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Mid-Labrador Marine Megafauna Visual and Acoustic Study

Enquête sur la mégafaune et relevés acoustiques sur la côte du Labrador-centre

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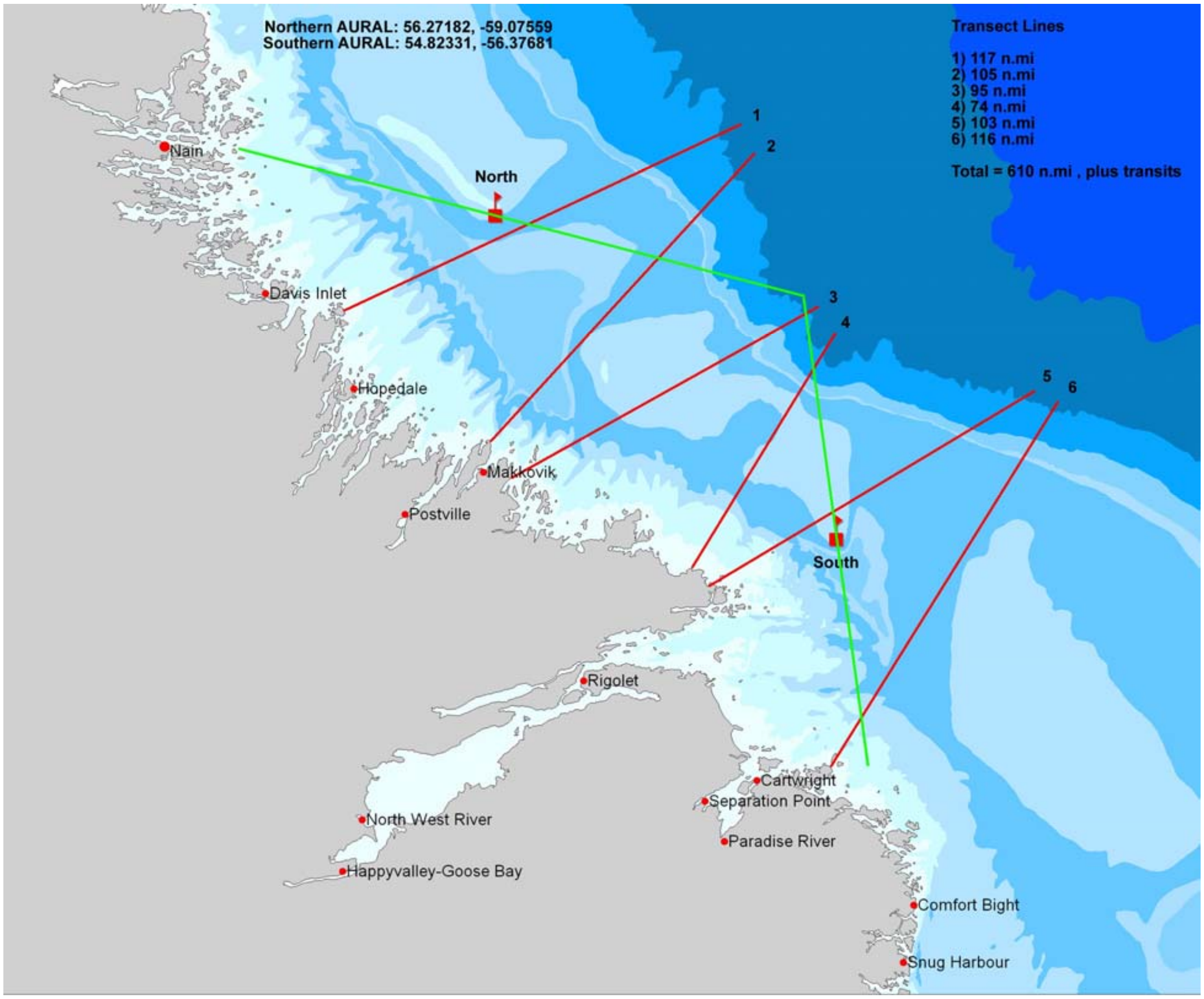
Final Report: DFO Mid-Labrador Marine Megafauna Visual and Acoustic Study



A Marine Mammal Section, Department of Fisheries and Oceans (DFO) Project, funded by the Environmental Studies Research Fund (ESRF) and SARA

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1. Executive Summary

1.1. Study Rationale

The Labrador coast and its offshore shelf may be significant sources of oil and gas in the future. There is a paucity of baseline knowledge concerning the abundance and distribution of marine mammals, seabirds, and other marine fauna which might be affected by oil and gas extraction activities. Previous visual surveys of the Labrador Shelf have detected fewer marine mammals than areas such as southern Newfoundland, but were limited in temporal scope. To address these shortcomings, marine mammal researchers at DFO and elsewhere have placed increased emphasis on underwater sound monitoring approaches to detect and identify animals. In addition, baseline measures of natural and anthropogenic sounds on the Labrador coast are needed to assess the potential impacts of the noise from oil and gas development on marine mammals such as endangered cetaceans (e.g., beluga and blue whales), and coastal ringed and harp seal populations which are important to hunters.

1.2. Study Methodology

Visual surveys were conducted in the study area from a small vessel platform (opportunistic) and a fixed-wing aircraft (designed, even-coverage transect design). Replicate aerial surveys were conducted and zig-zag transects covered the study area from the shore to beyond the shelf break. Multiple observers in the aircraft, stationed at bubble windows, recorded the location and identity of marine megafauna (whales, dolphins, seals, sharks) within visual range of the aircraft. These data provided the means to assess distribution and, in the case of white-beaked dolphins, abundance of sighted animals.

Two autonomous acoustic recorders were deployed at underwater sites at the north and south margin of the study area, approximately half way between the coast and the shelf break. These recorders operated for many months and recorded underwater sounds of biological, oceanographic, and anthropogenic origin during 2013 and 2014. A combination of automated and manual analyses were employed to detect and identify sound sources on the recordings.

We integrated the ESRF and historic survey data, and investigated the influence of oceanographic features on cetacean habitat preferences in the study area, by employing habitat suitability modelling (HSM). These models paired cetacean sightings data with oceanographic and biological features to build a set of species-specific, predictive distribution maps.

1.3. Study Results

Compared with the summer Trans North Atlantic Sightings Survey (TNASS) survey of 2007, the 2013 and 2014 ESRF visual surveys collected more sightings, and of a more diverse range of marine mammals. Nonetheless, these surveys yielded a relatively lower density of cetaceans than similar aerial surveys in the summer on the south coast of Newfoundland and the Scotian Shelf (TNASS and Laurentian Channel MPA). The larger number of sightings recorded in the 2013 survey (conducted in October and November) as compared to the 2014 survey (conducted in August) is consistent with the suggestion that cetaceans may be drawn to southern Labrador in fall, rather than earlier in the summer, likely to feed on fall spawning herring and/or mackerel; and this is corroborated with the acoustic detection data.

Marked differences in cetacean distribution between a survey that was conducted during a period when a seismic vessel was operating near the location of the northern AURAL (October 2013) and a survey conducted in the absence of seismic activities (three weeks later in early November 2013) suggest that cetaceans were displaced by this seismic noise.

White-beaked dolphins were the most commonly-sighted and numerous cetacean species sighted in 2013 and 2014 during the vessel and aerial surveys (and were common in the acoustic records). They were distributed throughout the survey area, and with a minimum abundance estimate of about 11,000 individuals for this area, this species is certain to have an important ecological role.

The AURAL acoustic recorders documented a variable, loud acoustic soundscape at the two recorder locations. The broadband (10 Hz to16 kHz) noise levels for the northern (110-120 dB rms SPL) and southern (110 dB rms SPL) AURALs in the summer and fall of 2014 were similar. Much of this sound energy was concentrated in the 0-200 Hz frequency band, with less evidence of significant seasonal differences than there was between the mooring sites; this is a frequency range containing vocalizations of most baleen whales and many toothed whale tonal calls. The JASCO automated detector analyses indicated that vessels contributed regularly to the soundscape and that multiple vessels (three to seven) passed the AURAL sites each day for much of the year. The acoustic soundscape of open ocean has daily SEL values of 150-155 dB, compared with this study's AURAL daily cSEL values which were regularly louder than 160-165 dB. Much of this sound energy in the study area appears to be contributed by vessel movement on and near the shelf (in addition to mooring self-noise). Overall, shipping noise dominated the broadband acoustic spectrum in the study area, and was detectable even when the area was ice-covered in the winter. In addition to a relatively continuous low-frequency component, the AURALs also recorded higher-frequency depth sounder pulses. Even in the winter, when fast and pack ice cover the study area, passages of ice-breaking vessels and cargo ships in open water off the shelf were detectable. Sound from seismic exploration arrays was a substantial acoustic energy contributor in 2013, when the source vessel was operating in the study area. Even in 2014 seismic pulses from more distant surveys on the Grand Banks were detectable above the ambient sounds, and thus contributed to the area's soundscape.

With automated detection and manual assessment we identified 14 marine mammal species, the most common being fin and humpback whales; this might be partly a function of the inherent difficulty in creating autodetection algorithms that can effectively discriminate amongst small toothed cetaceans such as dolphin species, and beaked whales (e.g., northern bottlenose and Sowerby's beaked whales).

MaxEnt habitat models identified highly suitable summer habitat along the offshore margin of the study area for three cetacean species (sperm, northern bottlenose, and sei whales), and to the north of the study area for two other species (minke whale and harbour porpoise). HSM results suggest that there is little suitable blue whale habitat on the Labrador Shelf. For fin whales, HSM results suggest there is extensive low-suitability habitat in summer, which changes to high-suitability on the Shelf in the fall. As for the fin whales, HSM results indicated there could be extensive low-suitability habitat for humpback and minke whales in the summer (although less and further south than fin whales) which changes to high-suitability on the Shelf (not quite to the northern AURAL site) in the fall.

For deep-diving sperm and pilot whales, the entire Labrador Shelf break and deeper on-shelf waters south of Nain Bank contain HSM-derived highly-suitable habitat in the summer and fall periods, although like the baleen species, moderate- and highly-suitable habitat for sperm whales is more widespread on the Shelf in the fall.

The seal species that breed in this area (e.g., harp, hooded, ringed, and bearded seals) are most abundant during the late winter when sea ice is present and they are reproducing; most of these species leave the study area during the summer.

1.4. Recommendations For Further Study

In 2013, and to a lesser extent in 2014, the ESRF aerial survey efforts were hampered by poor weather which limited the observers' abilities to detect and identify marine megafauna. Researchers could counteract this type of weather impact by flying replicate surveys several weeks apart during the period(s) of interest.

Longer transect lines would better capture marine megafauna presence in the offshore area beyond the shelf break, particularly as these animals will be exposed to anthropogenic noise from activities on the shelf and the acoustic records suggest that some cetaceans remain offshore but adjacent to the shelf throughout the winter when sea ice covers the shelf itself.

Future visual surveys should concentrate their efforts in the Fall as the data showed that more species and more animals are likely present on the Labrador Shelf at this time of year.

Acoustic studies could be enhanced with full-year recordings (see JASCO Applied Sciences' ESRF Project 2014-02S "Acoustic Modelling and Monitoring on Canada's East Coast"), quieter moorings, and recorders with a higher frequency response to detect more small cetaceans and better characterise the Labrador Shelf soundscape.

Continued development of species-specific acoustic detectors is warranted – particularly for species with complex vocal patterns (e.g., humpback and killer whales), or patterns that overlap in frequency and intensity with anthropogenic sounds (e.g., humpback and pilot whales). These will further speed and enhance the reliability of acoustic data processing.

One of the key environmental data types needed for further refinement of the cetacean habitat modelling consists of indices of relative concentration of prey at a temporal and spatial scale relevant to the marine mammal species of interest, rather than the current use of chlorophyll magnitude and persistence as a proxy for higher trophic level prey.

1. Sommaire exécutif

1.1. Justification de l'étude

La côte du Labrador et son plateau extracôtier peuvent constituer des sources importantes de pétrole et de gaz pour l'avenir. On manque de connaissances de base sur l'abondance et la répartition des mammifères marins, des oiseaux marins et des autres représentants de la faune marine susceptibles d'être affectés par les activités d'extraction du pétrole et du gaz. Les levés visuels antérieurs réalisés sur le plateau du Labrador ont permis de détecter moins de mammifères marins que dans d'autres secteurs, comme le sud de Terre-Neuve, mais étaient d'une durée limitée. Afin de combler ces lacunes, les chercheurs spécialisés en mammifères marins du MPO et d'ailleurs ont mis davantage l'accent sur les approches de surveillance sonore sous-marine pour détecter et identifier les animaux. En outre, des mesures de base des sons naturels et anthropiques sur la côte du Labrador sont requises pour évaluer les impacts potentiels du bruit produit par la mise en valeur du pétrole et du gaz sur les mammifères marins comme les cétacés en péril (p. ex. les bélugas et les baleines bleues) et sur les populations de phoque annelé et de phoque du Groenland, qui sont importantes pour les chasseurs.

1.2. Méthodologie de l'étude

Des levés visuels ont été réalisés dans la zone de l'étude à partir d'un petit navire (levés opportunistes) et d'un aéronef à voilure fixe (levé planifié, à couverture uniforme par transects). Des levés aériens ont été reproduits et les transects en dents de scie couvraient la zone à l'étude de la côte jusqu'au-delà du rebord de la pente continentale. De multiples observateurs dans l'aéronef, postés à des coupoles d'observation, consignaient l'emplacement et l'identité des représentants de la mégafaune marine (baleines, dauphins, phoques, requins) visibles depuis l'aéronef. Ces données ont permis d'évaluer la répartition et, dans le cas du dauphin à bec blanc, l'abondance des animaux vus.

Deux enregistreurs acoustiques autonomes ont été déployés dans des sites sous-marins aux extrémités nord et sud de la zone à l'étude, environ à mi-chemin entre la côte et le rebord de la plateforme continentale. Ces enregistreurs ont fonctionné pendant de nombreux mois et ont enregistré les sons sous-marins d'origine biologique, océanographique et anthropique pendant les années 2013 et 2014. On a utilisé une combinaison d'analyses automatisées et manuelles pour détecter et identifier les sources des sons sur les enregistrements.

Nous avons intégré les données des levés du Fonds pour l'étude de l'environnement (FEE) et des levés historiques, et nous avons étudié l'influence des caractéristiques océanographiques sur les préférences des cétacés en matière d'habitat dans la zone à l'étude, en utilisant la modélisation de la qualité de l'habitat (*Habitat Suitability Modelling* – HSM). Ces modèles combinaient les données d'observation des cétacés aux données sur les caractéristiques océanographiques et biologiques pour bâtir un ensemble de cartes de répartition prévisionnelles propre à chaque espèce.

1.3. Résultats de l'étude

Par comparaison avec le Relevé visuel transatlantique Nord (*Trans North Atlantic Sightings Survey* – TNASS) estival réalisé en 2007, les levés visuels de 2013 et 2014 du FEE ont permis d'effectuer un plus grand nombre d'observations d'une plus grande variété de mammifères marins. Néanmoins, ces levés ont révélé une densité de cétacés plus faible que les levés aériens semblables réalisés à l'été sur la côte sud de Terre-Neuve et sur la plateforme Néo-Écossaise (TNASS et aire marine protégée du chenal Laurentien). Le grand nombre d'observations consignées lors du levé de 2013 (réalisé en octobre et novembre), par comparaison avec le levé de 2014 (réalisé en août), est conforme avec la suggestion que les cétacés pourraient être attirés vers le sud du Labrador en automne plutôt qu'au début de l'été, probablement pour se nourrir des harengs et maquereaux nés en automne; cette théorie est corroborée par les données de détection acoustique.

Des différences marquées dans la répartition des cétacés entre un levé réalisé pendant à une période pendant laquelle un navire sismologique exerçait ses activités près de l'hydrophone AURAL septentrional (octobre 2013) et un levé réalisé en l'absence d'activité sismologique (trois semaines plus tard, au début de novembre 2013) laissent croire que les cétacés ont été déplacés par ce bruit sismologique.

Le dauphin à bec blanc était l'espèce de cétacé la plus souvent observée et la plus nombreuses en 2013 et 2014 lors des levés effectués à partir de navires et d'aéronefs (et était une espèce commune dans les registres acoustiques). Il était réparti dans l'ensemble de la zone du levé, et avec une abondance minimale estimée d'environ 11 000 individus dans cette zone, il est certain que cette espèce joue un rôle écologique important.

Les enregistreurs acoustiques AURAL ont documenté un paysage acoustique variable et puissant aux deux emplacements. Les niveaux de bruit à bande étendue (10 Hz à 16 kHz) pour l'hydrophone AURAL septentrional (valeur quadratique moyenne du niveau sonore de 110 à 120 dB) et pour l'hydrophone AURAL austral (valeur quadratique moyenne du niveau sonore de 110 dB) étaient semblables au cours de l'été et de l'automne 2014. Une grande partie de cette énergie sonore était concentrée dans la bande de fréquence de 0 à 200 Hz, avec moins de preuves de différences saisonnières qu'il n'y en avait entre les sites de mouillage; il s'agit d'une gamme de fréquences contenant les vocalisations de la plupart des cétacés à fanons et les appels toniques de nombreux cétacés à dents. Les analyses du détecteur automatisé JASCO ont indiqué que des navires contribuaient régulièrement au paysage sonore et que de multiples navires (entre trois et sept) passaient chaque jour près des sites AURAL pendant une grande partie de l'année. Le paysage sonore de la haute mer présente des valeurs de niveau d'exposition au bruit (NEB) quotidiennes de 150 à 155 dB, par comparaison avec les valeurs de NEB cumulatif AURAL de cette étude, qui dépassaient régulièrement 160 à 165 dB. La majeure partie de cette énergie sonore dans la zone à l'étude semble découler des déplacements des navires au-dessus et à proximité de la plateforme continentale (en plus du bruit propre du mouillage). Dans l'ensemble, le bruit causé par la navigation dominait le spectre acoustique à large bande dans la zone à l'étude et était détectable même lorsque la zone était couverte de glace en hiver. En plus d'une composante à basse fréquence relativement continue, les hydrophones AURAL ont également enregistré les pulsions à plus haute fréquence des échosondeurs. Même en hiver, lorsque de la glace rapide et de la banquise couvrent la zone à l'étude, les passages des brise-glaces et des navires de charge en eau libre au large de la plateforme continentale étaient détectables. Le son issu des équipements de prospection sismique était une importante source d'énergie acoustique en 2013, alors que le navire d'origine naviguait dans la zone à l'étude. Même en 2014, les pulsions sismiques de levés plus lointains sur les Grands Bancs étaient détectables par-dessus les sons ambiants, et contribuaient donc au paysage sonore de la zone.

Grâce à la détection automatisée et à l’évaluation manuelle, nous avons identifié 14 espèces de mammifères marins, dont les plus communes étaient le rorqual commun et le rorqual à bosse; cela peut découler en partie de la difficulté inhérente de créer des algorithmes d’autodétection capables de différencier efficacement les petits cétacés à dents, comme les espèces de dauphins, des ziphiidés (p. ex. la baleine-à-bec boréale et la baleine-à-bec de Sowerby).

Les modèles d’habitat MaxEnt ont identifié un habitat estival très convenable le long du rebord extracôtier de la zone à l’étude pour trois espèces de cétacés (cachalot, baleine-à-bec boréale et rorqual boréal), et au nord de la zone à l’étude pour deux autres espèces (petit rorqual et marsouin commun). Les résultats de la grille de concordance de l’habitat (*Habitat Suitability Matrix* – HSM) laissent croire qu’il y a peu d’habitats convenant au rorqual bleu sur la plateforme continentale du Labrador. Pour le rorqual commun, les résultats de la HSM laissent croire qu’il y a sur la plateforme continentale un vaste habitat peu convenable en été qui se transforme en habitat très convenable à l’automne. En ce qui concerne le rorqual commun, les résultats de la HSM ont indiqué qu’il pourrait y avoir sur la plateforme continentale un vaste habitat peu convenable pour le rorqual à bosse et le petit rorqual en été (quoi que moins vaste et plus au sud que celui du rorqual commun) qui se transforme en habitat très convenable (quoi que pas autant que le site AURAL septentrional) à l’automne.

Pour le cachalot et le globicéphale, qui plongent profondément, l’ensemble du rebord de la plateforme continentale du Labrador et des eaux plus profondes de la plateforme continentale, au sud du banc Nain, présente d’après la HSM un habitat très convenable en été et en automne, même si, comme pour les espèces de cétacés à fanons, l’habitat moyennement et très convenable pour le cachalot est plus étendu sur la plateforme continentale en automne.

Les espèces de phoques qui se reproduisent dans cette zone (p. ex. phoque du Groenland, à capuchon, annelé et barbu) sont plus abondantes à la fin de l’hiver, alors qu’il y a de la glace marine et qu’elles se reproduisent; la plupart de ces espèces quittent la zone à l’étude pendant l’été.

1.4. Autres études recommandées

En 2013 et, dans une moindre mesure, en 2014, les efforts de levés aériens du FEE ont été entravés par les mauvaises conditions météorologiques qui ont limité la capacité des observateurs de détecter et d’identifier les représentants de la mégafaune marine. Les chercheurs pourraient contrer ce type d’impact météorologique en reproduisant le levé aérien à quelques semaines d’intervalle pendant la ou les périodes d’intérêt.

Des lignes de transect plus longues permettraient de mieux détecter la présence de représentants de la mégafaune marine dans la zone extracôtière au large du rebord de la plateforme continentale, en particulier parce que ces animaux seront exposés aux bruits anthropiques créés par les activités sur la plateforme continentale et que les enregistrements acoustiques laissent croire que certains cétacés restent au large mais à proximité de la plateforme continentale pendant tout l’hiver, alors que la glace marine recouvre la plateforme continentale.

Les levés visuels futurs devraient concentrer leurs efforts à l’automne, puisque les données ont montré que davantage d’espèces et d’animaux sont probablement présents sur la plateforme continentale du Labrador à cette époque de l’année.

Les études acoustiques pourraient être améliorées par des enregistrements d'une année complète (reportez-vous au projet 2014-02S de JASCO Applied Sciences, financé par le FEE et intitulé « Acoustic Modelling and Monitoring on Canada's East Coast »), des mouillages plus calmes et des enregistreurs ayant une réponse de fréquence plus élevée afin de détecter davantage de petits cétacés et de mieux caractériser le paysage sonore de la plateforme continentale du Labrador.

La poursuite de la mise au point de détecteurs acoustiques propres à une espèce particulière est justifiée – en particulier pour les espèces présentant des schémas vocaux complexes (p. ex. rorqual à bosse et épaulard), ou des schémas dont la fréquence et l'intensité chevauchent les sons anthropiques (p. ex. rorqual à bosse et globicéphale). Ces enregistreurs accéléreront et amélioreront la fiabilité du traitement des données acoustiques.

L'un des principaux types de données environnementales dont on a besoin pour raffiner davantage les modèles d'habitat des cétacés est constitué d'indices de concentration relative des proies à une échelle temporelle et spatiale pertinente à l'espèce de mammifère marin à laquelle on s'intéresse, plutôt que l'utilisation actuelle d'ampleur et de persistance de la chlorophylle comme indicateur de proies de niveau trophique plus élevé.

2. Labrador Marine Megafauna Study Rationale

The Labrador coast and its offshore shelf may be significant sources of oil and gas products in the future. Residents' concerns about the potential impacts of industrial efforts to extract oil and gas off Hopedale and other sites on the Labrador Shelf is paired with a paucity of baseline knowledge concerning the abundance and distribution of marine mammals, seabirds, and other marine fauna which might be affected by such anthropogenic activities.

During an effort to address this paucity of information, a large-scale aerial survey of Atlantic Canada by the Department of Fisheries and Oceans (DFO) collected too few sightings on the Labrador Shelf to estimate marine mammal abundances. The Labrador Shelf component of this survey (TNASS; 5,363 nautical miles of transect effort) was flown by DFO scientists on 17-20 July, 2007 (Lawson and Gosselin 2009). Relative to the rest of the Newfoundland survey areas, the 2007 effort reported the lowest rate and number of sightings (19 out of 584 total sighting events for the TNASS) on the Labrador coast (Figure 1). Species sighted in Labrador during the 2007 survey included beluga (*Delphinapterus leucas*) and long-finned pilot whales (*Globicephala melas*), several dolphin species {white-beaked dolphin (*Lagenorhynchus albirostris*); common dolphin (*Delphinus delphis*)}, and minke (*Balaenoptera acutorostrata*), fin (*Balaenoptera physalus*), and northern bottlenose whales (*Hyperoodon ampulattus*). As well, endangered species such as blue (*Balaenoptera musculus*) and north Atlantic right whales (*Eubalaena glacialis*) have been seen in this area during previous surveys (Lawson and Gosselin 2009; McLaren et al. 1982).

Marine mammal researchers at DFO and elsewhere place increased emphasis on underwater sound monitoring approaches to detect and identify animals. In addition, baseline measures of natural and anthropogenic sounds on the Labrador coast are needed to assess the potential impacts of the noise from oil and gas development on marine mammals such as endangered cetaceans, and coastal ringed (*Phoca hispida*) and harp seal (*Pagophilus groenlandicus*) populations which are important to hunters (e.g., ESRF Project 2014-02S "Acoustic Modelling and Monitoring on Canada's East Coast").

The best way to gather these data is with multiple approaches: aerial, shipboard, and acoustic surveys. Each offers complementary strengths to minimize risks of failure, and facilitates involvement of local residents in conducting the tasks as a capacity-building exercise. Habitat modelling provided a logical extension to these data by facilitating data extrapolation to areas and periods outside of the ESRF survey scope.

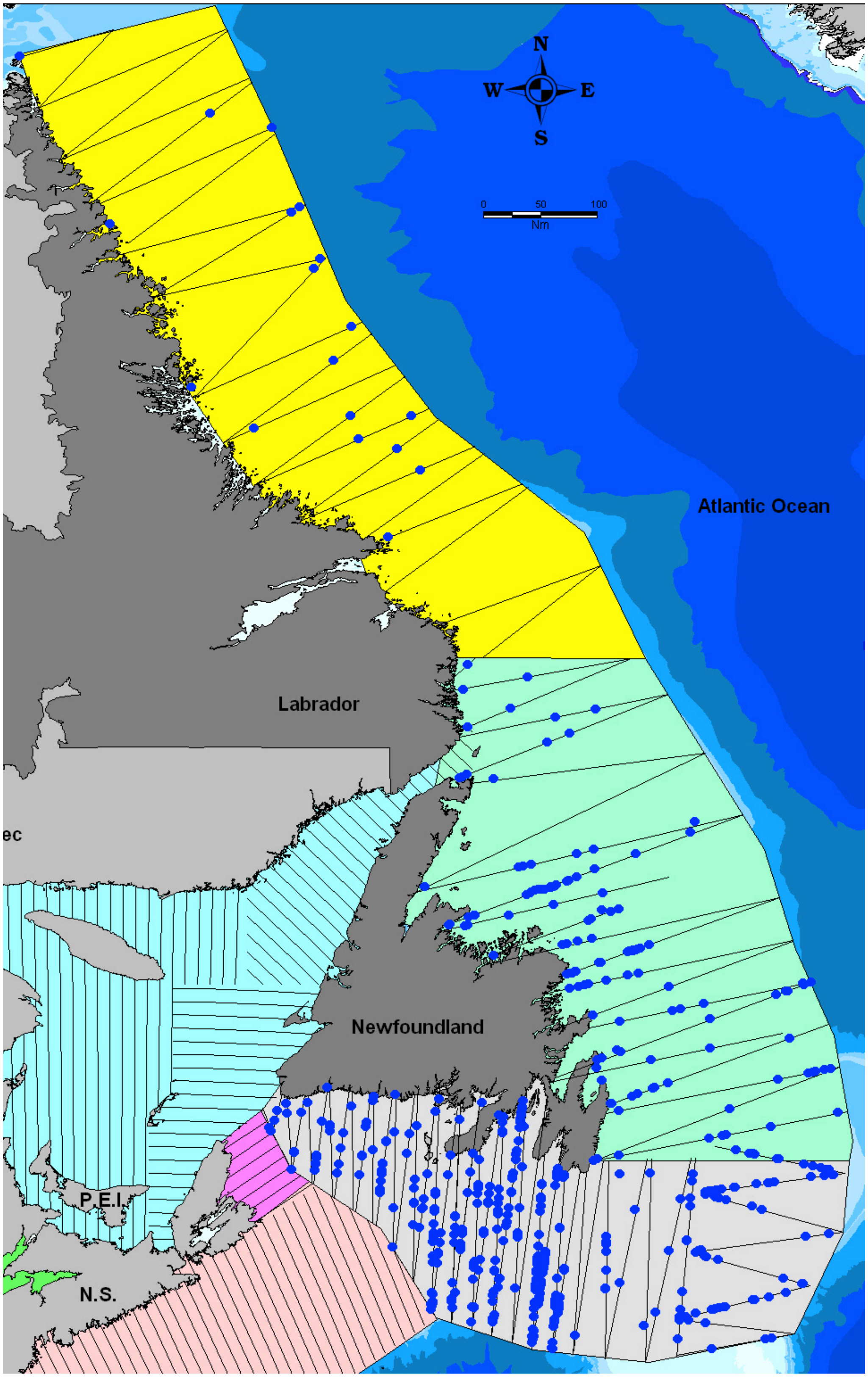

Figure 1. Sighting effort and marine mammal and sea turtle sighting events (blue circles) recorded during the 2007 TNASS aerial survey off the Newfoundland and Labrador coast, with relatively lower numbers of sightings apparent in the Labrador stratum (yellow polygon).

Environmental Studies Research Fund (ESRF) provided funding to DFO and Environment Canada (EC) to conduct aerial and boat-based surveys of a study area, in waters adjacent to the southern Labrador coast, to estimate the distribution and abundance of marine fauna - including marine mammals and seabirds. The research team also analysed acoustic data collected in the study area to corroborate the visual surveys, and provide measures of biological and anthropogenic noise. Additional equipment and expertise was provided by DFO and EC.

The goals of this ESRF project included:

- Estimate presence, distribution, and abundance of marine mammals, seabirds (Environment Canada), and other marine megafauna (e.g., leatherback sea turtles, sharks) in the study area
- Identify and measure the natural and anthropogenic contributions to the study area's ambient soundscape
- Build capacity to conduct field studies in the marine environment by local residents

This final report details the methods and results for the first (2013-14) and second (2014-15) phases of the ESRF-funded southern Labrador study for marine mammals and sea turtles, plus marine acoustics, and (supplementary) habitat modelling. Environment Canada also produced a report to describe their concurrent seabird research activities for this project; "Baseline Surveys for Seabirds on the Labrador Sea", ESRF Report #205. The marine megafauna data collected during the visual surveys and acoustic deployments is stored by DFO; those wishing to obtain a copy of this data can contact Dr. Jack Lawson, Northwest Atlantic Fisheries Centre, 80 E. White Hills Rd, P.O. Box 5667, St. John's, NL Canada A1C 5X1 – Telephone (709) 772-2285 – Email Jack.Lawson@dfo-mpo.gc.ca.

3. Labrador Study Area and Methods (Overview)

The study area was defined approximately by the boundaries of the planned exploration licenses on the mid Labrador Shelf, with extensions from the nearshore, and to the north and south (Figures 2 and 3). Study methodology was designed to be comparable to other multi-platform marine fauna surveys (e.g., Boles 1980; Lawson and Gosselin 2009; McLaren et al. 1982; Palka 2012) – particularly in coastal shelf areas such as are found on Canada's coasts.

The DFO research team employed three approaches to gather marine megafauna occurrence data: vessel visual surveys, aerial visual surveys, and acoustic surveys using fixed monitoring stations. Some of these data were then used as primary inputs to habitat modelling that extended the survey and monitoring results spatially and temporally.

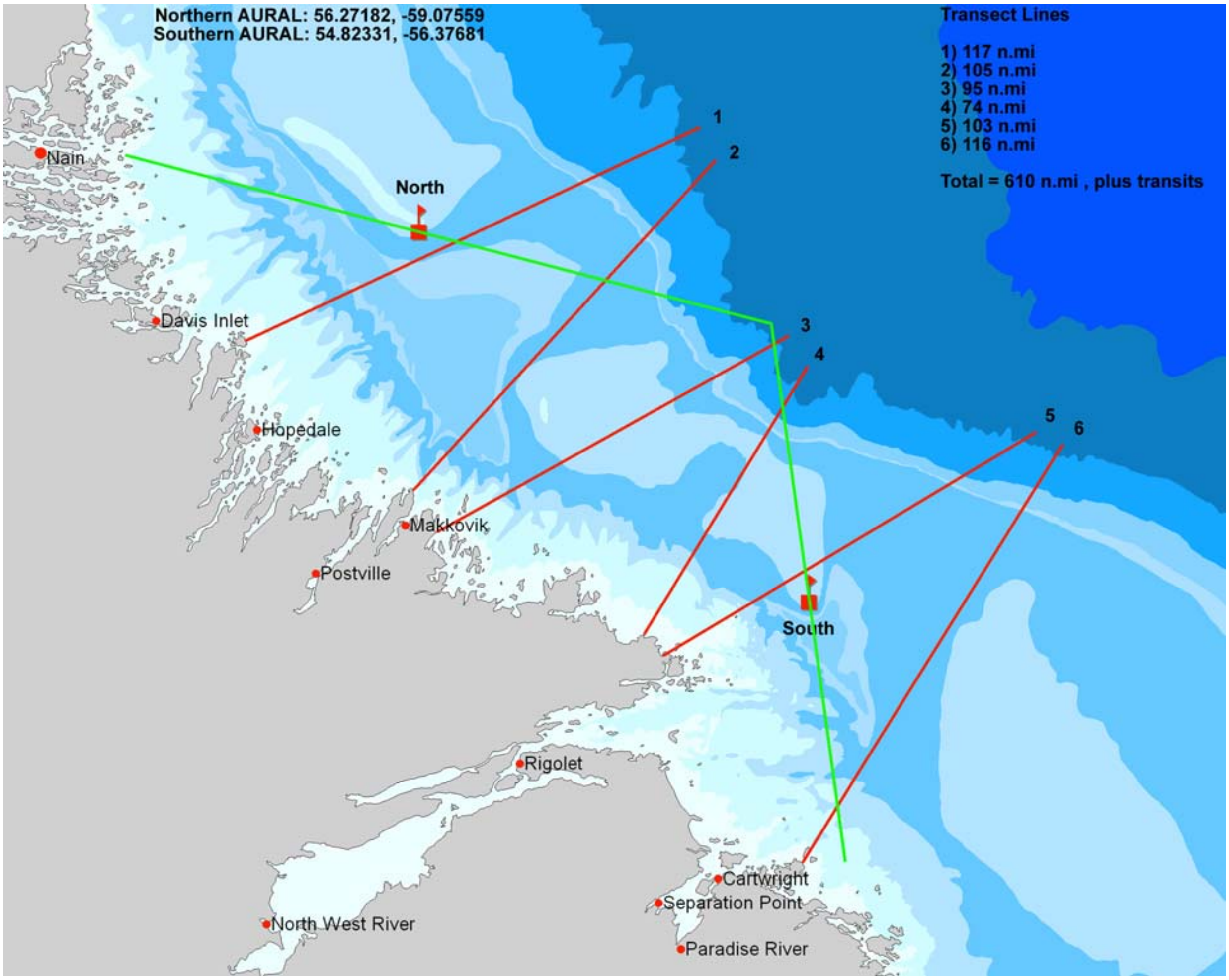

Figure 2. Six planned zigzag-shaped transect lines for the 2013 ESRF survey (red lines) extended from shore to just beyond the southern Labrador shelf break. The planned vessel track (green lines) allowed for visual observation and the deployment of the two AURAL recorders in October (red, flagged boxes at the northern and southern ends of the project area).

4. Vessel-based Visual Surveys (2013)

4.1. Vessel Platform Visual Survey Approach

Due to unanticipated delays with developing research agreements and funding allocation, the first project surveys did not commence until October, 2013 (although the survey approach, equipment, and acoustic moorings had been prepared in anticipation of the original summer start date). The delayed timing of the 2013 surveys precluded using the vessel platform to conduct concurrent aerial- and vessel-based visual surveys. Nevertheless, an EC observer aboard the vessel conducted a visual survey during the acoustic recorder deployment trip aboard a fishing vessel.

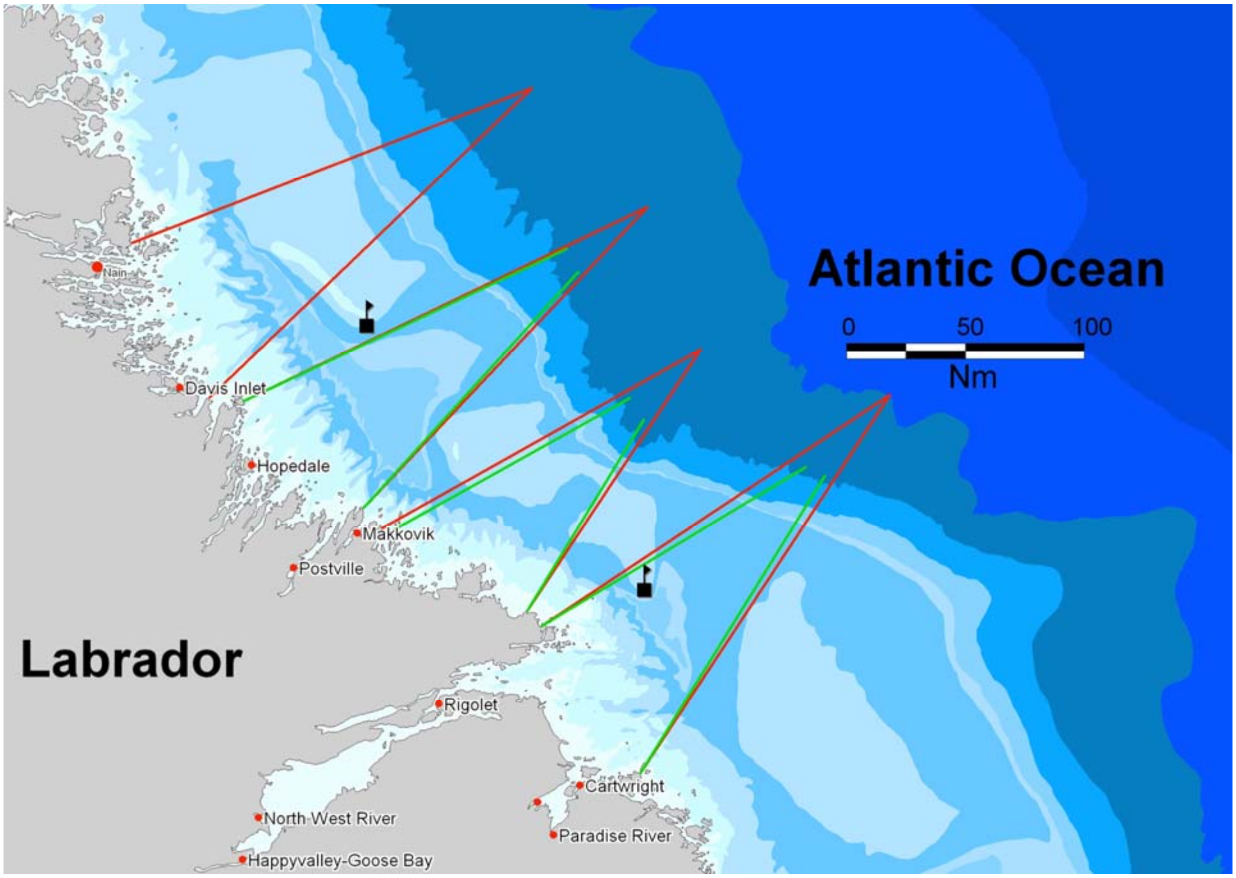

Figure 3. Eight planned zigzag-shaped transect lines for the 2014 ESRF survey (red lines) were longer, extended further offshore, and two transects encompassed more northerly waters than the 2013 transects (green lines). The AURAL recorders (black, flagged boxes) were redeployed in 2014 at the same locations as for 2013.

The observer had a virtually unobstructed view around the vessel from an open station above the bridge, and was equipped with 10×50 waterproof reticule binoculars, and recorded sightings using a dedicated laptop and custom Environment Canada data logging software.

The vessel left Nain in the early morning of 17 October 2013 and arrived in the evening at the deployment point for the northern AURAL recorder (see next section, and Figure 2). With poor weather forecast, the vessel steamed directly to the deployment point for the southern AURAL recorder, arriving there on 19 October. The vessel then returned to Nain on 20 October.

4.2. Effort and Sightings – Vessel Platform

The vessel M/V *What's Happening* departed and returned to Nain, Labrador, over a 4-day period beginning on 17 October. The test of this platform was successful in terms of assessing the data collection methodology, although the timing of the survey start, poor weather, and lack of local observers precluded plans to conduct a large-scale visual survey concurrent with the aerial platform. On 17 October a seismic exploration vessel was operating an airgun array a few kilometres from the *What's Happening*'s position as it steamed to the location to deploy the AURAL recorders. (In fact, the day after deployment the seismic vessel passed directly over the northern recorder position.)

As for the 2013 aerial survey, the most commonly-sighted cetacean species was the white-beaked dolphin, followed by minke whales and harbour porpoises (*Phocoena phocoena*) (Table 1).

The observer also sighted two pinniped species, bearded (*Erignathus barbatus*) and harp seals, in small numbers.

5. Aerial Visual Surveys (2013, 2014)

5.1. Aerial Visual Survey Planned Approach

Two survey flights of several days duration each were planned, with the first survey to be conducted in July, and the second in September, of 2013. The vessel portion of the work was planned to include several research trips of three days duration each; during these trips two acoustic recorders would be deployed/retrieved at the northern and southern ends of the development parcels, with a marine megafauna visual (and perhaps acoustic) survey conducted by observers as the vessel moved along the same survey lines as the aerial team. Timing of these two types of surveys was initially planned to provide data for the summer, fall, and (using the acoustic recorders) winter periods. Additional observer coverage on platforms of opportunity (such as the ore-carrying icebreaker *Umiak* in the winter, and the Labrador coastal ferry) were to be investigated.

DFO would provide the specialized survey bubble windows for the aircraft, the custom data recording and navigation software for the marine mammal observers, build the acoustic recorder moorings, and provide the acoustic system necessary to retrieve the recorders. EC would provide the custom data recording and navigation software for the seabird observers aboard the aircraft and the survey vessel.

Table 1. As for the aerial survey, white-beaked dolphins were the most frequently-sighted mammals during the vessel survey in October, 2013.

	Oct 17		**Oct 18**		**Oct 19**		**Oct 20**		**Overall**	
Cetacean Species	**Number Sightings**	**Number Animals**	**Number Sightings**	**Number Animals**	**Number Sightings**	**Number Animals**	**Number Sightings**	**Number Animals**	**Number Sightings**	**Number Animals**
Minke Whale			1	1			2	2	3	3
Harbour Porpoise	1	1			1	1			2	2
White-beaked Dolphin			2	16	1	3	1	3	4	22
Unknown Dolphin			2	4					2	4
Grand Totals	**1**	**1**	**5**	**21**	**2**	**4**	**3**	**5**	**11**	**31**

5.2. Aerial Visual Survey Realized Approach

5.2.1. Aerial Visual Survey Timing and Transect Design (2013)

The aerial surveys commenced in October, 2013 (see §4.1, above). By the October time frame weather conditions in southern Labrador had become much more unpredictable, with frequent storms and high winds often creating high sea states. The dates flown represented the best windows of opportunity to complete the survey with lower sea state and good visibility.

The distribution of marine megafauna in the southern Labrador study area was estimated for a stratum extending out to the edge of the continental shelf (Figure 2). Using the boundaries of this survey strata and the planned survey effort, the Distance computer programme (V. 6.0, Release 1, Thomas et al. 2010; Thomas et al. 2007) was used to design an equal-angle, zigzag line transect survey in which the transects were oriented across bathymetry gradients, and could be flown in a single day to control for marine mammal movements. This transect design also reduced the occurrence and duration of flight legs made when no formal observations were collected. The planned transects totalled 610 nautical miles (1,230 km) in length.

5.2.2. Aerial Visual Survey Timing and Transect Design (2014)

In 2014, the aerial surveys commenced on 25 August, 2014. There had been multiple storm systems pass through the study area in July and August, so the team chose an interval where the conditions turned out to be better than most; the dates flown represented the best windows of opportunity to complete the survey with lower sea states and good visibility.

The abundance and distribution of marine megafauna in the southern Labrador study area was estimated for a stratum extending out beyond the edge of the continental shelf in 2014 since the team was able to fly with a Twin Otter with greater range (Figure 3), and the revised survey plan could be flown in a single day to control for marine mammal movements. The planned transects totalled 1,074 nautical miles (1,989 km) in length.

5.2.3. Observer Methodology – Aircraft Platform

The aerial survey component of the project was flown using a deHavilland Twin Otter 300 aircraft, operating at an altitude of 183 m and groundspeed of approximately 185 km/hr (as determined with a radar altimeter aboard the aircraft, and monitored by both the flight crew and the DFO navigator). Aircraft position, obtained from a GPS receiver, was recorded automatically every 2 sec with custom software (see below). This aircraft was equipped with three large bubble windows {one left front, one right front (Figure 4), and a right rear bubble door (Figure 5)}. In 2013, three observers (one EC and two DFO) were stationed at the bubble windows, with a fourth observer (EC) positioned at a flat window on the left side of the aircraft. A fifth team member acted as marine mammal data recorder and flight navigator (see Appendix A for a list of project participants). In 2014, all four observers (two EC and two DFO) were stationed at bubble windows, DFO observers positioned on the right side of the aircraft and EC on the left. Again, a fifth team member acted as marine mammal data recorder, flight navigator, and video trackline camera operator.

Observers and aircrew were able to communicate via headsets, and a replicate map display on the control yoke of the aircraft showed the pilots the same navigation information as for the data recorder. The data recorder controlled observer auditory interactions by way of a custom-built intercom system that allowed the data recorder to query the observers about sightings, yet observers could not hear each other. Observers were stationed such that they were not able to see each other while collecting observations ("on effort"). Thus, each observer was visually and acoustically isolated from the rest, ensuring independence of observation data.

While on-effort, the observers noted marine mammals as well as weather conditions (sea state, glare from the sun, cloud cover). This information was recorded using a specialized software programme (Visual Observer Recording, VOR) operated by the data recorder/navigator (Figure 6) in which the time of a sighting event was recorded in VOR in a new data line when the observer pressed a key on a USB keypad at their station. Distances of each sighting from the trackline were derived during analyses from angle measurements obtained by observers using inclinometers (Suunto) when the locations of individual animals or groups were passing abeam (e.g., Lerczak and Hobbs 1998). We did not close on sightings but continued on the survey line.

5.2.1. Video Record of Trackline (2014)

In 2014 we installed a small, high-resolution video camera in the belly of the aircraft (Figures 7 and 8). The camera was aimed so as to record imagery directly below the aircraft as it flew along a transect. When flying at 183 m, the Hero3+ Black camera (GoPro, Inc.) had a strip width of 232.7 m and an along-track field of view of 413.7 m. The resultant 4K-resolution imagery was recorded at a speed of 15 frames per second, and was stored in high-capacity memory cards and later downloaded for analysis. During flight the imagery was also streamed to a 19" LCD monitor on aircraft (Figure 6) for use by the navigator to assess sea state and system operation.

In the laboratory, the video files were played back from a Apple MacBook Pro laptop to a 21" monitor with 4K resolution, and contrast and brightness adjusted to maximize image utility for detection and identification of animals below the aircraft.

Figure 4. Right front bubble window, as viewed from the right rear bubble door.

Figure 5. Large right rear bubble door.

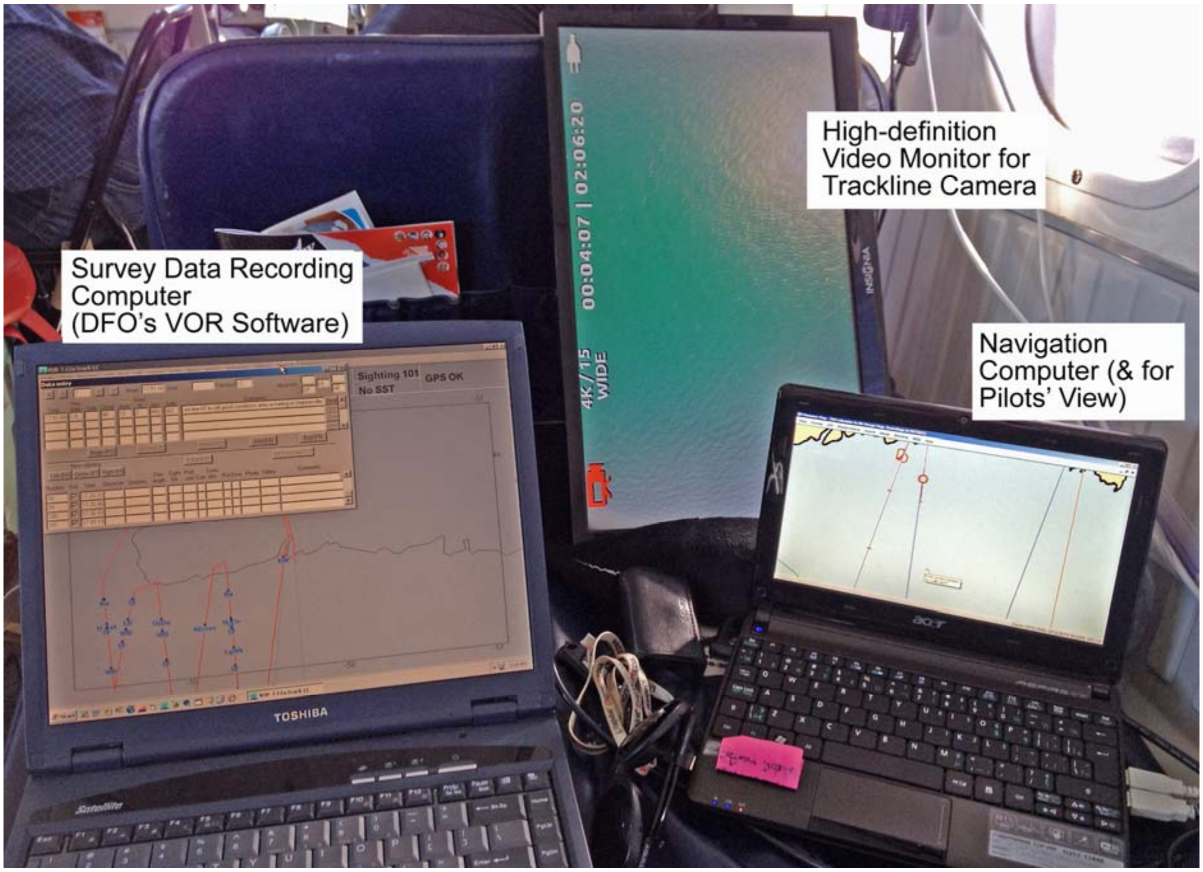

Figure 6. Survey laptop, navigation laptop, trackline video monitor, and other data recording equipment for data recorder/navigation position.

