Application of Marxan with Zones as a marine spatial planning decision-support tool: a case study for offshore wind planning in Nova Scotia

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1.0 ABSTRACT

Nagel, E.J., Pardy, G., Gordon, K., and Long, M.-A. 2024. Application of Marxan with Zones as a marine spatial planning decision-support tool: a case study for offshore wind planning in Nova Scotia. Can Tech. Rep. Fish Aquat. Sci. 3601: xi + 91 p.

In the offshore of Nova Scotia, work is underway to identify potential areas for future offshore wind energy (OWE) development. 'Marxan with Zones' has been widely used in conservation network planning and has been applied as a decision-support tool for marine spatial planning and OWE planning in Europe and the United States. This study demonstrates how Marxan with Zones can be applied to spatial planning of OWE to aid in conflict avoidance, by identifying potential areas which may be suitable for OWE and overlap less with existing uses and ecological features. Eighteen planning scenarios were explored, with a combination of single-sector scenarios which assessed OWE against individual ocean sectors and uses (commercial fishing and conservation), and multi-sector scenarios which assess OWE against a combination of ocean sectors and uses (including oil & gas and aquaculture). These 18 scenarios provide information about the current distribution of human uses and ecological features in the study area, represented by 108 data layers, in relation to potentially suitable areas for OWE. In this analysis, several areas emerged which may be suitable for future OWE and avoid overlap with >90% of each individual commercial fishery and with vessel traffic. However, some of these areas have ecological features present that should be assessed further as part of the OWE site identification process. Marxan with Zones is a flexible tool, and these methods can be modified to investigate areas of interest for OWE at different scales.

2.0 RÉSUMÉ

Nagel, E.J., Pardy, G., Gordon, K., and Long, M.-A. 2024. Application of Marxan with Zones as a marine spatial planning decision-support tool: a case study for offshore wind planning in Nova Scotia. Can Tech. Rep. Fish Aquat. Sci. 3601: xi + 91 p.

Au large de la Nouvelle-Écosse, des travaux sont en cours pour cibler des zones potentielles pour le développement futur de projets d'énergie éolienne en mer (ÉÉM). « Marxan with Zones » est un logiciel utilisé aux fins de la planification des réseaux de conservation ainsi comme outil d'aide à la décision aux fins de la planification spatiale marine et de la planification de l'ÉÉM en Europe et aux États-Unis. La présente étude démontre l'application de Marxan with Zones à la planification spatiale de l'ÉÉM pour aider à éviter les conflits en déterminant les zones potentielles qui peuvent convenir à l'ÉÉM et qui chevauchent moins les utilisations et les caractéristiques écologiques existantes. On a exploré dix-huit scénarios de planification, avec une combinaison de scénarios unisectoriels qui évaluaient l'ÉÉM par rapport à des secteurs et des utilisations océaniques individuels (pêche commerciale et conservation), et de scénarios multisectoriels qui évaluaient l'ÉÉM par rapport à une combinaison de secteurs et d'utilisations océaniques (y compris le pétrole et le gaz ainsi que l'aquaculture). Ces 18 scénarios fournissent des renseignements sur la répartition actuelle des utilisations humaines et des caractéristiques écologiques dans la zone d'étude, représentée par 108 couches de données, en relation avec les zones potentiellement appropriées pour l'ÉÉM. Cette analyse a permis de cibler plusieurs zones susceptibles de convenir à de futurs projets d'ÉÉM et où il est possible d'éviter tout chevauchement avec plus de 90 % des pêches commerciales et avec le trafic maritime. Cependant, certaines de ces zones présentent des caractéristiques écologiques que l'on devrait évaluer plus en détail dans le cadre du processus de détermination des sites potentiels d'ÉÉM. Marxan with Zones est un outil polyvalent, et il est possible de modifier les méthodes utilisées pour évaluer la planification de l'ÉÉM à différentes échelles et pour examiner plus en profondeur les zones d'intérêt pour l'ÉÉM.

3.0 INTRODUCTION

3.1 Marine spatial planning

Increasing demands on ocean space and marine resources are driving the need for proactive marine spatial planning (MSP) to achieve multiple and often competing objectives. Marine spatial planning is an internationally recognized process that considers multiple objectives in decision making to support the sustainable use of ocean spaces. In Canada, the approach to MSP considers ecological, economic, cultural, and social objectives (DFO 2023a). Fisheries and Oceans Canada (DFO) is the lead federal department for advancing MSP in Canada and is doing so by building on previous integrated management processes. A first-generation marine spatial plan is being developed for DFO Maritimes Region, also known as the Scotian Shelf and Bay of Fundy planning area.

In Canada, MSP is intended to guide and inform decision making by making information and tools more readily available. Marine spatial planning does not replace single-sector management but seeks to improve coordination between decision makers. The MSP process can aid decision making by gathering data and knowledge and facilitating collaboration between federal departments, provincial/ territorial, and Indigenous governments, as well as relevant stakeholders (DFO 2023a).

Marine spatial planning can include both processes and products. Processes may include governance mechanisms that bring planning partners together to achieve shared goals. The process for collaboratively defining these goals is described in more detail within marine spatial plans themselves. Marine spatial planning products are intended to support and increase the transparency of decision making. Examples of this include making spatial data and information available via the Canada Marine Planning Atlas (DFO 2023b) and the development of other decision-support tools. This report describes the development of a decision-support tool for MSP that can be used to analyze potential areas for new ocean uses, using offshore wind energy (OWE) as a case study.

3.2 Regulatory regime for offshore wind energy in Canada

Offshore wind energy development is at an early stage in Canada. Federal and provincial announcements throughout 2022 and 2023, including the Province of Nova Scotia's announcement to lease 5 GW of OWE capacity by 2030 (Province of Nova Scotia 2022) and the launch of a *Regional Assessment of Offshore Wind Development in Nova Scotia* by the Impact Assessment Agency of Canada (IAAC) in 2023, signal that OWE development is being considered in earnest in Nova Scotia. A Regional Assessment process is also underway in Newfoundland and Labrador, however this study focused on Nova Scotia. The mandates of the two *Regional Assessment* processes, which are led by IAAC, include making recommendations to federal and provincial ministers related to potential development areas for offshore wind.[3]

[3] IAAC. 2023. Final Agreement and Terms of Reference between the Governments of Canada and Nova Scotia

This study was intended to inform the Nova Scotia *Regional Assessment* by providing information on the distribution of human uses and ecological features in relation to areas which may be feasible for offshore wind, based on data available in DFO's Maritimes Region and Gulf Region.

Work is ongoing to establish a legislative and regulatory regime for OWE development in Canada, including through federal and provincial mirrored amendments to the *Canada-Nova Scotia Offshore Petroleum Resources Accord Implementation Act* and the *Canada-Newfoundland and Labrador Atlantic Accord Implementation Act*, as presented federally in 2023 via Bill C-49.[4] Should the mirrored federal and provincial legislation be enacted, the Canada-Nova Scotia Offshore Petroleum Board (CNSOPB) would be renamed as the Canada-Nova Scotia Offshore Energy Regulator (CNSOER) and become the lifecycle regulator for offshore renewable energy projects, including OWE, in the offshore area defined in the Act. The CNSOER would be an independent joint regulator of the Government of Canada and the Government of Nova Scotia. These amendments would establish a land tenure regime for offshore renewable energy, which would include the Regulator making recommendations to Provincial and Federal Ministers to issue submerged land licenses in areas it identifies within the offshore area. An adjacent process is also underway for the Canada-Newfoundland and Labrador Atlantic Accord offshore area and the Canada-Newfoundland and Labrador Offshore Petroleum Board.

The Government of Nova Scotia, through its Department of Natural Resources and Renewables, regulates energy resource projects within provincial jurisdiction (*Marine Renewable Energy Act* 2015). Natural Resources Canada (NRCan), through the federal Canada Energy Regulator, regulates offshore renewable energy projects within sole federal jurisdiction (*Canadian Energy Regulator Act* 2019). At present, NRCan is leading development of the Offshore Renewable Energy Regulations, which would further define requirements specific to offshore renewable energy activities (NRCan 2023).

3.3 Offshore wind energy technology

Offshore wind energy has become one of the fastest-growing sources of renewable energy around the globe, with an estimated total energy generation capacity of 64.3 gigawatts (GW) as of 2022 (Global Wind Energy Council 2023). Two types of foundations are currently used for OWE: fixed-base foundations and floating foundations.

Fixed-base foundations are the most common, accounting for 99.8% of installed global capacity (Musial et al. 2022). They are physically emplaced on or in the seabed and can be classified into four main categories: gravity-based, monopiles, suction caissons, or multi-piles. Suitability requirements for fixed-base foundations can vary, however, they are typically installed in depths

[4] Bill C-49, An Act to amend the *Canada—Newfoundland and Labrador Atlantic Accord Implementation Act* and the *Canada-Nova Scotia Offshore Petroleum Resources Accord Implementation Act* and to make consequential amendments to other Acts, 1st session, 44th Parliament, 2021

up to 60 m (Eamer et al. 2021). Installing fixed foundations in depths up to 70 m may be feasible now or in the future (Jiang 2021, U.S. Department of Energy 2023, Yeter and Garbatov 2022). Additionally, fixed foundations in water depth greater than 30 m (i.e., other than gravity-based foundations) require thick deposits of unconsolidated sediment, which are typically sands or gravels (Taylor 2011 in Eamer et al. 2021; Oh et al. 2018).

Floating foundations are anchored to the seabed using a mooring system with the turbine floating in the water column. This mooring system allows foundations to be deployed in deeper waters, and there is growing market interest in this technology due to this capability (Musial et al. 2023). Floating OWE is advancing from demonstration-scale projects to commercial scale projects (Global Wind Energy Council 2023). In the United States, the first commercial lease for floating OWE was announced in 2022, and national research initiatives are underway to reduce the costs of floating OWE (U.S. Department of Energy 2023).

3.4 Offshore wind spatial planning processes

Internationally, OWE has been a common driver for the development of marine spatial planning processes. In the United States, the Rhode Island Ocean Special Area Management Plan (Ocean SAMP) was primarily driven by state interests in developing OWE farms to achieve renewable energy targets (RI CRMC 2010). The Ocean SAMP was developed to protect human uses and natural resources while also identifying zones for OWE development. The Block Island Wind Farm was constructed within the Ocean SAMP area and represented the first OWE farm in the United States (Ørsted 2023). The Northeast Ocean Plan for New England states (Maine New Hampshire, Vermont, Massachusetts, Rhode Island, and Connecticut) also includes information about how OWE can be approached as a new ocean use (Northeast Regional Planning Body 2016). The plan covered both federal and state waters and seeks to improve coordination to advance shared goals for the marine environment.

A range of methodologies are available to conduct spatial planning exercises to identify areas for OWE. This process often includes a spatial analysis to identify potential areas, an engagement process to collect feedback from relevant stakeholders, rights holders, and ocean users, and refinement of the potential areas based on input received during the engagement process (Gordon 2022). Data can be analyzed using spatial overlays of individual data layers, and spatial models are often combined with engagement of rights holders, stakeholders, regulators, and ocean users to further discuss the areas identified (Gordon 2022, Randall et al. 2024). This type of process is being used to guide the Nova Scotia *Regional Assessment*.

