Advancing Protection for Acoustically Sensitive Species: Assessing Acoustic Sanctuary Suitability on the Scotian Shelf

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ABSTRACT

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Acoustic sanctuaries, designed to protect marine species from the detrimental effects of underwater noise, are becoming increasingly vital in regions heavily impacted by human activities. This report presents a comprehensive framework designed to identify potential areas for establishing acoustic sanctuaries on the Scotian Shelf. Utilizing a Geographic Information Systems-based multicriteria decision analysis method, this study integrated the best available spatial information on at-risk cetacean species and vessel traffic patterns to identify quiet areas that warrant the implementation of robust noise management strategies as human activities and ocean usage continue to increase in the region. The analysis revealed that the Gully and Haldimand Canyon show promise as suitable areas for the establishment of acoustic sanctuaries. These findings underscore the scarcity of such sanctuaries in a region dominated by human-generated noise, emphasizing the urgent need for swift prioritization and action regarding these identified locations. Notably, the interpretation of the results requires caution, as they do not incorporate the risk factor associated with proximity to high-density shipping lanes. However, the framework remains flexible and open to further refinements as better data and information become available, enabling continuous improvement in sanctuary planning and management. Ultimately, this approach contributes to the conservation and protection of at-risk cetacean species in the region, ensuring a healthier and more sustainable coexistence between marine ecosystems and human activities.

RÉSUMÉ

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Les sanctuaires acoustiques, conçus pour protéger les espèces marines des effets néfastes du bruit sous-marin, sont de plus en plus indispensables dans les régions fortement touchées par les activités humaines. Ce rapport présente un cadre conçu pour cibler des zones potentielles où l'on pourrait établir des sanctuaires acoustiques sur le plateau néo-écossais. À l'aide d'une méthode d'analyse décisionnelle à critères multiples axée sur les systèmes d'information géographique, cette étude a intégré les meilleurs renseignements spatiaux accessibles sur les espèces de cétacés à risque et les tendances du trafic maritime en vue de cibler les zones calmes qui justifieraient la mise en œuvre de stratégies robustes de gestion du bruit, dans un contexte où les activités humaines et l'utilisation de l'océan continuent d'augmenter dans la région. L'analyse a révélé que le Gully et le canyon Haldimand constituent des zones prometteuses pour l'établissement de sanctuaires acoustiques. Ces résultats soulignent la rareté de ces sanctuaires dans une région dominée par le bruit généré par l'homme, et mettent l'accent sur la nécessité d'établir rapidement des priorités et de prendre des mesures concernant les sites ciblés. En particulier, l'interprétation des résultats doit être faite avec prudence, car ceux-ci n'intègrent pas le facteur de risque associé à la proximité des routes maritimes à forte densité. Cependant, le cadre demeure flexible et ouvert à d'autres améliorations au fur et à mesure qu'on aura accès à de meilleures données et informations, ce qui favorisera une amélioration continue de la planification et de la gestion des sanctuaires. En fin de compte, cette approche contribue à la conservation et à la protection des espèces de cétacés en danger dans la région, permettant une coexistence plus saine et plus durable entre les écosystèmes marins et les activités humaines.

1.0 INTRODUCTION

Noise from human sources, also referred to as anthropogenic noise, has become increasingly pervasive in underwater environments since the industrial revolution and presents a multifaceted challenge for species that depend on sound for their survival (Duarte et al., 2021). In some areas, anthropogenic noise has doubled every decade for the past 60 years as a consequence of the increasing use of explosives, oceanographic experiments, geophysical research, construction, military active sonar, oil and gas activities, and international shipping (Andrew et al., 2011; Frisk, 2012). The Scotian Shelf Bioregion (hereafter known as the Scotian Shelf), including the Bay of Fundy, the Atlantic Coast of Nova Scotia, the Offshore Scotian Shelf, and part of the Gulf of Maine (Philibert et al., 2022), is no exception. With eight primary ocean use sectors identified on the Scotian Shelf (Breeze et al., 2013), it supports both an economically productive and highly biodiverse ecosystem (Archambault et al., 2010; Zwanenburg et al., 2006). However, the increase in anthropogenic activities in this region, particularly vessel activity (Cominelli et al., 2020; Walmsley & Theriault, 2011), has led to concerns about the impact of noise on marine life, as the characteristically low-frequency signatures from vessels allow for long-distance propagation in underwater environments (Studds & Wright, 2007).

While the effects of vessel-related noise are evident across taxa from invertebrates to marine mammals, research has primarily been focused on cetacean species (Duarte et al., 2021). Vessel noise can interfere with or disrupt vital life functions through behavioural changes (Holt et al., 2009; Kassamali-Fox et al., 2020; Lusseau et al. 2009; Williams et al., 2006, 2014a), habitat displacement (Erbe et al., 2016), hearing damage (NOAA, 2018), physiological stress (Broom, 2013; Rolland et al., 2012; Romano et al., 2004; Wright et al., 2007), and masking effects (Au et al., 2004; Hermannsen et al. 2014; Li et al. 2015; Miller, 2006; Clark et al., 2009), leading to acute or chronic effects across a broad timescale and spatial distribution (Dekeling et al., 2020).

More than fifteen different cetacean species regularly occur on the Scotian Shelf (Gomez et al., 2020) and vessel noise is a concern for all of them. However, the Canadian *Species at Risk Act* (SARA) lists five particularly vulnerable cetacean species on the Scotian Shelf with vessel noise identified as a threat to their survival. These SARA-listed cetaceans include the endangered North Atlantic right whale (NARW) (*Eubalaena glacialis*), Scotian Shelf northern bottlenose whale (*Hyperoodon ampullatus*), and Atlantic blue whale (*Balaenoptera musculus*), as well as the special concern species Atlantic fin whale (*Balaenoptera physalus*), and Sowerby's beaked whale (*Mesoplodon bidens*) (DFO, 2014; DFO, 2017a; DFO, 2017b; DFO, 2017c; DFO, 2020a; DFO, 2022).

Given the vulnerability of these species to vessel noise, it is imperative to implement effective protection measures to safeguard their habitats and mitigate the potential impacts of underwater noise. However, difficulty in understanding the extent of the effects of vessel noise on these highly mobile species has left large scientific gaps that are reflected in policies, laws, and mitigation strategies in Canada (Green, 2022; Williams et al., 2014b). Marine conservation and noise management strategies on the Scotian Shelf are further challenged by increasingly busy ports in Saint John and Halifax, as well as the entrance to the St. Lawrence Seaway, where international shipping lanes overlap with the habitat of the SARA-listed cetacean populations in eastern Canadian waters (DFO, 2018d). Ongoing efforts to determine the underwater acoustical energy budget in coastal sites where whales are present (Wingfield et al., 2022) and the deployment of passive acoustic monitoring (PAM) systems in various offshore sites offer valuable contributions to these research gaps (Davis et al., 2017, 2020; Delarue et al., 2018; Delarue et al., 2022; Durette-Morin et al., 2019), however, further action is required to develop effective noise management strategies.

The concept of acoustic sanctuaries has emerged as a potential tool for managing the impacts of anthropogenic noise on marine species and habitats, aligning with recommended regional or ecosystem-based management directives (Erbe et al., 2014; Williams et al., 2015a). These sanctuaries aim to create or safeguard areas with reduced anthropogenic noise levels to benefit acoustically sensitive species (Drackett & Dragićević, 2021; McWhinnie et al., 2017). By providing undisturbed spaces where species can communicate, forage, and reproduce without excessive anthropogenic noise interference, these areas play a crucial role in supporting conservation efforts (Weilgart, 2007). In this context, the designation of important whale habitat, the Gully (Moors-Murphy, 2014), as a marine protected area in 2004 and the subsequent reduction in anthropogenic noise have been hypothesized to have contributed to the increase in Sowerby's beaked whales and the stability of endangered northern bottlenose whales in the area (O'Brien & Whitehead, 2013; Whitehead, 2013). These findings underscore the potential of acoustic sanctuaries in aiding the recovery of at-risk species and emphasize the need to explore similar strategies in other habitats to ensure the well-being and persistence of vulnerable cetacean populations.

An acoustic sanctuary suitability analysis serves as a valuable approach to identify potential areas that can be considered acoustic sanctuaries, characterizing them, in part, by low noise levels. Geographic Information Systems (GIS)-based multicriteria decision analysis (MCDA) is a powerful tool that has been used in habitat suitability analyses to identify areas that are most suitable for conservation efforts (Mendoza & Martins, 2006). This method allows for the integration of multiple criteria, such as habitat quality, species distribution, and distribution of anthropogenic activities, to evaluate the suitability of different areas for protection (Katsanevakis, 2011; Saaty, 1980). MCDA has been successfully used in previous studies to identify suitable regions for marine protected areas, fisheries management, and other conservation planning applications (Huang et al., 2011; Store and Kangas, 2001), as well as for acoustic sanctuaries (Drackett and Dragićević, 2021).

Given that it has been applied successfully in other studies, the primary objective of this study was to employ an MCDA to identify suitable locations for the establishment of acoustic sanctuaries on the Scotian Shelf. The analysis focused on exploring the overlap between vessel traffic and spatial information on SARA-listed cetacean habitat, such as critical habitat, important habitat, as well as distribution data including the outputs of species distribution models (SDM). For this study, suitable areas were defined as those characterized by the presence of SARA-listed cetacean habitat and low vessel density. The choice to prioritize vessel traffic in this analysis was based on several factors: the availability of comprehensive vessel data compared to other noise sources, the significant contribution of vessels to overall noise levels on the Scotian Shelf (Walmsley & Theriault, 2011), and the existence of legal frameworks, such as the *Fisheries Act* (1985), *Oceans Act* (1996), *Canada Shipping Act* (2001), and the SARA (2002), that have the potential to address vessel noise (Green, 2022). Furthermore, the focus on SARA-listed cetacean habitats was justified by their conservation status and the recognition of vessel noise as a threat to their survival. Therefore, understanding the overlap between vessel noise and the occurrence of these species is crucial for informing recovery and management measures. The MCDA approach employed in this study was used to reveal existing locations that are suitable for enhanced protection measures specifically related to noise from vessels. The report also discusses the legal frameworks for implementing acoustic sanctuaries, highlighting the opportunities and challenges associated with this approach for protecting cetaceans on the Scotian Shelf.