Figure 7. Trackline video camera mount in the rear belly of the Twin Otter survey aircraft.

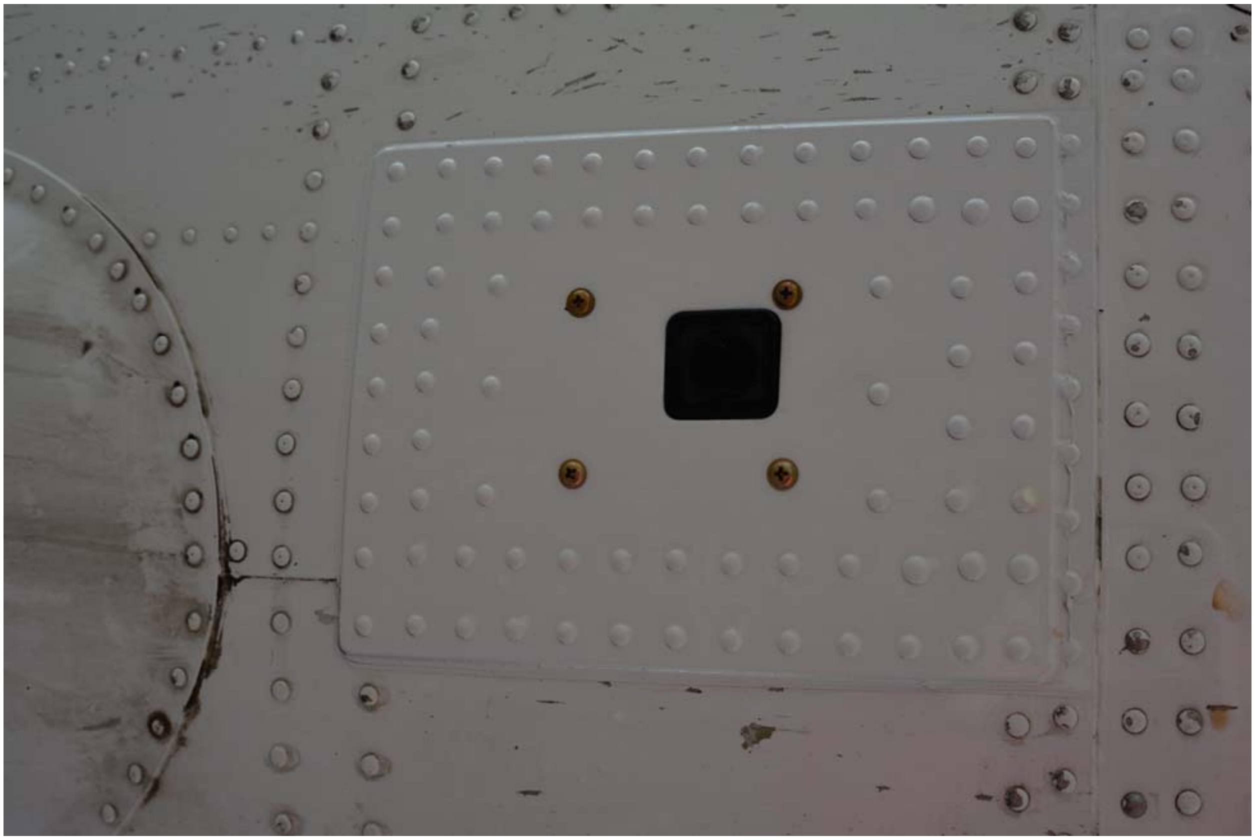

Figure 8. Custom viewport for the high-resolution trackline video system which provided a continuous record of objects directly below the survey aircraft during flight.

5.2.2. Aerial Survey Target Species

All aquatic megafauna species encountered were recorded, although in the project survey area pinnipeds sightings were infrequent, and the abundance of harp and hooded seals had been estimated previously using other means by DFO (Stenson et al. 2010; Stenson et al. 2014; Stenson and Kavanagh 1993). Sightings of marine megafauna included whales, dolphins, porpoises, seals, large sharks, and seabirds.

5.2.3. Analytical Methods

Line transect density and abundance analyses were planned to be completed using the programme Distance (version 6.0, Thomas et al. 2005). During these initial surveys we did not collect sufficient unique sightings to obtain reliable abundance estimates (see §4.3, below) in the survey area; a minimum sample size of at least 30 sightings is recommended for this analytical approach (e.g., Buckland et al. 2001). However, we collected a total of 38 unique sightings for white-beaked dolphins over the two years of surveys, and estimated a density and abundance in the study area for this species by using the combined data and the total survey effort for all survey days. We collected fewer sightings of other species and did not analyse them further. However, we endeavoured to mitigate this sightings paucity through habitat suitability modelling (see §7, below)

5.3. Aerial Visual Survey Results

5.3.1. Effort – Aerial Platform (2013)

The aircraft and observers were based in Goose Bay, which was approximately an hour's flight time from the nearest transect line. The aircraft re-fuelled at the Labrador coast in Nain, Makkovik, and Cartwright to ensure that transects were started with a full fuel complement. Total survey effort (observers watching actively for marine megafauna and seabirds) was 1,264 nautical miles, with 645 nautical miles flown in October and 619 nautical miles flown in November (Figure 9). October 16 was flown in poor survey conditions, with relatively strong winds (compared with 7 November) and fog banks, resulting in a reduced on-effort coverage (Table 2 and Figures 9 and 10) – although we flew along most of the lines in hopes of improved conditions. October 17 was flown in better survey conditions, with lighter winds and less fog, resulting in better coverage (Table 2 and Figures 9 and 11). November 7th was flown in the best conditions of the three days, and two flights on that day allowed complete coverage of the six survey lines (Table 2, Figures 9 and 12) with little coverage lost to fog or higher sea states.

Table 2. On-effort survey distance and time flown during the southern-Labrador aerial survey in October and November, 2013. Nm = nautical mile.

Date	Transect Distance Flown On-effort (Nm)	Time in Flight (including transit) (hr)
October 16, 2013	60	6.5
October 17, 2013	585	8.5
November 7, 2013	619	10.0
Total	**1,264**	**25.0**

Despite a delayed start, the survey flights were a success in terms of testing of the data collection approaches, assessment of platform and specialized data collection hardware and software, development of technical capacity for Labradoreans (Air Labrador and the crew of the *What's Happening*), and collection of sightings data on a diverse array of marine species seen.

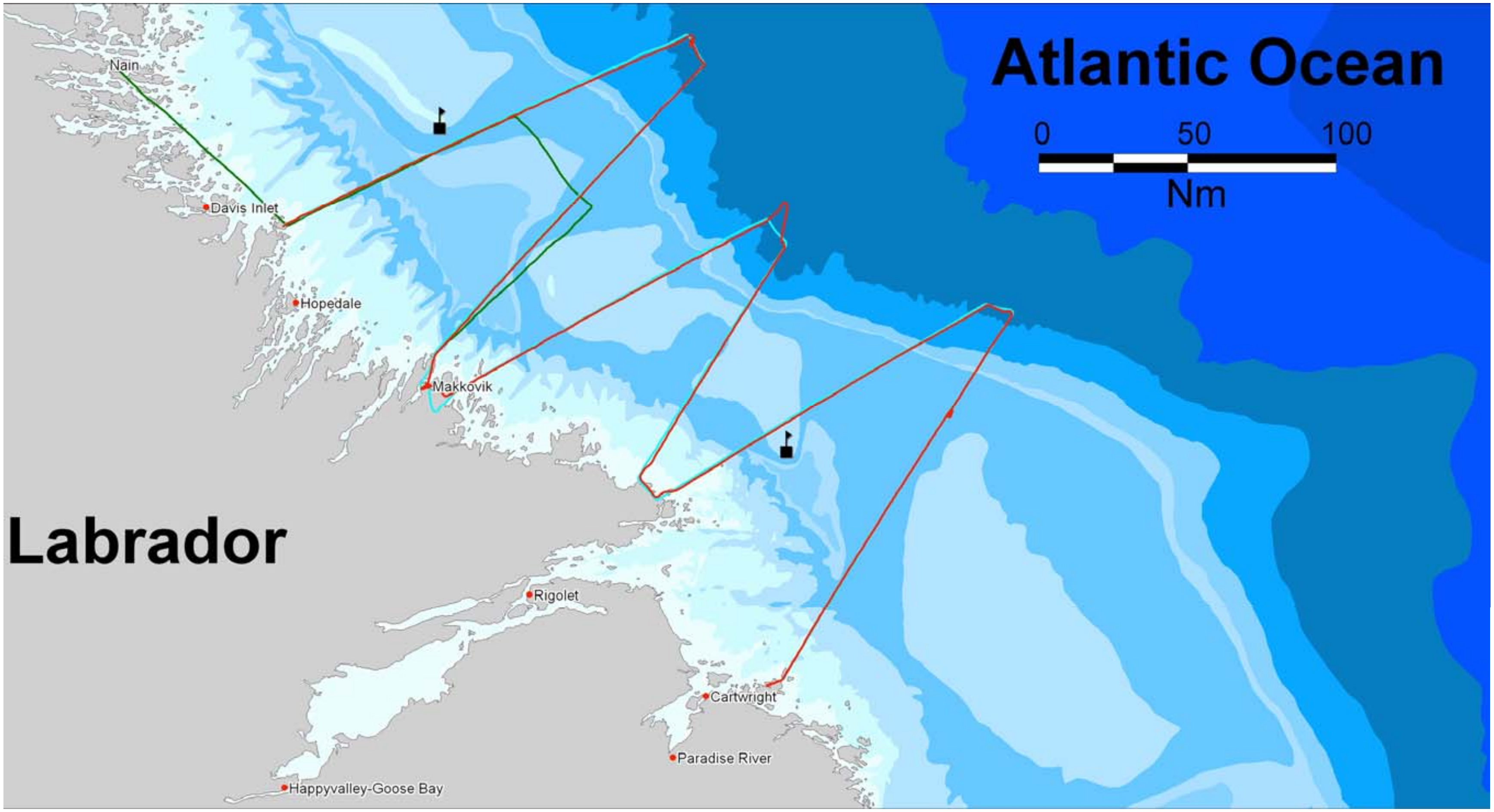

Figure 9. Replicate aerial surveys were flown on 16 and 17 October (dark green and light blue lines, respectively) and 7 November (red lines) 2013 off the southern coast of Labrador. Deployment locations of the two AURAL acoustic recorders are indicted with the black, flagged square symbols. Water depths are indicated by colours with white near the coast (50 m, white) ranging through 100, 200, 400, 500, 1,000, 2,000, 3,000, and 4,000 m offshore (darkest blue).

5.3.2. *Marine Mammal Sightings – Aerial Platform (2013)*

Observers recorded 81 cetacean sighting events, totalling an estimated 360 individual animals (Table 3). After replicate sightings were removed (re-sighted animals seen by either the right front or rear observers) there were 66 cetacean sighting events, totalling an estimated 296 individual animals (Table 4); most species were sighted in groups with the exception of several of the sightings of lone large whales {fin and humpbacks (*Megaptera novaeangliae*)}.

Approximately half (55%) of the sightings were recorded during 7 November (36 cetacean sighting events out of the total for both months) (Table 4; Figures 11, 12, and 13). Only five groups of 20 white-beaked dolphins were seen close to shore during the truncated 16 October survey, but effort did not extend to the southern four planned transects. While the absolute numbers of sightings and animals recorded on 7 November were greater, after weighting for survey effort the sightings rates were similar across the three survey dates in 2013.

There was evidence of southward displacement of cetaceans on the 17 October survey; the distribution of cetaceans was markedly different between the 17 October and 7 November surveys, with most sightings made in the southern portion of the study area in October (e.g., Figures 12 and 13), and subsequently more evenly distributed across the latitudinal gradient three weeks later (Figure 18). During the October surveys a seismic vessel was operating near the location of the northern AURAL (see Figure 2) – see §8.1, below.

For example, fin, humpback, and minke whales were sighted (Table 4; Figures 14 and 15), during both the October and November surveys. However, all of the humpback whales and most of the fin whales were sighted only on the southernmost transect line on 17 October, with two fin whales seen further north three weeks later.

Cetaceans positions exhibited no relationship with water depth except for the white-beaked (Figure 16) and Risso's dolphins (*Grampus griseus*) (Figure 17), and long-finned pilot whales, which were primarily found near the deeper waters of the offshore shelf break. It was apparent that some of the multi-species aggregations of fin and humpback whales (Figures 14 and 15) were feeding, likely on fish, but we did not observe the prey. There are fall spawning aggregations of herring and mackerel on the Labrador south coast (e.g., Pinhorn 1976), so it is likely these whales were targeting these.

During the November survey, a sighting was made of what was likely a small group of Sowerby's beaked whales, at the eastern end of the southernmost transect line near the offshore shelf break.

Killer whales (*Orcinus orca*) were not sighted during the surveys, or while in Nain loading the acoustic equipment on the vessel, despite a group of six of these whales reported to have been seen over a number of days in that area. This species is known to frequent southern Labrador, and its range extends into the eastern Canadian Arctic (Lawson and Stevens 2013).

Several individual harp seals were seen near transect lines closer to shore on 16 October and 17 October. Large aggregations were not sighted although such groups have been reported previously further south on the Grand Banks or in offshore areas of Labrador (Stenson and Kavanagh 1993).

5.3.3. Other Species Sightings – Aerial Platform (2013)

A group of three larger sharks, species unknown, was sighted mid-line on 17 October. With declining water temperatures, reduced primary productivity, and the difficulty of detecting them in moderate sea states, it was not surprising that the observers did not sight leatherback sea turtles during the October and November survey periods. Data from southern Newfoundland have shown that by October many of the leatherbacks that have fed in Newfoundland waters have left to return to tropical habitats (Brock 2006; Mosnier et al. Submitted).

Table 3. White-beaked dolphins were the most frequently-sighted marine mammals during the ESRF-funded aerial survey in October and November, 2013. These data include replicate sightings (see Table 4). Effort was 60 nm on 16 October, 585 nm on 17 October, and 619 nm on 7 November, totalling 1,264 nm.

	Oct 16		**Oct 17**		**Nov 7**		**Overall**	
Cetacean Species	**# Sightings**	**# Animals**	**# Sightings**	**# Animals**	**# Sightings**	**# Animals**	**# Sightings**	**# Animals**
Fin Whale			5	9	3	16	8	25
Humpback Whale			8	14			8	14
Minke Whale					4	6	4	6
Long-finned Pilot Whale			1	5	2	37	3	42
Risso's Dolphin			2	4	11	37	13	41
Sowerby's Beaked Whale					2	8	2	8
Harbour Porpoise			2	19	1	1	3	20
White-beaked Dolphin	6	22	3	14	16	137	25	173
Unknown Dolphin					3	10	3	10
Unknown Small Whale			4	7	2	3	6	10
Unknown Large Whale			3	5	1	1	4	6
Total	**6**	**22**	**30**	**82**	**45**	**256**	**81**	**360**
Sighting Rate per Nm of Effort	**0.10**	**0.37**	**0.05**	**0.14**	**0.07**	**0.41**	**0.04**	**0.28**

Table 4. White-beaked dolphins were the most frequently-sighted marine mammals during the ESRF-funded aerial survey in October and November, 2013. These data are unique (non-replicate) sightings only (see Table 3 for all sightings). Effort was 60 nm on 16 October, 585 nm on 17 October, and 619 nm on 7 November, totalling 1,264 nm.

	Oct 16		**Oct 17**		**Nov 7**		**Overall**	
Cetacean Species	**# Sightings**	**# Animals**	**# Sightings**	**# Animals**	**# Sightings**	**# Animals**	**# Sightings**	**# Animals**
Fin Whale			5	9	3	10	8	19
Humpback Whale			6	12			6	12
Minke Whale					3	4	3	4
Long-finned Pilot Whale			1	5	3	43	4	48
Risso's Dolphin			2	4	8	20	10	24
Sowerby's Beaked Whale					1	7	1	7
Harbour Porpoise			2	19	1	1	3	20
White-beaked Dolphin	5	20	2	8	10	107	17	135
Unknown Dolphin					3	10	3	10
Unknown Small Whale			5	14	3	4	7	11
Unknown Large Whale			3	5	1	1	4	6
Total	**5**	**20**	**25**	**69**	**36**	**207**	**66**	**296**
Sighting Rate per Nm of Effort	**0.08**	**0.33**	**0.04**	**0.12**	**0.06**	**0.33**	**0.05**	**0.23**

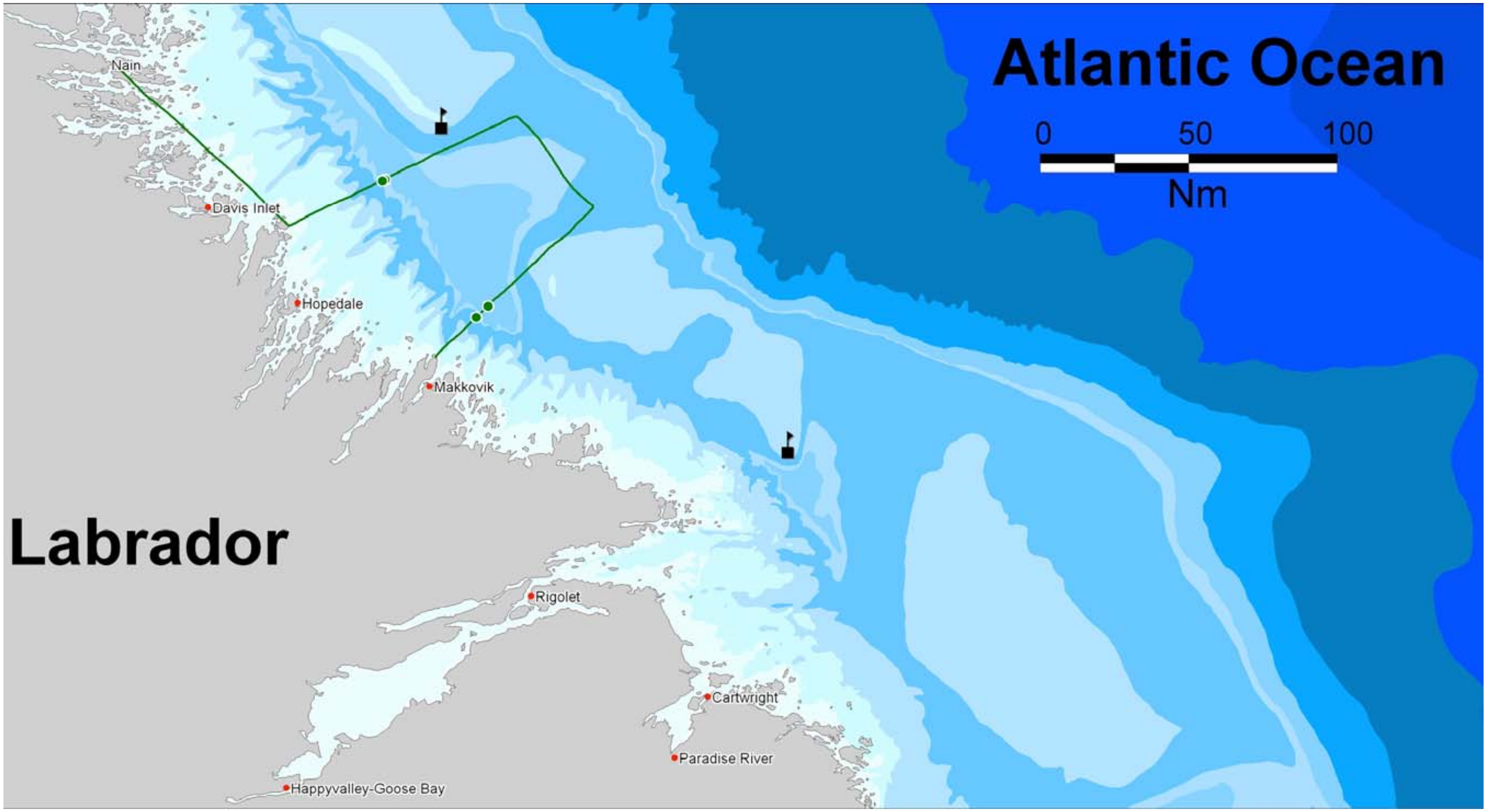

Figure 10. During the effort-limited ESRF 16 October 2013 aerial survey (dark green line), cetaceans were sighted mainly closer to shore (dark green circles). Deployment locations of the two AURAL acoustic recorders are indicted with the black, flagged square symbols. Depths are indicated by colours with white near the coast (50 m, white) ranging through 100, 200, 400, 500, 1,000, 2,000, 3,000 and 4,000 m (darkest blue).

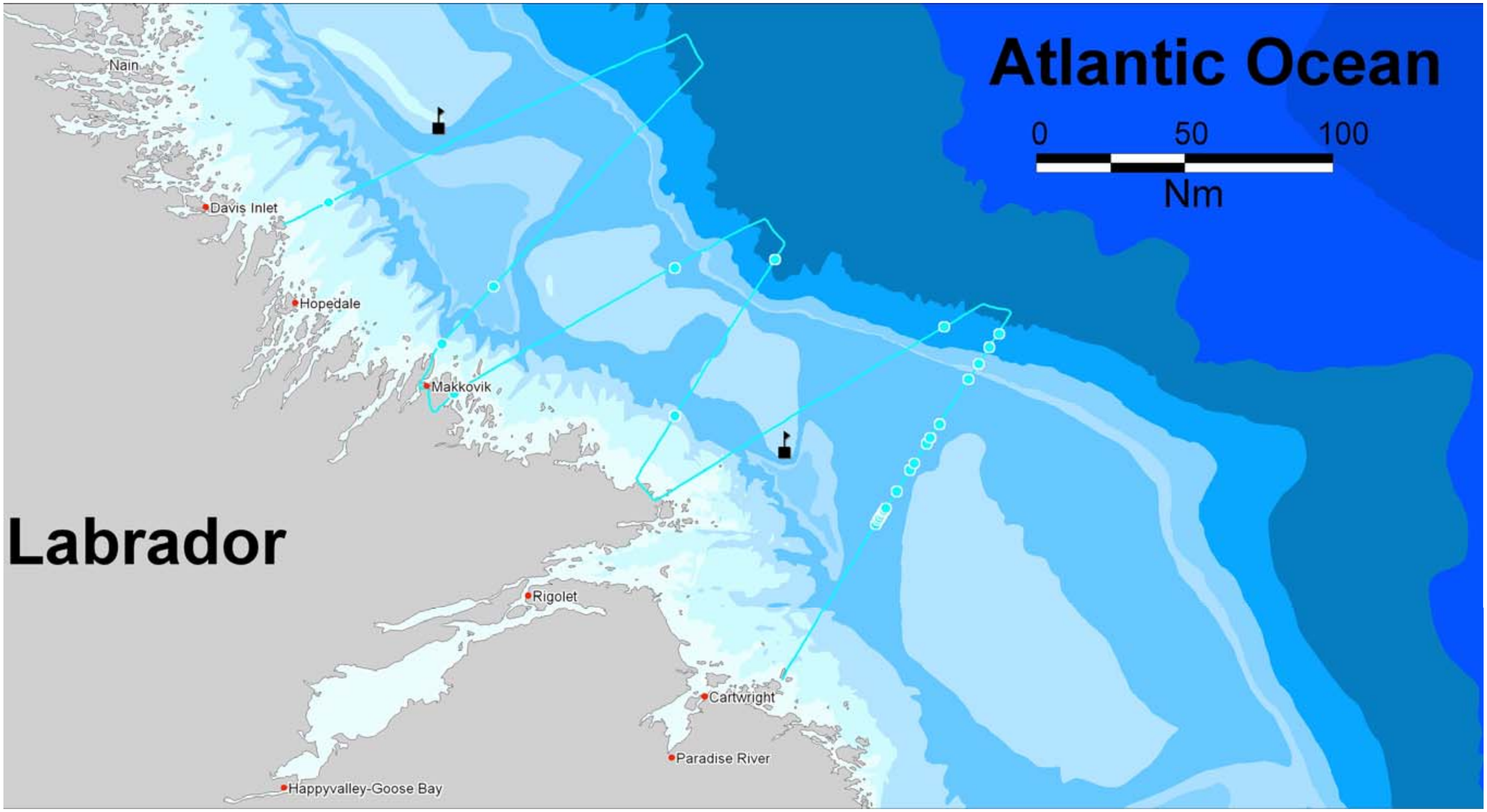

Figure 11. During the ESRF 17 October 2013 aerial survey (light blue line), cetaceans were sighted mainly on the southern-most survey transect (light blue circles). Deployment locations of the two AURAL acoustic recorders are indicted with the black, flagged square symbols. Depths are indicated by colours with white near the coast (50 m, white) ranging through 100, 200, 400, 500, 1,000, 2,000, 3,000, and 4,000 m (darkest blue).

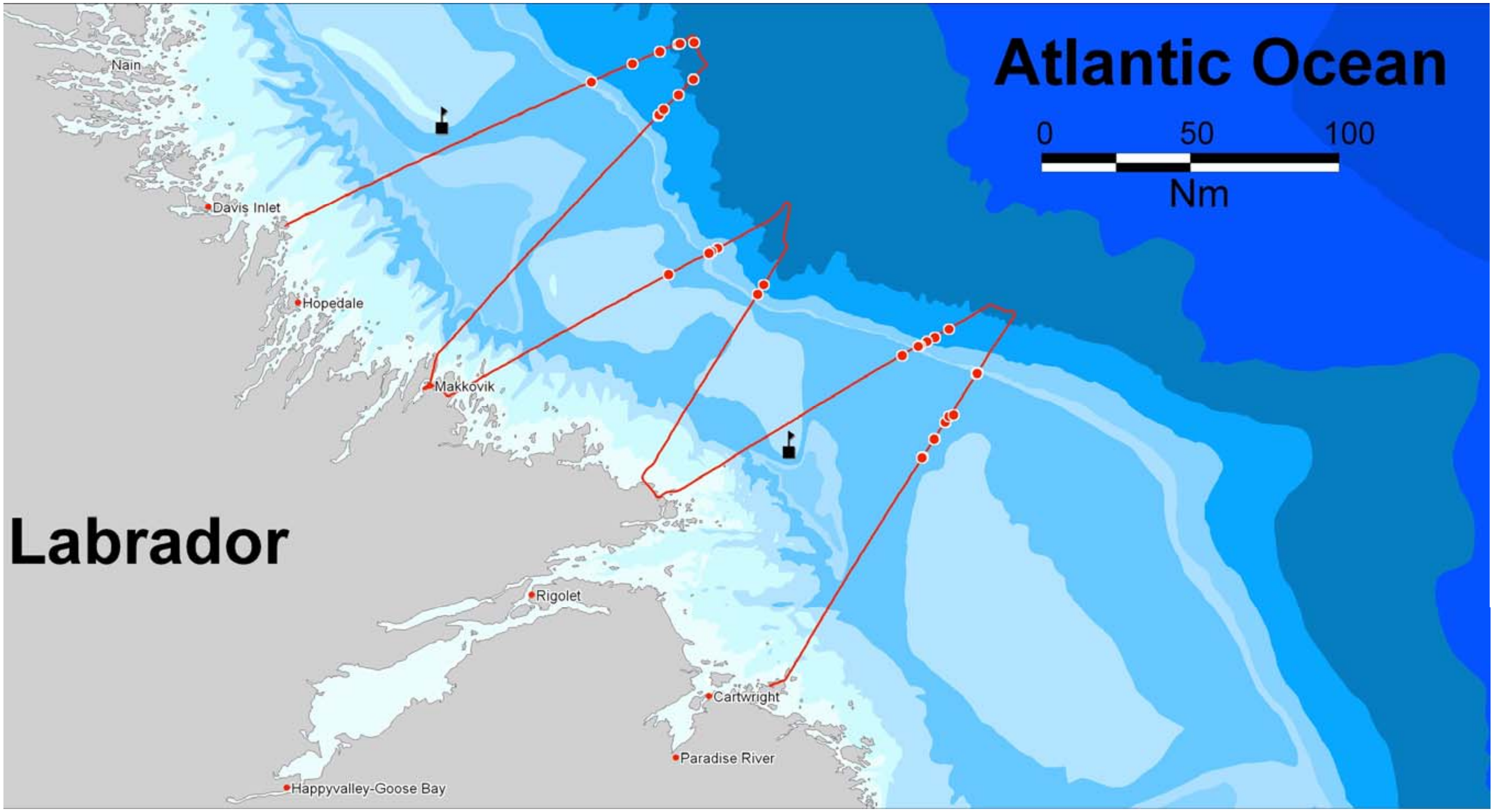

Figure 12. During the ESRF 7 November 2013 aerial survey (red line), cetaceans were mainly sighted near the offshore shelf break (red circles). Deployment locations of the two AURAL acoustic recorders are indicted with the black, flagged square symbols. Depths are indicated by colours with white near the coast (50 m, white) ranging through 100, 200, 400, 500, 1,000, 2,000, 3,000, and 4,000 m (darkest blue).

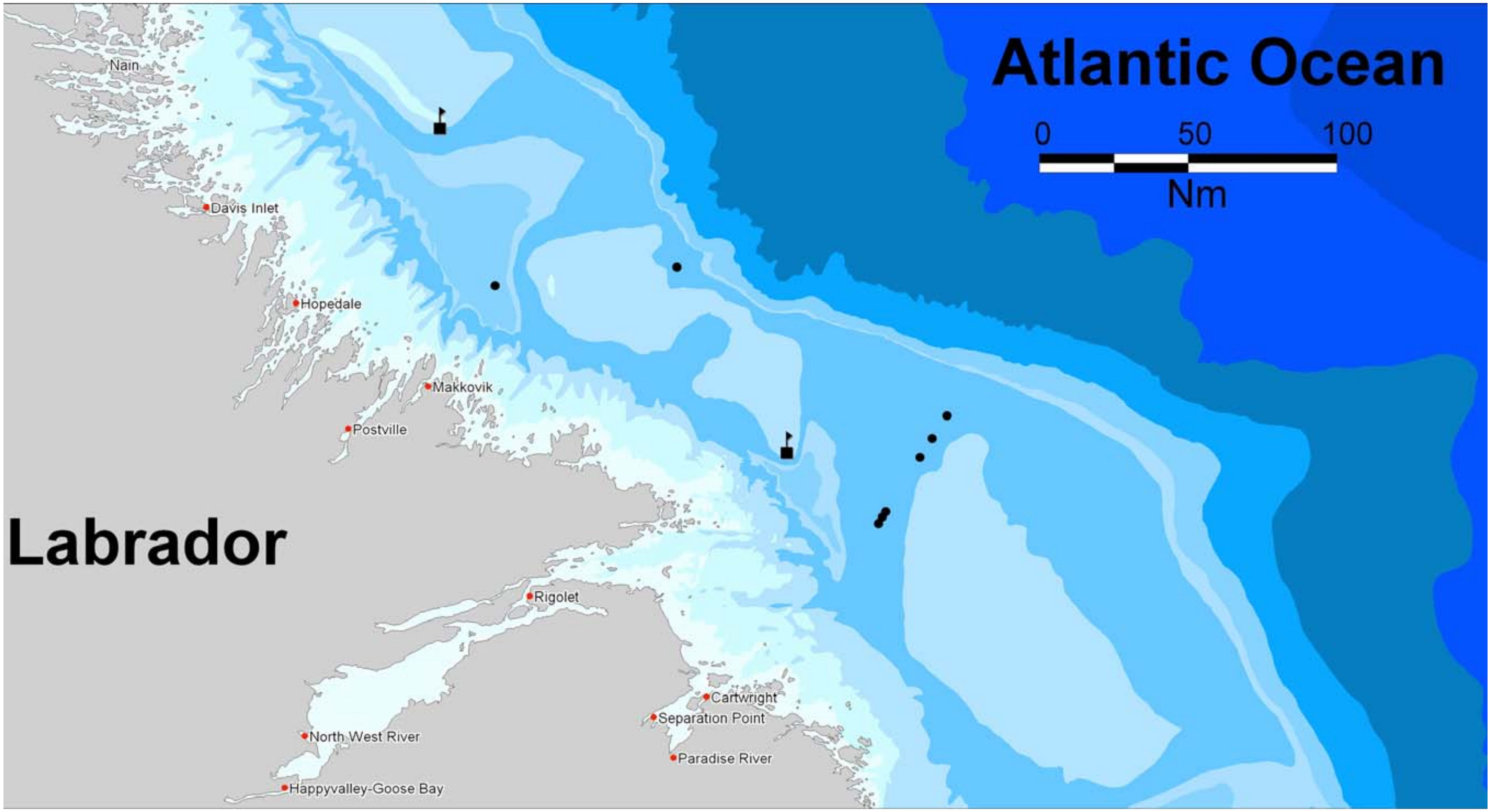

Figure 13. Fin whale sighting events (black circles) observed during the ESRF 2013 aerial survey, on 17 October and 7 November.

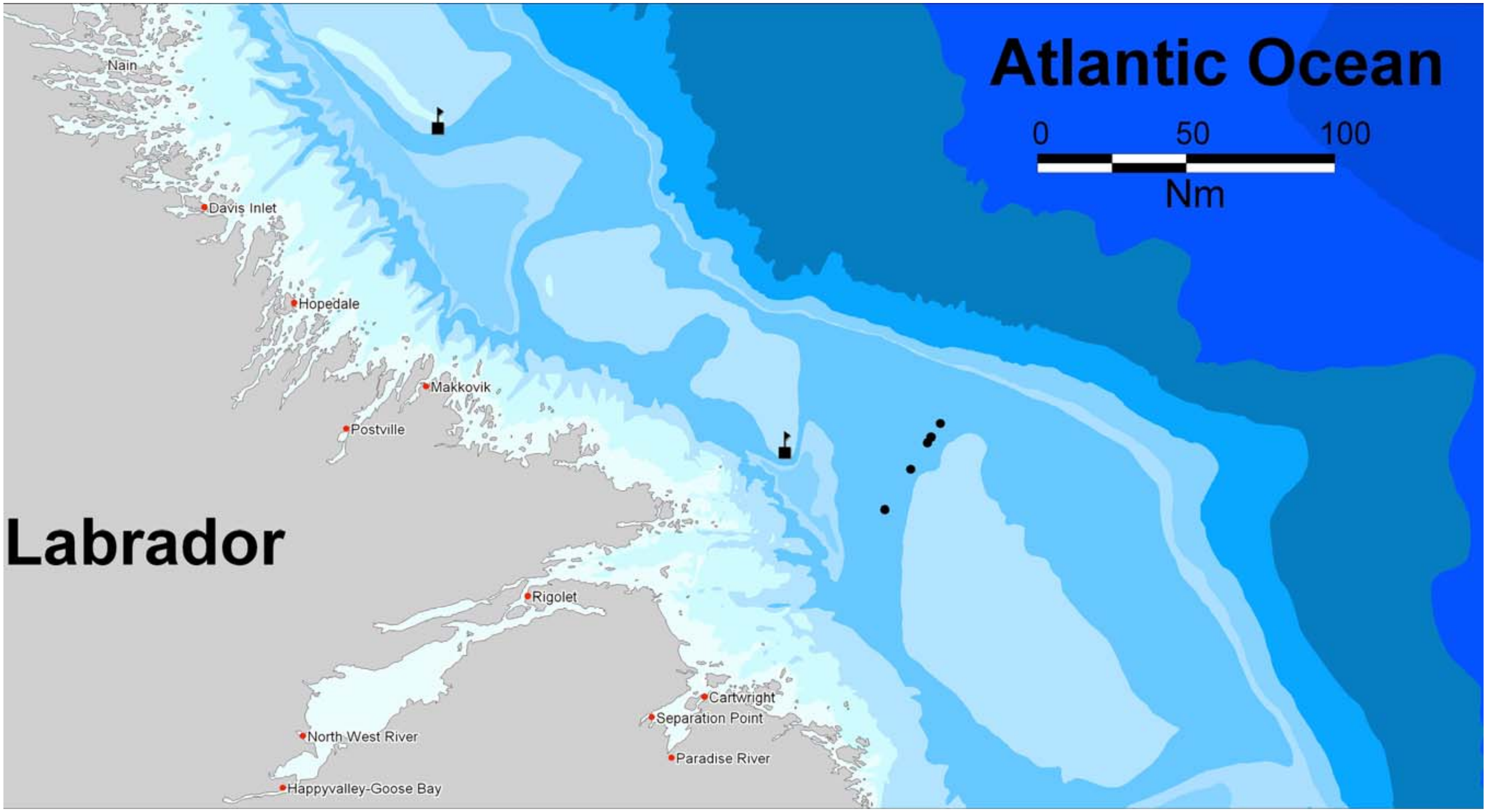

Figure 14. Humpback whale sighting events (black circles) observed during the ESRF 2013 aerial survey, and all on 17 October.

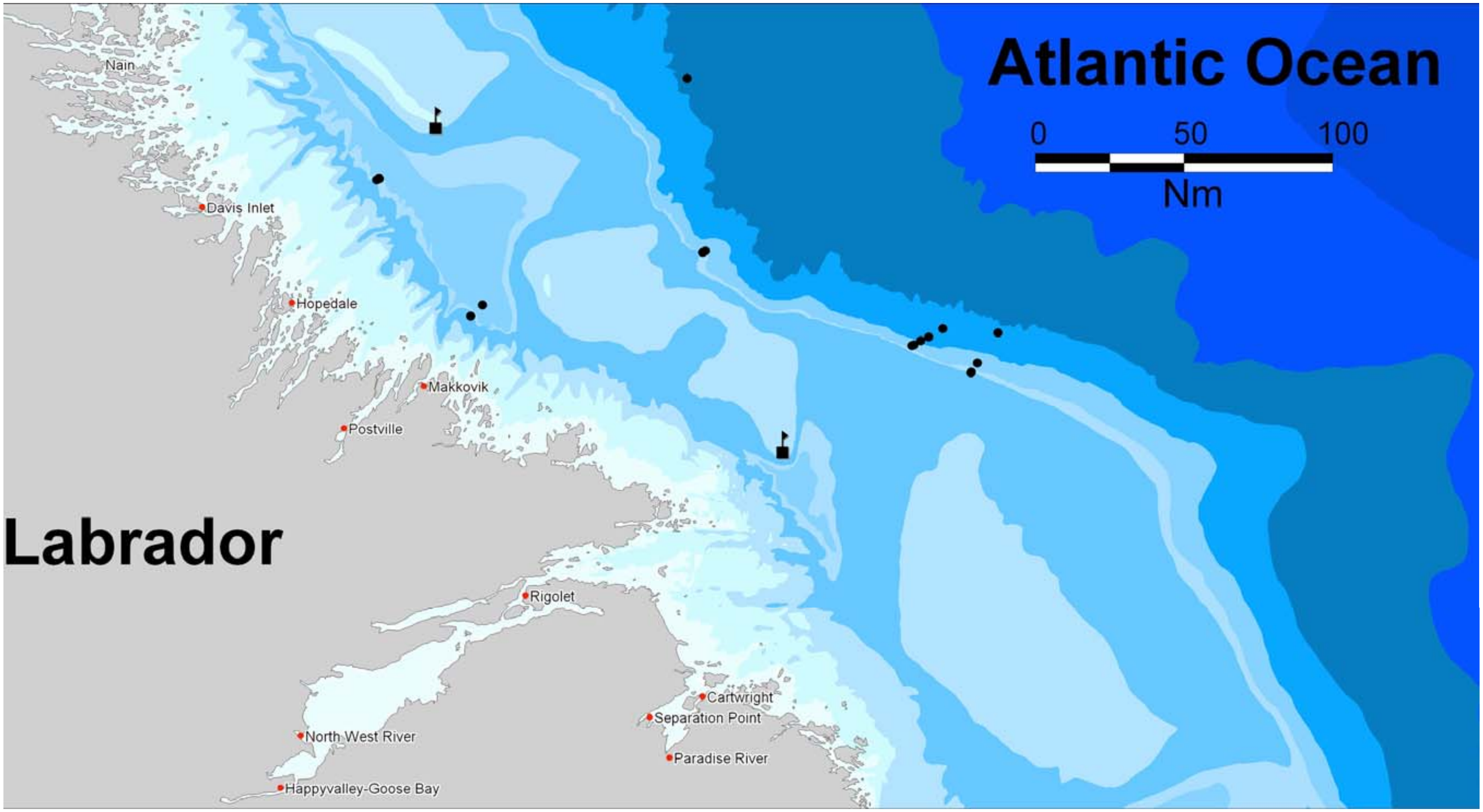

Figure 15. White-beaked dolphin sighting events (black circles) observed during the ESRF 2013 aerial survey. They were seen on all three survey days but primarily on 7 November.

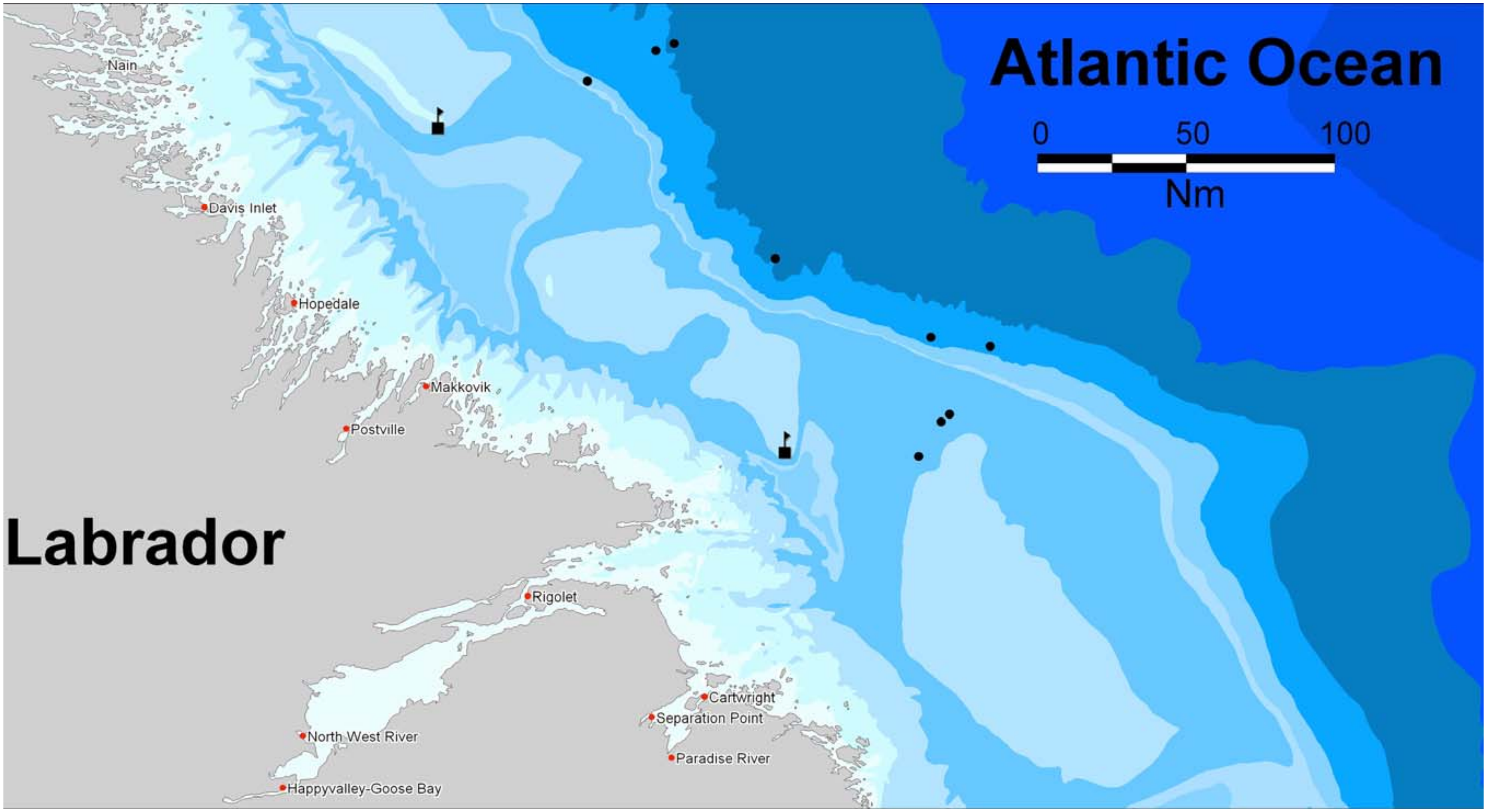

Figure 16. Risso's dolphin sighting events (black circles) observed during the ESRF 2013 aerial survey, primarily on 7 November and further offshore.

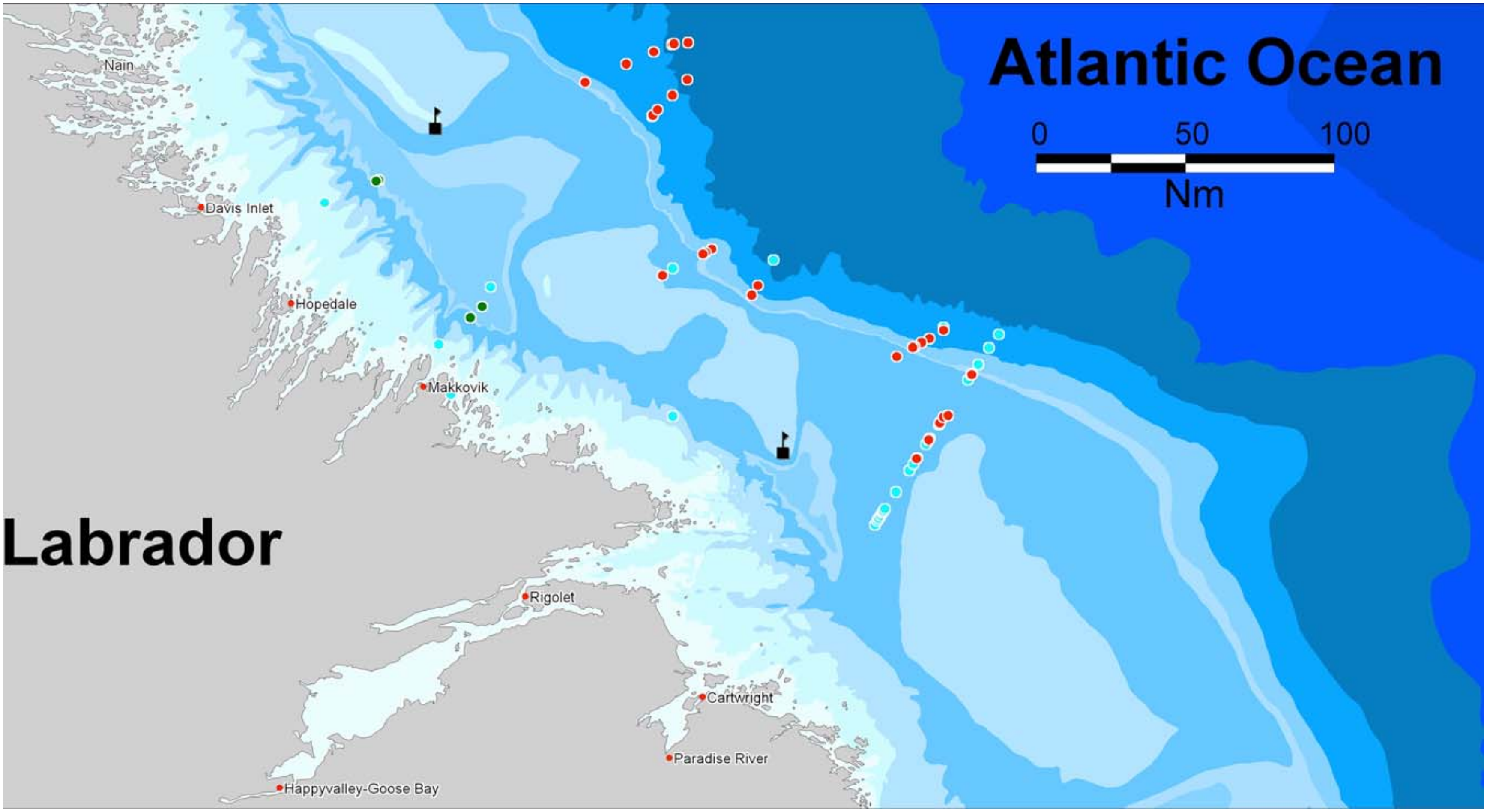

Figure 17. When summarised for all sightings, most cetaceans were at locations nearer to the offshore shelf break, and in both the October and November 2013 survey replicates, towards the southern end of the project area (green circles = 16 October, blue circles = 17 October, and red circles = 7 November).

5.3.4. Effort – Aerial Platform (2014)

In 2014, total survey effort (observers watching actively for marine megafauna and seabirds) was almost doubled relative to the 2013 surveys to 2,408 nautical miles, with all survey flights flown at the end of August. August 25 was the deployment flight from St. John's, during which we flew north to the survey area at survey altitude and airspeed to test the full data collection system; for the last hour a low-level coastal flight profile was adopted to search for seabirds and test the trackline video system (Table 5). The start of the survey was delayed on 25 August due to aircraft power supply issues, after which the southerly four transects were flown in generally good survey conditions. On 26 August the northerly four transect lines were flown, but were curtailed early due to deteriorating weather conditions. A storm passed through the study area on August 27 so no flying was possible. With flattening seas, we flew two flights to complete all eight planned survey transects on 28 August, with almost complete coverage (Table 5 and Figure 18).