In the United States, the National Oceanic and Atmospheric Administration (NOAA) and Bureau of Ocean Energy Management (BOEM) have developed a spatial planning approach using suitability modeling to inform siting of Wind Energy Areas and minimize conflict with other ocean uses (Farmer et al. 2023, Randall et al. 2024). Suitability modeling has informed OWE siting in the Gulf of Mexico, Central Atlantic, and Pacific regions (Randall et al. 2024). In this approach, multiple sub-models were developed to assess the compatibility of sectors with OWE, including natural and cultural resources, fisheries, transportation, and military uses. For marine species, areas of high and low use by protected species were scored and combined to identify areas of higher probability of species occurrence. Areas with higher probability of occurrence indicated areas with higher risks of conflict with OWE or where regulatory challenges may be encountered (Farmer et al. 2023). This information was then integrated into a broader model which incorporated additional constraints and the sub-models for other sectors (Farmer et al. 2023). This spatial planning approach identifies areas of higher or lower potential conflict between OWE and existing uses, so that conflicts could be proactively avoided or mitigated (Farmer et al. 2023, Randall et al. 2024). In the United States draft Wind Energy Areas are also discussed with rights holders and stakeholders to refine the final Wind Energy Areas (Randall et al. 2024).

In Canada, Natural Resources Canada used a weighted overlay approach to identify candidate areas for OWE in Atlantic Canada in a preliminary considerations analysis (Kilpatrick et al. 2023). In this analysis, spatial datasets describing factors for OWE suitability, such as wind speeds, sea ice cover, distance from shore and existing infrastructure, were each scored from 0-9 to define areas of higher or lower suitability (Kilpatrick et al. 2023). Other human uses and ecological factors, including commercial fisheries, defined ecological areas, and risk to marine birds, were also scored for suitability based on activity level or other ecological considerations. These inputs were then combined using different weightings of each data layer to develop a range of scenarios emphasizing physical, infrastructure, or ecological features (Kilpatrick et al. 2023). Spatial outputs demonstrated areas of higher or lower overall suitability for OWE based on the combination of all input layers. This analysis also varied the weighting of considerations to examine the impact on results (Kilpatrick et al. 2023).

Marxan is a suite of open-source software tools most commonly used for systematic conservation planning (Ball et al. 2009), which have also been used for MSP and OWE planning. Marxan develops spatial solutions which solve the minimum set problem by minimizing costs while meeting input planning objectives (Marxan 2022). A suite of different Marxan tools are available which can incorporate considerations such as connectivity, or, in the case of Marxan with Zones (MarZones, the software used in this analysis) develop multiple spatial zones simultaneously. Göke et al. (2018) applied a pilot approach that used Marxan to meet OWE planning targets at the lowest cost while avoiding conflicts with ecological functions and human use. The area for this project spanned 4 exclusive economic zones (EEZ) in the Baltic Sea, and this work was driven by the European Union (EU) Maritime Policy to implement a common approach to MSP which balanced multiple objectives. Marxan was applied as a systematic decision-support tool for MSP by incorporating user defined targets and by using wind speed as a target layer for energy production. Cost inputs included construction costs and conflicting features such as tourism, shipping, and ecological features. The results of this study included several spatial scenarios that identified areas predicted to be suitable for OWE (Göke et al. 2018).

Marxan has been used for MSP in Washington State, to assess the potential for conflict between OWE and existing uses and resources (Bates et al. 2017). In the Marine Spatial Plan for Washington's Pacific Coast*,* Marxan was used to develop scenarios to meet specific targets for OWE and for existing uses. This analysis was exploratory and intended to demonstrate the variety of different ways Marxan can be configured. The objective was not to identify the "best" location for OWE, but to illustrate how existing activities may interact with potential areas for OWE. Results from this Marxan analysis were compared to and used alongside other analyses to develop recommendations and guidelines for the MSP Management Framework (Bates et al. 2017).

Gordon (2022) performed a preliminary analysis using Marxan to demonstrate how an MSP approach could be used to inform the planning of a new ocean use in Atlantic Canada. Using Marxan, several scenarios were developed to identify areas with higher or lower potential for spatial conflict between future fixed foundation OWE development and the existing commercial fishing industry in the Scotian Shelf and Bay of Fundy planning area (Gordon, 2022). This analysis was exploratory and intended to provide a methodological framework to demonstrate how Marxan could be used as a decision-support tool within the greater MSP process (Gordon, 2022).

The analysis described in this report takes a similar approach to the above-mentioned efforts by using MarZones to assess parameters affecting OWE suitability, as well as existing uses that may conflict with OWE development. This analysis builds on Gordon (2022) and fills several data gaps identified by Kilpatrick et al. (2023) by including additional commercial fishing data such as new models developed for DFO Gulf Region, and assessing each fishery individually instead of collectively. This analysis also incorporates existing conservation areas and areas that may be selected for conservation in the future, as part of the marine conservation network plan for the Scotian Shelf and Bay of Fundy planning area (DFO 2024, King et al. 2021, Serdynska et al. 2021).

3.5 DFO applications of Marxan with Zones

King et al. (2021) used MarZones in their data-driven approach to developing the offshore portion of the marine conservation network in the Scotian Shelf and Bay of Fundy planning area. This approach was systematic, repeatable, transparent, and logic-based in its application of feature targets to achieve adequate representation of ecological features within a reserve network.

The offshore portion of the network represented a multi-objective analysis that was intended to balance conservation and socioeconomic priorities (Serdynska et al. 2021). Objectives included protecting biodiversity, minimizing potential impacts on commercial fishing, and minimizing potential impacts on the oil and gas industry and maritime shipping sector (Serdynska et al. 2021). MarZones scenarios were developed to meet ecological targets and results were refined to minimize socioeconomic impacts, using data available at the time (Serdynska et al. 2021). The resulting outputs were used as a starting point to identify potential conservation areas, with additional information being considered in the identification of marine conservation network sites. Additional information describing how socioeconomic features can be assessed using Marxan is available in DFO 2017.

3.6 Study objectives

This analysis was completed using a similar multi-objective approach to development of the marine conservation network plan (DFO 2024), but with an aim to identify potential lower-conflict areas that could be considered for OWE instead of identifying areas for conservation consideration. MarZones was used to develop a range of spatial solutions to meet objectives for OWE development, while also minimizing spatial conflict. Specific targets were set to avoid overlap between OWE and between 80–100% of existing human uses and several ecological features, to assess whether there were areas which may be suitable for OWE and have less overlap with these features. MarZones was selected as it allows for multiple quantitative targets to be set to meet specific planning objectives in multiple zones simultaneously. Outputs from MarZones also quantify the potential overlap between features and different zones and indicate whether it may be feasible to meet planning objectives.

Results are intended to add to the growing body of scientific knowledge about the distribution of uses and features in the study area in relation to potential future OWE development. The results are also intended to inform the Nova Scotia *Regional Assessment*. However, the analysis and outputs of this study do not constitute Government of Canada direction on future siting of offshore wind energy, rather, areas for OWE will be determined by the lifecycle regulators and will be informed by the Nova Scotia *Regional Assessment*.

This analysis uses a repeatable and transparent methodology for MSP that can provide information to regulators and decision makers during planning processes for new ocean activities such as OWE. The scenarios presented are not determinations of areas most appropriate for OWE development. The range of scenarios developed depicts several ways this tool can be configured to answer specific questions based on the input data. Multiple other configuration options which are available to use in future analyses are also discussed. The analysis can be repeated and refined by including information that fills identified data gaps or adjusting the Marxan parameters. This information can support improved planning and decision making for OWE in a manner that incorporates conflict avoidance, and also considers the conservation and protection of marine ecosystems.

4.0 METHODS

This analysis used MarZones to generate spatial solutions that met OWE area targets in areas of higher technical suitability in an offshore wind zone, while minimizing overlap with existing human uses and ecological features. This avoidance was achieved primarily by meeting existing-use feature targets in a non-overlapping existing-use zone, and by treating certain existing use features as exclusion areas where planning units could not be selected in the wind zone.

A range of scenarios were developed to incorporate different sets of existing-use features and area targets for OWE. Multiple scenarios were developed to explore the relative influence of different sectors. Sections 4.1 – 4.6 describe the MarZones setup, the economic, physical, human use, and ecological data layers, and the parameters for each of the 18 scenarios developed in this version of the tool.

4.1 Marxan with Zones setup

4.1.1 Study area

The study area encompassed the Scotian Shelf and Bay of Fundy planning area and a portion of the Estuary and Gulf of St. Lawrence planning area that falls within the boundary of the Nova Scotia *Regional Assessment* (IAAC 2023) (Figure 1). The Nova Scotia Regional Assessment boundaries align with the offshore area under the jurisdiction of the CNSOPB (again, which is in the process of being renamed to the Canada-Nova Scotia Offshore Energy Regulator).

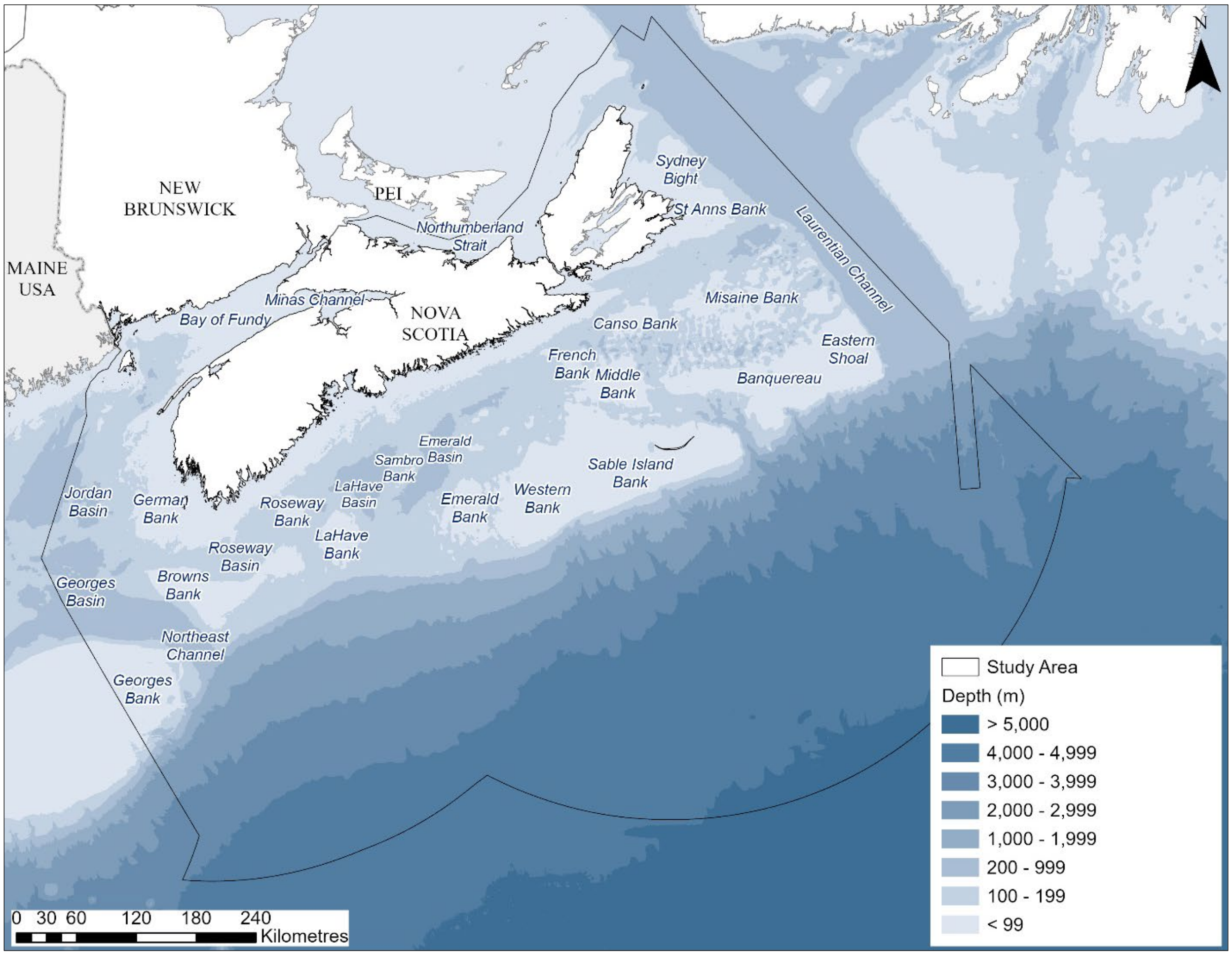

Figure 1. Project study area and locations of prominent undersea features including banks, basins, channels, and shoals.