2.0 METHODS

2.1 Spatial Information on SARA-Listed Cetaceans

Most cetacean sightings on the Scotian Shelf are opportunistic, and comprehensive systematic surveys that cover the entire region are limited (Gomez-Salazar & Moors-Murphy, 2014). Given this limitation, this study aimed to bridge this data gap by utilizing informative spatial information readily accessible for SARA-listed cetacean species on the Scotian Shelf. While refined distribution data for the entire region is not available, suitable proxies with varying quality were considered to approximate key presence areas for each species within the region. This study integrated three types of spatial information (Figure 1): 1) Critical habitat, designated and protected under SARA, encompasses habitat necessary for the survival and recovery of endangered, threatened, or special concern species (SARA, 2002). 2) Important habitat denotes areas recognized as significant for the species but lack the same legal designation or regulatory requirements as critical habitat (DFO, 2020c). 3) Distribution data representing the estimated species distribution or the priority areas for enhanced monitoring derived from SDM efforts (Gomez et al., 2020; Government of Canada, 2023).

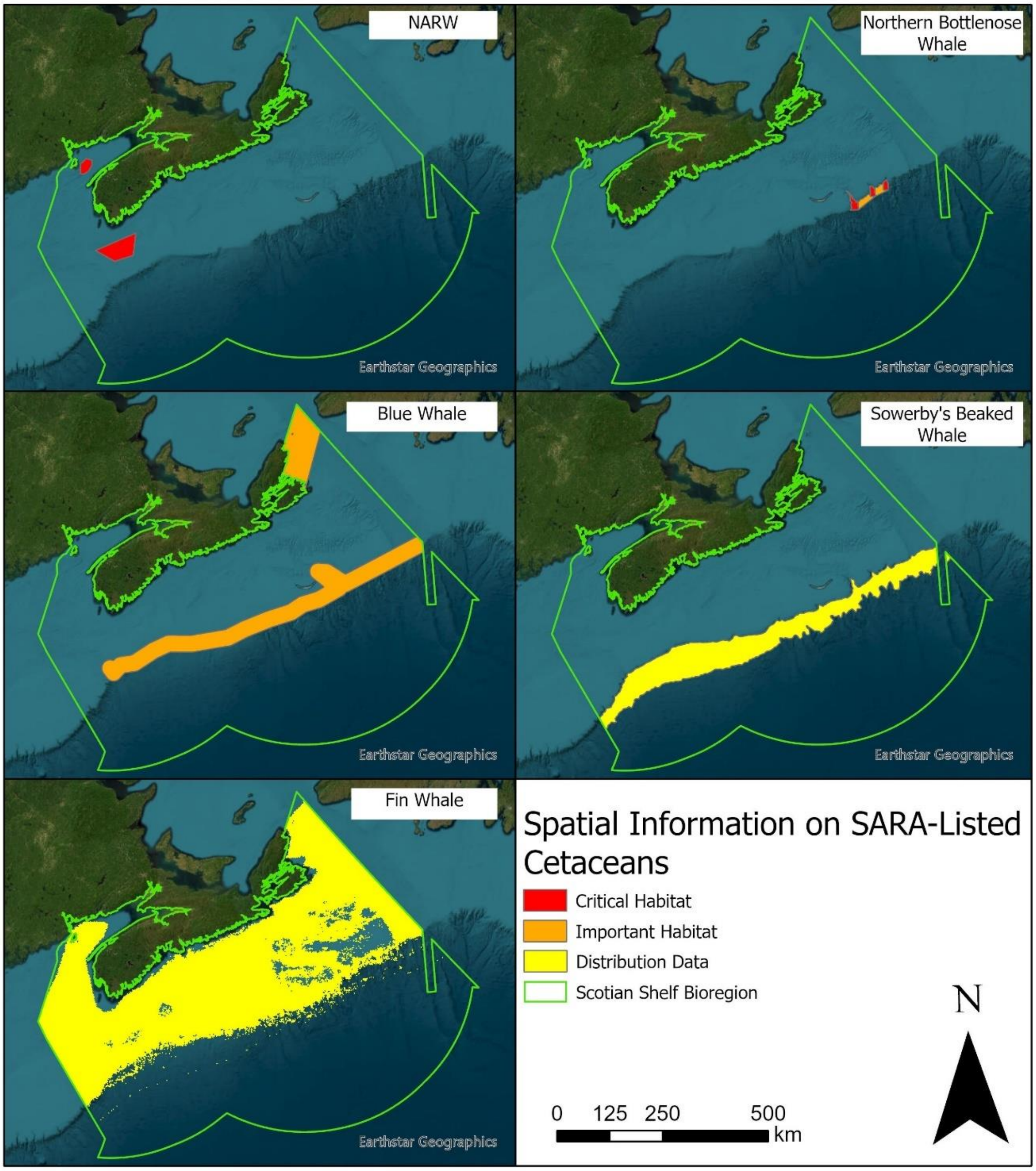

Figure 1: Spatial information on SARA-listed cetaceans in the study area, the Scotian Shelf Bioregion. Top left: critical habitat for NARW (DFO, 2014); top right: critical habitat and important habitat for northern bottlenose whales (DFO, 2016; Stanistreet et al., 2021); middle left: important habitat for blue whales (Lesage et al., 2018); middle right: estimated distribution of Sowerby's beaked whales (Government of Canada, 2023); bottom left: species distribution model for fin whales, representing highly suitable habitat (60-100%) where enhanced monitoring efforts may be prioritized (Gomez et al., 2020). Geospatial data for the Scotian Shelf boundary was imported from the Government of Canada Open Data Portal (Government of Canada, 2021).

While most of the spatial information used in this study focused on critical behaviours and ecological requirements of each species, they did not fully represent the general distribution patterns of the SARA-listed species' habitats (Table 1). The critical habitat datasets for NARW and northern bottlenose whales, obtained from the Government of Canada Open Data Portal (ECCC, 2022), were determined using the "Area of Occurrence Approach" which establishes boundaries based on sightings data and assumes the presence of necessary habitat functions and features for species survival or recovery (DFO, 2016; DFO, 2014). Despite this approach, critical habitat designations do not encompass other significant habitat areas for these species. For instance, the Cabot Strait and the Gulf of St. Lawrence are known to be traversed by NARW in substantial numbers and are key areas for their seasonal migration (Transport Canada, 2023), however, explicit spatial information in these areas remains unavailable and was therefore not included in this analysis.

Similarly, recognized important habitat datasets also contain spatial limitations. The data identifying important habitats for northern bottlenose whales, derived from PAM and visual and acoustic surveys, obtained from Stanistreet et al. (2021), was limited to the Eastern Scotian Shelf (DFO, 2020b). As a result, there is a possibility that other important habitat areas for this species remain unidentified. The identified important habitat for blue whales, obtained from Lesage et al. (2018), was determined using species-presence data in combination with environmental variables, representing areas important for foraging, feeding, and socializing (DFO, 2018a; DFO, 2020c; Lesage et al., 2018). These areas were derived from various data sources, such as whaling catch records, PAM, visual and acoustic surveys, species distribution modelling, and distribution information of observed or predicted prey (krill) aggregations (DFO, 2018a). Nevertheless, it remains unknown whether the identified important habitats are sufficient to ensure the survival of blue whales, and they may not fully represent the species' complete seasonal distribution patterns (DFO, 2018a).

For Sowerby's beaked whales, the distribution data were obtained from the Government of Canada Open Data Portal (Government of Canada, 2023) and were primarily derived from visual sightings, acoustic detections, and stranding information (COSEWIC, 2019; DFO, 2017c). However, detailed information on the temporal and spatial habitat use within these areas is not well known, as much of this data was collected opportunistically and tends to be concentrated in areas with higher survey efforts on the Scotian Shelf (COSEWIC, 2019; Whitehead, 2013). As a result, the lack of visual or acoustic detections outside of the habitat boundary does not necessarily indicate a lack of species presence.

Lastly, the SDM for fin whales was obtained from Gomez et al. (2020) and derived from sightings information and environmental variables to predict areas of high habitat suitability where fin whales are likely to occur, and therefore priority areas where monitoring efforts may be targeted. These results do not necessarily indicate actual species presence.

To determine the areas of greatest overlap between the spatial information on SARA-listed cetaceans, and thereby identifying areas where acoustic sanctuaries could have the greatest impact, a Cetacean Importance Index was created. First, all spatial datasets were converted into a raster data model with a spatial resolution of 1 km^2. In these models, a value of 1 indicated the presence of spatial information identifying cetacean habitat, while a value of 0 indicated the area outside of the habitat boundaries. A scoring system was then applied to all species layers to quantify the relative importance of the spatial information.

As only threatened and endangered species listed on Schedule 1 of the SARA are required by law to have their habitat protected (SARA, 2002, s. 58(1)), the spatial information that was designated "important habitat" or "critical habitat" for NARW, northern bottlenose whales, and blue whales were given precedence in the analysis to reflect the urgent need for conservation measures to improve their population status. The habitat layers were assigned a score between 0 and 10, where 10 represented habitat areas of cetaceans with an endangered status under SARA (i.e., requiring the highest level of protection), and subsequent SARA statuses were assigned decreasing scores by a factor of 2 (e.g., threatened = 8, special concern = 6, data deficient = 4, not at risk = 2). Based on this system, a score of 10 was assigned to the habitat layers of NARW, northern bottlenose whales, and blue whales, and a score of 6 was assigned to the habitat layers of Sowerby's beaked whales and fin whales (Table 1). Areas outside of the spatial information on SARA-listed cetaceans were assigned a value of 0.

Once the data layers were scored, a geospatial analysis technique called a Boolean overlay was employed to identify areas of overlap between the spatial information on SARA-listed cetaceans. This overlay combined all layers of spatial information on SARA-listed cetaceans to generate a new layer representing the intersection of the original layers: the Cetacean Importance Index (Malczewski & Rinner, 2015). In typical Boolean overlays, grid cells that have a value of 0 would be excluded from further analysis (Malczewski & Rinner, 2015). However, given the highly mobile nature of cetaceans and the limitations in data coverage, areas that are outside of the delineated habitat boundaries were still considered for further protection as a value of 0 does not necessarily indicate species absence. This approach ensured that important areas beyond the delineated habitat boundaries were not overlooked in the analysis.

