signals in November and December may be associated with individuals entering the Gulf of St. Lawrence. The harp seal vocalizations at stn 1 in March 2017 may correspond to individuals leaving the Gulf. The results presented here are based on manual review and therefore underestimate the acoustic occurrence of this species. Nevertheless, the temporal overlap between acoustic results and the breeding season is consistent with the acoustic behaviour of harp seals (Moors and Terhune 2005), and ice seals more generally (Stirling and Thomas 2003).

4.2.4. Multi-species Area-wide Synthesis and Future Work

This study illustrates the importance of several surveyed areas to marine mammals. Although fish sounds were not targeted in this study, we did not encounter recurring sounds produced by, or presumed to be produced by, fish that would have warranted further investigation.

Species diversity is usually described using indices combining species diversity and evenness. The latter describes the relative proportion of individuals of each species in the community. Abundance estimates are unavailable for most species in the study area and because species vary widely in vocal activity and detection probability, call counts were not suitable substitutes for abundance (even relative) estimates. Species counts by were therefore used as a conservative index of species diversity.

We noted a decrease in species diversity with increasing latitude, which was more pronounced in winter and spring. Stations along the continental slope had higher number of detected species and those in the southern part of the study area retained a relatively high species diversity throughout the year. Stations near the southern and northern entrance to the Flemish Pass are notable for their high species diversity and spatio-temporal overlap with oil and gas exploration activities. The continental slope south of the Grand Banks, is also an area of interest for this industry where significant overlap with marine mammal habitat can be expected.

The environmental, anthropogenic, and noise-related factors that may influence detection patterns at each station should be investigated further. It is clear that the decrease in species diversity at the northern “on-shelf” stations in winter and spring is linked to the presence of sea ice. The persistence of acoustic detections at the southern stations may be linked to higher sea surface temperatures and proximity to thermal fronts (see e.g., Doniol-Valcroze et al. 2007) resulting from the interaction of water masses associated with the Gulf Stream and Labrador current. Specifically, the factors driving the year-round occurrence of several deep-diving species north and south of the Flemish Pass deserves further attention.

Along the Scotian shelf, the Gully Marine Protected Area is known for its marine mammal species diversity and hosts a resident population of northern bottlenose whales. A comparison of detections obtained from a recorder of the same model as in this study and using the same automated detectors is in progress and should allow to further discuss the relative importance of the areas surveyed for this endangered species. More generally, acoustic data recorded in areas purposefully left out in this study (western Scotian shelf, south of Newfoundland) will be added to this dataset to further improve our understanding of marine mammal distribution and occurrence in Canadian waters.

Further development of the dolphin whistle detector is required to allow discriminating the different species contributing to the detection records. Similarly, at least one and possibly two unidentified species of beaked whales were detected off the Scotian Shelf and southern Grand Banks. Incorporating their signals to the click detector is required to track their occurrence in Canadian waters.

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Glossary

1/3-octave

One third of an octave. Note: A one-third octave is approximately equal to one decidecade (1/3 oct ≈ 1.003 ddec) (ISO 2017).

1/3-octave-band

Frequency band whose bandwidth is one one-third octave. Note: The bandwidth of a one-third octave-band increases with increasing centre frequency.

90%-energy time window

The time interval over which the cumulative energy rises from 5% to 95% of the total pulse energy. This interval contains 90% of the total pulse energy. Symbol: T_{90}.

90% sound pressure level (90% SPL)

The root-mean-square sound pressure levels calculated over the 90%-energy time window of a pulse. Used only for pulsed sounds.

acoustic signal

A sound within an acoustic file that could be detected or validated. In this report, the term encompasses all marine mammal vocalization types (including clicks, tonal sounds, and songs), but also any other signal that might be falsely detected, such as seismic pulses. Also see vocalization.

ambient noise

All-encompassing sound at a given place, usually a composite of sound from many sources near and far (ANSI S1.1-1994 R2004), e.g., shipping vessels, seismic activity, precipitation, sea ice movement, wave action, and biological activity.

background noise

Total of all sources of interference in a system used for the production, detection, measurement, or recording of a signal, independent of the presence of the signal (ANSI S1.1-1994 R2004). Ambient noise detected, measured, or recorded with a signal is part of the background noise.

bandwidth

The range of frequencies over which a sound occurs. Broadband refers to a source that produces sound over a broad range of frequencies (e.g., seismic airguns, vessels) whereas narrowband sources produce sounds over a narrow frequency range (e.g., sonar) (ANSI/ASA S1.13-2005 R2010).

bar

Unit of pressure equal to 100 kPa, which is approximately equal to the atmospheric pressure on Earth at sea level. 1 bar is equal to 10^6 Pa or 10^{11} μPa.

broadband sound level

The total sound pressure level measured over a specified frequency range. If the frequency range is unspecified, it refers to the entire measured frequency range.

cavitation

A rapid formation and collapse of vapor cavities (i.e., bubbles or voids) in water, most often caused by a rapid change in pressure. Fast-spinning vessel propellers typically cause cavitation, which creates a lot of noise.

cetacean

Any animal in the order Cetacea. These are aquatic, mostly marine mammals and include whales, dolphins, and porpoises.

compressional wave
A mechanical vibration wave in which the direction of particle motion is parallel to the direction of propagation. Also called primary wave or P-wave.

continuous sound
A sound whose sound pressure level remains above ambient sound during the observation period (ANSI/ASA S1.13-2005 R2010). A sound that gradually varies in intensity with time, for example, sound from a marine vessel.

decade
Logarithmic frequency interval whose upper bound is ten times larger than its lower bound (ISO 2006).

decidecade
One tenth of a decade (ISO 2017). Note: An alternative name for decidecade (symbol ddec) is 'one-tenth decade'. A decidecade is approximately equal to one third of an octave (1 ddec ≈ 0.3322 oct) and for this reason is sometimes referred to as a "one-third octave".

decidecade band
Frequency band whose bandwidth is one decidecade. Note: The bandwidth of a decidecade band increases with increasing centre frequency.

decibel (dB)
One-tenth of a bel. Unit of level when the base of the logarithm is the tenth root of ten, and the quantities concerned are proportional to power (ANSI S1.1-1994 R2004).

duty cycle
The time when sound is periodically recorded by an acoustic recording system.

ensonified
Exposed to sound.

far-field
The zone where, to an observer, sound originating from an array of sources (or a spatially-distributed source) appears to radiate from a single point. The distance to the acoustic far-field increases with frequency.

fast-average sound pressure level
The time-averaged sound pressure levels calculated over the duration of a pulse (e.g., 90%-energy time window), using the leaky time integrator from (Plomp and Bouman 1959) and a time constant of 125 ms. Typically used only for pulsed sounds.

fast Fourier transform (FFT)
A computationally efficiently algorithm for computing the discrete Fourier transform.

frequency
The rate of oscillation of a periodic function measured in cycles-per-unit-time. The reciprocal of the period. Unit: hertz (Hz). Symbol: *f*. 1 Hz is equal to 1 cycle per second.

hertz (Hz)
A unit of frequency defined as one cycle per second.

hydrophone
An underwater sound pressure transducer. A passive electronic device for recording or listening to underwater sound.

intermittent sound
A level of sound that abruptly drops to the background noise level several times during the observation period.

impulsive sound
Sound that is typically brief and intermittent with rapid (within a few seconds) rise time and decay back to ambient levels (NOAA 2013, ANSI S12.7-1986 R2006). For example, seismic airguns and impact pile driving.

masking
Obscuring of sounds of interest by sounds at similar frequencies.

median
The 50th percentile of a statistical distribution.

mysticete
Mysticeti, a suborder of cetaceans, use their baleen plates, rather than teeth, to filter food from water. They are not known to echolocate, but use sound for communication. Members of this group include rorquals (Balaenopteridae), right whales (Balaenidae), and grey whales (*Eschrichtius robustus*).

non-impulsive sound
Sound that is broadband, narrowband or tonal, brief or prolonged, continuous or intermittent, and typically does not have a high peak pressure with rapid rise time (typically only small fluctuations in decibel level) that impulsive signals have (ANSI/ASA S3.20-1995 R2008). For example, marine vessels, aircraft, machinery, construction, and vibratory pile driving (NIOSH 1998, NOAA 2015).

octave
The interval between a sound and another sound with double or half the frequency. For example, one octave above 200 Hz is 400 Hz, and one octave below 200 Hz is 100 Hz.

odontocete
The presence of teeth, rather than baleen, characterizes these whales. Members of the Odontoceti are a suborder of cetaceans, a group comprised of whales, dolphins, and porpoises. The toothed whales' skulls are mostly asymmetric, an adaptation for their echolocation. This group includes sperm whales, killer whales, belugas, narwhals, dolphins, and porpoises.

particle acceleration
The rate of change of particle velocity. Unit: meters per second squared (m/s^2). Symbol: a.

particle velocity
The physical speed of a particle in a material moving back and forth in the direction of the pressure wave. Unit: meters per second (m/s). Symbol: v.

peak pressure level (PK)
The maximum instantaneous sound pressure level, in a stated frequency band, within a stated period. Also called zero-to-peak pressure level. Unit: decibel (dB).

peak-to-peak pressure level (PK-PK)
The difference between the maximum and minimum instantaneous pressure levels. Unit: decibel (dB).

percentile level, exceedance
The sound level exceeded n% of the time during a measurement.

power spectrum density
The acoustic signal power per unit frequency as measured at a single frequency. Unit: µPa^2/Hz, or µPa^2·s.

power spectral density level
The decibel level ($10\log_{10}$) of the power spectrum density, usually presented in 1 Hz bins. Unit: dB re 1 µPa^2/Hz.

pressure, acoustic
The deviation from the ambient hydrostatic pressure caused by a sound wave. Also called overpressure. Unit: pascal (Pa). Symbol: p.

pressure, hydrostatic
The pressure at any given depth in a static liquid that is the result of the weight of the liquid acting on a unit area at that depth, plus any pressure acting on the surface of the liquid. Unit: pascal (Pa).

received level
The sound level measured at a receiver.

rms
root-mean-square.

signature
Pressure signal generated by a source.

sound
A time-varying pressure disturbance generated by mechanical vibration waves travelling through a fluid medium such as air or water.

sound exposure
Time integral of squared, instantaneous frequency-weighted sound pressure over a stated time interval or event. Unit: pascal-squared second (Pa^2·s) (ANSI S1.1-1994 R2004).

sound exposure level (SEL)
A cumulative measure related to the sound energy in one or more pulses. Unit: dB re 1 µPa^2·s. SEL is expressed over the summation period (e.g., per-pulse SEL [for airguns], single-strike SEL [for pile drivers], 24-hour SEL).

sound intensity
Sound energy flowing through a unit area perpendicular to the direction of propagation per unit time.

sound pressure level (SPL)
The decibel ratio of the time-mean-square sound pressure, in a stated frequency band, to the square of the reference sound pressure (ANSI S1.1-1994 R2004).

For sound in water, the reference sound pressure is one micropascal (p_0 = 1 µPa) and the unit for SPL is dB re 1 µPa:

$$\mathrm{SPL} = 10\log_{10}\left(p^2 / p_0^2\right) = 20\log_{10}\left(p / p_0\right)$$

Unless otherwise stated, SPL refers to the root-mean-square sound pressure level. See also 90% sound pressure level and fast-average sound pressure level. Non-rectangular time window functions may be applied during calculation of the rms value, in which case the SPL unit should identify the window type.

source level (SL)
The sound level measured in the far-field and scaled back to a standard reference distance of 1 metre from the acoustic centre of the source. Unit: dB re 1 µPa @ 1 m (sound pressure level) or dB re 1 $\mu Pa^2 \cdot s$ (sound exposure level).

spectrogram
A visual representation of acoustic amplitude compared with time and frequency.

spectrum
An acoustic signal represented in terms of its power (or energy) distribution compared with frequency.

transmission loss (TL)
The decibel reduction in sound level between two stated points that results from sound spreading away from an acoustic source subject to the influence of the surrounding environment. Also called propagation loss.

vocalization
Sounds produced by an animal (clicks, tonals, or songs). Also see acoustic signal.

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Appendix A. Fishing Effort

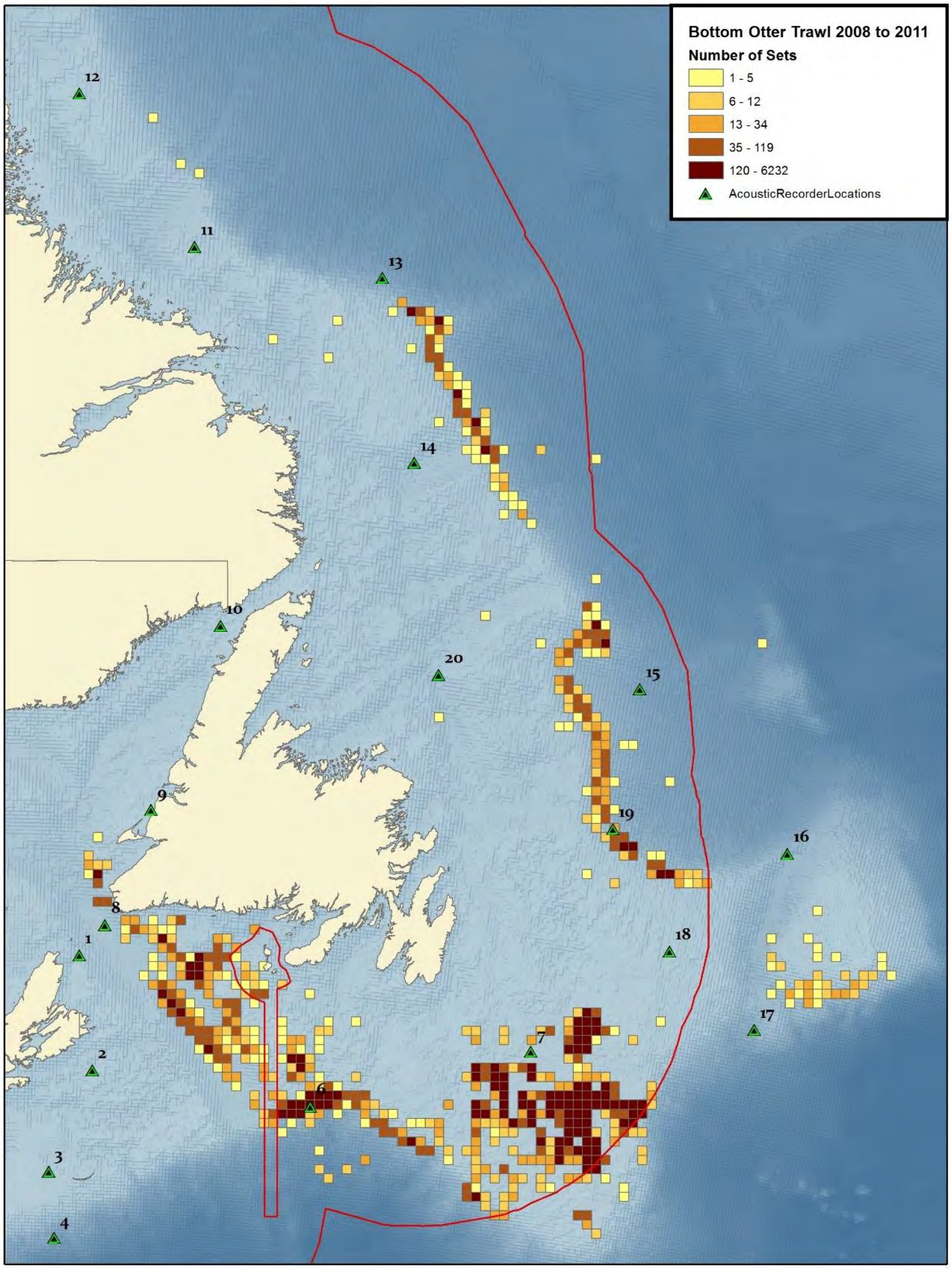


Figure 104. Bottom otter trawl: Fishing effort (2008–2011) in areas under the jurisdiction of DFO Newfoundland-Labrador. The acoustic recorders are displayed as green triangles.

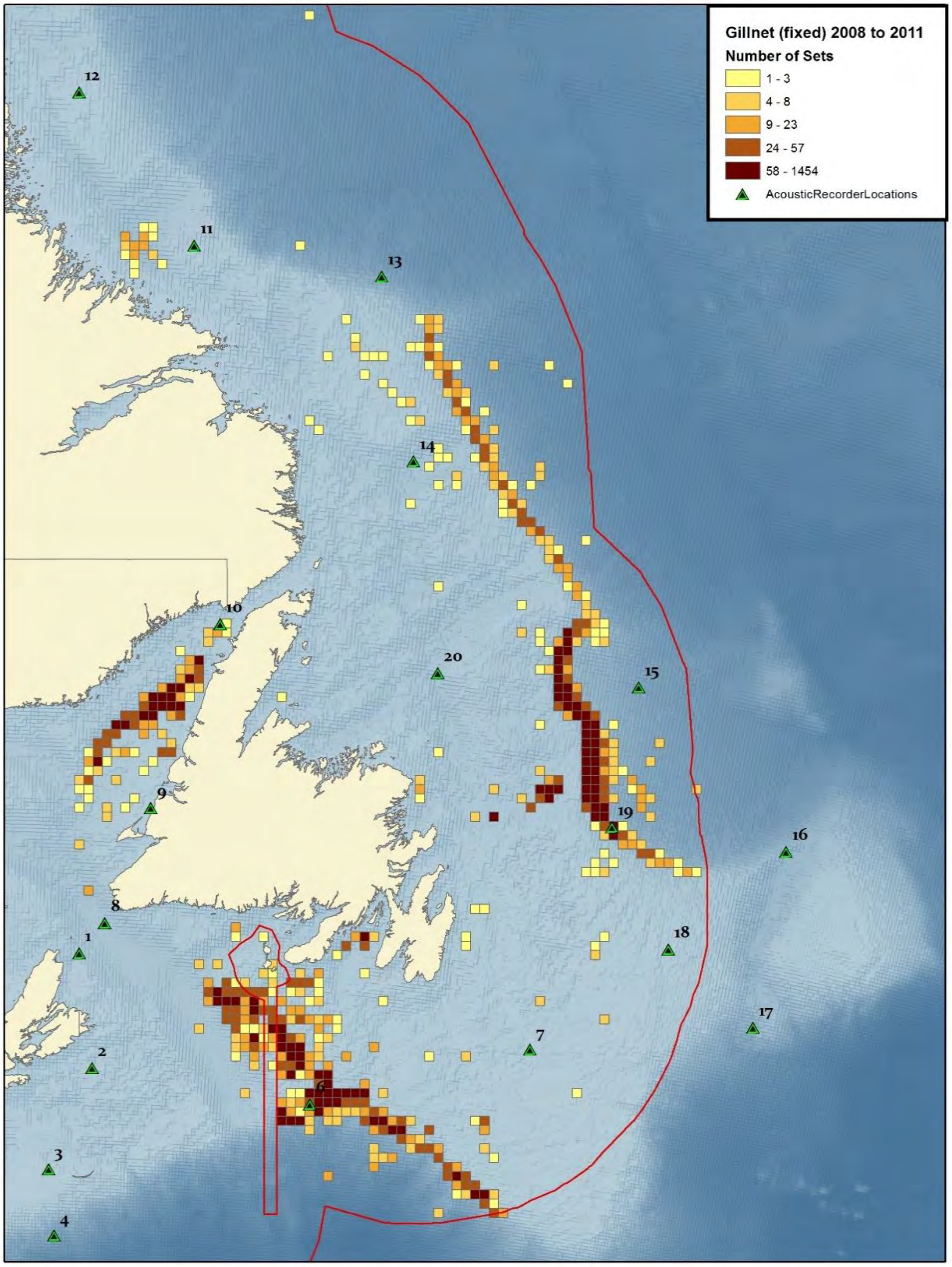


Figure 105. Gillnets: Fishing effort (2008–2011) in areas under the jurisdiction of DFO Newfoundland-Labrador. The acoustic recorders are displayed as green triangles.

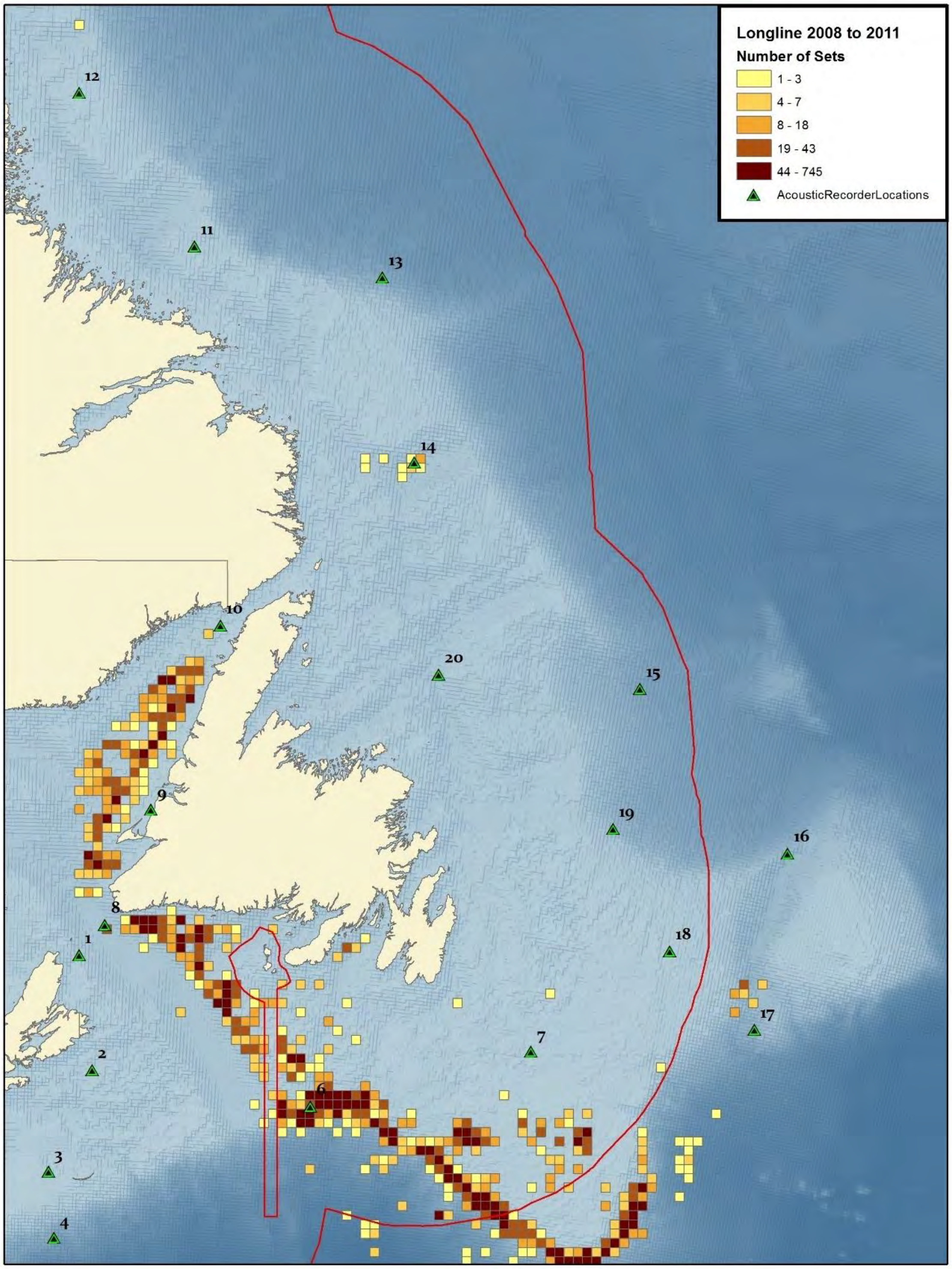


Figure 106. Longlines: Fishing effort (2008–2011) in areas under the jurisdiction of DFO Newfoundland-Labrador. The acoustic recorders are displayed as green triangles.

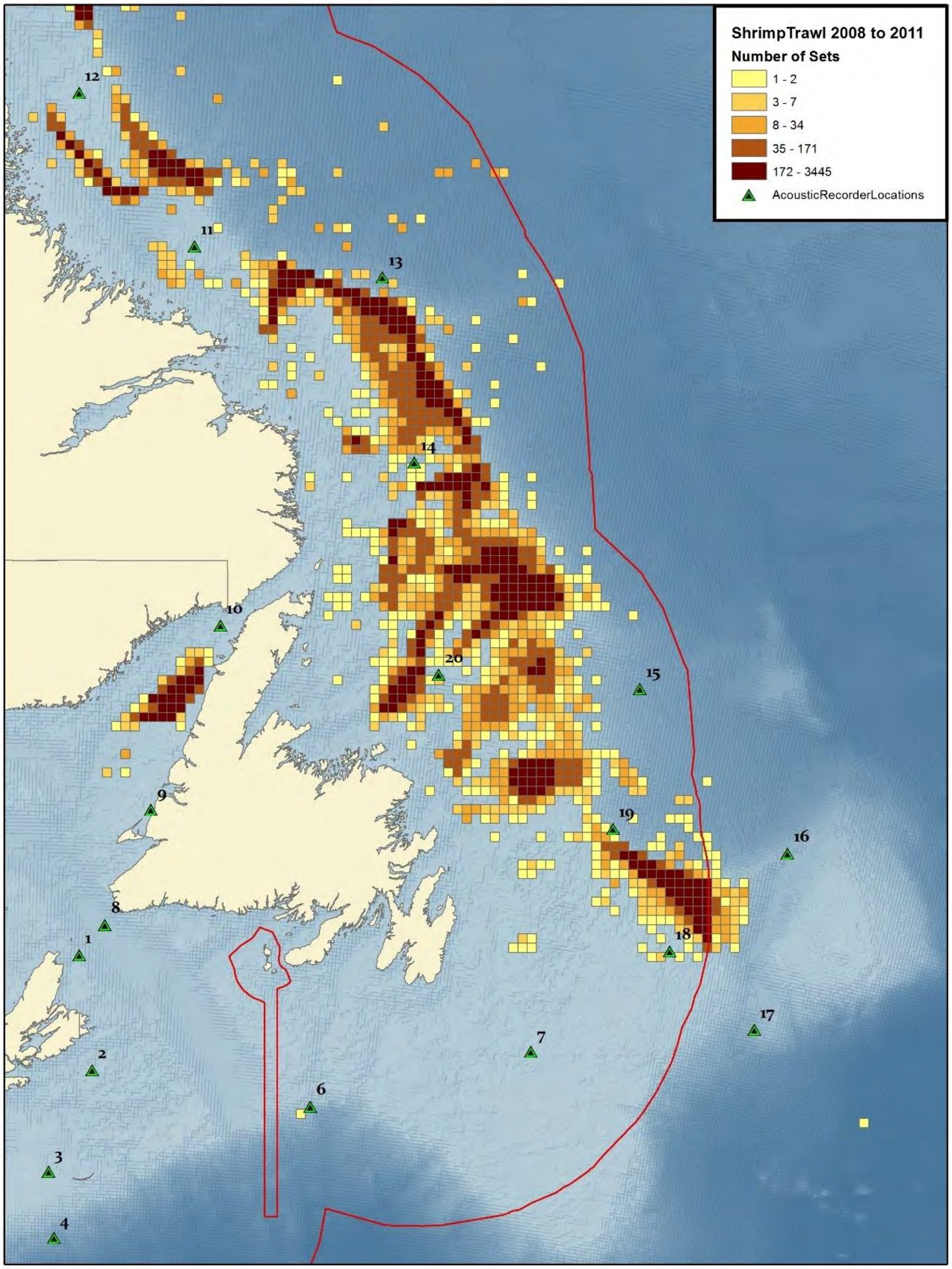


Figure 107. Shrimp trawl: Fishing effort (2008–2011) in areas under the jurisdiction of DFO Newfoundland-Labrador. The acoustic recorders are displayed as green triangles.