The total area assessed was approximately 500,000 km^2. It was divided into a planning unit grid with approximately 50,000 hexagons, each 10 km^2 in area, in order to align with the same grid used in other regional scale analyses such as the marine conservation network plan (DFO 2024, King et al. 2021), and the grid used to aggregate fisheries landings in Eastern Canada (DFO 2022a; 2023c). A higher resolution analysis is possible for future analyses, but would require the reprocessing of aggregated fisheries landings data to a non-published format.

The study area includes the Bay of Fundy and inshore areas, which are not part of the Nova Scotia *Regional Assessment* study area (IAAC 2023) but are part of both the Scotian Shelf and Bay of Fundy, and Estuary and Gulf of St. Lawrence marine planning areas (Figure 2). The Scotian Shelf and Bay of Fundy planning area aligns with DFO Maritimes Region. The Estuary and Gulf of St. Lawrence planning area aligns in part with DFO Gulf Region. Bras d'Or Lake was not included in this analysis, as the focus was on coastal and offshore areas; in addition, fine scale spatial data for the Bras d'Or Lake area were limited. This study area was chosen such that results of the study would be relevant both to DFO administrative areas and to the *Regional Assessment*.

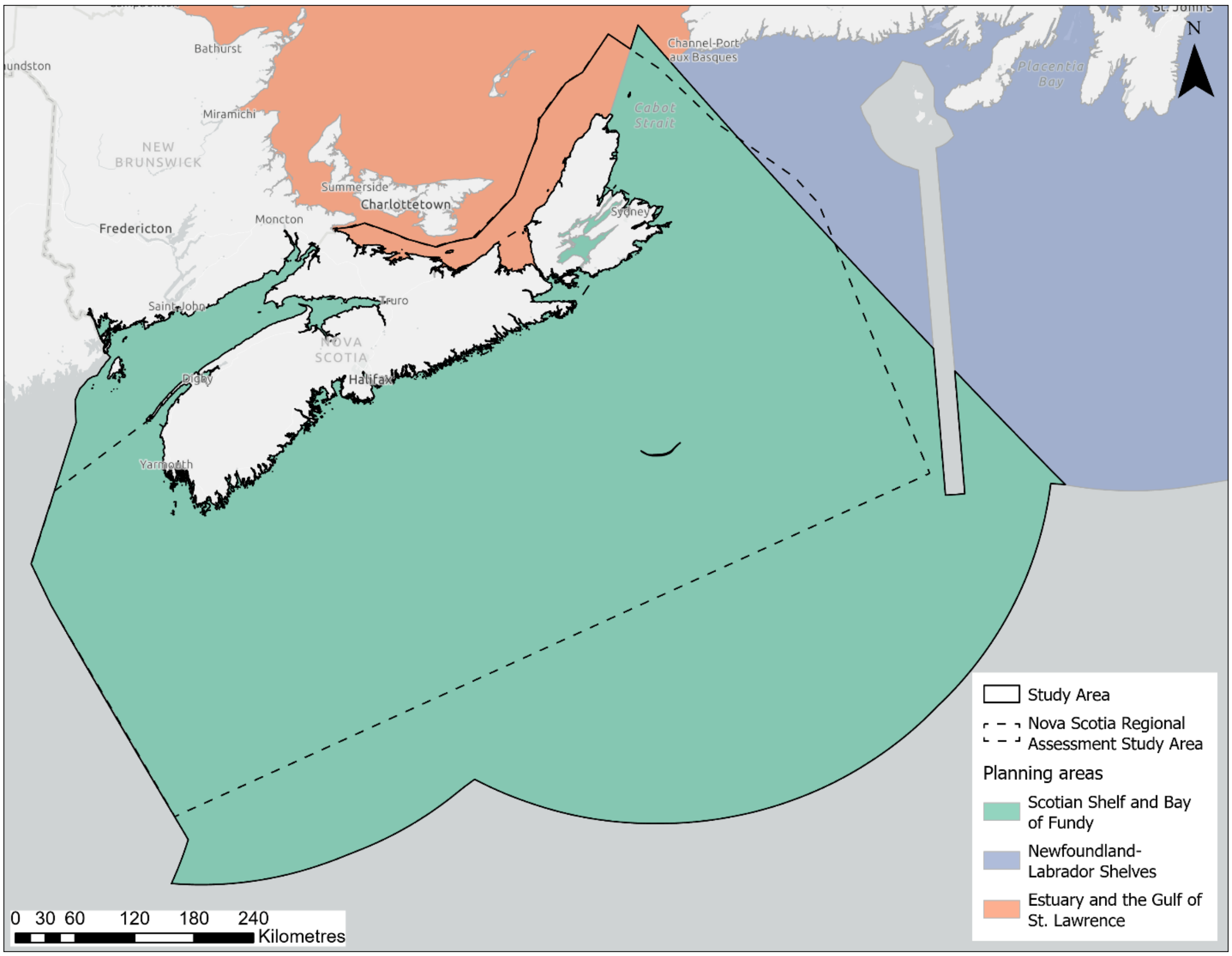

Figure 2. Overlap between the project study area, the Nova Scotia Regional Assessment study area, the Scotian Shelf and Bay of Fundy Planning Area (DFO Maritimes Region) and the Estuary and Gulf of St. Lawrence planning area (DFO Gulf Region).

4.1.2 Zones

Marxan with Zones builds on the principles of Marxan but allows for multiple zones, zoning contributions, costs, and the spatial relationships between zones to be considered in spatial optimization.[5] The approach used in this study builds upon the MarZones methodology used in the offshore conservation network analysis for DFO Maritimes Region (King et al. 2021), without duplicating efforts from that process. For example, existing use information such as commercial fisheries data were utilized and updated to the most current 10 years of available data (2012-2021), but the individual ecological data layers used in the marine conservation network analysis were not duplicated as the marine conservation network plan itself was included in this analysis. Other data that broadly represent habitats and species which may interact with OWE (i.e., important habitat for species at risk, important marine areas for seabirds) were incorporated into this analysis (see section 4.5).

As in the conservation network analysis (King et al. 2021), this analysis utilized a 3-zone approach: an existing-use zone, a wind zone, and an "available" zone. The existing use zone represented target areas of importance to human uses or ecological features. The wind zone represented target areas for OWE while incorporating constraints and costs for offshore wind energy. The "available" zone included areas that were not selected in either of the other two zones and were therefore not optimal for meeting targets for existing uses or OWE. Including the "available" zone was important to the setup of this tool to ensure the existing-use zone and wind zone provided useful results. Using a 2-zone analysis would not yield spatially-efficient solutions, as one of the two zones would have to occupy all the space not occupied by the other. For individual MarZones solutions, the existing-use zone, wind zone, and "available" zone did not overlap.

4.1.3 Feature targets

A key difference between Marxan and many other suitability analysis tools is the ability to set quantitative targets. By setting a target, Marxan attempts to capture feature occurrences within a zone at a minimum cost. Targets can be set as an absolute value (e.g., 1 km^2 of important habitat), a proportional value (e.g., 90% of catch weight) or a number of occurrences (e.g., 170 planning units). Marxan allows for targets to be set based on the values within the original data, which allows for comparability across datasets with different ranges or data types.

Specific targets for MarZones to meet were identified within the existing-use zone and wind zone and multiple scenarios were developed which used different combinations of targets and data. Targets for all existing uses and ecological features were set in the existing-use zone only, to represent areas for offshore wind energy to avoid. In the wind zone, an area target was set to define the size of the zone while incorporating exclusions, which were areas or features to be avoided such as marine protected areas (MPAs) and costs, which represented technical suitability

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[5] Additional information and training resources on Marxan are available from: Marxan (marxansolutions.org)

for OWE development. Wind zone solutions represented areas where OWE could take place to avoid conflict with existing uses while meeting the OWE area target.

In the offshore conservation network analysis, tailored design strategies were developed for the individual conservation features included to create rationales for applying different target ranges to different species and their habitats depending on their intrinsic vulnerability, uniqueness, and conservation status. The design strategies used to develop the Scotian Shelf and Bay of Fundy marine conservation network plan integrated a series of coastal and offshore ecological features to identify potential areas for future conservation measures (DFO 2018a; King et al. 2021).

In the absence of design strategies for this study, a consistent target of 90% was applied in most scenarios to all existing use features. Two scenarios were also developed which used 80% and 100% targets respectively, to demonstrate how adjusting this target affected results. The selection of 90% as a baseline was chosen as it exceeded the 80% target for fisheries used in the conservation network analysis (King et al. 2017), while allowing selection of some OWE planning units to occur in areas of relatively low cost and low existing use. For example, in this study most scenarios were set up to capture within the existing-use zone a minimum of 90% of fisheries landings or effort for each fishery management unit, 90% of the top decile of vessel traffic, and 90% of ecological feature abundance or area.

Ecological features were selected to broadly represent species or habitats which may have a negative interaction associated with OWE, in particular data layers representing sensitive or unique benthic features, aerofauna (seabirds and bats), and species at risk. These data layers are described in section 4.5. This approach was chosen to provide proactive information about how these features may overlap with OWE and where OWE could be located to avoid them.

4.1.4 Costs

Marxan solves the minimum set problem by selecting areas to meet targets at a minimum cost. For instance, in marine conservation planning costs can represent the area of the planning unit or the cost of management actions to identify sites that meet conservation targets within the smallest possible area of land or ocean or at the lowest overall cost.[6] MarZones meets targets at the lowest overall cost for each zone. The types of costs that can be evaluated using Marxan include boundary length, penalty, and planning unit costs. Boundary length costs are based on the perimeter length of planning units or clusters of planning units. Penalty costs are proportional to the shortfall of missing a feature target. Planning unit costs are location specific attributes that describe a feasibility challenge, cost of development, or other characteristic within a planning unit. This can include economic, social, physical, or other attributes that are relevant to spatial planning.

In this analysis, MarZones minimized planning unit cost and minimized penalty costs. When targets were achieved penalty costs were not applicable. When targets were not achieved, penalty

[6] Costs-Marxan. https://marxansolutions.org/costs/

costs were applied. This analysis did not incorporate boundary length cost, thereby eliminating the "clumping" effect where Marxan clusters planning units together to minimize boundary length. MarZones allows multiple cost layers to be assigned to the planning unit grid and for costs to be applied to specific zones. A uniform, equal cost was applied to planning units in the existing-use zone so that the solution would be spatially efficient when meeting feature targets, highlighting areas of greater importance per unit area. Therefore, target achievement for existing uses was driven by selecting planning units with high cumulative existing use values. This was efficient in terms of minimizing the amount of area required to meet existing use targets. This also allowed for original data attributes to be used instead of developing suitability scores for existing use feature layers (see section 4.1.3).