The overlay was completed using the following equation in each grid cell:

$$\text{Cetacean Importance Index} = (H_{NBW}*10) + (H_{NARW}*10) + (H_{BW}*10) + (H_{FW}*6) + (H_{SBW}*6)$$

Where H equals the cetacean habitat layer raster values (0 or 1). The minimum possible value was 0 and the maximum possible value was 42. However, the actual observed values ranged from 0 to 32.

The Cetacean Importance Index facilitated the identification of areas where the habitat layers converged, indicating areas where noise management measures would benefit the greatest number of SARA-listed cetaceans while also considering their conservation status. This Index was utilized to generate the acoustic sanctuary suitability maps in concert with vessel data, serving as a fundamental tool for determining suitable areas for acoustic sanctuaries.

Table 1: Layers of spatial information on SARA-listed cetaceans and their associated spatial uncertainties. A score value was assigned depending on their SARA-listed status, indicating the relative importance of the spatial information in the analysis.

Species (SARA Status)	Score Value	Type of Spatial Information	Link to Access Data	Reference	Sources of Uncertainty
NARW (Endangered)	10	Critical Habitat	https://open.canada.ca/data/en/dataset/db177a8c-5d7d-49eb-8290-31e6a45d786c	https://www.canada.ca/en/environment-climate-change/services/species-risk-public-registry/recovery-strategies/north-atlantic-right-whale.html#_1.9	• The legally designated critical habitat does not encompass all important areas for this species • Does not represent the seasonal variation in habitat use
Northern Bottlenose Whale (Endangered)	10	Critical Habitat	https://open.canada.ca/data/en/dataset/db177a8c-5d7d-49eb-8290-31e6a45d786c	https://publications.gc.ca/site/eng/9.830787/publication.html#:~:text=The%20Recovery%20Strategy%20for%20the%20Northern%20Bottlenose%20Whale,goals%20and%20strategies%20outlined%20in%20the%20Recovery%20Strategy	• The legally designated critical habitat does not encompass all important areas for this species
		Important Habitat	https://open.canada.ca/data/en/dataset/9fd7d004-970c-11eb-a2f3-1860247f53e3	https://publications.gc.ca/collections/collection_2020/mpo-dfo/fs70-6/Fs70-6-2020-008-eng.pdf	• Study focused on the Eastern Scotian Shelf, therefore there may remain additional important habitats not yet identified • Important habitat does not represent the entire distribution of this species
Blue Whale (Endangered)	10	Important Habitat	https://open.canada.ca/data/en/dataset/8fafd919-fcbe-43a3-a911-3d946127344	https://waves-vagues.dfo-mpo.gc.ca/Library/40687776.pdf	• Important habitat does not represent the entire distribution of this species; they represent important areas for foraging, feeding, and socializing for blue whales. • Does not represent seasonal variation in habitat use

Sowerby's Beaked Whale (Special Concern)	6	Distribution	https://open.canada.ca/data/en/dataset/e0fabad5-9379-4077-87b9-5705f28c490b	N/A	• Data was assembled by regional biologists using the best available information, including status reports, recovery potential assessments, academic literature, and expert opinion • Does not specify which areas are most important for the species • Data gaps may exist in areas with poor survey coverage
Fin Whale (Special Concern)	6	Priority Areas for Enhanced Monitoring	https://open.canada.ca/data/en/dataset/c094782e-0d6f-4cc0-b5a3-58908493a433	https://waves-vagues.dfo-mpo.gc.ca/Library/40869155.pdf	• SDM was used to predict and identify priority areas for enhanced monitoring • Habitats with high suitability are interpreted as areas where cetacean monitoring efforts may be prioritized, and results can help direct future survey efforts • Results do not necessarily indicate species occurrence

2.2 Vessel Data

Automatic Identification Systems (AIS) is a vessel tracking system that relays navigational information through radio-based transponders. The use of AIS in Canada is required of all vessels of 150 gross tonnage or greater carrying more than 12 passengers on an international voyage, vessels 300 gross tonnage or greater on an international voyage (fishing vessels exempt), all vessels of 500 gross tonnage or greater on a domestic voyage (fishing vessels exempt), and passenger ships of all sizes (*Navigation Safety Regulations*, 2020). While AIS is often used voluntarily by fishing and recreational vessels for navigational safety purposes (IMO, n.d.), it is important to note this gap in data coverage.

AIS data received by terrestrial-based receiver stations in 2019 were provided to DFO by the Canadian Coast Guard (CCG). Processed satellite AIS data from 2019 were provided by Maerospace via Orbcomm under an agreement with the Government of Canada. The two datasets were combined to form a raster data model of the number of vessels present per day per 1 km^2 (Veinot et al., 2023). See Veinot et al. (2023) for a detailed description of the steps taken to process the AIS data. This dataset was developed to map vessel class densities of satellite and terrestrial AIS data to summarize vessel patterns for 2019 (Veinot et al., 2023). Once imported into ArcPro desktop software, the AIS data were aggregated into three vessel classes: commercial vessels (cargo ships and tankers), fishing vessels, and all other vessels (passenger vessels, research vessels, tugboats, etc.) so major industries operating on the Scotian Shelf could be compared.

Within each of the three vessel classes, data layers representing the overall annual average, as well as monthly averages, of vessels per day per 1 km^2 were created. The vessel data were then sorted in ascending order based on their density values in each grid cell. A classification of 20% quantiles was used to divide the data of each layer into five equal parts, with each part representing 20% of the distribution. By focusing on the lower category within each data layer, the study aimed to identify areas that exhibited lower vessel density values that would be suitable for acoustic sanctuaries. However, it is important to note that these results are not directly comparable over the temporal scale as the quantiles were calculated on a per-month basis, thus yielding different corresponding values for each data layer. This approach was adopted to represent the relative spread of vessel density during each month and better capture temporal variations in vessel traffic.

As noise modelling was beyond the scope of this report, vessel density was used as a proxy to represent relative vessel noise levels in each grid cell. The density quantile values from each layer were scored to represent their relative importance in the suitability model. In an MCDA procedure, the scores assigned to one criterion should generally reflect the range of values for the other criteria (Malczewski, 2011). Since the Cetacean Importance Index had actual values with a maximum of 32, a linear scale of -30 to 30 was employed to roughly match the range of values, both positively and negatively. In this scale, the lowest vessel density quantile was assigned a value of 30 (signifying low vessel noise) and the values sequentially decreased by 15 as the density quantiles approached 100 (Table 2). The highest density category was assigned a value of -30 (signifying high vessel noise).

Table 2: Scoring system applied to vessel density layers. Quantile values represent the percent of vessel data points. Lower quantiles correspond to areas with lower vessel densities, which subsequently result in higher linear scale values.

Quantile Values (%)	Linear Scale Values
20	30
40	15
60	0
80	-15
100	-30

By employing the linear scale, the analysis effectively differentiated and compared the varying levels of influence of each criterion across different areas, ensuring a proportional and easily interpretable scoring (Malczewski, 2000). This approach improved the representation of the potential impact of vessel noise, aligning the values with the study's defined goal. Specifically, areas with low vessel density and high cetacean importance emerged as suitable locations for acoustic sanctuaries, while areas with high vessel density counteracted those with high cetacean importance and were deemed unsuitable for an acoustic sanctuary. The use of a linear scale provided a balanced representation of the criteria's relative importance, contributing to a more robust and comprehensive suitability assessment for establishing acoustic sanctuaries.

2.3 Identifying Optimal Locations for Acoustic Sanctuaries: Acoustic Sanctuary Suitability

The basis of an MCDA is to gather a set of input criteria, usually in a raster data model, and assign weightings that represent the relative importance of those criteria (Huang et al., 2011). These data layers are represented as values in a grid and aggregated to generate an acoustic sanctuary suitability score in a GIS application. Numerous MCDA methods have been applied in habitat suitability analyses (see Drackett and Dragićević, 2021 and Store and Kangas, 2001 for examples), however, a common approach is using a simple additive suitability model (Malczewski, 1999; Malczewski & Rinner, 2015). This involves identifying the significant criteria, transforming the values within each criterion to a common scoring scale, and assigning weights to input criteria that are representative of their relative importance to the overall decision or goal before adding them together (Dujmović & De Tré 2011; ESRI, n.d.; Massam, 1988).

This analysis used the simple additive suitability model to determine acoustic sanctuary suitability, where the previously discussed cetacean and vessel data layers were aggregated. All spatial datasets were projected to UTM Zone 20N coordinates and converted to a raster data model with a 1 km^2 spatial resolution. The MCDA method was completed in ArcPro desktop software version 2.9.3.

2.3.1 Criteria Weighting

As previously mentioned, GIS-based MCDAs include a step that applies a defined weighting to each criterion to indicate the relative importance *between* the criteria (Malczewski, 2000). Various weighting schemes can be applied to each criterion when evaluating habitat suitability (Store & Kangas, 2001). For example, this can be important when one criterion is preferred over another in consideration of the defined goal. However, given the knowledge gap surrounding the effects of vessel noise on cetaceans through space and time, as well as the noise emissions and propagation from various vessel types through the environment, the relative importance of each criterion (vessel density and the Cetacean Importance Index) were treated equally in this analysis. The pairwise comparison method, described by Saaty (1980), was used to assign the relative importance of each attribute layer. To remain unbiased, both the Cetacean Importance Index layer and vessel layer were assigned a weighting of 1 to represent equal relative importance in the analysis.

2.3.2 Acoustic Sanctuary Suitability

To generate suitability maps, the annual and monthly averaged vessel layers for each vessel category (commercial, fishing, and other vessels) were combined with the Cetacean Importance Index layer to calculate the overall suitability scores for each 1 km^2 grid cell. This process involved summing the scored vessel layers and the Cetacean Importance Index layer. The resulting scores indicated the suitability of each grid cell as an acoustic sanctuary.