Appendix B. Calibration and Mooring Designs

B.1. Recorder Calibrations

Each AMAR was calibrated before deployment and upon retrieval (battery life permitting) with a pistonphone type 42AC precision sound source (G.R.A.S. Sound & Vibration A/S; Figure 108). The pistonphone calibrator produces a constant tone at 250 Hz at a fixed distance from the hydrophone sensor in an airtight space with known volume. The recorded level of the reference tone on the AMAR yields the system gain for the AMAR and hydrophone. To determine absolute sound pressure levels, this gain was applied during data analysis. Typical calibration variance using this method is less than 0.7 dB absolute pressure.

Figure 108. Split view of a G.R.A.S. 42AC pistonphone calibrator with an M36 hydrophone.

B.2. Mooring Designs

Four mooring configurations were used to account for the large differences in depth between recording sites. Stn 3, 7, and 9 were deployed at depths less than 80 m. The AMARs at these three stations were mounted on bottom plates, which prevented motion due to currents (Figure 109). All other stations were deployed using three variants of suspended mooring design and recorder housing based on depth (Figures 110–112). In all deep mooring designs, the AMAR was suspended ~25 m above the seafloor. At each site, the only difference between years was the type hydrophone used (HTI-99 in 2015–16 and GTI M36-V35-100 in 2016–17).

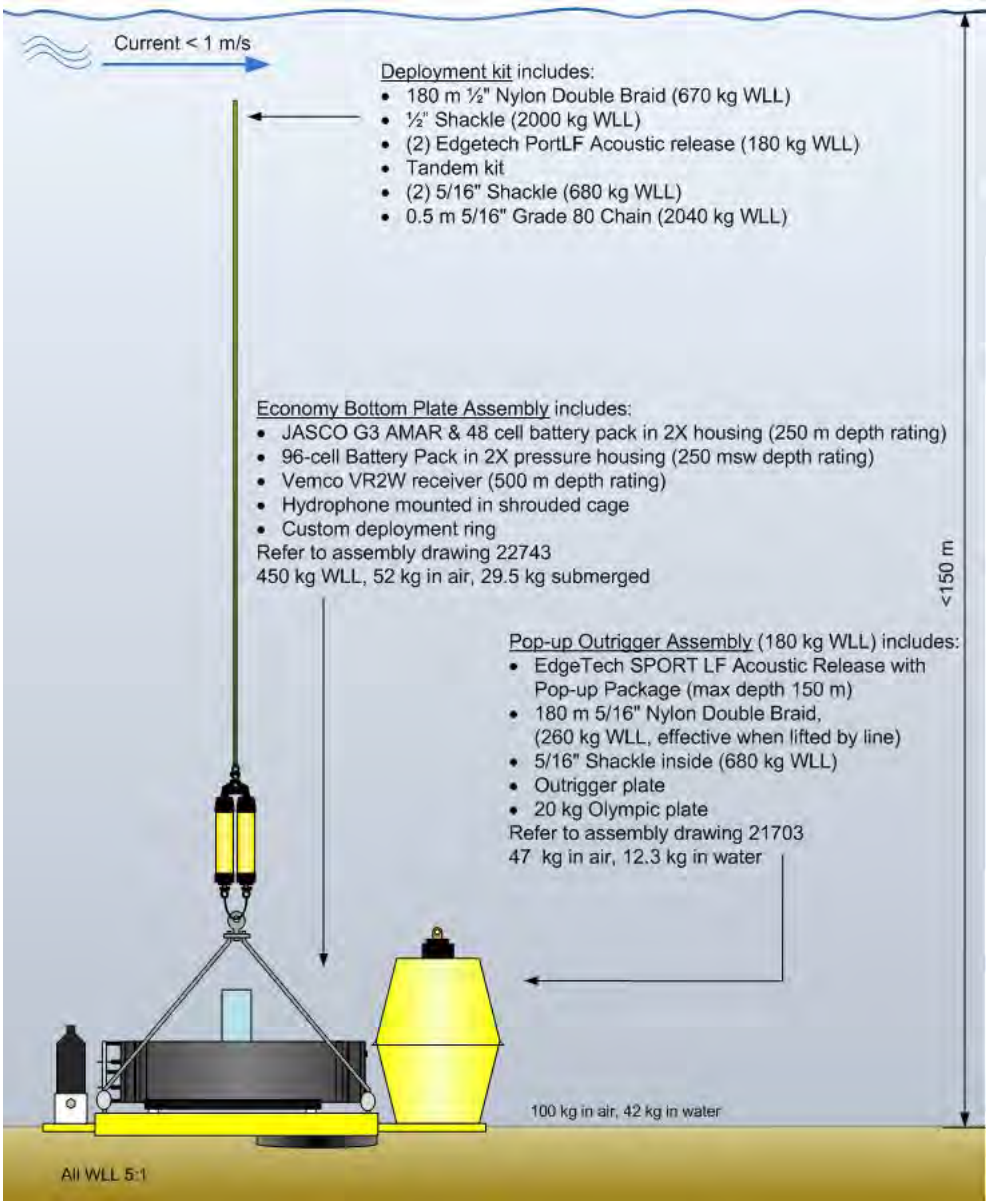


Figure 109. Shallow mooring design with one PVC-housing AMAR attached to a bottom plate with a pop-up release and a fish logger. This configuration was used at stn 3, 7, and 9.

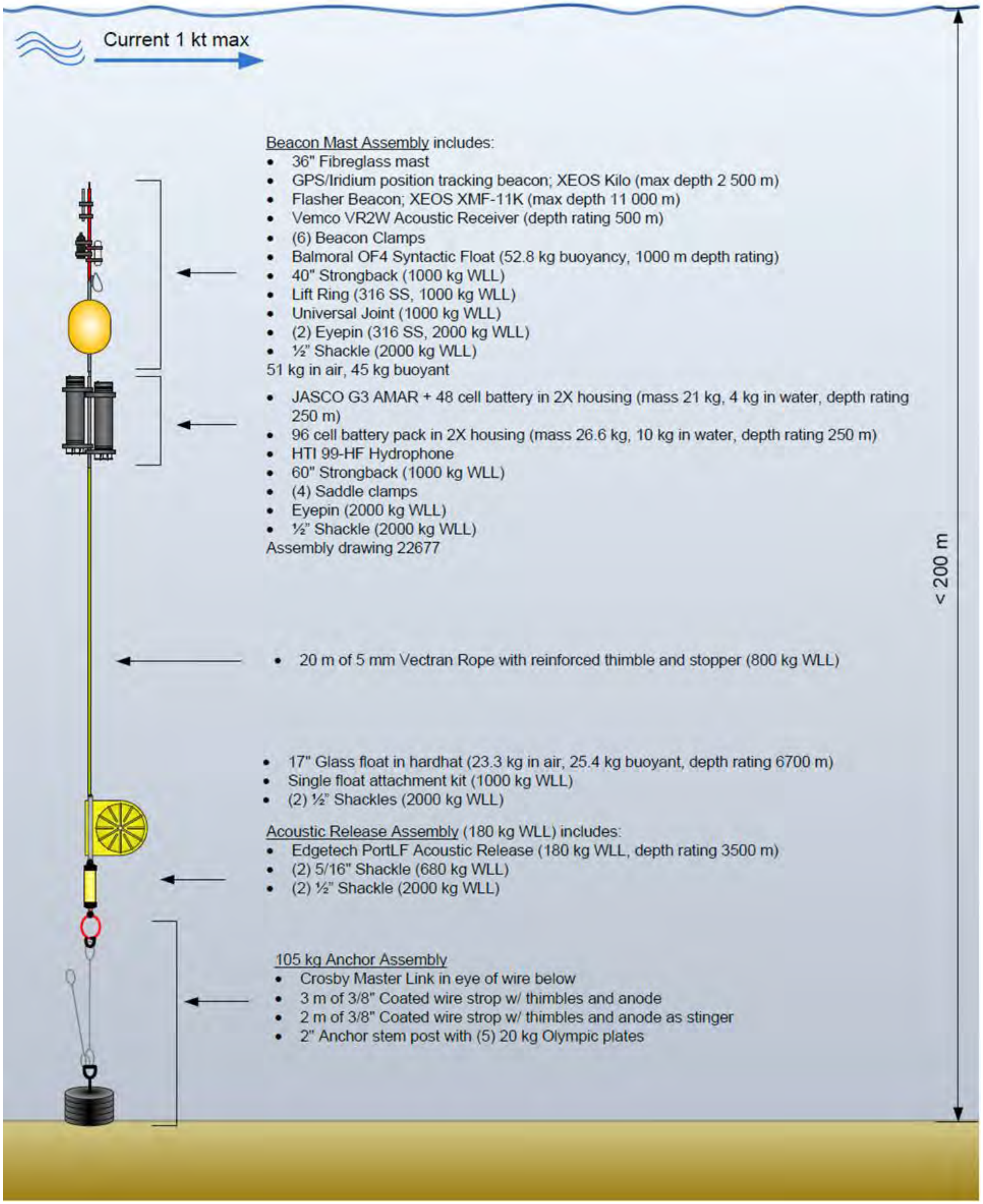
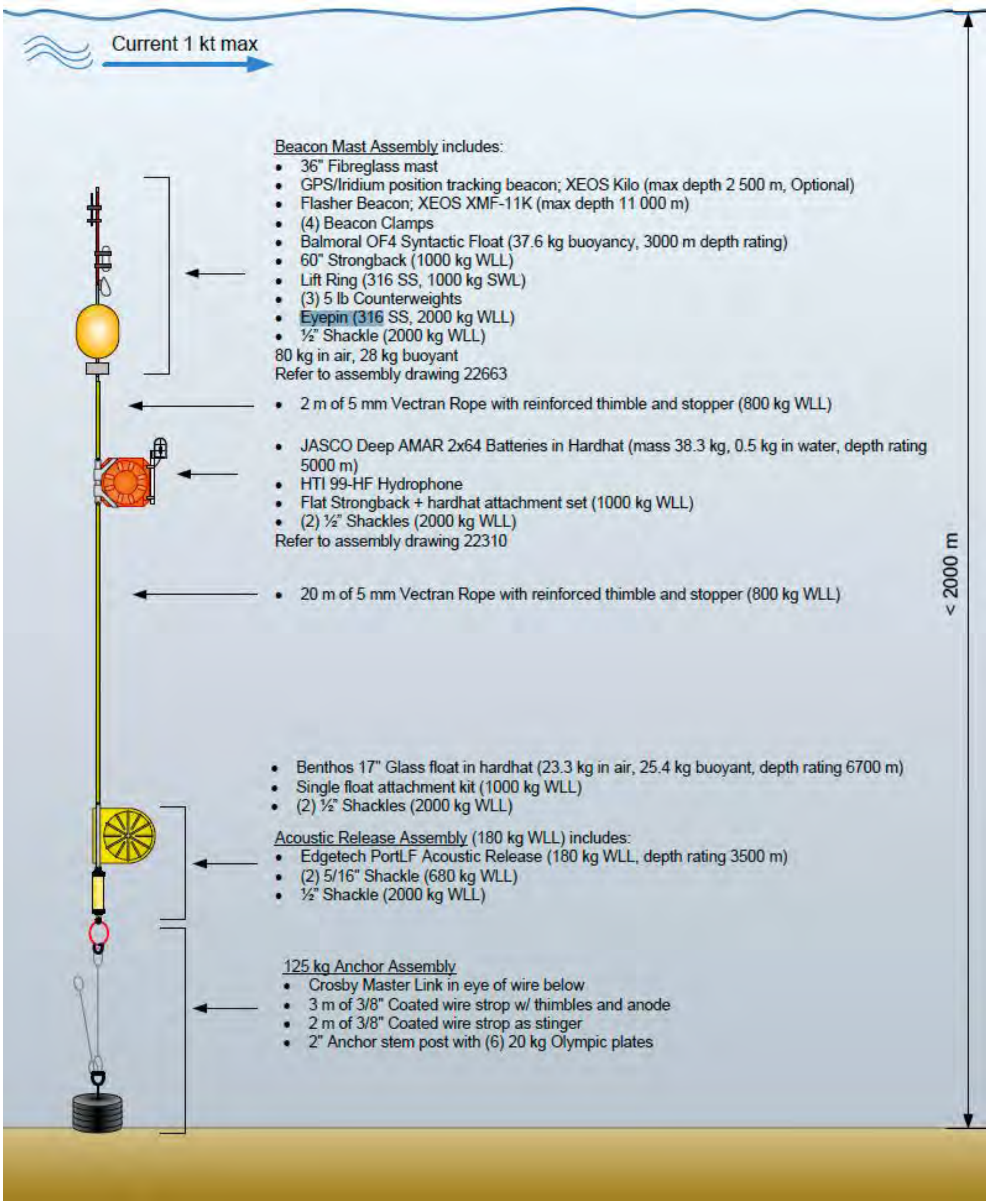


Figure 110. Shallow mooring design with a PVC-housing AMAR and battery pack attached to an anchor. This configuration was used at used at stn 1, 2, 10, 11, 12, 18, and 20.



Beacon Mast Assembly includes:
- 36" Fibreglass mast
- GPS/Iridium position tracking beacon; XEOS Kilo (max depth 2 500 m, Optional)
- Flasher Beacon; XEOS XMF-11K (max depth 11 000 m)
- (4) Beacon Clamps
- Balmoral OF4 Syntactic Float (37.6 kg buoyancy, 3000 m depth rating)
- 60" Strongback (1000 kg WLL)
- Lift Ring (316 SS, 1000 kg SWL)
- (3) 5 lb Counterweights
- Eyepin (316 SS, 2000 kg WLL)
- ½" Shackle (2000 kg WLL)

80 kg in air, 28 kg buoyant
Refer to assembly drawing 22663

- 2 m of 5 mm Vectran Rope with reinforced thimble and stopper (800 kg WLL)

- JASCO Deep AMAR 2x64 Batteries in Hardhat (mass 38.3 kg, 0.5 kg in water, depth rating 5000 m)
- HTI 99-HF Hydrophone
- Flat Strongback + hardhat attachment set (1000 kg WLL)
- (2) ½" Shackles (2000 kg WLL)

Refer to assembly drawing 22310

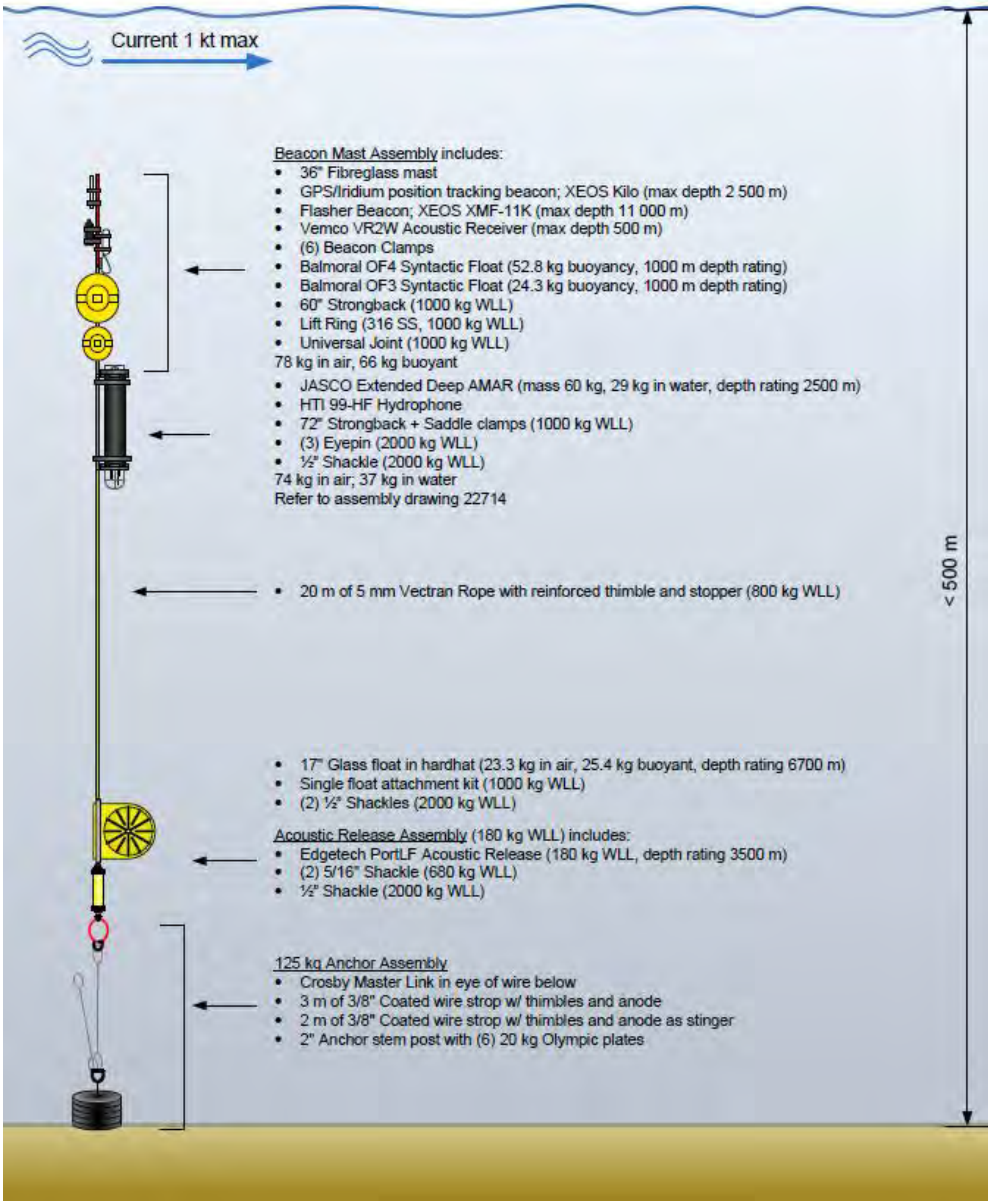
- 20 m of 5 mm Vectran Rope with reinforced thimble and stopper (800 kg WLL)

- Benthos 17" Glass float in hardhat (23.3 kg in air, 25.4 kg buoyant, depth rating 6700 m)
- Single float attachment kit (1000 kg WLL)
- (2) ½" Shackles (2000 kg WLL)

Acoustic Release Assembly (180 kg WLL) includes:
- Edgetech PortLF Acoustic Release (180 kg WLL, depth rating 3500 m)
- (2) 5/16" Shackle (680 kg WLL)
- ½" Shackle (2000 kg WLL)

125 kg Anchor Assembly
- Crosby Master Link in eye of wire below
- 3 m of 3/8" Coated wire strop w/ thimbles and anode
- 2 m of 3/8" Coated wire strop as stinger
- 2" Anchor stem post with (6) 20 kg Olympic plates

Figure 111. Deep mooring design with one AMAR ultra-deep (UD) attached to an anchor. This configuration was used at stn 4, 5, 6, 13, 14, 15, 16, 17, and 19.



Beacon Mast Assembly includes:
- 36" Fibreglass mast
- GPS/Iridium position tracking beacon; XEOS Kilo (max depth 2 500 m)
- Flasher Beacon; XEOS XMF-11K (max depth 11 000 m)
- Vemco VR2W Acoustic Receiver (max depth 500 m)
- (6) Beacon Clamps
- Balmoral OF4 Syntactic Float (52.8 kg buoyancy, 1000 m depth rating)
- Balmoral OF3 Syntactic Float (24.3 kg buoyancy, 1000 m depth rating)
- 60" Strongback (1000 kg WLL)
- Lift Ring (316 SS, 1000 kg WLL)
- Universal Joint (1000 kg WLL)

78 kg in air, 66 kg buoyant

- JASCO Extended Deep AMAR (mass 60 kg, 29 kg in water, depth rating 2500 m)
- HTI 99-HF Hydrophone
- 72" Strongback + Saddle clamps (1000 kg WLL)
- (3) Eyepin (2000 kg WLL)
- ½" Shackle (2000 kg WLL)

74 kg in air; 37 kg in water
Refer to assembly drawing 22714

- 20 m of 5 mm Vectran Rope with reinforced thimble and stopper (800 kg WLL)

- 17" Glass float in hardhat (23.3 kg in air, 25.4 kg buoyant, depth rating 6700 m)
- Single float attachment kit (1000 kg WLL)
- (2) ½" Shackles (2000 kg WLL)

Acoustic Release Assembly (180 kg WLL) includes:
- Edgetech PortLF Acoustic Release (180 kg WLL, depth rating 3500 m)
- (2) 5/16" Shackle (680 kg WLL)
- ½" Shackle (2000 kg WLL)

125 kg Anchor Assembly
- Crosby Master Link in eye of wire below
- 3 m of 3/8" Coated wire strop w/ thimbles and anode
- 2 m of 3/8" Coated wire strop w/ thimbles and anode as stinger
- 2" Anchor stem post with (6) 20 kg Olympic plates

Figure 112. Deep mooring design with one aluminum-housing AMAR attached to an anchor. This configuration was used at stn 8.

Appendix C. Automated Data Analysis Overview

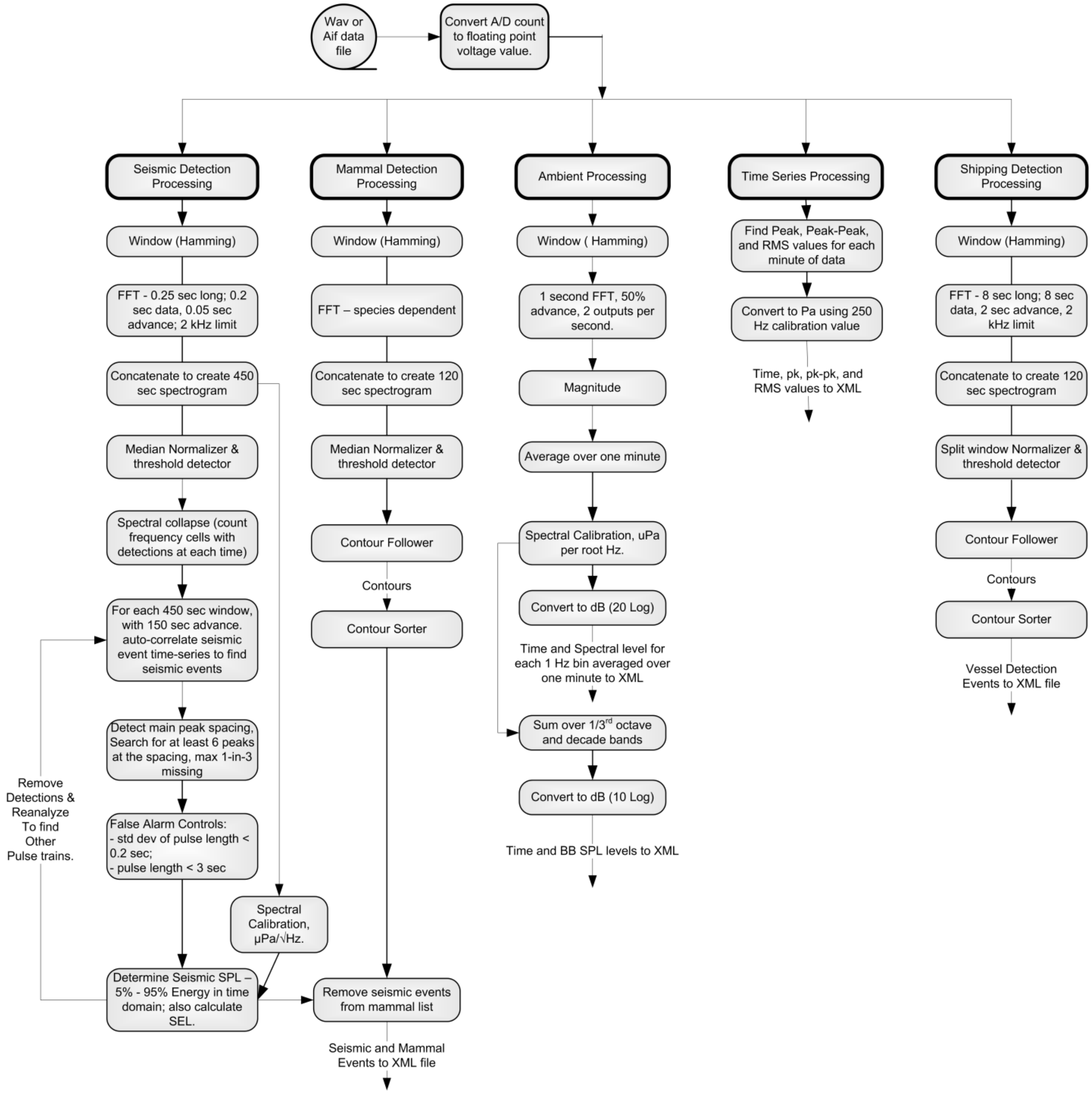


Figure 113. Major stages of the automated acoustic analysis software suite.

Appendix D. Noise Measurements Methodology

D.1. Sound Levels

Underwater sound pressure amplitude is measured in decibels (dB) relative to a fixed reference pressure of p_0 = 1 μPa. Because the perceived loudness of sound, especially impulsive noise such as from seismic airguns, pile driving, and sonar, is not generally proportional to the instantaneous acoustic pressure, several sound level metrics are commonly used to evaluate noise and its effects on marine life. We provide specific definitions of relevant metrics used in the accompanying report. Where possible we follow the ANSI and ISO standard definitions and symbols for sound metrics, but these standards are not always consistent.

The zero-to-peak pressure level, or peak pressure level (PK; dB re 1 μPa), is the maximum instantaneous sound pressure level in a stated frequency band attained by an acoustic pressure signal, $p(t)$:

$$PK = 10\log_{10}\left[\frac{\max\left(\left|p^2(t)\right|\right)}{p_0^2}\right] \tag{1}$$

$L_{p,pk}$ is often included as criterion for assessing whether a sound is potentially injurious; however, because it does not account for the duration of a noise event, it is generally a poor indicator of perceived loudness.

The sound pressure level (SPL or L_p; dB re 1 μPa) is the root-mean-square (rms) pressure level in a stated frequency band over a specified time window (T, s) containing the acoustic event of interest. It is important to note that SPL always refers to an rms pressure level and therefore not instantaneous pressure:

$$SPL = 10\log_{10}\left(\frac{1}{T}\int_T p^2(t)dt \Big/ p_0^2\right) \tag{2}$$

The SPL represents a nominal effective continuous sound over the duration of an acoustic event, such as the emission of one acoustic pulse, a marine mammal vocalization, the passage of a vessel, or over a fixed duration. Because the window length, T, is the divisor, events with similar sound exposure level (SEL), but more spread out in time, have a lower SPL.