In the wind zone, OWE-specific cost layers were applied to incorporate suitability at the planning unit level when meeting the area target, to highlight areas more conducive to OWE development. The cost layers for the wind zone represented feasibility challenges that increased with increasing sea ice concentration, depth, distance from coast, and in areas of lower wind speed or of less optimal surficial geology.

Depending on the scenario, either a combined cost layer based on suitability layers (similar to the approach in Kilpatrick et al. 2023), or a Levelized Cost of Energy (LCoE) layer developed by Aegir Insights (2023) was used. The combined suitability cost layer was developed by inverting the compatibility scores in the baseline scenario of Kilpatrick et al. (2023), where cost score in this study was 9 minus the compatibility score. For example, if a compatibility score was 9 in Kilpatrick et al. (2023), the cost score in this analysis was 0. Variations from this method are described for each suitability layer in section 4.3.

The input Marxan cost layer for the wind zone was the mean value of the normalized sea ice, depth, wind speed, distance to coast, and surficial geology cost layers. The same input suitability cost scores were used in the fixed foundation OWE scenarios compared to the fixed and floating foundations scenarios with the exception of surficial geology, where a different cost layer was used for the fixed and floating foundations scenarios (see section 4.3.5).

4.1.5 Exclusions

In some single sector and multi-sector scenarios, exclusions were added to prevent the wind zone from selecting planning units that included known constraints such as water depths that exceeded the technical limits for a given foundation type, areas have existing management measures that may not allow for OWE development, or are known to include existing human uses, such as shipping lanes. The incorporation of exclusion areas was achieved by defining which zone was available for each planning unit. This was chosen over the other option of forcing areas to be selected in the existing-use zone, which could result in less efficient solutions.

Specifically, area-based conservation measures with legal designation that contribute to Canada's Marine Conservation Targets, including *Oceans Act* MPAs and *Fisheries Act* marine refuges were considered exclusion areas for the wind zone in the conservation single-sector scenarios and the multi-sector scenarios in this study. Through regulations under the *Oceans Act*, OWE will not be permitted in existing regional MPAs as this activity has not been listed as an exception in the regulations. Similarly, this activity has not been scoped into consideration for Areas of Interest (AOIs) which are being assessed for potential designation as *Oceans Act* MPAs. Potential consideration of offshore wind in future *Oceans Act* MPAs will involve the application of the federal MPA protection standard for ocean dumping in conjunction with site-specific ecological risk assessment and design processes.

At this time, OWE has not been assessed as compatible within existing regional marine refuges. However, for marine refuges to maintain their status as an Other Effective area-based Conservation Measure (OECM), and continue to contribute to Canada's Marine Conservation Targets, they must be managed to align with the 2022 OECM Guidance,[7] including the protection standard *"All activities in marine refuges will continue to be assessed on a case-by-case basis to ensure that . . .the risks to the biodiversity outcomes of the area have been avoided or mitigated effectively."* As a result, this analysis adopted a precautionary approach through considering marine refuges as exclusion areas for the wind zone. In several scenarios, critical habitat for Species at Risk and AOIs for protected area designation were also set as exclusion areas, to demonstrate how spatial planning can develop precautionary scenarios to avoid areas with current or future regulatory designations.

Exclusions also reflect assumptions made in this study about existing lease areas for aquaculture and oil and gas, and vessel traffic routes. In the multi-sector scenarios, lease areas were considered exclusion areas to prevent overlap between the wind zone and these existing uses. Potential compatibility between OWE and other uses was not assessed in this first application of this decision-support tool, as the focus was on avoidance of areas currently in use.

4.2 Economic data

4.2.1 Wind zone target

The target for the wind zone was informed by the current economic goal set by the Province of Nova Scotia to lease 5 GW of offshore wind energy by 2030 (Province of Nova Scotia 2022). An area target for the wind zone was developed based on this total capacity by estimating the space that 5 GW of OWE may occupy. This area target could be updated in future analyses as economic goals evolve or as more information becomes available on factors such as wind turbine spacing or generating capacity to be applied or used for OWE in Atlantic Canada.

The wind zone area target was developed by applying a planning density estimate for OWE. Planning density can also be referred to as capacity density or power density, and is used in this study to refer to the ratio between the total rated capacity of a wind farm and the area it occupies. This density is influenced by turbine spacing, the rated power of turbines, and the layout of an OWE farm (Deutsche WindGuard GmbH 2018). Regulatory requirements may require more compact spacing to minimize the area occupied (higher capacity density) or greater spacing to

[7] Guidance for recognizing marine Other Effective Area-Based Conservation Measures 2022 (dfo-mpo.gc.ca)

accommodate other ocean users (lower capacity density), leading to a wide range of potential planning density estimates (Deutsche WindGuard GmbH 2018).

In countries such as Germany and Belgium, higher densities have been observed due to limited space available in the offshore (Deutsche WindGuard GmbH 2018). For European wind farms, prospective densities developed to estimate OWE potential ranged from 5.0-5.4 megawatt (MW)/km^2 (Deutsche WindGuard GmbH 2018). Recent recommendations for OWE development in Vietnam noted that optimal capacity densities are between 2-5 MW/km^2 and that the actual areas occupied by OWE could be up to 4 times larger than estimated using capacity density alone, due to site specific turbine placement and accommodations for other ocean users (COWI 2021).

The United States Department of Energy (2015) has used an estimated power density of 3 MW/km^2 for OWE and onshore wind in their national wind vision. The U.S. Bureau of Energy Management (BOEM) has used a planning density of 3 MW/km^2 in recent OWE planning during the wind energy area identification process for the Gulf of Maine and New York Bight (BOEM 2023a; 2023b; 2023c). The Bureau notes that this density is a conservative estimate, as installation capacities may change as OWE technology improves (BOEM 2023c).

Kilpatrick et al. (2023) used power density estimates of 3 MW/km^2 and 5 MW/km^2 as starting points to estimate the footprint of theoretical OWE farms in Atlantic Canada. The value of 3 MW/km^2 was based on 19 operational European wind farms described by Enevoldsen and Jacobson (2020). Given that the actual power density of future wind farms in Canada will be determined by various technical, design, and economic factors, several options were included in this study to cover a range of possibilities.

For this study, a planning density of 3 MW/km^2 was applied to most scenarios as a conservative estimate of the space OWE could occupy in the study area (Kilpatrick et al. 2023; BOEM 2023a; 2023b; 2023c). This estimate was based on the larger area potentially available for OWE in Nova Scotia compared to the restricted space available in the exclusive economic zones of countries such as Germany and Belgium (Deutsche WindGuard GmbH 2018), and the lack of current regulatory direction on spacing between OWE turbines in Canada.

Applying the planning density estimate of 3 MW/km^2 to the Nova Scotia provincial target of 5 GW resulted in an estimated space requirement of 1,666 km^2, which was rounded to 1,700 km^2. This equated to 170 planning units for the wind zone. This area target was used for all scenarios except C2 and C3 (see section 4.6). A higher planning density of 5 MW/km^2 was used to demonstrate the results of modifying the area target in scenario C2, using a target of 1,000 km^2 and 100 planning units. The target was increased to 300 planning units in scenario C3 to demonstrate how results changed when the areas selected for the wind zone was larger. The area target could be further modified in future applications of this decision-support tool to assess smaller or larger area targets for OWE.

The wind zone was constrained only to areas where LCoE values were available (see section 4.2.2) to allow for comparability across scenarios. For scenarios that explored fixed-base foundation OWE suitability, the wind zone was further limited to planning units with a mean depth of less than 70 m and where the surficial geology type was suitable for fixed-base foundation technologies (see section 4.3.5).

4.2.2 Levelized Cost of Energy

Levelized Cost of Energy was used as the single cost layer in scenario C5 (see section 4.6) to represent a combination of costs associated with OWE development. The LCoE data for the waters surrounding Nova Scotia were provided by Aegir Insights (2023). The calculation of LCoE included water depth, wind speed, distance to ports in Nova Scotia, and distance to the provincial power grid (Aegir Insights 2023).The LCoE values were lowest in areas estimated to be more economical for OWE, for example, areas with shallower depths, higher wind speeds, lower distances to ports, and lower distances to the power grid (Aegir Insights 2023). The selection of ports and power grid connection points are described by Aegir Insights (2023). The source LCoE values were 4 km^2 in resolution and were resampled using mean values to align with the planning unit grid. The LCoE values were normalized linearly from 0-8 to allow comparability with the suitability layers, where cost scores of 0 corresponded to LCoE values of 57.1 $CAD/MWh (i.e., Canadian dollars per megawatt-hour) and cost scores of 8 corresponded to LCoE values of 126.4 $CAD/MWh (Figure 3, Table 1). These LCoE values are subject to change and only reflect the results of one economic study on OWE currently available (i.e., Aegir Insights 2023).

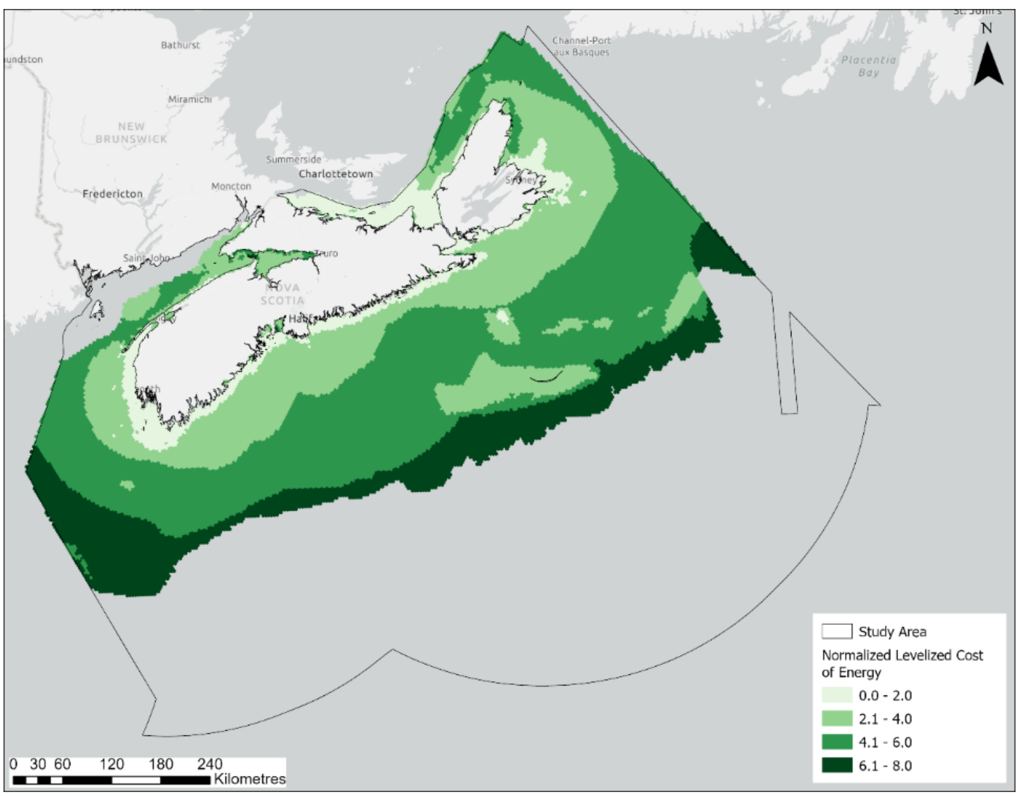


Figure 3. Normalized cost scores for Levelized Cost of Energy (LCoE), data provided by Aegir Insights (2023). Lower normalized scores correspond to lower LCoE.