In this study, the stretch classification method was employed to classify the resulting suitability scores, aiming to represent the relative acoustic sanctuary suitability across the Scotian Shelf. The stretch classification method is a technique commonly used in raster data analysis to enhance the visual representation of data based on its statistical properties (ESRI, 2021). This method assigns a specific colour gradient to represent suitability values, allowing for a clear and intuitive visualization of suitability levels. Areas with very low suitability were depicted by black and purple colours, indicating that these regions are not well-suited as acoustic sanctuaries due to the lack of identified cetacean habitat or elevated levels of vessel activity. Areas with moderate suitability were depicted by pink and orange colours, signifying that while there may be some potential for sanctuary status, there are certain limitations or factors that reduce their suitability, such as moderate levels of vessel traffic or the presence of only a single protected species. Finally, areas with high suitability were displayed in bright yellow, representing regions that are highly suitable for acoustic sanctuaries due to the presence of multiple SARA-listed cetacean habitats and low vessel density.

Determining whether an area should be classified as 'moderately' or 'highly' suitable depends on a combination of factors. For example, it could be argued that the areas with the highest conservation value, where an acoustic sanctuary would most benefit SARA-listed species, may be those with the most species present and the highest noise levels. Implementation of an acoustic sanctuary in such highly dense areas could effectively reduce the threat risk more significantly than in areas with already limited vessel traffic. However, in the context of this study, the goal was to identify acoustic sanctuaries to protect areas that are important to SARA-listed cetaceans and are relatively quiet at present, to prevent these crucial areas from becoming noisier in the future as human activities and ocean usage continue to increase on the Scotian Shelf.

3.0 RESULTS

In this study, input criteria representing the best available information for SARA-listed habitat and vessel traffic were aggregated using a pairwise comparison structure to obtain suitable locations for acoustic sanctuaries on the Scotian Shelf. The GIS-based MDCA method was used to develop suitability scores for three different vessel classes (commercial vessels, fishing vessels, and all other vessels), both using the annual and monthly averages of vessel density per class. The obtained suitability scores for each output are presented as acoustic sanctuary suitability maps.

3.1 Cetacean Importance Index

The Cetacean Importance Index (Figure 2) played a crucial role in this study by providing an understanding of the spatial interconnections among the habitat information of SARA-listed cetaceans. The Cetacean Importance Index ranged from 0 to 32. Lower values on the index indicated relatively lower importance, implying that the corresponding areas had less overlap of the SARA-listed cetacean habitat layers. Conversely, higher values on the index represented relatively higher importance, suggesting that these areas exhibited a greater overlap of the habitat layers. The convergence of multiple habitat layers in these high-value areas made them more favourable for consideration as potential locations for acoustic sanctuaries. The Cetacean Importance Index was used in this study to generate acoustic sanctuary suitability maps for the annual and monthly vessel outputs.

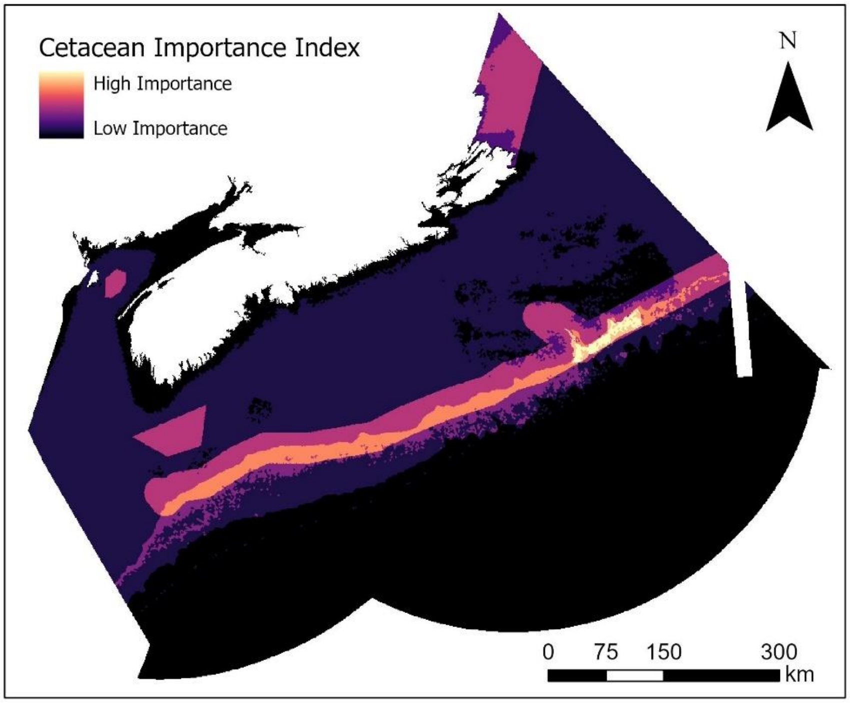

Figure 2: Cetacean Importance Index. Areas with lower importance are depicted in black and purple, indicating less overlap of spatial information on SARA-listed cetaceans. Moderately important areas are shown in pink and orange, suggesting some level of overlap with the spatial information of at least one endangered cetacean. The higher-importance areas, shown in bright yellow, demonstrate a more substantial overlap of the spatial information of multiple SARA-listed cetaceans, making them more favourable as potential locations for acoustic sanctuaries.

3.2 Annual Analysis of Acoustic Sanctuary Suitability

The suitability maps generated for each vessel category provided a comprehensive overview of the acoustic sanctuary potential on the Scotian Shelf. The suitability maps were colour-coded representations that depicted the varying levels of suitability scores across the study area. These scores helped to assess the suitability of different grid cells for acoustic sanctuaries, with brighter colours indicating greater suitability. By examining the distribution and extent of highly suitable, moderately suitable, and unsuitable areas, the maps provided valuable insights into the spatial patterns of potential sanctuary locations.

Figures 3, 4, and 5 present the results of the suitability output using the annual average of vessel densities for commercial vessels, fishing vessels, and other vessels, respectively. In these outputs, the most suitable locations for acoustic sanctuaries were along the continental shelf. Most notably, the Grand Manan Basin, south Sable Island Bank extending toward the Gully, and Haldimand Canyon emerged as suitable for a sanctuary in the commercial vessel output (Figure 3). The Gully, Shortland Canyon, Haldimand Canyon and inter-canyon areas were also highly suitable for the fishing and other vessel outputs (Figures 4 and 5).

Several areas of low suitability were also visible in the suitability maps, indicative of highly dense vessel traffic. These areas occurred in shipping lanes, fishing areas, and other regions with concentrated vessel activity. Along the shipping lanes, such as the routes connecting Canada to Europe and the United States, there was a prominent presence of low-suitability areas due to the high density of commercial vessel traffic. Similarly, coastal areas were low on the suitability scale in the fishing vessel output, reflecting the intense fishing activity in these areas.

The suitability maps also revealed the presence of moderately suitable areas, which were regions that may have some potential for accommodating acoustic sanctuaries but with certain limitations. These areas often occurred adjacent to the highly suitable regions, providing potential buffer zones or transitional spaces between high and low-suitability areas. They offer opportunities for managing vessel activity and reducing the impacts of underwater noise on cetaceans while considering the practical aspects of implementing sanctuary measures.

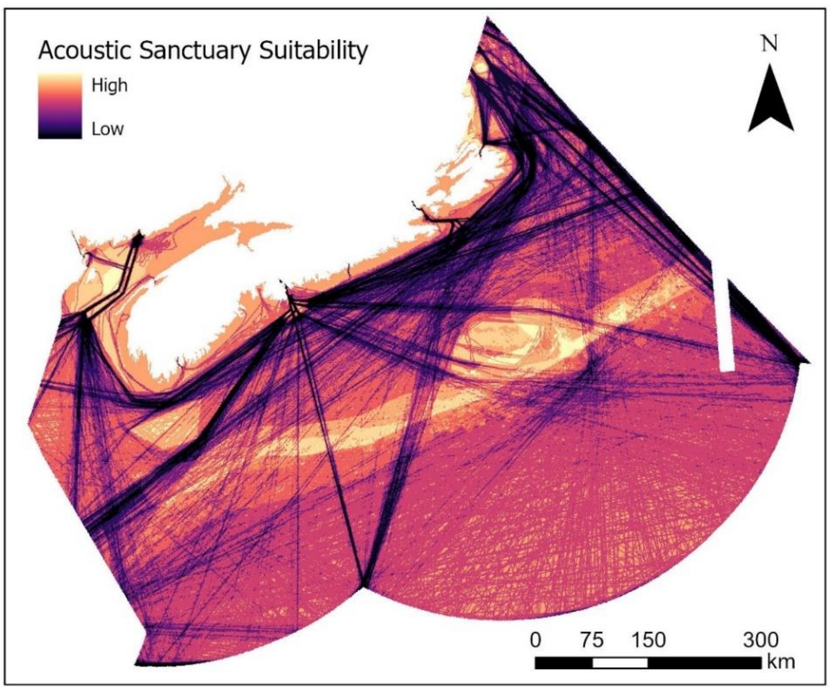

Figure 3: Resulting suitability map for the annual average of commercial vessels. Highly suitable areas for acoustic sanctuaries emerged in the Grand Manan Basin, south Sable Island Bank extending toward the Gully, and Haldimand Canyon, as indicated by the lighter-coloured areas. AIS data from 2019 with a spatial resolution of 1 km^2 was used in the analysis.