Table 5. On-effort survey distance and time flown during the southern-Labrador aerial survey in August, 2014. Nm = nautical mile.

Date	Transect Distance Flown On-effort (Nm)	Time in Flight (including transit) (hr)
August 24, 2014[a]	279	2.5
August 25, 2014	757	8.5
August 26, 2014	534	6.5
August 28, 2014	1,117	12.7
Total	**2,408** + 279	**30.2**

[a] This was a deployment and seabird search flight flown north from St. John's at survey altitude.

We did not see feeding aggregations of large whales in the study area as we did in 2013, but given that southern Labrador is presumed to be a feeding area for marine mammals (e.g., Foy et al. 1981; McLaren et al. 1982; Olsen et al. 2009; Sergeant 1966) in the fall, lack of such aggregations was not unexpected for the earlier survey effort in August 2014.

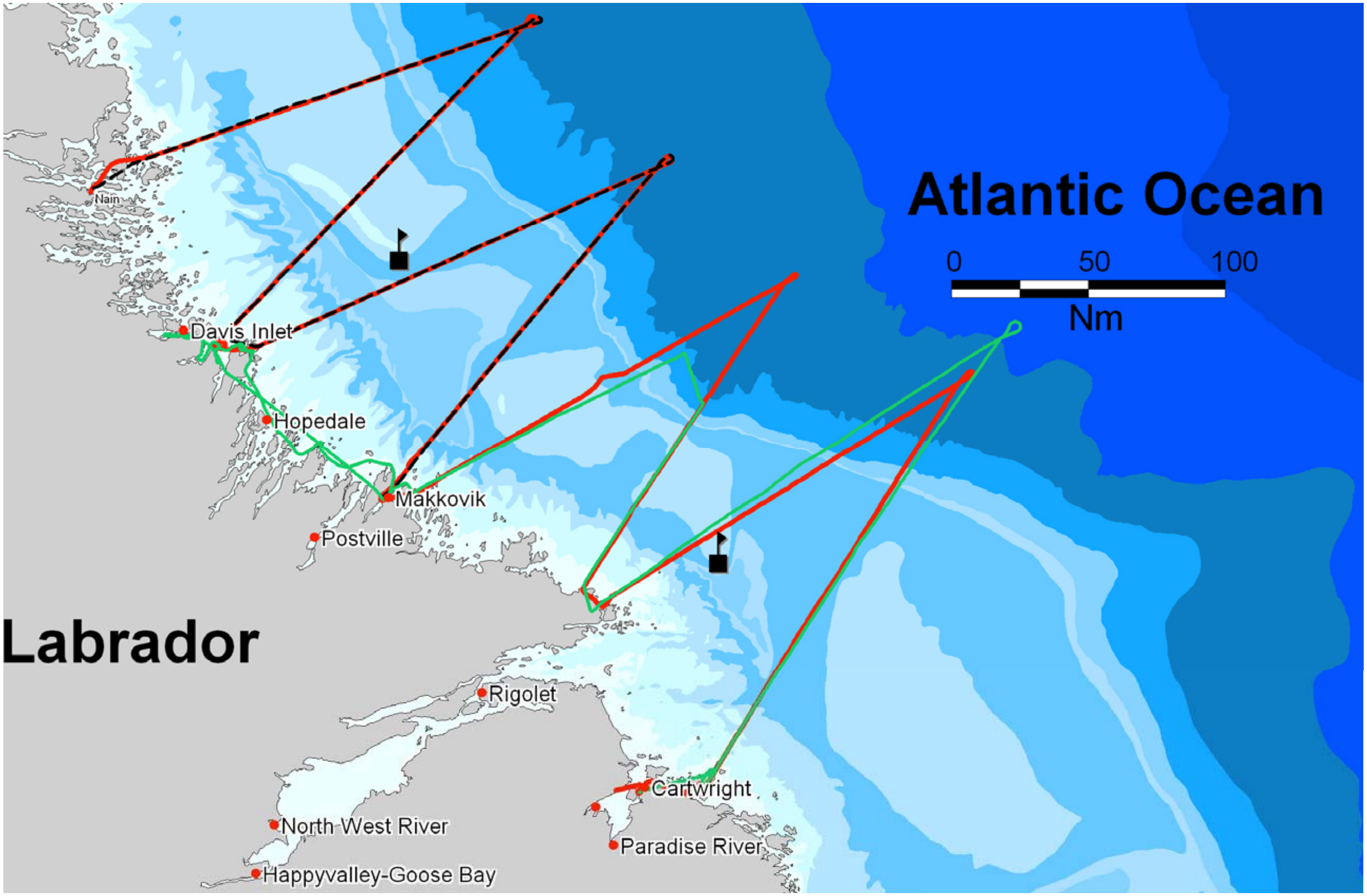

Figure 18. Replicate aerial surveys were flown on 25, 26, and 28 August 2014 (dark green and dashed black, and red lines, respectively) off the southern coast of Labrador. Deployment locations of the two AURAL acoustic recorders are indicted with the black, flagged square symbols. Water depths are indicated by colours with white near the coast (50 m, white) ranging through 100, 200, 400, 500, 1,000, 2,000, 3,000, and 4,000 m offshore (darkest blue).

5.3.5. Marine Mammal Sightings – Aerial Platform (2014)

During the August surveys in 2014 there was no seismic survey activities within hundreds of kilometres. Observers recorded a total of 52 cetacean sighting events, totalling an estimated 159 individual animals (Table 6). After replicate sightings were excluded (sightings seen by both the right front and rear observers) there were 45 cetacean sighting events, totalling an estimated 141 individual animals (Table 7). This sighting total and the effort-weighted rates were lower than in the 2013 survey.

Approximately half (53%) of the sightings were recorded during 28 August (24 cetacean sighting events out of the total for the month) (Table 7; Figures 19, 20, and 21). As in 2013, white-beaked dolphins were the most commonly sighted marine mammal, and were distributed close to shore, on the Shelf, as well as near the shelf break. While the absolute numbers of sightings and animals recorded on 28 August were greater, after weighting for survey effort the sightings rates were similar across the three survey dates in 2014. Unlike 2013, there was no evidence of a southward displacement of cetaceans during the August 2014 surveys.

While fin whales were sighted in 2014, they were not numerous, and we did not see humpback or minke whales as we did in 2013 (Table 7; Figure 22).

Cetacean positions exhibited no apparent relationship with water depth except for long-finned pilot whales (Figure 23), Risso’s dolphins (Figure 24), and northern bottlenose whales (Figure 25), which were primarily found near the offshore shelf break. White-beaked (Figure 26) and unknown dolphins (Figure 27) were detected throughout the survey area.

As in 2013, killer whales were not sighted during the 2014 surveys, even though this species is known to frequent southern Labrador waters (Lawson and Stevens 2013).

Several individual harp seals were seen during survey effort, usually closer to shore, on each survey day. Large aggregations were not sighted.

5.3.6. Other Species Sightings – Aerial Platform (2014)

In addition to many seabirds (see associated EC report for ESRF cross-referenced on p. 20 of this report), observers on the aircraft sighted several large sharks (species unknown) and occasional fish schools. With the difficulty of detecting them in the moderate sea states, it was not surprising that the observers did not sight leatherback sea turtles during conditions experienced during surveys in 2014. By August many of the leatherbacks that feed in southern Newfoundland waters have left to return to tropical habitats (Brock 2006), so the same is likely true for the Labrador Shelf at the northern margin of their known range.

Table 6. As in 2013, white-beaked dolphins were the most frequently-sighted marine mammals during the ESRF-funded aerial survey in August, 2014. These data include replicate sightings (see Table 7). A small proportion of these data include sightings recorded by the EC observers aboard the aircraft as well, whose primary goal was to collect seabird information. Effort was 757 nm on 25 August, 534 nm on 26 August, and 1,117 nm on 28 August, totalling 2,408 nm flown.

	August 25		**August 26**		**August 28**		**Overall**	
Cetacean Species	**# Sightings**	**# Animals**	**# Sightings**	**# Animals**	**# Sightings**	**# Animals**	**# Sightings**	**# Animals**
Fin Whale	1	2	1	1	2	2	4	5
Long-finned Pilot Whale	1	1			4	25	5	26
Risso's Dolphin	4	5	2	3			6	8
Northern Bottlenose Whale					2	4	2	4
Harbour Porpoise					2	7	2	7
White-beaked Dolphin	2	11	6	20	17	51	25	82
Unknown Dolphin	2	16	2	6	2	2	6	24
Unknown Large Whale			2	3			2	3
Total	**10**	**35**	**13**	**33**	**29**	**91**	**52**	**159**
Sighting Rate per Nm of Effort	**0.01**	**0.05**	**0.02**	**0.06**	**0.03**	**0.08**	**0.02**	**0.07**

Table 7. As in 2013, white-beaked dolphins were the most frequently-sighted marine mammals during the ESRF-funded aerial survey in August, 2014. These data are (non-replicate) sightings only (see Table 6 for all sightings). A small proportion of these data include sightings recorded by the EC observers aboard the aircraft as well, whose primary goal was to collect seabird information. Effort was 757 nm on 25 August, 534 nm on 26 August, and 1,117 nm on 28 August, totalling 2,408 nm flown.

	August 25		**August 26**		**August 28**		**Overall**	
Cetacean Species	**# Sightings**	**# Animals**	**# Sightings**	**# Animals**	**# Sightings**	**# Animals**	**# Sightings**	**# Animals**
Fin Whale	1	2	1	1	2	2	4	5
Long-finned Pilot Whale	1	1			3	19	4	20
Risso's Dolphin	4	5	2	3			6	8
Northern Bottlenose Whale					1	2	1	2
Harbour Porpoise					2	7	2	7
White-beaked Dolphin	2	11	5	19	14	43	21	73
Unknown Dolphin	1	15	2	6	2	2	5	23
Unknown Large Whale			2	3			2	3
Total	**9**	**34**	**12**	**32**	**24**	**75**	**45**	**141**
Sighting Rate per Nm of Effort	**0.01**	**0.04**	**0.02**	**0.06**	**0.02**	**0.07**	**0.02**	**0.06**

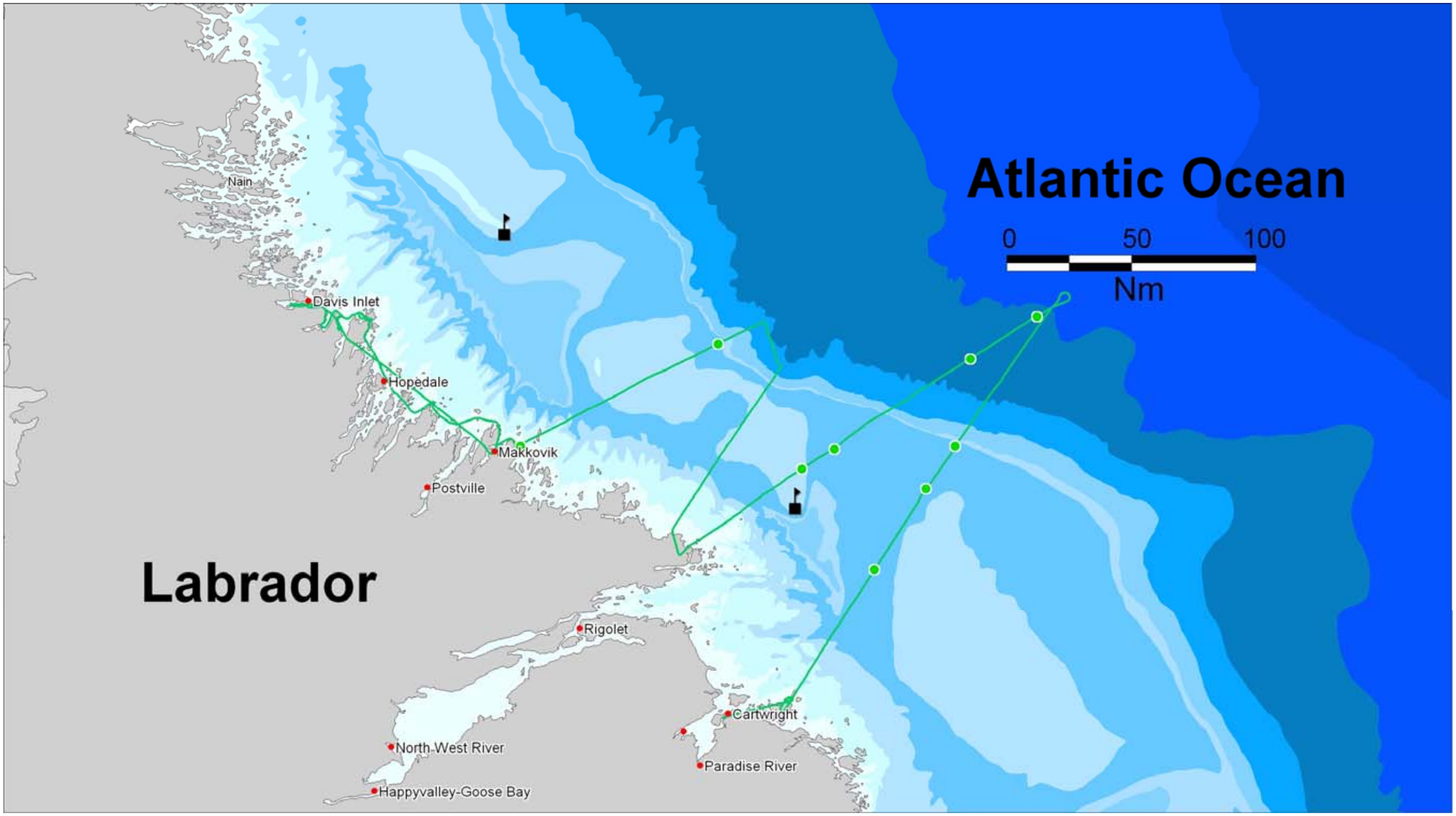

Figure 19. During the ESRF 25 August 2014 aerial survey (green line), cetaceans were sighted mainly on the southern-most two survey transect (green circles). Deployment locations of the two AURAL acoustic recorders are indicted with the black, flagged square symbols. Depths are indicated by colours with white near the coast (50 m, white) ranging through 100, 200, 400, 500, 1,000, 2,000, 3,000, and 4,000 m (darkest blue).

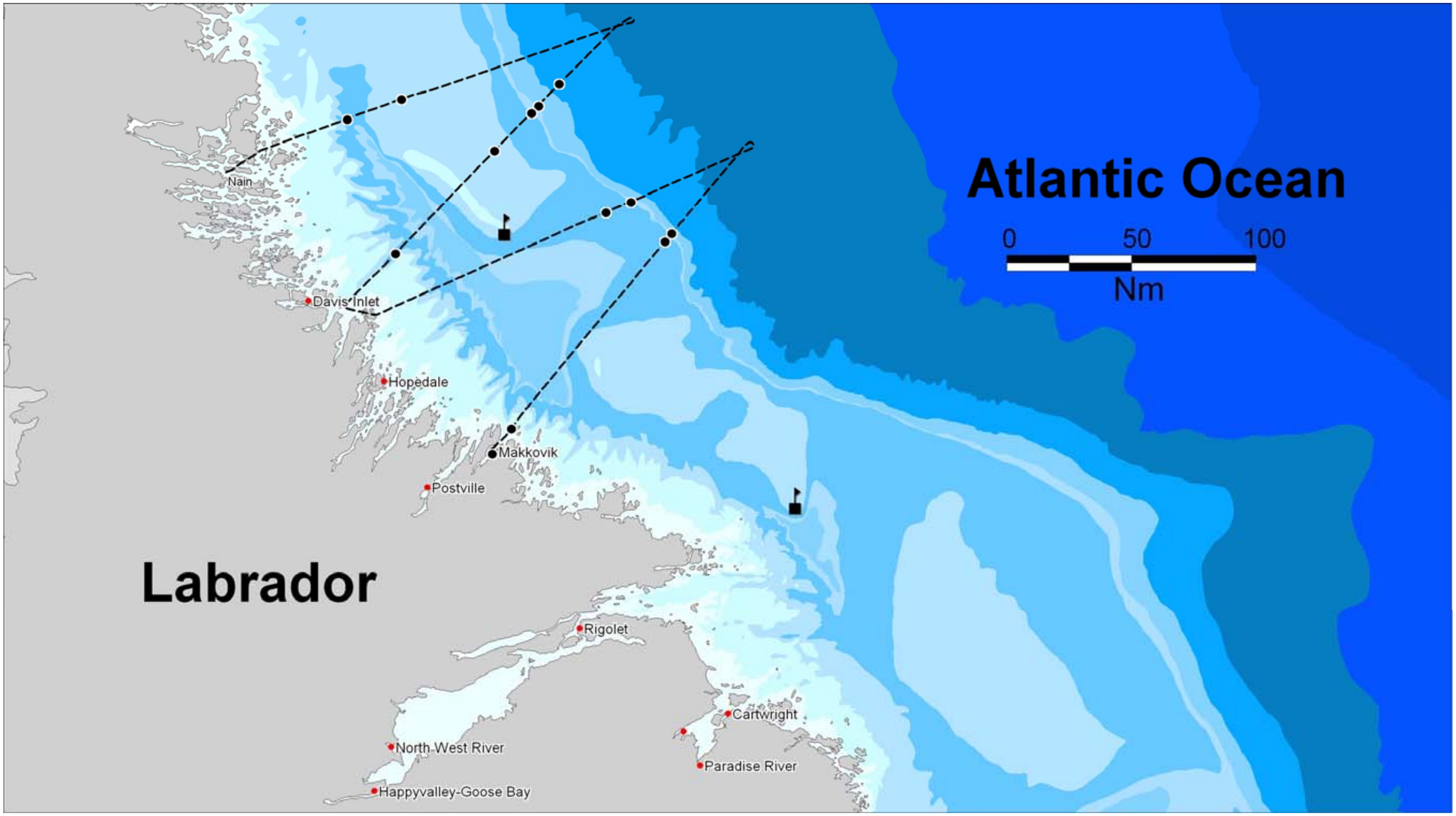

Figure 20. During the ESRF 26 August 2014 aerial survey (dashed black line), cetaceans were sighted on all four transects (black circles). Deployment locations of the two AURAL acoustic recorders are indicted with the black, flagged square symbols. Depths are indicated by colours with white near the coast (50 m, white) ranging through 100, 200, 400, 500, 1,000, 2,000, 3,000, and 4,000 m (darkest blue).

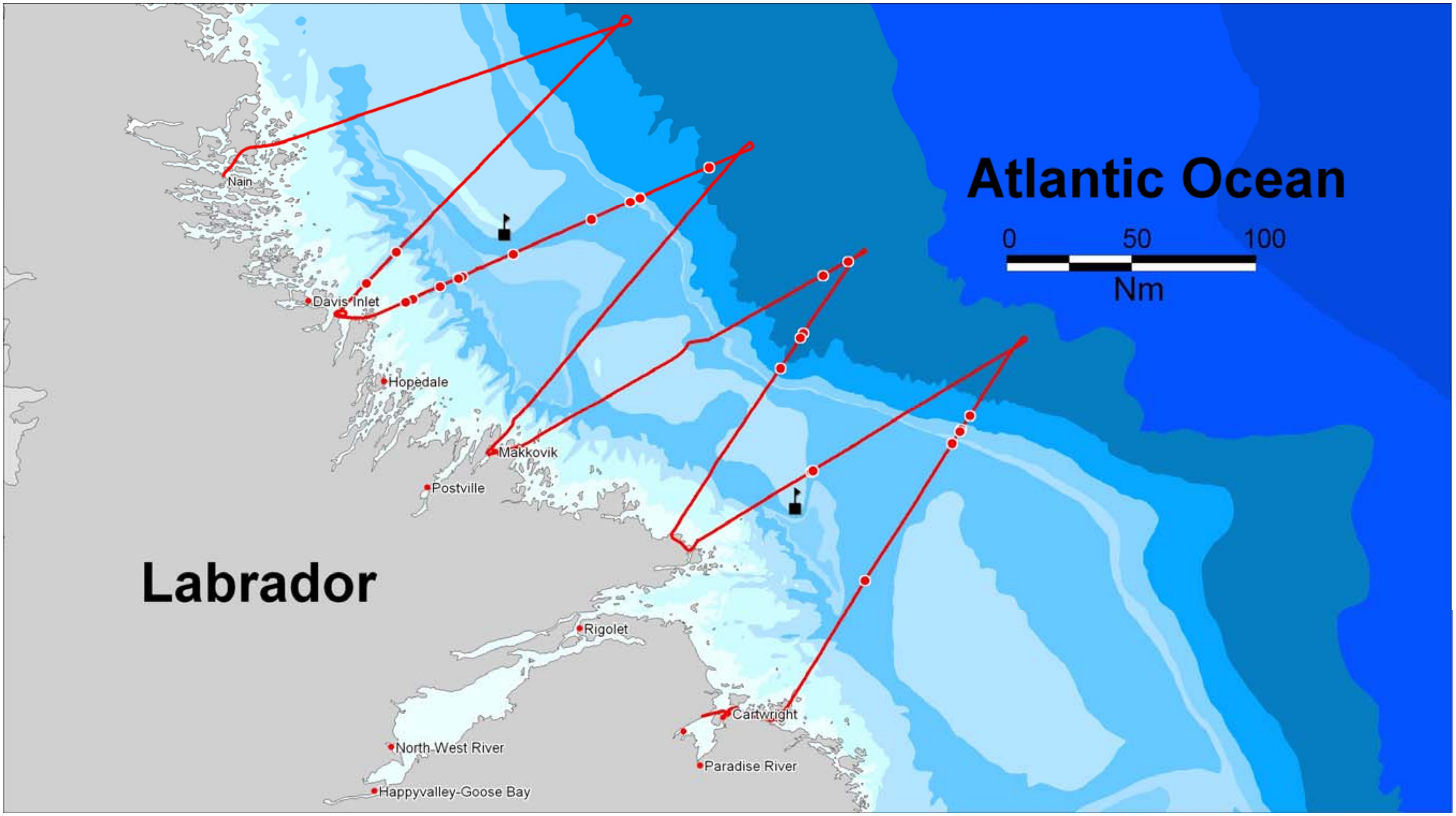

Figure 21. During the ESRF 28 August 2014 aerial survey (red lines), cetaceans were sighted on all but the northernmost transect red circles). Deployment locations of the two AURAL acoustic recorders are indicted with the black, flagged square symbols. Depths are indicated by colours with white near the coast (50 m, white) ranging through 100, 200, 400, 500, 1,000, 2,000, 3,000, and 4,000 m (darkest blue).

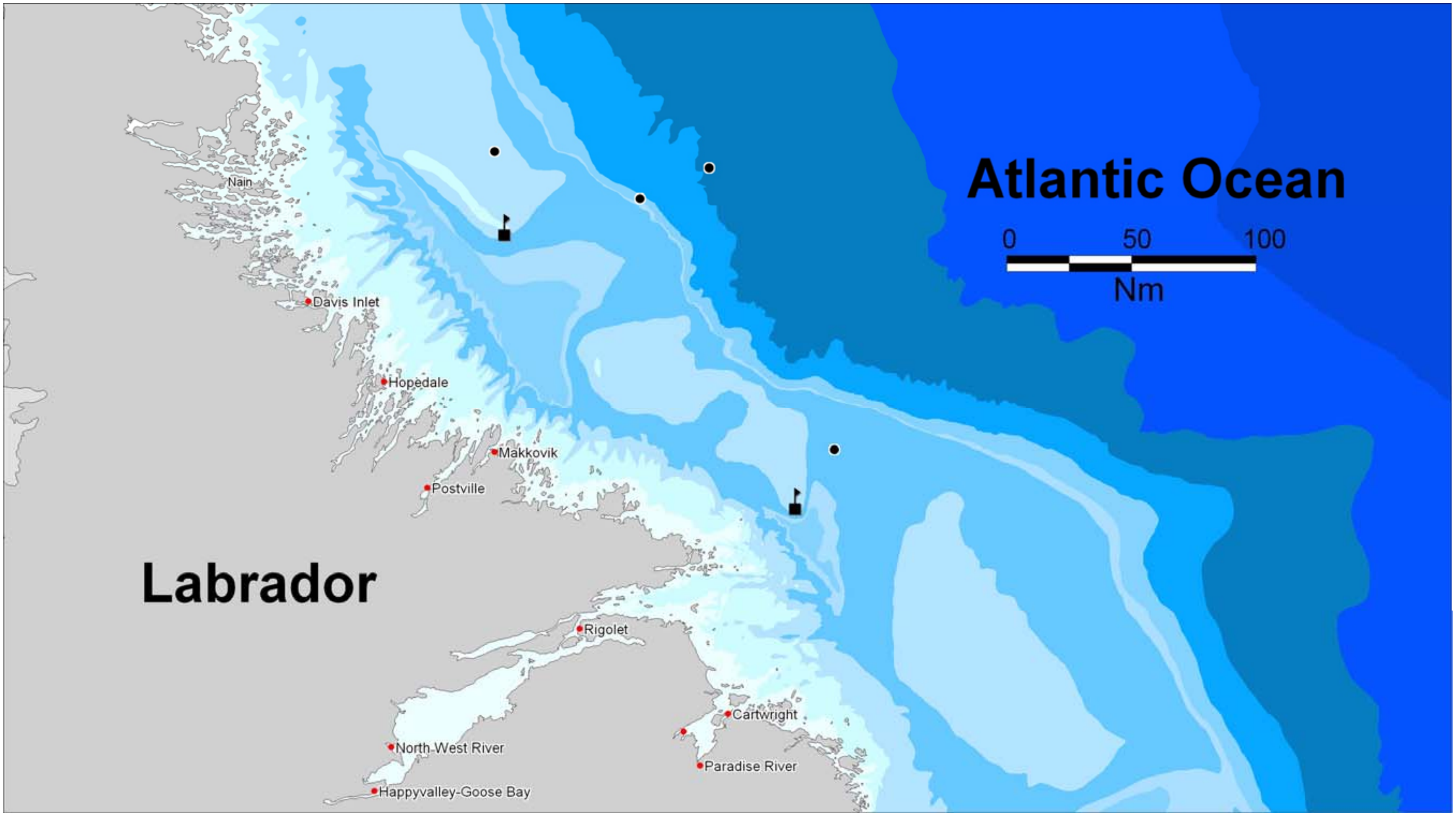

Figure 22. Fin whale sighting events (black circles) observed during the ESRF 2014 aerial survey, on all three survey days in August.

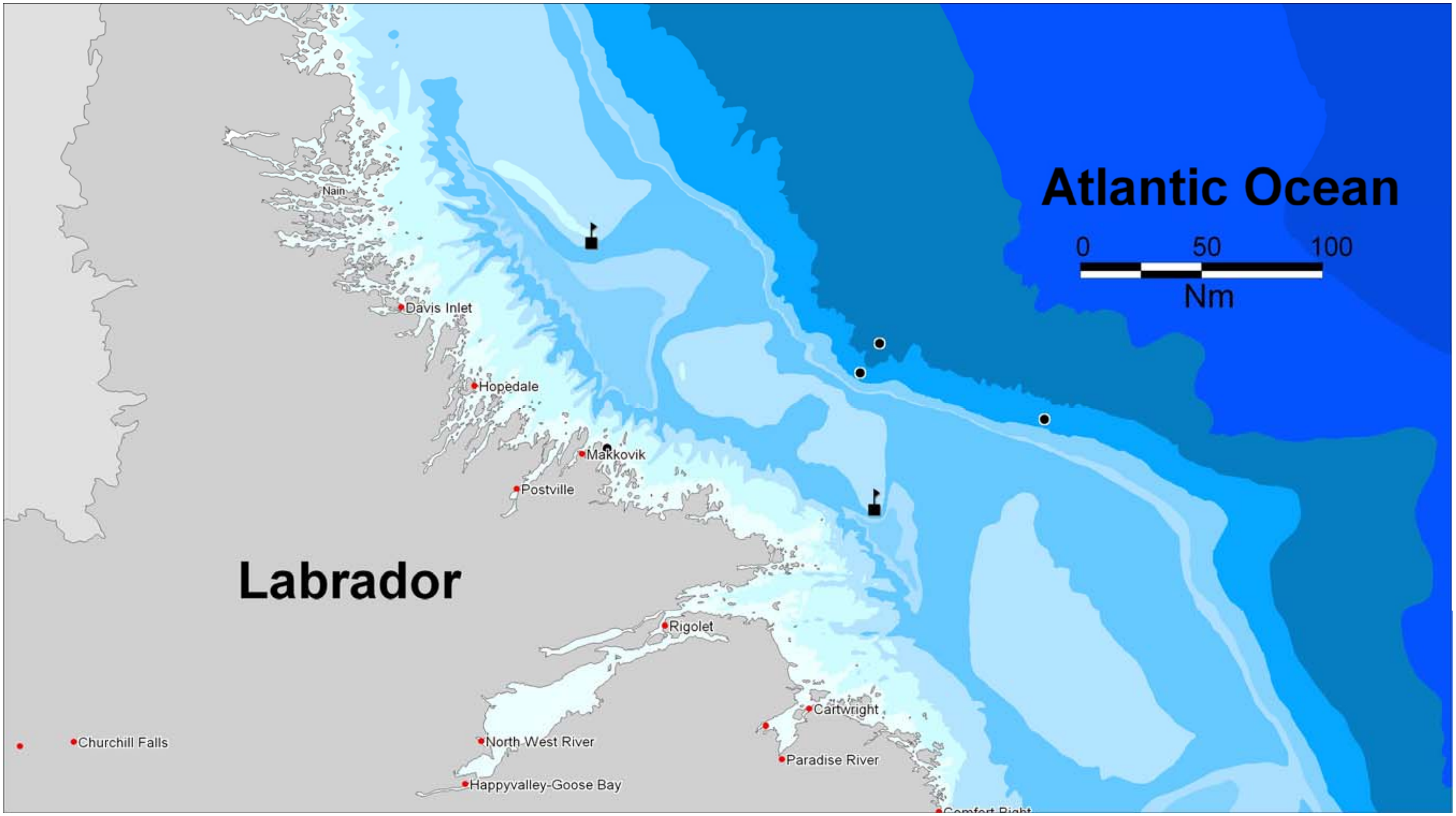

Figure 23. Long-finned pilot whale sighting events (black circles) observed during the ESRF 2013 aerial survey, and on 25 and 28 August near the shelf break.

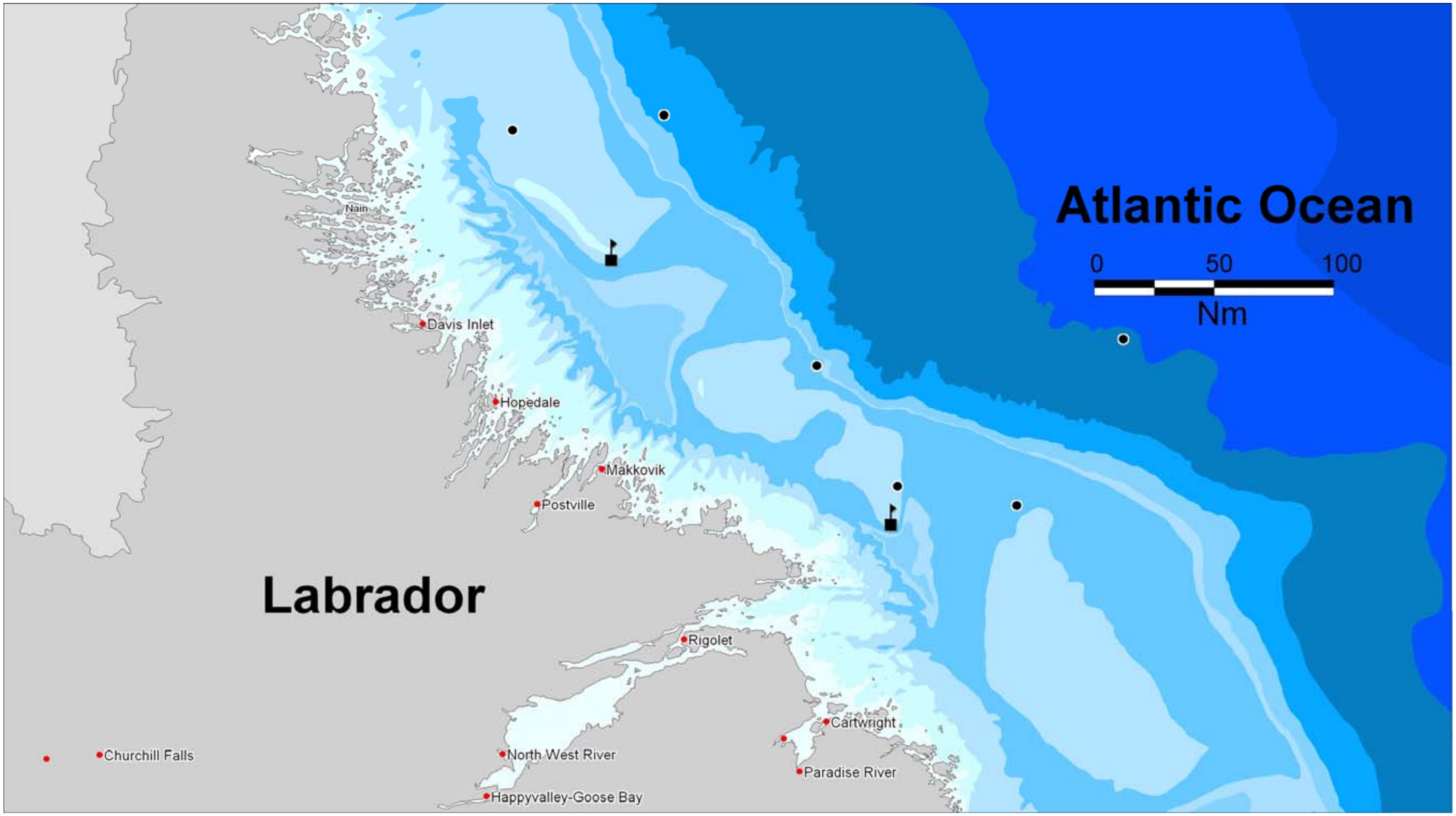

Figure 24. Risso's dolphin sighting events (black circles) observed during the ESRF 2014 aerial survey on 25 and 26 August.

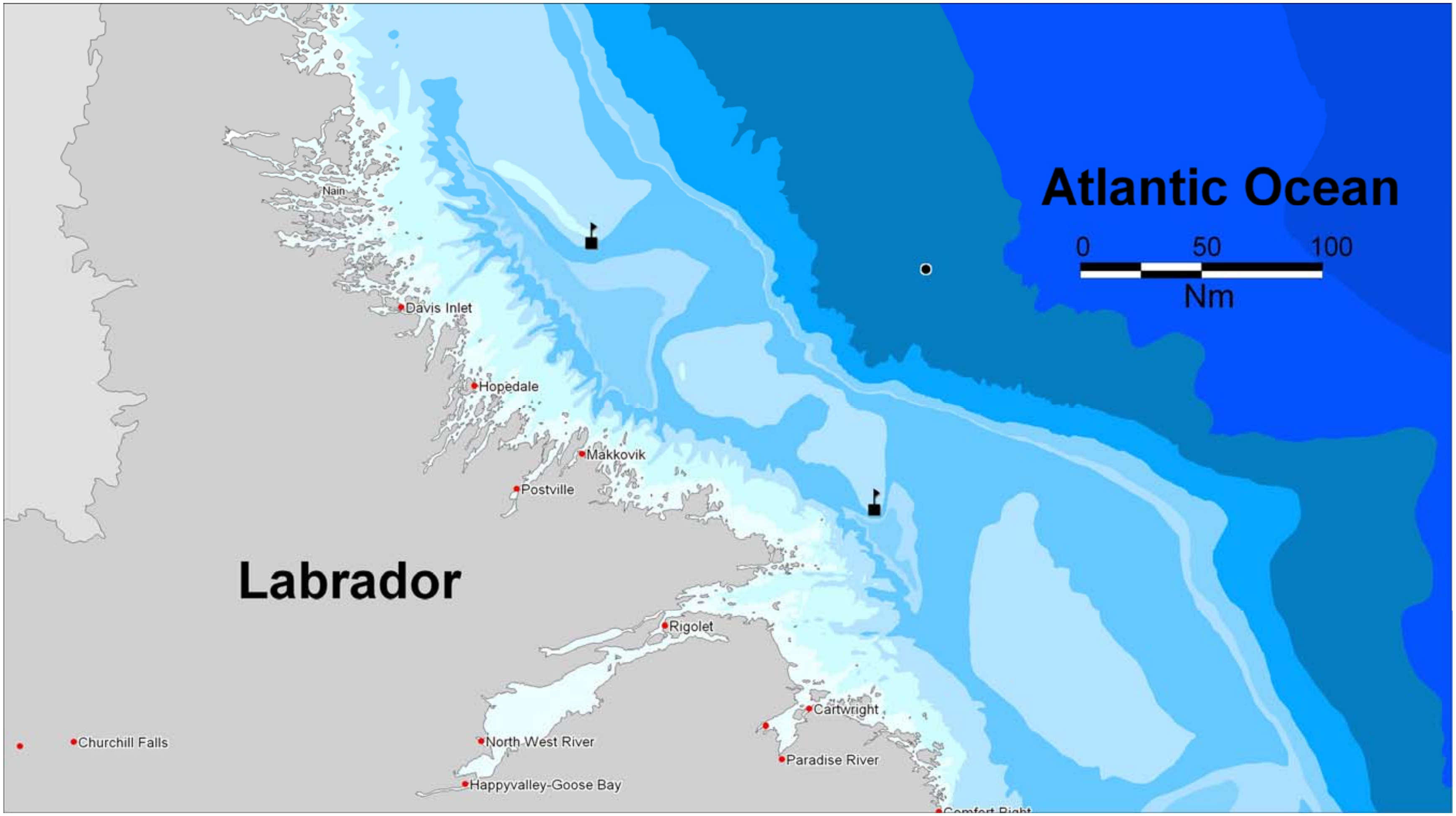

Figure 25. A single pair of northern bottlenose whales (black circle) were sighted during the ESRF 2014 aerial survey, on 28 August and further offshore.

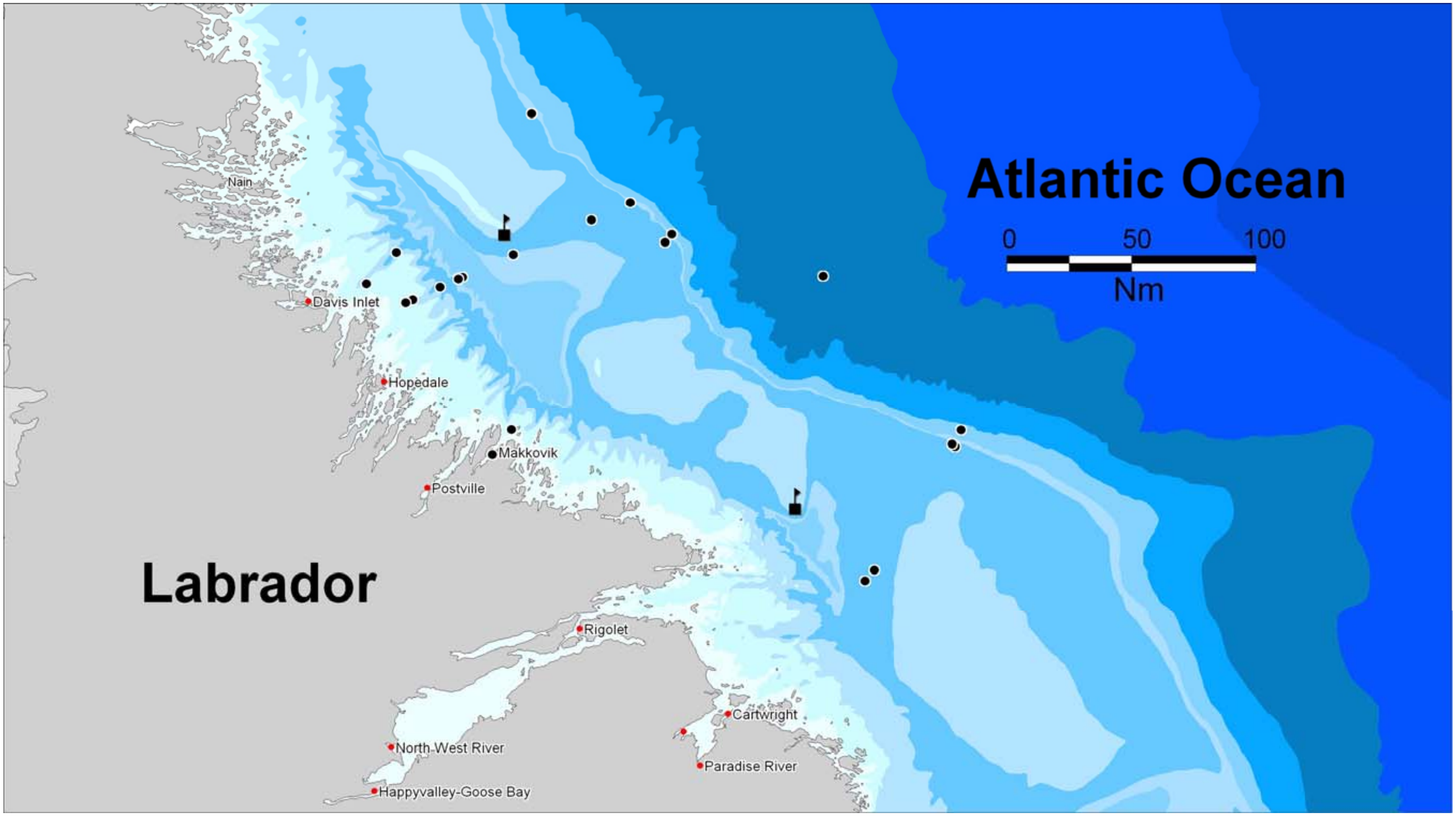

Figure 26. As in 2013, white-beaked dolphins (black circles) were the most commonly-sighted cetacean during the ESRF 2014 aerial survey, on all survey days.

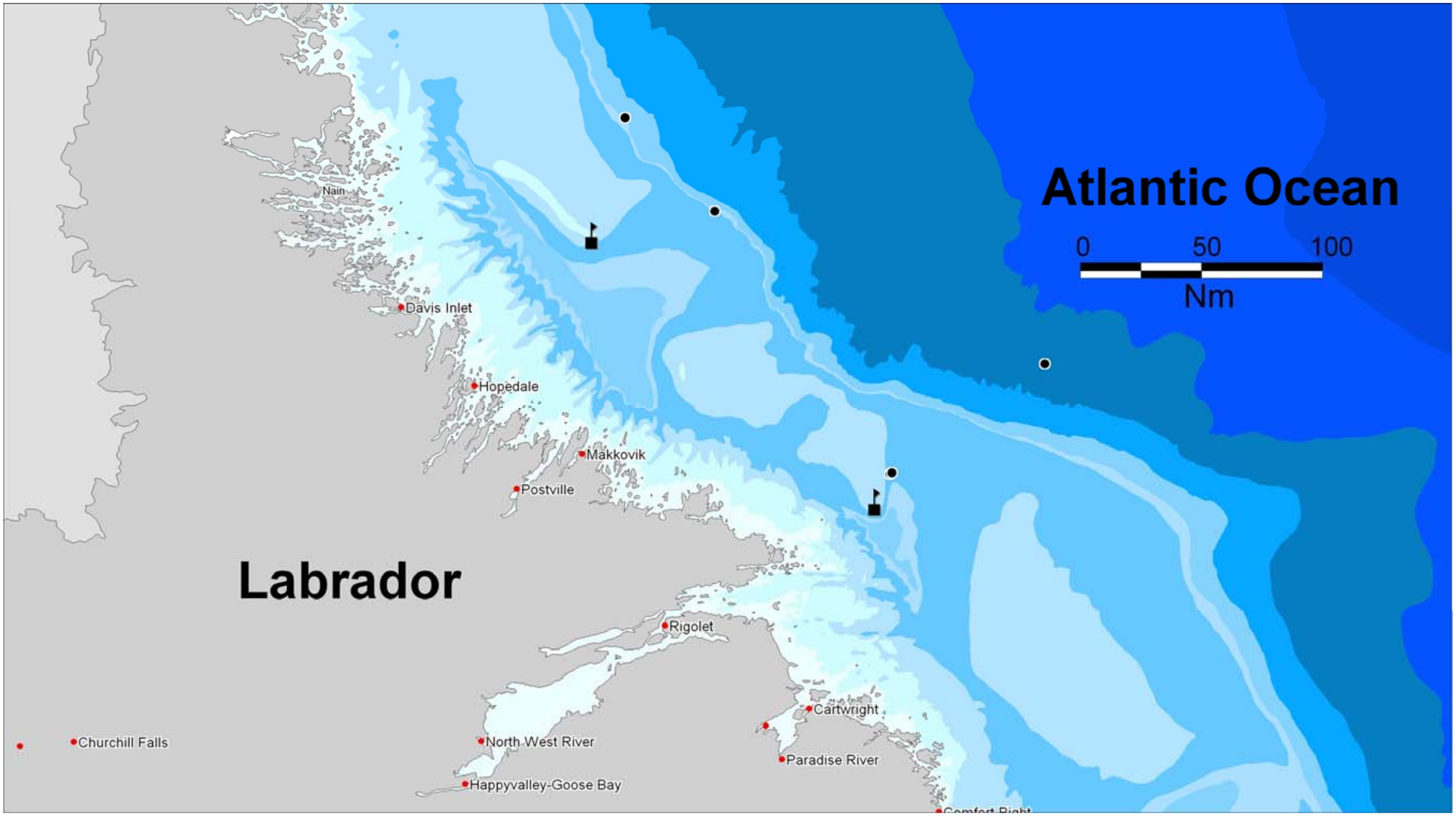

Figure 27. Groups of unknown dolphins (black circles) were sighted during the ESRF 2014 aerial survey, on all survey days.

5.3.7. Sightings From Trackline Video Records (2014)

Due to the wide angle of the lens on the GoPro video camera, animals sighted on the video were seen at a very small scale, even on the 4K monitor and enlarged. Unless moving and in ideal sea conditions (rare during the ESRF project surveys), smaller animals such as seabirds and small cetaceans were difficult to identify.

We were able to use the video to confirm sightings of several cetacean species sighted near the trackline by the visual observers (pilot whales, white-beaked dolphins, humpback whales).

5.3.1. Study Area Population Estimate For White-beaked Dolphins

Line transect density and abundance analyses for white-beaked dolphins were completed using the software Distance 7.0, Release 1 (Thomas et al. 2010). Sighting data were right-truncated using the approach recommended in Buckland et al. (2001) whereby a single sighting beyond 300 m was omitted to improve model fit. Model selection and inclusion of covariates followed the stepwise procedure of Marques and Buckland (2003). A detection function was fitted a) without considering model covariates to investigate sighting distance variation and other data qualities, and b) considering model covariates such as sighting conditions, observer, and sighting cue. Half-normal, hazard-rate, or uniform models without adjustment terms were fitted to the truncated distribution of sightings for this species and the best model was selected using the lowest corrected Akaike's information criterion (AICc). Using the best key function from the global distribution of pooled sightings, we examined the effect of dolphin group size, observer identity, and sighting conditions (poor, moderate, good, excellent) as covariates for deriving the best detection function (Buckland et al. 2004; Marques and Buckland 2003; Marques et al. 2007). The white-beaked density in the ESRF study area was estimated as the mean density of the stratum weighted by stratum area. The uncorrected density and abundance indices, variance, and confidence intervals were estimated empirically with a hazard rate + cosine function as the selected model.

When estimating marine mammal abundance using an aerial survey platform for data collection, sources of bias that can lead to underestimation of abundance include observers not detecting animals that are at or near the surface within observers' field of view (perception bias), and observers not detecting animals because the animals have descended below the water's surface or are out of the field of view (availability bias) (e.g., Fleming and Tracey 2008; Garner et al. 1999; Melville et al. 2008). We present an uncorrected abundance estimate, which is therefore a negatively-biased underestimate.

Examination of the distribution of sightings showed that the probability of detecting a white-beaked dolphin decreased with distance from the trackline (Figure 28), but that sightings were made directly below the aircraft as facilitated by the large bubble windows and rear bubble door. The effective strip width was calculated to be 145.2 metres (95% CI: 116.5-180.9), despite the generally “moderate” sighting conditions encountered during the surveys. While fewer white-beaked dolphins were detected closer to the trackline, left truncation of the data was not used as it did not improve the AICc value markedly (AICc = 139.8).

The white-beaked dolphin was encountered more commonly than other marine mammal species during this survey (encounter rate = 0.277 sightings/n mi^2; 95% CI = 0.149-0.519). These sightings data provided an abundance estimate of 11,050 (95% CI: 5,915-20,641) white-beaked dolphins present in this ESRF study area; this estimate should be considered a negatively-biased average for the late summer/fall period of 2013 and 2014.