Table 1. Source data and normalization applied to Levelized Cost of Energy, sea ice, depth, wind speed, and distance to coast.

Input layer	Original variable	Original value range	Cost scale or cost value applied
Levelized cost of Energy	$ CAD/MWh	57.1 – 126.4	Linear 0 – 8
Sea ice	% mean concentration	0 – 100	Linear 0 – 8
Depth	m	≤ 30	0
		≤ 70	1
		≤ 120	2
		≤ 200	3
		≤ 2000	4
		> 2000	8
Mean annual wind speed at 100 m	m/s	≤ 7 or No Data	8
		> 7	0
Distance to coast	km	≤ 60	0
		≤ 100	1
		≤ 185	2
		> 185	8

4.3 Physical suitability data

4.3.1 Sea ice

Sea ice concentration was included as a cost layer to represent the probability of sea ice occurrence. Sea ice may introduce additional costs to OWE due to factors such as more limited access to sites, increased equipment costs, and increased complexity of OWE installation (European Commission 2019, Kilpatrick et al. 2023). Mean sea ice concentration during the week of March 6-12 between the years 1991-2023 was used from archived ice data (Canadian Ice Service 2021). Mean sea ice concentration was normalized linearly from 0-2, where cost scores of 0 corresponded to 0% mean sea ice concentration and cost scores of 2 corresponded to 100% mean sea ice concentration (Table 1). Sea ice concentration was assigned a maximum cost score of 2 (out of a maximum of 8) due to uncertainty as to the effect sea ice may have on OWE operations in Atlantic Canada. In the Baltic Sea, markups of 7% have been applied to cost models in areas of highest sea ice risk, reflecting costs of more limited access to sites and equipment costs to deal with ice (European Commission 2019).

In this analysis, cost scores of 2 in areas of highest sea ice cover reflected that sea ice is a seasonal consideration, and that the presence of sea ice does not necessarily preclude OWE. However, OWE remains to be tested in the Atlantic Canadian climatic context. The normalized sea ice cost layer is displayed in Figure 4.

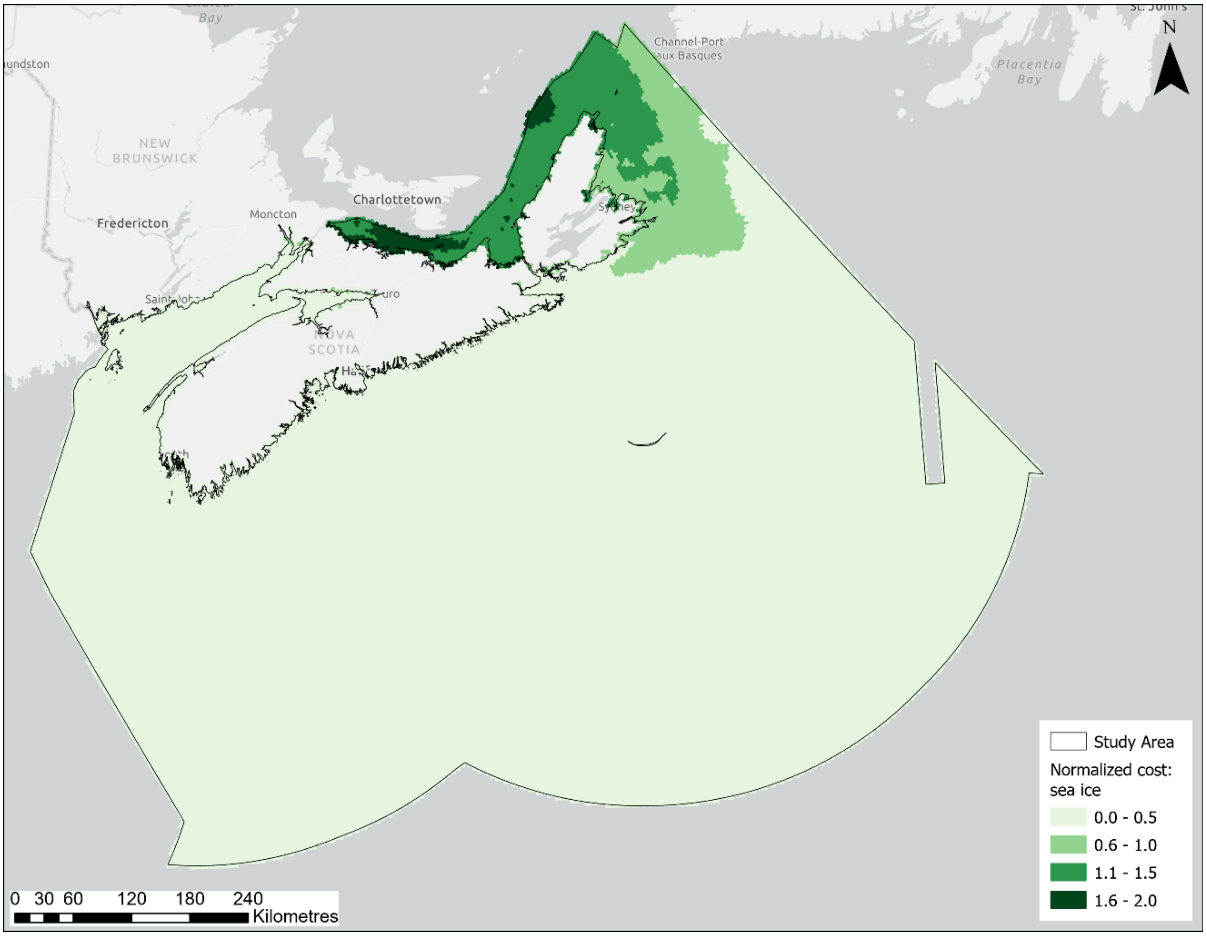


Figure 4. Normalized sea ice cost scores based on a 1991-2023 climatology time series from the Canadian Ice Service ice archive (2021). Higher normalized values correspond to higher mean sea ice concentration.

4.3.2 Depth

Increased costs were assigned to deeper areas using GEBCO gridded bathymetry (GEBCO 2023). Bathymetry values were summarized to planning units using zonal statistics. Fixed foundation OWE technology has been primarily installed in water depths up to 60 m (Eamer et al. 2021), however, installation of jacket or tripod structures may be feasible in water depths up to 70 m (Jiang 2021, U.S. Department of Energy 2023, Yeter and Garbatov 2022). Shallower water depths can allow for less expensive fixed OWE foundations to be deployed. For example, fixed foundations are more expensive for depths of 30-50 m compared to 10-30 m (Oh et al. 2018). Shallow waters for OWE are considered to be 0-30 m depth, (Oh et al. 2018), therefore, the lowest costs in this analysis were assigned to water depths less than 30 m and increased based on the depth intervals in Table 1.

Costs were assigned to water depths greater than 70 m, although these costs were only considered in the scenarios which included floating OWE foundations as fixed foundation scenarios were constrained to less than 70 m water depth (Table 1). Depth limits for floating OWE are evolving rapidly, therefore an upper limit was not set for the fixed and floating foundation scenarios. For example, BOEM has identified lease areas with depths up to 1,300 m (BOEM 2023d).Water depths greater than 2000 m were assigned the highest cost scores of 8, as in Kilpatrick et al. (2023) (Figure 5, Table 1).

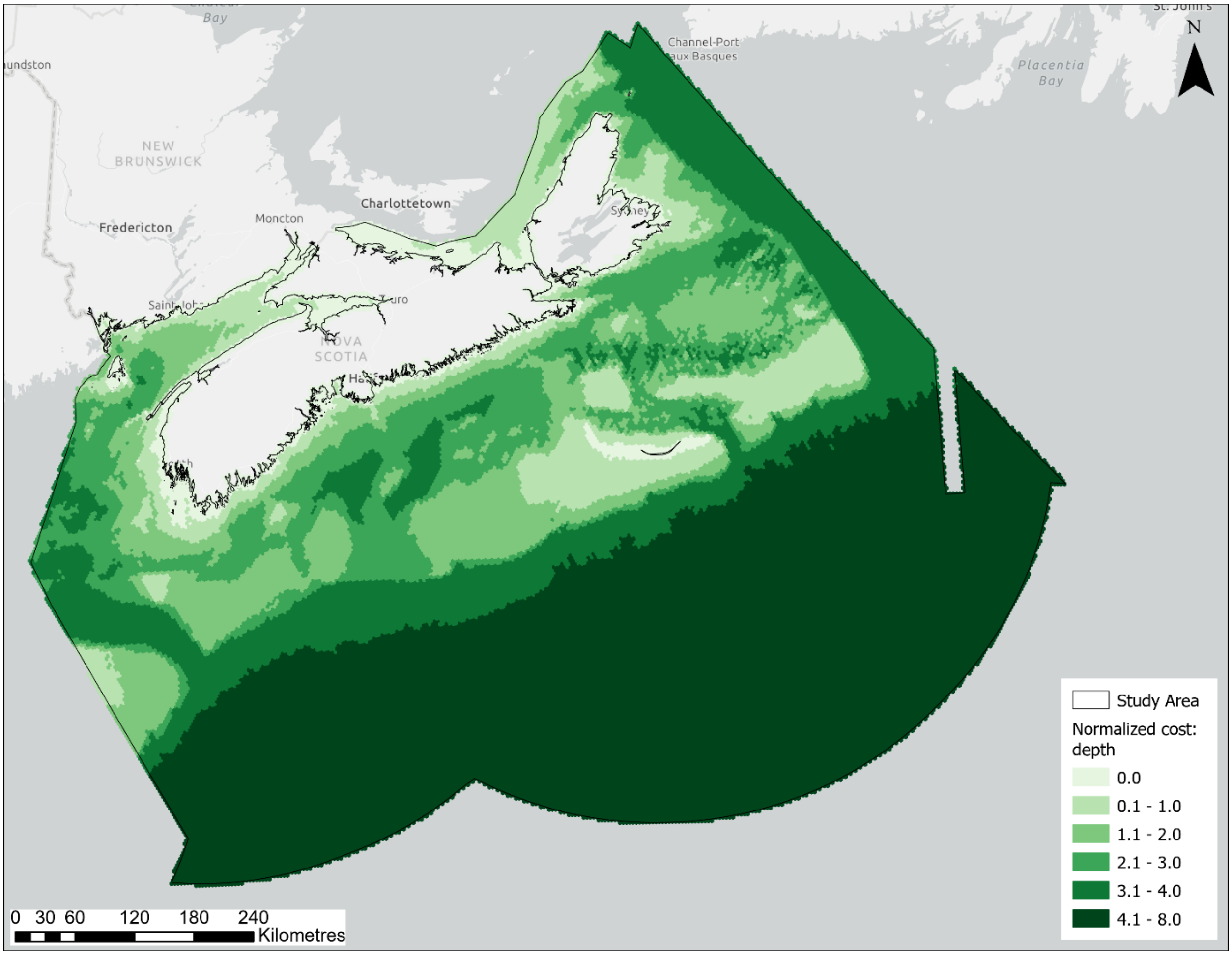


Figure 5. Normalized cost scores for depth, based on GEBCO gridded bathymetry (GEBCO 2023). Higher normalized scores correspond to deeper water depths.