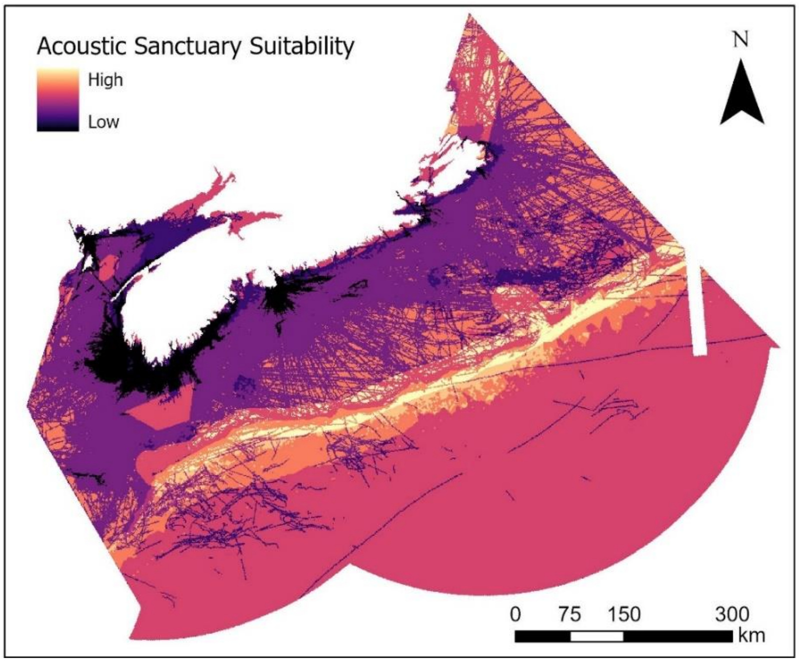

Figure 4: Resulting suitability map for the annual average of fishing vessels. Highly suitable areas for acoustic sanctuaries emerged in the Gully, Shortland Canyon, Haldimand Canyon and inter-canyon areas, as indicated by the lighter-coloured areas. AIS data from 2019 with a spatial resolution of 1 km^2 was used in the analysis.

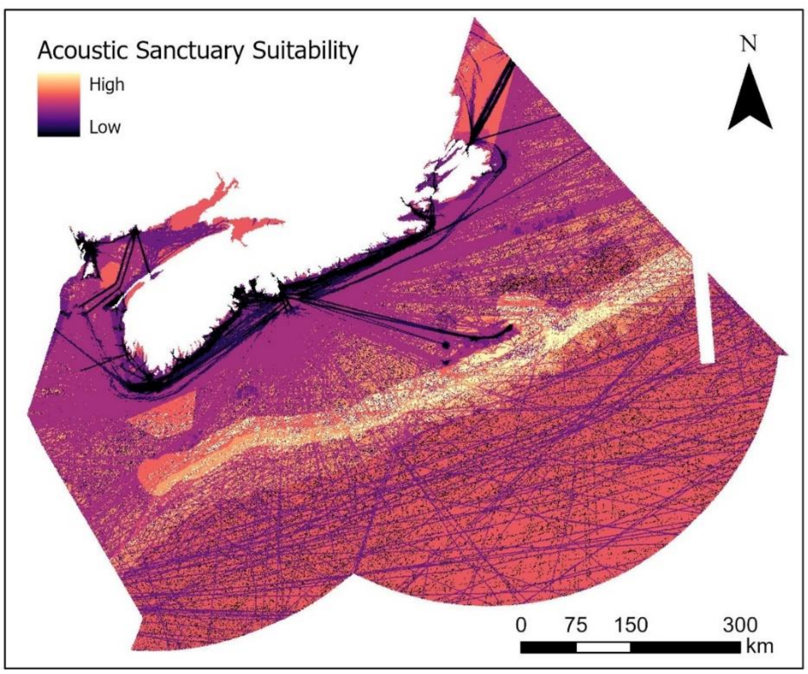

Figure 5: Resulting suitability map for the annual average of other vessels. Highly suitable areas for acoustic sanctuaries emerged in the Gully, Shortland Canyon, Haldimand Canyon and inter-canyon areas, as indicated by the lighter-coloured areas. AIS data from 2019 with a spatial resolution of 1 km^2 was used in the analysis.

3.3 Monthly Analysis of Acoustic Sanctuary Suitability

Figures 6, 7, and 8 present the results of the suitability analysis for acoustic sanctuaries based on a monthly analysis of vessel density for commercial vessels, fishing vessels, and other vessels, respectively, within the Scotian Shelf. The monthly breakdown allowed for a more detailed examination of the temporal dynamics and potential seasonal patterns in sanctuary suitability.

In the analysis of commercial vessels, it was observed that like the annual average, the Gully and the Haldimand Canyon consistently exhibited high suitability scores, indicating their significance as potential sanctuary locations (Figure 6). However, Grand Manan Basin, as well as South Sable Island Bank, demonstrated moderate suitability scores and the latter was separated from the Gully region by a region of highly dense vessel traffic. Furthermore, the Roseway Basin appeared to be a moderately suitable area in June through October and December, suggesting seasonal variation in vessel density that should be considered in sanctuary planning.

In the fishing vessel output, the analysis revealed that the Gully, Shortland Canyon, Haldimand Canyon, inter-canyon areas, and locations along the continental shelf consistently demonstrated high suitability scores (Figure 7). These areas are associated with important habitat features for SARA-listed cetaceans, making them promising candidates for sanctuary designation. Notably, there was a marked increase in fishing vessel activity along the continental shelf in August and September, indicating a peak in fishing activity during these months.

Similarly, in the other vessel scenario, high suitability scores were observed in the Gully, Shortland Canyon, Haldimand Canyon, inter-canyon areas, and along the continental shelf (Figure 8). These locations consistently demonstrated their importance as potential sanctuary areas for SARA-listed cetaceans. Unlike fishing vessels, commercial vessels and other vessels showed relatively consistent densities throughout the year, indicating a more stable absence in these areas.

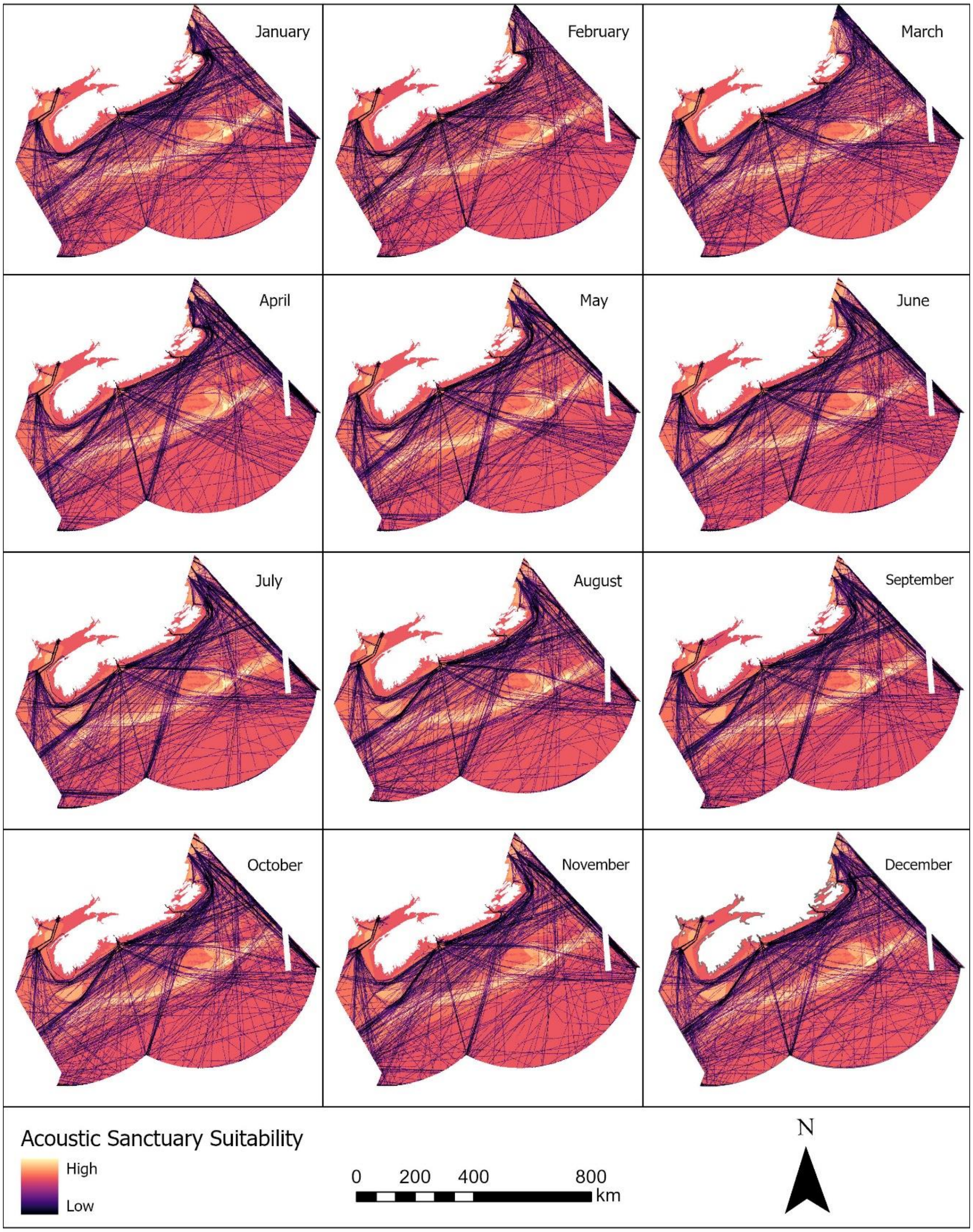

Figure 6: Suitability maps for the monthly breakdown of commercial vessels. Highly suitable areas for acoustic sanctuaries emerged in the Gully and the Haldimand Canyon, as indicated by the lighter-coloured areas. AIS data from 2019 with a spatial resolution of 1 km^2 was used in the analysis.