The sound exposure level (SEL, dB re 1 μPa^2·s) is a measure related to the acoustic energy contained in one or more acoustic events (N). The SEL for a single event is computed from the time-integral of the squared pressure over the full event duration (T):

$$SEL = 10\log_{10}\left(\int_T p^2(t)dt \Big/ T_0 p_0^2\right) \tag{3}$$

where T_0 is a reference time interval of 1 s. The SEL continues to increase with time when non-zero pressure signals are present. It therefore can be construed as a dose-type measurement, so the integration time used must be carefully considered in terms of relevance for impact to the exposed recipients.

SEL can be calculated over periods with multiple events or over a fixed duration. For a fixed duration, the square pressure is integrated over the duration of interest. For multiple events, the SEL can be computed by summing (in linear units) the SEL of the N individual events:

$$L_{E,N} = 10\log_{10}\left(\sum_{i=1}^{N} 10^{\frac{L_{E,i}}{10}}\right). \tag{4}$$

To compute the SPL(T_{90}) and SEL of acoustic events in the presence of high levels of background noise, equations Equation 5 and 6 are modified to subtract the background noise contribution:

$$L_{p90} = 10\log_{10}\left(\frac{1}{T_{90}}\int_{T_{90}}(p^2(t) - \overline{n^2})dt \Big/ p_0^2\right) \tag{5}$$

$$L_E = 10\log_{10}\left(\int_T (p^2(t) - \overline{n^2})dt \Big/ T_0 p_0^2\right) \tag{6}$$

where $\overline{n^2}$ is the mean square pressure of the background noise, generally computed by averaging the squared pressure of a temporally-proximal segment of the acoustic recording during which acoustic events are absent (e.g., between pulses).

Because the SPL(T_{90}) and SEL are both computed from the integral of square pressure, these metrics are related by the following expression, which depends only on the duration of the time window T:

$$L_p = L_E - 10\log_{10}(T) \tag{7}$$

$$L_{p90} = L_E - 10\log_{10}(T_{90}) - 0.458 \tag{8}$$

where the 0.458 dB factor accounts for the 10% of SEL missing from the SPL(T_{90}) integration time window.

Energy equivalent SPL (dB re 1 µPa) denotes the SPL of a stationary (constant amplitude) sound that generates the same SEL as the signal being examined, $p(t)$, over the same time period, T:

$$L_{eq} = 10\log_{10}\left(\frac{1}{T}\int_T p^2(t)dt \Big/ p_0^2\right). \tag{9}$$

The equations for SPL and the energy-equivalent SPL are numerically identical; conceptually, the difference between the two metrics is that the former is typically computed over short periods (typically of one second or less) and tracks the fluctuations of a non-steady acoustic signal, whereas the latter reflects the average SPL of an acoustic signal over times typically of one minute to several hours.

D.2. One-Third-Octave-Band Analysis

The distribution of a sound's power with frequency is described by the sound's spectrum. The sound spectrum can be split into a series of adjacent frequency bands. Splitting a spectrum into 1 Hz wide bands, called passbands, yields the power spectral density of the sound. These values directly compare to the Wenz curves, which represent typical deep ocean sound levels (Figure 2) (Wenz 1962). This splitting of the spectrum into passbands of a constant width of 1 Hz, however, does not represent how animals perceive sound.

Because animals perceive exponential increases in frequency rather than linear increases, analyzing a sound spectrum with bands that increase exponentially in size better approximates real-world scenarios. In underwater acoustics, a spectrum is commonly split into 1/3-octave-bands, which are one-third of an octave wide; each octave represents a doubling in sound frequency. A very similar measure is to logarithmically divide each frequency decade into 10 passbands, which are commonly misnamed the 1/3-octave-bands (base 10) rather than deci-decades; we use this naming in the report. The centre frequency of the ith 1/3-octave-band, $f_c(i)$, is defined as:

$$f_{\mathrm{c}}(i) = 10^{i/10} \,, \tag{10}$$

and the low (f_{lo}) and high (f_{hi}) frequency limits of the ith 1/3-octave-band are defined as:

$$f_{\mathrm{lo}} = 10^{-1/20} f_{\mathrm{c}}(i) \quad \text{and} \quad f_{\mathrm{hi}} = 10^{1/20} f_{\mathrm{c}}(i) \,. \tag{11}$$

The 1/3-octave-bands become wider with increasing frequency, and on a logarithmic scale the bands appear equally spaced (Figure 114).

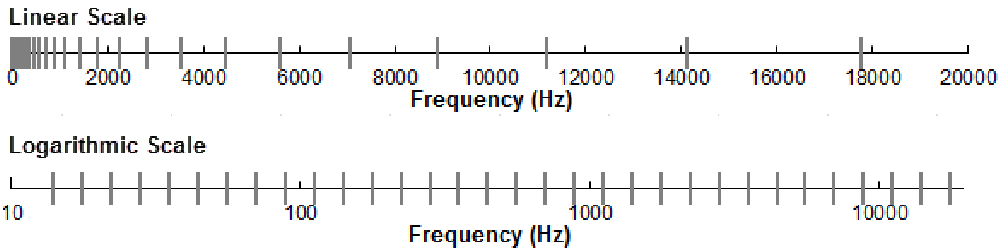


Figure 114. One-third-octave-bands shown on a linear frequency scale and on a logarithmic scale.

The sound pressure level in the ith 1/3-octave-band $(L_b^{(i)})$ is computed from the power spectrum $S(f)$ between f_{lo} and f_{hi}:

$$L_{\mathrm{b}}^{(i)} = 10\log_{10}\left(\int_{f_{lo}}^{f_{hi}} S(f)df\right) \tag{12}$$

Summing the sound pressure level of all the 1/3-octave-bands yields the broadband sound pressure level:

$$\text{Broadband SPL} = 10\log_{10}\sum_i 10^{L_{\mathrm{b}}^{(i)}/10} \tag{13}$$

Figure 115 shows an example of how the 1/3-octave-band sound pressure levels compare to the power spectrum of an ambient noise signal. Because the 1/3-octave-bands are wider with increasing frequency, the 1/3-octave-band SPL is higher than the power spectrum, especially at higher frequencies. 1/3-octave-band analysis is applied to both continuous and impulsive noise sources. For impulsive sources, the 1/3-octave-band SEL is typically reported.

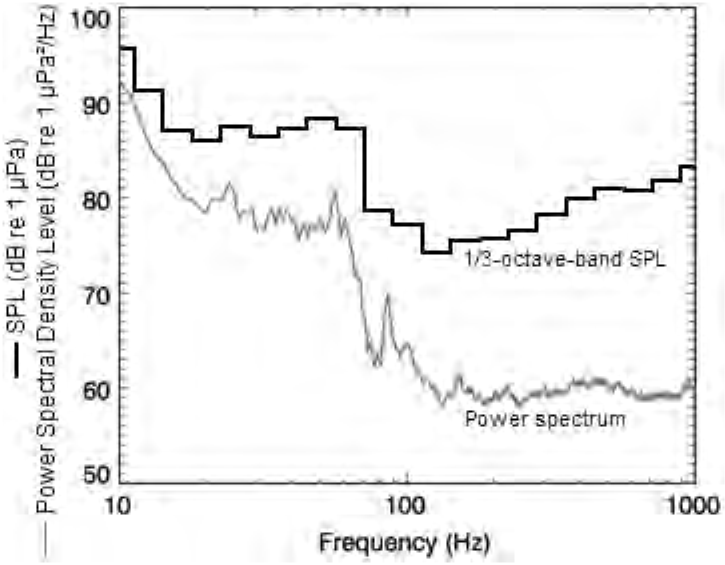


Figure 115. A power spectrum and the corresponding 1/3-octave-band sound pressure levels of example ambient noise shown on a logarithmic frequency scale. Because the 1/3-octave-bands are wider with increasing frequency, the 1/3-octave-band SPL is higher than the power spectrum.

Appendix E. Marine Mammal Detection Methodology

E.1. Click Detection

Odontocete clicks were detected by the following steps (Figure 116):

1. The raw data was high-pass filtered to remove all energy below 8 kHz. This removed most energy from other sources such as shrimp, vessels, wind, and cetacean tonal calls, while allowing the energy from all marine mammal click types to pass.
1. The filtered samples were summed to create a 0.5 ms rms time series. Most marine mammal clicks have a 0.1–1 ms duration.
2. Possible click events were identified with a Teager-Kaiser energy detector.
3. The maximum peak signal within 1 ms of the detected peak was found in the high-pass filtered data.
4. The high-pass filtered data was searched backwards and forwards to find the time span where the local data maxima were within 12 dB of the maximum peak. The algorithm allowed two zero-crossings to occur where the local peak was not within 12 dB of the maximum before stopping the search. This defined the time window of the detected click.
5. The classification parameters were extracted. The number of zero crossings within the click, the median time separation between zero crossings, and the slope of the change in time separation between zero crossings were computed. The slope parameter helps to identify beaked whale clicks, as beaked whale clicks increase in frequency (upsweep).
6. The Mahalanobis distance between the extracted classification parameters and the templates of known click types was computed. The covariance matrices for the known click types, computed from thousands of manually identified clicks for each species, were stored in an external file. Each click was classified as a type with the minimum Mahalanobis distance, unless none of them were less than the specified distance threshold.

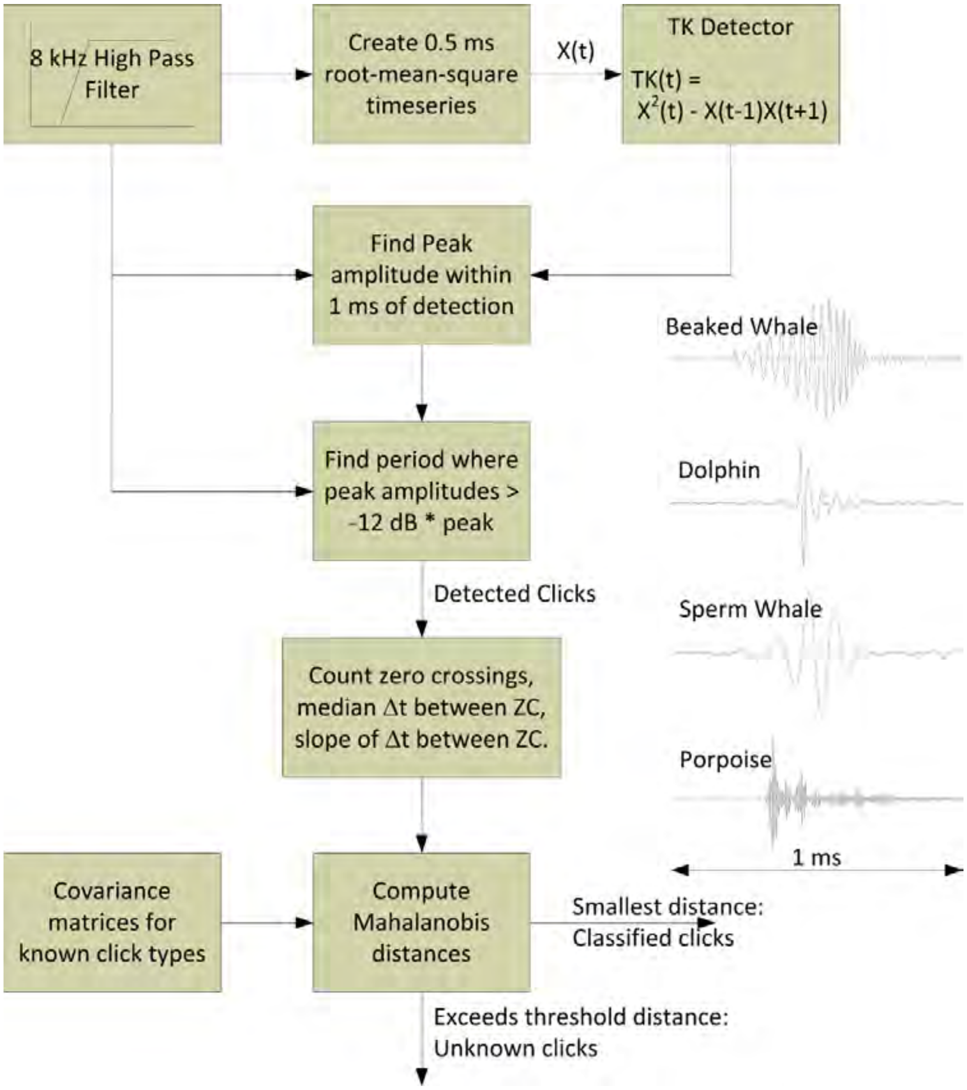


Figure 116. The click detector/classifier and a 1-ms time-series of four click types.

E.2. Tonal Signal Detection

Marine mammal tonal acoustic signals are detected by the following steps:

1. Spectrograms of the appropriate resolution for each mammal vocalization type that were normalized by the median value in each frequency bin for each detection window (Table 8) were created.
2. Adjacent bins were joined, and contours were created via a contour-following algorithm (Figure 117).
3. A sorting algorithm determined if the contours match the definition of a marine mammal vocalization (Table 9).

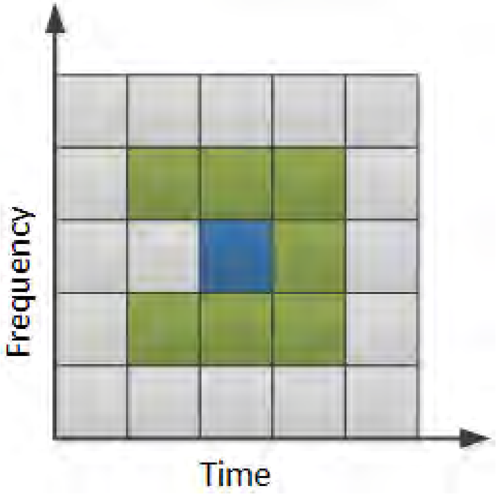


Figure 117. Illustration of the search area used to connect spectrogram bins. The blue square represents a bin of the binary spectrogram equalling 1 and the green squares represent the potential bins it could be connected to. The algorithm advances from left to right so grey cells left of the test cell need not be checked.

Table 8. Fast Fourier Transform (FFT) and detection window settings used to detect tonal vocalizations of marine mammal species expected in the data. Values are based on JASCO's experience and empirical evaluation on a variety of data sets.

Possible species	Vocalization	FFT			Detection window (s)	Detection threshold
		Resolution (Hz)	Frame length (s)	Timestep (s)		
Pilot whales	Whistle	16	0.03	0.015	5	3
Dolphins	Whistle	64	0.015	0.005	5	3
Humpback whales	Moan	4	0.2	0.05	5	3
Blue whales	Infrasonic moan	0.125	2	0.5	120	4
Right whales	Upcall	2	0.2	0.05	5	3
Fin whales	20-Hz note	1	0.2	0.05	5	4
Sei whales	Downsweep	3.25	0.2	0.035	5	3.5
Bearded seals	trills	2	0.2	0.05	10	3

Table 9. A sample of vocalization sorter definitions for the tonal vocalizations of cetacean species expected in the area.

Possible species	Vocalization	Frequency (Hz)	Duration (s)	Bandwidth (Hz)	Other detection parameters
Pilot whales	Whistle	1,000–10,000	0.5–5	>300	Minimum frequency <5,000 Hz
Dolphin	Whistle	4,000–20,000	0.3–3	>700	Maximum instantaneous bandwidth = 5,000 Hz
Humpback whales	Moan	100–700	0.5–5	>50	Maximum instantaneous bandwidth = 200 Hz
Blue whales	Infrasonic moan	15–22	8–30	1–5	Minimum frequency <18 Hz
Right whales	Upcall	50–300	0.4–2.2	60–250	Minimum frequency <120 Hz Maximum instantaneous bandwidth = 80 Hz Sweep rate = 30 to 200 Hz/s
Fin whales	20 Hz downsweep	8–40	0.3–3	>6	Minimum frequency <17 Hz Sweep rate = −100 to 0 Hz/s
Sei whales	Downsweep	20–150	0.5–1.7	19–120	Maximum instantaneous bandwidth = 100 Hz Sweep rate = −100 to −6 Hz/s
Bearded seals	Trill	200–1500	1–10	>100	Maximum instantaneous bandwidth = 120 Hz Sweep rate = −30 to −500 Hz/s

E.3. Validation of Automated Detectors

E.3.1. Selecting Data for Manual Validation

To standardize the file selection process, we developed an algorithm that automatically selects a sample of files for review. The sample size *N* is set based on the amount of time allocated to the review effort. The algorithm selects files to manually review based on the following criteria:

1. All species targeted by a detector whose performance needs to be assessed must be represented within a minimum of 10 files (unless fewer than 10 files have detections).
2. The sample should not include more than one file per day unless *N* is greater than the number of recording days or the "minimum 10 files per species" rule dictates that more than one file per day be reviewed.
3. Select files containing low, medium, and high numbers of detected species. Files with no detected species are excluded from the pool of eligible files. Files are selected such that the proportion of each species count bin within the sample matches the per-file species count distribution in the whole data set.
4. Select files with low, medium, and high numbers of detections per file for each species. The number of detections per file is split into low (but at least one), medium, and high bins, which corresponded to the lower, middle, and upper third percentile of the range, respectively. Files with no detection for each species will appear among those with detections of other species, allowing us to evaluate false negatives. We choose to slightly oversample the high detection counts (40% of files compared with 30% from the medium and low bins) to avoid biasing the threshold high. The three files with the highest detection counts are automatically included in those selected from the high bins for the same reason.

We score the goodness of fit of a sample of files according to how well it conforms to the "preferred" distribution of detections, as determined by the initial distribution and the preferred final sampling. A lower score implies a better fit. To score the goodness of fit, we perform the following step for a selected sample of files:

1. Determine the diversity (species count per file) proportions (Pc) of the selected sample of files, and calculate a diversity score based on how much the current proportions differ from the original diversity proportions (Po).

   DiversityScore = average(abs(Pc[i]–Po[i]))

2. For each species, determine the proportion of files (C) that have detection counts in the low/medium/high original species count distributions. Files with no detections are not included in the calculation for each species (0-detection files for a species will unavoidably be included in files selected for other species).

   PerSpeciesScore[i] = abs(C_{low}–0.3) + abs(C_{medium}–0.3) + abs(C_{high}–0.4)

   DetectionScore = average(PerSpeciesScore[1..n]), where n is the number of species

   FitScore = (DiversityScore + DetectionScore)/2

E.3.2. Detector Performance Calculation and Optimization

All files selected for manual validation were reviewed by one of three experienced analysts using JASCO's PAMlab software to determine the presence or absence of every species, regardless of whether a species was automatically detected in the file. Although the detectors classify specific signals, we validated the presence/absence of species at the file level, not the detection level. Acoustic signals were only assigned to a species if the analyst was confident in their assessment. When unsure, analysts would consult one another, peer reviewed literature, and other experts in the field. If certainty could not be reached, the file of concern would be classified as possibly containing the species in question, or containing an unknown acoustic signal. Next, the validated results were compared to the raw detector results in three phases to refine the results and ensure they accurately represent the occurrence of each species in the study area.

In phase 1, the validated versus detector results were plotted as time series and critically reviewed to determine when and where automated detections should be excluded. The size of the area monitored in this project coupled with extreme seasonal fluctuations at some recorder's locations throughout the year (i.e., open water in summer compared to ice covered in winter) results in a range of acoustic conditions that can challenge detectors differentially across stations. Questionable detections that overlap with the detection period of other species were scrutinized. By restricting detections spatially and/or temporally where appropriate, we can maximize the reliability of the results. The following restrictions were applied to our detector results:

1. If a species was automatically detected at a station for a given recording year, but was never manually validated, all automated detections at that station were considered false and the station in that year was not included in the results as the species was considered absent.
2. If a species was automatically detected over a specific timeframe, but manual validation revealed all detections to be falsely triggered by another sound source or species, all automated detections during that time at that station were excluded. The timeframes removed for each species at each station across both recording years are specified in Appendix G.

In phase 2, the performance of the detectors was calculated based on the phase 1 restrictions and optimized for each species using a threshold, defined as the number of detections per file at and above which detections of species were considered valid. This was completed for each station-year combination as automated detectors perform differently depending on factors, such as the species diversity of the area or human activity, which vary in space and time.

To determine the performance of each detector and any necessary thresholds, the automated and validated results (excluding files where an analyst indicated uncertainty in species occurrence) were fed to a maximum likelihood estimation algorithm that maximizes the probability of detection and minimizes the number of false alarms using the 'F-score':

$$F = \frac{(1+\beta^2)P * R}{(\beta^2)P + R}; P = \frac{TP}{TP + FP}; R = \frac{TP}{TP + FN}$$

where *TP* (true positive) is the number of correctly detected files, *FP* (false positive) is the number of files that are false detections, and *FN* (false negatives) is the number of files with missed detections.

P is the classifier's precision, representing the proportion of files with detections that are true positives. A *P* value of 0.9 means that 90% of the files with detections truly contain that species, but says nothing about whether all files containing acoustic signals from the species were identified. *R* is the classifier's recall, representing the proportion of files containing the species of interest that are identified by the detector. An *R* value of 0.8 means that 80% of all files containing acoustic signals from the species of interest also contained automated detections, but says nothing about how many files with detections were incorrect. Thus, a perfect detector would have *P* and *R* values equal to 1. An F-score is a combined measure of *P* and *R* where an F-score of 1 indicates perfect performance–all events are detected with no false alarms. The algorithm determines a detector threshold for each species, at every station, for both years, that maximizes the F-score. The resulting thresholds, Ps, and Rs are presented in Section 3.4.1 and in further detail in Appendix F. Table 10 shows the dependence of the classification threshold on the β-parameter and its effect on the precision and recall of the detector and classifier system. β is the relative weight between the recall and precision. Here, we made precision more important than recall as a β of 0.5 means the recall has half the weight of the precision.

Table 10. Effects of changing the F-score β-parameter on the classification threshold, precision, and recall for the odontocete clicks.

β	Classification threshold	Precision $P = \frac{TP}{TP + FP}$	Recall $R = \frac{TP}{TP + FN}$	F-score
2	25	0.87	0.95	0.93
0.5	50	0.91	0.91	0.91

Where the number of validated files was too low, and/or the overlap between manual and automated detections was too limited for the calculation of P, R, and F, automated detections were ignored and only validated results were used to describe the acoustic occurrence of a species.

In phase 3, the detections were further restricted to include only those where and when P was greater than or equal to 0.75. When P < 0.75, only the validated results were used to describe the acoustic occurrence of a species.

The occurrence of each species (both validated and automated, or validated only where appropriate) was plotted using JASCO's Ark software as time series showing presence/absence by hour over each day for the two recording periods. Marine mammal occurrence is also presented as spatial plots for each station and recording year. The spatial plots depict mean hourly detection counts (MHDC) or presence/absence over the whole recording period or selected sub-periods if justified by temporal patterns of acoustic detections revealed by the detection time series.

Appendix F. Ambient Noise Results

Section 3.1 presents ambient results for stn 1, 4, 5, 12,15, 18, and 19. Appendices F.1–F.4 presents the ambient results for all stations.

F.1. Broadband and Decade-Band Sound Pressure Levels and Spectrograms

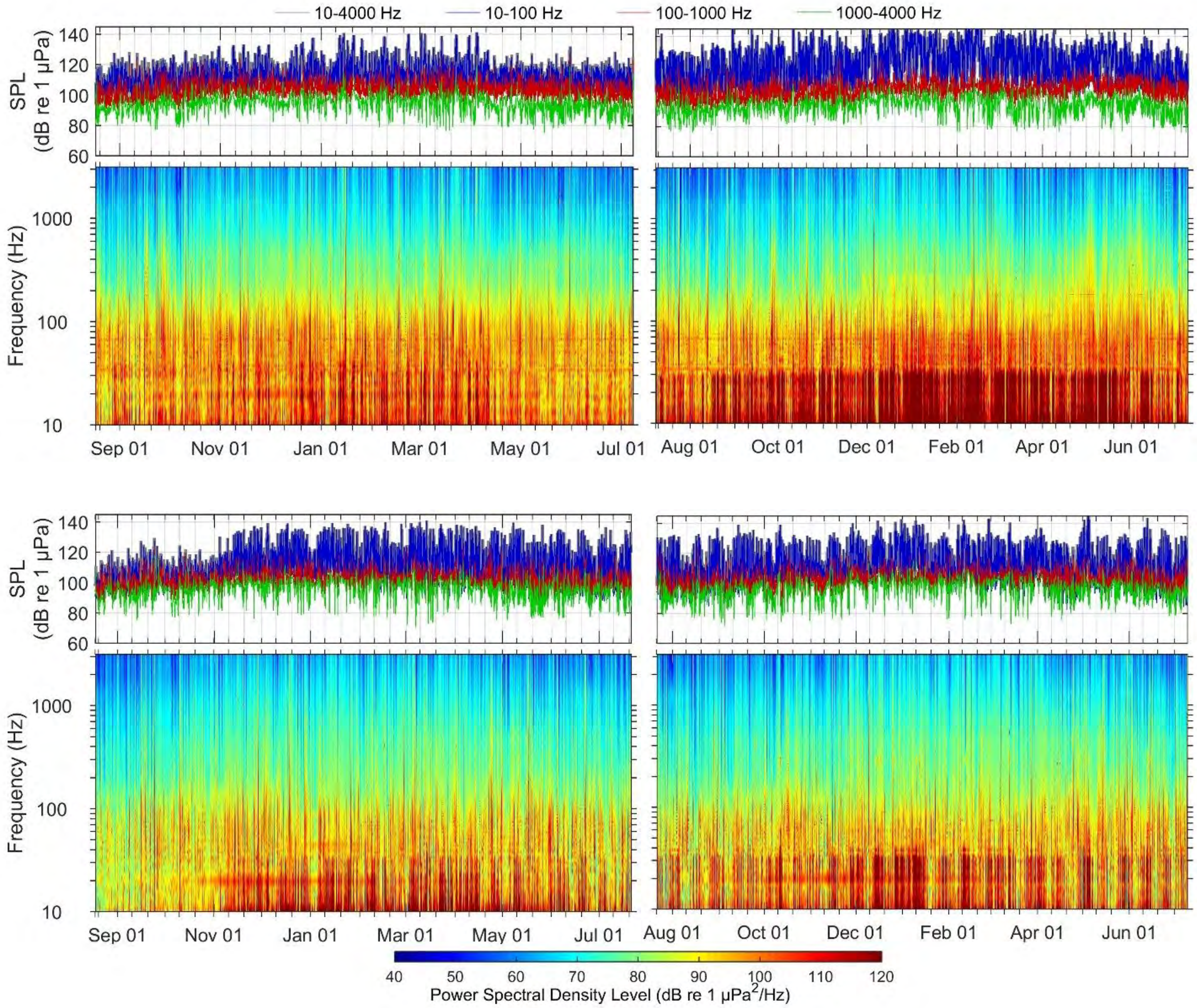


Figure 118. Stn 1 and 2 (top and bottom) for (left) 2015–16, (right) 2016–17: In-band SPL and spectrogram of underwater sound.