4.3.3 Wind speed

Mean wind speed at 100 m elevation above sea level was calculated for each planning unit using data from the Global Wind Atlas (Davis et al. 2023). Wind speeds were not available from this source beyond approximately 200 km from shore, however, the area for the wind zone typically did not extend to this distance as it was limited by the extent of the LCoE layer (see section 4.2.2).

Wind speeds less than or equal to 7 m/s, or where no data were available, were assigned a cost score of 8 to represent unlikely areas for OWE based on estimates of minimum viable wind speed for OWE development (ESMAP 2019, Kilpatrick et al. 2023) (Table 1). Areas with mean wind speeds greater than 7 m/s were assigned a cost score of 0 to represent suitable areas (Table 1). The cost scores for the wind speed layer are displayed in Figure 6.

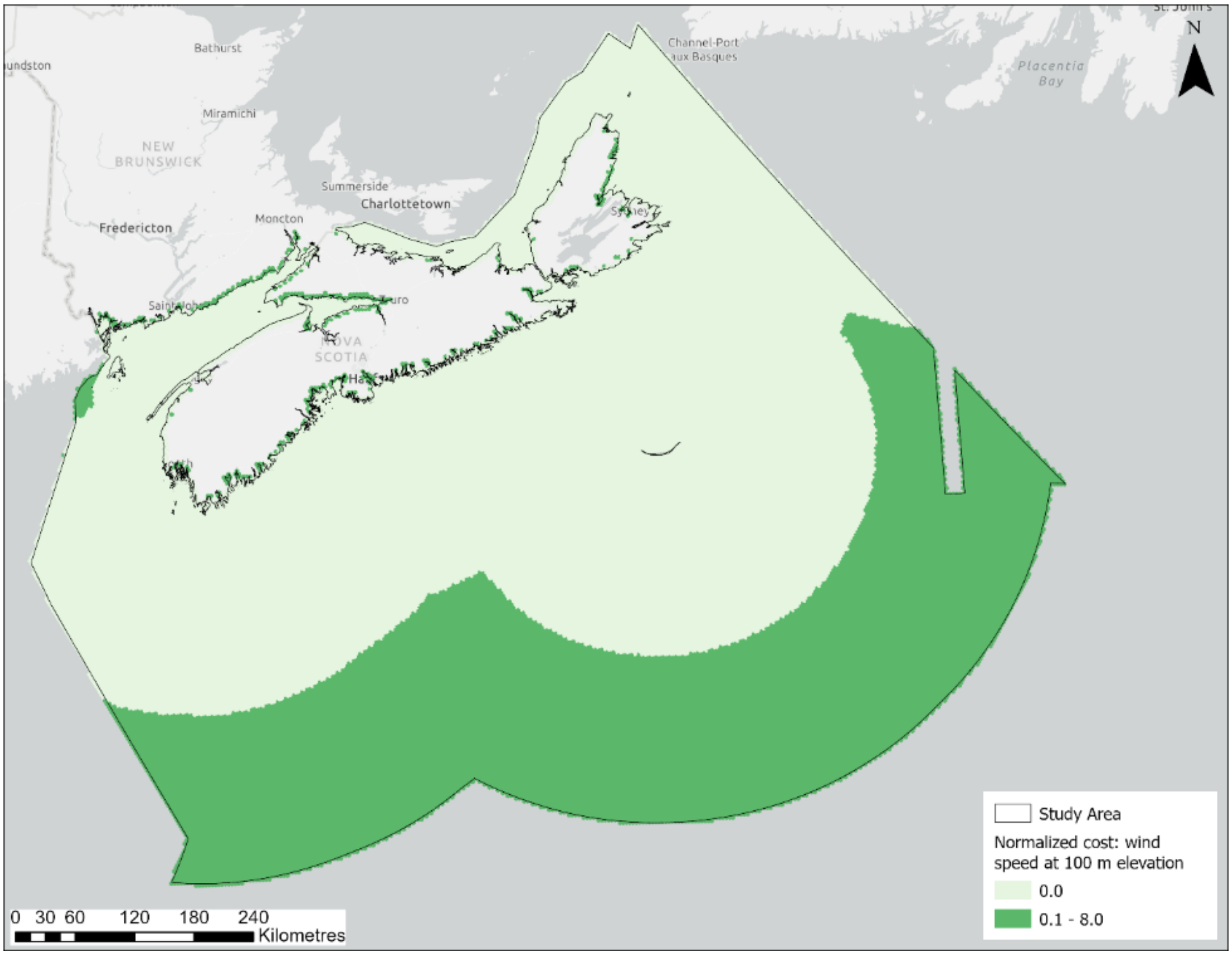


Figure 6. Normalized cost scores for wind speed at 100 m elevation, based on the Global Wind Atlas (Davis et al. 2023). Values of 0 represent areas with mean wind speeds at 100m greater than 7 m/s, and areas with scores of 8 represent areas with no data or where mean wind speeds were less than 7 m/s.

4.3.4 Distance to coast

Higher cost scores were assigned to areas at greater distances from coasts, where coasts were represented by landmasses greater than or equal in size to Prince Edward Island to exclude small islands (NRCan 2023). In this analysis distance to coast served as a proxy for distance to ports and logistics considerations for OWE sites, as in Kilpatrick et al. (2023). In Kilpatrick et al. (2023), the lowest suitability score was applied to distances within 5 nm of the coast, and areas from 5-10 nm received the highest suitability score with descending suitability scores further from the coast. This analysis differed from Kilpatrick et al. (2023) in that the distances closest to the coast (i.e., 0-60 km, Table 1) were assigned the lowest cost score. This approach was taken as human uses and ecological considerations were represented by feature layers, whereas in Kilpatrick et al. (2023) this proximity to coast was assigned lower suitability to account for existing activities and ecological factors.

Mean distance to coast per planning unit was based on grid centroid proximity, and any planning units that intersected landmasses were assigned distances of 0 km. Distance from coast intervals were informed by distances at which different types of transmission infrastructure may be required for OWE farms. These distance intervals are approximate and could be updated in future analysis with more precise estimates as more information becomes available related to how distance to coast affects OWE feasibility.

The lowest cost of 0 was assigned to distance intervals between 0-60 km, as high voltage alternating current (HVAC) is feasible and economical for projects at these distances (Yang et al. 2022) (Table 1). Distances between 60-100 km were assigned a higher cost score of 1, as at distances of 60 km high voltage direct current (HVDC) systems may be considered which have higher capital costs, but overall may be more cost effective for the wind farm (BVG Associates 2019; BOEM 2022; ICF 2018). Distances between 100-185 km were assigned a higher cost score of 2, as beyond 100 km from the coast OWE farms may to require HVDC (BVG Associates 2019). Distances beyond 185 km were scored as the highest cost, equivalent to the "NoData" category for the distance from coast suitability layer in Kilpatrick et al. (2023). Future analyses may reassess distance from coast costs, as OWE may extend to distances up to 190 km from the coast (Dogger Bank Wind Farm 2024). Normalized cost scores for distance to coast are shown in Figure 7.

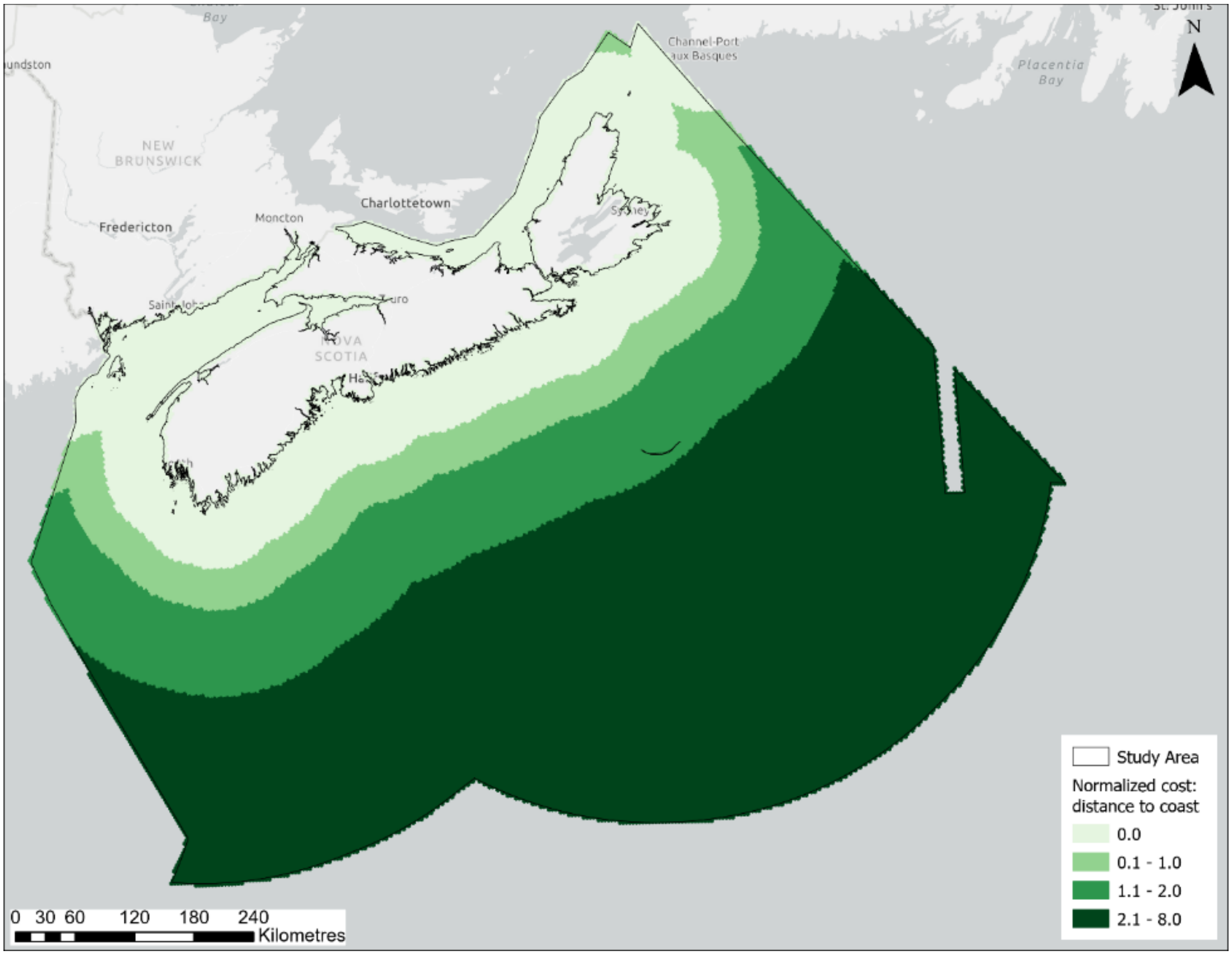


Figure 7. Normalized cost for distance to shore, based on landmasses in the Atlantic Canada and US Eastern Seaboard (NRCan 2019). Higher normalized values represent higher distances from shore.

4.3.5 Surficial geology

Physical constraints and costs to OWE were represented by surficial geology. Three surficial geology layers were combined into a single surface for the study area (Kranck 1971; Loring and Nota 1973; Philibert et al. 2022). Where data overlapped, values were taken where first available in the following order of priority based on expert advice from NRCan (J. Eamer, NRCan, pers. comm.): Philibert et al. (2022), Kranck (1971); Loring and Nota (1973). Surficial geology classifications were assigned different scores in the fixed foundation scenarios compared to the fixed and floating foundation scenarios (Table 2).

Table 2. Cost values applied to surficial geology classifications for the fixed foundation scenarios.