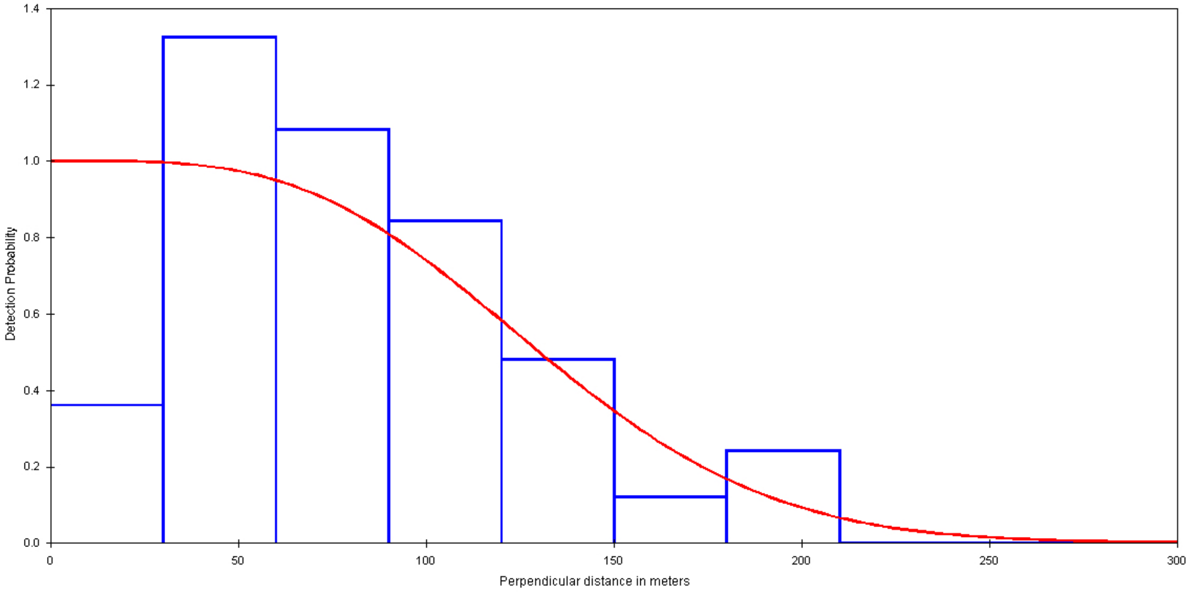

Figure 28. Number of sightings of white-beaked dolphins at different perpendicular distances from the survey trackline (N=37 in total, with data subdivided at 10 cut points). Data were not left-truncated, but were right truncated at 300 m (see text). The fitted detection probability curve (red line) was used to derive an abundance estimate for this species in the study area.

6. Acoustic Monitoring (2013, 2014)

Passive acoustic monitoring (PAM) offers a non-invasive approach for monitoring vocalizing cetaceans and pinnipeds throughout the year that is not limited by adverse weather conditions and poor visibility (see Mellinger et al. 2007; Miksis-Olds et al. 2016). Advancements in acoustic recording systems make it possible to detect and in many cases categorize vocalizing marine mammals. While there are some limitations to PAM, such as for less-vocal species, it can be used to gain valuable information on the occurrence of many cetacean and pinniped species (e.g., Berchok et al. 2006; Di Iorio and Clark 2010).

In this section, we describe acoustic research efforts to provide a measure of ambient noise levels, and contributions of anthropogenic activities such as seismic exploration and shipping. These studies also detected sounds from marine mammals in the ESRF study area as a means to describe their seasonal presence.

6.1. Acoustic Data Collection (2013 and 2014)

To collect acoustic data within the study area, two autonomous acoustic recording systems were deployed in October 2013 at locations at the northern and southern ends of the study area, then replaced in July 2014 for a second recording period (Table 8). The recorders were AURALs built by Multi-Électronique (MTE) Inc. in Rimouski, Quebec. These M2 models were equipped with 128 batteries and a double-drive option to provide extended recording time at higher sampling rates, with data to be stored in on-board hard drives. The AURALs were programmed to record at a duty cycle of 57% of each hour (34 min recording and 26 min off). The recordings were collected using calibrated HTI-96-MIN hydrophones and a sampling rate of 32 kHz, providing usable frequencies of 10 to 16,384 Hz. The 16 bit digital recording systems have an adjustable amplifier with 22 dB chosen for this study (the maximum value for this recording system). The resultant analogue signals passed through an anti-aliasing filter, and were then recorded as 128 MB WAV-format files. At this sampling rate the AURAL recorders stopped recording by early March 2014 and in the second year, by early December 2015 (Tables 8 and 9). The AURAL recorders ceased operations sooner than expected given drive capacity and predicted battery lifespan; this was likely due to cold waters limiting battery life more than expected (e.g., leaving a four-five month data gap in 2014, and a seven-month data gap in 2015).

The two recorder moorings were assembled on the deployment vessel and the acoustic releases (used for retrieval in the spring of 2014 and fall of 2015) were then armed (Figures 29 and 30). Both AURALs were deployed in approximately 100 metres of water, and the recorders were positioned at depths between 42 and 72 meters above the sea floor (Figure 31, Table 8).

The recorders were deployed from the 65-foot fishing vessel MV *What's Happenin*g based in Nain, Labrador. A recorder was deployed on 17 October, 2013 at the “North” location, indicated in Figure 2 (56.27182 N, -59.07559 W). The second recorder was deployed on 19 October at the “South” location, indicated in Figure 2 (54.82331 N, -56.37681 W). In the second year, a recorder was deployed to replace the previous unit on 25 July, 2014 at the “North” location (Table 8). A replacement recorder was deployed on 23 July at the “South” location.

Table 8. Description of AURAL acoustic recorder deployments included in the ESRF acoustic analysis.

Location	Date Deployed	Water Depth (m)	Hydrophone Depth (m)	Deployment Location	Date Recovered
North	17 Oct 2013	92	42	56.27497N, -59.07492W	24 July 2014
South	19 Oct 2013	92	42	54.82900N, -56.40090W	23 July 2014
North	25 July 2014	110	64	56.27576N, -59.08252W	19 July 2015
South	23 July 2014	130	72	54.82897N, -56.40162W	20 July 2015

Table 9. Description of recording parameters for AURAL recorders included in the ESRF acoustic analysis.

Location	Deployment	Date of First Recording	Date of Last Recording	Period Recorder Inactive	Number of Recordings
North	Fall-Winter	19 Oct 2013	25 Jan 2014	Feb-June	2,358
South	Fall-Winter	20 Oct 2013	1 Mar 2014	March-June	2,385
North	Summer-Fall	1 Aug 2014	28 Nov 2014	Dec-July	2,864
South	Summer-Fall	1 Aug 2014	4 Dec 2014	Dec-July	2,998
All					**10,605**

These recorders were to be retrieved after late summer and early fall aerial surveys. With the unexpected delay in the start of the project in 2013, it was decided that the acoustic recorders would be left in place until the summer of 2014 to collect longer-term information. A seismic exploration survey planned for the study area was already underway when the recorders were deployed. Local fishers were aware of the deployment locations, as was the seismic company.

When the recorders were retrieved in 2014, the hard drives were removed and the acoustic data files downloaded while at the deployment location. The AURALS were cleaned, re-batteried, matched to new acoustic releases, and deployed at the same locations until retrieval in the summer of 2015. Since the recorders were retrieved, refurbished, and re-deployed at the same time, we were unable to make adjustments to the recorder systems or the moorings based on a review of the recovered AURAL recordings. We could not review the AURAL recordings until we returned to the laboratory in 2015, at which point we discovered that the dynamic current environment on the Labrador Shelf had interacted with our mooring systems to yield noticeable self-noise. This made the analysis of these recordings much more time-consuming (see §6.2.1, below). Following this project we modified the mooring system to be quieter in such conditions.

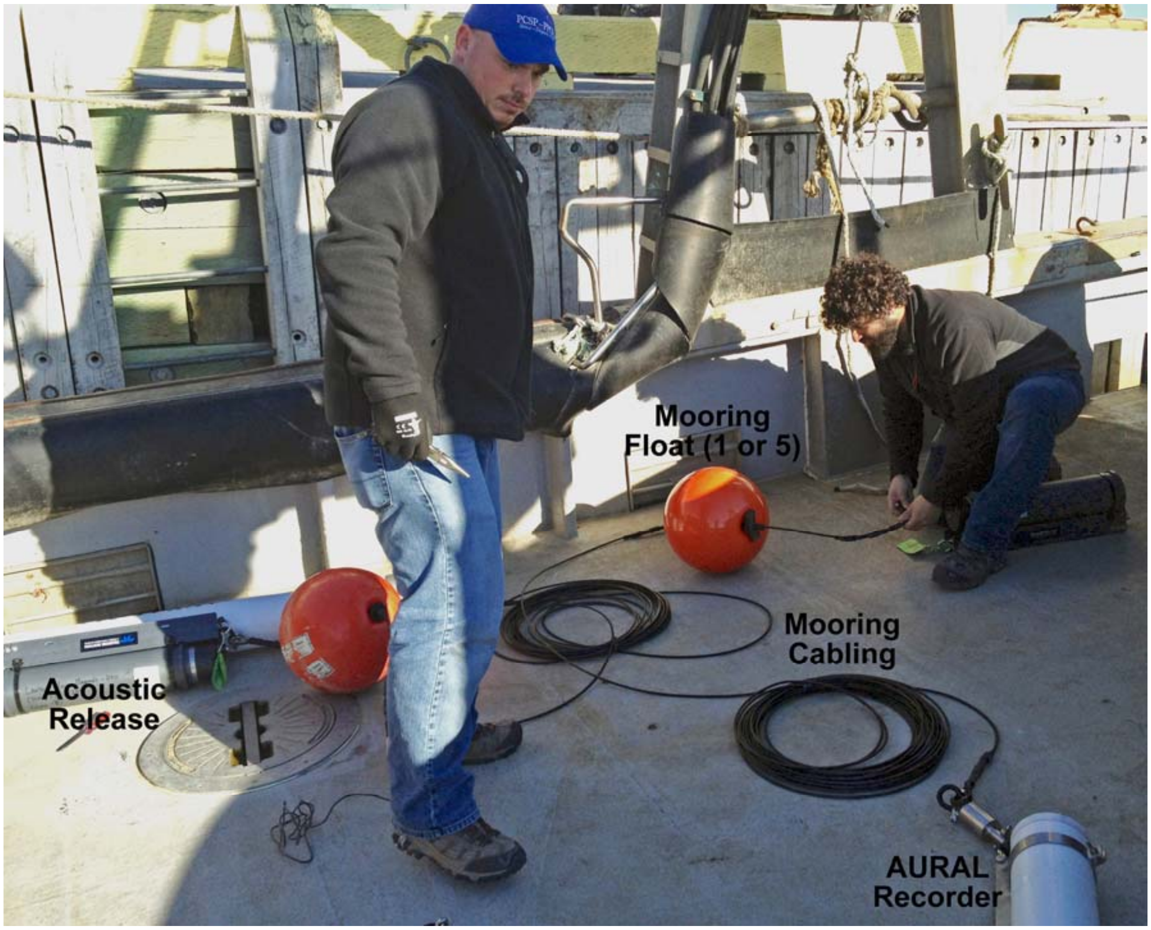

Figure 29. Assembling the mooring systems for AURAL acoustic recorders.

Figure 30. Mooring systems for two AURAL recorders (white cylinders) prepared and en route *for deployment in the study area in October 2013.*

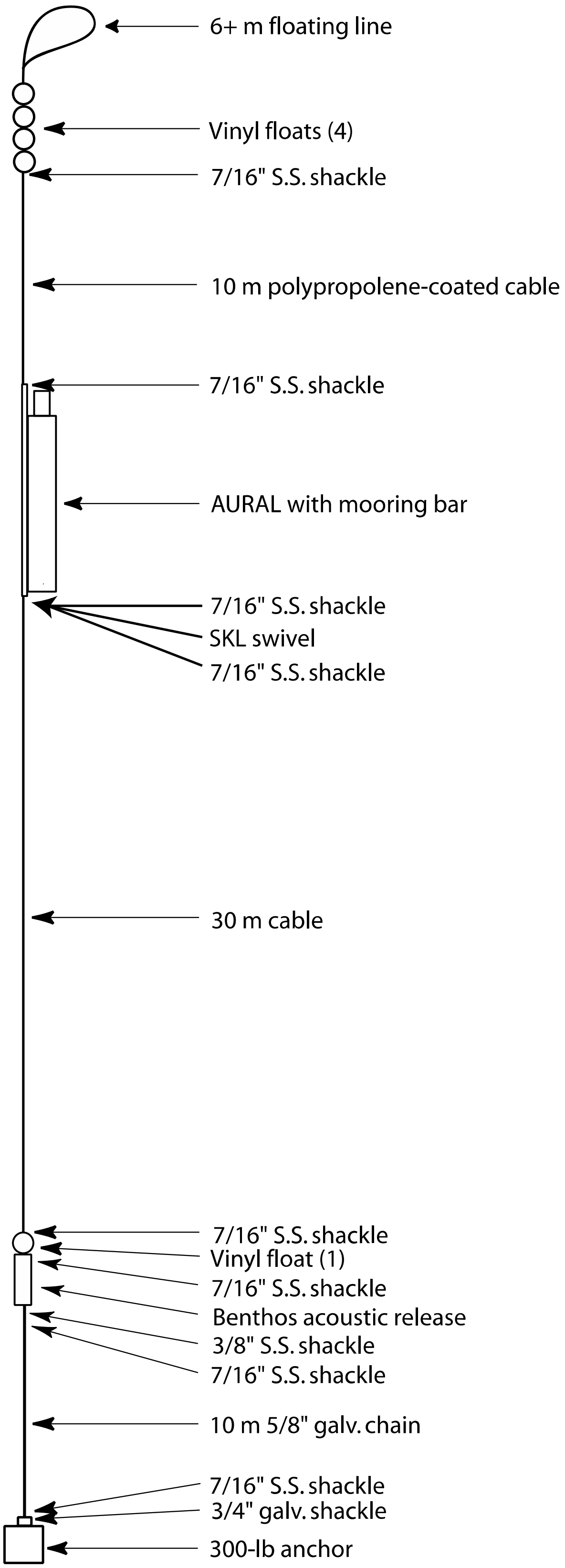

Figure 31. Mooring system for an AURAL acoustic recorder.

6.2. Acoustic Data Analysis

Due to the large quantity of acoustic data collected during this project (in excess of 2.0 terabytes of acoustic WAV files) a multi-step analysis approach was necessary to complete much of the analysis following retrieval of the AURAL recorders in 2015. The steps were:

(1) scanning of the acoustic WAV files with an automated detection system using species-specific algorithms developed by JASCO Applied Sciences Ltd. to detect and classify potential marine mammal sounds by species,

(2) manual (visual and aural) expert review of all, or representative subsamples, of the automatic detection events by an experienced acoustician to calculate marine mammal detection rates, subdivided by location and month,

(3) estimation of ambient noise levels (minimum, maximum, and mean levels) from different time periods over the course of the deployment using automated computer programmes developed by JASCO Applied Sciences Ltd., and

(4) review of the sounds that did not match known marine mammals, or that originated form manmade sources, to characterize them manually by a highly experienced acoustician.

6.2.1. Automated Sound Classification

Data from the two recording locations were analysed for the presence of marine mammal calls, ambient noise, and anthropogenic sounds. Recording coverage varied between the locations, but generally were obtained during the summer, fall, and winter. A total of 12,512 recordings were analysed.

Automated, contour-based call detectors developed by JASCO were used to discover possible marine mammal calls on the recordings; primarily baleen whales such as blue, fin, humpback, and sei whales, but also including sperm (*Physeter macrocephalus*), and long-finned pilot whales. The contour detectors operated by calculating a sound spectrogram and finding vocalizations with specified timing and frequency attributes on the recordings that exceed a certain sound amplitude threshold. Delphinid calls were detected automatically using echolocation click detectors, but not usually categorized to species. The click detectors are time-series based detectors that operate differently than the contour detectors. Also, most cetacean echolocation signals energy would be at frequencies higher than the AURALs could detect.

One set of contour detectors were configured to detect low frequency blue whale tonal (A, B, and AB calls) and higher frequency arch calls (D calls) (McDonald et al. 2009; and H. Moors-Murphy, DFO, Maritimes, pers. comm.). The WAV data was processed using the detectors at a relatively low threshold to increase the probability that any sound matching the parameters for these blue whale call types were detected. The detectors were therefore less likely to miss even very quiet blue whale calls (i.e., the false negative rate was minimized), but more likely to detect sounds that were not blue whale calls (i.e., had a high false alarm/false positive rate). Such trade-offs exist when configuring any type of automatic acoustic signal detector and for the purposes of the analyses of the AURAL datasets, it was more advantageous to minimize the number of blue whale calls missed by the detectors at the expense of increasing the number of false detections given the rarity of these calls. Detectors for the other cetacean species offered varying degrees of precision. Humpback whales have more complex and variable calls than blue, fin, or sei whales so the detectors weren't as efficient.

We discovered that the AURAL moorings used in this project exhibited relatively high self-noise in the strong currents on the Labrador Shelf (particularly the northern AURAL, Figure 32), and mainly in the low-frequency portion of the recorded sound energy spectrum, and so the automated detectors did not perform as well as they would with quieter recordings.

In addition, the recordings contained a substantial quantity of anthropogenic noise of relatively high amplitude (primarily from shipping and seismic exploration) that obscured marine mammal sounds. In 2013 there was a seismic array operating near the northern AURAL, and the strong acoustic signals it produced compromised the automated detectors' and the human analysts' abilities to detect marine mammals in the data from this recorder. This was due to three factors:

- strong signals can obscure relatively quieter mammal sounds (e.g., Figure 33)
- some whales reduce their vocalization rates when exposed to loud anthropogenic sounds (Lesage et al. 1999; Melcón et al. 2012; Pirotta et al. 2014; Tyack et al. 2004; Watkins and Schevill 1975)
- the AURAL recorders are designed with a self-protective signal-clamping feature that protects them from damage due to very loud sounds; a loud signal will reduce the signal gain of the AURAL for several seconds afterwards (Figure 34)

JASCO has performed numerous manual test validations of the auto-detectors and found that fin and delphinid whistles are generally detected reliably. In the ESRF acoustic data they found a single true detection of a sei whale, but no northern right whales. In general, most of these false detections were likely calls produced by humpback whales, when checked manually (B. Martin, JASCO Applied Sciences Ltd., pers. comm.). The blue, sei, and humpback detectors tended to have high false alarm rates.

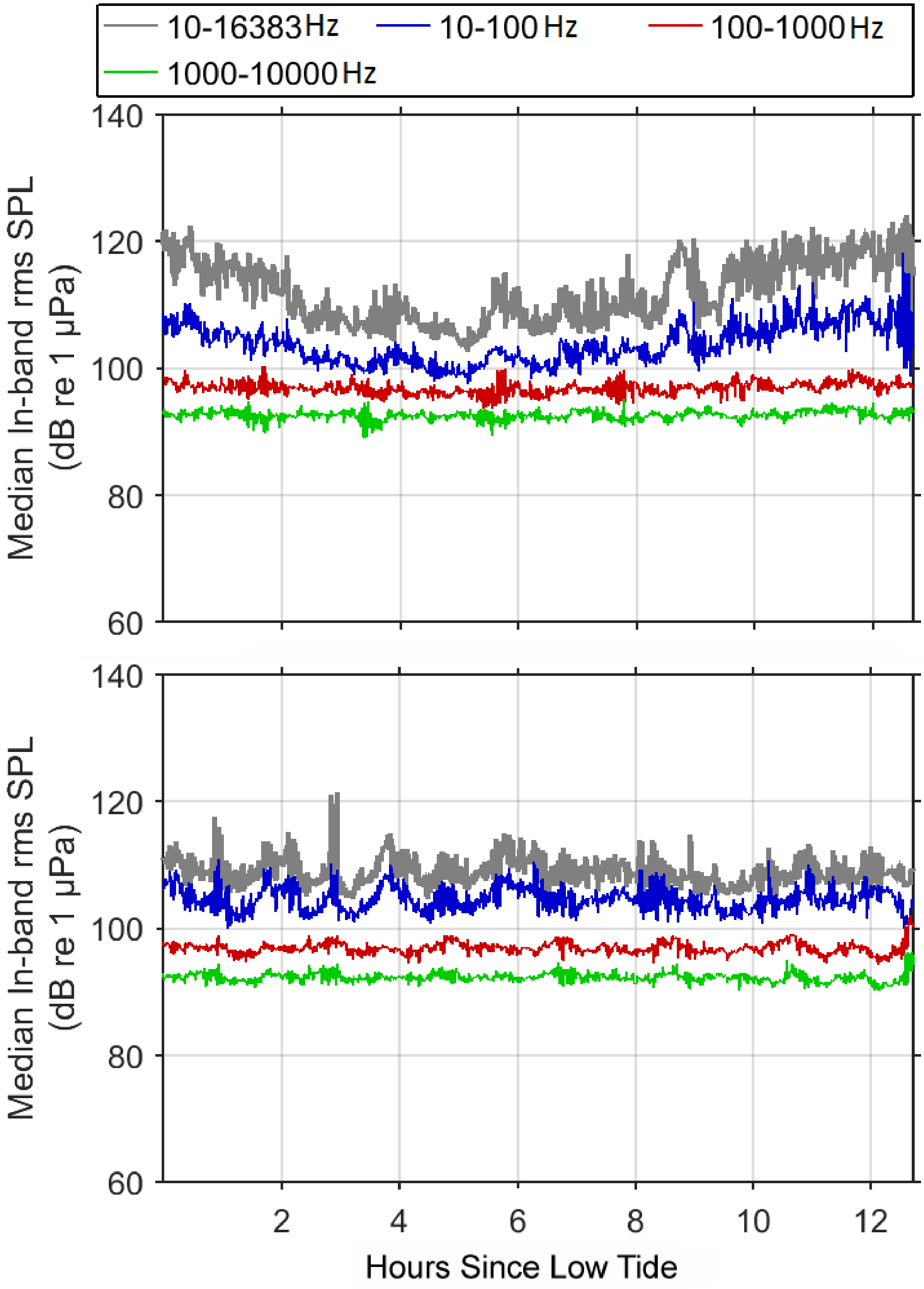

Figure 32. Overall and frequency band-specific median ambient noise measures at the northern (top) and southern (bottom) AURAL moorings for the period 1 August to 28 November, 2014. Noise levels are approximately 10 dB higher at the northern AURAL during tidal changes. Note that the plotted times are UTC, which are 2.5 (summer) and 3.5 (winter) hours earlier than the time at the recorder locations, and the tidal reporting stations are located on the Labrador coast.

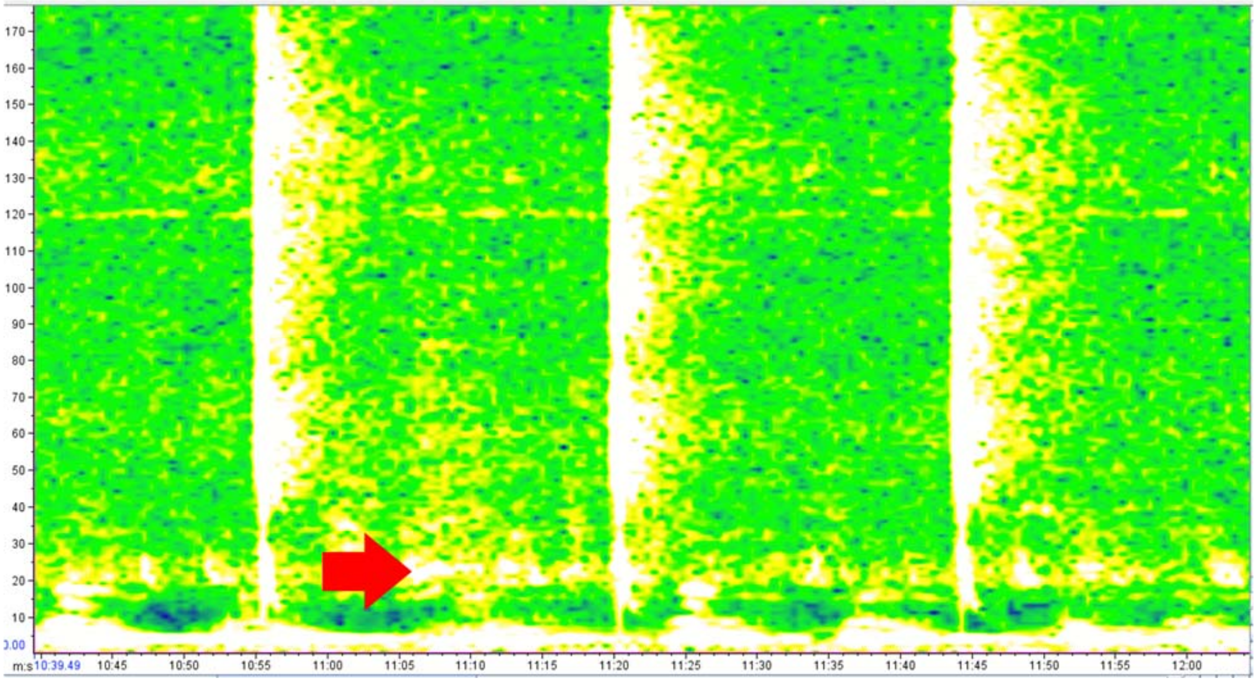

Figure 33. Seismic array pulses (three large, lighter-coloured vertical marks) temporally overlap the pulses emitted by fin whales at 20 Hz (red arrow), and continuous low-frequency vessel noise (0 to 15 Hz noise band, at bottom).

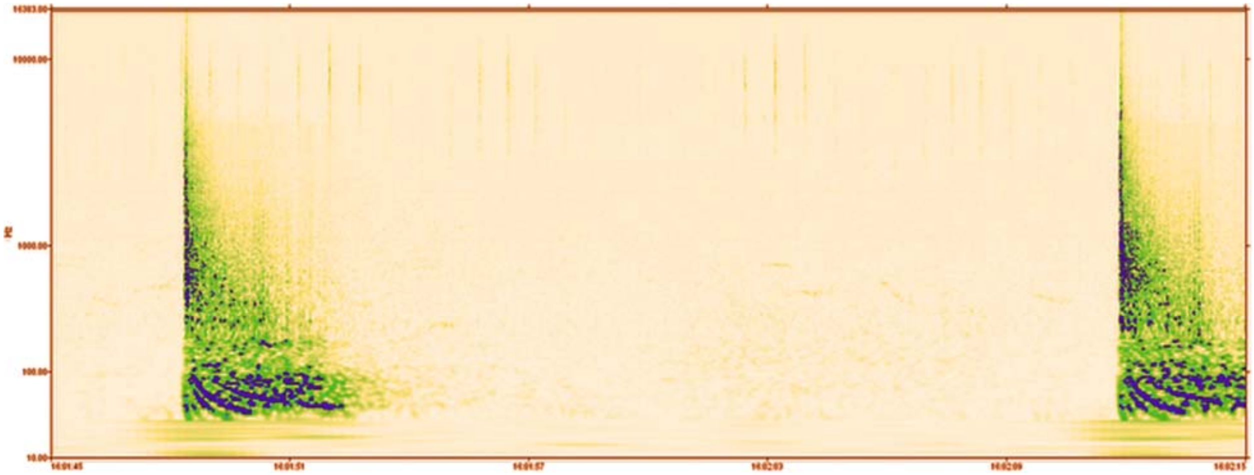

Figure 34. Due to both short-term sensitivity clamping by the AURAL recorder hardware and reverberance of the seismic signal, many seismic pulses recorded in 2013 were sufficiently loud to obscure intervening and concurrent calls from humpback and sperm whales.

6.2.2. Manual Sound Classification

Due to the high false positive rate in the acoustic data collected during this project[1], all WAV recordings from the AURALs that had at least one cetacean detection were manually (aurally and visually) inspected by an experienced acoustician (G. Renaud, DFO, Newfoundland and Labrador) using Raven Pro 1.4 sound analysis software (Cornell Laboratory of Ornithology, Bioacoustics Research Program) to verify the presence of baleen and toothed cetacean calls. Additionally, 500 recordings that did not have whale or dolphin calls detected on them were sampled randomly from the 2013 and 2014 deployments to verify and estimate the rate of false negative detections.

For some species, there were many vocalizations marked by the automated sound classification system. For fin and humpback whales, there were simply too many call detections to fully review manually. For these two species we reviewed a subsample of the detections; we reviewed one file with a detection within each three hour period for fin whales, and for humpbacks we examined one WAV file within a three-hour period for files that contained more than 10 automated detections. From these subsamples we estimated the number of true calls by each species per total number of automated detections (see §5.4 and 5.6, below).

6.2.3. Estimating Ambient Noise Levels and Anthropogenic Sound Contributions

This section contains the results of analyses of AURAL acoustic data using shipping, seismic array, and impulsive sound detectors for anthropogenic sound energy.

The acoustic metrics used to quantify the ambient sound in this report are:

- **root-mean-square sound pressure level (rms SPL)**: sound pressure level (SPL) averaged over each minute within a given frequency band, and expressed in decibels (dB) re 1 μPa
- **power spectral density level**: distribution of acoustic energy over different frequencies within a spectrum. It is expressed in dB re 1 $\mu Pa^2/Hz$
- **daily sound exposure levels** (**daily SELs**): linear sum of the 1-min SELs over 24 h, where the SEL describes the total sound energy flux density over a given period and is commonly used as a surrogate for the received energy

Where indicated on two summary plots (Figure 43), B. Martin of JASCO tried a novel approach to limit the contribution of mooring cable strumming and other self-noise to ambient noise level estimates by removing data in the 13 Hz 1/3 octave band when it was greater than 115 dB (see Table 11); while this reduced the amplitude of the noise levels, it may also have eliminated some acoustic energy contributions in the environment. A better assessment of the

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[1] False detections are a feature of any acoustic data collected in high-noise marine environments. This was the case off southern Labrador with its strong currents, anthropogenic noise such as seismic and shipping, and with the moorings used in this project.

efficacy of this method is needed, perhaps by comparing our results with those of JASCO for nearby stations in following years (see the ESRF report, referenced previously). The acoustic characterization results presented in other plots and tables in this report were not subject to this trial filtering process.

The AURAL hydrophones and electronics were not intended to record seismic signals and hence there was saturation of seismic signals when the array was operating nearby in 2013. This is especially evident in the peak SPL values, but would have affected all measures.

In the summaries of estimated received sound levels, we calculated the M-weighted SEL for each 24-h period. M-weightings are frequency weightings that can be applied to the SEL values to adjust for the hearing sensitivity of marine mammals to acoustic sources (Merchant et al. 2012; NMFS 2016; Southall et al. 2007).[2] The M-weighting group most receptive to the frequency range of shipping noise is low-frequency cetaceans (baleen whales).

6.3. Acoustic Data Results - Ambient Noise Levels and Anthropogenic Sound Contribution

6.3.1. Ambient Noise Levels

At both AURAL sites in the study area, but particularly at the northern site, there were relatively high ambient noise levels (Figures 35 to 40). Much of the recorded sound energy was contained in the 10 to 200 Hz frequency range, and largely attributable to anthropogenic activities (see §6.3.2, below); the two main sources of noise originated from shipping and seismic exploration. We also recorded pack ice noise during the winter (which can interfere with the automatic whale vocalization detectors). Overall, sound levels were greater at the northern AURAL site, and while variable from day-to-day, for both AURALs was slightly lower during the summer period (Figures 38 and 39) of the two-year ESRF project.

6.3.2. Anthropogenic Contributions to Recorded Sound Levels

Based on the AURAL records, there appear to be two main sources of noise originating from anthropogenic activities in this study area: shipping and seismic exploration. During this project there was a seismic project operating in the project area during the summer and fall of 2013, whereas in 2014 the seismic activities occurred hundreds of kilometres further south and east of the study area. In contrast, various types of shipping activity continued throughout the year in and offshore of the study area, even when seasonal sea ice was present.

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[2] Some feel the application of M-weightings to low amplitude, chronic sources of noise is uncertain since they may overestimate the sensitivity of hearing (McQuin et al. 2011).

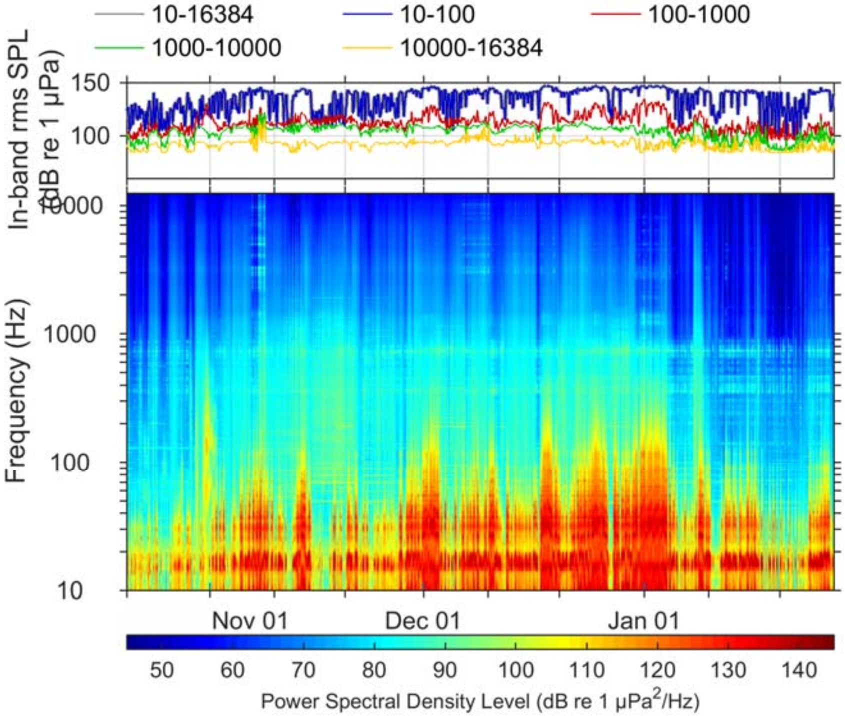

Figure 35. Frequency-band-specific ambient noise levels, and frequency-specific power spectral density ambient noise levels estimated for recordings made by the northern AURAL for the period of 20 October, 2013 to 27 January, 2014. Most of the sound energy is contained in the lower frequency range.

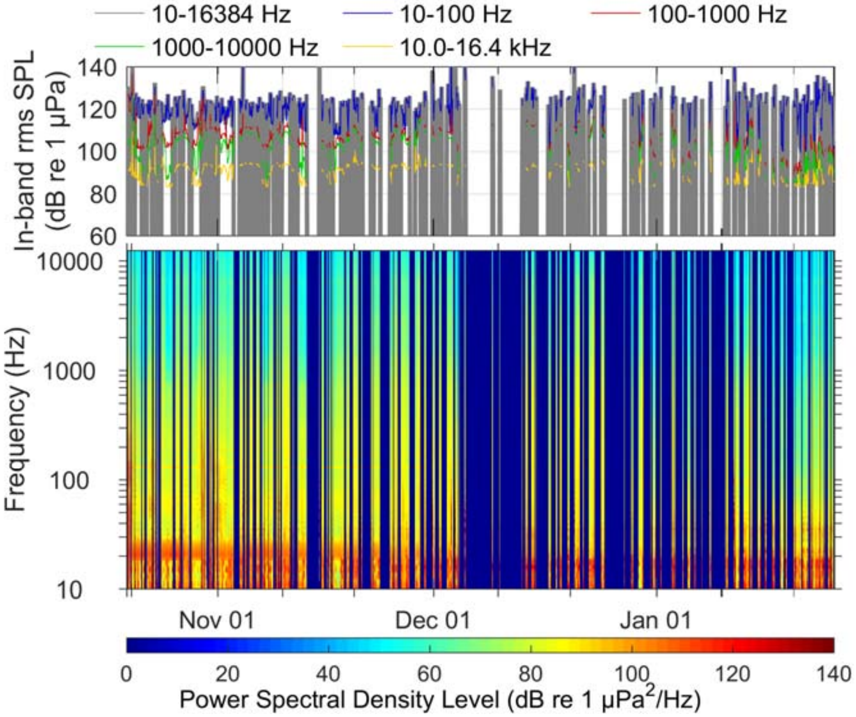

Figure 36. Frequency-band-specific ambient noise levels, and frequency-specific power spectral density ambient noise levels estimated for recordings made by the southern AURAL for the period of 20 October, 2013 to 27 January, 2014. Most of the sound energy is contained in the lower frequency range.

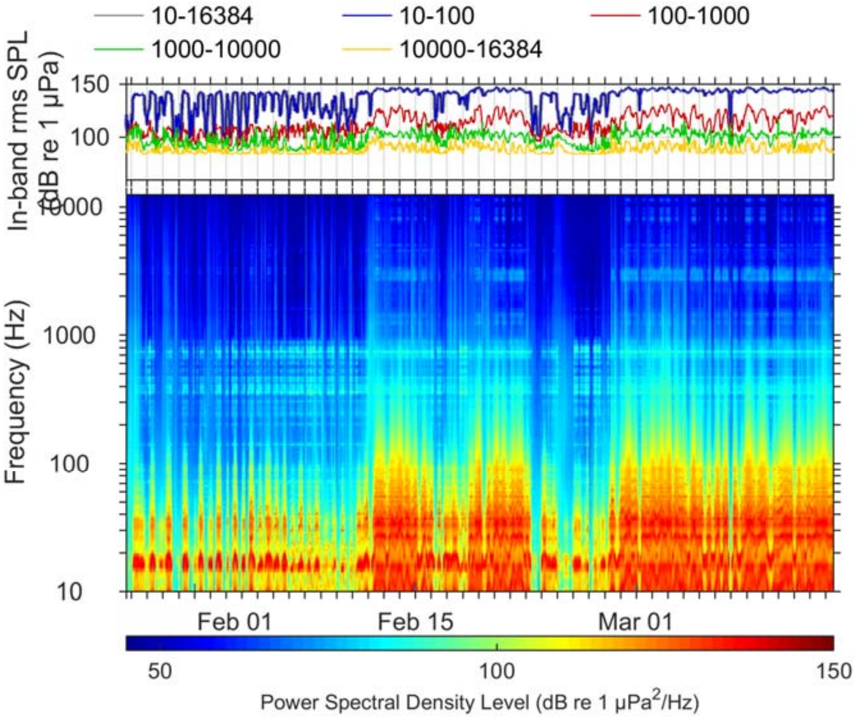

Figure 37. Frequency-band-specific ambient noise levels, and frequency-specific power spectral density ambient noise levels estimated for recordings made by the northern AURAL for the period of 25 January to 1 March, 2014. Most of the sound energy is contained in the lower frequency range.

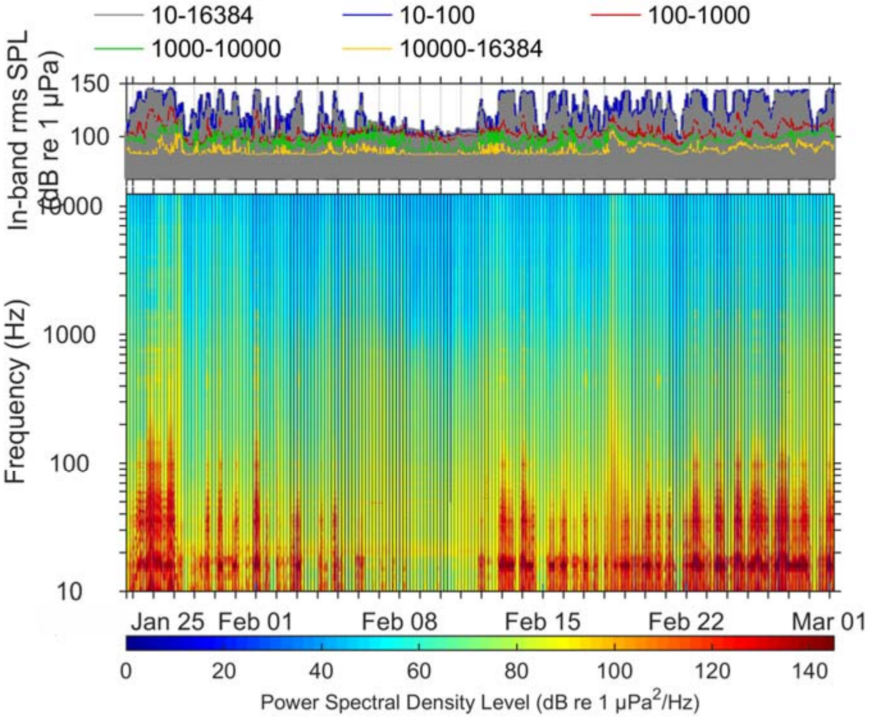

Figure 38. Frequency-band-specific ambient noise levels, and frequency-specific power spectral density ambient noise levels estimated for recordings made by the southern AURAL for the period of 25 January to 1 March, 2014. Most of the sound energy is contained in the lower frequency range.

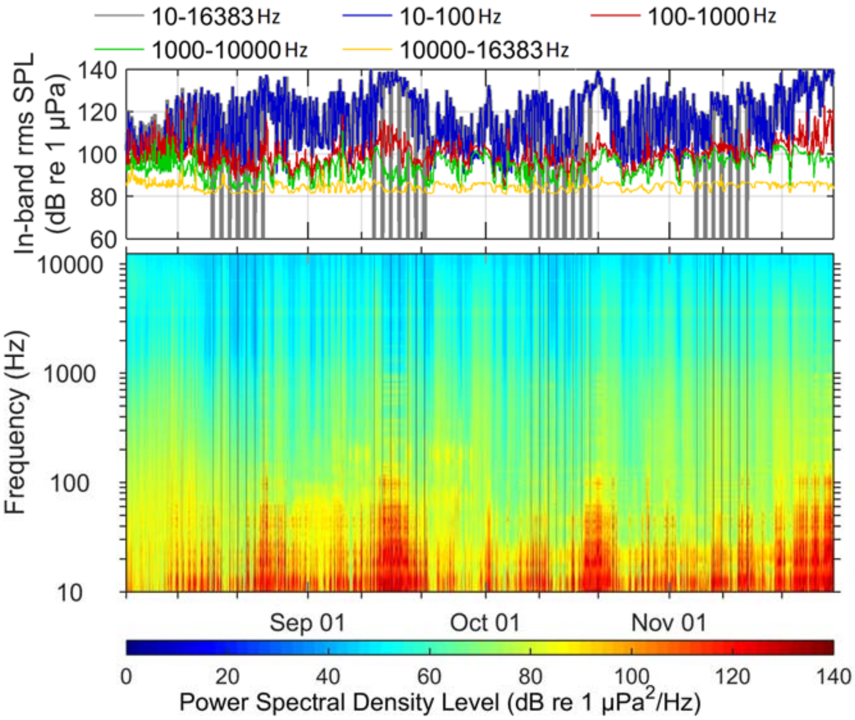

Figure 39. Frequency-band-specific ambient noise levels, and frequency-specific power spectral density ambient noise levels estimated for recordings made by the northern AURAL for the period of 1 August to 4 December, 2014. Most of the sound energy is contained in the lower frequency range.

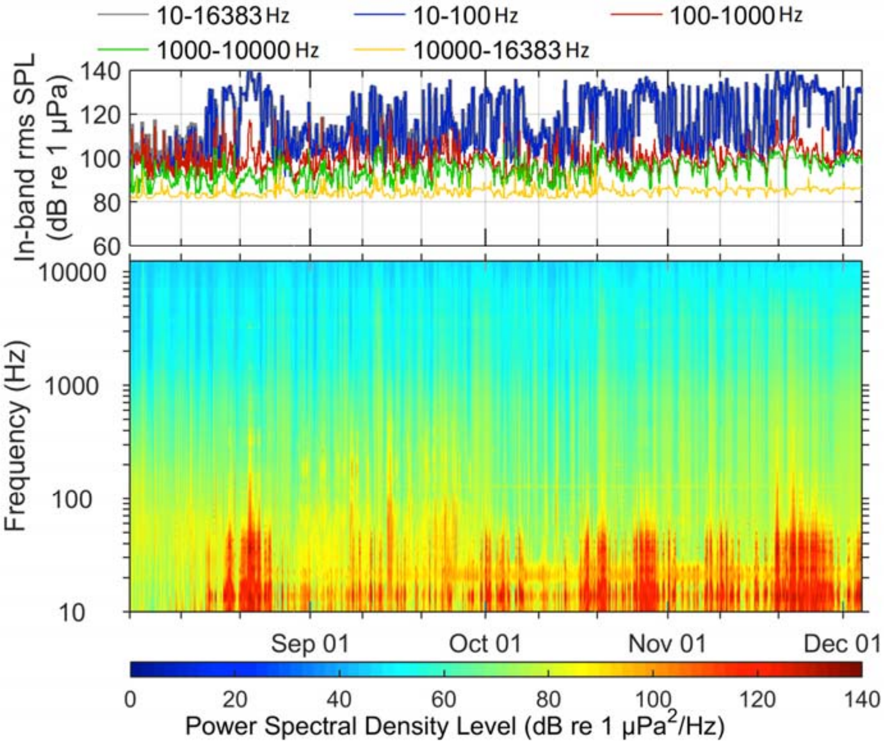

Figure 40. Frequency-band-specific ambient noise levels, and frequency-specific power spectral density ambient noise levels estimated for recordings made by the southern AURAL for the period of 1 August to 4 December, 2014. Most of the sound energy is contained in the lower frequency range.

Shipping activity records are poor for the Labrador coast. The Canadian Coast Guard's Automated Identification System (AIS) does not collect information north of 55^{o} currently, which is the latitude of the southern AURAL recorder location (Figure 41). Nonetheless there are a variety of ship types that operate in and near the ESRF study area, including loud icebreakers and ice-breaking ore transports in the winter. The noise from these vessels contributed a significant amount of the cumulative acoustic energy, mainly in the lower frequency bands, across all years, seasons, and at both AURAL sites (see below).

Data from the northern AURAL for the period 19 October, 2013 to 25 January, 2014 yielded similar levels of anthropogenic sound as the southern mooring. Sound classified as "seismic" did not appear in the fall 2013 period for the northern mooring likely because of the clipping of high-amplitude sounds by the AURAL and the process we employed to reduce the influence of mooring self-noise. Daily values (unfiltered) ranged from 164.0 to 193.1 dB re 1 µPa2·s cSEL(24h)[3], with a mean of 186.4 dB re 1 µPa2·s (Figure 41 and Table 10). Anthropogenic sounds contributed a mean of 8.6% and a maximum of 73.7% of the daily cSEL estimate. On average, five vessel passages were detected each day at this site during this study period.

The data from the southern AURAL site for the period 19 October, 2013 to 25 January, 2014 yielded similar levels of anthropogenic sound (including some sounds classified as seismic), with daily values (unfiltered) ranging from 164.2 to 190.2 dB re 1 µPa2·s cSEL(24h), with a mean of 185.0 dB re 1 µPa2·s (Figure 43 and Table 11). With unfiltered data, anthropogenic sounds contributed a mean of 19.6% and a maximum of 96.7% of the daily cSEL estimate. We detected a mean of 50 seismic pulses per day (normalized for effort) at this site, with a maximum of 4,379 on a day when the array was operating nearby. We detected seven vessel passages per day at this site during this period. When we then filtered the southern AURAL data at 13 Hz in an effort to control for mooring self-noise which predominated at this frequency, the daily values (filtered) decreased to range from 142.4 to 172.6 dB re 1 µPa2·s cSEL(24h), with a mean of 161.7 dB re 1 µPa2·s (Figure 43 and Table 11). But this reduction in the contribution of vessel noise using the lower-frequency noise filtering method is unrealistically large since periods estimated to have no shipping noise contributions (for example mid-December to early January in Figure 43), did have ship noise when reviewed manually. A satisfactory method of controlling for mooring self-noise in this dataset has yet to be developed, although we have now improved our moorings to be significantly quieter in areas with strong currents.

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[3] cSEL(24h) is the total sound energy estimate cumulated over a 24 hour time period.

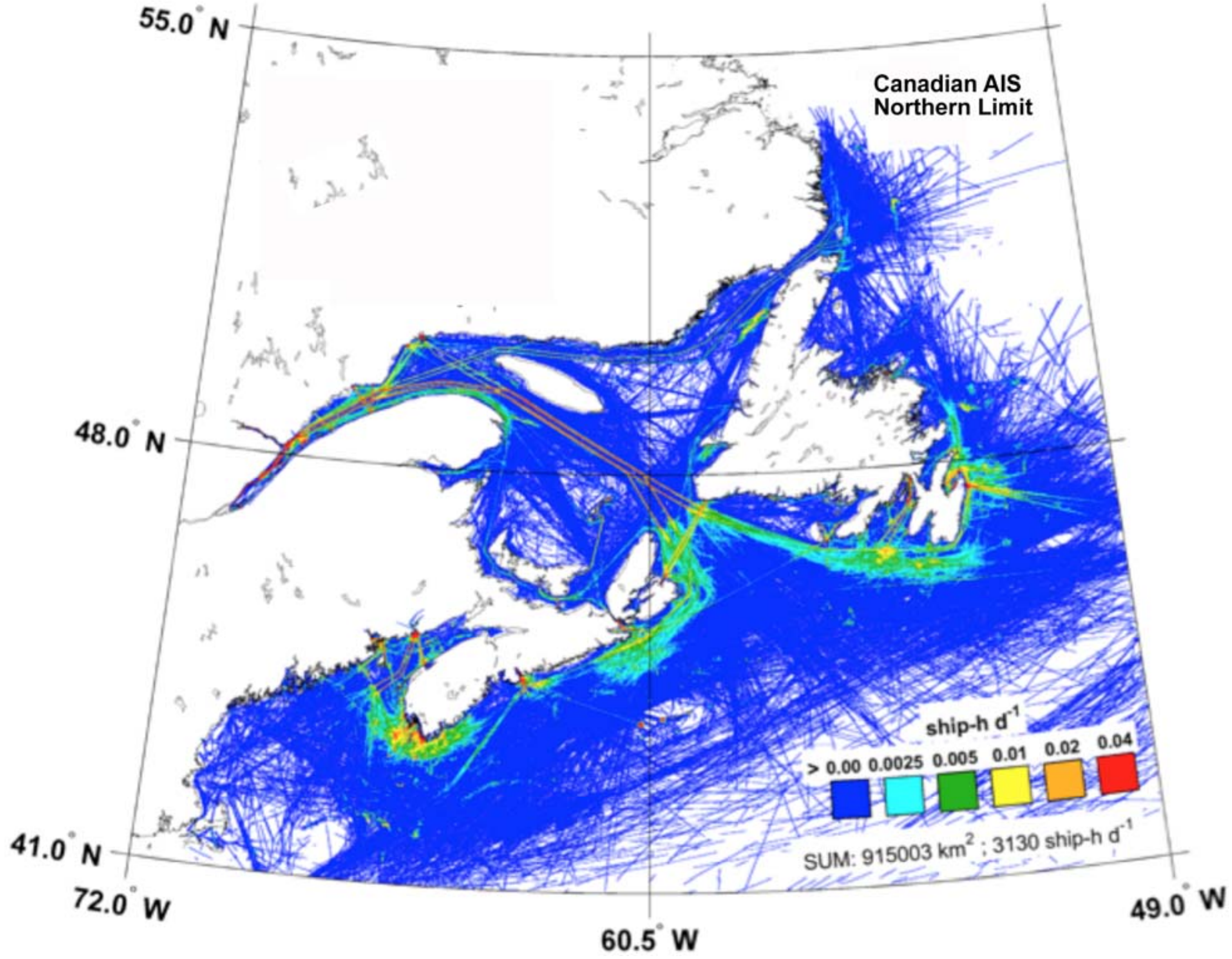

Figure 41. Map of Automated Identification System mean traffic density of all ships (fishing, tanker, cargo, passenger, tug etc.) in 2013 (ship-hours per day) (adapted from Simard et al. 2014). Note that the data collection terminates north of 55º north, which is the latitude of the southern AURAL recorder location, and therefore much shipping traffic off mid and northern Labrador is not monitored using this system.