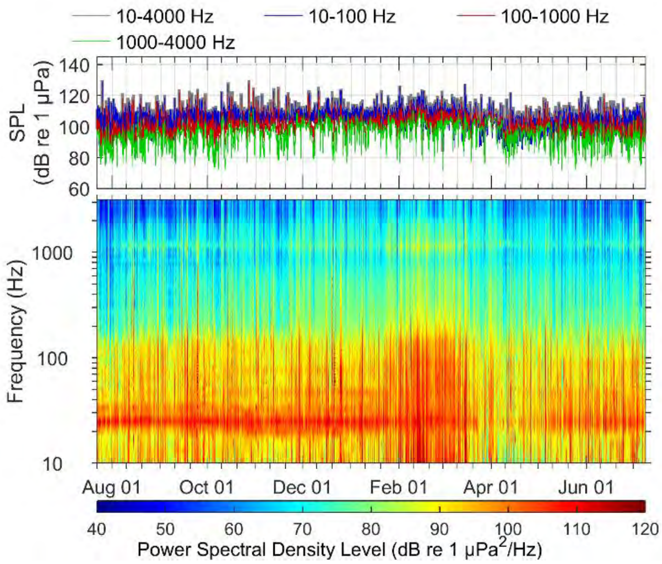


Figure 119. Stn 3 2016–17 (recorder lost in 2015–16): In-band SPL and spectrogram of underwater sound.

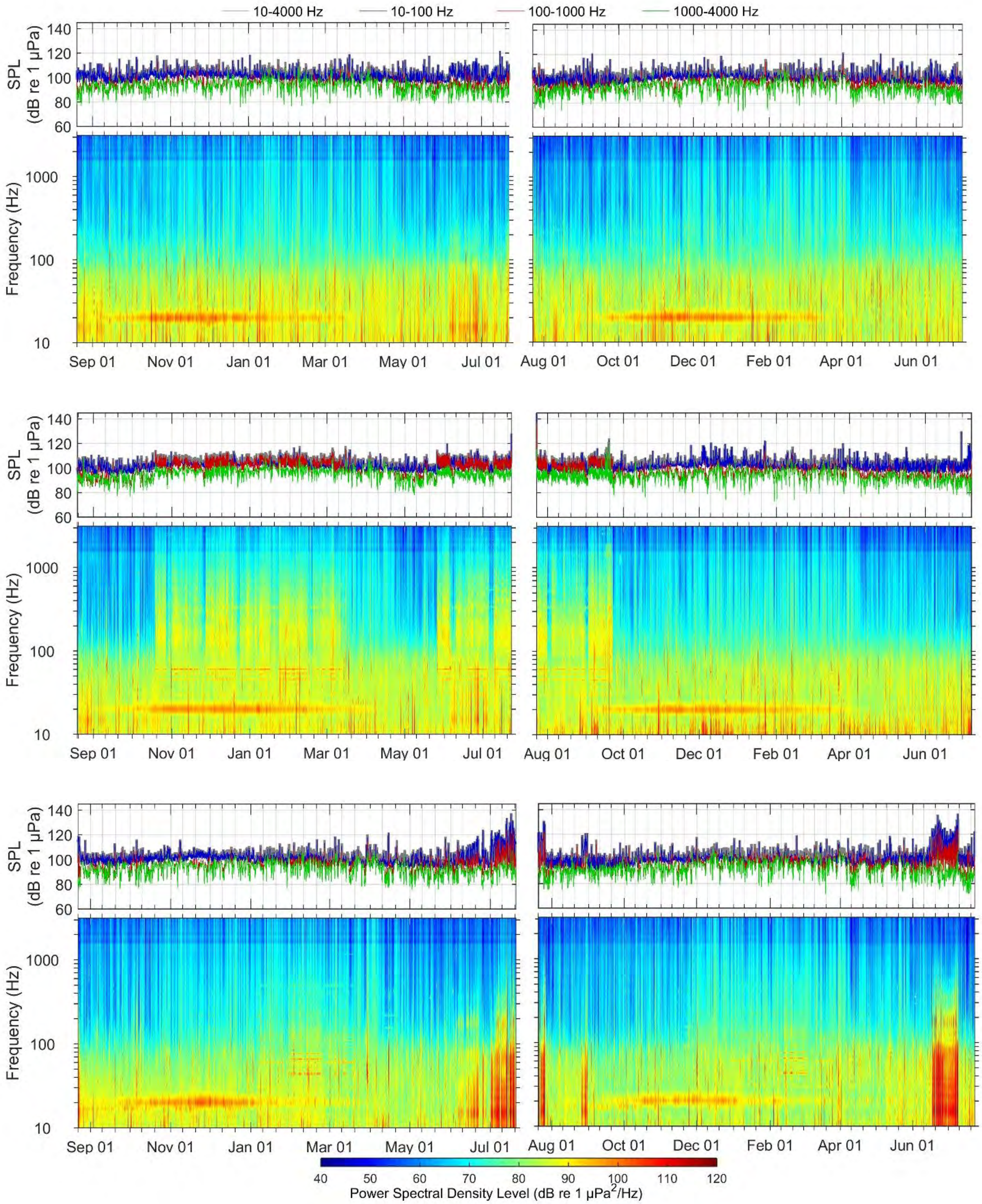


Figure 120. Stn 4, 5, and 6 (top, middle, bottom) for 2015–16 (left) and 2016–17 (right): In-band SPL and spectrogram of underwater sound.

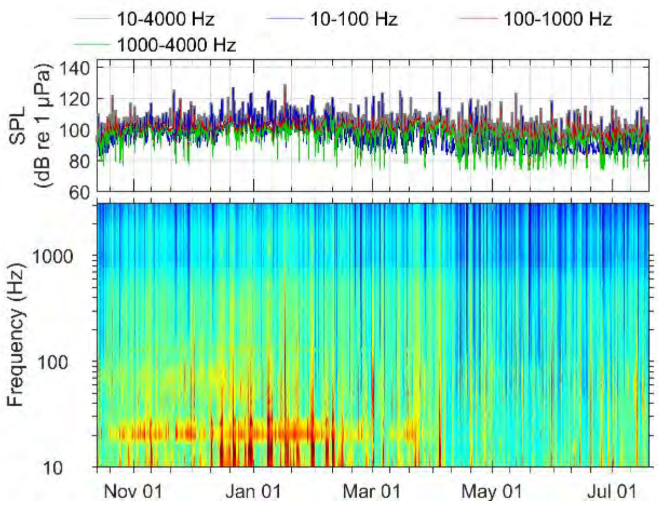


Figure 121. Stn 7, 2015–16 (recorder lost in 2016–17): In-band SPL and spectrogram of underwater noise.

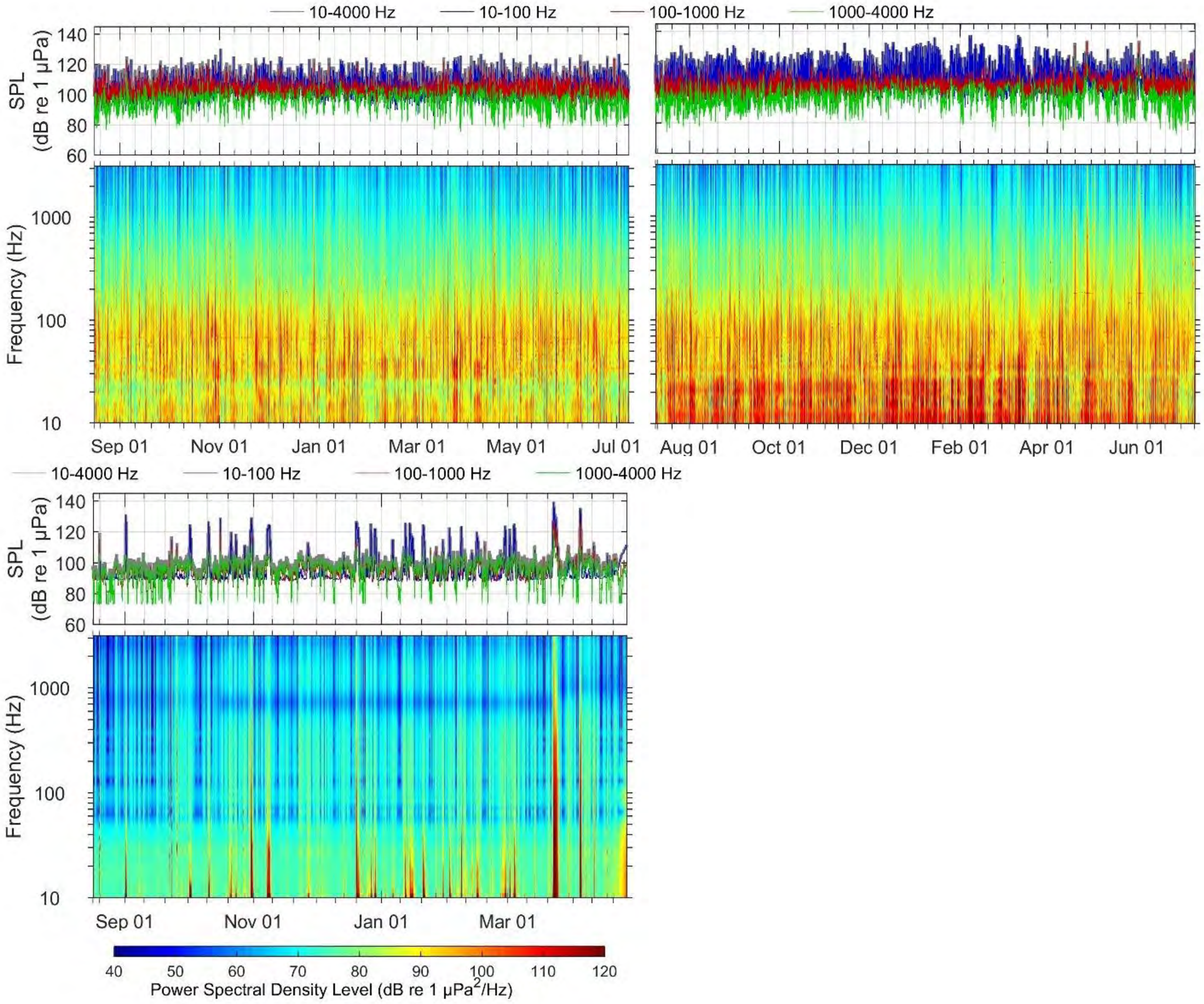


Figure 122. Stn 8 and 9 (top and bottom) (left) 2015–16, (right) 2016–17: In-band SPL and spectrogram of underwater sound.

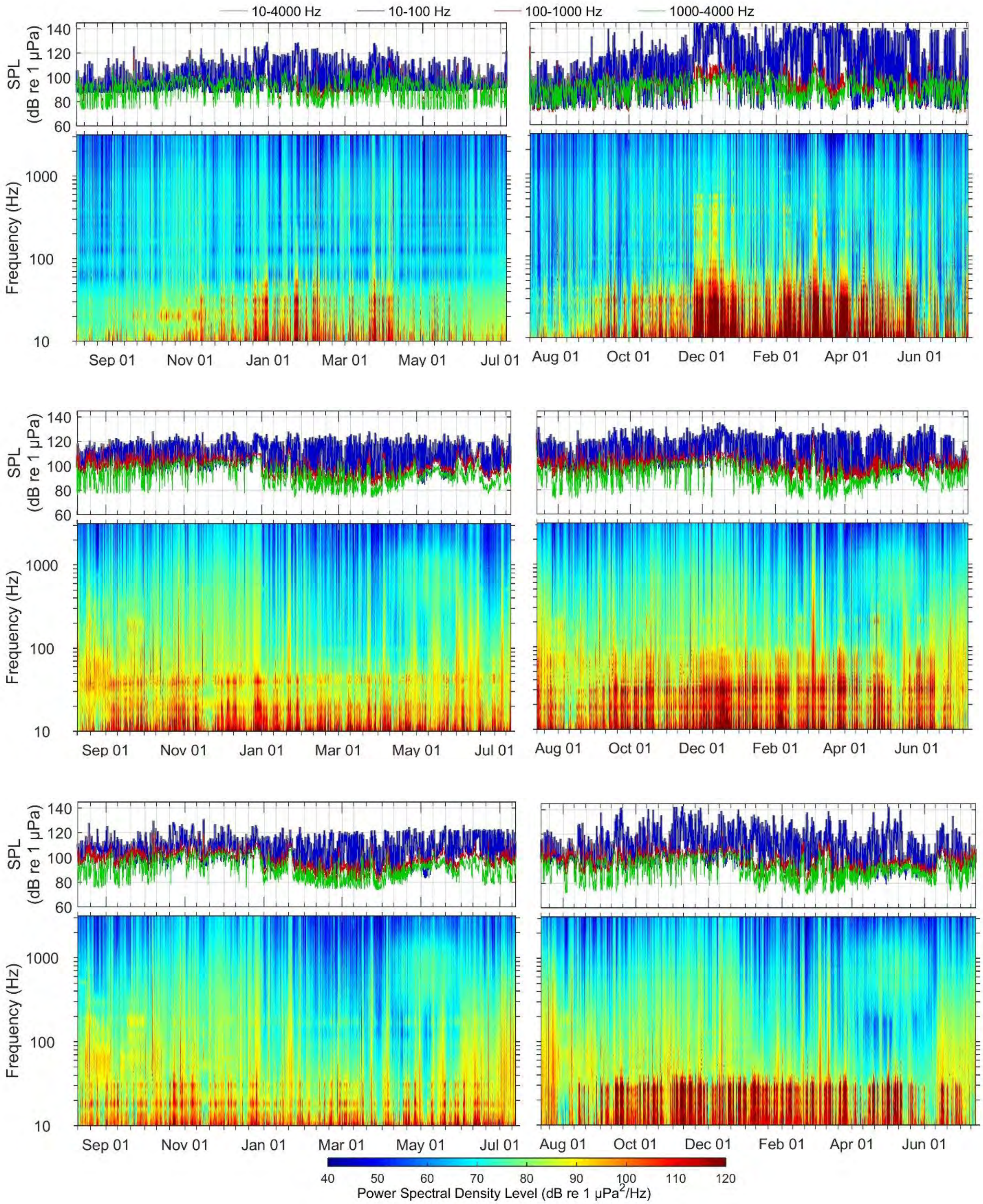


Figure 123. Stn 10, 11, and 12 (top, middle, bottom) for 2015–16 (left) and 2016–17 (right): In-band SPL and spectrogram of underwater sound.

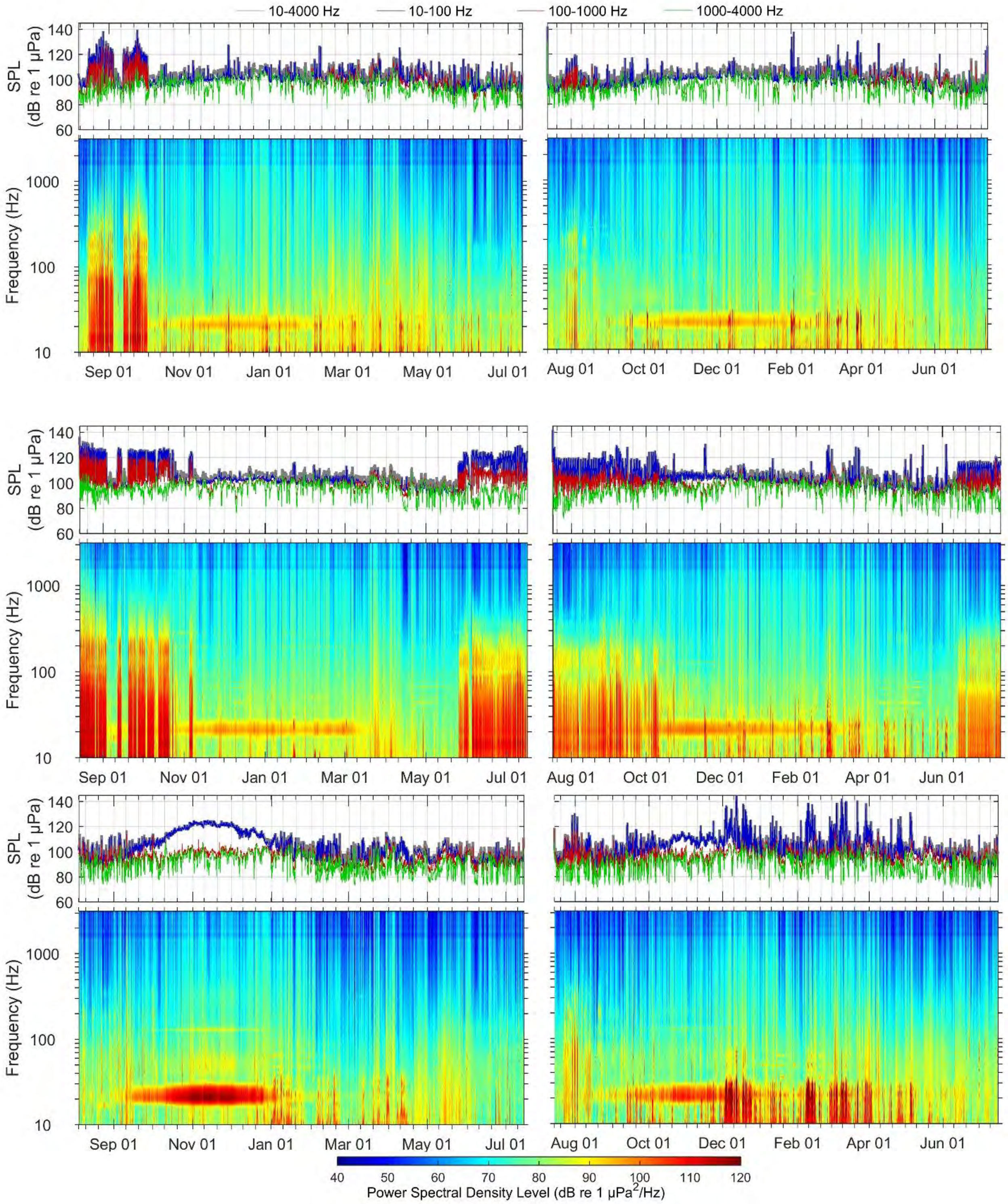


Figure 124. Stn 13, 14, and 15 (top, middle, bottom) for 2015–16 (left) and 2016–17 (right): In-band SPL and spectrogram of underwater sound.

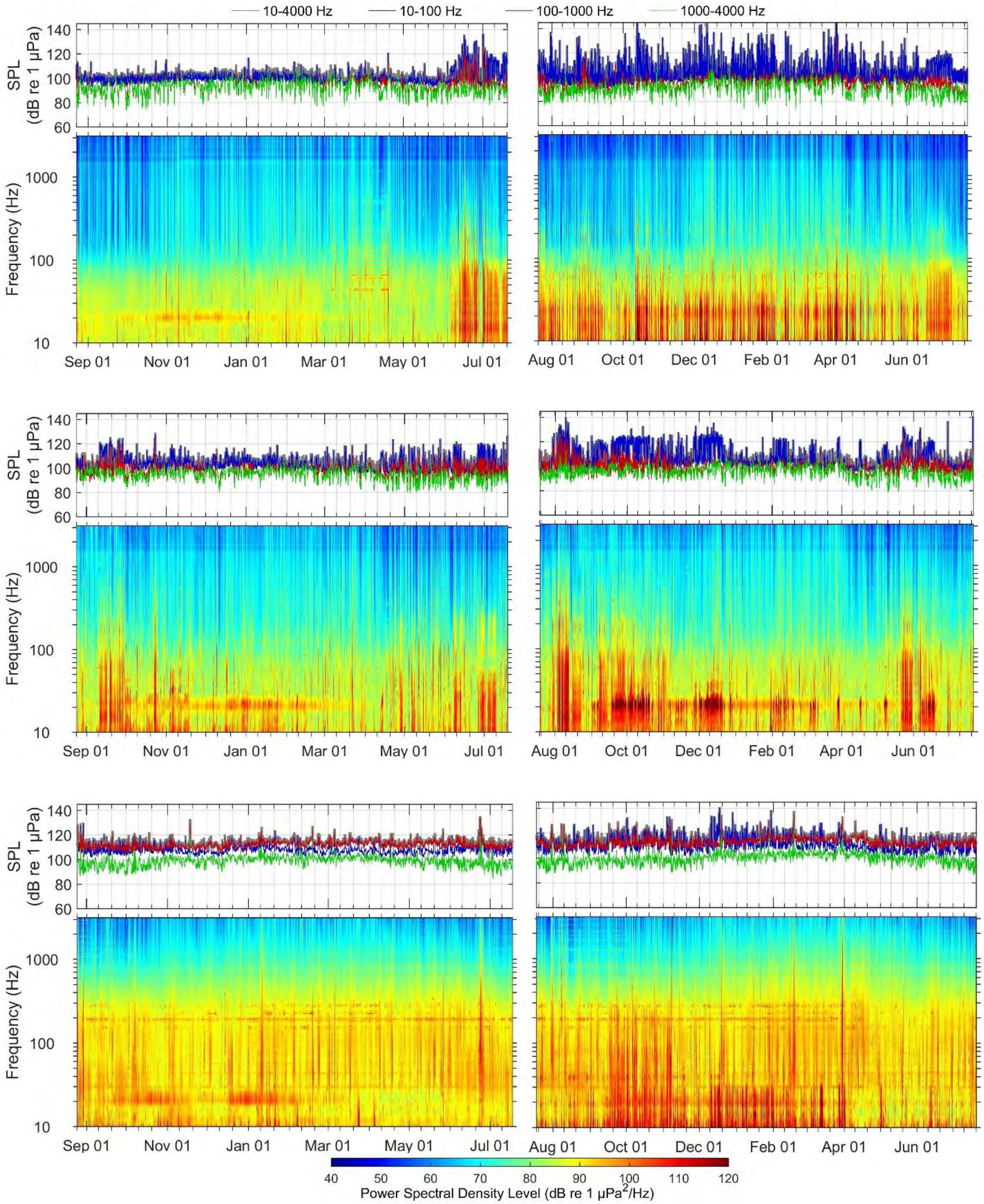


Figure 125. Stn 16, 17 and 18 (top, middle, bottom) for 2015–16 (left) and 2016–17 (right): In-band SPL and spectrogram of underwater sound.

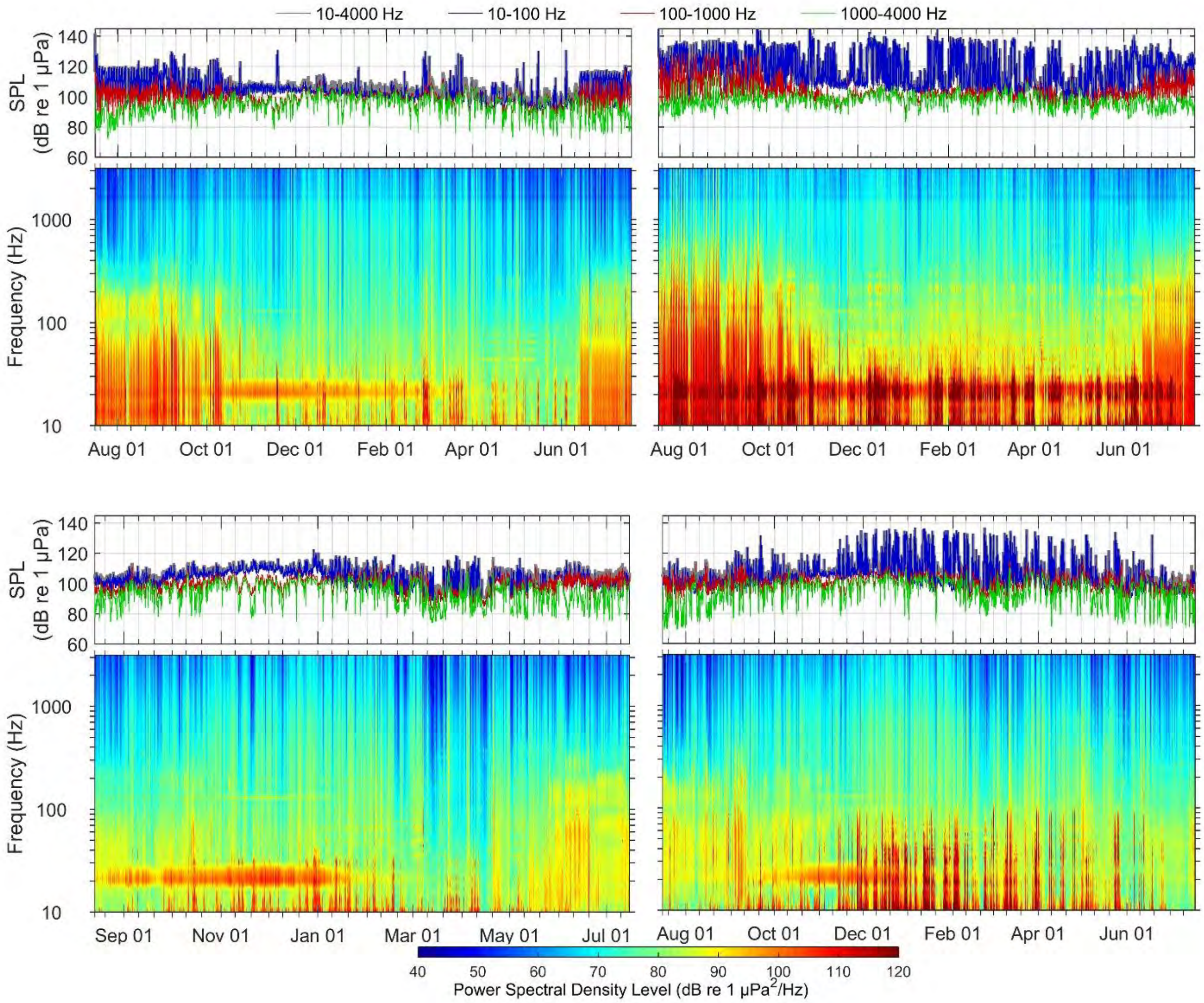


Figure 126. Stn 19 and 20 (top, middle, bottom) for 2015–16 (left) and 2016–17 (right): In-band SPL and spectrogram of underwater sound.