Input layer	Original variable	Original value range	Cost value applied
		Fixed foundation scenarios	
Surficial geology: sands and gravels	Classification	Post-glacial sand and gravel, pro-glacial sand and gravel, pro-glacial sand (Philibert et al. 2022); sand, gravel-sand (Loring and Nota 1973); 5a Buctouche sand and gravel - mainly sand, 7 Egmont sand, 8c Pugwash mud - muddy sand (Kranck 1971)	0
Surficial geology: other types feasible for fixed foundations	Classification	Glacial sublittoral sand, glacial marine mud, interbedded sand and mud, undifferentiated post-glacial sediments, bedrock ≤ 30m depth (Philibert et al. 2022); sand-gravier, pelite-sand, gravel, glacial deposits (Loring and Nota 1973); 5b Buctouche sand and gravel - mainly sandy gravel, 8b Pugwash mud - sandy mud (Kranck 1971)	1
Surficial geology: feasible for fixed and floating foundation technology	Classification	Post-glacial marine mud, interbedded silt and mud, glacial diamict, bedrock >30m depth, hemipelagic mud, overconsolidated mud to diamict, overconsolidated diamict (Philibert et al. 2022); pelite (Loring and Nota 1973); 3 Pomquet drift - glacial till, 6 Malagash mud -sandy mud, 8a Pugwash mud -silty mud (Kranck 1971)	2
Surficial geology: challenges	Classification	Mass transport deposit, undifferentiated bedrock or glacial diamict (Philibert et al. 2022); mixed bottom (Kranck 1971)	8
Surficial geology: No data	N/A	N/A	8

In the fixed foundation scenarios, surficial geologies were assigned cost scores of 0 for sands and gravels, which are less expensive to develop fixed foundation OWE technologies (Taylor 2011 in Eamer et al. 2021; Oh et al. 2018) (Table 2). Scores of 1 were assigned where other surficial geologies were present which were feasible for fixed foundation OWE, other than sands and gravels. Scores of 1 were also assigned where the surficial geology category was bedrock and the depth was ≤30 m, as these areas may be suitable for gravity-based foundations (Tang and Kilpatrick 2021).

Scores of 2 were assigned to surficial geologies likely to be suitable for only floating foundations, based on expert advice from NRCan (J. Eamer, NRCan, pers. comm.). In the fixed foundation scenarios, scores of 8 were assigned for challenges or where there were no surficial geology data available (Table 2). The Summarize Within tool (ArcGIS Pro) was used to calculate the area-weighted mean cost score for each planning unit (Figure 8).

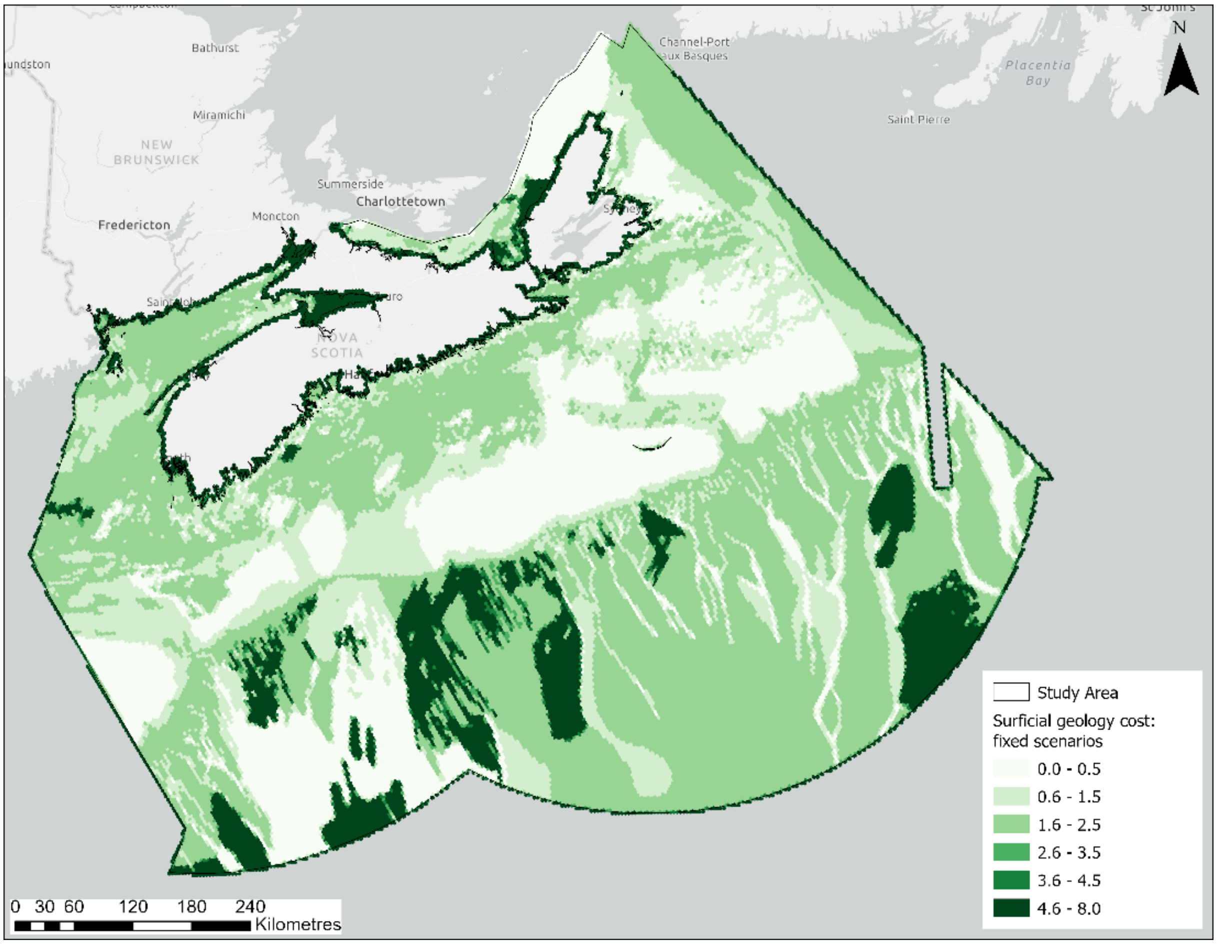


Figure 8. Area weighted mean cost for surficial geology in fixed foundation offshore wind energy scenarios, based on data from Kranck (1971), Loring and Nota (1973) and Philibert et al. (2022). Higher normalized scores represent areas with less suitability or more challenges for fixed foundation OWE.

For areas less than or equal to 70 m water depth, where the surficial geology was categorized as suitable for only floating foundations (Table 2), the extent of the wind zone for the fixed foundation scenarios was limited to exclude these areas (Figure 9).

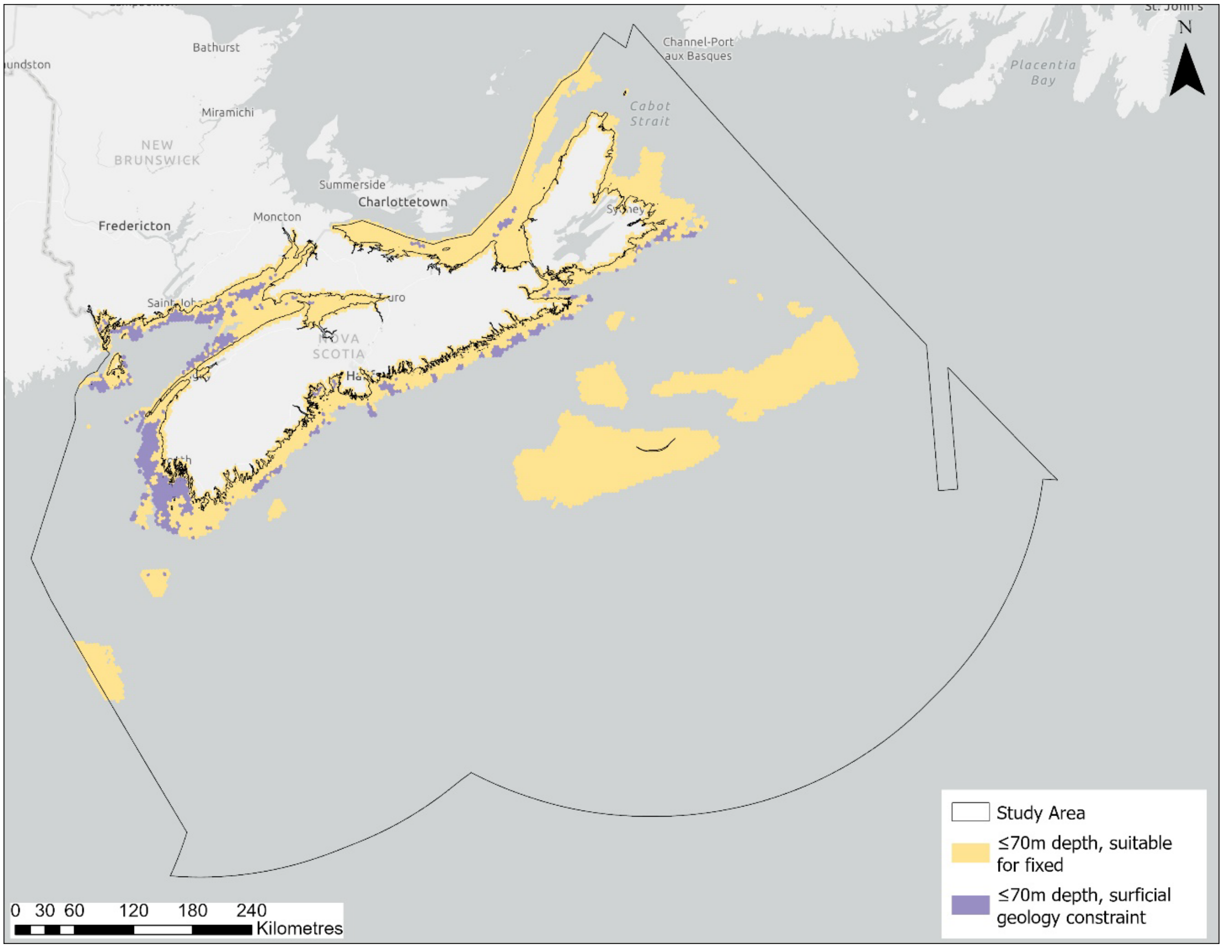


Figure 9. Depth and surficial geology constraints for the fixed foundation offshore wind energy scenarios. Areas with surficial geology constraints were considered only suitable for floating foundation OWE and were excluded from the fixed foundation scenarios.

For the floating foundation scenarios (which represent a combination of both fixed and floating foundation wind technologies), areas suitable for fixed or floating foundations were assigned cost scores of 0 (Table 3). Areas considered challenges or where no data were available were scored 8. The Summarize Within tool (ArcGIS Pro) was used to calculate the area-weighted mean cost score for each planning unit (Figure 10).

Table 3. Cost values applied to surficial geology classifications for the fixed and floating foundation scenarios.