The data from the northern AURAL site for the period 27 January to 1 March, 2014 yielded similar levels of anthropogenic sound to the fall period, with daily values (unweighted) ranging from 166.9 to 192.0 dB re 1 μPa2·s cSEL(24h), with a mean of 188.3 dB re 1 μPa2·s (Table 12). Anthropogenic sounds contributed a mean of 3.2% and a maximum of 31.3% of the daily cSEL estimate. We detected three vessel passages per day at this site during this period – likely ice breakers, or the ice-breaking ore carrier *M.V. Umiak*.

Data from the southern AURAL site for 27 January to 1 March, 2014 yielded relatively higher levels of anthropogenic sound than the fall period, with daily values (unweighted) ranging from 150.2 to 188.7 dB re 1 μPa2·s cSEL(24h), with a mean of 182.6 dB re 1 μPa2·s (Table 13).

Anthropogenic sounds contributed a mean of 20.5% and a maximum of 88.4% of the daily cSEL estimate. We detected four vessel passages per day at this site during this period.

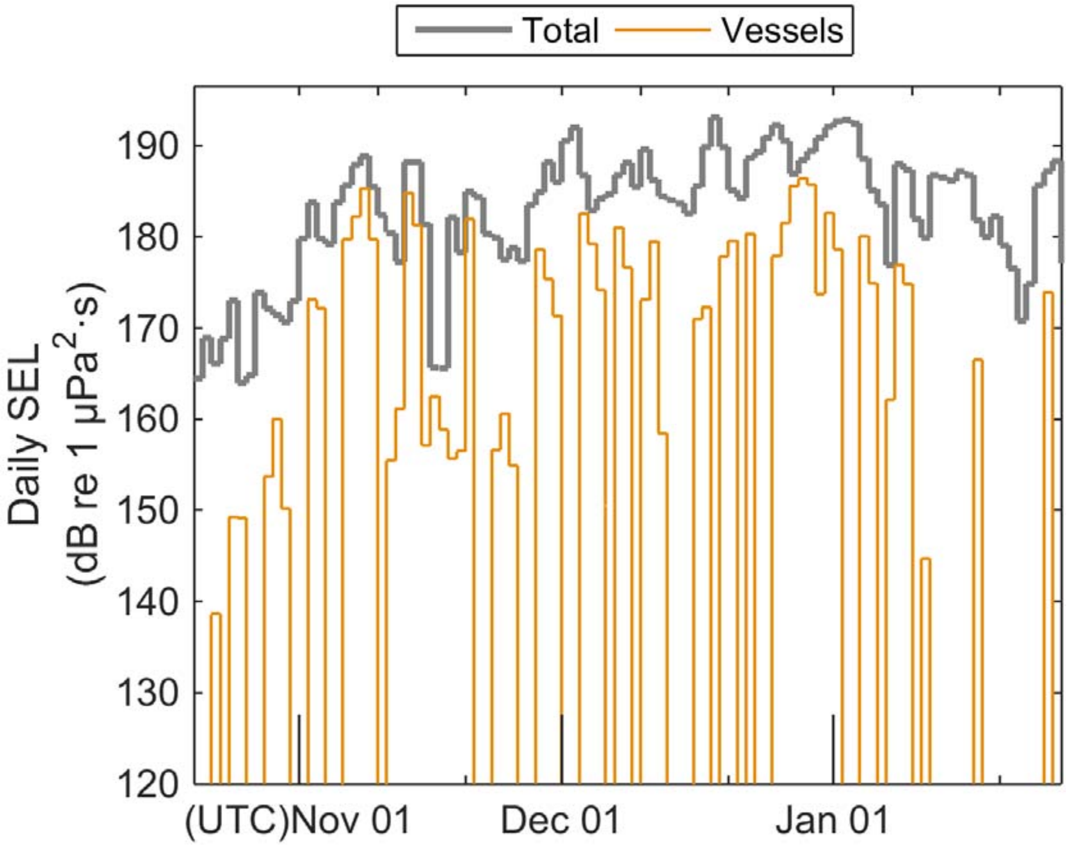

Figure 42. Daily Sound Exposure Level (SEL) values for vessels, seismic signals, and overall anthropogenic sounds at the northern AURAL for the period 19 October, 2013 to 25 January, 2014 (for statistics see Table 10, below).

Table 10. Estimated received sound levels for the northern AURAL for the period 19 October, 2013 to 25 January, 2014. Each column contains sound level statistics for the cSEL(24h) using M-weightings from NMFS (2016). Units are dB re 1 µPa2·s.

Sound Level Statistic	Total	Low-Frequency M-Weighted	Mid-Frequency M-Weighted	High-Frequency M-Weighted
Minimum	164.0	143.0	131.9	130.5
Maximum	193.1	166.5	156.2	154.1
Mean	186.4	159.0	144.6	142.0

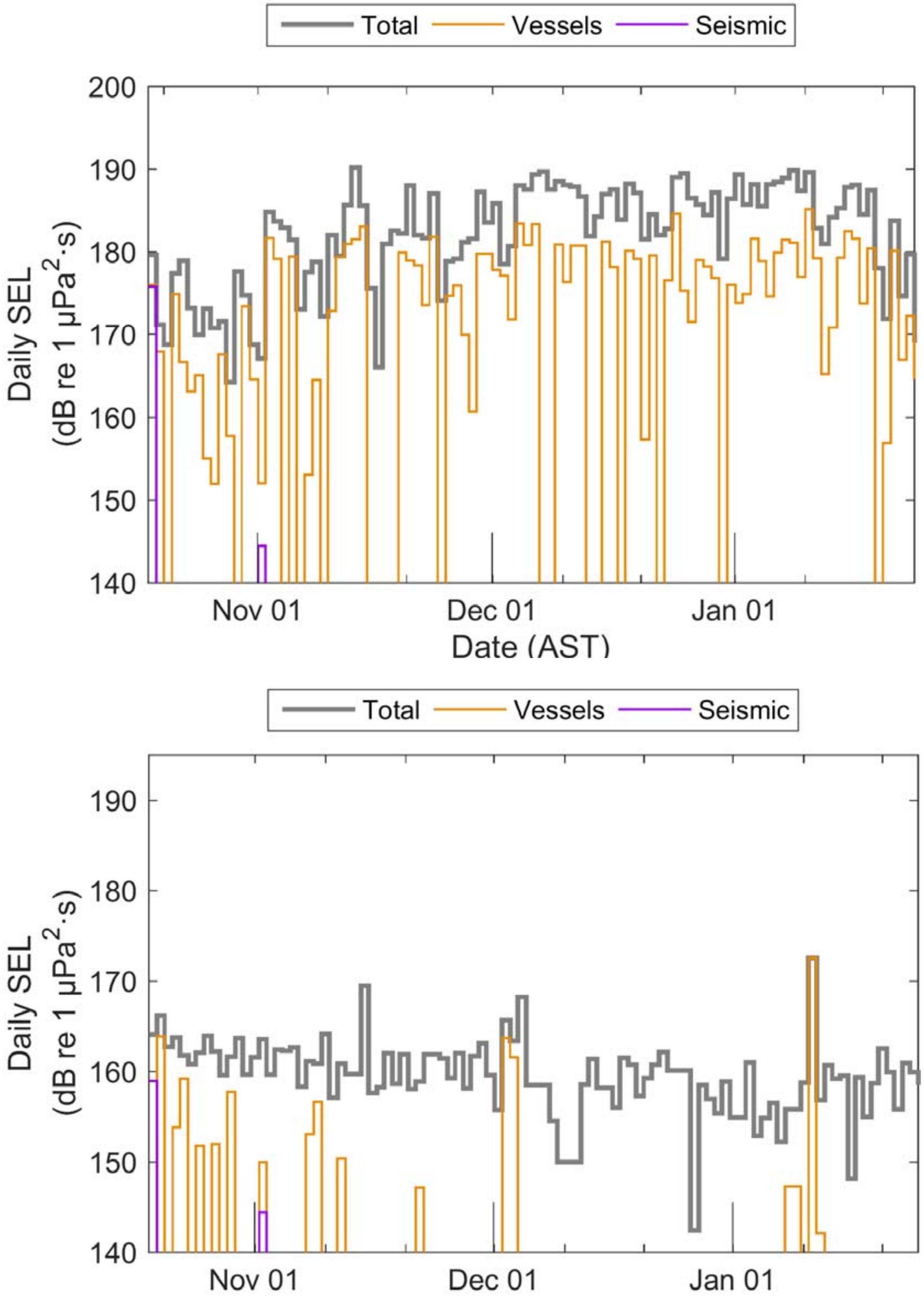

Figure 43. Daily Sound Exposure Level (SEL) values for vessels, seismic signals, and overall anthropogenic sounds at the southern AURAL for the period 19 October, 2013 to 25 January, 2014 (for statistics see Table 11). The unprocessed data are in the top frame; in the bottom frame, an effort was made to limit the contribution of cable strumming and other mooring self-noise by analytically removing data in the 13 Hz 1/3 octave band when it exceeded 115 dB.

Table 11. Estimated received sound levels for the southern AURAL for the period 19 October, 2013 to 25 January, 2014. Each column contains sound level statistics for the cSEL(24h) using M-weightings from NMFS (2016). Units are dB re 1 µPa2·s. The unfiltered data are in sub-table A; in sub-table B, a novel approach was employed to limit the contribution of cable strumming and other mooring self-noise by analytically removing data in the 13 Hz 1/3 octave band when it exceeded 115 dB.

(A) Unfiltered Acoustic Data

Sound Level Statistic	Total	Low-Frequency M-Weighted	Mid-Frequency M-Weighted	High-Frequency M-Weighted
Minimum	164.2	163.7	151.6	149.9
Maximum	190.2	189.8	176.8	174.6
Mean	185.0	184.4	170.1	167.9

(B) 13 Hz Filtered Acoustic Data

Sound Level Statistic	Total	Low-Frequency M-Weighted	Mid-Frequency M-Weighted	High-Frequency M-Weighted
Minimum	142.4	141.2	126.1	125.0
Maximum	172.6	171.9	160.1	159.1
Mean	161.7	160.9	152.6	151.9

Table 12. Estimated received sound levels for the northern AURAL for the period 25 January, 2014 to 1 March, 2014. Each column contains sound level statistics for the cSEL(24h) using M-weightings from NMFS (2016). Units are dB re 1 µPa2·s. We did not limit the contribution of mooring cable strumming and other self noise.

Sound Level Statistic	Total	Low-Frequency M-Weighted	Mid-Frequency M-Weighted	High-Frequency M-Weighted
Minimum	150.2	139.9	131.4	129.9
Maximum	188.7	160.0	147.2	144.3
Mean	182.6	151.8	138.3	136.0

Table 13. Estimated received sound levels for the southern AURAL for the period 25 January, 2014 to 1 March, 2014. Each column contains sound level statistics for the cSEL(24h) using M-weightings from NMFS (2016). Units are dB re 1 µPa2·s. We did not limit the contribution of mooring cable strumming and other self-noise.

Sound Level Statistic	Total	Low-Frequency M-Weighted	Mid-Frequency M-Weighted	High-Frequency M-Weighted
Minimum	166.9	148.1	132.3	130.7
Maximum	192.0	164.5	144.8	142.5
Mean	188.3	159.2	139.7	137.3

In summary, the primary anthropogenic contribution to the southern Labrador soundscape is vessel noise, with daily passage of three to seven vessels detected clearly, plus much more lower-level background vessel noise from more distant shipping. The level of anthropogenic noise did not decline significantly in the winter, although ice movement and storms became more important contributors. The northern AURAL site was slightly noisier than the southern site in 2013, but quieter in the winter of 2014.

As a novel approach, we attempted to filter out the contributions of cable strumming and other self-noise from the AURAL data by removing low-frequency (13 Hz) sound energy above a 115 dB amplitude; by doing so we reduced AURAL broadband sound energy measures by 15 to 20 dB. Whether this filtering is the optimal means to control for self-noise is unknown, as it removes the contribution of some vessel noise during periods when we were able to hear vessels on the recordings. The effect of this filtering would be best assessed using recordings made at these locations with quieter moorings (such as during the JASCO ESRF project, referenced above).

6.4. Acoustic Data Results - Marine Mammal Detections and Classifications

There were many baleen and toothed whale calls and echolocation signals detected by the automated system (see Tables 14 to 17). However, when a large proportion of these were examined manually, it was apparent that the high level of anthropogenic noise, mooring self-noise, and overall ambient noise energy levels had caused the automated system to misclassify many. For instance, the low rate of call detection for blue whales was likely an underestimate given these high-noise conditions.

6.4.1. Baleen Whale Detection

Given the high-noise environment in which the acoustic recorders operated, the detection of the primarily low-frequency calls of baleen whales was challenging for the autodetection software and subsequent manual checks. Nonetheless, the calls of humpback, fin, blue, and sei whales were detected in the study area in both 2013 and 2014.

There were fewer humpback and fin whale calls in winter compared with summer and fall (Tables 14 to 17), but nonetheless these whales were detected even when ice covered much of the Labrador Shelf. Given the limits to call detection in such high-noise conditions, these whales were likely in nearby deeper waters off the shelf break, rather than more distant locations.

The number of detected humpback whale calls increased in the Fall, then declined again by December. This was seasonal change was not a function of detector efficacy; the fin whale autodetector filters performed better than that for the humpback whale the latter which have a more variable vocal repertoire (Figures 44 and 45). Humpback whale calls were detected even when seismic sounds predominated the acoustic soundscape (Figures 46).

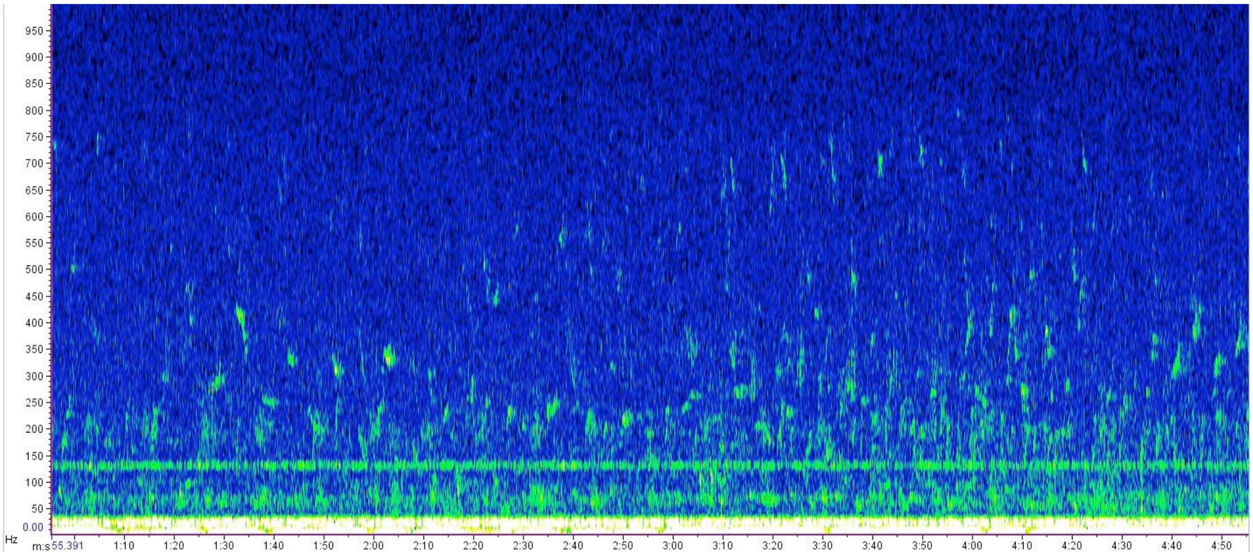

Figure 44. Humpback whale song recorded by the southern AURAL in October 2013. Fin whale call pulses are visible at 130 Hz, and also at 20 Hz (but not well shown on this screen image).

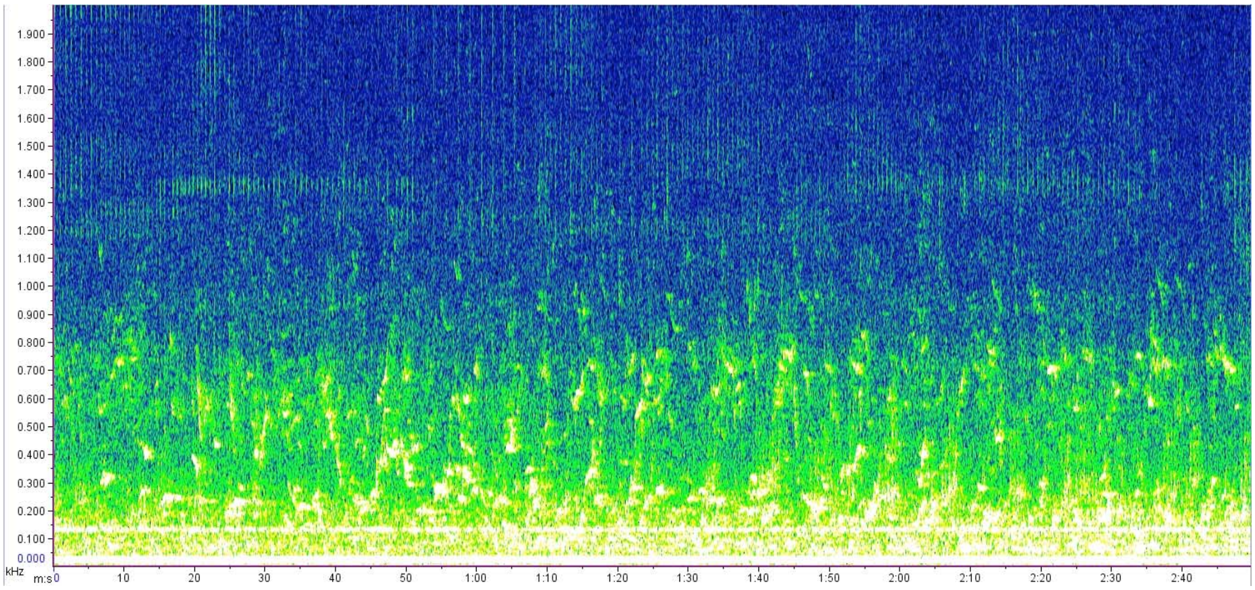

Figure 45. Humpback whale calls, sperm whale clicks, and 130 Hz fin whale pulses.

Table 14. Mysticete whale call detections for the northern AURAL during October 2013 to January 2014.

	Blue Whale Tonal Calls	**Blue Whale Arch Calls**	**Fin Whale**	**Humpback Whale**	**Sei Whale**
Total number of files	2,358	2,358	2,358	2,358	2,358
No. of detections	695	6	694	2,078	105
No. of detections examined	695	6	390	572	105
No. of true detections	6	1	180	329	1
Proportion of true detections	0.01	0.17	0.46	0.57	0.01
False alarm rate	99.14	83.33	53.85	42.48	99.05
No. of zeros examined	4	0	52	0	
No. of true zeros (0 or ?)	4	0	1	0	
Confirmed Calls By Month					
Hours with confirmed calls in Oct	4	1	56	163	1
Hours with confirmed calls in Nov	0	0	109	138	
Hours with confirmed calls in Dec	0	0	41	27	
Hours with confirmed calls in Jan 2014	2	0	25	1	

Table 15. Mysticete whale call detections for the southern AURAL during October 2013 to January 2014.

	Blue Whale Tonal Calls	**Blue Whale Arch Calls**	**Fin Whale**	**Humpback Whale**	**Sei Whale**
Total number of files	2,384	2,384	2,384	2,384	2,384
No. of detections	556	2	826	1954	76
No. of detections examined	556	2	398	290	76
No. of true detections	1	1	134	55	0
Proportion of true detections	0.002	0.50	0.34	0.19	0.00
False alarm rate	99.82	50.00	66.33	81.03	100.0
No. of zeros examined	0	0	20	0	3
No. of true zeros (0 or ?)	0	0	17	0	3
Confirmed Calls By Month					
Hours with confirmed calls in Oct	1	1	47	35	0
Hours with confirmed calls in Nov	0	0	69	20	0
Hours with confirmed calls in Dec	0	0	11	0	0
Hours with confirmed calls in Jan 2014	0	0	10	0	0

Table 16. Mysticete whale call detections for the northern AURAL during July to November, 2014.

	Blue Whale Tonal Calls	**Blue Whale Arch Calls**	**Fin Whale**	**Humpback Whale**	**Sei Whale**
Total number of files	1,077	1,077	1,077	1,077	1,077
No. of detections	285	38	2,145	2,145	19
No. of detections examined	285	38	1,500	1,648	19
No. of true detections	16	17	911	142	6
Proportion of true detections	0.06	0.47	0.73	0.08	0.05
False alarm rate	94.39	52.63	26.32	91.38	98.80
No. of zeros examined	0	32	200	0	
No. of true zeros (0 or ?)	0	0	40	0	
Confirmed Calls By Month					
Hours with confirmed calls in Aug	13	15	104	4	1
Hours with confirmed calls in Sept	3	0	198	2	0
Hours with confirmed calls in Oct	0	2	338	72	1
Hours with confirmed calls in Nov	0	0	271	64	0

Table 17. Mysticete whale call detections for the southern AURAL during July to December, 2014.

	Blue Whale Tonal Calls	**Blue Whale Arch Calls**	**Fin Whale**	**Humpback Whale**	**Sei Whale**
Total number of files recorded	830	830	830	830	830
No. of detections	273	193	1,326	1,285	56
No. of detections examined	273	193	1,000	1,659	56
Number of true detections	2	2	929	213	2
Proportion of true detections	0.01	0.15	0.70	0.13	0.04
False alarm rate	99.27	85.78	29.94	87.16	96.43
No. of zeros examined	30	71	243	0	
No. of true zeros (0 or ?)	0	0	39	0	
Confirmed Calls By Month					
Hours with confirmed calls in Aug	0	2	106	1	0
Hours with confirmed calls in Sept	2	0	308	15	2
Hours with confirmed calls in Oct	0	0	257	96	0
Hours with confirmed calls in Nov	0	0	238	101	0

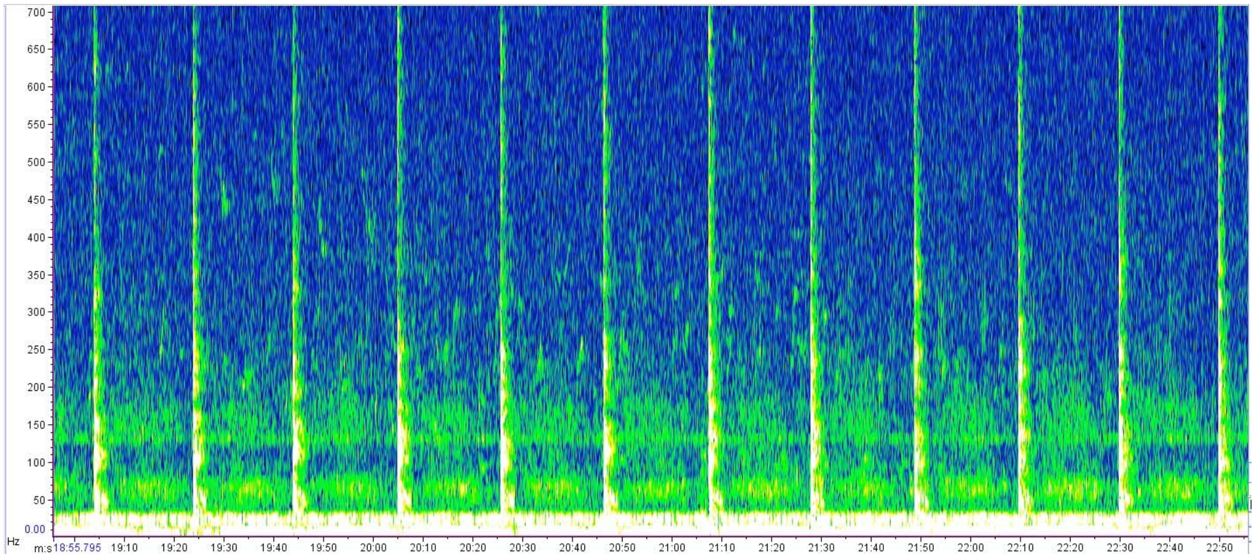

Figure 46. Humpback whale calls (lighter marks) among seismic array pulses (large vertical signals) in 2013.

Like the humpback whale, the AURALs recorded many fin whales in the study area during Fall months (Tables 14 to 17). When muliple fin whales vocalize at 20-25 Hz the autodetection software misses some of the calls as it may be hard to pick up a single 20 Hz pulse among the multiple animals. Seismic shots trigger the autodetection software’s fin whale detector and ship noise will often block the 20-25 Hz frequency range. However, there were occasionally concurrent 130 Hz fin whale pulses that assisted us in manually detecting fin whale presence in recordings (Figure 47). An automated detector for this 130 Hz pulse would benefit analysis of these recordings to counter the low-frequency vessel and other background noise that partially masked fin and blue whale calls. Nonetheless, noise from multiple ships and seismic sources in the summer months of August and September, as well as ship noise at the 130 Hz level throughout the year, make finding fin whale calls more difficult (Figure 48).

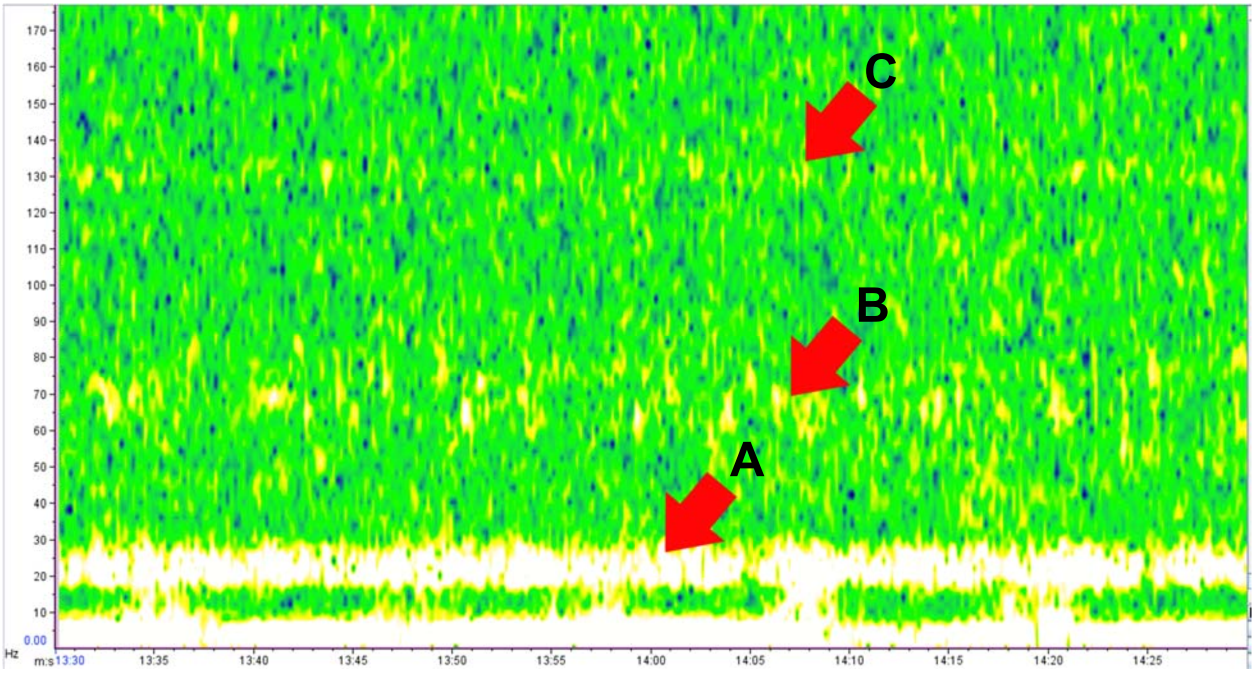

Figure 47. Fin whale calls on November 2013 at the northern AURAL location demonstrate three call types, indicated by red arrows; one set of dominant pulses at 18-25 Hz (A), one at 60-70 Hz (B), and one at 130 Hz (C).

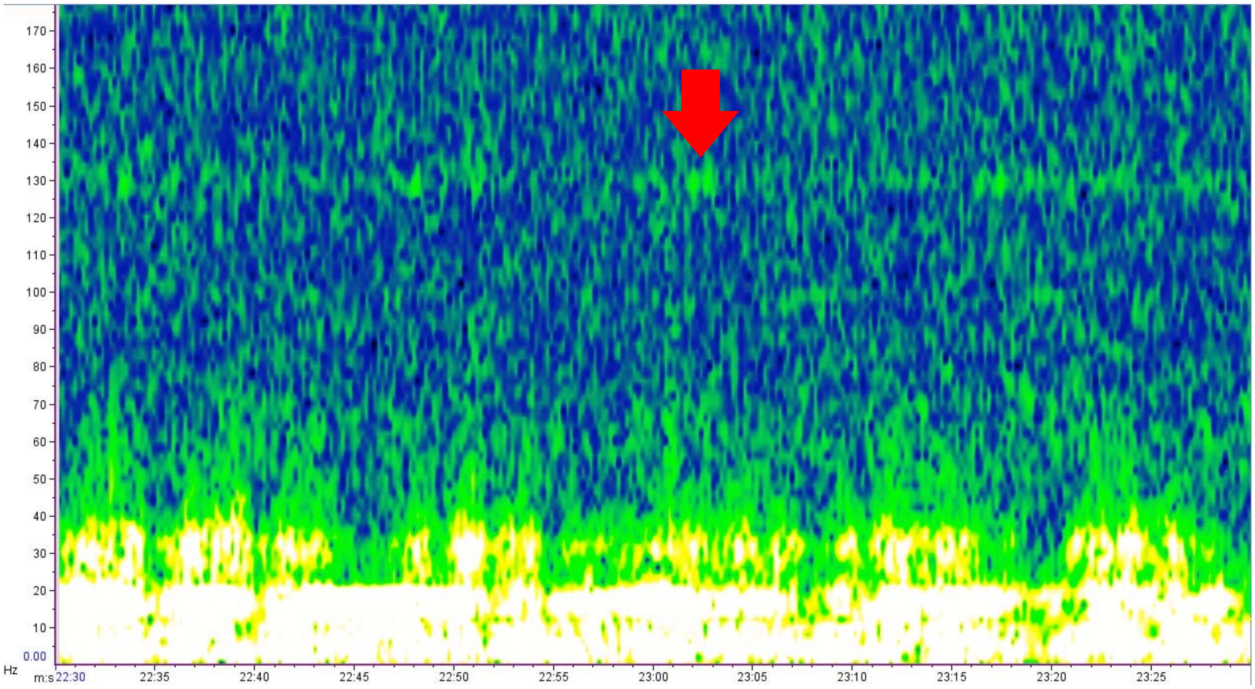

Figure 48. The low-frequency background noise in this AURAL recording sample illustrates conditions that made detecting 20-25 Hz fin whale pulse calls very difficult. However, there were 130 Hz fin whale pulses as well (indicated by red arrow) that assisted us in manually detecting fin whale presence in this recording.

A small number of both tonal and arch calls of blue whales were confirmed in October 2013 and January 2014 (Figure 49), as well as August and September of 2014 (Tables 14 to 17). Without a higher-frequency energy component to their vocalizations, blue whale sound were more likely to be masked by low-frequency shipping and seismic sounds.

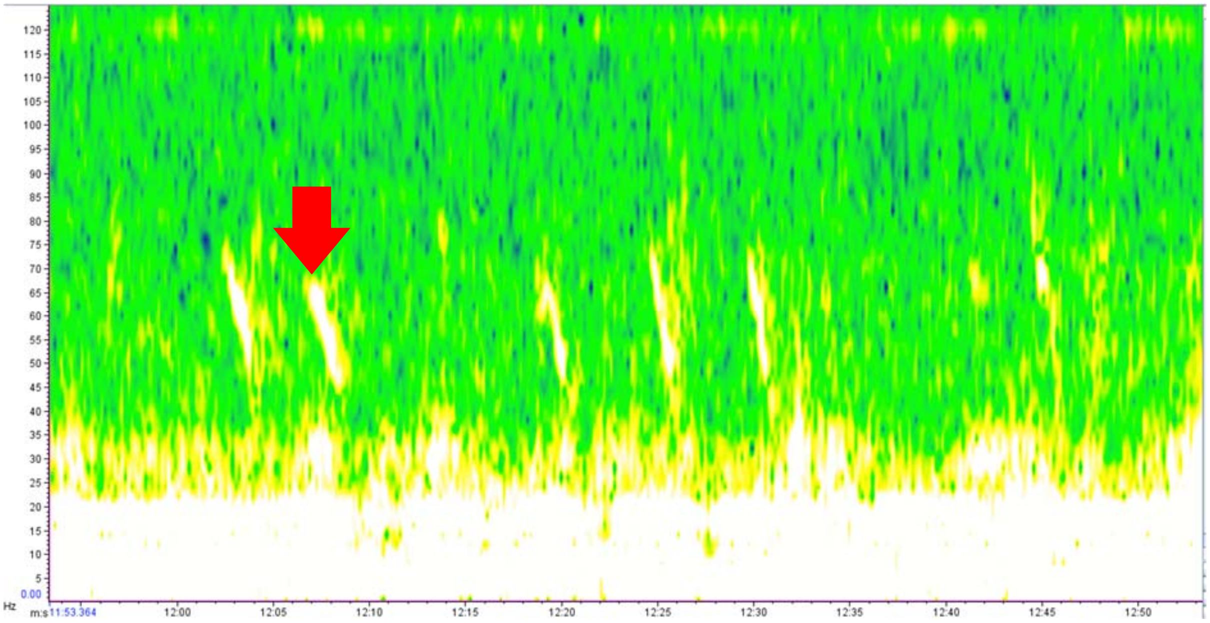

Figure 49. Blue whale D arch calls (one indicated by red arrow) from a subset of the 2013 data that were identified correctly by JASCO's automated detector.

Sei whale calls were confirmed nine times in the data (in August, October, and February; Tables 14 to 17; Figure 50), but have been sighted on the Labrador Shelf in past visual surveys.

Sounds similar to northern right whales triggered the detectors, but when checked manually were found to be classified incorrectly.

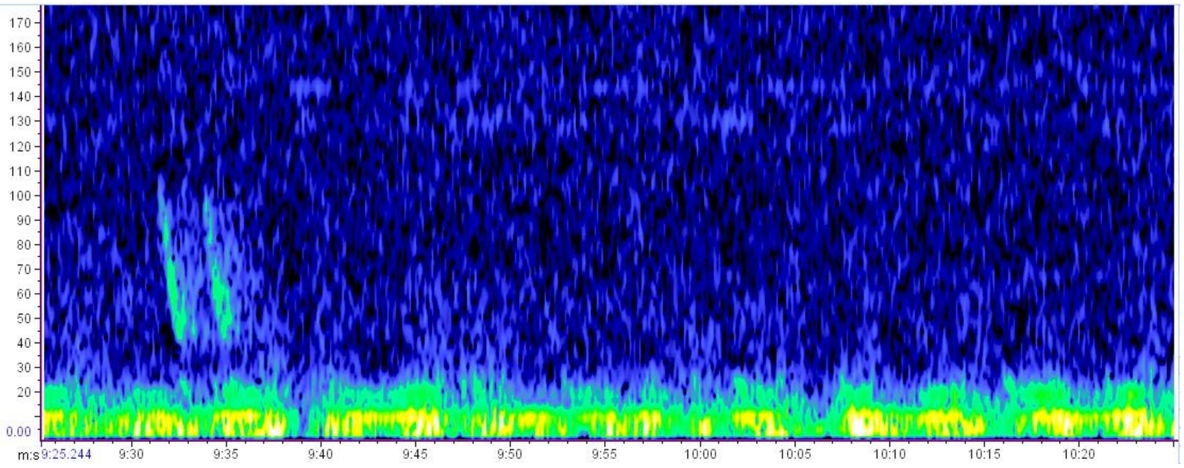

Figure 50. Pair of sei whale down swept calls recorded in October 2014 on the northern AURAL.

6.4.2. Toothed Whale Detection

Detection of toothed whale calls and echolocation was limited by several factors in this study. These higher-frequency sounds do not propagate as far as the low-frequency sounds produced by baleen whales, thus reducing the effective detection range for these sounds by the AURALs. The autodetection software is also falsely triggered by ship sonar and depth sounders, which is a common feature of the underwater soundscape in the study area. The highest-frequency toothed whale echolocation signals (such as by harbour porpoises above 100 kHz) have most of their acoustic energy above the sensitivity range of the AURAL recorders (which detect up to 16 kHz).

Sperm whales were detected by the acoustic recorders, although mooring noise caused false detections (Tables 18 and 19). For the data from the southern AURAL collected in 2014, manual review of files with multiple sperm whale click detections revealed that the JASCO autodetector worked well. Seventy percent of the sperm whale detections were accurate, with false detections being due to mooring noise. On the other hand, in the data from the northern AURAL in 2014, manual review of all files with more than nine sperm whale detections as well as six files with 1-8 detections (totalling 12 files) revealed that none of these contained true sperm whale sounds; the autodetectors were falsely triggered by mooring and/or vessel depth sounder noise. The frequency of sperm whale sounds in dark and light daylight periods was not clearly different (Figure 51). During this study, there were more sperm whales detected during the late Fall, than during the August-September period, or December; 2013 data revealed a similar pattern.

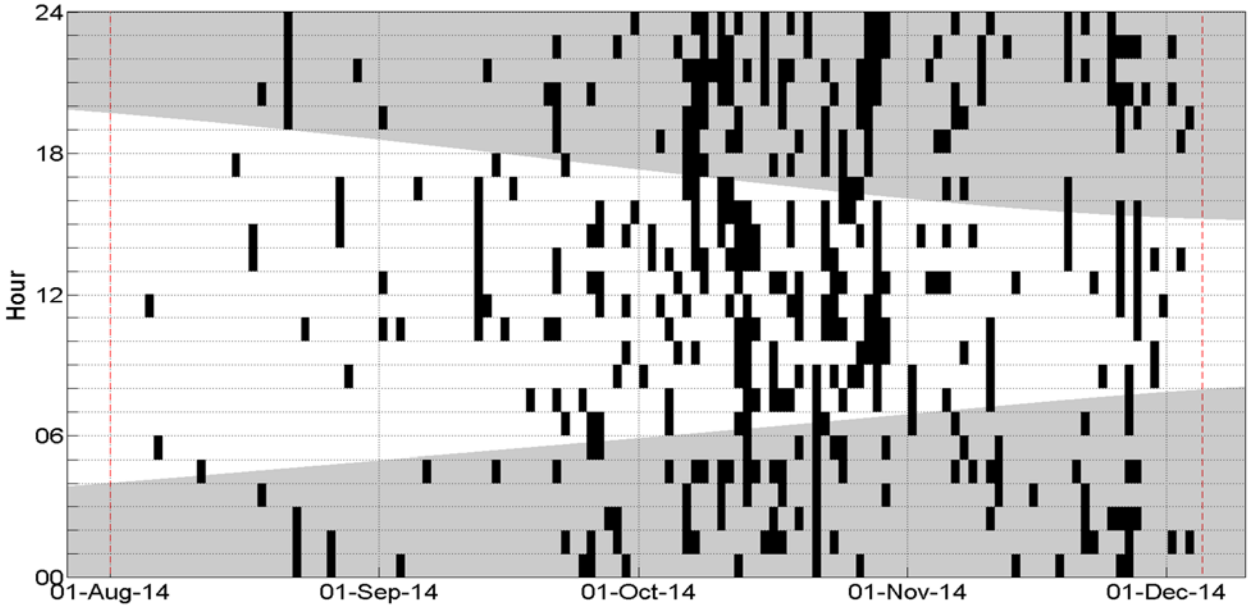

Figure 51. Hourly sperm whale clicks from the southern Labrador AURAL in August to December, 2014. The grey areas indicate hours of darkness and the red dashed lines indicate the limits of the recording period. No confirmed sperm whale sounds were detected in the data from the northern AURAL.

The high-frequency whistles, tonal calls, and echolocation clicks of dolphin species (principally the white-beaked dolphin) were detected by both recorders and in both years. Autodetector false alarm rates were generally less than 20%. Given the short propagation range of these sound types, it is likely the dolphins were within hundreds of metres of the recorders when they were detected. For the white-beaked dolphins, the frequency of detected calls was higher in the Fall than August.

Pilot whales were sighted during the aerial surveys, and detected by the acoustic recorders, although relatively rarely in both cases. The echolocation clicks were detected only once in October and November of 2014 (Tables 18 and 19); this is likely because the recorders were located on the middle of the Labrador Shelf, whereas most pilot whales were sighted on the distant shelf edge. The high-frequency echolocation and call sounds will not propagate far and so would not be detected by the mid-shelf recorders – particularly in the context of the high ambient noise levels in the study area. While investigated manually, the 2013 data revealed a similar pattern.

Killer whale calls were present in the data from the 2014 recorder deployments (Tables 18 and 19) in all months from August to November, although they were not sighted in the aerial visual surveys in 2013 or 2014.

Table 18. Odontocete-type whale call and echolocation detections made using automated systems for the northern AURAL during August to November, 2014. Note that not all of these have been manually checked, so are not the true number of detections.

	Total	Unk Click	Sperm Whale	Killer Whale	Pilot Whale
August	4,876	4,761	113	2	0
September	5,946	5,695	251	0	0
October	10,297	9,947	346	4	0
November	5,746	5,473	267	5	1
Total	**26,865**	**25,876**	**977**	**11**	**1**
Total True			**684**	**14**	**1**

Table 19. Odontocete-type whale call and echolocation detections made using automated systems for the southern AURAL during August to November, 2014. Note that not all of these have been manually checked, so are not the true number of detections.

	Total	Unk Click	Sperm Whale	Killer Whale	Pilot Whale
August	15,430	290	15,131	9	0
September	11,200	213	10,985	2	0
October	69,525	1,157	68,365	3	0
November	22,828	430	22,397	0	1
December	393	20	373	0	0
Total	**119,376**	**2110**	**117,251**	**14**	**1**
Total True			**82,076**	**14**	**1**

6.4.3. Seal Detection

The number of pinniped call detections varied by season. Species that arrived in the study area to reproduce and moult in large numbers, such as harp and hooded seals, were detected mainly in February and March. Then, their calls were often faint as they are not of high amplitude and the seals aggregated far south of the two recorder sites.

Bearded seal calls were detected in recordings of both the north and south AURALs in January, February, and March of 2013 and 2014, although the number of hours with detectable bearded seal calls was much higher in February. This was also the month when hours with detectable shipping noise was highest.

We could not identify the calls of ringed seals, but this may be a function of the high call frequency, the distance to the nearshore ice habitat of wintering ringed seals, and high background noise levels.

7. Cetacean Habitat Suitability Modelling (HSM)

7.1. HSM Modelling Approach for Cetaceans

There are a number of approaches researchers can employ to better understand the distribution of organisms in space and time. And such prediction and delineation of species' distribution can be used to identify important habitat that is most suitable as breeding or foraging grounds, or migratory pathways (for instance: Arkema et al. 2014; Becker et al. 2016; Gomez-Salazar and Moors-Murphy 2014; Gregr et al. 2013; Hammond et al. 2013; Lesage et al. 2017; Roberts et al. 2016; Thorson et al. 2015). By identifying areas that are important to a given species, we can better understand where vulnerability to anthropogenic activities may be increased (e.g., Arkema et al. 2014; Azzellino et al. 2011; Moore et al. 2012; Torres et al. 2013).

Habitat suitability models (HSMs) are one statistical tool that can be used to assess the relationship between species' occurrence data (e.g., sightings or acoustic detections) and environmental variables, and based on the model outputs, subsequently quantitatively predict and delineate species range and distribution (Redfern et al. 2006). HSMs have been used to investigate the distribution of various cetacean species over a variety of spatial scales, from global or ocean basin-wide distribution (such as Kaschner et al. 2006), to medium (e.g., bioregional) and smaller-scales (e.g., local). To provide higher resolution information on species distribution patterns Ingram et al. (2007) used generalized linear models (GLMs) and generalized additive models (GAMs) to evaluate the distribution of minke and fin whales in the Bay of Fundy. However these require information on the effort spent to collect the sightings data and we do not have this for many of the sightings in the DFO database.

As HSMs identify areas where cetaceans are more likely to occur, they have been used to propose key areas for conservation such as critical habitat, marine protected areas, and ecological hotspots (e.g., Cañadas et al. 2005; Gomez et al. 2017; Gregr and Trites 2001; Hooker et al. 1999). Abgrall (2009) used an Ecological Niche Factor Analysis (ENFA) approach to determine if blue, sei (*Balaenoptera borealis*), and fin whale distributions off Newfoundland and Labrador were related to water depth, seabed slope, sea surface temperature, or chlorophyll concentrations. Wheeler et al. (2012) also used an ENFA approach to identify summer and autumn critical habitat for bowhead whales (*Balaena mysticetus*) in the eastern Canadian Arctic using a variety of data sets and considering sea surface temperature, chlorophyll, ice, depth, slope, and distance to shore.

Information on the distribution of cetacean species on the Labrador Shelf has been primarily derived from hand-drawn maps of the maximum range of occurrence that have been developed using qualitative processes based on expert knowledge and sightings information (for an example on the Scotian Shelf, see Breeze et al. 2002). Such methods are biased because they tend to identify habitats primarily in areas that have been surveyed in detail, while areas not surveyed are not well considered (Hamazaki 2002). As they would make the most of the limited information currently available, HSMs are alternative tools for assessing cetacean distribution patterns in the Labrador Shelf region.

We chose to develop MaxEnt spatial distribution models because we have primarily cetacean “presence” data for the northwest Atlantic – locations where a cetacean has been sighted.[4] In locations where we do not have a cetacean sighting record we cannot currently discern if this was due to a cetacean not being present, or there being no survey effort to detect any cetacean species here. MaxEnt (Phillips et al. 2006; Phillips and Dudík 2008) is a modelling approach used to assess the relative suitability of an area for a given species when absence data are not available (e.g., Ananjeva et al. 2015; Bombosch et al. 2014; Elith et al. 2011; Fourcade et al. 2014; Merow et al. 2013; Phillips et al. 2006; Phillips and Dudík 2008; Phillips et al. 2009; Phillips and Elith 2013). In brief, if a sample area has a cetacean detection record of any cetacean species, then search effort was expended there, and the MaxEnt model then assumes that the lack of detection of the species of interest is more likely to represent a real absence of the species of concern from that area.

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[4] “Presence/absence” data results from a systematic survey or acoustic monitoring programme during which all areas are surveyed, and areas where a species was not detected would represent “true absences”; in those cases one could investigate cetacean distribution using General Linear Models (GLMs) or General Additive Models (GAMs).

We used HSMs to predict cetacean distribution on the Labrador Shelf by compiling (1) sightings information for the northwest Atlantic from scientific literature, (2) regional cetacean sightings data collected by visual and acoustic surveys in the study area during this project, and (3) biophysical data collected for the northwest Atlantic from scientific literature and remote sensing platforms. Using these data, HSMs were generated and used to predict suitable habitat for cetaceans off Nova Scotia, Newfoundland, and Labrador (e.g., Gomez et al. in prep). For the purposes of this report, we highlight the area off the eastern coast of Labrador in the presentation of model results. Suitable habitat is interpreted as regions where a given cetacean species has, and would be, more likely to be found, and perhaps where further cetacean monitoring efforts should be prioritized (Gomez et al. 2017) (see §7.3, below).

7.2. Cetacean Sightings Data: Response Variable

We built a database of cetacean sightings that were collected off the Labrador coast during 2013-14 cetacean surveys funded by ESRF, in addition to previous sightings that were collected throughout the northwest Atlantic as part of long-term cetacean monitoring efforts by Environment Canada (EC) and the Department of Fisheries and Oceans (DFO; Table 20). The database includes sightings observed during systematic surveys as well as sightings obtained through platforms of opportunity without effort data. Using all records in the database occurring in summer between 1975 and 2015, we developed and ran MaxEnt habitat suitability models for eleven cetacean species that were sighted during the surveys or detected by the acoustic recorders: blue, fin, humpback, minke, sperm, long-finned pilot, northern bottlenose, and killer whales, plus the smaller harbour porpoise, and common and white-beaked dolphins. We did not model cetacean distribution in the Gulf of St. Lawrence in this study. As there were too few sightings for several species in the fall – either during this study or historically, the MaxEnt models could not be run for those species (e.g., Table 20) (see below).

To account for the fact that target species records in potentially suitable habitat may be absent, but not due to lack of survey effort, we created a sampling bias map. This involved generating a polygon of a defined area adjacent to a sighting of any cetacean species other than the one being modelled. Sightings of cetacean species other than those of particular interest in this study are available, and we term these ‘non-target group species’ (non-TGS). We created a sampling distribution bias map by plotting these non-TGS records within the study area. We considered cells that were within a given radius of a non-TGS record to be ‘surveyed cells’ and used these cells to generate a bias file which provided an *a priori* relative sampling probability (Merow et al. 2013; Phillips et al. 2006). We used non-TGS records to generate bias maps that represent “sampled” areas in the ESRF study area (Figure 52). To explore how these bias maps impacted the SDM results, we ran the model with and without the bias file. We further refined this approach to assess the effect of the scale of the spatial search by adjusting the radius of the surveyed cells to 3 levels: 1, 2.5, and 5 km.

Table 20. Number of sightings per cetacean species, subdivided by season, obtained during this project, and a combination of other data from DFO and the Whitehead Lab (Dalhousie University; see Gomez-Salazar and Moors-Murphy 2014). An asterisk indicates instances with insufficient data for model runs.