F.2. One-Third-Octave-Band Sound Pressure and Power Spectral Density Levels

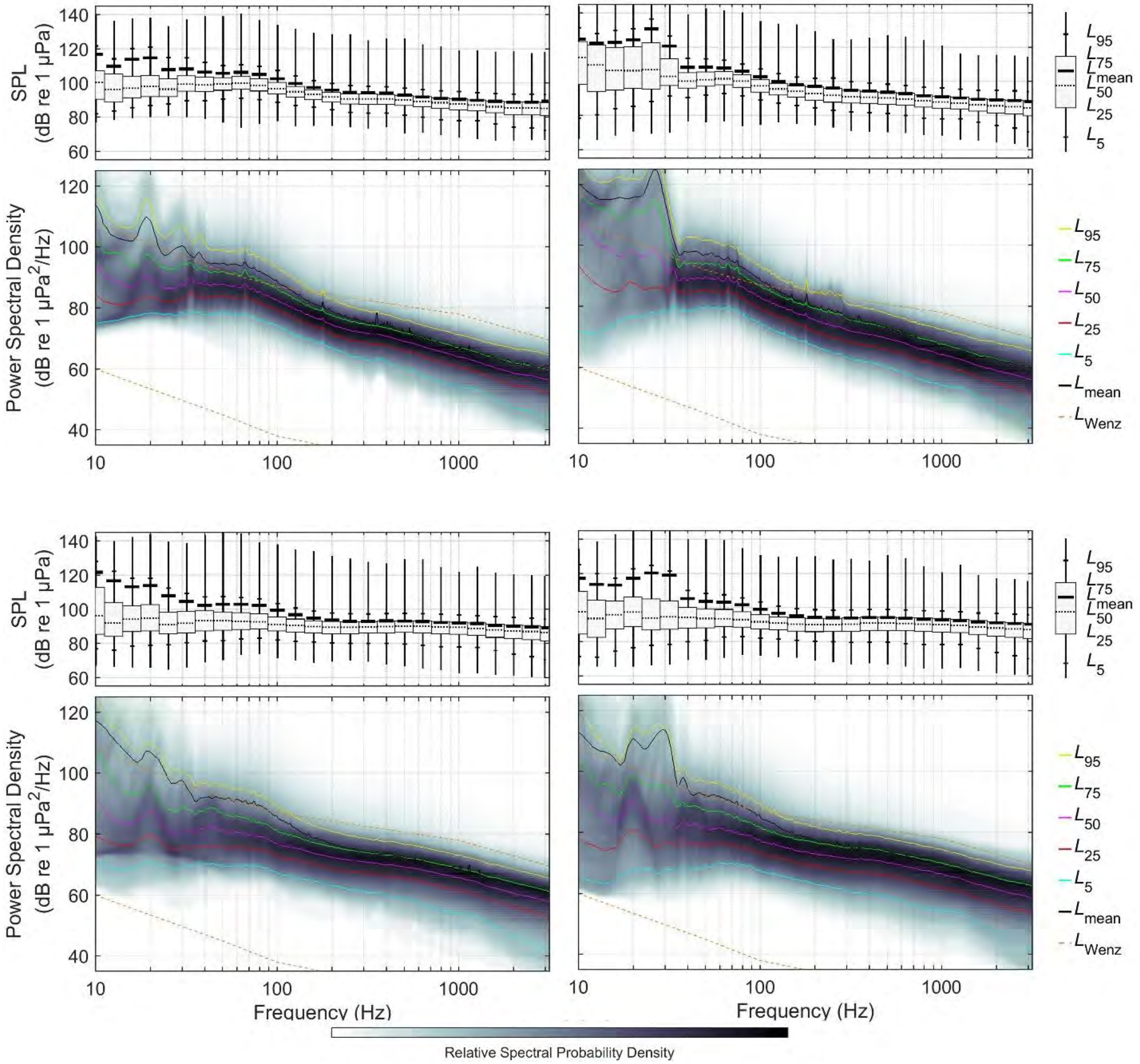


Figure 127. Stn 1 and 2 (top and bottom) for 2015–16 (left), 2016–17 (right): Exceedance percentiles and mean of 1/3-octave-band SPL and exceedance percentiles and probability density (grayscale) of 1-min PSD levels compared to the limits of prevailing noise (Wenz 1962).

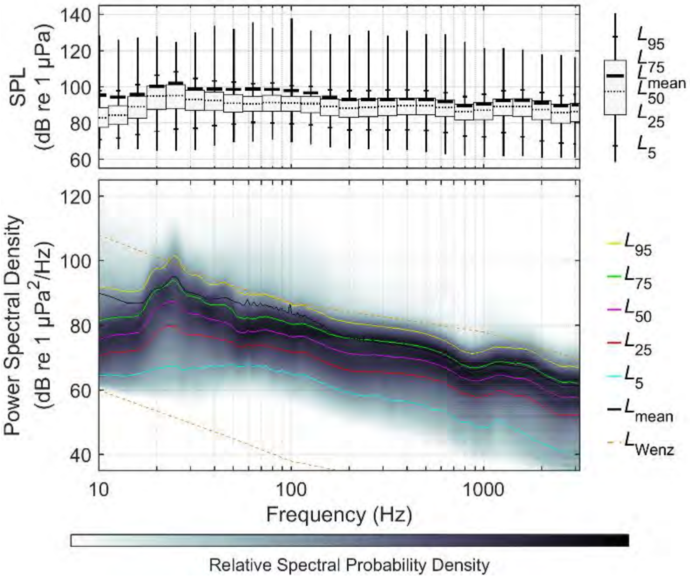


Figure 128. Stn 3, 2016–17 (recorder lost in 2015–16): Exceedance percentiles and mean of 1/3-octave-band SPL and exceedance percentiles and probability density (grayscale) of 1-min PSD levels compared to the limits of prevailing noise (Wenz 1962).

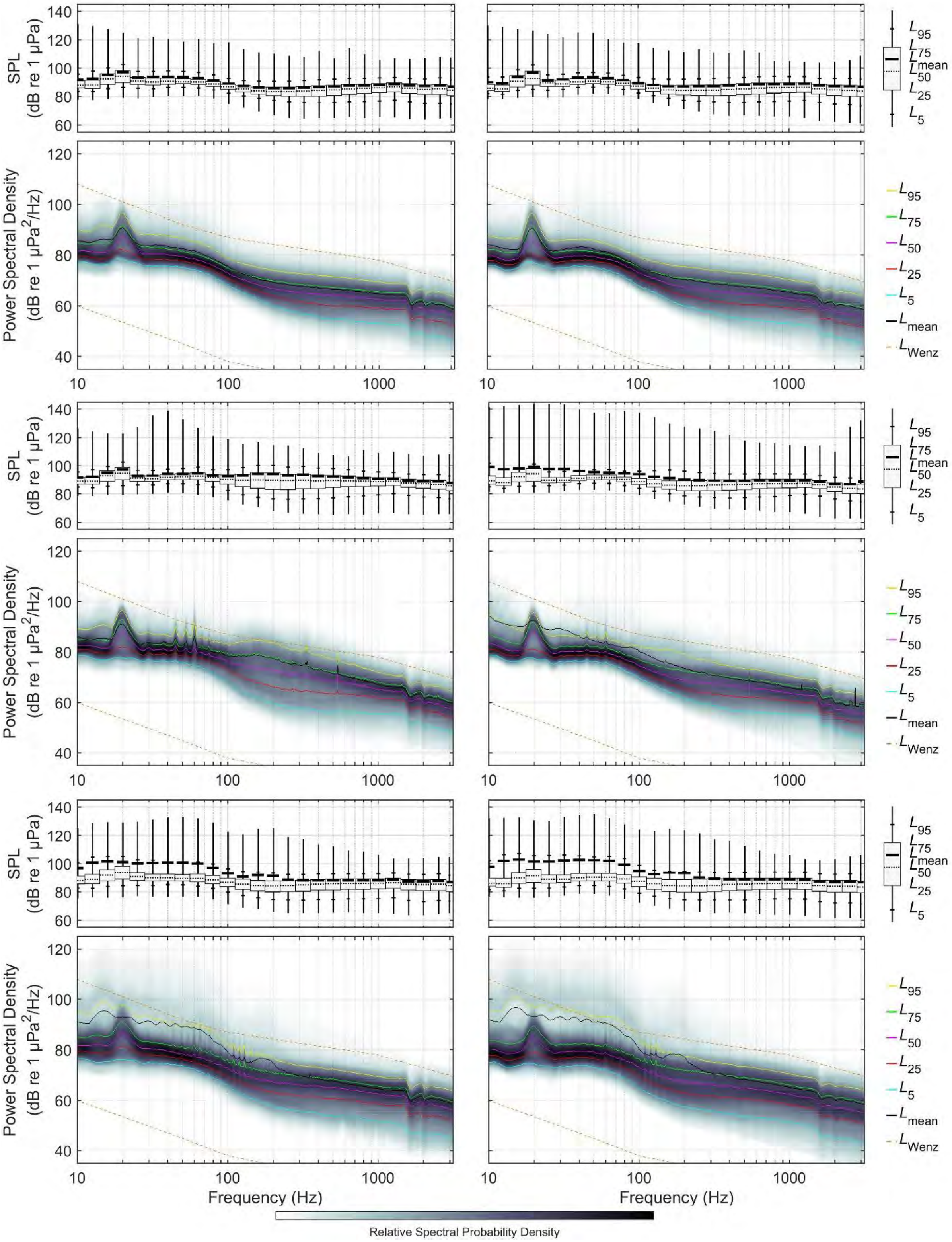


Figure 129. Stn 4, 5 and 6 (top, middle, bottom) for 2015–16 (left) and 2016–17 (right): Exceedance percentiles and mean of 1/3-octave-band SPL and exceedance percentiles and probability density (grayscale) of 1-min PSD levels compared to the limits of prevailing noise (Wenz 1962).

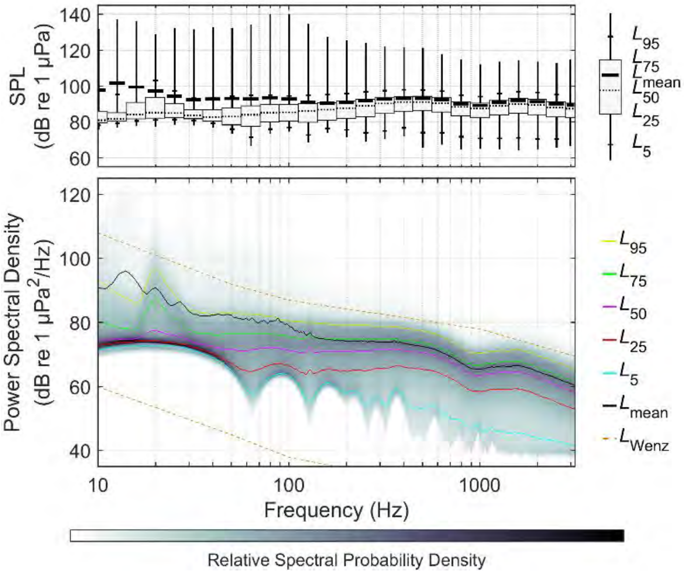


Figure 130. Stn 7, 2015–16 (recorder in 2016–17 lost): Exceedance percentiles and mean of 1/3-octave-band SPL and exceedance percentiles and probability density (grayscale) of 1-min PSD levels compared to the limits of prevailing noise (Wenz 1962).

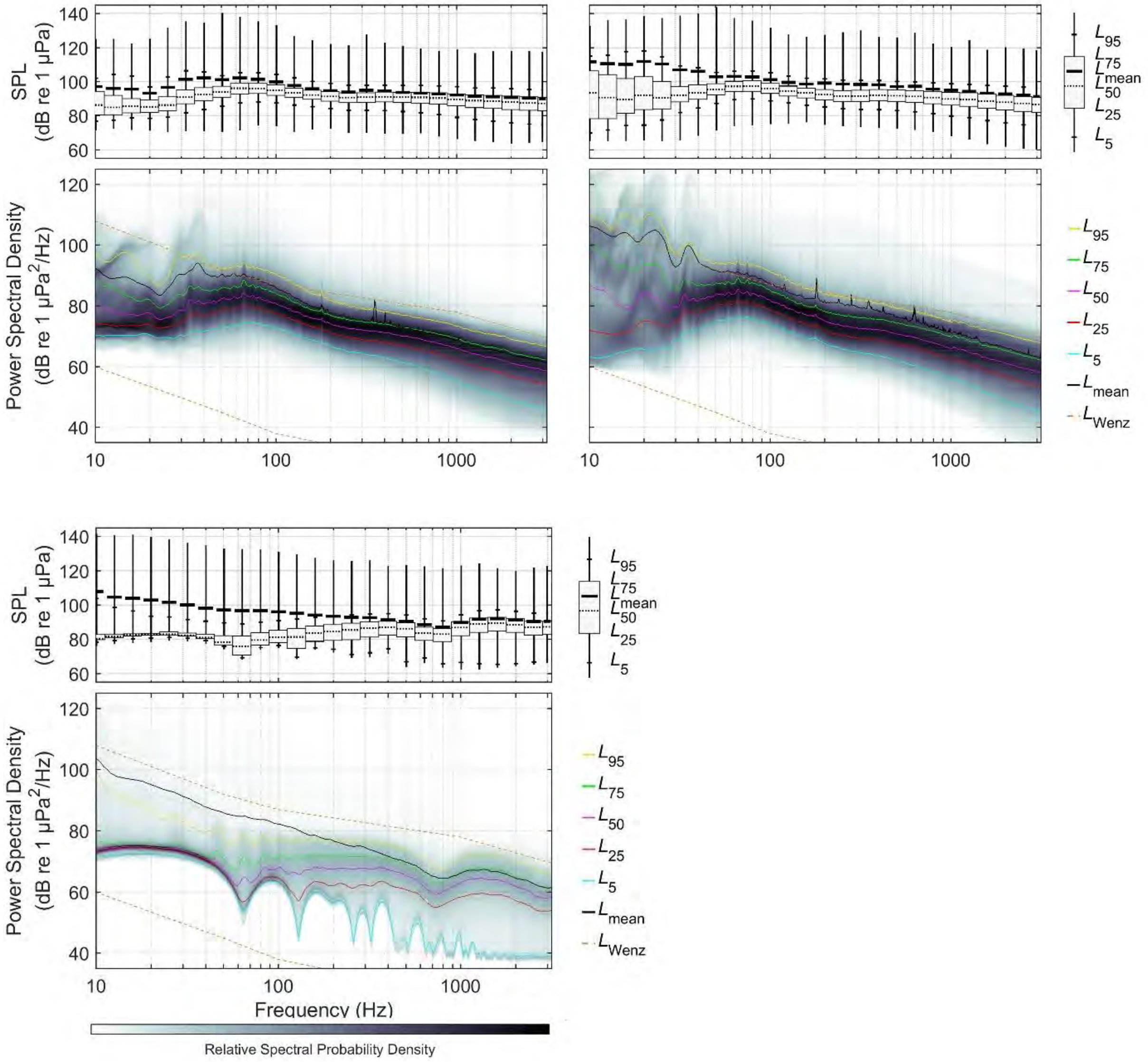


Figure 131. Stn 8 and 9 (top and bottom) for 2015–16 (left), 2016–17 (right): Exceedance percentiles and mean of 1/3-octave-band SPL and exceedance percentiles and probability density (grayscale) of 1-min PSD levels compared to the limits of prevailing noise (Wenz 1962).

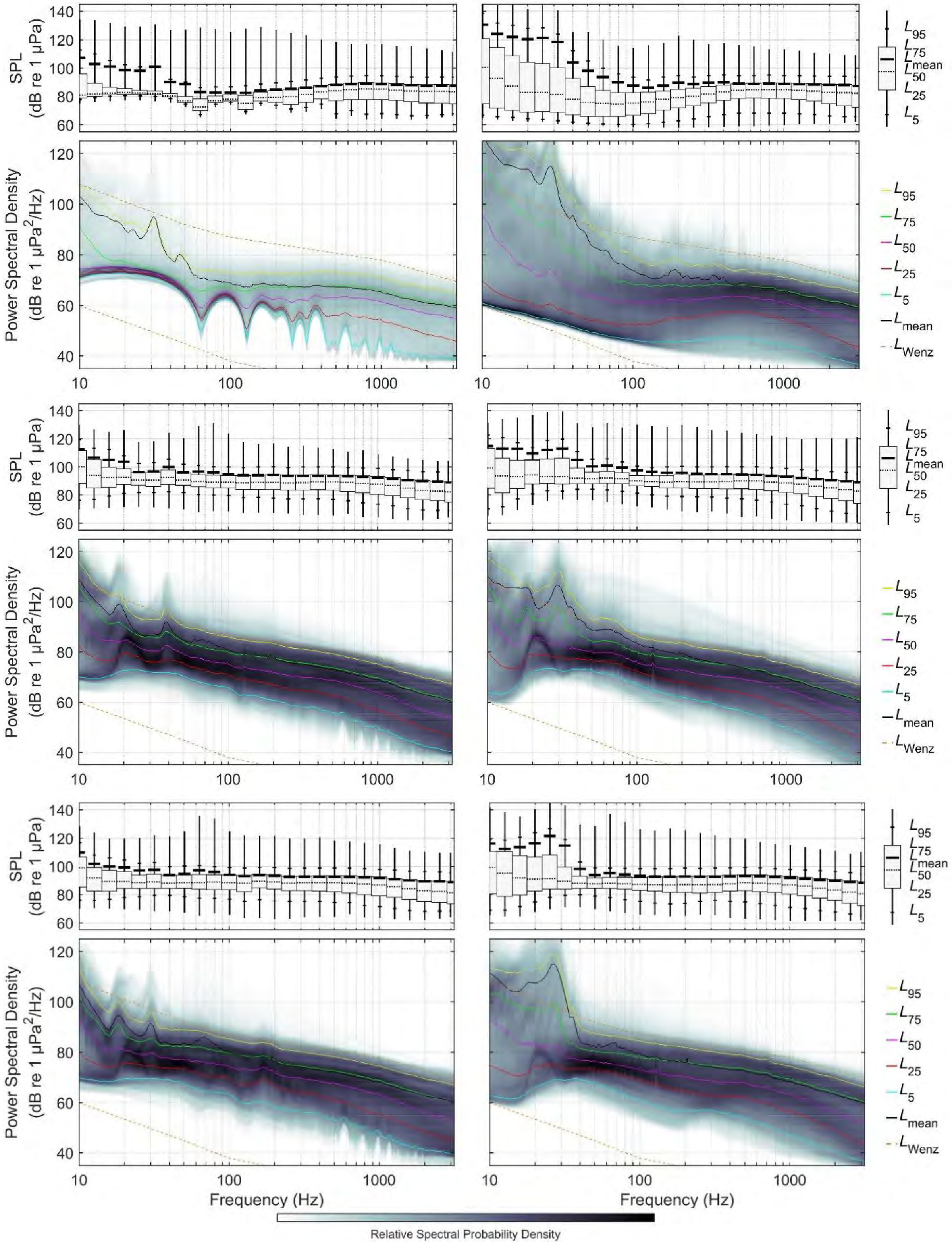


Figure 132. Stn 10, 11 and 12 (top, middle, bottom) for 2015–16 (left) and 2016–17 (right): Exceedance percentiles and mean of 1/3-octave-band SPL and exceedance percentiles and probability density (grayscale) of 1-min PSD levels compared to the limits of prevailing noise (Wenz 1962).

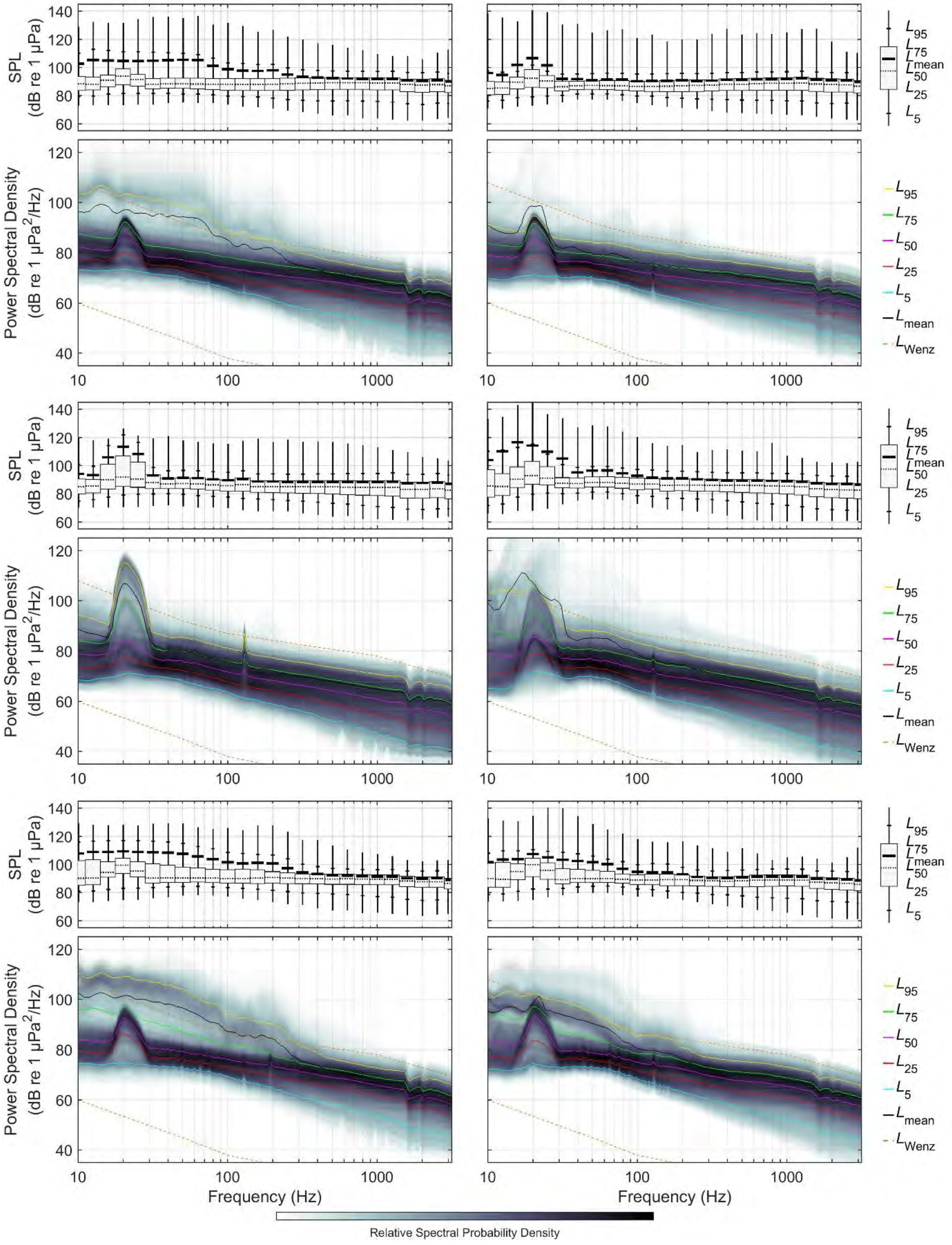


Figure 133. Stn 13, 14 and 15 (top, middle, bottom) for 2015–16 (left) and 2016–17 (right): Exceedance percentiles and mean of 1/3-octave-band SPL and exceedance percentiles and probability density (grayscale) of 1-min PSD levels compared to the limits of prevailing noise (Wenz 1962).

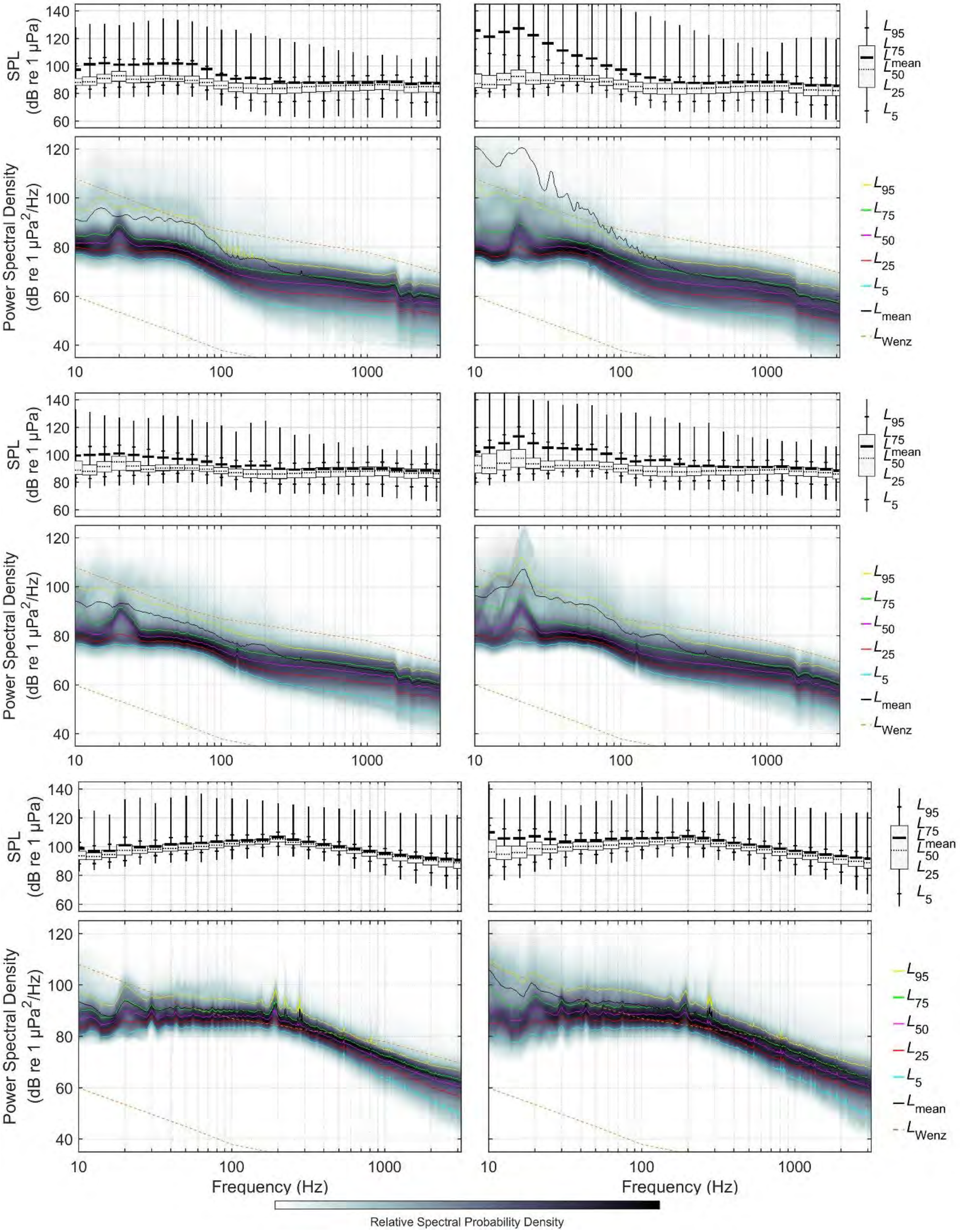


Figure 134. Stn 16, 17 and 18 (top, middle, bottom) for 2015–16 (left) and 2016–17 (right): Exceedance percentiles and mean of 1/3-octave-band SPL and exceedance percentiles and probability density (grayscale) of 1-min PSD levels compared to the limits of prevailing noise (Wenz 1962).