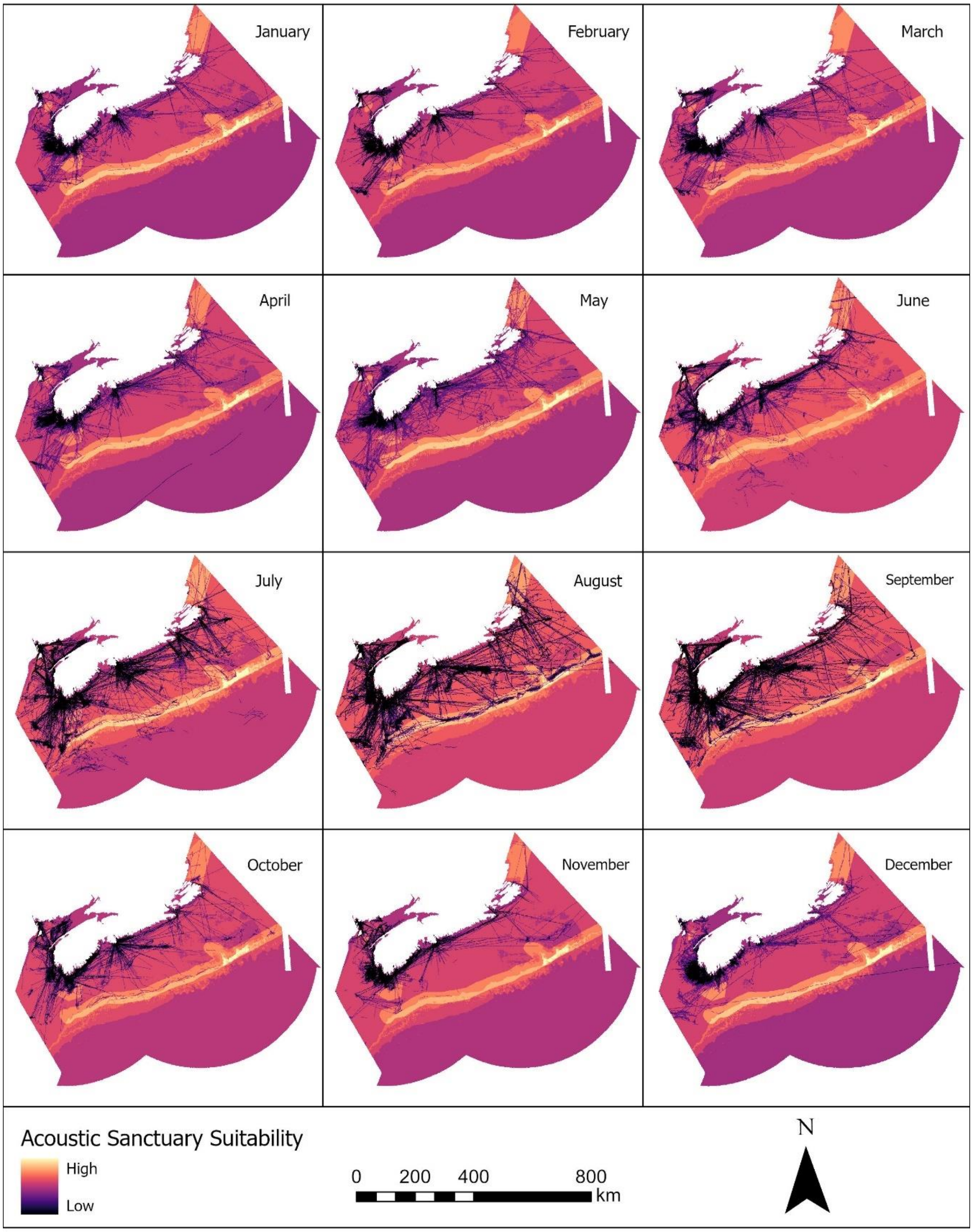

Figure 7: Suitability maps for the monthly breakdown of fishing vessels. Highly suitable areas for acoustic sanctuaries emerged in the Gully, Shortland Canyon, Haldimand Canyon, inter-canyon areas, and locations along the continental shelf, as indicated by the lighter-coloured areas. AIS data from 2019 with a spatial resolution of 1 km^2 was used in the analysis.

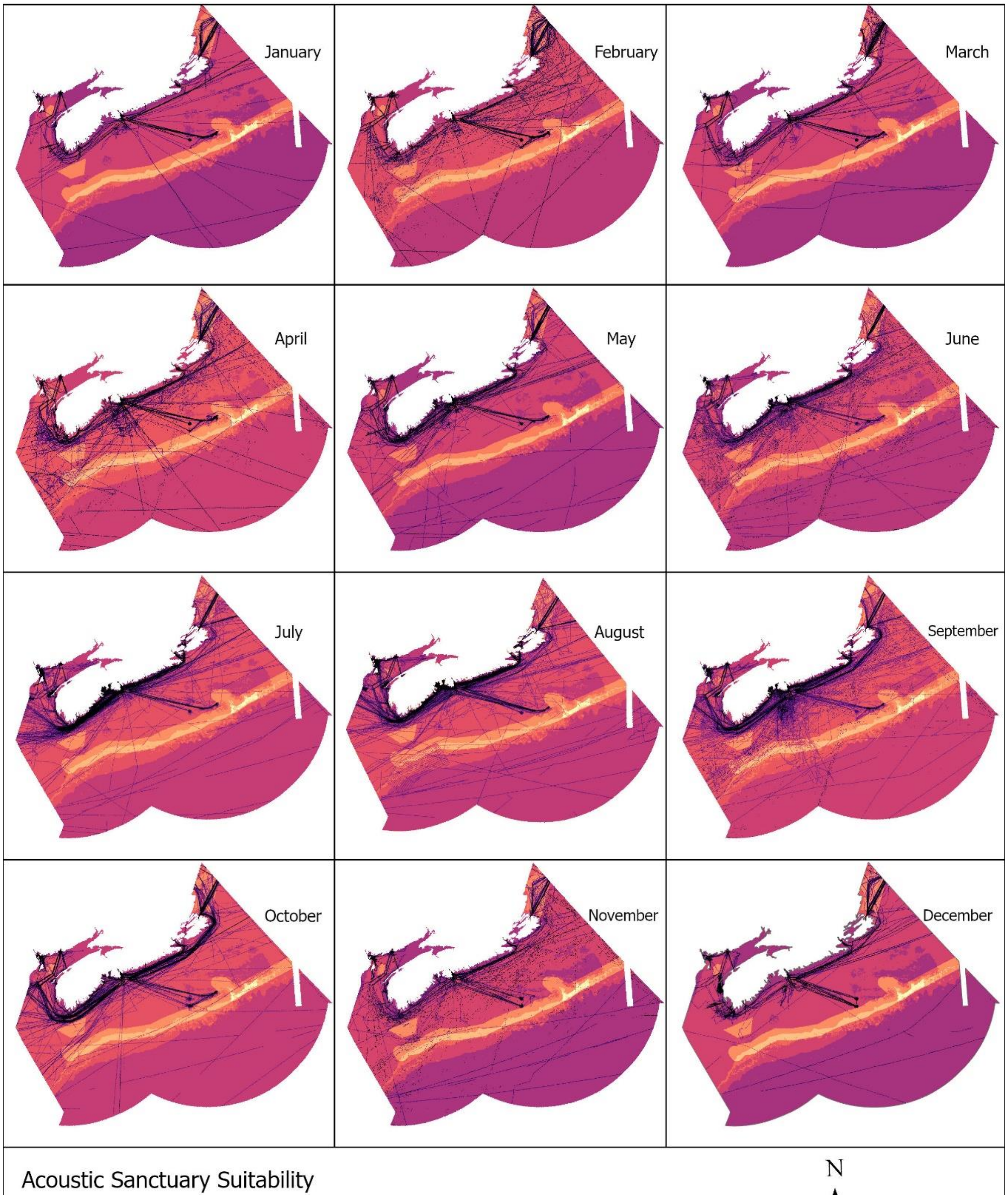

Figure 8: Suitability maps for the monthly breakdown of other vessels. Highly suitable areas for acoustic sanctuaries emerged in the Gully, Shortland Canyon, Haldimand Canyon, inter-canyon areas, and along the continental shelf, as indicated by the lighter-coloured areas. AIS data from 2019 with a spatial resolution of 1 km^2 was used in the analysis.

4.0 DISCUSSION

4.1 Highly Suitable Areas for Further Protection

This study, similar to previous research on sound exposure risk (Williams et al., 2015a; Cominelli et al., 2018), employed habitat data based on population density, sighting locations, and SDMs along with AIS vessel traffic data to compute suitability scores for potential acoustic sanctuary locations. Comparing the annual suitability maps across different vessel classes and the monthly suitability maps within each vessel class provided valuable insights into suitable areas for establishing acoustic sanctuaries where cetaceans could be protected from any future increase in underwater noise. The results revealed two key areas on the Scotian Shelf, namely the Gully and Haldimand Canyon, which met the criteria of being important cetacean habitat with low vessel density across various vessel types throughout the year. These locations exhibit a favourable combination of habitat that is utilized by multiple at-risk cetacean species and limited vessel activity, making them promising candidates for implementing acoustic sanctuary measures to protect SARA-listed cetacean species from the adverse impacts of underwater noise.

These results lay the groundwork for focused conservation efforts and the development of targeted noise management strategies, supporting the SARA-listed species recovery measures outlined in their respective recovery documents (e.g., DFO, 2014, 2017a, 2017b, 2017c, 2020a). Moreover, these findings align with Whitehead's initial hypothesis in 2013, suggesting that mitigating underwater noise could potentially foster the population growth of cetacean species in these regions, further validating the significant importance of these areas as potential acoustic sanctuaries for cetaceans. However, while these areas prove beneficial for several SARA-listed species examined in this report, their advantages may vary for each species. For example, NARWs, being migratory and tending to congregate in areas outside of the identified acoustic sanctuaries (DFO, 2018c), may not derive the same level of benefits from the protection of these areas as other species. Nonetheless, the Gully and Haldimand Canyon still offer significant benefits for beaked whales, particularly northern bottlenose whales, as they inhabit these areas year-round (DFO, 2017a).

While this analysis only considered the temporal dynamics of vessel activity, the monthly analysis of each vessel type not only provided a more precise depiction of suitable sanctuary locations but also unveiled the potential for implementing a dynamic management system. This approach effectively captured variations in vessel activity across specific areas and at various times, allowing for the possibility of seasonal relocation or adaptive boundaries for the sanctuary (Maxwell et al., 2015). For instance, even during months of increased fishing activity along the continental shelf, highly suitable areas remained consistent with the commercial and other vessel outputs. This indicates the feasibility of employing a dynamic approach to manage fishing activity and mitigate the impact of underwater noise during busier periods and when a greater number of baleen whales are present on the Scotian Shelf (Davis et al., 2020; DFO, 2014). Similar dynamic management strategies have proven successful in the Stellwagen Bank National Marine Sanctuary (SBNMS) in the United States, where measures such as rerouting shipping lanes, implementing speed reduction strategies, and employing PAM have successfully reduced vessel collisions with baleen whales (U.S. Office of National Marine Sanctuaries, 2010). Furthermore, the "Whale Alert" app has facilitated the introduction of short-term, dynamic management areas through fishing closures, speed restrictions, and avoidance zones throughout Eastern American waters (NOAA, 2022).