Species	**Number of Sightings (ESRF, Labrador)**		**Number of Sightings (Other Sources, Atlantic Canada)**	
	Summer	**Fall**	**Summer**	**Fall**
Blue Whale	0	0	181	41*
Fin Whale	6	8	3,692	1,196
Humpback Whale	15	6	7,457	3,116
Minke Whale	2	3	4,177	675
Common Dolphin	11	0	796	392
Harbour Porpoise	2	3	6,195	980
Killer Whale	0	0	213	70*
Long-finned Pilot Whale	8	4	787	274
Northern Bottlenose Whale	2	0	2,307	164*
Sperm Whale	0	0	583	146*
White-beaked Dolphin	21	17	516	83*

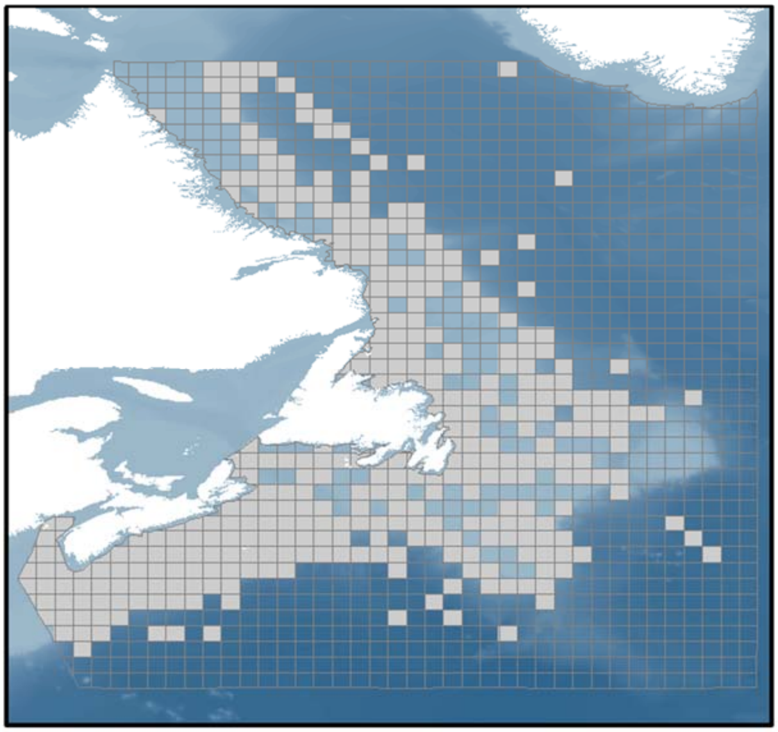


Figure 52. Sampling bias map of all Atlantic Canadian cetacean sightings other than the 11 ESRF study species, termed target group species (TGS). This map was created by plotting TGS records on a 30x60 km grid. Cells that contained non-TGS records were "surveyed cells" and used to generate a bias file which provided an a priori *relative sampling probability in the HSM.*

7.3. Biophysical Data: Predictor Variables

A fundamental component of HSMs is a selected suite of environmental variables that exhibit a spatial relationship with the geographic location of each species, and thus, are useful to predict suitable habitat. Information on the prey of the cetacean species to be modelled is an ideal predictor variable (e.g., Pendleton et al. 2012); however, information about the spatial and temporal distribution of prey of many cetacean species is lacking for the northwest Atlantic. As an alternative, five environmental variables that represent physical and biological conditions in the northwest Atlantic were selected to predict the distribution of chosen cetaceans (Table 21, Figures 53 and 54).

Table 21. Environmental layers selected to predict the distribution of cetaceans on the Labrador Shelf. Seasons were defined as spring (March to May, summer (June to August), and fall (September to November).

Variable	Units	Temporal Resolution	Spatial Resolution	Source
Ocean depth	metres	Static variable	1 km	Oceans and Coastal Management, Maritimes Region, DFO, BIO
Compound topographic index (CTI)[a]	-	Static variable	1 km	Calculated using the Geomorphometry and Gradient Metrics Toolbox version 2.0 in ArcGIS (Evans et al. 2014)
Sea surface temperature (SST)	degrees Celsius	Seasonal (used in model: summer and fall)	1.5 km pixel	Derived from remotely-sensed images of the Moderate Resolution Imaging Spectroradiometer (MODIS) satellite instrument. Seasonal climatologies (2003-2014) were derived from semi-monthly composites (2003-2014). http://www.bio-iob.gc.ca/science/newtech-technouvelles/sensing-teledetection/index-en.php
Areas of persistent high chlorophyll-a concentration ($CHL_{persistence}$)	%	Seasonal (used in model: spring, summer, and fall)	1.5 km pixel	Derived from images obtained from MODIS Aqua satellite (Fuentes-Yaco et al. 2015).
Concentrations of chlorophyll-a ($CHL_{magnitude}$)	mg/m^3	Seasonal (used in model: spring, summer, and fall)	1.5 km pixel	Derived from images obtained from MODIS Aqua satellite (Fuentes-Yaco et al. 2015).

[a]This can be thought of as “rugosity” or bottom roughness.

Maps of chlorophyll persistence and magnitude were produced for three seasons: spring (the time at which locations of cetaceans were gathered for the HSM), summer (to account for the time-lag needed for primary productivity to transfer to top predators), and fall (the period when the ESRF aerial surveys were conducted, and when it was expected that most marine animals would be present in the study area. Ocean depth and CTI predictor layers were used for both fall and summer sightings. For fall sightings, the following predictor layers were also used: summer and fall chlorophyll magnitude, summer and fall chlorophyll persistence, and Fall sea surface temperature. For summer sightings, spring and summer chlorophyll persistence, spring and summer chlorophyll magnitude, and summer sea surface temperature were used.

The number of cetacean sightings available for the fall modelling effort is significantly less than for the summer. In addition, the number of cetacean sightings that were collected prior to this ESRF study, and which fell within the boundaries of the predictive environmental layers, is smaller. This could change in the future if we add CWS, Whitehead Lab, and OBIS sightings (more than 50,000 records), which are beyond the scope of this ESRF study.

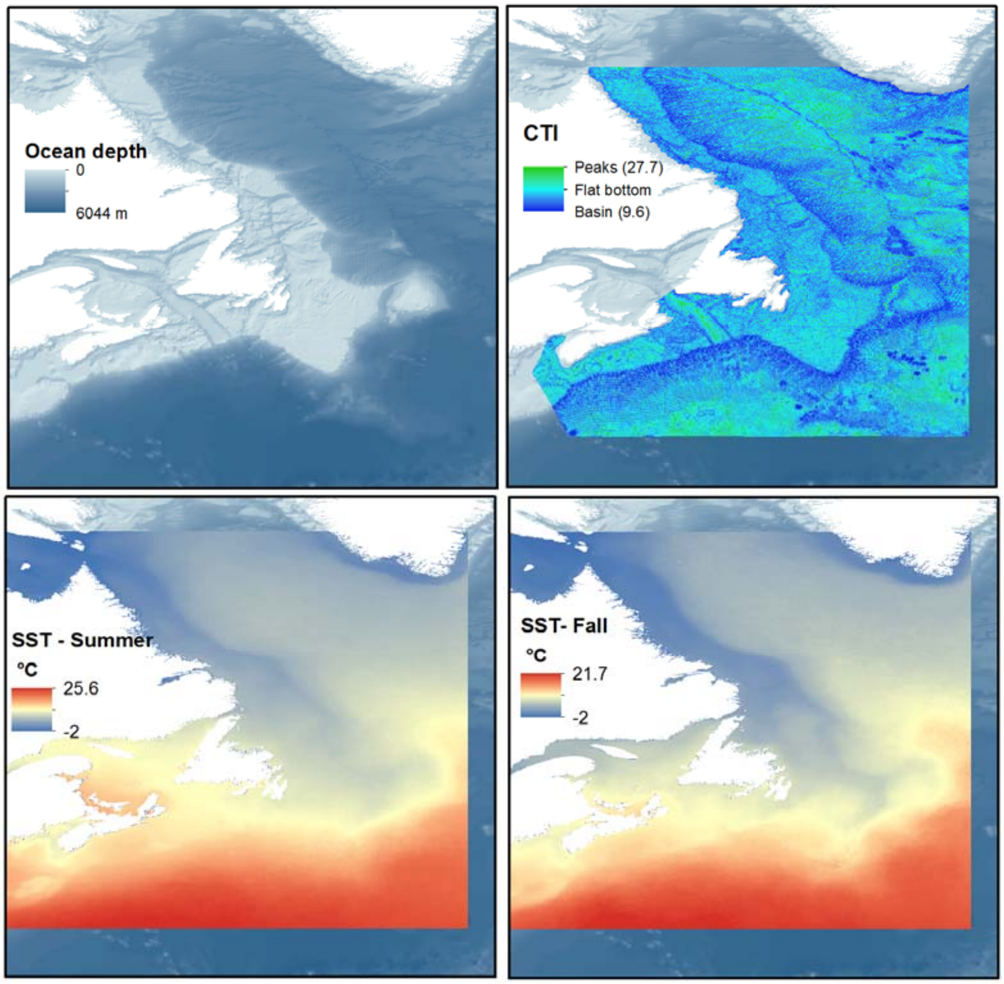


Figure 53. Physical environmental data used to predict the distribution of cetaceans on the Labrador Shelf study area included (upper left) ocean depth (in m), (upper right) compound topographic index (CTI), derived from ocean depth, illustrates the peaks (high numeric values of CTI), basins (low values), and flat surfaces (intermediate values) of the ocean floor (Andersen et al. 2013; Gessler et al. 1995; Moore et al. 1993), (lower left) average water temperature at the sea surface (sea surface temperature, SST) in summer, and fall (lower right).

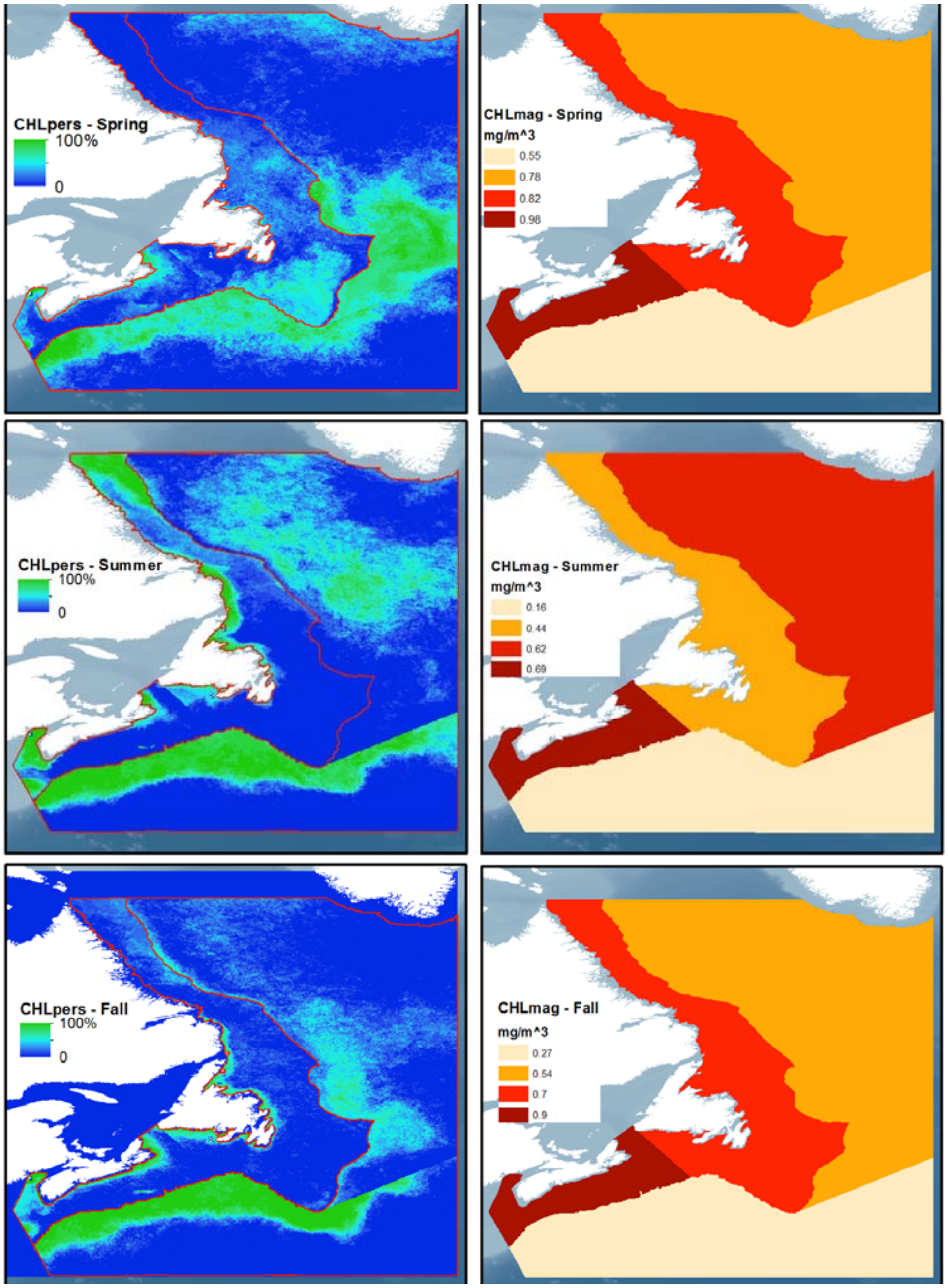


Figure 54. Biological environmental data used to predict the distribution of cetaceans. Data includes areas of persistently high chlorophyll-a concentration (CHLpers) in spring (upper left), summer (middle left), and fall (lower left), and regional concentrations of chlorophyll-a (CHLmagn) in spring (upper right), summer (middle right), and fall (lower right). Maps were produced at three seasonal resolutions: spring, summer (the time at which locations of cetaceans were gathered for the HSM), and fall (given the time-lag needed for primary productivity to transfer to top predators, Croll et al. 2005; Jaquet 1996; Wong 2012).

These biological environmental variables (Figure 54) were proposed recently by Fuentes-Yaco et al. (2015) to provide an indication of primary productivity by identifying and seasonally mapping phytoplankton-rich zones. These zones are detected via remotely-sensed images by locating regions of persistent high chlorophyll-a concentration. For this, the study area was divided in neritic (between 50 and 600 m depth) and oceanic regions (>600m depth), and further divided in north and south following the limits of the divisions 3 and 4 of the Northwest Atlantic Fisheries Organization (which may or may not reflect some biological differences). The procedures used to compute these are presented in Fuentes-Yaco et al. (2015).

7.4. Analytical Methodology To Predict Habitat Suitable For Cetaceans

We use MaxEnt software (version 3.3.3k; www.cs.princeton.edu/~schapire/maxent, Phillips et al. 2006) to build habitat suitability models to predict habitat suitable for different cetacean species. This tool performs comparably to approaches that use species presence locations, and when sample size is relatively small (Elith et al. 2011; Phillips et al. 2006; Tittensor 2013). See Figure 55 for a summary of the approach used to build the HSMs used in this report. MaxEnt incorporates the geographic location of each species presence (presence-only data) and a set of environmental data predictors across the area of study (landscape). MaxEnt then extracts a sample of locations of species presence and a sample of point locations within the landscape; these two locations are contrasted to explore the relative occurrence rate (ROR, Fithian et al. 2015). Given that an individual cetacean was observed, the ROR describes the relative probability of presence of the individual in the landscape (Merow et al. 2013; Phillips et al. 2006). MaxEnt's raw output is interpreted as a ROR. We built and ran separate HSM outputs for 11 target cetacean species using the model settings in Table 22. The raw output was rescaled to range between 0 and 100. This cumulative output was then used to generate habitat suitability maps, which indicate areas that are suitable for the target species of the model (Merow et al. 2013). These maps sort habitat suitability for the target species based on four categories: High (100 - 60%), Medium (60 - 40%), Low (40 - 10%), and Very Low Suitability (<10%) (for an example with similar suitability category ranges, see Ananjeva et al. 2015).

The Area Under the Curve (AUC) metric of the receiver operating characteristic (ROC) plots were used to evaluate the ability of the HSMs to distinguish correctly between sites associated with the target cetacean species' presence and the sample of points from the landscape (Phillips et al. 2006). For this, we selected the cross-validation option in MaxEnt as recommended in Merow et al. (2013) and used the AUC to investigate the probability that a randomly chosen whale presence location was ranked higher than a randomly chosen location in the landscape. An AUC value close to 1.0 indicates that an SDM has good discriminatory power, whereas a value ≤0.5 indicates that model prediction is no better than random (Fielding and Bell 1997).

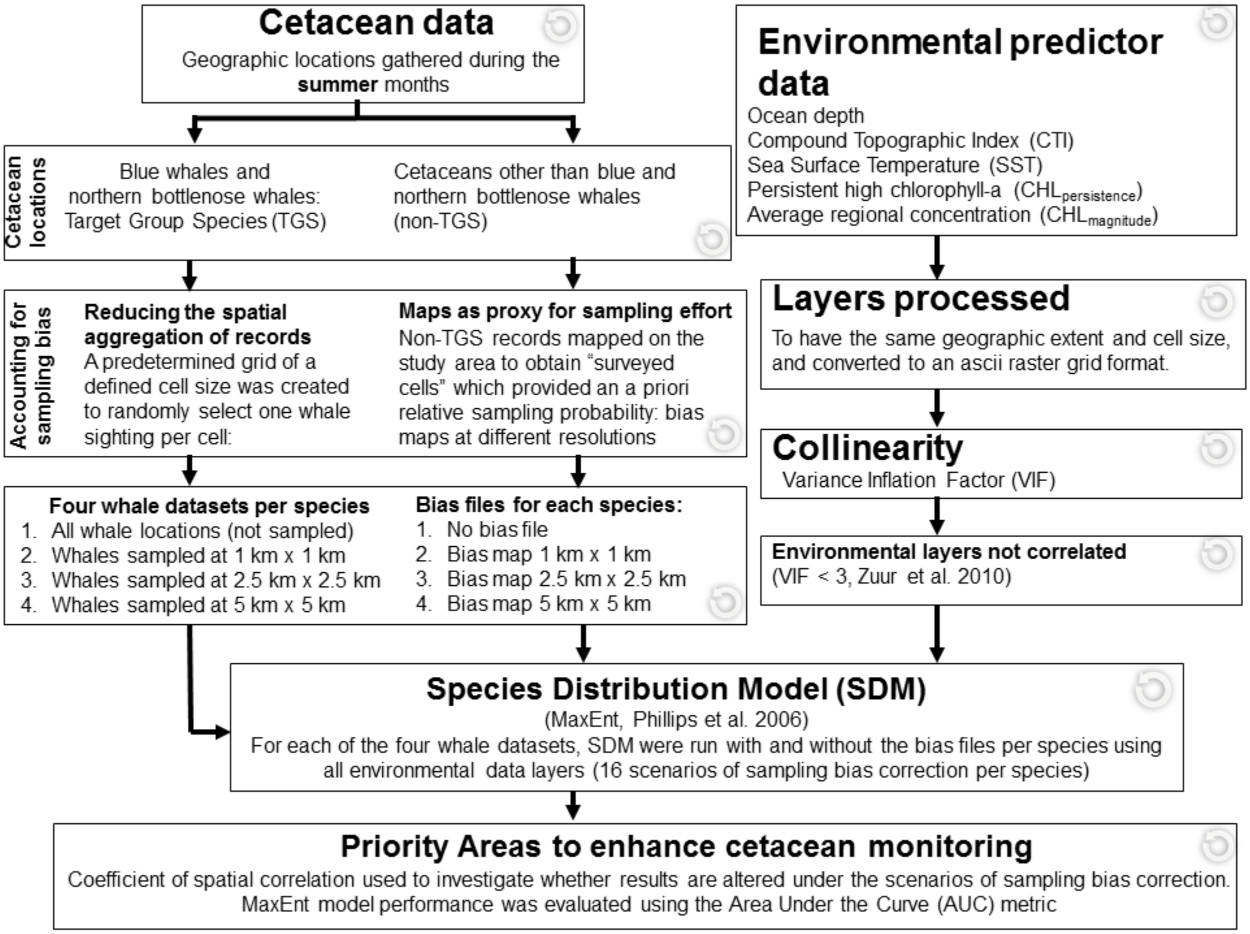


Figure 55. The approach used to build the HSM that predicts suitable habitat for the target species (in this example, blue and northern bottlenose whales) by integrating information about the locations of cetaceans and environmental variables. A bias file was included in the model to account for the fact that target species records in potential suitable habitat may be absent due to lack of survey effort.

Table 22. The MaxEnt model runs were conducted using analysis settings that followed Phillips et al. (2006) and Merow et al. (2013).

Variable	Setting	Comments
Random seed	Yes	A number (or vector) used to initialize the pseudorandom number generator in the MaxEnt model
Maximum number of background points	10,000	A random sample of point locations from the landscape to represent the environmental conditions in the study area
Regularization multiplier	1	Included to reduce over-fitting
Number of replicates	100	Multiple runs for the same species/season provide averages of the results from all models created
Output grids	None	
Maximum iterations	5,000	Allows the model to have adequate opportunity for convergence
Convergence threshold	0.00001	
Replicated run type	Crossvalidate	Assesses uncertainty in model predictions Incorporates all available sightings, thereby making better use of smaller datasets (Merow et al. 2013).
Output type	Cumulative	Does not rely on post-processing assumptions and is useful when illustrating potential species range boundaries (Merow et al. 2013).

7.5. HSM Results - Suitable Habitat For Cetaceans On The Labrador Shelf

7.5.1. Contribution of Biophysical Variables

The environmental variables selected in this study were not correlated and thus were all used in the HSM (as indicated by a Variance Inflation Factor less than 3, Zuur et al. 2010) (Table 23). All models had high AUC values (mean greater than 0.90, suggesting that the SDMs had good discriminatory power, Fielding and Bell 1997) (Table 24). In this study, the results of the HSM are interpreted as indicators of locations where future monitoring efforts should be enhanced, rather than the most precise occurrence distribution of target cetacean species in the Labrador Shelf study area. This is because there is a the lack of survey effort in significant portions of the northwest Atlantic (particularly in deep water beyond the shelf break) and there is a lack of a randomized sampling design because most cetacean sightings are collected through platforms of opportunity (Gomez-Salazar and Moors-Murphy 2014); the SDM outputs should be considered as plausible predictions, until more dedicated survey effort and model validation becomes available.

Table 23. Variance Inflation Factor (VIF) used to investigate collinearity between environmental variables. $CHL_{magnitude}$ is comprised of only four values, one for each region, thus is not included in this analysis.

Environmental Variable	VIF
Ocean Depth	1.61
CTI	1.41
SST summer	1.44
$CHL_{persistence}$ (summer)	1.58
$CHL_{persistence}$ (spring)	1.80

Table 24. Area Under the Curve (AUC) metrics of the receiver operating characteristic (ROC) plot used to evaluate the ability of the SDM to discriminate correctly between sites associated with cetacean presence and the sample of points from the landscape (Phillips et al. 2006). An AUC value close to 1.0 indicates that the SDM has good discriminatory power; a value less than or equal to 0.5 indicates that the model prediction is no better than random (Fielding and Bell 1997).

Species	AUC (SD)		Number of Training Samples	
	Summer	**Fall**	**Summer**	**Fall**
Blue Whale	0.9161 (0.047)	-	149.49	-
Fin Whale	0.7931 (0.060)	0.8441 (0.064)	1,173.15	586.08
Humpback Whale	0.7806 (0.041)	0.8238 (0.049)	2079	1,247.40
Minke Whale	0.8224 (0.059)	0.7940 (0.090)	1,037.52	407.88
Sperm Whale	0.889 (0.053)	0.8133 (0.551)	435.6	139.59
Northern Bottlenose Whale	0.896 (0.052)	-	416.79	-
Long-finned Pilot Whale	0.7781 (0.074)	0.8195 (0.075)	729.63	267.30
Killer Whale	-	-	-	-
Harbour Porpoise	0.9038 (0.039)	0.9120 (0.048)	831.60	376.20
Common Dolphin	0.8243 (0.066)	0.7595 (0.091)	549.45	316.80
White-beaked Dolphin	0.8289 (0.071)	-	430.65	-

The relative contributions of the environmental variables to the MaxEnt model results for each of the selected species are given in Table 25, for the summer (June to August), and in Table 26 for the fall (September to November). For the summer period, sea surface temperature provided the greatest contribution for blue whales, common dolphins, long-finned pilot whales, northern bottlenose whales, and white-beaked dolphins (41-52% for these species). Ocean depth had the greatest contribution for humpback whales (49%) and sperm whales (63%), and was also significant for long-finned pilot whales (40%) and northern bottlenose whales (41%). Summer chlorophyll persistence had the greatest contribution for harbour porpoises (36%) and fin whales (32%), while summer chlorophyll magnitude had the greatest contribution for minke whales (35%). For the fall period, sea surface temperature was again important since it provided the greatest model contribution for humpback whales, common dolphins, and long-finned pilot whales (38-43% for these species). Ocean depth had the greatest contribution for minke whales (27%) and sperm whales (49%), and was also significant for long-finned pilot whales (38%). Summer chlorophyll persistence had the greatest contribution for fin whales (31%), but not in the fall for any other species, while summer chlorophyll magnitude had the greatest contribution for minke whales in the fall model (27%). Harbour porpoise models were driven mostly by fall chlorophyll magnitude (33%).

Table 25. Analysis of the relative contributions of the environmental variables to the MaxEnt models for the summer months (June to August). The greatest contribution for each species is indicated by ***bolded*** *values*

Species	Ocean Depth	CHL_{mag} Spring	CHL_{mag} Summer	CHL_{pers} Spring	CHL_{pers} Summer	SST Summer	CTI
Blue Whale	16.71	2.62	4.63	2.83	17.93	**52.06**	3.22
Fin Whale	14.59	13.06	17.74	1.54	**32.71**	18.97	1.40
Humpback Whale	**49.24**	1.41	2.229	1.99	17.68	26.38	1.02
Minke Whale	24.83	8.12	**34.54**	20.23	12.26	18.88	1.14
Sperm Whale	**62.77**	1.31	2.04	2.82	1.41	18.55	11.10
N. Bottlenose Whale	**40.80**	0.72	1.14	1.27	1.49	**48.03**	6.55
Long-finned Pilot Whale	40.21	7.60	6.36	2.07	1.08	41.29	1.40
Killer Whale	**52.14**	3.94	12.03	3.74	6.44	15.03	6.69
Harbour Porpoise	4.17	18.12	28.36	1.28	**36.18**	11.44	0.45
Common Dolphin	21.10	3.17	4.05	3.12	0.42	**51.59**	16.57
White-beaked Dolphin	34.04	0.11	0.76	9.35	8.63	**44.12**	3.00

Table 26. Analysis of the relative contributions of the environmental variables to the MaxEnt models for the fall months (September to November). The greatest contribution for each species is indicated by ***bolded*** *values.*

Species	Ocean Depth	CHL_{mag} Fall	CHL_{mag} Summer	CHL_{pers} Fall	CHL_{pers} Summer	SST Fall	CTI
Fin Whale	22.27	8.259	18.85	1.79	**30.70**	17.06	1.08
Humpback Whale	27.93	16.05	1.67	1.52	15.11	**37.59**	0.14
Minke Whale	**27.28**	3.68	**27.38**	1.89	19.33	16.63	3.81
Sperm Whale	**48.75**	0.15	15.47	2.47	4.93	24.56	3.67
Long-finned Pilot Whale	37.92	8.72	1.27	6.36	1.64	38.91	5.18
Harbour Porpoise	4.24	**32.91**	9.68	1.34	26.42	24.88	0.54
Common Dolphin	38.88	2.99	3.97	1.88	7.89	**43.35**	1.04

The rugosity (bottom roughness) (CTI) of the sea bottom did not contribute significantly to the MaxEnt models for any of the species we investigated. This may be a function of the dietary habits for these species – most of which forage in the upper to mid-water depths – or that the other environmental variables were so much more important.

7.5.2. Habitat Suitability Maps For Selected Cetaceans - Summer

For the summer period (June to August), maps of habitat suitability within the northwest Atlantic were created for each cetacean species selected in this study, and for which there was sufficient sample sizes and environmental data. These maps indicate areas categorized by the MaxEnt approach as habitat of high, moderate, low and very low suitability along the Labrador coast (Figures 56 to 67). The maps also include the location of significant discovery and exploration licenses associated with oil and gas exploration and production are indicated with a blue polygon {some of these licenses have since been relinquished, and some new bids have opened for southern Labrador (not mapped here); data obtained from the Canada-Newfoundland and Labrador Offshore Petroleum Board (C-NLOPB). The locations of the deployments of two AURAL acoustic recorders are indicated on each map as well (*).

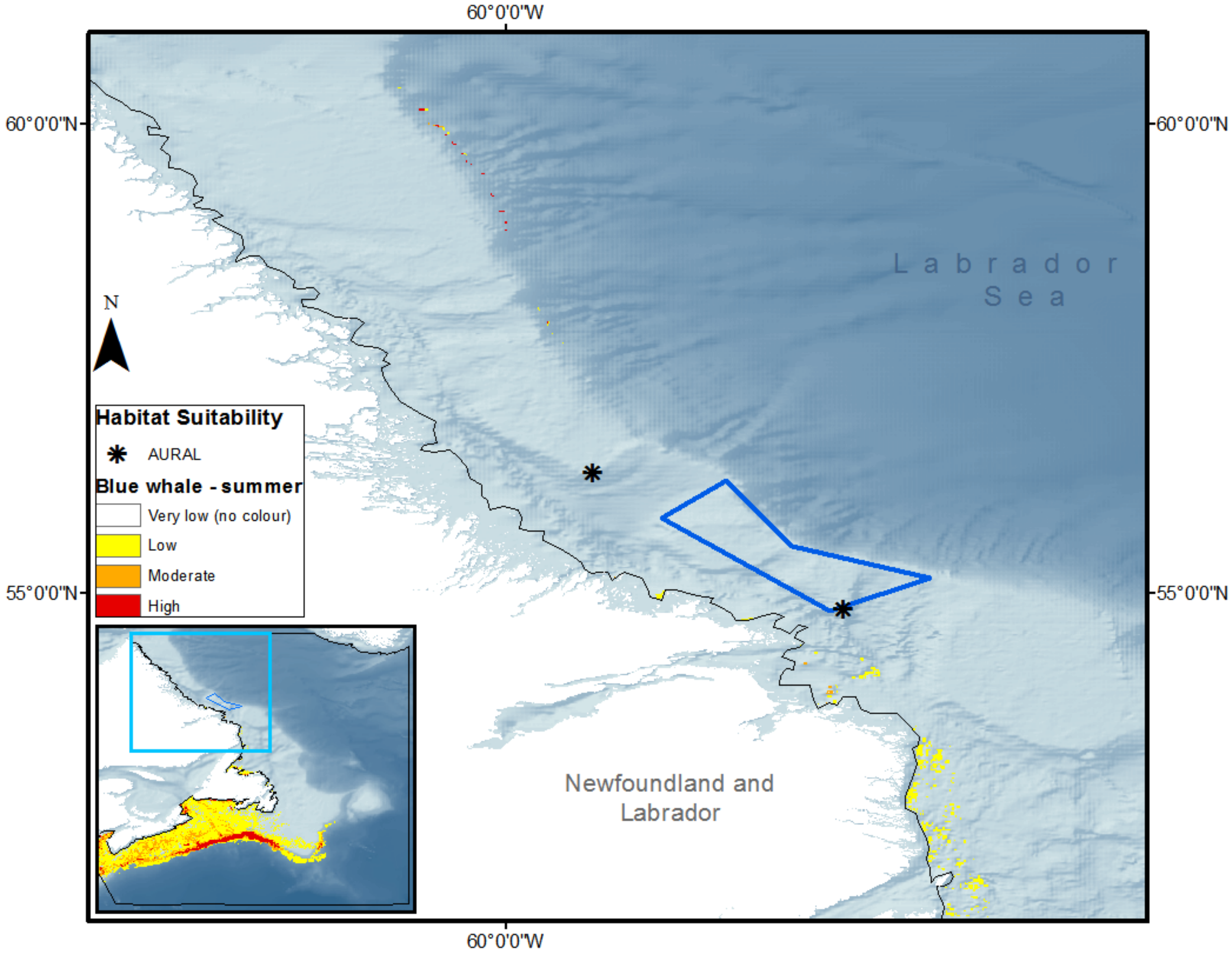


Figure 56. A map illustrating the apparent absence of suitable habitat along the Labrador coast for blue whales in the summer period. The inset map shows the modelled suitable summer habitat for blue whales for all Canadian Atlantic waters.

The habitat suitability modelling for blue whales (Figure 56) suggests that the ESRF study area, and in fact the entire Labrador Shelf, is generally not highly suitable habitat for this species during the summer, except for minor nearshore areas on the southern Labrador coast. The continental shelf breaks further south have much higher suitability for this species during the summer (for a recent Atlantic summary of blue whale habitat mapping see also Moors-Murphy et al. 2016).

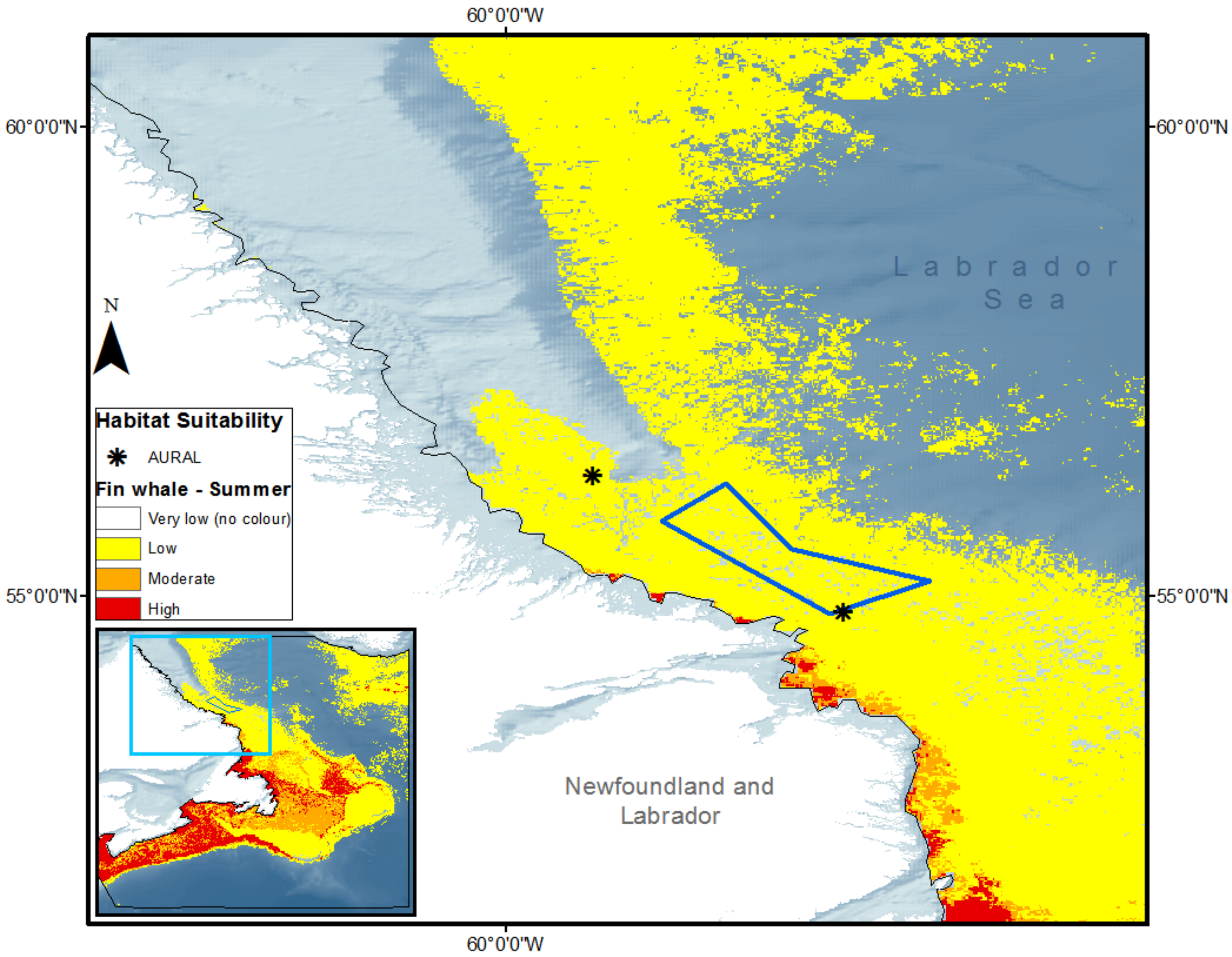


Figure 57. Areas of suitable habitat along the Labrador coast for fin whales in the summer period. The inset map shows the modelled suitable summer habitat for fin whales for all Canadian Atlantic waters.

The habitat suitability modelling for fin whales suggests that the ESRF study area and most of the outer Labrador Shelf does not contain highly suitable habitat for this species during the summer (Figure 57). Although fin whales were sighted during the aerial surveys and detected by the acoustic recorders, the most suitable fin whale habitat appears to lie close to the southern Labrador coastal margin, to the west of Harrison and Hamilton Banks. Similar to blue whales, highly suitable summer habitat for fin whales occurs on large portions of the Grand Banks and most of the Scotian Shelf.

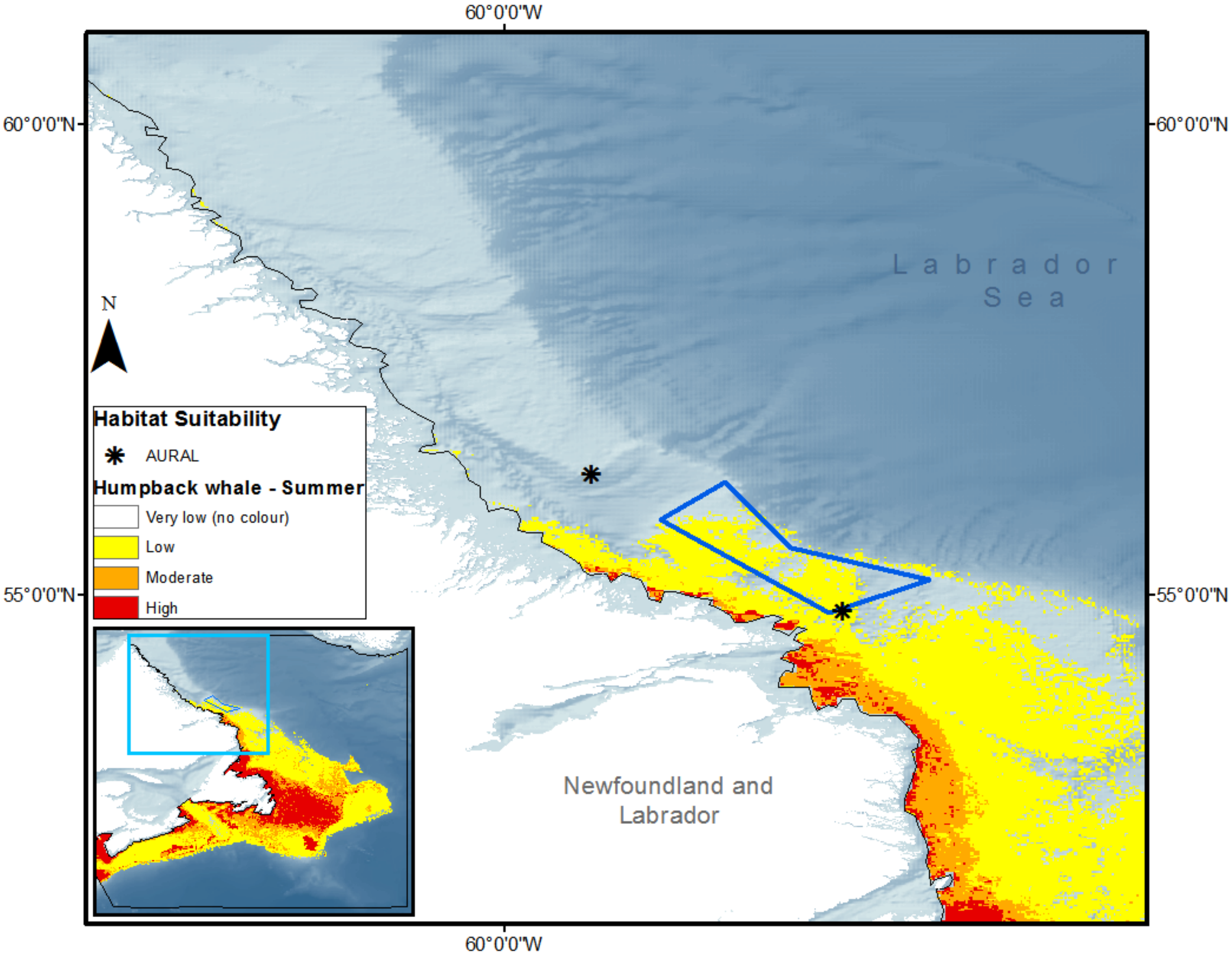


Figure 58. Areas of suitable habitat along the Labrador coast for humpback whales in the summer period. The inset map shows the highly suitable summer habitat for humpback whales for all Canadian Atlantic waters.

The habitat suitability modelling for humpback whales suggests that, as for fin whales, the ESRF study area and most of the outer Labrador Shelf is not highly suitable habitat for this species during the summer (Figure 58). Although they were sighted during the aerial surveys and detected frequently by the acoustic recorders, the most suitable humpback whale habitat appears to lie close to the southern Labrador coastal margin, west of Hamilton Bank. Similar to results for blue and fin whales, large portions of the Grand Banks and the margins of the Scotian Shelf have highly suitable summer habitat for this species.

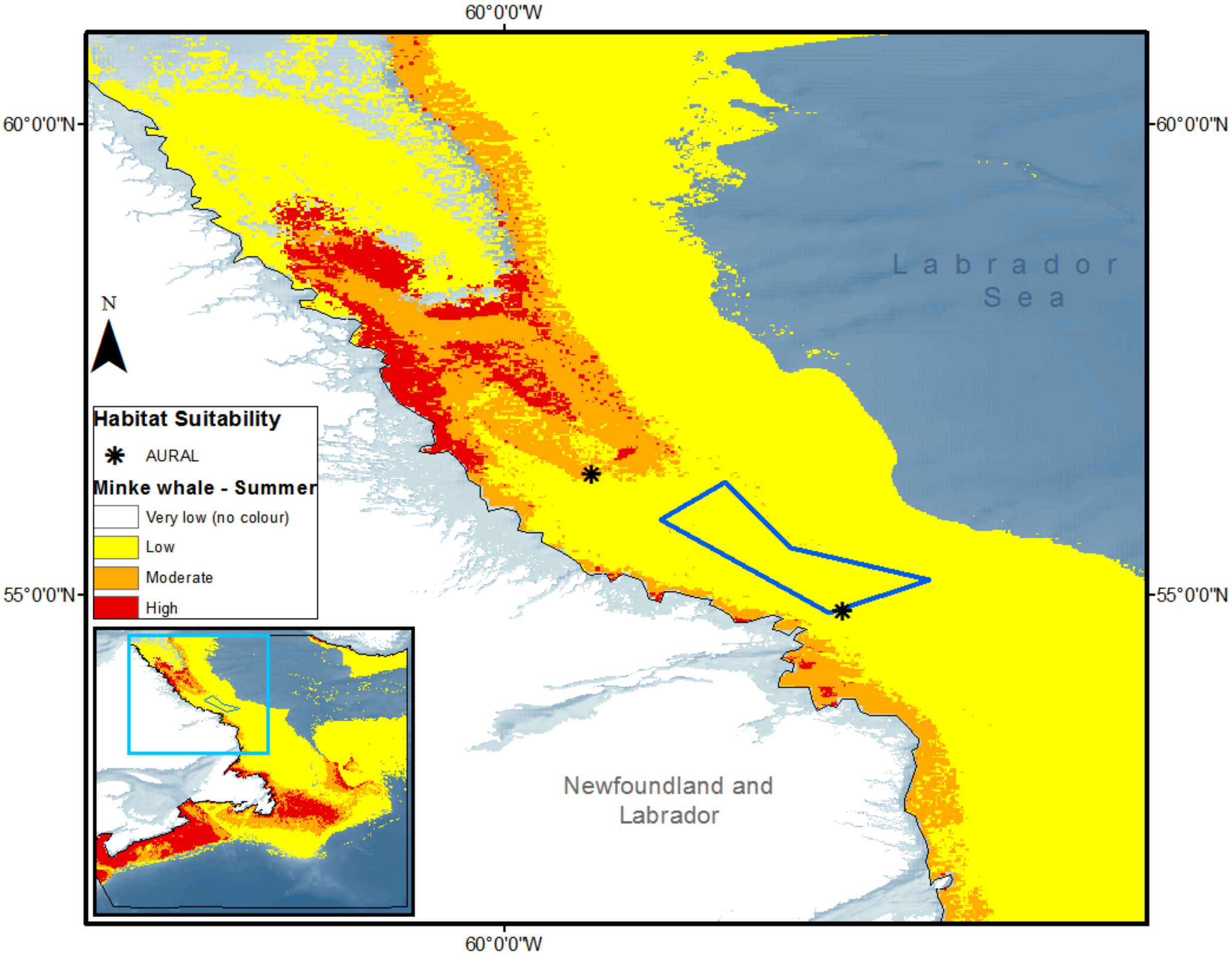


Figure 59. Areas of suitable habitat along the Labrador coast for minke whales in the summer period. The inset map shows the highly suitable summer habitat for minke whales for all Canadian Atlantic waters.

The habitat suitability modelling for minke whales suggests that while the ESRF study area is not highly suitable habitat for this species during the summer, the Labrador Shelf to the north (e.g., Nain Bank) does contain highly suitable habitat for this species. Some of this is associated with subsea channel margins (Figure 59). Although they were sighted during the aerial surveys and detected by the acoustic recorders, suitable minke whale habitat also exists close to the southern Labrador coastal margin, as it does for fin and humpback whales (Figures 57 and 58). Similar to results for larger baleen whales, large portions of the Grand Banks and the Scotian Shelf have highly suitable summer habitat for minke whale.

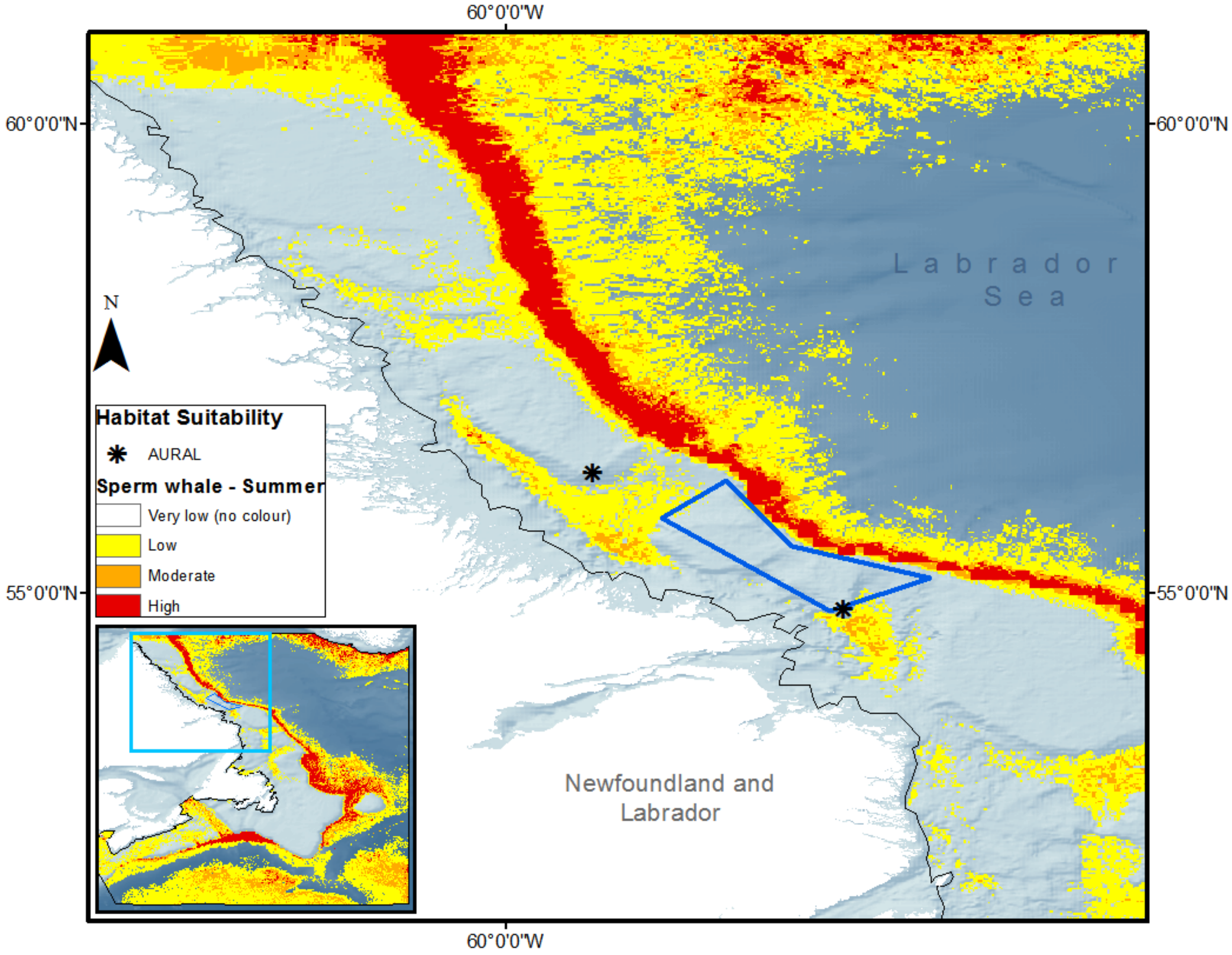


Figure 60. Areas of suitable habitat along the Labrador coast for sperm whales in the summer period. The inset map shows the highly suitable summer habitat for sperm whales for all Canadian Atlantic waters.