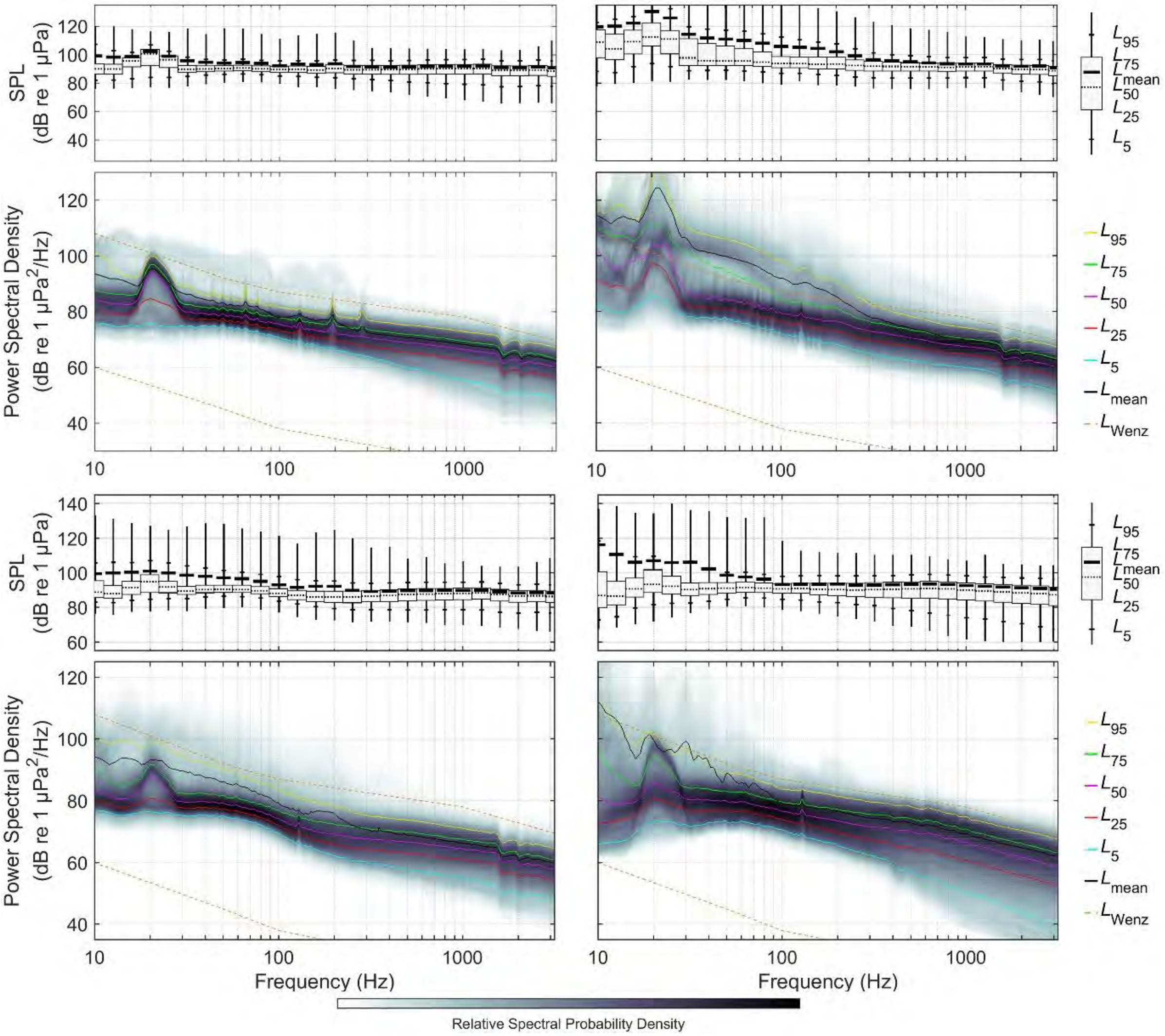


Figure 135. Stn 19 and 20 (top and bottom) for 2015–16 (left), 2016–17 (right): Exceedance percentiles and mean of 1/3-octave-band SPL and exceedance percentiles and probability density (grayscale) of 1-min PSD levels compared to the limits of prevailing noise (Wenz 1962).

F.3. Daily Sound Exposure Level

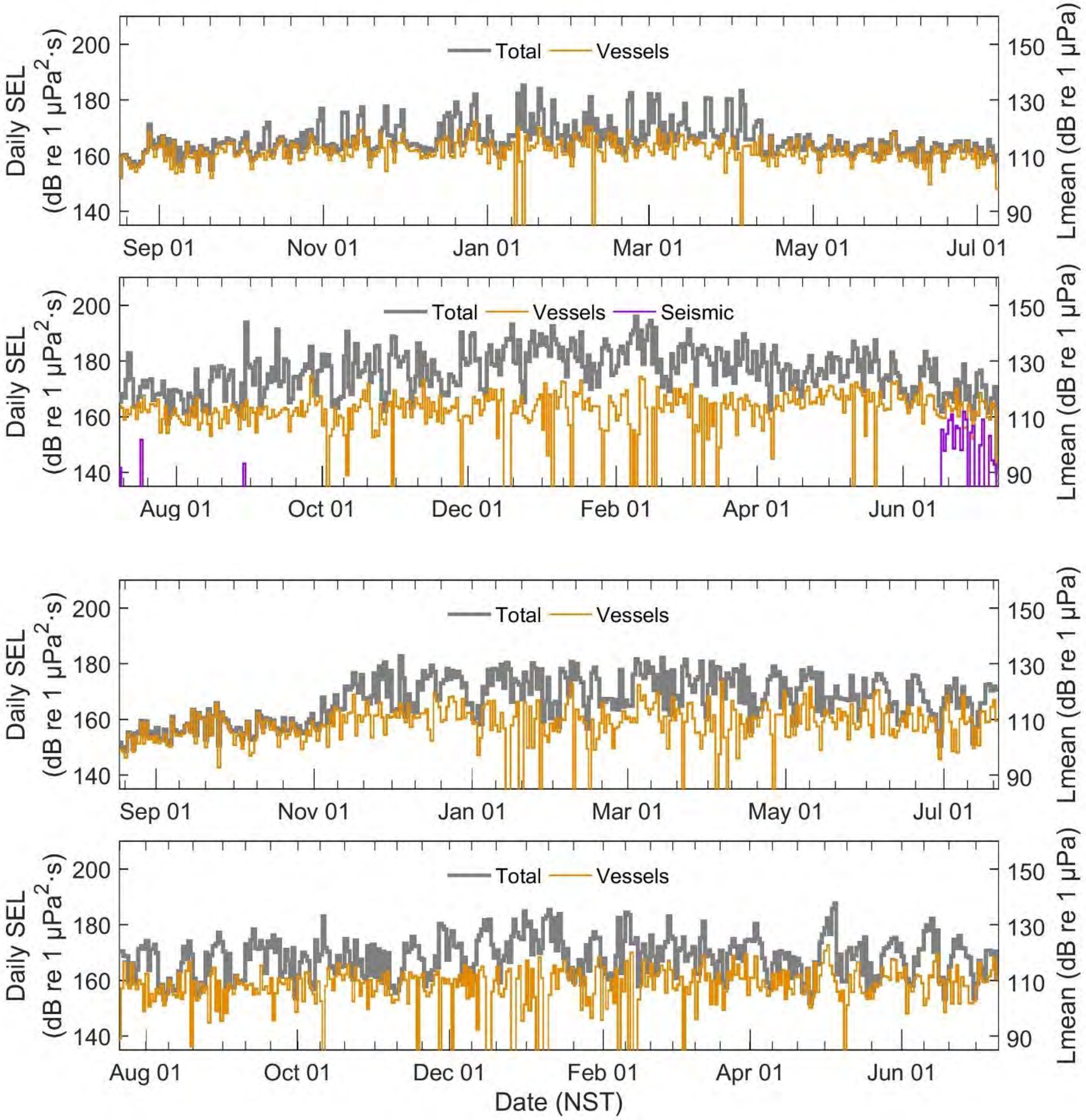


Figure 136. From top to bottom: Stn 1 2015–16, stn 1 2016–17, stn 2 2015–16, and stn 2 2016–17:Total, vessel, and seismic-associated daily SEL and equivalent continuous noise levels (L_{eq}).

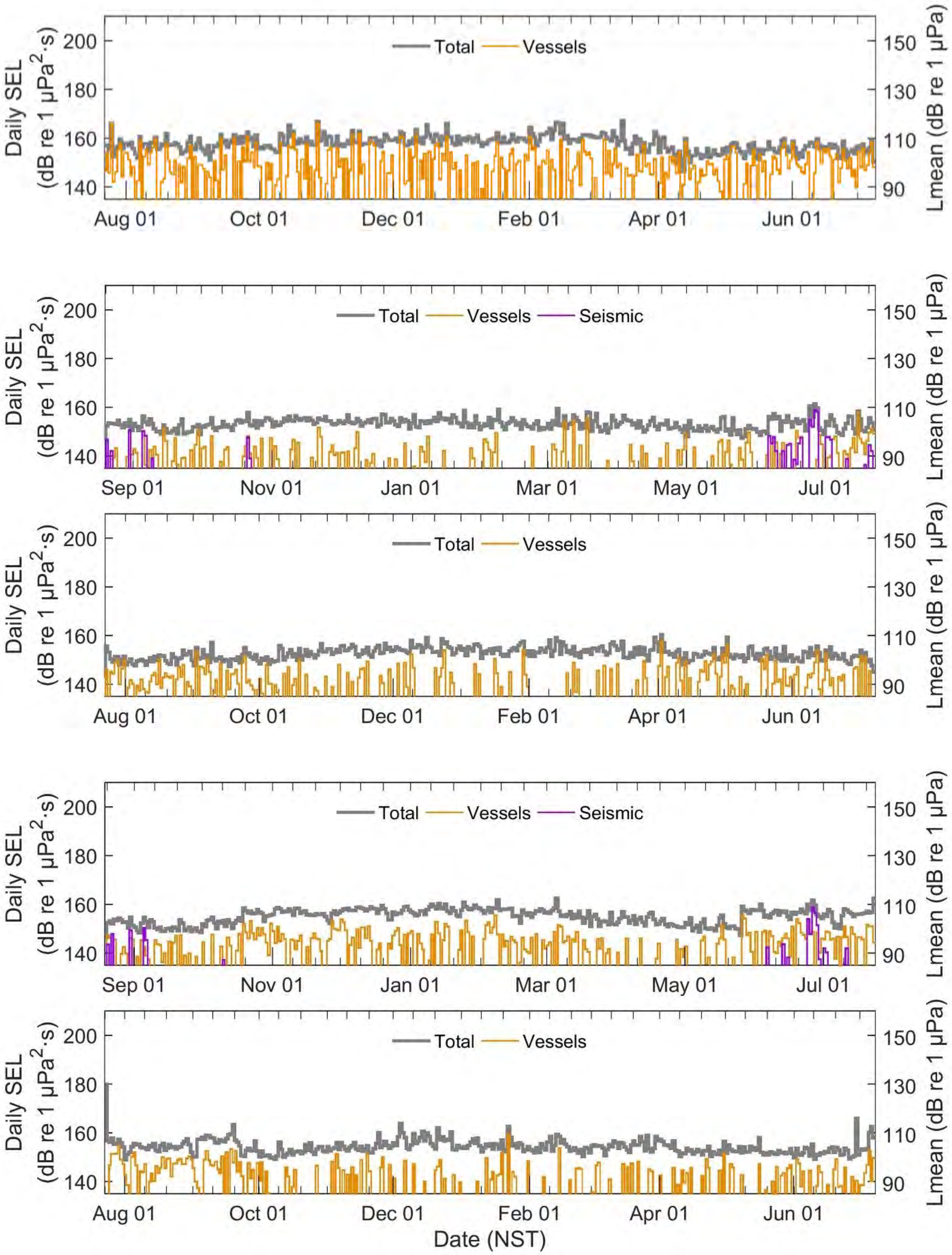


Figure 137. From top to bottom: Stn 3 2016–17, stn 4 2015–16, stn 4 2016–17, stn 5 2015–16, and stn 5 2016–17:Total, vessel, and seismic-associated daily SEL and equivalent continuous noise levels (L_{eq}).

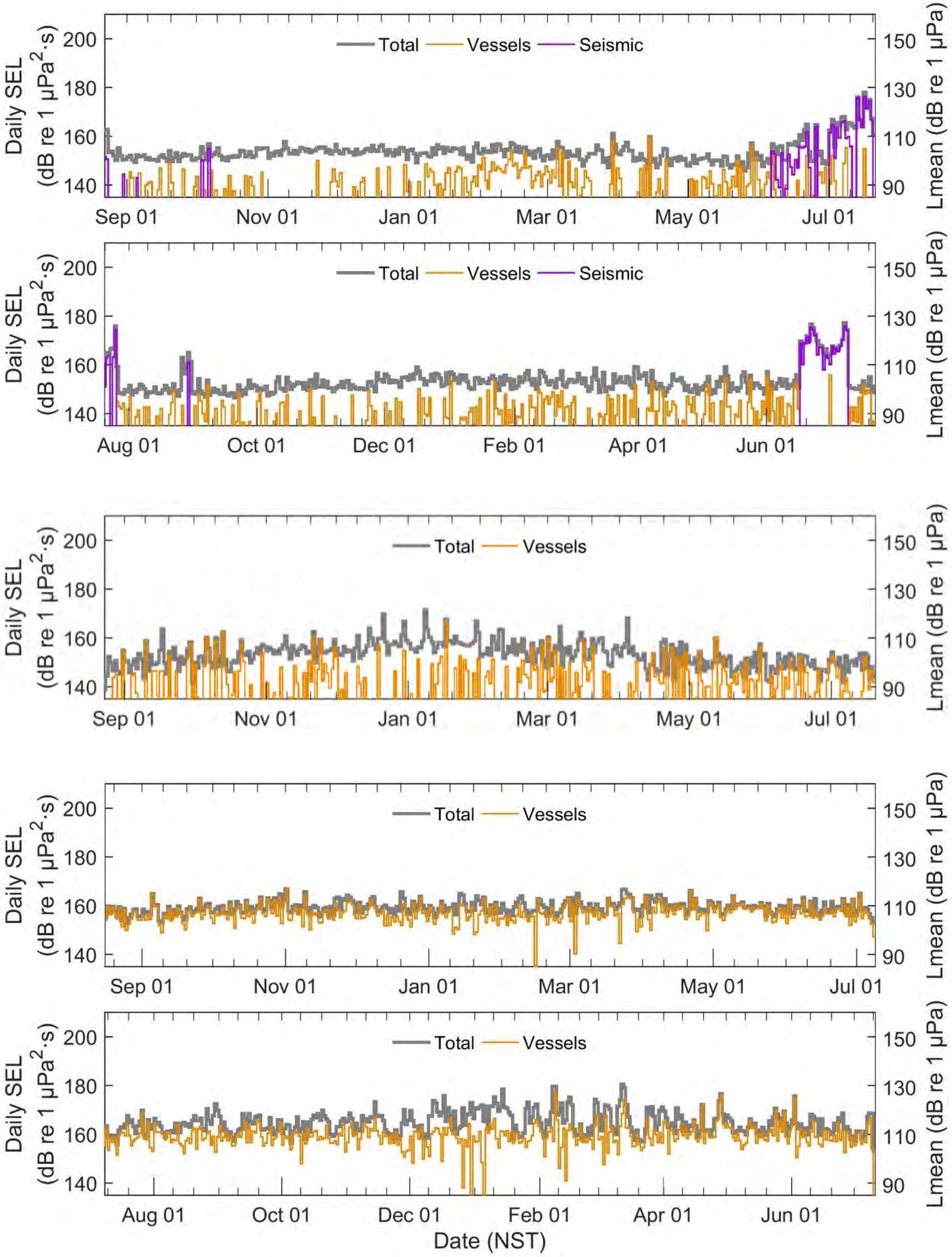


Figure 138. From top to bottom: Stn 6 2015–16, stn 6 2016–17, stn 7 2015–16, stn 8 2015–16 and stn 8 2016–17:Total, vessel, and seismic-associated daily SEL and equivalent continuous noise levels (L_{eq}).

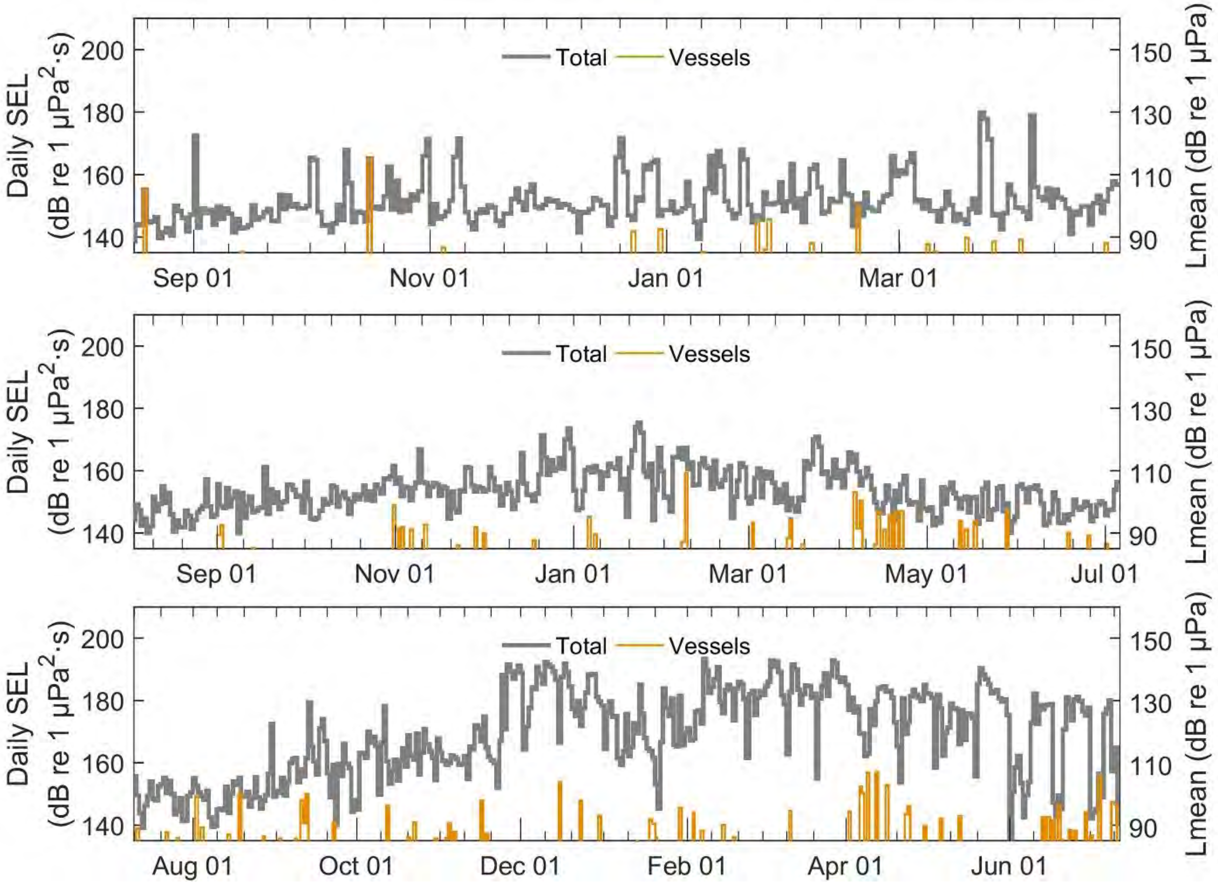


Figure 139. From top to bottom: Stn 9 2015–16, stn 10 2015–16 and stn 10 2016–17:Total, vessel, and seismic-associated daily SEL and equivalent continuous noise levels (L_{eq}).

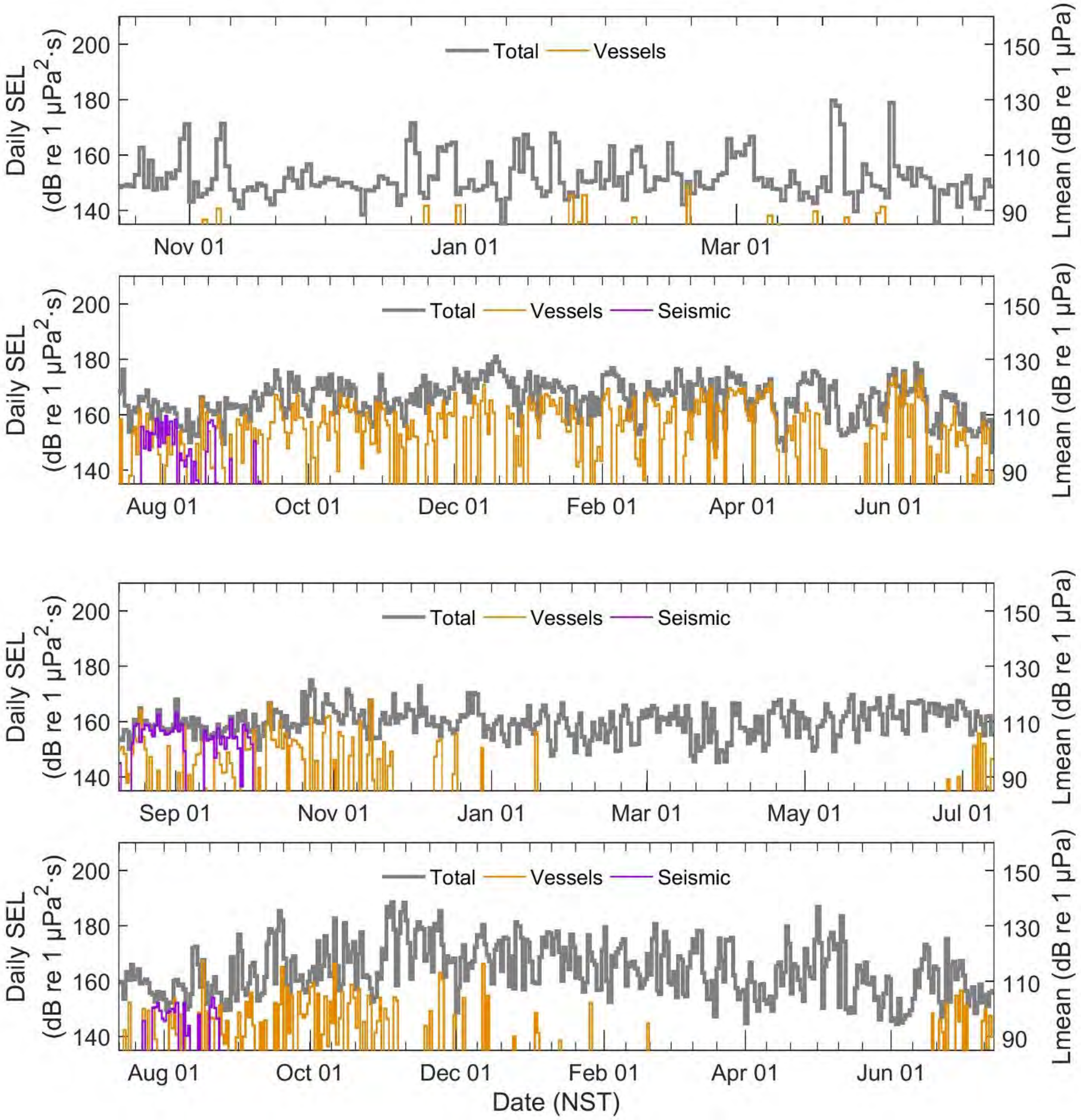


Figure 140. From top to bottom: Stn 11 2015–16, stn 11 2016–17, stn 12 2015–16 and stn 12 2016–17:Total, vessel, and seismic-associated daily SEL and equivalent continuous noise levels (L_{eq}).

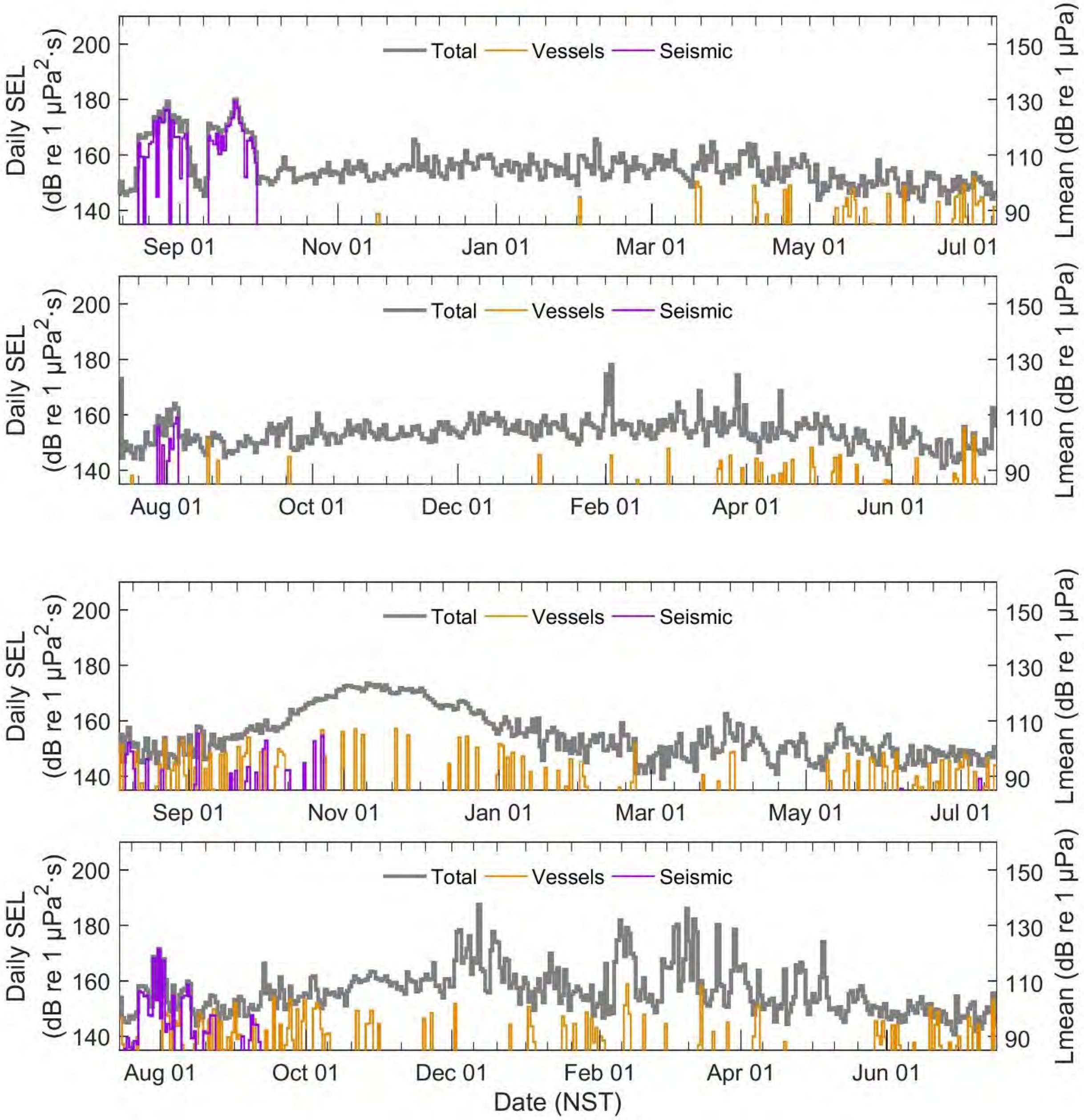


Figure 141. From top to bottom: Stn 13 2015–16, stn 13 2016–17, stn 14 2015–16 and stn 14 2016–17:Total, vessel, and seismic-associated daily SEL and equivalent continuous noise levels (L_{eq}).