Other spatiotemporal avoidance measures have demonstrated successful outcomes in reducing vessel traffic and enhancing suitability scores in specific areas. For instance, the International Maritime Organization (IMO) sanctioned Area to be Avoided (ATBA) and Traffic Separation Scheme (TSS) in the Roseway and Grand Manan Basins, respectively, have contributed to the moderate-high suitability scores observed in these areas. The seasonal closure of the Roseway ATBA, as reported by Vanderlaan & Taggart (2009), resulted in a significant reduction in vessel traffic from June through December. Similarly, the amended TSS in the Grand Manan Basin successfully rerouted vessels to avoid collisions with NARW, as highlighted by Vanderlaan et al. (2008). These examples underscore the potential of dynamic management practices in effectively addressing vessel-related challenges and optimizing the functioning of acoustic sanctuaries for protecting cetacean habitats on both a spatial and temporal scale.

However, to make more informed management decisions and truly optimize the functioning of acoustic sanctuaries, it is crucial to consider the cumulative effects of underwater noise, especially for species already threatened by other anthropogenic stressors such as ship strikes, fishing gear entanglements, and oil spills (Wright, 2014). While this study identifies potential locations for acoustic sanctuaries, it does not analyze the propagation and accumulation of underwater noise. Therefore, interpreting the suitability maps for management decisions requires caution, as they do not incorporate the risk factor associated with proximity to high-density shipping lanes. As previously noted, the Grand Manan and Roseway Basins within the NARW critical habitat emerged as somewhat suitable in the commercial vessel outputs (Figures 3 and 6). However, these results do not account for the accumulating nature of noise from the surrounding high-density shipping lanes. Accordingly, it has been determined that NARWs experienced increased stress levels when exposed to noisy habitats near shipping traffic lanes (Rolland et al., 2012). Given that louder and lower-frequency sounds can travel long distances before attenuating (Hatch & Fristrup, 2009), the potential impacts of noise on cetaceans in these areas are not adequately reflected in this analysis.

The MCDA analysis did, however, expose the impact of high vessel density on suitability scores in localized areas. Designated shipping lanes and coastal fishing areas exhibited low to moderate suitability scores, indicating that these regions may be more susceptible to increased noise impacts on cetaceans and are less suitable for acoustic sanctuaries. However, the interpretation of suitability scores must be carefully considered. Some areas with high vessel traffic but hosting multiple SARA-listed cetacean habitats were classified as having moderate suitability. This is important because an acoustic sanctuary should not be deemed suitable if noise levels are likely to disrupt animal behaviour or impair the functionality of their habitat (Drackett & Dragićević, 2020). While these areas should, theoretically, not be considered for the establishment of acoustic sanctuaries, large knowledge gaps surrounding the impacts of various noise levels on cetaceans presented challenges for quantifying the effect of high vessel density in these habitats. Furthermore, the correlation between vessel density and noise emissions, supported by previous studies (e.g., Veirs et al., 2016), emphasizes the challenge posed by concentrated vessel traffic for noise management. It further captures the need for targeted mitigation measures and noise reduction strategies in sanctuary-adjacent high-density regions to minimize disturbance to vulnerable marine species and foster optimal conditions for the establishment of acoustic sanctuaries that effectively safeguard cetacean habitats.

Moderately suitable areas were also characterized by minimal vessel traffic and minimal presence of cetacean habitat. Similarly, the interpretation of these areas should be carefully considered. In these cases, moderately suitable areas may offer viable options for the application of an acoustic sanctuary management framework as the movement of cetaceans on the Scotian Shelf is not constrained within the boundaries of the spatial information obtained for each species (Gomez et al., 2020). Therefore, it is essential to consider not only vessel traffic but also the specific habitat requirements and behavioural patterns of cetaceans when evaluating the suitability of areas for the establishment of effective acoustic sanctuaries. The specific classification criteria and thresholds for determining moderate versus highly suitable areas can vary based on management objectives and the conservation priorities in the region and should be defined in consultation with relevant stakeholders and experts in the field, however, this was beyond the scope of this report.

The identification of only a small proportion of highly suitable areas on the Scotian Shelf, specifically the Gully and Haldimand Canyon, as potential acoustic sanctuaries raises concerns regarding the limited availability of suitable habitats for the protection of marine soundscapes. This study focused solely on noise generated by vessels, highlighting the need for further research to assess and address other sources of underwater noise in the region. The fact that such a small number of areas were identified as potential sanctuaries within a bioregion heavily occupied by various human activities emphasizes the urgency and importance of these findings. Swift action must be taken to recognize and preserve these areas to ensure the long-term health and well-being of marine species and their acoustic environments. Moreover, the limited availability of acoustic sanctuary opportunities on the Scotian Shelf necessitates careful consideration and strategic planning to effectively balance conservation objectives with sustainable human activities (Williams, 2014b). In doing so, stakeholders and decision-makers can collaboratively work towards achieving effective marine conservation while promoting responsible and sustainable ocean use.

4.2 Limitations

In interpreting the results of the MCDA analysis, it is important to recognize and consider the limitations within the datasets, including incomplete species distribution models, gaps in AIS coverage, and the assumptions made while processing the data in the MCDA method used.

4.2.1 Spatial Information on SARA-Listed Cetaceans

One limitation of this study pertains to the potential for incomplete or inaccurate datasets used for species distribution modelling and identifying critical and important habitats. Species distribution models rely on available data, which may suffer from limitations in spatial coverage and data gaps. Factors such as sampling bias, limited survey efforts, and incomplete data coverage can influence the information used in these models (Jiménez-Valverde et al., 2009). Furthermore, the accuracy of these models is contingent upon the quality of input data and the assumptions made during the modelling process (Elith & Graham, 2009). Similarly, the identification of critical or important habitat by DFO may be based on available data at the time, which could be subject to limitations such as spatial resolution or data quality (ECCC, 2016).

Another limitation of the study relates to the reliance on certain assumptions and simplifications during the analysis. While the spatial information on SARA-listed cetaceans aims to illustrate areas that support listed species' life processes and fulfill population and distribution objectives (ECCC, 2016), it is worth considering whether other areas could have been equally important for protection if more accurate and robust data were available. For instance, assigning a score of zero to all areas outside of designated habitat boundaries inherently restricts the potential for identifying acoustic sanctuary locations, as these boundaries do not fully represent the species' complete distributions (see section 2.1). Additionally, the absence of data on the seasonal preferences of migratory SARA-listed baleen species (blue whale, NARW, and fin whale) in the monthly suitability maps limits the representation of their habitat use, and thus, the potential relative importance of different areas for these species throughout the year.

Enhancing our understanding of the specific locations where SARA-listed cetaceans engage in various life functions, including their seasonal preferences, holds immense potential for advancing the development of more comprehensive scoring and weighting schemes for the data layers. This, in turn, would significantly enhance the overall accuracy and reliability of the suitability scores in both the annual and the monthly suitability outputs. By identifying the precise areas where cetaceans prefer to engage in critical activities such as feeding, breeding, socializing, and migration, we can better prioritize the allocation of acoustic sanctuary management measures and optimize conservation efforts.

4.2.2 Vessel Data

It is possible that vessel density was underestimated in this study due to a variety of factors impacting the accuracy and coverage of AIS datasets. While some fishing and recreational vessels voluntarily use AIS for collision avoidance (Iacarella et al., 2020), not all fishing vessels on the Scotian Shelf are required to use AIS transponders, resulting in limited coverage of fishing vessels (IMO, n.d.). Moreover, errors can occur in AIS messages due to equipment malfunctions or human error during data entry (Harati-Mokhtari et al., 2007), and operators may manipulate or falsify transmitted information, potentially creating data gaps and affecting the assessment of suitability for acoustic sanctuaries (Iacarella et al., 2020). Temporal gaps in satellite data can occur due to variations in satellite passes (Iacarella et al., 2020). Furthermore, terrestrial data only extend to 50 nautical miles, creating a spatial limitation (Iacarella et al., 2020).

In addition to these limitations, the spatial and temporal scales of the datasets used in this study may introduce further constraints. Species distribution models or habitat datasets may have been developed or identified at a different scale than the vessel data obtained from the AIS, which can lead to inconsistencies or biases in the analysis (Hirzel et al., 2006). Furthermore, by considering only one year of data (2019), the study assumes that vessel patterns remain relatively consistent within each vessel class from year to year. However, this approach may overlook shorter- and longer-term variations in habitat use or vessel traffic patterns, potentially limiting the comprehensive understanding of vessel dynamics (Hirzel et al., 2006).

Using AIS data to estimate underwater noise also poses certain challenges, as vessel density does not always directly correspond to noise levels. While the suitability maps in this study illustrate vessel tracks within areas of high shipping traffic, a high level of caution should be taken when considering these results in the context of policy and decision-making, as the study does not reflect actual noise emissions from vessels due to data limitations and gaps.

Understanding the potential for noise to extend beyond high-density vessel areas highlights the importance of using noise metrics and propagation models that consider multiple factors within the MCDA methodology. However, accurately quantifying the distance over which vessel noise impacts cetaceans is extremely challenging due to variations in sound propagation environments and noise emissions from different vessel characteristics. Environmental variables such as water temperature, salinity, and seabed characteristics, as well as differences in the intensity level and frequency of noise emitted from vessels based on their size, speed, engine type, and propeller specifications all play a role in noise propagation and its impact on cetaceans (Bahtiarian, 2019; Veirs et al., 2016). Therefore, studies that strive to integrate additional data sources, such as actual noise measurements, species-specific sensitivity to noise, and the influence of local environmental conditions, would refine our understanding of noise propagation patterns and enable more accurate assessments of the suitability of acoustic sanctuaries.