As expected based on their deep-diving foraging ecology, the habitat suitability modelling for sperm whales suggests that the offshore margin of the ESRF study area is more suitable than the inshore margin for this species during the summer, with the Labrador Shelf edge and deeper subsea channels (e.g., Hopedale and Cartwright Saddles) encompassing highly suitable habitat (Figure 60). Although they were sighted during the aerial surveys and detected by the acoustic recorders on the Labrador Shelf in Oct-Nov (so not the summer period modelled here), a lower proportion of suitable sperm whale habitat exists close to the southern Labrador coast. The waters at the shelf breaks of the Grand Banks, the Laurentian Channel mouth, and the Scotian Shelf also have highly suitable summer habitat for sperm whales.

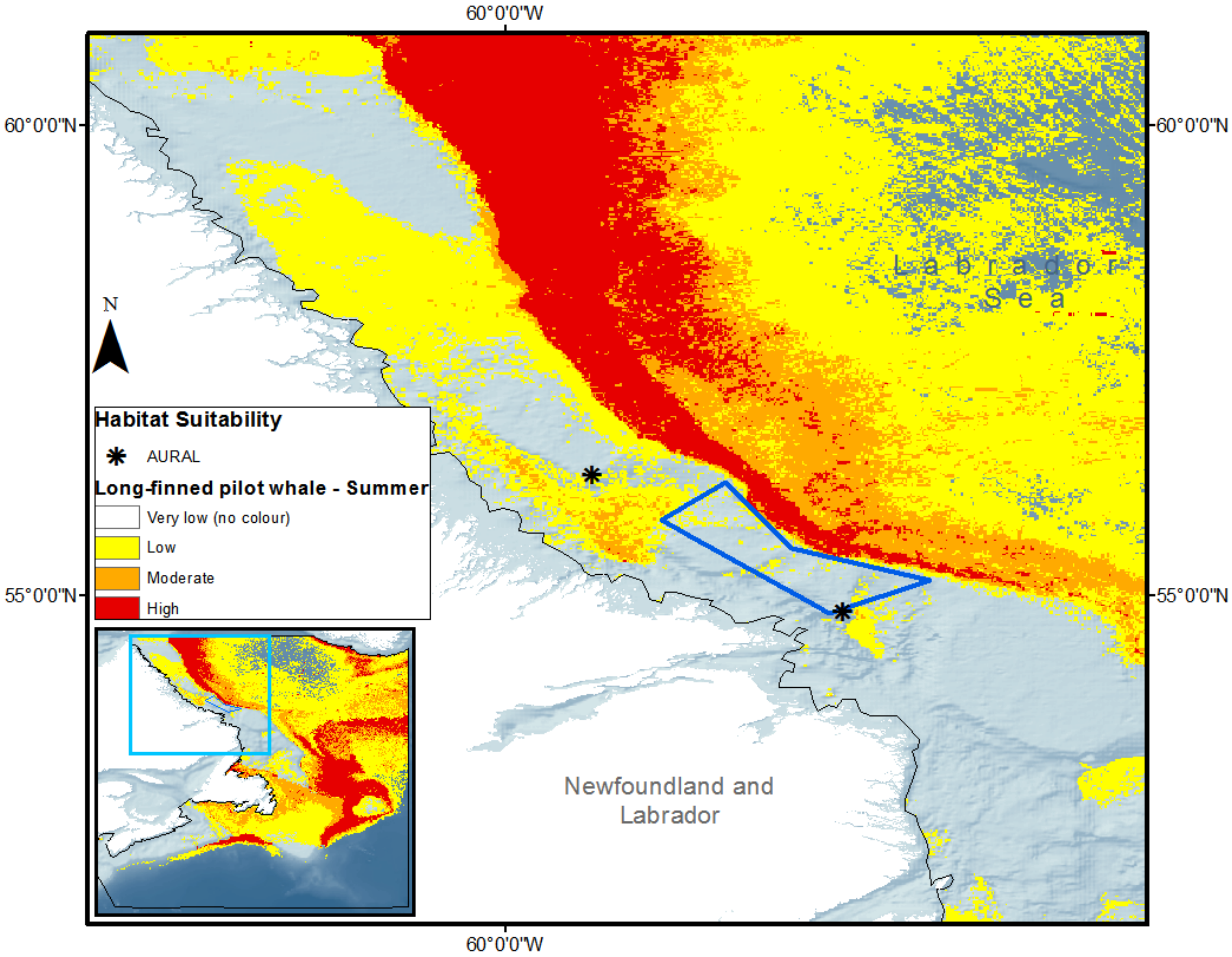


Figure 61. Areas of suitable habitat along the Labrador coast for long-finned pilot whales in the summer period. The inset map shows the highly suitable summer habitat for pilot whales for all Canadian Atlantic waters.

Similar to results for sperm whales, the habitat suitability modelling for long-finned pilot whales suggests that the offshore margin of the ESRF study area is more suitable than inshore for this species during the summer, with the Labrador Shelf edge encompassing highly suitable habitat (Figure 61). Although they were sighted during the aerial surveys and detected by the acoustic recorders, a low proportion of suitable pilot whale habitat exists closer to the southern Labrador coast, aside from the region northwest of Makkovik Bank. The waters at the shelf breaks of the Grand Banks, Flemish Cap, Laurentian Channel mouth, and the Scotian Shelf also have highly suitable summer habitat for pilot whales.

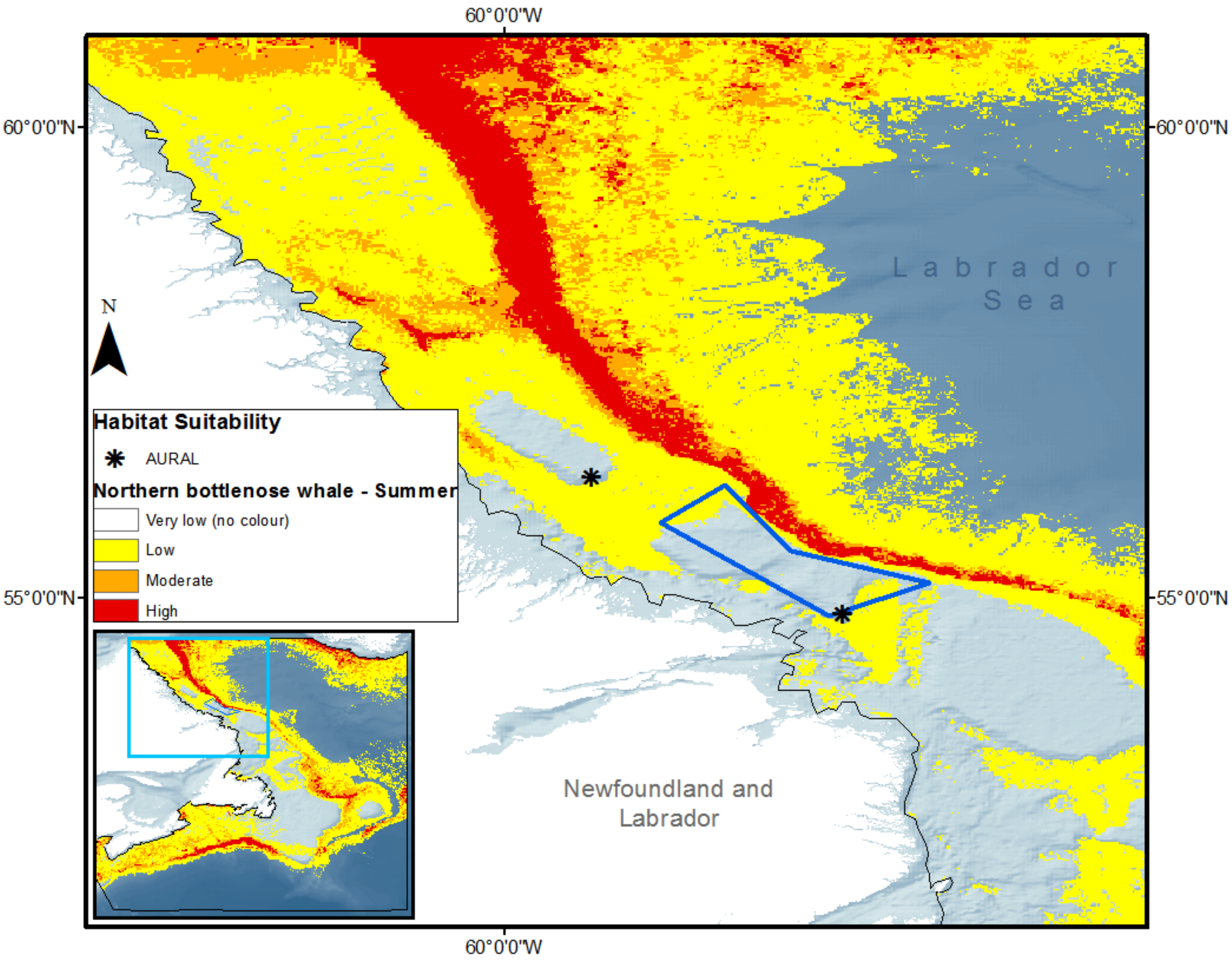


Figure 62. Areas of suitable habitat along the Labrador coast for northern bottlenose whales in the summer period. The inset map shows the highly suitable summer habitat for northern bottlenose whales for all Canadian Atlantic waters.

Similar to the results for sperm whales (Figure 61), the habitat suitability modelling for northern bottlenose whales suggests that the offshore margin of the ESRF study area is more suitable than nearshore for this species during the summer, with the Labrador Shelf edge encompassing highly suitable habitat (Figure 62). They were sighted during the aerial surveys and likely detected by the acoustic recorders. The waters at the shelf breaks of the Grand Banks, Flemish Cap, Laurentian Channel mouth, and the Scotian Shelf also have highly suitable summer habitat for this species.

Note that the northern bottlenose sightings off northern Labrador were made during historic whaling operations there, and by deep-sea fishing vessels recently, so to some extent these are driving the larger area of high suitability offshore of northern Labrador.

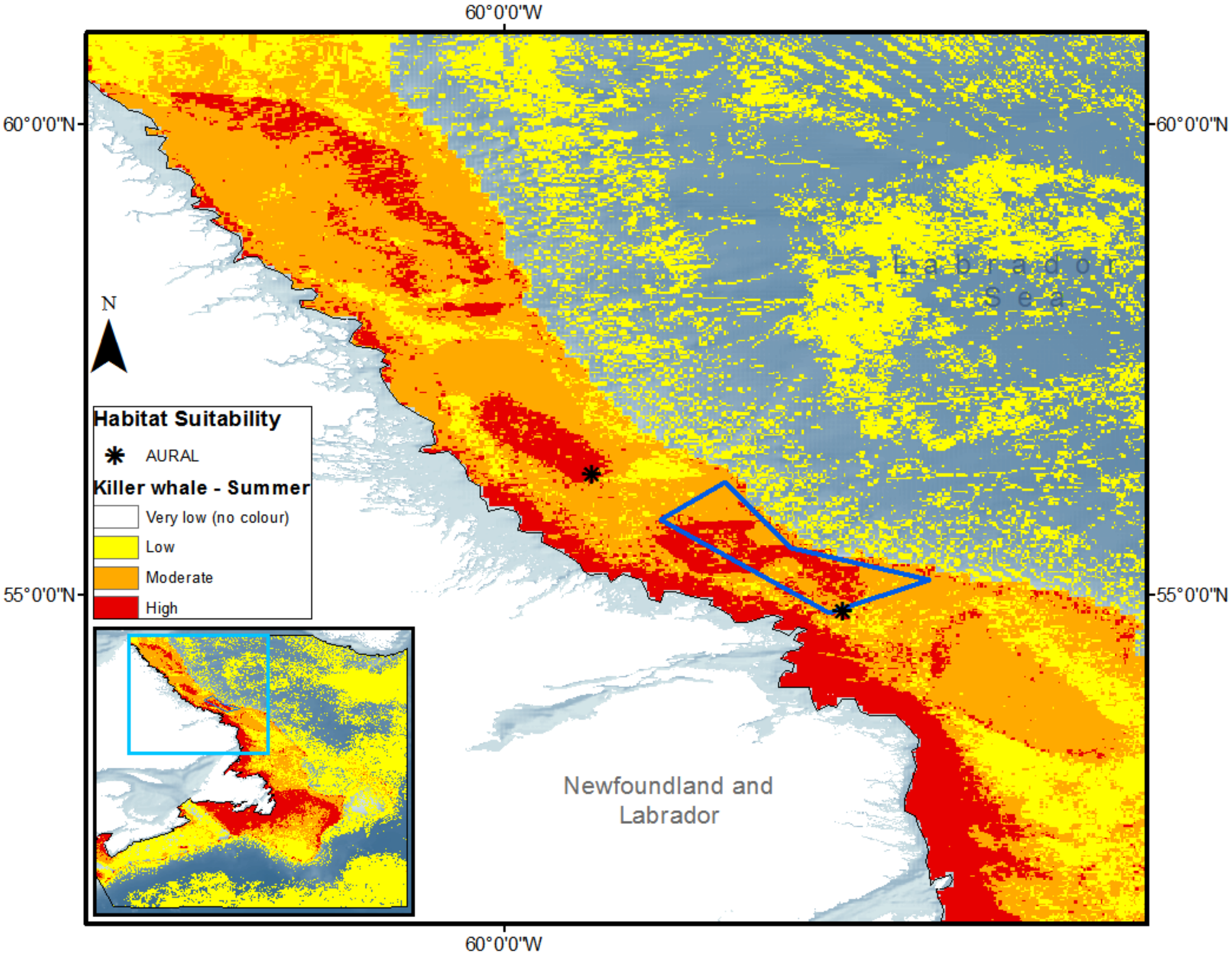


Figure 63. Areas of suitable habitat along the Labrador coast for killer whales in the summer period. The inset map shows the highly suitable summer habitat for killer whales for all Canadian Atlantic waters.

Killer whales were not sighted during the visual surveys (not surprising given their small population; Lawson and Stevens 2013), but the habitat suitability modelling for these whales suggests that much of the ESRF study area is highly suitable habitat for this species during the summer (Figure 63). The most suitable killer whale habitat appears to lie close to the Labrador coastal margin, and on the mid-shelf banks. Large portions of the Grand Banks have highly suitable summer habitat for this apex predator.

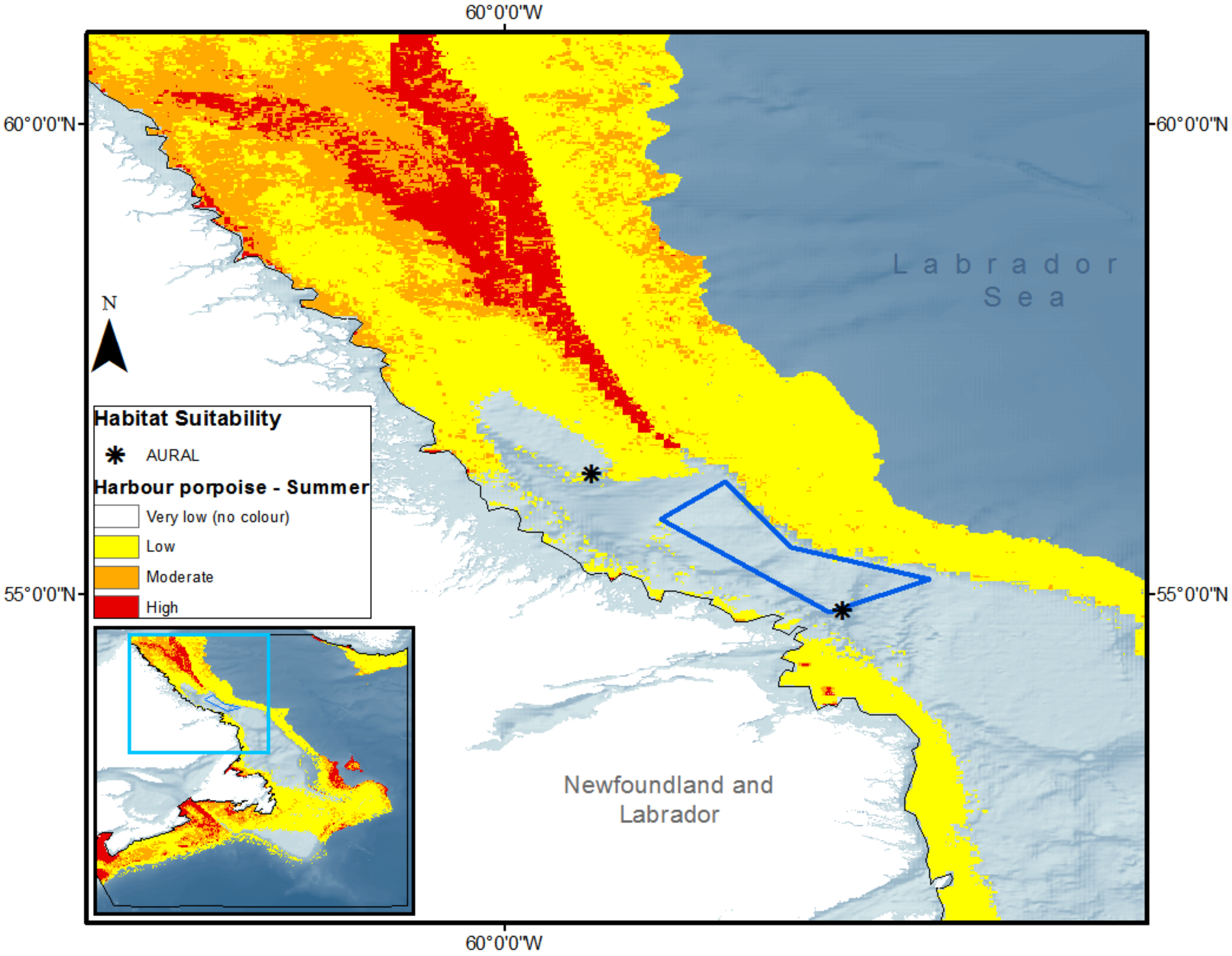


Figure 64. Areas of suitable habitat along the Labrador coast for harbour porpoises in the summer period. The inset map shows the highly suitable summer habitat for harbour porpoises for all Canadian Atlantic waters.

The habitat suitability modelling for harbour porpoises (Figure 64) suggests that much of the ESRF study area does not encompass highly suitable habitat for this species during the summer. The Labrador Shelf to the northeast of Nain Bank does contain highly suitable habitat for this species, despite its general categorization as a “coastal species” further south in Atlantic Canada. This species was sighted during the aerial surveys, but was likely not detected by the AURAL acoustic recorders sampling at lower acoustic frequencies. Suitable harbour porpoise habitat also exists close to the southern Labrador coastal margin, as it does for fin and humpback whales (Figures 57 and 58).

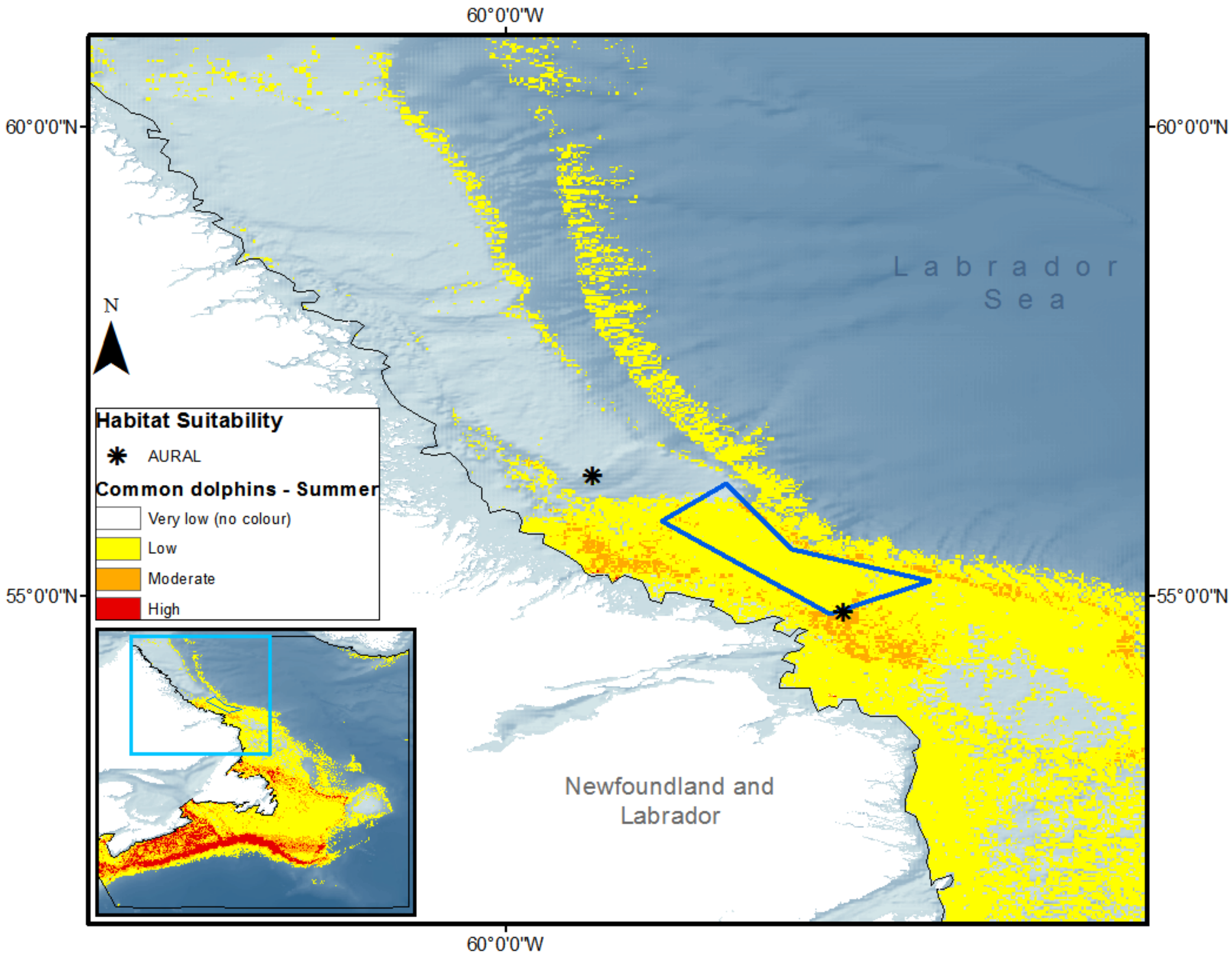


Figure 65. Areas of suitable habitat along the Labrador coast for common dolphins in the summer period. The inset map shows the highly suitable summer habitat for common dolphins for all Canadian Atlantic waters.

The habitat suitability modelling for common dolphins suggests that the ESRF study area does not include highly suitable habitat for this species during the summer. They were sighted during the aerial surveys and detected by the acoustic recorders. Small areas of highly suitable common dolphin habitat exists along the Labrador Marginal Trough (Figure 65). Similar to results for larger baleen whales, large portions of the Grand Banks shelf margins and the Scotian Shelf have highly suitable summer habitat for common dolphins.

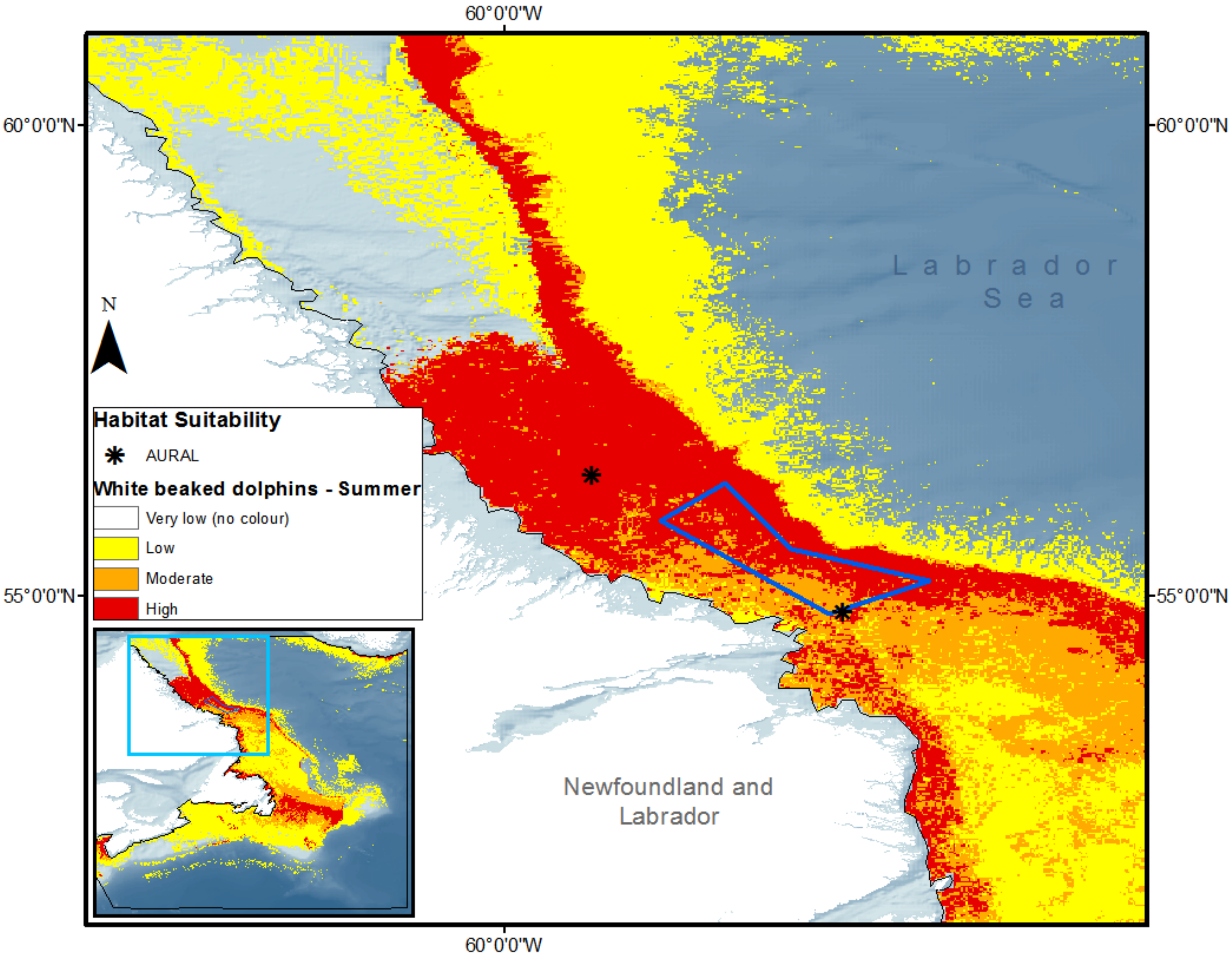


Figure 66. Areas of suitable habitat along the Labrador coast for white-beaked dolphins in the summer period. The inset map shows the highly suitable summer habitat for white-beaked dolphins for all Canadian Atlantic waters.

White-beaked dolphins are abundant in Atlantic Canadian waters, and were the most commonly-sighted cetacean species during the ESRF visual surveys. This is reflected in the habitat suitability modelling for these dolphins which indicates that much of the ESRF study area is highly suitable habitat for this species during the summer (Figure 66). The most suitable white-beaked dolphin habitat appears offshore and to the northern end of the study area, and close to the Labrador coastal margin. Portions of the mid-Grand Banks and Bay of Fundy also have highly suitable summer habitat for this species.

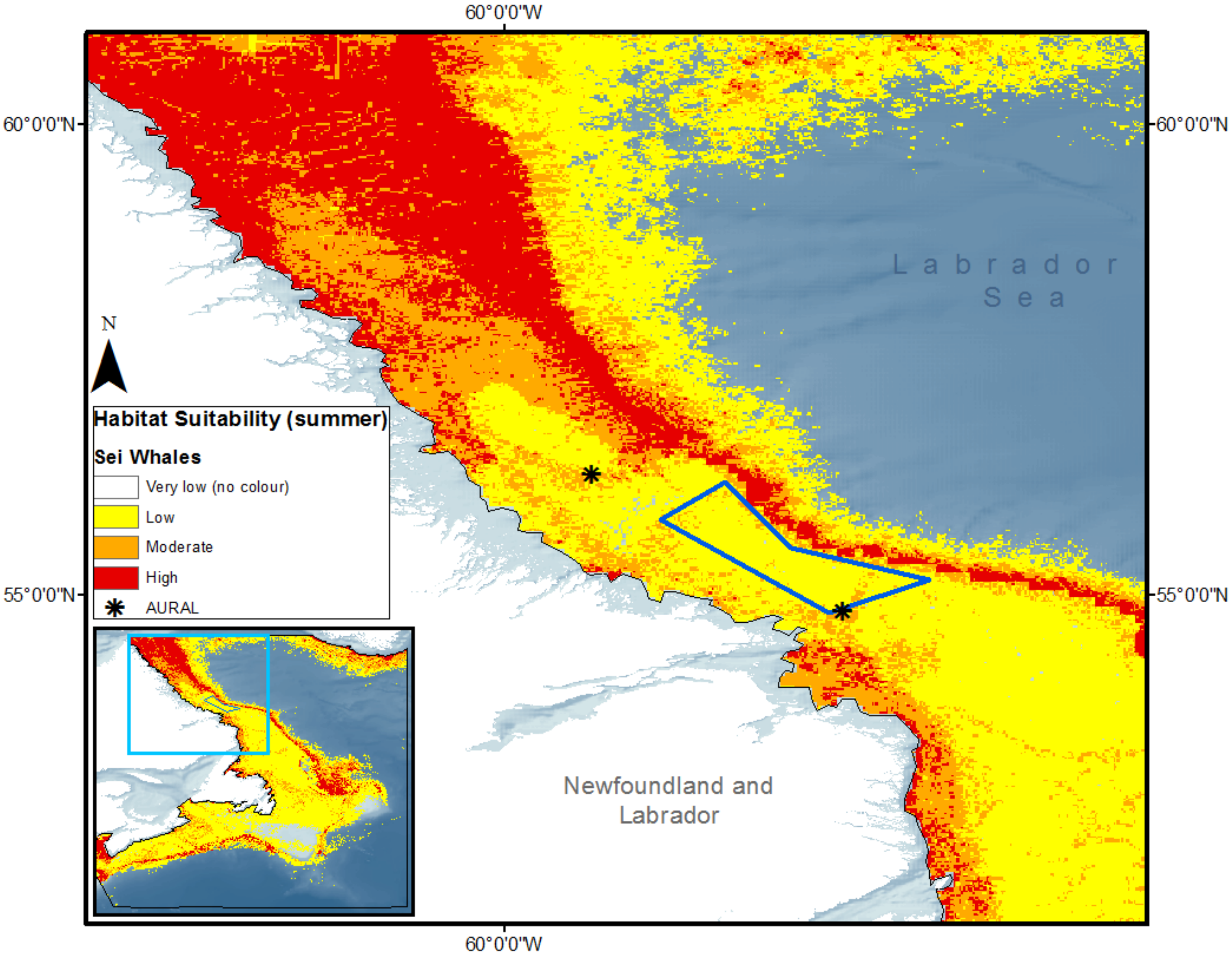


Figure 67. Areas of suitable habitat along the Labrador coast for sei whale in the summer period. The inset map shows the highly suitable summer habitat for sei whales for all Canadian Atlantic waters.

Habitat suitability modelling for sei whales suggests that the offshore margin of the ESRF study area is more suitable than nearshore for this species during the summer, with the Labrador Shelf edge and shelf waters north of Nain Bank encompassing highly suitable habitat (Figure 67). They were detected by the acoustic recorders in October 2013. The waters at the shelf breaks of the Grand Banks, Flemish Cap, Laurentian Channel mouth, and the Scotian Shelf also have highly suitable summer habitat for this species.

7.5.3. Habitat Suitability Maps For Selected Cetaceans - Fall

Model maps of habitat suitability within the northwest Atlantic were created for each cetacean species selected in this study for the fall period (September to November). These maps indicate areas categorized as habitat of high, moderate, and low suitability along the Labrador coast (Figures 68 to 74).

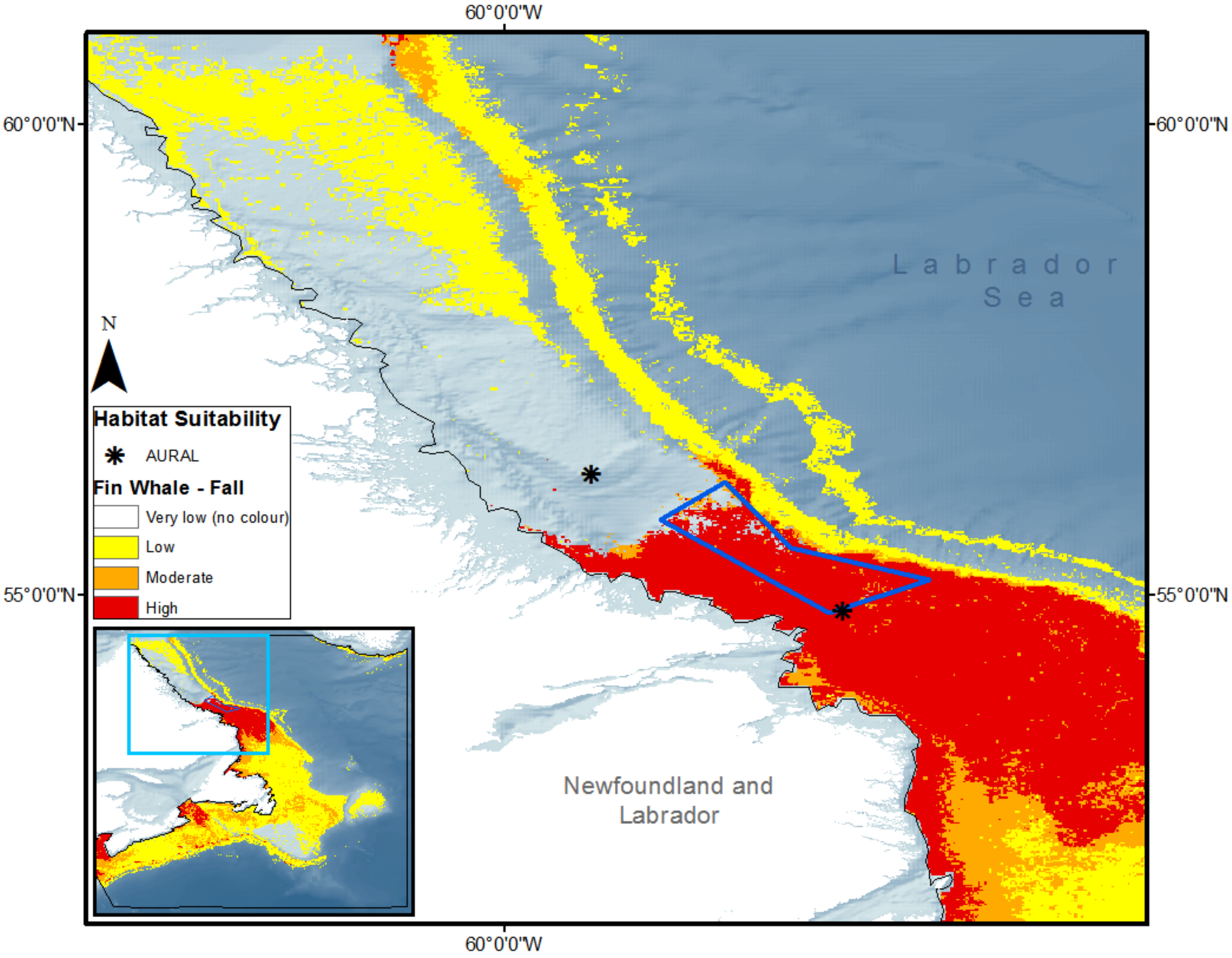


Figure 68. Areas of suitable habitat along the Labrador coast for fin whales in the fall period. The inset map shows the highly suitable summer habitat for fin whales for all Canadian Atlantic waters.

In contrast to summer, the habitat suitability modelling for fin whales suggests that the ESRF study area and most of the southern Labrador Shelf contains highly suitable habitat for this species during the fall (Figure 68). Fin whales were sighted during the aerial surveys and detected by the acoustic recorders during the fall. The only other highly suitable fall habitat areas are smaller portions of the mid Grand Banks, the Laurentian Channel off southwest Newfoundland, and the Bay of Fundy.

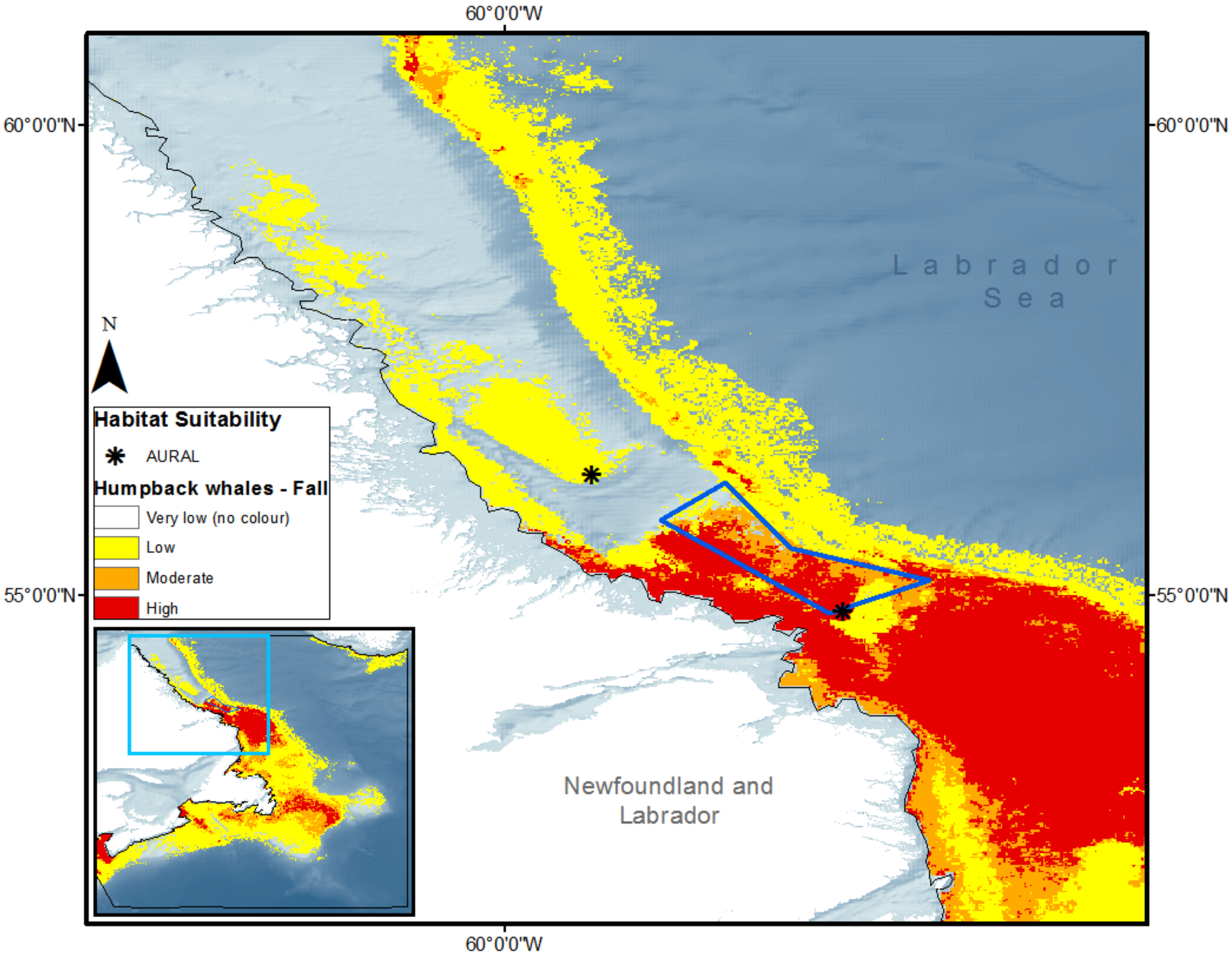


Figure 69. Areas of suitable habitat along the Labrador coast for humpback whales in the fall period. The inset map shows the highly suitable summer habitat for humpback whales for all Canadian Atlantic waters.

As for fin whales, the habitat suitability modelling for humpback whales during the fall produced significantly different results than for the summer; the southern Labrador Shelf area, including the ESRF study area, is rated as highly suitable humpback whale habitat during the fall period (Figure 69). Portions of the mid-Grand Banks and the Bay of Fundy also have highly suitable fall habitat for this species.

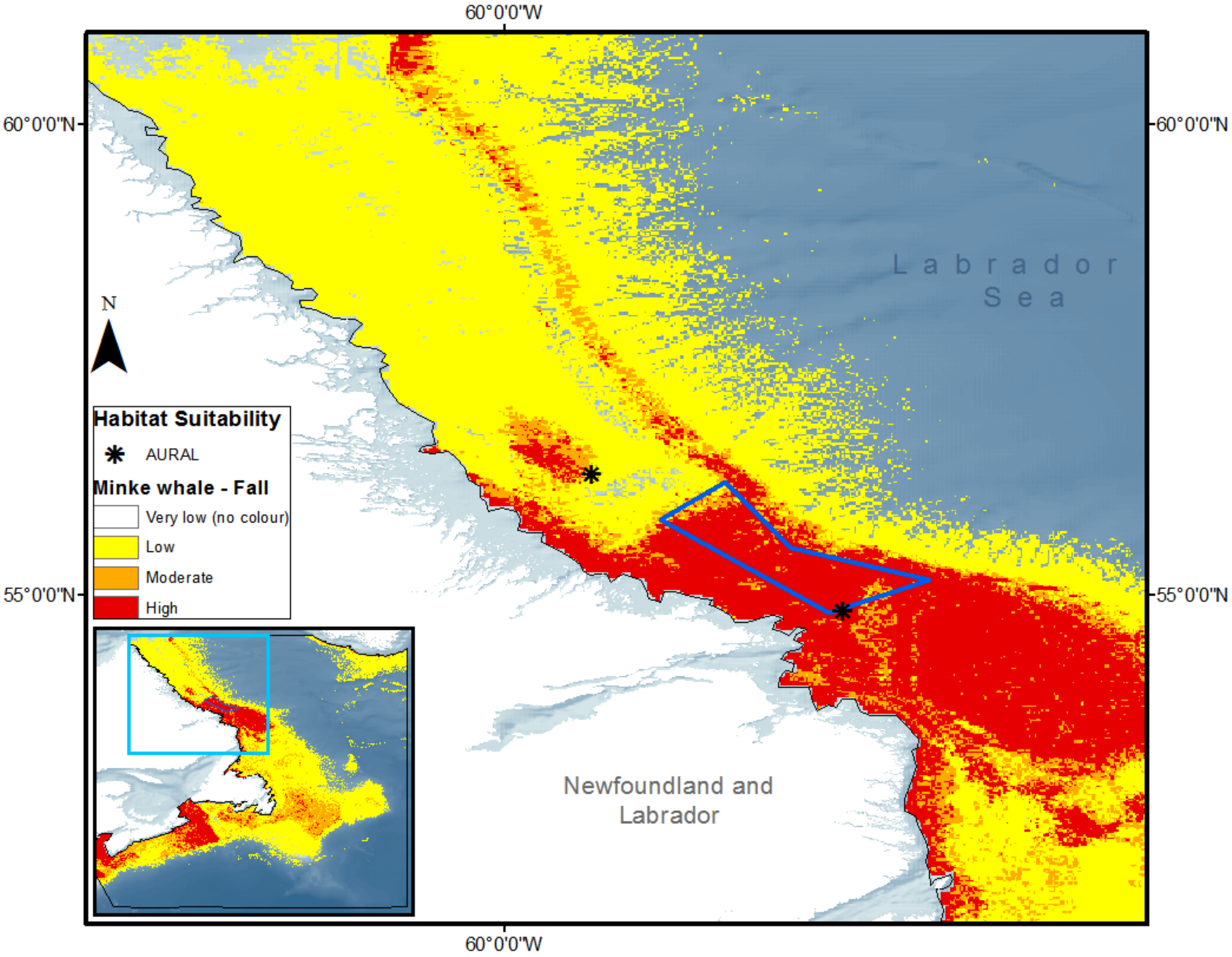


Figure 70. Areas of suitable habitat along the Labrador coast for minke whales in the fall period. The inset map shows the highly suitable summer habitat for minke whales for all Canadian Atlantic waters.

The habitat suitability modelling for minke whales during the fall produced a significantly different pattern than for the summer; the southern Labrador Shelf including the ESRF study area is rated as highly suitable minke whale habitat during the fall period (Figure 70). This large shift to more southerly portions of the Labrador Shelf is striking as a southward shift in highly suitable habitat is not evident in other parts of the minke whale's Atlantic Canadian range.

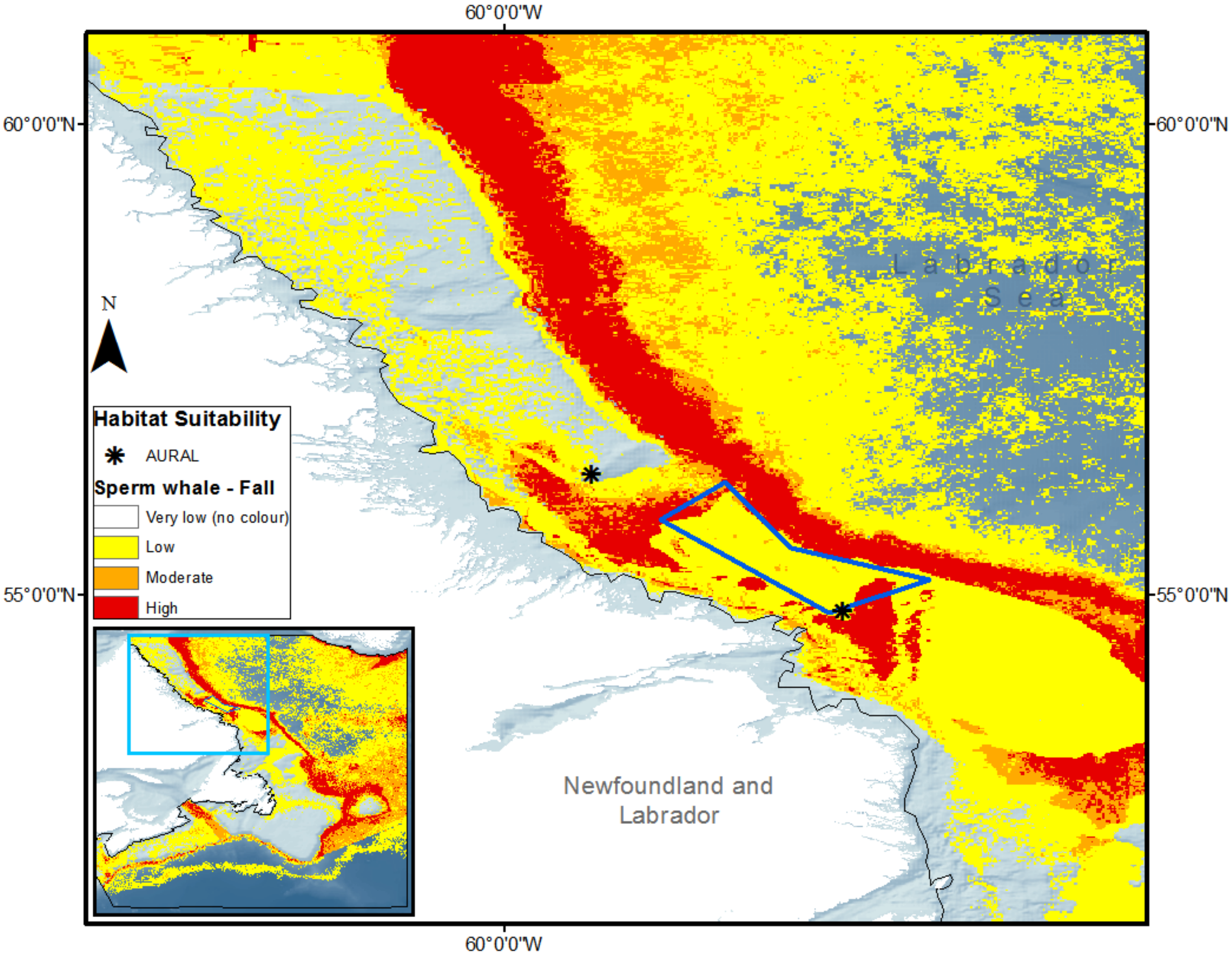


Figure 71. Areas of suitable habitat along the Labrador coast for sperm whales in the fall period. The inset map shows the highly suitable summer habitat for sperm whales for all Canadian Atlantic waters.

The habitat suitability modelling for sperm whales during the fall produced significantly different results than for the summer; the southern Labrador Shelf, including the ESRF study area, rated as highly suitable sperm whale habitat during the fall period (Figure 71). Portions of the mid-Grand Banks and the Bay of Fundy also have highly suitable fall habitat for this species.