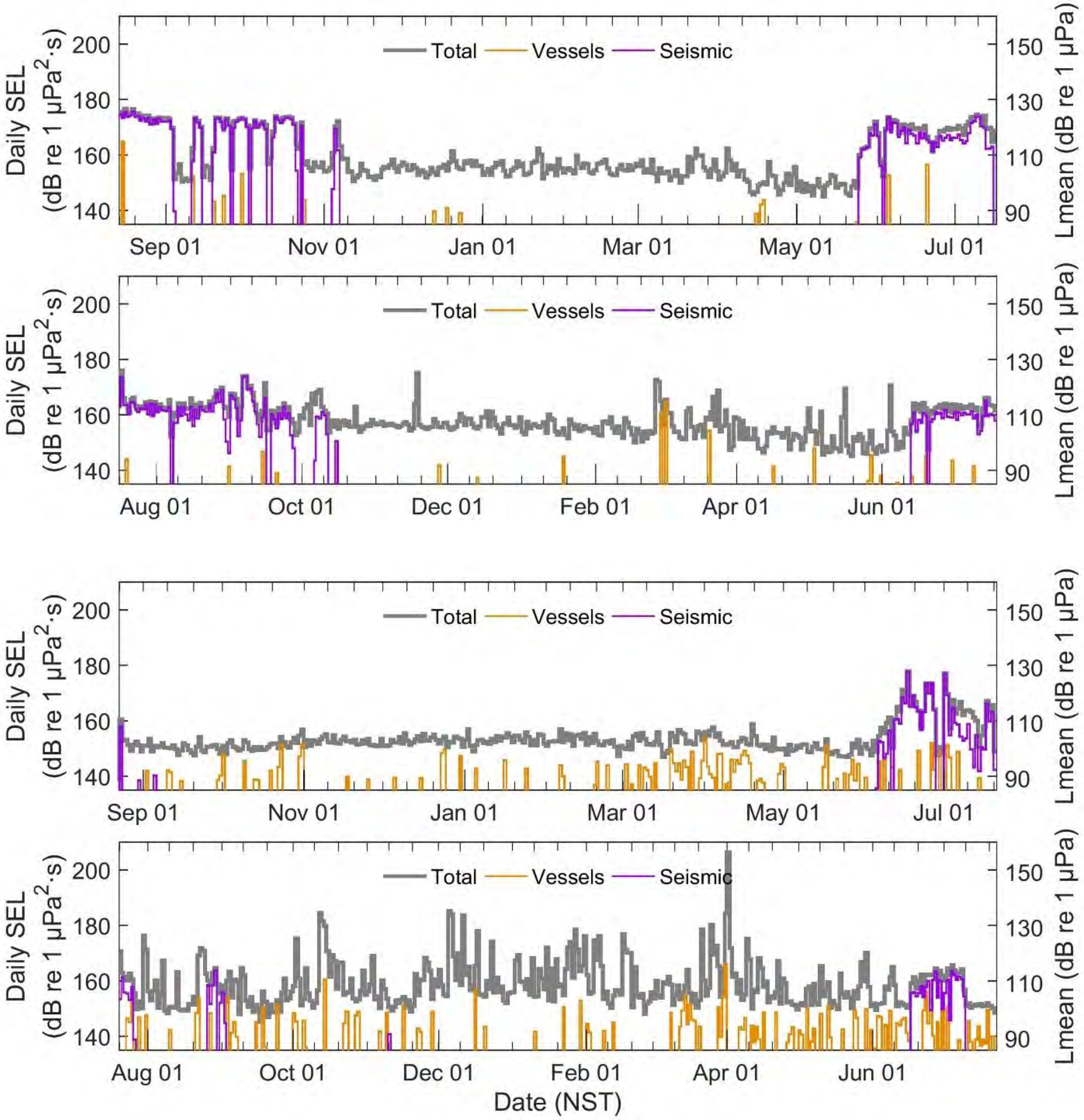


Figure 142. From top to bottom: Stn 15 2015–16, stn 15 2016–17, stn 16 2015–16 and stn 16 2016–17:Total, vessel, and seismic-associated daily SEL and equivalent continuous noise levels (L_{eq}).

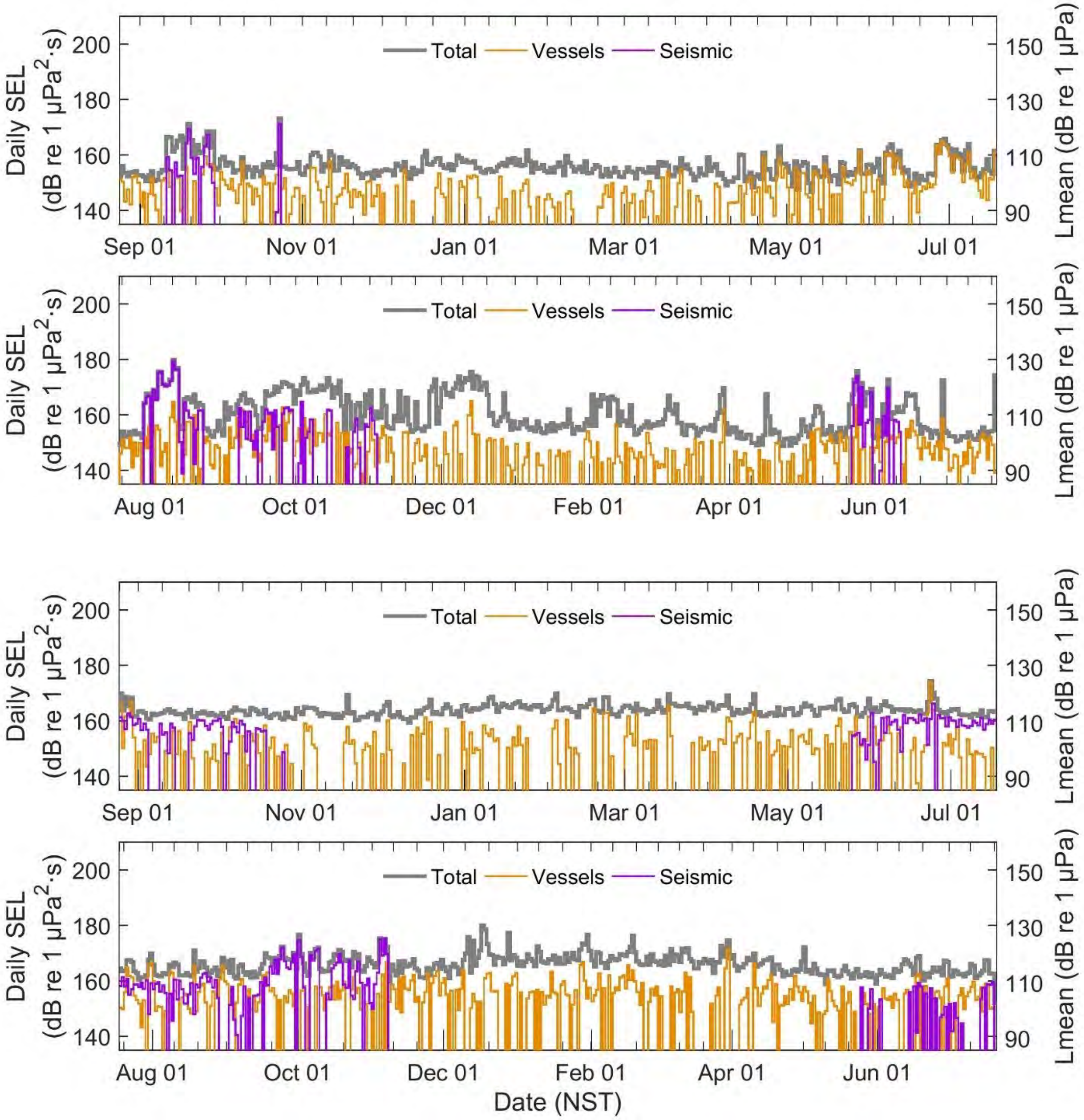


Figure 143. From top to bottom: Stn 17 2015–16, stn 17 2016–17, stn 18 2015–16 and stn 18 2016–17:Total, vessel, and seismic-associated daily SEL and equivalent continuous noise levels (L_{eq}).

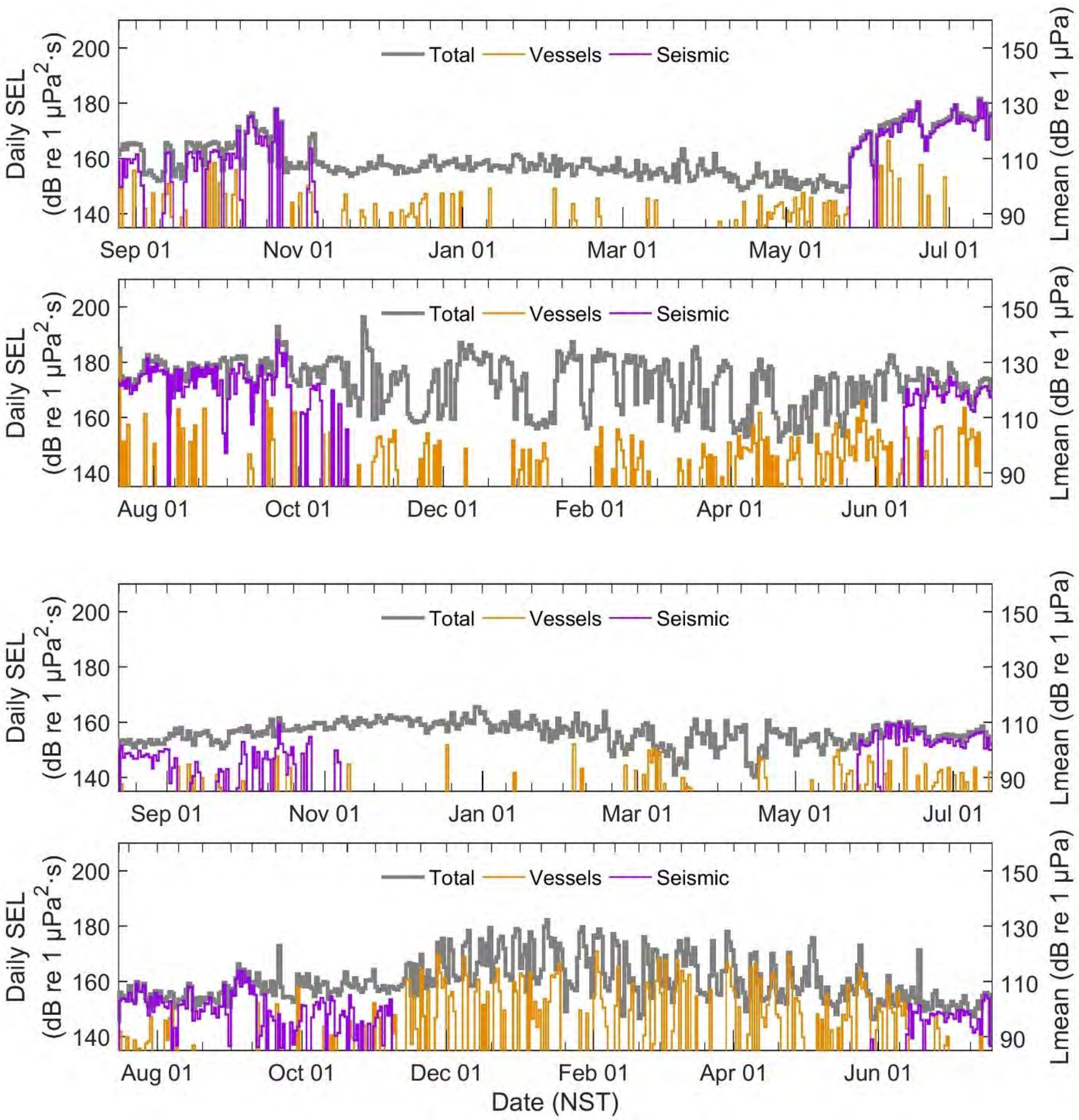


Figure 144. From top to bottom: Stn 19 2015–16, stn 19 2016–17, stn 20 2015–16 and stn 20 2016–17:Total, vessel, and seismic-associated daily SEL and equivalent continuous noise levels (L_{eq}).

F.4. One-third-octave-band and Decade-band Frequencies

Table F-1. Third-octave-band frequencies (Hz).

Band	Lower frequency	Nominal centre frequency	Upper frequency
1	8.9	10	11.2
2	11.6	13	14.6
3	14.3	16	17.9
4	17.8	20	22.4
5	22.3	25	28.0
6	28.5	32	35.9
7	35.6	40	44.9
8	45.0	51	57.2
9	57.0	64	71.8
10	72.0	81	90.9
11	90.9	102	114.4
12	114.1	128	143.7
13	143.4	161	180.7
14	180.8	203	227.9
15	228.0	256	287.4
16	287.7	323	362.6
17	362.7	406	455.7
18	456.1	512	574.7
19	574.6	645	723.9
20	724.2	813	912.6
21	912.3	1024	1149
22	1,150	1,290	1,447
23	1,448	1,625	1,824
24	1,824	2,048	2,297
25	2,298	2,580	2,896
26	2,896	3,251	3,649
27	3,649	4,096	4,597
28	4,598	5,161	5,793
29	5,793	6,502	7,298
30	7,298	8,192	9,195
31	9,195	10,321	11,585
32	11,585	13,004	14,597

Table F-2. Decade-band frequencies (Hz).

Decade band	Lower frequency	Nominal centre frequency	Upper frequency
2	10	50	100
3	100	500	1,000
4	1,000	5,000	10,000

Appendix G. Detector Performance

G.1. Fin Whales

Table 11. Fin whales: Timeframes (inclusive) for recording years 2015–16 and 2016–17 when automated detections were excluded because presence was not validated by analysts. 'Start' and 'End' indicate the first and last day of a recording period. Stations excluded from the table did not have this species validated in 2015–16 or 2016–17. 'ND' indicates periods when no data was available. 'NA' indicates that no exclusion period was applied.

Station	Fin whale detector exclusion periods	
	2015–16	2016–17
1	1 Apr 2016 - End	15 Apr 2017 - End
2	1 May 2016 - End	21 Apr 2017 - End
3	ND	Start - 31 Jul 2017
		27 Apr 2017 - End
4	1 May 2016 - End	3 Apr 2017 - End
5	1 May 2016 - End	12 Apr - End
6	1 Jun 2016 - End	Start - 26 Jul 2016
		5 Jun 2017 - End
7	1 Jun 2016 - End	ND
8	1 Apr 2016 - End	Start - 5 Aug 2016
		13 Apr 2017 - End
10	3 Dec 2015 - End	Start - 8 Aug 2016
		6 Dec 2016 - End
11	Start - 21 Sep 2015	Start - 4 Sep 2016
	2 Dec 2015 - End	27 Nov 2016 - End
12	Start - 21 Sep 2015	Start - 30 Aug 2016
	2 Dec 2015 - End	4 Dec 2016 - End
13	Start - 21 Sep 2015	19 Feb 2017 - End
	16 Feb 2016 - End	
14	Start - 20 Aug 2015	Start - 29 Jul 2016
	1 Feb 2016 - End	24 Jan 2017 - End
15	23 Mar 2016 - End	14 Apr 2017 - End
16	1 Jun 2016 - End	Start - 4 Sep 2016
		24 Mar 2017 - End
17	1 Jun 2016 - End	17 May 2017 - 13 Jun 2017
18	2 May 2016 - End	28 May 2017 - End
19	24 May 2016 - End	Start - 8 Oct 2016
		11 Jun 2017 - End
20	2 Feb 2016 - End	Start - 8 Oct 2016
		23 May 2017 - End

Table 12. Fin whales: Performance of the automated detector for each station and year including the Threshold implemented, the resulting detector Precision (P) and Recall (R), the number of files included in the calculation (# Files; excluding any files where an analyst was uncertain of species presence), the number of files in the calculation containing an annotation for this species/ vocalization type (# Annotation files), and the number of files in the calculation containing automated fin whale detections (# Detection files). Stations not included in the table did not have this species/ vocalization type validated in 2015–16 or 2016–17. 'ND' indicates stations/years with no (useable) data. This species/ vocalization type was considered absent (A) when their presence was not validated by an analyst.

Station	Year	Threshold	Precision	Recall	# Files	# Annotation files	# Detection files
1	2015–16	2	1.00	0.79	119	29	30
	2016–17	1	0.79	0.66	121	35	29
2	2015–16	3	0.97	0.64	120	44	44
	2016–17	2	1.00	0.64	99	42	35
3	2015–16	ND	ND	ND	ND	ND	ND
	2016–17	12	1.00	0.51	119	49	76
4	2015–16	1	0.94	0.68	120	47	34
	2016–17	1	0.95	0.83	124	87	76
5	2015–16	1	0.84	0.67	120	39	31
	2016–17	1	0.93	0.67	121	76	55
6	2015–16	1	0.88	0.64	120	47	34
	2016–17	1	0.95	0.81	132	73	62
7	2015–16	3	1.00	0.78	120	63	62
	2016–17	ND	ND	ND	ND	ND	ND
8	2015–16	1	0.88	0.72	120	29	24
	2016–17	2	0.90	0.48	128	40	40
10	2015–16	3	1.00	0.89	120	9	25
	2016–17	1	0.83	0.56	125	9	6
11	2015–16	3	0.60	0.38	120	8	21
	2016–17	1	0.85	0.69	116	16	13
12	2015–16	10	1.00	0.30	120	10	26
	2016–17	1	0.50	0.67	131	3	4
13	2015–16	5	0.83	0.23	96	22	22
	2016–17	1	0.93	0.30	128	43	14
14	2015–16	32	1.00	0.20	120	15	43
	2016–17	1	0.85	0.55	127	42	27
15	2015–16	3	1.00	0.27	120	44	20
	2016–17	1	0.90	0.40	124	48	21
16	2015–16	3	0.79	0.33	120	33	37
	2016–17	1	0.76	0.73	128	30	29
17	2015–16	1	0.87	0.41	120	64	30
	2016–17	1	0.82	0.88	128	56	60
18	2015–16	3	0.91	0.95	120	56	61
	2016–17	6	0.96	0.35	124	68	78

Station	Year	Threshold	Precision	Recall	# Files	# Annotation files	# Detection files
19	2015–16	1	0.94	0.65	120	68	47
	2016–17	1	1.00	0.15	127	26	4
20	2015–16	2	0.61	0.41	120	54	56
	2016–17	7	0.83	0.28	128	18	26

G.2. Blue Whales

Table 13. Blue whales: Timeframes (inclusive) for recording years 2015–16 and 2016–17 when automated detections were excluded because presence was not validated by analysts. 'Start' and 'End' indicate the first and last day of a recording period. Stations excluded from the table did not have this species validated in 2015–16 or 2016–17. 'ND' indicates periods when no data was available. 'NA' indicates that no exclusion period was applied.

Station	Blue whale detector exclusion periods	
	2015–16	2016–17
1	1 Apr 2016 - End	7 Apr 2017 - End
2	2 Feb 2016 - End	2 May 2017 - End
3	ND	11 Jan 2017 - End
4	1 Feb 2016 - End	3 Apr 2017 to 15 Jun 2017
5	1 Feb 2016 - End	23 Mar 2017 to 15 Jun 2017
6	1 Feb 2016 - End	21 Feb 2017 - End
7	1 Feb 2016 - End	ND
8	1 Apr 2016 - End	7 Apr 2017 - End
11	NA	1 Dec 2016 - End
13	12 Dec 2015 - End	1 Feb 2017 - End
14	1 Jan 2016 - End	3–12 Dec 2016 3 Feb 2017 - End
15	8 Jan 2016 - End	7 Mar 2017 - End
16	1 Feb 2016 - End	6 Jan 2017 - End
17	5 Jan 2016 - End	26 Feb 2017 - End
18	Start - 20 Oct 2015 29 Oct 2015 to 28 Dec 2015 3 Jan 2016 - End	NA
19	4 Jan 2016 - End	1 Feb 2017 - End
20	26 Nov 2015 to 1 Jan 2016 11 Jan 2016 - End	1 Jan 2017 - End

Table 14. Blue whales: Performance of the automated detector for each station and year including the Threshold implemented, the resulting detector Precision (P) and Recall (R), the number of files included in the calculation (# Files; excluding any files where an analyst was uncertain of species presence), the number of files in the calculation containing an annotation for this species/ vocalization type (# Annotation files), and the number of files in the calculation containing automated fin whale detections (# Detection files). Stations not included in the table did not have this species/ vocalization type validated in 2015–16 or 2016–17. 'ND' indicates stations/years with no (useable) data. This species/ vocalization type was considered absent (A) when their presence was not validated by an analyst.

Station	Year	Threshold	Precision	Recall	# Files	# Annotation files	# Detection files
1	2015–16	1	0.69	0.58	120	19	16
	2016–17	3	1.00	0.21	117	24	9
2	2015–16	2	1.00	0.46	120	13	11
	2016–17	2	1.00	0.42	121	19	10
3	2015–16	ND	ND	ND	ND	ND	ND
	2016–17	1	0.93	0.88	122	16	15
4	2015–16	1	1.00	0.59	120	17	10
	2016–17	2	1.00	0.35	123	20	9
5	2015–16	1	1.00	0.77	120	13	10
	2016–17	2	1.00	0.20	102	25	10
6	2015–16	1	0.94	0.56	120	27	16
	2016–17	1	1.00	0.74	130	38	28
7	2015–16	1	1.00	0.91	120	11	10
	2016–17	ND	ND	ND	ND	ND	ND
8	2015–16	1	0.89	0.80	120	20	18
	2016–17	2	0.83	0.50	125	20	12
11	2015–16	A	A	A	A	A	A
	2016–17	8	1.00	0.17	127	6	18
13	2015–16	1	0.30	0.50	114	6	10
	2016–17	3	1.00	0.10	127	31	14
14	2015–16	1	1.00	1.00	120	7	7
	2016–17	3	1.00	0.44	130	9	16
15	2015–16	1	1.00	0.48	120	25	12
	2016–17	1	0.63	0.14	118	35	8
16	2015–16	1	1.00	0.57	120	30	17
	2016–17	1	0.86	0.59	125	32	22
17	2015–16	1	0.89	0.29	120	28	9
	2016–17	2	0.89	0.35	132	23	34
18	2015–16	1	1.00	1.00	120	5	5
	2016–17	6	0.50	0.50	130	2	10
19	2015–16	1	0.86	0.52	120	23	14
	2016–17	2	1.00	0.20	127	15	15
20	2015–16	2	1.00	0.57	120	7	5
	2016–17	0	0.00	0.00	131	1	4

G.3. Humpback Whales

Table 15. Humpback whales: Timeframes (inclusive) for recording years 2015–16 and 2016–17 when automated detections were excluded because presence was not validated by analysts. 'Start' and 'End' indicate the first and last day of a recording period. Stations excluded from the table did not have this species validated in 2015–16 or 2016–17. 'ND' indicates periods when no data was available. 'NA' indicates that no exclusion period was applied.

Station	Humpback whale detector exclusion periods	
	2015–16	2016–17
1	NA	1 Jun 2017 - End
2	NA	NA
3	ND	NA
4	Start - 4 Nov 2015	NA
	5 Jun 2016 - End	
5	Start - 22 Oct 2015	NA
	6 Jun 2016 - End	
6	Start - 25 Oct 2015	NA
	5 Jan 2016 - End	
7	NA	ND
8	NA	NA
10	1 Jan 2016 to 18 Apr 2016	8 Jan 2017 to 4 Jun 2017
11	Start - 9 Nov 2015	24 Jul 2016 to 4 Sep 2016
	25 Nov 2015 - End	8 Jan 2017 to 9 Jun 2017
12	Start - 30 Sep 2015	27 Jul 2016 to 29 Aug 2016
	1 Jan 2016 - End	8 Jan 2017 to 7 Jun 2017
13	NA	NA
14	Start - 2 Oct 2015	NA
	1 Jan 2016 - End	
15	Start - 11 Nov 2015	NA
	10 Feb 2016 - End	
16	Start - 8 Jan 2016	16 Jun 2017 to 8 Jul 2017
	28 Feb 2016 - End	
17	Start - 1 Dec 2015	8 Sep 2016 to 3 Nov 2016
	01 Apr 2016 - End	1 Mar 2017 - End
18	Start - 26 Oct 2015	2 Jun 2017 - End
	25 May 2016 - End	
19	Start - 7 Nov 2015	Start - 3 Nov 2016
	2 Feb 2016 - End	1 Mar 2017 - End
20	Start - 15 Nov 2015	Start - 8 Nov 2016
		1 Feb 2017 to 1 May 2017
	5 Feb 2016 - End	25 May 2017 - End

Table 16. Humpback whales: Performance of the automated detector for each station and year including the Threshold implemented, the resulting detector Precision (P) and Recall (R), the number of files included in the calculation (# Files; excluding any files where an analyst was uncertain of species presence), the number of files in the calculation containing an annotation for this species/ vocalization type (# Annotation files), and the number of files in the calculation containing automated fin whale detections (# Detection files). Stations not included in the table did not have this species/ vocalization type validated in 2015–16 or 2016–17. 'ND' indicates stations/years with no (useable) data. This species/ vocalization type was considered absent (A) when their presence was not validated by an analyst. 'NA' indicates values that could not be calculated due to an insufficient number of TP, FN, and FP files to calculate the P and R.

Station	Year	Threshold	Precision	Recall	# Files	# Annotation files	# Detection files
1	2015–16	2	0.90	0.72	120	25	29
	2016–17	4	0.92	0.69	125	16	23
2	2015–16	2	0.91	0.63	120	32	34
	2016–17	2	0.94	0.43	112	68	46
3	2015–16	ND	ND	ND	ND	ND	ND
	2016–17	23	1.00	0.43	121	14	34
4	2015–16	1	1.00	0.92	120	13	12
	2016–17	10	1.00	0.61	124	28	21
5	2015–16	1	1.00	1.00	120	12	12
	2016–17	41	0.86	0.55	124	11	21
6	2015–16	2	1.00	0.20	120	5	2
	2016–17	3	0.08	0.17	130	6	16
7	2015–16	1	0.84	0.65	120	57	44
	2016–17	ND	ND	ND	ND	ND	ND
8	2015–16	2	0.75	0.86	120	7	11
	2016–17	11	0.29	0.67	126	3	19
10	2015–16	2	1.00	0.47	120	15	13
	2016–17	1	0.81	0.48	123	27	16
11	2015–16	A	A	A	A	A	A
	2016–17	NA	NA	NA	123	6	5
12	2015–16	NA	NA	NA	120	3	4
	2016–17	9	1.00	1.00	128	1	6
13	2015–16	A	A	A	A	A	A
	2016–17	NA	NA	NA	132	1	16
14	2015–16	1	1.00	0.75	120	16	12
	2016–17	NA	NA	NA	129	2	22
15	2015–16	1	0.67	1.00	120	2	3
	2016–17	NA	NA	NA	132	5	35
16	2015–16	A	A	A	A	A	A
	2016–17	17	0.50	0.33	125	3	11
17	2015–16	1	1.00	0.47	120	17	8
	2016–17	0	0.00	0.00	131	5	15
18	2015–16	1	1.00	1.00	120	1	1

Station	Year	Threshold	Precision	Recall	# Files	# Annotation files	# Detection files
	2016–17	37	0.22	0.15	130	13	27
19	2015–16	NA	NA	NA	120	1	0
	2016–17	4	1.00	0.20	131	5	12
20	2015–16	1	1.00	0.46	120	13	6
	2016–17	1	1.00	0.17	130	6	1

G.4. Bearded Seals

Table 17. Bearded seals: Timeframes (inclusive) for recording years 2015–16 and 2016–17 when automated detections were excluded because presence was not validated by analysts. 'Start' and 'End' indicate the first and last day of a recording period. Stations excluded from the table did not have this species validated in 2015–16 or 2016–17. 'NA' indicates that no exclusion period was applied.