Lastly, this study focuses specifically on the noise generated by vessels and does not consider other sources of underwater noise. While vessel noise is a significant contributor to the underwater soundscape on the Scotian Shelf, various other anthropogenic activities generate underwater noise, such as seismic surveys, pile driving, and other marine construction (Walmsley & Theriault, 2011). Integrating these additional noise sources into the proposed methodological approach would provide a more comprehensive assessment of underwater noise in the study area.

4.2.3 Data Processing: The MCDA Method

It is important to acknowledge that MCDA involves subjective judgments and the assignment of weights to criteria, which can introduce biases or uncertainties (Roy, 1996). The selection of criteria and their relative importance may vary depending on stakeholder perspectives or expert opinions, potentially affecting the final results (Store & Kangas, 2001). Altering the values or classification of the scored criteria can lead to significant shifts in the identification of highly suitable locations. Furthermore, neglecting potential interactions among the criteria by assuming equal weights in the MCDA can influence the visual interpretation of the suitability maps (Malczewski, 2006). These limitations highlight the subjective nature of the MCDA approach and emphasize the need for careful consideration and transparency when applying this method in decision-making processes related to the identification of acoustic sanctuaries.

4.3 Management Implications

The identification of potential areas for acoustic sanctuaries on the Scotian Shelf presents a valuable opportunity to implement effective management tools for protecting cetacean species and mitigating the impacts of anthropogenic noise (Williams et al., 2015a). Achieving this goal requires striking a delicate balance between reducing noise impacts on sensitive species and minimizing disruptions to vessel activities. The suitability analysis aimed to identify relatively quiet areas, seeking a compromise that allows for some reduction in underwater noise without causing major disruptions to human users. While reducing vessel traffic in areas with the highest concentration of SARA-listed species may reduce risks to the greatest extent, a more feasible approach is to focus on highly suitable regions for implementing more stringent noise management measures, rather than attempting to restore quiet in areas already experiencing high levels of vessel traffic (Williams et al., 2015b).

Considering different vessel classes (such as commercial, fishing, and other vessels) separately is important as different vessel types are managed differently within the Canadian governance system and exhibit distinct noise profiles (Veirs et al., 2016). Understanding the specific characteristics and impacts associated with each vessel type enables the formulation of tailored strategies and guidelines. These may include the implementation of speed restrictions (Joy et al., 2019), routing measures (DFO, 2022a), fishing closures (DFO, 2018b), and the adoption of vessel-specific noise reduction technologies (Harris, 2017; IMO, 2014).

While the potential for establishing acoustic sanctuaries on the Scotian Shelf is evident, the current Canadian legislation that has the potential to address underwater noise, including the SARA (2002), the *Fisheries Act* (1985), the *Oceans Act* (1996), and the *Canada Shipping Act* (2001), needs to be revisited. These Acts enable DFO authority to take certain measures with respect to marine species and habitats, including the authority to establish marine protected areas (MPAs) and the protection of critical habitats. However, they do not explicitly regulate or manage underwater noise to address the unique requirements of acoustic sanctuaries. For instance, while the Gully MPA contains some of the most suitable areas for an acoustic sanctuary and has been hypothesized to have led to a reduction of the impacts of underwater noise on certain cetacean species (O'Brien & Whitehead, 2013; Whitehead, 2013), explicit regulations or guidelines specifically targeting noise do not exist within the MPA. Despite mariners voluntarily adhering to the issued Notices to Mariners, resulting in reduced vessel density and increased suitability for an acoustic sanctuary, noise may still penetrate the highly suitable area. The absence of noise regulations and specific noise management measures highlights the necessity for additional regulatory actions or amendments to the existing legislation, emphasizing the need to address this gap and provide dedicated protection for an acoustic sanctuary within the Gully MPA.

To establish effective acoustic sanctuaries, the limitations of the current legislation must be addressed and the overlap between proposed sanctuaries and designated MPAs or critical habitats must be considered. By doing so, it becomes possible to leverage ongoing conservation efforts and strengthen the protection of vulnerable marine species. Aligning the management tools and objectives with the local SARA-listed species, oceanic conditions, and anthropogenic activities will be crucial for facilitating the successful implementation of an acoustic sanctuary management framework and ensuring the long-term sustainability of marine environments in the region. Therefore, it is imperative to explore opportunities for incorporating explicit noise regulations and guidelines into the existing Canadian legislation and available management frameworks, enhancing the conservation and preservation of marine species and habitats on the Scotian Shelf.

4.4 Future Research

While the identification of suitable areas for acoustic sanctuaries is a significant step towards understanding and protecting cetacean habitats, further research is needed to enhance our knowledge of acoustic sanctuaries on the Scotian Shelf. This report presents a framework for identifying potential areas for establishing acoustic sanctuaries, however, this framework can be further refined as better data and information become available. The inclusion of additional criteria, such as other human activity types, seasonal habitat preferences, behavioural responses, and habitat use of other noise-sensitive species would add value to the suitability outputs, however, a lack of information and data surrounding these topics made them beyond the scope of this report. To further evaluate the robustness and reliability of the findings, a sensitivity analysis should be conducted to assess the potential impacts of incorporating new information into the study, as it becomes available. This analysis would involve examining the effects of varying input parameters or datasets on the results, providing insights into the sensitivity of the framework and the implications for acoustic sanctuaries. This would enable a more holistic understanding of the acoustic environment and its implications for marine species within potential acoustic sanctuaries.

To address the existing knowledge and data gaps, future studies should aim to investigate the specific acoustic characteristics of the identified sanctuaries in more detail, including detailed noise measurements and noise modelling, to provide a better understanding of the extent of noise attenuation and the spatial and temporal impact of underwater anthropogenic noise in these highly suitable areas (Dekeling et al., 2020). Moreover, scenario-building techniques to measure vessel noise emissions at different speeds and ship types would help to understand their dynamic impact on noise-sensitive habitats (McWhinnie et al., 2017). These initiatives would not only contribute to our understanding of underwater noise in Canadian waters but also play a vital role in developing noise management strategies within the proposed acoustic sanctuaries.

Furthermore, it is recommended that researchers prioritize species distribution modelling, particularly for SARA-listed species that are vulnerable to noise pollution. Assessing the temporal dynamics of cetacean habitat, considering seasonal variations in cetacean presence, potential migration patterns, and population density will help to develop comprehensive data models that account for changing conditions on the Scotian Shelf. Additionally, exploring connectivity between potential sanctuaries identified in this study and other important habitats on the Scotian Shelf, considering cetacean movement patterns and potential corridors for acoustic refuge, would contribute to a holistic approach to cetacean conservation and marine spatial planning in the region. These studies would highlight the potential for dynamic management measures and open opportunities for adaptive strategies to protect acoustic sanctuaries and more effectively mitigate the impact of vessel noise on cetaceans.

Expanding the ongoing coastal and offshore acoustic monitoring programs on the Scotian Shelf would provide valuable insights into SARA-listed species occurrence, important habitat identification, and temporal trends and changes in noise levels, helping to facilitate recovery. Such information could also be used to better understand necessary mitigation measures to reduce the overall impacts of noise in certain areas. However, effectively monitoring cetacean behaviour poses significant challenges. These challenges can impede the development of more comprehensive data models that encompass the complex dynamics of cetacean behaviour and their responses to underwater noise. Factors such as the vastness of the marine environment, the elusive nature of cetacean movements, and the limitations of current tracking technologies contribute to these challenges. Overcoming these obstacles necessitates continued research, the exploration of innovative monitoring techniques, and advancements in data collection and analysis.

By diligently addressing these challenges and bridging the gaps in our knowledge, we can achieve a more nuanced understanding of cetacean behaviour and its interactions with underwater noise (Gomez et al., 2016). This deeper understanding will pave the way for refining data models, leading to more accurate and robust assessments of the impacts of noise on cetaceans and, in turn, the design and management of effective acoustic sanctuaries. In this pursuit, it is crucial to prioritize collaborative research efforts among scientists, policymakers, and stakeholders to gather comprehensive data, integrate analyses of multiple noise sources, and fine-tune management approaches to ensure the effective protection of cetacean habitats. These concerted efforts will empower policymakers and stakeholders to implement targeted and impactful management strategies, protecting and conserving cetacean species not only on the Scotian Shelf but also in other marine environments.

The ongoing development of Canada's Ocean Noise Strategy under the Oceans Protection Plan's Marine Environmental Quality initiative will play a crucial role in coordinating research efforts and shaping policies on ocean noise, thereby filling data gaps, and informing future conservation initiatives (DFO, 2020d). This initiative emphasizes the importance of collaborative research and policy development to address noise-related issues in marine environments. By coordinating research efforts and fostering interdisciplinary collaborations, the strategy aims to gather essential data, promote knowledge sharing, and guide evidence-based decision-making to protect marine species from the impacts of underwater noise (DFO, 2020d). It is through these collective efforts that we can ensure the preservation of the unique acoustic environments and the well-being of noise-sensitive species not only in the Scotian Shelf but also in marine ecosystems worldwide.

4.5 Conclusion

The GIS-based multicriteria decision analysis identified the Gully and Haldimand Canyon as having high suitability as potential acoustic sanctuaries across space, time, and vessel types. The identification of these areas presents a valuable opportunity to implement targeted conservation measures and establish protected zones to safeguard the acoustic habitat and mitigate the impacts of anthropogenic noise on SARA-listed cetaceans. By adopting a comprehensive approach to analyzing the suitability of the Scotian Shelf for acoustic sanctuaries, valuable insights have been provided for policymakers, stakeholders, and researchers.

Moving forward, addressing the challenges and limitations encountered during this study is crucial. Data constraints, analytical assumptions, and spatial/temporal considerations have impacted the interpretation of the results. Further research is needed to enhance our understanding of the specific acoustic characteristics of identified sanctuaries, as well as to investigate the seasonal variations, migration patterns, and connectivity between these sanctuaries and other important cetacean habitats. Such research efforts can drive regulatory action and inform the development of new or amended management directives that contribute to the long-term conservation and preservation of marine ecosystems.

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