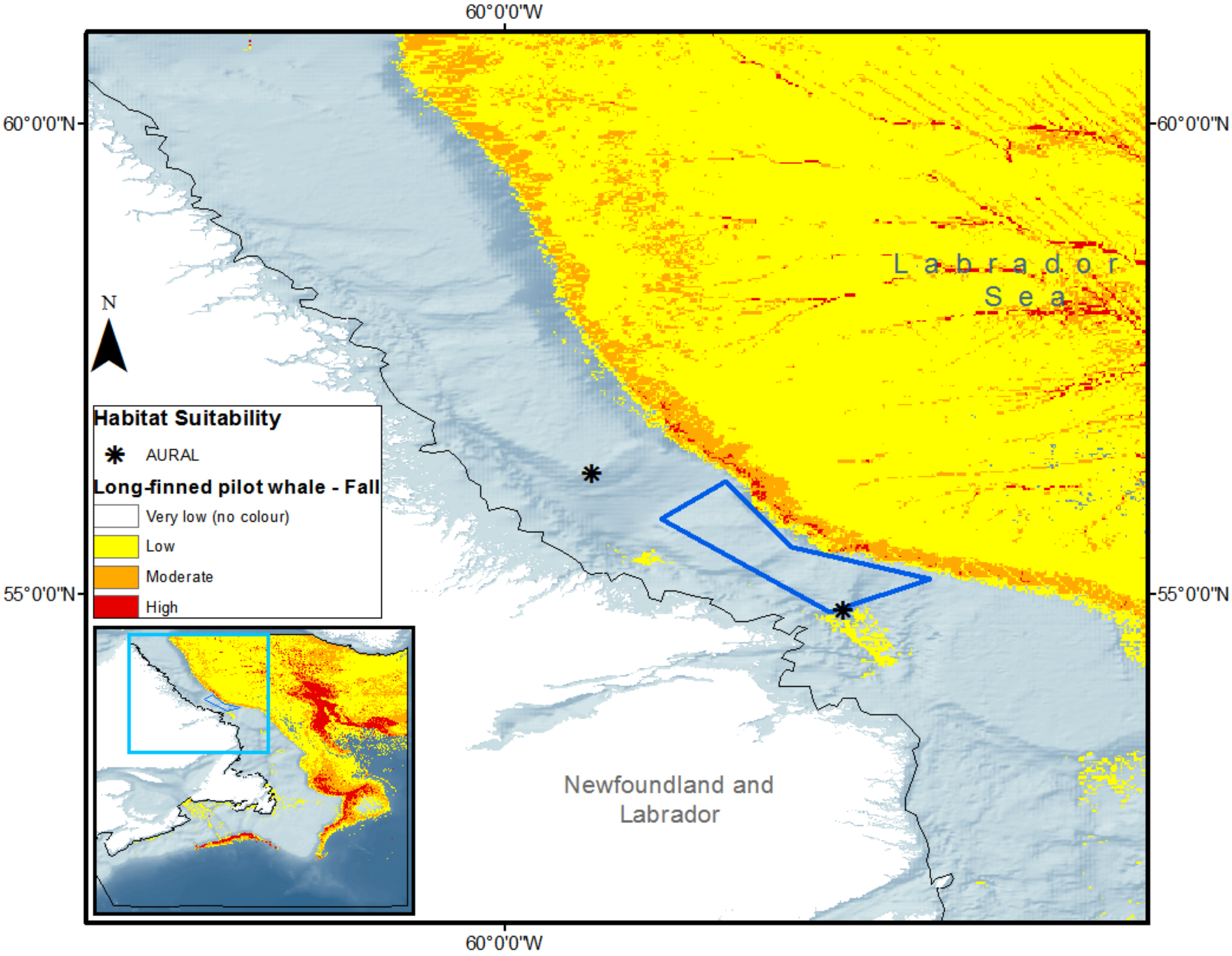


Figure 72. Areas of suitable habitat along the Labrador coast for long-finned pilot whales in the fall period. The inset map shows the highly suitable summer habitat for long-finned pilot whales for all Canadian Atlantic waters.

Similar to results for summer, the fall habitat suitability modelling for long-finned pilot whales suggested that the offshore margin of the ESRF study area is more suitable than nearshore for this species. During the fall period, the Labrador Shelf edge encompassed a narrow area along the shelf break ranked as highly suitable habitat, and larger areas ranked as moderately suitable habitat further out in deeper waters (Figure 72).

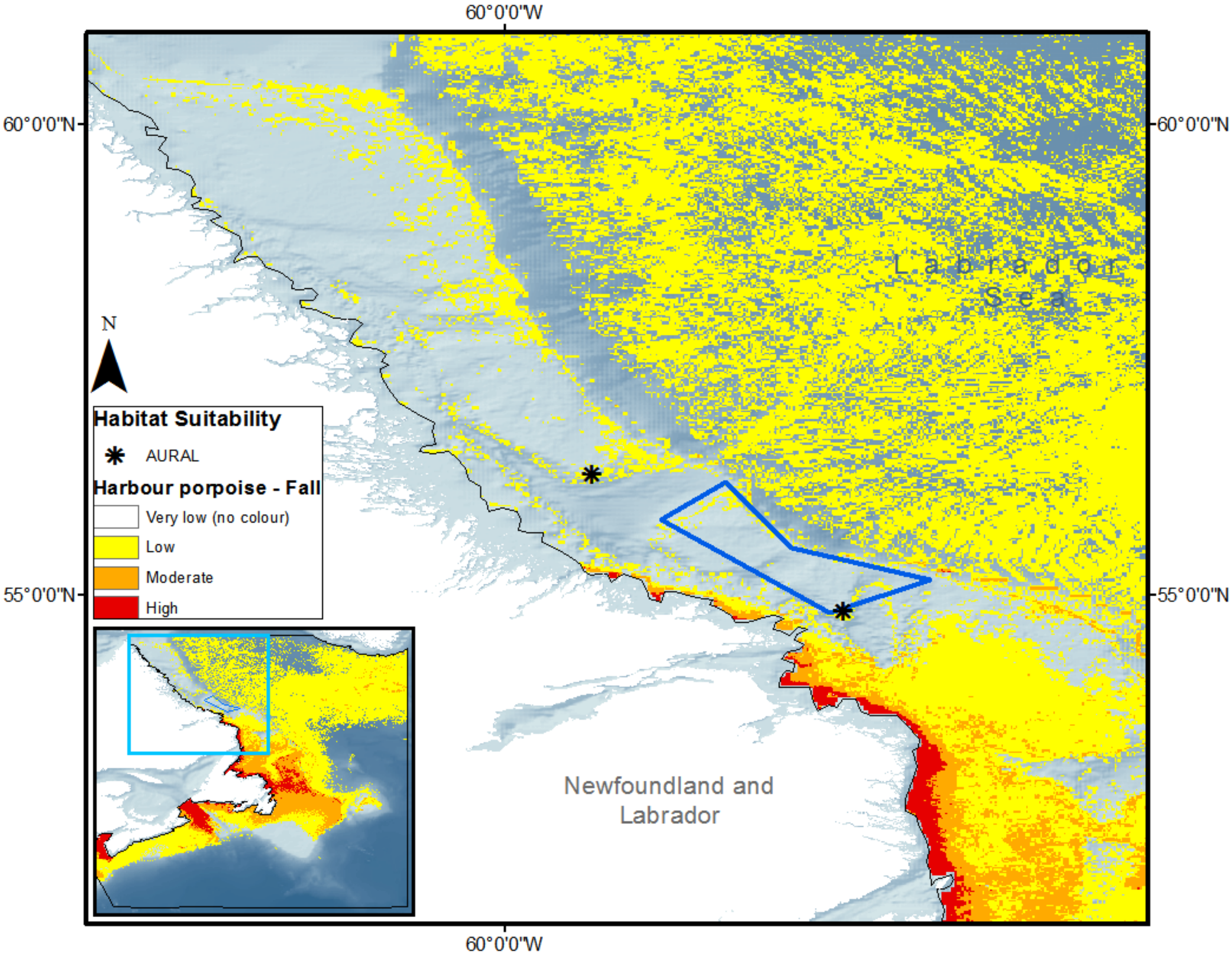


Figure 73. Areas of suitable habitat along the Labrador coast for harbour porpoises in the fall period. The inset map shows the highly suitable summer habitat for harbour porpoises for all Canadian Atlantic waters.

Similar to results for summer, the fall habitat suitability modelling for harbour porpoises suggests that most of the ESRF study area does not encompass suitable habitat for this species, although areas close to the southern Labrador coastal margin do contain highly and moderate suitable harbour porpoise habitat (Figure 73). Unlike results for summer, fall models showed only areas of low habitat suitability for porpoises on the Labrador Shelf to the northeast of Nain.

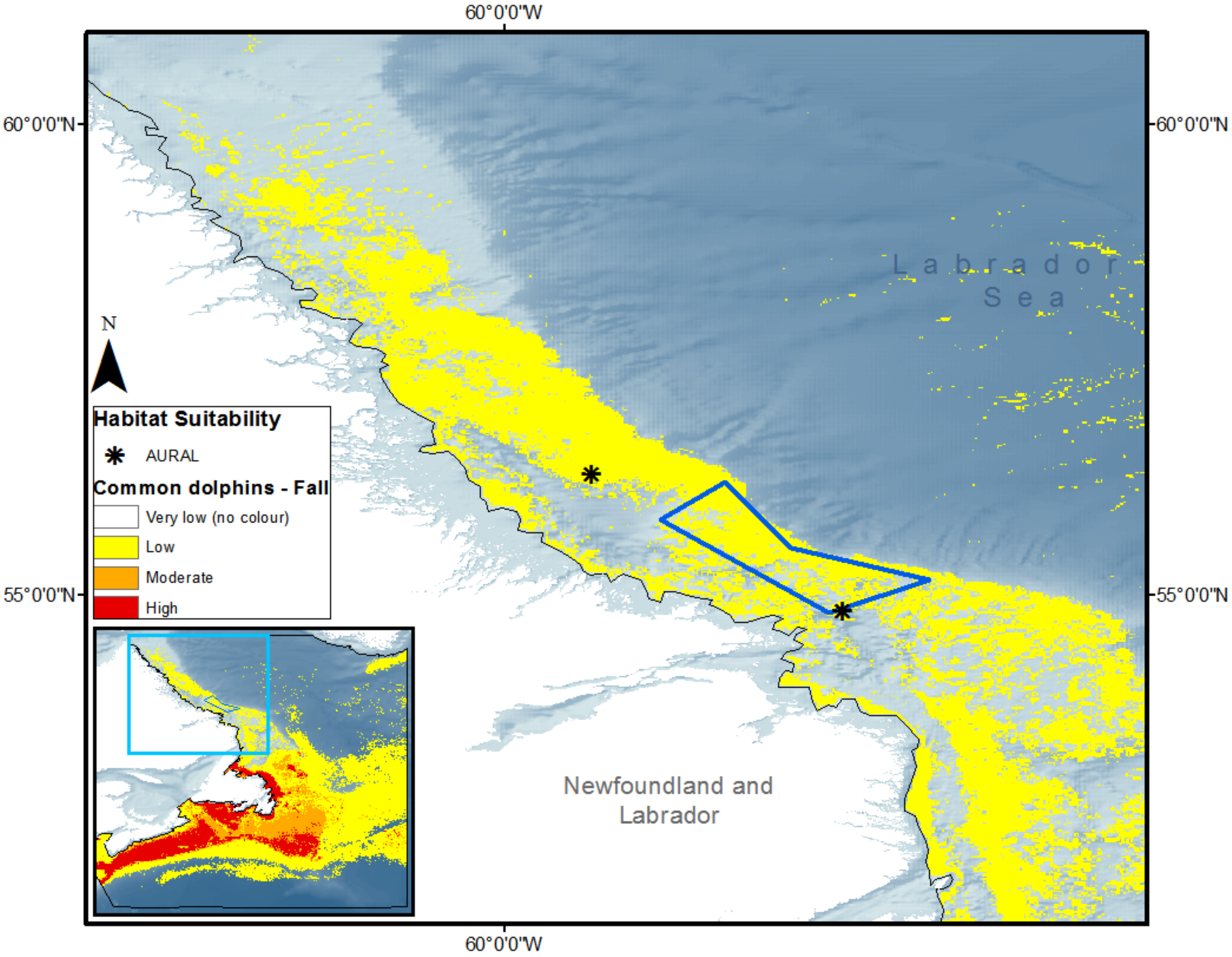


Figure 74. Areas of suitable habitat along the Labrador coast for common dolphins in the fall period. The inset map shows the highly suitable summer habitat for common dolphins for all Canadian Atlantic waters.

Similar to results for summer, the habitat suitability modelling for common dolphins suggests that the ESRF study area does not include highly or moderately suitable habitat for this species during the fall (Figure 74). In contrast, large portions of the Grand Banks shelf margins and the Scotian Shelf have highly suitable fall habitat for common dolphins.

Marine mammal species listed under the Species at Risk Act are of particular regulatory and conservation concern, and a brief summary of the habitat modelling results for blue, northern bottlenose, north Atlantic right, fin, and Sowerby's beaked whales are highlighted in Table 27.

Table 27. The MaxEnt habitat model results and SARA status for those species listed under SARA that had moderate and high modelled habitat suitability in and near the ESRF study area, including important biophysical variables explaining these species' distributions.

Common Name	**SARA Status**	**Greatest Biophysical Contributor(s) to Distribution Models**	**Important Habitat in Labrador**
Blue Whale	Endangered	Summer SST	*Summer*: The ESRF study area and entire Labrador Shelf are not highly su habitat for this species, except for small nearshore areas on the southern Labrador coast *Fall*: No data
Northern Bottlenose Whale	Endangered on Scotian Shelf	Ocean Depth Summer SST	*Summer*: The offshore margin of the ESRF study area is more suitable tha nearshore for this species during the summer, with the Labrador Shelf brea encompassing highly suitable habitat *Fall*: No data
North Atlantic Right Whale	Endangered	No data	No data for summer or fall; rarely sighted in the region
Fin Whale	Special Concern	Summer Chlorophyll Persistence	*Summer*: the ESRF study area and most of the outer Labrador Shelf does contain highly suitable habitat for this species. The most suitable fin whale appears to lie close to the southern Labrador coastal margin, to the west of Harrison and Hamilton Banks *Fall*: The ESRF study area and most of the southern Labrador Shelf contai highly suitable habitat for this species
Sowerby's Beaked Whale	Special Concern	No data	No data for summer or fall

8. Discussion of Study Results

8.1. Visual Surveys

Compared with the late summer TNASS survey of 2007, the 2013 and 2014 ESRF visual surveys collected more sightings, and of a more diverse range of marine mammals. Nonetheless, the 2013 and 2014 surveys yielded a relatively lower density of cetaceans than similar aerial surveys in the summer on the south coast of Newfoundland and the Scotian Shelf (TNASS and Laurentian Channel MPA). However, as discussed in §8.2, marine mammal detections in data from the AURAL acoustic recorders indicated that there was a greater diversity and number of marine mammals on the Labrador coast than was detected during the visual surveys. Given the detection limits of visual surveys (such as animals at the surface but not detected by the observers, and animals diving below the surface that are not available for detection by visual observers) and the temporal and spatial limits of the visual surveys, this disparity in the acoustic and visual survey results was expected. As in the 2007 TNASS aerial survey (Lawson and Gosselin 2009, 2011), there were insufficient numbers of all but white-beaked dolphins (see below) to produce a reliable abundance estimate based on distance sampling methods. Density surface modelling (e.g., Becker et al. 2016; Hammond et al. 2013; Roberts et al. 2016; Williamson et al. 2016) is an alternate approach to build species distribution to predict suitable habitat for marine species in support of conservation and management. However, with the currently limited survey data in this study area, habitat modelling such as MaxEnt (see §7.3) provides a solution to at least better understand marine mammal distribution, and identify factors that might be influencing it.

Cetacean sightings total and effort-weighted sighting rates were higher in the 2013 survey than in the 2014 survey, with white-beaked dolphins seen most often, and in the largest groups in both years. Multi-species aggregations of fin and humpback whales were observed feeding during surveys conducted in the fall (of 2013), suggesting that these cetaceans may take advantage of the spawning aggregations of herring and mackerel that occur on the Labrador south coast in the fall (e.g., Pinhorn 1976). The larger number of sightings recorded in the 2013 survey (conducted in October and November) as compared to the 2014 survey (conducted in August) is consistent with the suggestion that cetaceans may be drawn to southern Labrador in fall, rather than earlier in the summer (Lawson and Gosselin 2009), likely to feed on fall spawning herring and/or mackerel.

Marked differences in cetacean distribution between a survey that was conducted during a period when a seismic vessel was operating near the location of the northern AURAL (October

2013) and a survey conducted in the absence of seismic activities (three weeks later in early November 2013; Table 4 and Figure 11) suggest that cetaceans were displaced by seismic noise. In October 2013, most cetacean sightings were made in the southern portion of the study area, while such sightings were more evenly distributed across the latitudinal gradient in a survey three weeks later. Specifically, fin, humpback, and minke whales were sighted during both the October and November surveys; however, all of the humpback whales and most of the fin whales were sighted only on the southernmost transect line in October, with fin whales seen further north three weeks later (e.g., Figures 13 and 14). These observations suggest that cetaceans may have been avoiding the seismic vessel, as has been documented in other areas (Abgrall et al. 2008; Castellote et al. 2009; Nowacek et al. 2007). Further evidence that seismic operations might have influenced cetacean distributions is found in results of the 2014 survey (August), there was no seismic activity within hundreds of kilometres, and no evidence of a southward displacement of cetacean sightings. Indeed, the 2014 sightings appeared more evenly distributed than during either survey in 2013 (Figures 19, 20, and 21).

White-beaked dolphins were the most commonly-sighted and numerous cetacean species sighted in 2013 and 2014 during the vessel and aerial surveys (and were common in the acoustic records). They were distributed throughout the survey area, and from nearshore waters to areas beyond the shelf break. There are indications that this species is becoming more common in the northwest Atlantic in recent decades, and this is borne out by the ESRF and other surveys. With a minimum abundance estimate of about 11,000 individuals for this portion of the Labrador Shelf, this species is certain to have an important ecological role.

As expected, most sightings for cetacean species known to be deep-water foragers (e.g., long-finned pilot whale, Risso’s dolphin, and Sowerby’s beaked whale) were made at or beyond the Labrador Shelf break (Figures 23, 24, and 25).

Few pinniped species were sighted during these two aerial surveys and the vessel-based survey. This was expected since the most numerous pinniped species in the northwest Atlantic, harp and hooded seals (*Cystophora cristata*), return to the Arctic to feed during the spring to fall period. Bearded seals were sighted by the vessel-based observer, and a common feature of the acoustic recordings, particularly during the early winter period.

8.2. Acoustic Monitoring

The acoustic monitoring component of this project proved to be successful despite issues with mooring and environmental noise, and unexpectedly-curtailed AURAL recorder operations.

The acoustic recorders documented a variable, loud acoustic soundscape at the two recorder locations on the Labrador Shelf. The broadband (10 Hz to16 kHz) noise levels for the northern (110-120 dB rms SPL) and southern (110 dB rms SPL) AURALs in the summer and fall of 2014 (e.g., Figure 32) were similar. Much of this sound energy was concentrated in the 0-200 Hz frequency band, with less evidence of significant seasonal differences (Figures 35 to 40) than there was between the mooring sites. The JASCO automated detector analyses indicated that vessels contributed regularly to the soundscape and that multiple vessels (three to seven) passed the AURAL sites, close enough to be recorded, each day for much of the year.

Many different types of sound sources, such as shipping, industrial activities, storms, and seismic exploration, contribute to the low-frequency ambient soundscape of the ESRF study area (National Research Council 2005; Urick 1986) (Figure 75). At the ESRF acoustic mooring sites, another source of ambient noise would include moving ice in the winter and spring.

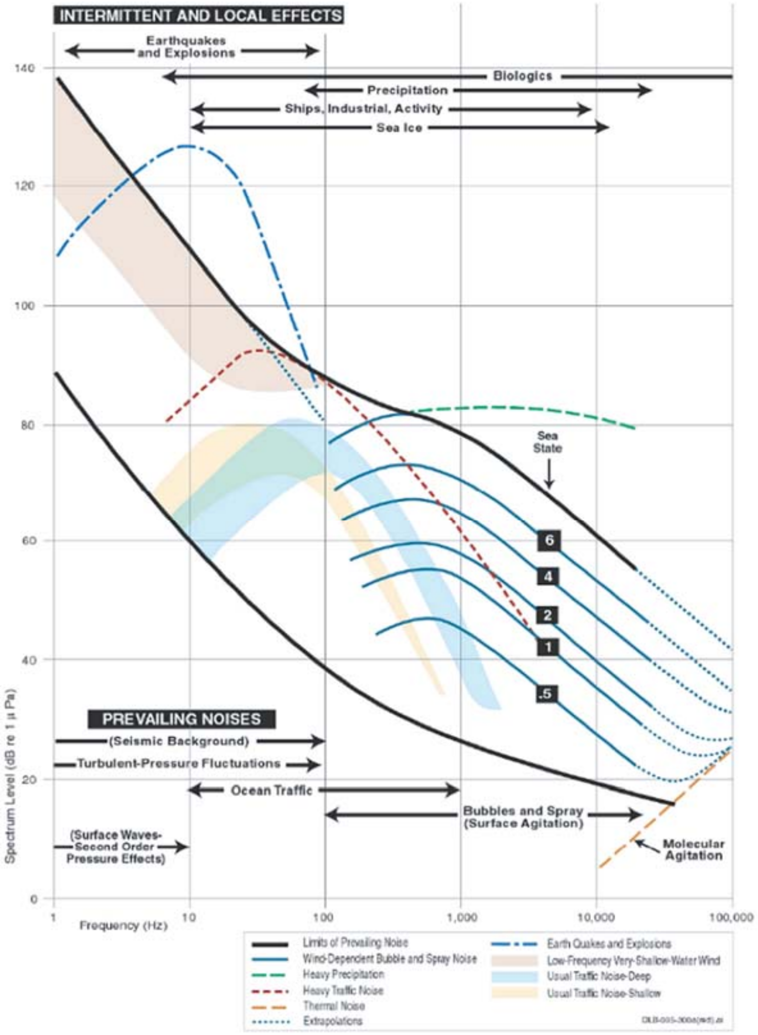


Figure 75. Wenz curves describing pressure spectral density levels of marine ambient sound from weather, geologic activity, and commercial shipping. Thick lines indicate limits of prevailing noise. Figure reproduced from Wenz (1962) and National Research Council (2005).

Since the acoustic soundscape of open ocean often has daily SEL values of 150-155 dB, it is probable that AURAL daily cSEL values (regularly louder than 160-165 dB) are a function of either mooring self-noise (such as strumming of the mooring cables and battery rattling), or nearby shipping activity received efficiently by our relatively shallow moorings. As a test, we filtered out possible contributions of cable strumming and other self-noise from one set of the AURAL data by removing low-frequency (13 Hz) sound energy above a 115 dB amplitude. This reduced the AURAL broadband sound energy measures for this particular data by 15 to 20 dB. Whether this filtering is the optimal means to control for AURAL mooring self-noise is unknown. For the southern AURAL in the fall-winter 2014 period this reduced the estimated daily SEL to between 160.9 dB (low frequency M-weighted) to 151.9 db (high frequency M-weighted) (bottom sub-table in Table 11). Figures 35 to 40 show unfiltered ESRF AURAL frequency band-specific ambient noise levels that were perhaps 10-15 dB higher than those reported for the mid-Grand Banks (Figure 76) (Kowarski et al. 2016). That is, the ESRF AURAL data regularly exceeded 130 dB (and often up to 140 dB) for extended periods, whereas the Grand Banks data was at or below 120 dB most of the time, with small excursions above 120 dB that appear to be caused by vessel passages (B. Martin, JASCO Ltd., pers. comm.); recall that a 10 dB increase in SEL value equates to 10 times more sound energy.

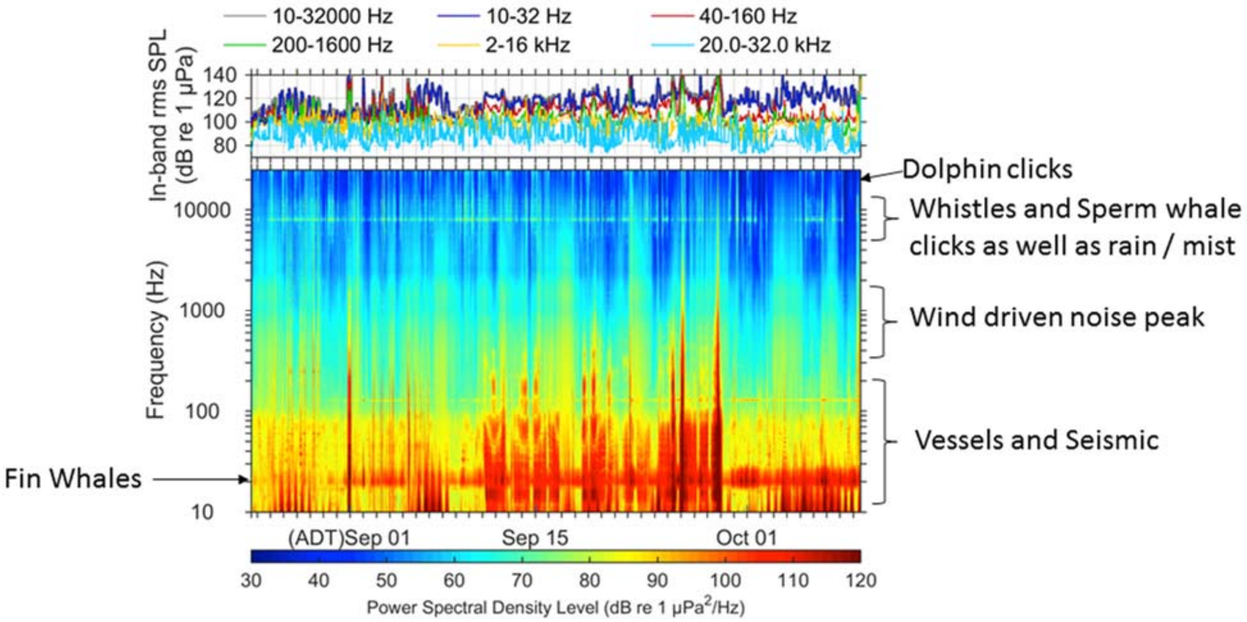


Figure 76. Spectrogram (bottom) and (top) in-band rms SPL values for a mid-Grand Banks shelf edge recording site between 24 August and 9 October, 2015. From Kowarski et al. (2016).

Irrespective of the signal processing methodology chosen, the ESRF study area on the Labrador Shelf featured relatively high ambient noise levels, and much of this sound energy appears to be contributed by vessel movement on and near the shelf (in addition to mooring self-noise). Overall, shipping noise dominates the broadband acoustic spectrum in the study area, and was detectable even when the area was ice-covered in the winter. In addition to a relatively continuous low-frequency component, the AURALs also recorded higher-frequency depth sounder pulses (which often confused the toothed whale autodetectors). Even in the winter, when fast and pack ice cover the study area, passages of ice-breaking vessels and cargo ships in open water off the shelf were detectable.

Sound from seismic exploration arrays was a substantial acoustic energy contributor in 2013, when the source vessel was operating in the study area. But even in 2014 seismic pulses from more distant surveys on the Grand banks were detected on the Labrador Shelf. (such as in Figures 42 and 43)

The AURALs detected high amounts of seismic airgun sound energy in the initial fall 2013 deployment. In particular, the 2013 data from the northern AURAL recorder has high-levels of seismic sounds on the deployment date (Figure 77), and the day after when the source vessel was operating very close to that mooring sites. It should be noted that a self-protection feature of the AURAL recorders results in very high amplitude signals, such as the pulses from nearby seismic, to be clipped as the signal exceeded the receiver capacity (approximately 159 dB). This mechanism would have reduced the maximum measurements of the seismic noise contribution, and so for this study the contributions of seismic noise to the study area soundscape should be considered undervalued when the seismic operation was within several kilometres of the recorders.

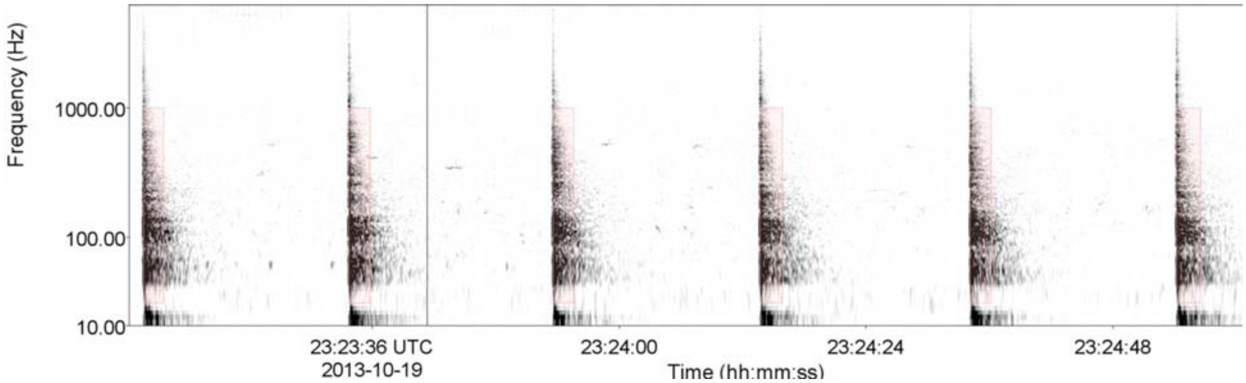


Figure 77. Sample of seismic airgun pulses recorded by the northern ESRF AURAL on 19 October, 2013. Sperm whale and humpback sounds are visible in the background.

The fact that the northern AURAL was at shallow depth and on the southern end of Nain Bank might have "shadowed” this recorder from the most intense seismic signals. These factors would be additive to the masking by other high noise inputs from ambient sources and from the mooring self-noise. Additionally if there are softer bottom sediments in the area, these greatly reduce acoustic signal propagation range. A recent seismic array study on the Grand banks for DFO found longer range detection in deep water and shorter range detection in shallow water (Kowarski et al. 2016), the latter which was also a feature of the ESRF AURAL mooring sites.

Overall, anthropogenic sound levels (particularly seismic pulses) were high enough the change the behaviour patterns of some baleen whale species (based on U.S. National Marine Fisheries Service studies, but see Gomez et al. 2016), but for no species high enough to cause more than perhaps temporary hearing sensitivity changes if they remained very close to the seismic array in 2013.

In addition to the contributions of anthropogenic and geophysical processes to the soundscape of the ESRF study area, the AURALs recorded many marine mammal sounds. With automated detection and manual assessment we were identified 14 marine mammal species (Tables 14 to 19), the most common being fin and humpback whales (Tables 14 to 17, and 28); this might be partly a function of the inherent difficulty in creating autodetection algorithms that can effectively discriminate amongst small toothed cetaceans such as dolphin species, and between beaked whales (e.g., northern bottlenose and Sowerby’s beaked whales).

High amplitude, low-frequency fin whale sounds will be detectable at much great distances than the quieter, high-frequency calls and echolocation signals of harbour porpoises. These interspecific differences in vocal characteristics must be considered when describing the marine mammal detection records of the AURALs.

In concordance with the results of the visual aerial survey, the fall period seemed to be the time when large whales such as fin and humpback whales were more commonly detected by the AURAL recorders in the study area. While it is likely they were present to feed during this period, the presence of stereotyped tonal calls of humpback whales throughout the fall and winter implies the humpback whales were also on or near the Labrador Shelf to socialize.

High amplitude, low-frequency fin whale sounds will be detectable at much great distances than the quieter, high-frequency calls and echolocation signals of harbour porpoises. These interspecific differences in vocal characteristics must be considered when describing the marine mammal detection records of the AURALs.

Table 28. Seasonal summary of marine mammal species detected acoustically during the ESRF study.

Species	Detected in Spring/Summer	Detected in Fall/Winter
Blue Whale	Rarely	Rarely
Fin Whale	Often	Often
Humpback Whale	Often	Rarer in Winter
Sei Whale	Rarely	Rarely
Minke Whale	Rarely	Rarely
Sperm Whale	Often	Often
Long-finned Pilot Whale	Rarely	Rarely
Risso’s Dolphin	Unk	Unk
Sowerby’s Beaked Whale	Unk	Unk
Northern Bottlenose Whale	Unk	Unk
Killer Whale	Rarely	No
White-beaked Dolphin	Often	Often
Harbour Porpoise	No	No
Bearded Seal	No	Often
Harp Seal	No	Often

8.3. Habitat Modelling

Information on the distribution of cetacean species on the Labrador Shelf has been primarily derived from hand-drawn maps of the maximum range of occurrence developed using qualitative processes based on expert knowledge and sightings information. Such methods are biased because they tend to identify habitats primarily in areas that have been surveyed in detail, while areas not surveyed are not well considered (Hamazaki 2002). Abgrall (2009) was the first to employ a quantitative modelling approach (Ecological Niche Factor Analysis) to determine if blue, fin, and sei whale distributions off Newfoundland and Labrador were related to water depth, seabed slope, sea surface temperature, or chlorophyll concentrations. This was a rudimentary effort as the input data on sightings were limited then. Habitat suitability models (HSMs) – such as the MaxEnt approach employed in this ESRF report - are an enhanced tool to assess the relationship between species’ occurrence data (e.g., sightings and/or acoustic detections) and environmental variables, and based on the model outputs, quantitatively predict and delineate species range and distribution (Redfern et al. 2006). While MaxEnt has not been used previously in this region, we chose this approach because we have primarily “presence” data for the northwest Atlantic – locations where a cetacean has been sighted. In locations where we do not have a cetacean sighting record we cannot currently discern if this is due to a cetacean not being present, or there being no survey effort to detect that species (see §6.1).

For the purposes of this report, we highlight the area off the eastern coast of Labrador in the presentation of model results. But we also place these ESRF findings within the broader context of modelled cetacean distribution for all eastern Canadian waters (except the Gulf of St. Lawrence).

Output from habitat models identified highly suitable habitat within the ESRF study area for two out of 12 cetacean species during summer, and four out of seven cetaceans during fall (Figures 56 to 74). Additionally, habitat models identified highly suitable summer habitat along the offshore margin of the ESRF study area for three cetacean species (sperm, northern bottlenose, and sei whales), and to the north of the ESRF study area for two other species (minke whale and harbour porpoise). These results indicate that the waters off the coast of Labrador may be important for cetacean conservation because they have the capacity to provide habitat that is highly suitable for a variety of cetacean species, some of which are listed under the Species at Risk Act (Table 27).

The HSM results suggest that there is little suitable blue whale habitat on the Labrador Shelf, and the small amount of low suitability habitat is scattered along the southern coast of Labrador during the summer (Figure 56; not enough date for a fall or winter analysis). Few blue whales have been sighted here, or captured during the historic whaling efforts at the turn of the century (Abgrall 2009; Dickinson and Sanger 2005). Sporadic confirmed blue whale calls were detected by the AURALs in August to February, but with good propagation conditions could have been from blue whales in the Strait of Belle Isle or offshore, as well.

In contrast, there was much highly-suitable habitat for fin, humpback, and minke whales on the Labrador Shelf, although the larger proportion of highly-suitability habitat for all of these species occurred in the fall period. For fin whales, HSM results suggest there is extensive low-suitability habitat in summer (Figure 57), which changes to high-suitability on the Shelf (not reaching as far north as the northern AURAL site) and some lower-suitability habitat off the shelf break in the fall (Figure 68). This reflects the historic importance of this area for whalers capturing fin whales (Dickinson and Sanger 2005; Sergeant 1953). The greatest number of confirmed fin whale calls were detected by the AURALs in the fall periods, as well (Tables 14 to 17). As for the fin whales, HSM results indicated there could be extensive low-suitability habitat for humpback and minke whales in the summer (although less and further south than fin whales) (Figures 58 and 59) which changes to high-suitability on the Shelf (not quite as far north as the northern AURAL site) and lower-suitability off the break in the fall (Figures 69 and 70). Unlike the larger baleen whales, there is some high-suitability minke whale habitat just north of the study area on Nain Bank in the summer. All three of these species likely aggregate on the southern Labrador Shelf to feed on fall spawning assemblages of herring and mackerel.

For deep-diving sperm and pilot whales (e.g., Watwood et al. 2006), the entire Labrador Shelf break and deeper on-shelf waters south of Nain Bank contain HSM-derived highly-suitable habitat in the summer and fall periods (Figures 60, 601, 71, and 72), although like the baleen species, moderate- and highly-suitable habitat for sperm whales is more widespread on the Shelf in the fall (Figure 71). The seasonal abundance and distribution patterns of the primary prey of sperm and long-finned pilot whales (squids and deep-sea fishes; e.g., Simon et al. 2003) is not well known along the coast of Labrador, so it is unknown if this is the primary factor driving seasonal changes in habitat suitability for these two species.

The HSM predicts little high-suitability habitat for northern bottlenose whales on the ESRF area of the Labrador Shelf in the summer period (Figure 62; too little data to model in the fall). As expected for a deep-foraging species (Hooker and Baird 1999; Hooker et al. 2001), though, there was much highly-suitable habitat in the deeper waters off the entire Labrador Shelf break, in addition to the Orphan Basin and Laurentian Fan areas. Many of DFO’s northern bottlenose sightings data for offshore northern Labrador were made during historic whaling operations there, and by observers aboard deep-sea fishing vessels recently, so to some extent these are driving the larger area of high suitability offshore of northern Labrador. Greater effort to visually and acoustically monitor waters at and beyond the shelf breaks would improve our confidence in the HSM maps for deep-water species like northern bottlenose, sperm, and pilot whales.

Killer whales, the region’s apex predator (Lawson and Stevens 2013), are predicted to have much high- and moderate-suitability habitat on the Labrador Shelf (Figure 63), which is partly a reflection of their broad distribution and rapid movement. As expected, the nearshore southern Labrador shelf west of Harrison and Hamilton Bank is an area of high suitability in the summer months, when these whales are sighted frequently. Nain and Makkovik Banks are also areas of high summer suitability, as are large portions of the mid and southern Grand Banks. We had insufficient data to model the fall and winter periods for this species, but likely they begin to leave the area prior to the arrival of sea ice.

The smallest cetacean in the northwest Atlantic, the harbour porpoise, appears to have little highly-suitable habitat in the study area in summer or fall (Figures 64 and 73). A narrow nearshore band of highly-suitable porpoise habitat was predicted for the fall period only, with the southern tip of an area of high-suitability habitat to the northeast of the ESRF study area off

Nain and Saglek Banks. Although this species is considered by some to be a “nearshore” cetacean, this ESRF study (using sightings and habitat modelling) and previous accounts (e.g., Palka et al. 1996; Read and Hohn 1995) demonstrate that this species also occupies offshore water beyond the shelf breaks, including the ESRF study area, the Orphan Basin and the western Laurentian Channel.

The other two small cetaceans for which we derived habitat models, common dolphins and white-beaked dolphins demonstrated distinct differences. Common dolphin habitat was broadly-distributed through the study area (and indeed the entire northwest Atlantic shelf waters), but was generally of lower suitability in the northern latitudes relative to the southern Grand banks and Scotian Shelf (Figures 65 and 74). This species is sighted less commonly during recent aerial surveys than it was decades ago (Lawson and Gosselin 2009; Parsons and Brownlie 1981), perhaps reflecting a change in ecosystem features important for common dolphins.

In contrast, much of the Labrador Shelf contained highly-suitable habitat for white-beaked dolphins (Figure 66) in the summer, particularly along the shelf break, but also in the deeper waters of the Hopedale Saddle. This is a function of this species being encountered throughout Atlantic Canadian waters during aerial survey efforts (e.g., Kingsley and Reeves 1998; Lawson and Gosselin 2009). We did not have enough sightings data to conduct habitat modelling for the winter period, when this species is presumed to occupy north Atlantic waters, including the Labrador Shelf (Lien et al. 2001; Sergeant and Fisher 1957).

The seal species that breed in this area (e.g., harp, hooded, ringed, and bearded seals) are most abundant during the late winter when sea ice is present and they are reproducing; most of these species leave the ESRF study area during the summer. Large groups of harp seals have been sighted on the Labrador Shelf during the spring, as they complete their moult and begin to migrate north to the Arctic to feed for the summer (e.g., Stenson and Kavanagh 1993; Stenson et al. 2009); a similar pattern is evidenced by hooded seals. Harp seal breeding calls were detected in February and March, although the main breeding patches were located mainly to the south of the ESRF study area. The summer and fall distribution of ringed and bearded seals is less well known, although both species are seen near the Labrador coast in the summer and fall (for example, Boles 1979), prior to their winter breeding period. Certainly many bearded seal calls were detected by the ESRF AURAL recorders, although most were breeding calls in January to March.

Relative contributions of environmental variables to HSM results were different among species, suggesting that what makes habitat highly suitable for one species may not be as important for another. Sea surface temperature and/or ocean depth were the top contributors for a number of cetacean species in both summer and fall models, while chlorophyll magnitude and/or persistence were the top contributors for only a few species (Tables 25 and 26).

In summary, the habitat suitability modelling effort demonstrates that there is highly-suitable habitat in and near the ESRF study area for a number of whale species. The modelling also revealed that these patterns usually varied between summer and fall periods, with the fall influx of large whales likely driven by the fall spawning aggregations of fish such as herring. The seal species that breed in this area are usually most abundant during the late winter when sea ice is present and they are reproducing; most of these leave the ESRF study area during the summer.

9. Recommendations for Further Study

In this section we offer a number of recommendations for further study that would enhance our understanding of this particular region, and in some cases, would enhance our ability to do research in other Canadian and international waters as well.

9.1. Visual Surveys

In 2013, and to a lesser extent in 2014, the ESRF aerial survey efforts were hampered by poor weather (primarily high wind speeds). This created larger sea states, which in turn limited the observers' abilities to detect and identify marine megafauna. This is one of the reasons why we also deployed autonomous acoustic recorders, which is a monitoring technique less affected by weather conditions (see §8.2, below). Going forward, there are at least two strategies to counteract this type of weather impact; chief among these would be to fly replicate surveys several weeks apart during the period(s) of interest (see for instance Jewell et al. 2012). Secondly, a trackline video camera with a higher magnification optical system could prove to be very useful. The GoPro video system used in 2014 did not have sufficient magnification to allow researchers to consistently resolve smaller animals or seabirds.

We sighted many cetaceans at or beyond the shelf break, often at or near the end of our planned survey track lines. Longer transect lines would allow us to better capture marine megafauna presence in this offshore area, particularly as these animals will be exposed to anthropogenic noise from activities on the shelf and the acoustic records suggest that some cetaceans remain offshore but adjacent to the shelf throughout the winter when sea ice covers the shelf itself.

Given the results from the aerial surveys and acoustic monitoring, it is apparent that any future visual surveys should concentrate their efforts on the fall period; more species and more animals are likely present on the Labrador Shelf at this time of year.

9.2. Acoustic Surveys and Analytical Methodologies

The results from the acoustic monitoring, despite issues with recorder operational duration and mooring self-noise, provided extremely useful supporting data to interpret the visual surveys and inform the habitat modelling. The acoustic study could be enhanced with full-year recordings, quieter moorings, and recorders with a higher frequency response to detect more small cetaceans and better characterise the Labrador Shelf soundscape. Currently it appears that these recommendations are being fulfilled by AMAR underwater recording systems that have been deployed recently by JASCO Ltd.as part of another ESRF study in almost the same locations as the AURALs in this study; it would be useful to compare these datasets

Continued development of species-specific acoustic detectors is warranted – particularly for species with complex vocal patterns (e.g., humpback and killer whales), or patterns that overlap in frequency and intensity with anthropogenic sounds (e.g., humpback and pilot whales). These will further speed and enhance the reliability of acoustic data processing, and more importantly, reduce the time demands for manual examination of the autodetector results.

Further analyses and modelling might provide a more dynamic means to adjust the AURAL recordings to control for the undesirable input of mooring self-noise to ambient noise measures. For example, flow noise effects appear to be greater at one mooring site than the other, and of varying magnitude over the course of a tidal cycle. The trial correction we employed by filtering out loud sounds at frequencies below 13 Hz may be overly conservative during periods of louder shipping or seismic exposures.

9.3. Habitat Modelling

One of the key environmental data types needed for further refinement of the habitat modelling consists of indices of relative concentration of prey at a temporal and spatial scale relevant to the marine mammal species of interest. This layer can provide an indicator of potential hotspots for whales (Pendleton et al. 2012). In most studies to date chlorophyll magnitude and persistence have been used as a proxy for higher trophic level prey due to a lack of data for these prey. For example, potential scenarios of future changes in the spatial indices of relative concentration of krill are desirable to quantify how different scenarios of prey distribution may alter the suitable habitat of blue whales. This information is vital to inform stakeholders about upcoming changes in the ecosystem, driven either by climate change or fisheries activities that may impact the distribution of blue whales in the northwest Atlantic. The same will be true for keystone prey species such as capelin, whose life history and abundance is tied to environmental features such as sea ice (Buren et al. 2014).

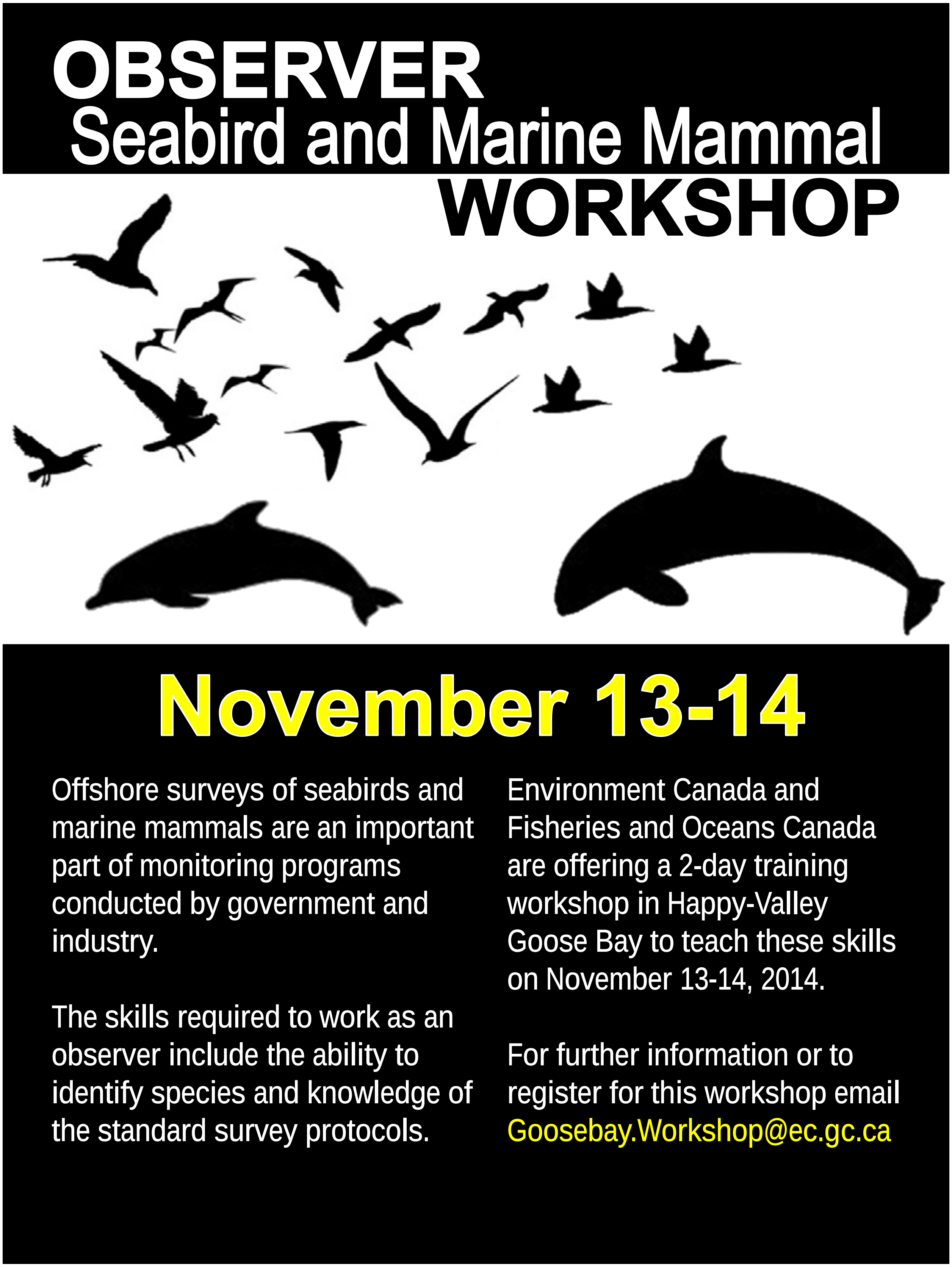
Federal government research funds are currently supporting DFO and EC efforts to gather data on distribution, abundance, and persistence of prey types at higher trophic levels (e.g., krill, capelin, herring, and mackerel) to further extend the types of habitat modelling, such as conducted in this report.

10. Local Capacity Building: Observer Training in Goose Bay, Labrador

On 13-14 November, 2014, members of the DFO and CWS team met in Goose Bay, Labrador to conduct a two-day marine mammal observer training session (Figure 77). The purpose of this training was: "To involve, train, and transfer expertise to local and in particular, aboriginal individuals, the technical skills involved in conducting surveys whenever possible".

Participants were trained in the skills needed to detect, identify, and record seabirds and marine mammals. It was an excellent opportunity to train Labradorean participants (100%), particularly Aboriginals (~70%), and to build capacity in the northern portion of the province. The workshop had 20 attendees from six communities (Port Hope Simpson, North West River, Happy Valley Goose Bay, Hopedale, Makkovik and Nain) representing a diverse range of experience. Coordination with the Nunatsiavut Government facilitated attendance of nine Nunatsiavut beneficiaries, and we enjoyed a strong NunatuKavut presence, as well as individuals from Parks Canada, the Torngat Secretariat, Carleton University, and Memorial University. Despite the diverse background of attendees (55% arrived with limited understanding of the subject), 90% reported that they felt the workshop was extremely useful.

Following the workshop, participants received a certificate of participation and materials to aid them in future related work (a hard copy of the Eastern Canada Seabird at Sea Protocol, and bird and marine mammal field guide books). There were multiple inquiries about formal certification but neither EC nor DFO have accreditation programmes for observers at this time. Nonetheless, these individuals are now well-informed for field-based training opportunities and following that, employment opportunities (e.g., aboard seismic vessels).



OBSERVER
Seabird and Marine Mammal
WORKSHOP

November 13-14

Offshore surveys of seabirds and marine mammals are an important part of monitoring programs conducted by government and industry.

The skills required to work as an observer include the ability to identify species and knowledge of the standard survey protocols.

Environment Canada and Fisheries and Oceans Canada are offering a 2-day training workshop in Happy-Valley Goose Bay to teach these skills on November 13-14, 2014.

For further information or to register for this workshop email Goosebay.Workshop@ec.gc.ca

Figure 78. Notice for the Marine Mammal Observer Training workshop in Goose Bay, Labrador.

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Appendix A - Mid-Labrador Marine Megafauna & Acoustic Study - Participants and Coordination

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