Station	Bearded seal detector exclusion periods	
	2015–16	2016–17
10	Start - 14 Dec 2015	Start - 14 Dec 2016
	16 Jun 2016 - End	16 Jun 2017 - End
11	Start −14 Dec 2015	Start - 14 Dec 2016
	16 Jun 2016 - End	16 Jun 2017 - End
12	Start - 14 Dec 2015	Start - 14 Dec 2016
	16 Jun 2016 - End	16 Jun 2017 - End
14	Start - 17 Mar 2016	NA
	5 May 2016 - End	

Table 18. Bearded seals : Performance of the automated detector for each station and year including the Threshold implemented, the resulting detector Precision (P) and Recall (R), the number of files included in the calculation (# Files; excluding any files where an analyst was uncertain of species presence), the number of files in the calculation containing an annotation for this species/ vocalization type (# Annotation files), and the number of files in the calculation containing automated fin whale detections (# Detection files). Stations not included in the table did not have this species/ vocalization type validated in 2015–16 or 2016–17.

Station	Year	Threshold	Precision	Recall	# Files	# Annotation files	# Detection files
10	2015–16	1	1.00	0.94	120	32	30
	2016–17	2	1.00	0.88	122	52	49
11	2015–16	1	0.98	0.81	120	57	47
	2016–17	1	1.00	0.84	130	31	26
12	2015–16	1	0.93	0.80	120	50	43
	2016–17	1	1.00	0.89	128	64	57
14	2015–16	1	1.00	0.75	120	4	3
	2016–17	A	A	A	A	A	A

G.5. Pilot Whale Whistles

Table 19. Pilot whale whistles: Timeframes (inclusive) for recording years 2015–16 and 2016–17 when automated detections were excluded because presence was not validated by analysts. 'Start' and 'End' indicate the first and last day of a recording period. Stations excluded from the table did not have this species validated in 2015–16 or 2016–17. 'ND' indicates periods when no data was available. 'NA' indicates that no exclusion period was applied.

Station	Pilot whale whistle detector exclusion periods	
	2015–16	2016–17
1	NA	1 Jan 2017 to 1 May 2017
2	8 Oct 2015 to 29 Apr 2016	1 Dec 2016 to 1 May 2017
3	ND	1 Jan 2016 to 15 Jun 2017
4	NA	NA
5	NA	NA
6	NA	NA
7	NA	ND
8	1 Jan 2016 to 15 May 2016	1 Feb 2017 to 1 Apr 2017
11	1 Jan 2016 to 1 Jun 2016	1 Oct 2016 to 1 Jun 2017
12	NA	1 Oct 2016 to 14 Jun 2017
13	15 Jan 2016 to 20 Mar 2016	15 Dec 2016 to 1 May 2017
14	17 Dec 2015 - End	1 Dec 2016 to 1 Jun 2017
15	NA	1 Jan 2017 to 1 Apr 2017
16	NA	NA
17	NA	NA
18	NA	1 Dec 2016 to 1 Jul 2017
19	11 Dec 2015 to 22 Apr 2016	NA
20	NA	NA

Table 20. Pilot whale whistles: Performance of the automated detector for each station and year including the Threshold implemented, the resulting detector Precision (P) and Recall (R), the number of files included in the calculation (# Files; excluding any files where an analyst was uncertain of species presence), the number of files in the calculation containing an annotation for this species/ vocalization type (# Annotation files), and the number of files in the calculation containing automated fin whale detections (# Detection files). Stations not included in the table did not have this species/ vocalization type validated in 2015–16 or 2016–17. 'ND' indicates stations/years with no (useable) data. This species/ vocalization type was considered absent (A) when their presence was not validated by an analyst. 'NA' indicates values that could not be calculated due to an insufficient number of TP, FN, and FP files to calculate the P and R.

Station	Year	Threshold	Precision	Recall	# Files	# Annotation files	# Detection files
1	2015–16	1	0.67	0.32	118	31	15
	2016–17	1	1.00	0.41	128	37	15
2	2015–16	1	0.88	0.93	110	15	16
	2016–17	1	0.75	0.47	123	19	12
3	2015–16	ND	ND	ND	ND	ND	ND

Station	Year	Threshold	Precision	Recall	# Files	# Annotation files	# Detection files
	2016–17	1	0.50	0.67	124	3	4
4	2015–16	1	0.97	0.47	119	68	33
	2016–17	5	0.89	0.28	122	29	16
5	2015–16	1	0.77	0.45	120	38	22
	2016–17	59	1.00	0.17	114	6	17
6	2015–16	1	0.98	0.53	117	75	41
	2016–17	1	0.96	0.44	131	62	28
7	2015–16	1	0.38	0.25	119	20	13
	2016–17	ND	ND	ND	ND	ND	ND
8	2015–16	1	0.93	0.75	118	36	29
	2016–17	1	0.53	0.53	128	17	17
11	2015–16	1	0.20	0.33	119	3	5
	2016–17	NA	NA	NA	128	3	0
12	2015–16	A	A	A	A	A	A
	2016–17	1	1.00	0.33	129	3	1
13	2015–16	1	0.94	0.53	118	62	35
	2016–17	1	1.00	0.31	122	49	15
14	2015–16	1	0.86	0.55	118	33	21
	2016–17	1	1.00	0.47	131	17	8
15	2015–16	1	1.00	0.56	112	48	27
	2016–17	1	0.93	0.30	121	47	15
16	2015–16	1	1.00	0.61	110	61	37
	2016–17	1	0.94	0.50	127	62	33
17	2015–16	1	0.96	0.34	115	68	24
	2016–17	1	1.00	0.33	124	51	17
18	2015–16	53	1.00	0.60	118	5	8
	2016–17	NA	NA	NA	126	1	2
19	2015–16	1	0.81	0.52	114	25	16
	2016–17	1	0.89	0.18	130	45	9
20	2015–16	A	A	A	A	A	A
	2016–17	5	0.67	0.17	132	12	6

G.6. Dolphin Whistles

Table 21. Dolphin whistles: Timeframes (inclusive) for recording years 2015–16 and 2016–17 when automated detections were excluded because presence was not validated by analysts. 'Start' and 'End' indicate the first and last day of a recording period. Stations excluded from the table did not have this species validated in 2015–16 or 2016–17. 'ND' indicates periods when no data was available. 'NA' indicates that no exclusion period was applied.

Station	Dolphin whistle detector exclusion periods	
	2015–16	2016–17
1	NA	1 Feb 2017 to 1 Apr 2017
2	NA	1 Nov 2016 to 1 May 2017
3	ND	1 Feb 2017 to 1 Jun 2017
4	NA	NA
5	NA	NA
6	NA	NA
7	31 Jan 2016 - End	ND
8	NA	NA
9	NA	ND
10	8 Jan 2016 - End	1 Dec 2016 to 1 Jun 2017
11	13 Jan 2016 - End	NA
12	8 Nov 2015 - End	NA
13	NA	NA
14	12 Jan 2016 - End	1 Jan 2017 to 1 Jun 2017
15	NA	NA
16	NA	NA
17	NA	NA
18	NA	1 Dec 2016 to 1 Jul 2017
19	NA	NA
20	2 Feb 2016 - End	NA

Table 22. Dolphin whistles: Performance of the automated detector for each station and year including the Threshold implemented, the resulting detector Precision (P) and Recall (R), the number of files included in the calculation (# Files; excluding any files where an analyst was uncertain of species presence), the number of files in the calculation containing an annotation for this species/ vocalization type (# Annotation files), and the number of files in the calculation containing automated fin whale detections (# Detection files). Stations not included in the table did not have this species/ vocalization type validated in 2015–16 or 2016–17. 'ND' indicates stations/years with no (useable) data. This species/ vocalization type was considered absent (A) when their presence was not validated by an analyst.

Station	Year	Threshold	Precision	Recall	# Files	# Annotation files	# Detection files
1	2015–16	2	0.96	0.59	94	41	27
	2016–17	1	0.97	0.65	131	52	35
2	2015–16	2	0.96	0.76	120	29	27
	2016–17	1	0.86	0.79	127	39	36

Station	Year	Threshold	Precision	Recall	# Files	# Annotation files	# Detection files
3	2015–16	ND	ND	ND	ND	ND	ND
	2016–17	1	1.00	0.72	126	58	42
4	2015–16	2	0.69	0.29	119	31	26
	2016–17	1	0.96	0.29	122	80	24
5	2015–16	2	0.83	0.25	119	20	19
	2016–17	1	0.87	0.25	122	52	15
6	2015–16	2	0.69	0.41	117	22	28
	2016–17	1	0.97	0.44	128	71	32
7	2015–16	6	1.00	0.44	115	18	24
	2016–17	ND	ND	ND	ND	ND	ND
8	2015–16	1	1.00	0.62	111	50	31
	2016–17	1	0.95	0.59	129	59	37
9	2015–16	4	1.00	0.40	119	5	9
	2016–17	ND	ND	ND	ND	ND	ND
10	2015–16	1	1.00	0.68	97	28	19
	2016–17	3	1.00	0.65	129	23	18
11	2015–16	3	1.00	0.60	119	5	6
	2016–17	A	A	A	A	A	A
12	2015–16	1	1.00	0.50	120	2	1
	2016–17	61	1.00	1.00	130	1	12
13	2015–16	1	0.80	0.33	115	24	10
	2016–17	3	1.00	0.49	130	37	23
14	2015–16	1	0.91	0.51	110	41	23
	2016–17	1	0.98	0.70	129	56	40
15	2015–16	1	0.93	0.61	116	44	29
	2016–17	1	0.85	0.36	126	47	20
16	2015–16	1	0.93	0.31	114	45	15
	2016–17	1	1.00	0.46	129	79	36
17	2015–16	1	0.93	0.48	114	84	43
	2016–17	1	1.00	0.56	130	84	47
18	2015–16	1	0.67	0.57	98	14	12
	2016–17	1	0.93	0.86	131	44	41
19	2015–16	1	0.97	0.63	120	52	34
	2016–17	1	0.94	0.50	130	98	52
20	2015–16	1	1.00	0.84	99	31	26
	2016–17	1	1.00	0.79	129	38	30

G.7. Delphinid Clicks

Table 23. Delphinid clicks: Timeframes (inclusive) for recording years 2015–16 and 2016–17 when automated detections were excluded because presence was not validated by analysts. 'Start' and 'End' indicates the first and last day of the recording period, respectively. Stations excluded from the table did not have delphinid clicks validated in 2015–16 or 2016–17. 'ND' indicates periods when no data was available. 'NA' indicates that no exclusion period was applied.

Station	Delphinid click detector exclusion periods	
	2015–16	2016–17
1	NA	15 Jan 2017 to 15 May 2017
2	11 Feb 2016 to 15 May 2016	1 Jan 2017 to 1 Apr 2017
3	ND	15 Dec 2016 to 1 Jun 2017
4	NA	NA
5	NA	NA
6	NA	NA
7	NA	ND
8	NA	NA
10	11 Dec 2015 - End	1 Feb 2017 to 1 June 2017
11	25 Oct 2015 - End	1 Dec 2016 to 1 Jun 2017
12	18 Sep 2015 - End	1 Oct 2016 to 1 Apr 2017
13	17 Feb 2016 to 27 Mar 2016	1 Feb 2017 to 1 Apr 2017
14	NA	NA
15	23 Feb 2016 to 18 Apr 2016	NA
16	NA	NA
17	NA	NA
18	9 Nov 2015 to 1 Mar 2016 21 Mar 2016 to 3 Jul 2016	15 Feb 2017 to 1 Jun 2017
19	NA	NA
20	18 Jan 2016 to 30 Apr 2016	1 Feb 2017 to 15 May 2017

Table 24 Delphinid clicks: Performance of the automated detector for each station and year including the Threshold implemented, the resulting detector Precision (P) and Recall (R), the number of files included in the calculation (# Files; excluding any files where an analyst was uncertain of species presence), the number of files in the calculation containing an annotation for this species/ vocalization type (# Annotation files), and the number of files in the calculation containing automated fin whale detections (# Detection files). Stations not included in the table did not have this species/ vocalization type validated in 2015–16 or 2016–17. 'ND' indicates stations/years with no (useable) data.

Station	Year	Threshold	Precision	Recall	# Files	# Annotation files	# Detection files
1	2015–16	3	0.90	0.43	101	44	41
	2016–17	7	0.94	0.80	131	55	74
2	2015–16	4	0.91	0.53	96	19	26

Station	Year	Threshold	Precision	Recall	# Files	# Annotation files	# Detection files
	2016–17	2	1.00	0.80	126	54	54
3	2015–16	ND	ND	ND	ND	ND	ND
	2016–17	7	1.00	0.60	125	47	58
4	2015–16	16	0.76	0.63	120	35	52
	2016–17	1	0.96	0.66	123	76	52
5	2015–16	11	1.00	0.67	119	24	37
	2016–17	1	0.85	0.67	119	60	47
6	2015–16	25	1.00	0.46	120	28	46
	2016–17	4	0.98	0.63	129	62	52
7	2015–16	13	0.95	0.72	118	29	44
	2016–17	ND	ND	ND	ND	ND	ND
8	2015–16	3	1.00	0.60	118	63	48
	2016–17	2	1.00	0.85	129	66	58
10	2015–16	2	1.00	0.91	119	33	34
	2016–17	13	0.88	0.64	131	36	70
11	2015–16	1	0.89	1.00	118	8	9
	2016–17	6	1.00	0.80	126	10	22
12	2015–16	1	1.00	1.00	120	5	5
	2016–17	4	0.25	1.00	130	3	53
13	2015–16	1	0.64	0.43	120	49	33
	2016–17	1	0.64	0.44	128	52	36
14	2015–16	1	0.96	0.71	118	65	48
	2016–17	1	1.00	0.85	126	85	72
15	2015–16	3	0.86	0.34	119	56	33
	2016–17	1	0.65	0.48	120	46	34
16	2015–16	1	0.83	0.64	120	59	46
	2016–17	2	0.91	0.54	129	80	57
17	2015–16	1	0.88	0.58	116	73	48
	2016–17	4	0.83	0.51	129	78	67
18	2015–16	2	1.00	0.85	119	26	24
	2016–17	8	1.00	0.64	121	47	40
19	2015–16	4	0.76	0.53	117	55	51
	2016–17	1	0.76	0.62	121	61	50
20	2015–16	2	1.00	0.71	117	35	34
	2016–17	2	0.97	0.71	131	51	39

G.8. Sperm Whales

Table 25. Sperm whales: Timeframes (inclusive) for recording years 2015–16 and 2016–17 when automated detections were excluded because presence was not validated by analysts. 'Start' and 'End' indicate the first and last day of a recording period. Stations excluded from the table did not have this species validated in 2015–16 or 2016–17. 'NA' indicates that no exclusion period was applied.

Station	Delphinid click detector exclusion periods	
	2015–16	2016–17
1	NA	NA
4	NA	NA
5	NA	NA
6	NA	NA
8	NA	NA
11	1 Nov 2015 - End	1 Dec 2016 to 1 Jun 2017
12	NA	1 Nov 2016 to 1 Jun 2017
13	11 Feb 2016 to 10 May 2016	NA
14	29 Dec 2015 to 20 May 2016	1 Feb 2017 to 1 May 2017
15	Start - 6 Sep 2015	NA
	5 May 2016 - End	
16	NA	NA
17	NA	NA
18	NA	NA
19	NA	NA
20	NA	1 Feb 2017 to 15 Apr 2017

Table 26. Sperm whales : Performance of the automated detector for each station and year including the Threshold implemented, the resulting detector Precision (P) and Recall (R), the number of files included in the calculation (# Files; excluding any files where an analyst was uncertain of species presence), the number of files in the calculation containing an annotation for this species/ vocalization type (# Annotation files), and the number of files in the calculation containing automated fin whale detections (# Detection files). Stations not included in the table did not have this species/ vocalization type validated in 2015–16 or 2016–17. This species/ vocalization type was considered absent (A) when their presence was not validated by an analyst. 'NA' indicates values that could not be calculated due to an insufficient number of TP, FN, and FP files to calculate the P and R.

Station	Year	Threshold	Precision	Recall	# Files	# Annotation files	# Detection files
1	2015–16	11	0.67	0.40	99	5	23
	2016–17	NA	NA	NA	130	1	22
4	2015–16	18	1.00	0.31	96	16	26
	2016–17	1	0.84	0.63	122	43	32
5	2015–16	19	1.00	0.33	120	18	33
	2016–17	2	0.86	0.58	120	31	36
6	2015–16	6	0.60	0.60	100	15	29
	2016–17	5	0.77	0.38	131	26	30

Station	Year	Threshold	Precision	Recall	# Files	# Annotation files	# Detection files
8	2015–16	152	1.00	0.12	117	17	25
	2016–17	4	0.50	0.36	130	22	29
11	2015–16	1	0.20	0.25	118	4	5
	2016–17	3	0.50	0.11	127	9	6
12	2015–16	A	A	A	A	A	A
	2016–17	3	0.14	1.00	131	1	21
13	2015–16	2	0.74	0.56	118	25	30
	2016–17	3	0.76	0.62	127	21	32
14	2015–16	10	1.00	0.27	118	11	16
	2016–17	1	0.48	0.58	124	24	29
15	2015–16	1	0.78	0.72	115	25	23
	2016–17	3	0.96	0.51	121	47	35
16	2015–16	1	0.80	0.71	118	34	30
	2016–17	9	0.78	0.39	129	18	20
17	2015–16	1	0.90	0.61	116	59	40
	2016–17	1	0.91	0.68	121	77	57
18	2015–16	2	1.00	0.50	119	4	12
	2016–17	A	A	A	A	A	A
19	2015–16	3	0.78	0.54	114	39	44
	2016–17	4	0.95	0.56	129	68	53
20	2015–16	55	1.00	0.33	117	3	15
	2016–17	3	1.00	0.75	130	4	7

G.9. Porpoises

Table 27. Porpoises: Timeframes (inclusive) for recording years 2015–16 and 2016–17 when automated detections were excluded because presence was not validated by analysts. 'Start' and 'End' indicate the first and last day of a recording period. Stations excluded from the table did not have this species validated in 2015–16 or 2016–17. 'ND' indicates periods when no data was available. 'NA' indicates that no exclusion period was applied.

Station	Porpoise detector exclusion periods	
	2015–16	2016–17
1	NA	NA
2	NA	NA
3	ND	NA
7	NA	ND
8	5 Apr 2016 - End	NA
9	10 Feb 2016 - End	ND
10	2 Oct 2015 - End	1 Dec 2016 to 1 Jun 2017
11	21 Dec 2015 - End	1 Jan 2017 to 1 Jun 2017
12	19 Dec 2015 - End	1 Dec 2016 to 1 Jun 2017
14	NA	1 Dec 2016 to 1 Jun 2017
18	NA	NA
20	12 Dec 2015 - End	1 Feb 2017–1 Jun 2017

Table 28. Porpoises : Performance of the automated detector for each station and year including the Threshold implemented, the resulting detector Precision (P) and Recall (R), the number of files included in the calculation (# Files; excluding any files where an analyst was uncertain of species presence), the number of files in the calculation containing an annotation for this species/ vocalization type (# Annotation files), and the number of files in the calculation containing automated fin whale detections (# Detection files). Stations not included in the table did not have this species/ vocalization type validated in 2015–16 or 2016–17. 'ND' indicates stations/years with no (useable) data.

Station	Year	Threshold	Precision	Recall	# Files	# Annotation files	# Detection files
1	2015–16	2	1.00	0.77	124	13	14
	2016–17	11	1.00	1.00	132	3	15
2	2015–16	5	1.00	0.75	120	8	13
	2016–17	2	1.00	0.95	122	22	24
3	2015–16	ND	ND	ND	ND	ND	ND
	2016–17	3	1.00	0.27	120	11	15
7	2015–16	3	1	1	126	6	9
	2016–17	ND	ND	ND	ND	ND	ND
8	2015–16	1	1.00	0.91	130	11	10
	2016–17	2	0.72	1.00	131	13	19
9	2015–16	2	1.00	0.67	128	6	8
	2016–17	ND	ND	ND	ND	ND	ND
10	2015–16	1	1.00	1.00	129	6	6
	2016–17	8	1.00	0.75	128	4	16
11	2015–16	3	1.00	0.80	128	5	13
	2016–17	1	0.80	0.92	130	13	15
12	2015–16	4	1.00	0.50	127	8	10
	2016–17	5	1.00	1.00	130	4	14
14	2015–16	1	1.00	1.00	130	10	10
	2016–17	1	1.00	1.00	131	10	10
18	2015–16	5	1.00	0.83	21	6	9
	2016–17	3	1.00	1.00	132	3	10
20	2015–16	2	1.00	0.88	129	8	9
	2016–17	2	0.85	1.00	132	17	21

G.10. Northern Bottlenose Whales

Table 29. Northern bottlenose whales: Timeframes (inclusive) for recording years 2015–16 and 2016–17 when automated detections were excluded because presence was not validated by analysts. 'Start' and 'End' indicate the first and last day of a recording period. Stations excluded from the table did not have this species validated in 2015–16 or 2016–17. 'NA' indicates that no exclusion period was applied.

Station	Northern bottlenose whale detector exclusion periods	
	2015–16	2016–17
4	NA	NA
6	NA	NA
13	NA	NA
15	NA	NA
16	NA	NA
17	NA	NA
19	NA	NA

Table 30. Northern bottlenose whales : Performance of the automated detector for each station and year including the Threshold implemented, the resulting detector Precision (P) and Recall (R), the number of files included in the calculation (# Files; excluding any files where an analyst was uncertain of species presence), the number of files in the calculation containing an annotation for this species/ vocalization type (# Annotation files), and the number of files in the calculation containing automated fin whale detections (# Detection files). Stations not included in the table did not have this species/ vocalization type validated in 2015–16 or 2016–17. 'NA' indicates values that could not be calculated due to an insufficient number of TP, FN, and FP files to calculate the P and R.

Station	Year	Threshold	Precision	Recall	# Files	# Annotation files	# Detection files
4	2015–16	NA	NA	NA	118	1	10
	2016–17	NA	NA	NA	117	0	10
6	2015–16	8	1.00	1.00	119	4	10
	2016–17	3	1.00	0.54	129	13	19
13	2015–16	1	0.91	1.00	116	31	34
	2016–17	2	0.90	0.74	127	35	36
15	2015–16	2	1.00	0.89	119	18	19
	2016–17	1	0.95	0.95	129	20	20
16	2015–16	4	0.86	0.60	118	10	21
	2016–17	7	1.00	0.42	127	12	18
17	2015–16	1	0.74	0.89	116	19	23
	2016–17	2	0.80	0.92	128	13	16
19	2015–16	1	0.92	0.94	116	35	36
	2016–17	1	0.94	0.92	127	37	36

G.11. Sowerby's Beaked Whales

Table 31. Sowerby's beaked whales: Timeframes (inclusive) for recording years 2015–16 and 2016–17 when automated detections were excluded because presence was not validated by analysts. 'Start' and 'End' indicate the first and last day of a recording period. Stations excluded from the table did not have this species validated in 2015–16 or 2016–17. 'NA' indicates that no exclusion period was applied.

Station	Sowerby's beaked whale detector exclusion periods	
	2015–16	2016–17
4	NA	NA
5	NA	NA
6	NA	NA
8	NA	NA
15	NA	NA
16	NA	NA
17	NA	NA

Table 32. Sowerby's beaked whales : Performance of the automated detector for each station and year including the Threshold implemented, the resulting detector Precision (P) and Recall (R), the number of files included in the calculation (# Files; excluding any files where an analyst was uncertain of species presence), the number of files in the calculation containing an annotation for this species/ vocalization type (# Annotation files), and the number of files in the calculation containing automated fin whale detections (# Detection files). Stations not included in the table did not have this species/ vocalization type validated in 2015–16 or 2016–17. This species/ vocalization type was considered absent (A) when their presence was not validated by an analyst.

Station	Year	Threshold	Precision	Recall	# Files	# Annotation files	# Detection files
4	2015–16	1	0.90	1.00	120	9	10
	2016–17	1	1.00	1.00	117	7	7
5	2015–16	2	1.00	0.75	120	4	4
	2016–17	1	1.00	0.67	117	9	6
6	2015–16	1	1.00	1.00	120	10	10
	2016–17	2	1.00	1.00	129	9	10
8	2015–16	A	A	A	A	A	A
	2016–17	1	0.10	1.00	131	1	10
15	2015–16	1	1.00	1.00	119	2	2
	2016–17	1	1.00	1.00	130	10	10
16	2015–16	2	1.00	1.00	117	8	9
	2016–17	2	1.00	0.67	129	12	10
17	2015–16	1	1.00	0.90	120	10	9
	2016–17	2	1.00	1.00	131	9	10
19	2015–16	A	A	A	A	A	A
	2016–17	1	1.00	1.00	131	10	10

G.12. Cuvier's Beaked Whales

Table 33. Cuvier's beaked whales: Timeframes (inclusive) for recording years 2015–16 and 2016–17 when automated detections were excluded because presence was not validated by analysts. 'Start' and 'End' indicate the first and last day of a recording period. Stations excluded from the table did not have this species validated in 2015–16 or 2016–17. 'NA' indicates that no exclusion period was applied.

Station	Cuvier's beaked whale detector exclusion periods	
	2015–16	2016–17
4	Start - 29 Nov 2015	NA
5	NA	NA
6	NA	NA
15	NA	NA
16	NA	NA
17	Start - 5 Mar 2016	NA
19	NA	NA

Table 34. Cuvier's beaked whales: Performance of the automated detector for each station and year including the Threshold implemented, the resulting detector Precision (P) and Recall (R), the number of files included in the calculation (# Files; excluding any files where an analyst was uncertain of species presence), the number of files in the calculation containing an annotation for this species/ vocalization type (# Annotation files), and the number of files in the calculation containing automated fin whale detections (# Detection files). Stations not included in the table did not have this species/ vocalization type validated in 2015–16 or 2016–17. This species/ vocalization type was considered absent (A) when their presence was not validated by an analyst.

Station	Year	Threshold	Precision	Recall	# Files	# Annotation files	# Detection files
4	2015–16	7	1.00	1.00	118	3	15
	2016–17	2	0.79	0.58	117	19	22
5	2015–16	5	1.00	0.29	115	7	24
	2016–17	3	1.00	0.55	119	11	12
6	2015–16	9	1.00	0.38	119	8	24
	2016–17	1	0.68	0.83	130	18	22
15	2015–16	1	0.92	0.92	118	12	12
	2016–17	1	0.85	0.79	130	14	13
16	2015–16	1	0.68	0.86	118	22	28
	2016–17	1	0.67	1.00	127	14	21
17	2015–16	1	1.00	0.50	117	4	2
	2016–17	2	0.72	0.87	130	15	26
19	2015–16	A	A	A	A	A	A
	2016–17	5	0.40	0.67	130	3	18