Input layer	Original variable	Original value range	Cost value applied
Surficial geology: Feasible for fixed or floating foundations	Classification	Post-glacial sand and gravel, pro-glacial sand and gravel, pro-glacial sand, Glacial sublittoral sand, glacial marine mud, interbedded sand and mud, undifferentiated post-glacial sediments, bedrock, post-glacial marine mud, interbedded silt and mud, glacial diamict, hemipelagic mud, overconsolidated mud to diamict, overconsolidated diamict (Philibert et al. 2022); sand, gravel-sand, sand-gravier, pelite-sand, gravel, glacial deposits, pelite (Loring and Nota 1973); 5a Buctouche sand and gravel – mainly sand, 7 Egmont sand, 8c Pugwash mud – muddy sand, 5b Buctouche sand and gravel – mainly sandy gravel, 8b Pugwash mud – sandy mud, 3 Pomquet drift – glacial till, 6 Malagash mud - sandy mud, 8a Pugwash mud -silty mud (Kranck 1971)	0
Surficial geology: Challenges	Classification	Mass transport deposit, undifferentiated bedrock or glacial diamict (Philibert et al. 2022); mixed bottom (Kranck 1971)	8
Surficial geology: No data	N/A	N/A	8

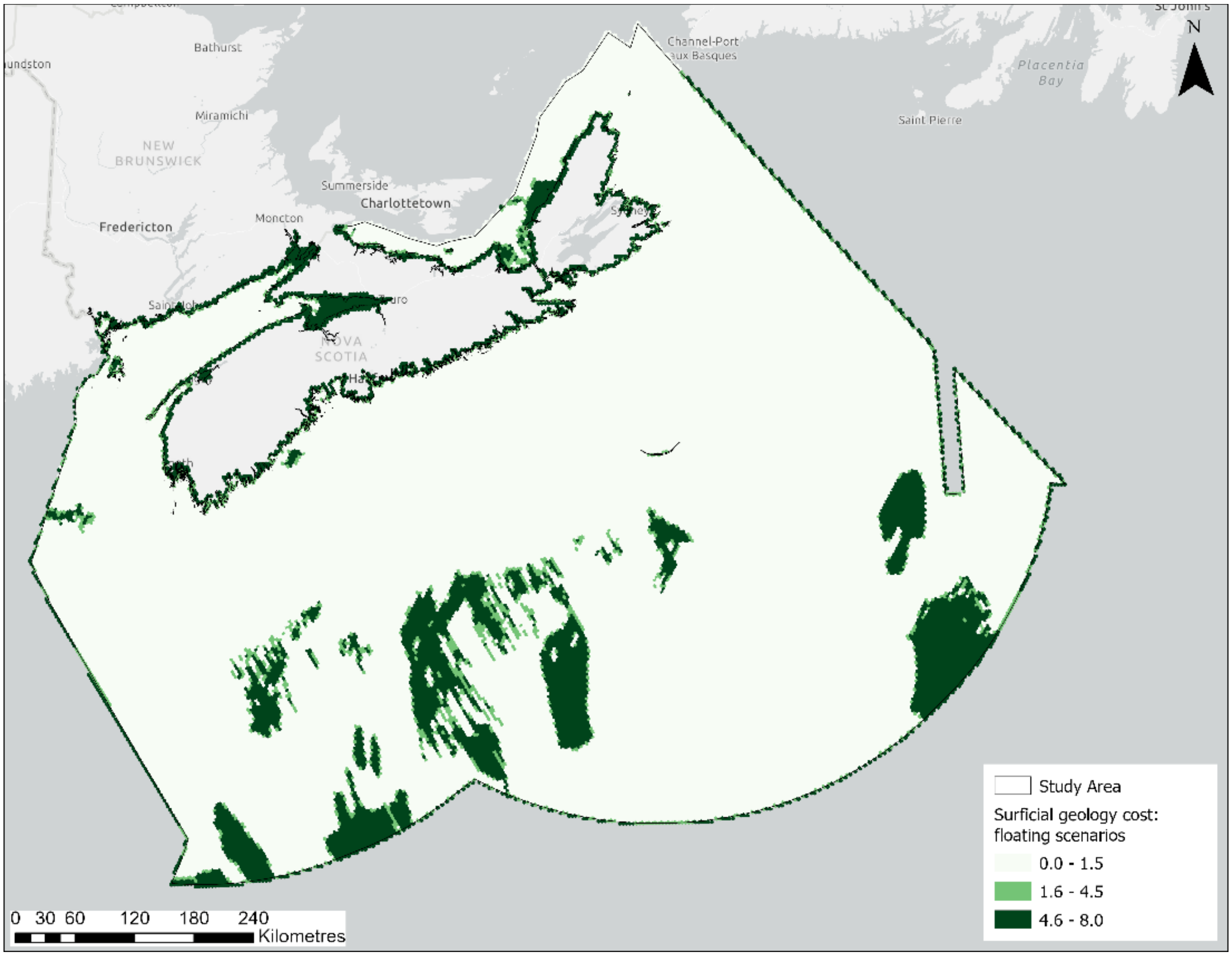


Figure 10. Area weighted mean cost for surficial geology in the floating offshore wind energy scenarios based on data from Kranck (1971), Loring and Nota (1973), and Philibert et al. (2022). Higher normalized scores corresponded to areas with no data or surficial geology challenges for floating foundation ORE.

4.4 Human use data

4.4.1 Commercial fishing

Targets were set for commercial fishing in the existing-use zone using data from DFO Maritimes Region and DFO Gulf Region within the study area. All fisheries were treated equally through the target setting approach, which allowed fisheries with lower total landings or smaller geographic ranges to be assessed the same way as fisheries with higher landings. This allowed for equal treatment regardless of economic value or scale of each fishery, and for important areas for each fishery to be avoided for the wind zone.

For DFO Maritimes Region, landings from the national ZIFF (zonal interchange file format) database were used to represent the majority of fisheries. The ZIFF data consisted of landings from logbook records, and the most recent available 10-year period records (2012-2021) were selected. Landings were summed within each planning unit. Individual targets were set for each management unit within each fishery (Table 4).

Vessel Monitoring System (VMS) data from 2003 to 2018 were used to estimate the pelagic longline fishing footprint and effort intensity, filtered to include vessels moving at speeds consistent with fishing-like behaviour and interpolating vessel positions between hourly detections (Butler et al. 2019). The mean value of the base-10 logarithm of vessel minutes was assigned to each planning unit. A single target was set for pelagic longline fishing (Table 4).

Table 4. Data used to set targets for each fishery in DFO Maritimes Region, and the separation of targets by fishery and management unit.

Fishery	Data used	Separation
Atlantic Cod (*Gadus morhua*), Haddock (*Melanogrammus aeglefinus*)	Logbook landings	4X5Y fixed, 4X5Y mobile, 5zE fixed, 5zE mobile
Clam, offshore	Logbook landings	All combined (Maritimes Region)
Crab	Logbook landings	CFA 20-22, 23, 24, 4X
Flounder	Logbook landings	4VW, 4X5Y, 5Ze
Atlantic Hagfish (*Myxine glutinosa*)	Logbook landings	4X, 4W, 4V, 5Ze
Atlantic Halibut (*Hippoglossus hippoglossus*)	Logbook landings	<45ft 4Vn, <45ft 4VsW, <45ft 4X, <45ft 5Ze, 45ft-65ft fixed, >65ft fixed,
Atlantic Herring (*Clupea harengus*)	Logbook landings	Mobile, fixed
American Lobster (*Homarus americanus*), inshore	Inshore statistical grid	LFA 27, 29, 30 31A, 31B, 32, 33, 34, 35, 36, 37, 38
American Lobster (*Homarus americanus*), offshore	Logbook landings	All combined (Maritimes Region)
Atlantic Mackerel (*Scomber scombrus*)	Logbook landings	Fixed
Pelagic longline (Bluefin Tuna, other tunas, Swordfish)	VMS	All combined (Maritimes Region)
Pollock (*Pollachius virens*)	Logbook landings	Mobile, gillnet
Redfish (*Sebastes* spp.)	Logbook landings	U2, U3
Sea cucumber	Logbook landings	SWNB, 4X inshore, 4W midshore, 4W offshore, 4Vs offshore
Scallop	Logbook landings	SFA 25, 26, 27, 28, 29E, 29W
Shrimp (*Pandalus* spp.)	Logbook landings	Mobile, fixed
Silver Hake (*Merluccius bilinearis*)	Logbook landings	Mobile
Swordfish (*Xiphias gladius*), rod, reel, or harpoon	Logbook landings	All combined (Maritimes Region)
Tuna (*Thunnus* spp.), rod, reel, or harpoon	Logbook landings	Bluefin, other

For the inshore lobster fishery in DFO Maritimes Region, data were combined from two time periods (2012-2014 and 2015-2019) for a total duration of eight years (2012-2019) (DFO 2020a; 2023d). Catch weight data were standardized by area (kg/km^2) and a weighted mean was calculated within each planning unit. Targets were set for each lobster fishing area (LFA) (Table 4).

For DFO Gulf Region commercial fisheries, landings were represented by either georeferenced ZIFF logbook landings, models, traditional fisheries knowledge, or a combination thereof (Table 5). Four types of models were developed for 11 species identified based on important economic value for the fishing industry, available data, and feasibility of mapping (Bennour et al. in prep). Models only incorporated data from fishing licenses which landed catches in DFO Gulf Region (from DFO Gulf Region Statistics), and therefore for several species the models were combined with georeferenced logbook landings for records landed in other DFO regions (Table 5).

Table 5. Data used to set targets for each fishery in DFO Gulf Region, the method used to represent landings, and the separation of targets by fishery and management unit.

Fishery	Data used	Model method	Separation
Scallop	Proxy model and logbook landings	M3	All combined (SFA 24)
Atlantic Halibut (*Hippoglossus hippoglossus*)	Proxy model and logbook landings	M1	All combined (4T)
Atlantic Rock Crab (*Cancer irroratus*)	Proxy model and logbook landings	M3	RCFA 25, 26A, 26B
American Plaice (*Hippoglossoides platessoides*)	Proxy model and logbook landings	M1	All combined (4T)
Bluefin Tuna (*Thunnus thynnus*)	Proxy model and logbook landings	M1	All combined (4RST)
Atlantic Herring (*Clupea harengus*)	Proxy model	M4 (proxy)	All combined (HFA 16F)
American Lobster (*Homarus americanus*)	Proxy model, TFK	M4 (proxy)	LFA 25, 26A, 26B
Atlantic Mackerel (*Scomber scombrus*)	Proxy model, TFK and logbook landings	M4 (proxy)	All combined (16)
Redfish (*Sebastes* spp.)	Logbook landings	N/A	All combined (U1)
Snow Crab (*Chionoecetes opilio*)	Proxy model and logbook landings	M1	CFA 12, 12F, 18, 19, 25
Winter Flounder (*Pseudopleuronectes americanus*)	Proxy model and logbook landings	M1	All combined (4T)
Witch Flounder /Greysole (*Glyptocephalus cynoglossus*)	Proxy model and logbook landings	M1	All combined (4T)

Mapping methods were developed by DFO Quebec Region and adapted to DFO Gulf Region (Bennour et al. in prep). Different model methods were used depending on the georeferencing percentage of fishing areas in the study area. Model method 1 (M1) was applied to species with more than 70% of georeferenced data per fishing area, method 3 (M3) to species with less than

70% of georeferenced data, and method 4 (M4) to species with 0% georeferenced data (proxy)[8] (Table 5). For M1, models were created to add the landings (kg) of each georeferenced point in the underlying planning units. The remaining non-georeferenced landings were distributed in their respective fishing area using a coefficient. The total values for each planning unit reflects 100% of the landing quantities in each fishing area. For M3, non-georeferenced data were distributed to planning units. The method involved determining a catch index calculated using several criteria to identify areas with probable catch (higher index = higher landings probability). The criteria used to develop the index were the distance to landing port, depth, and catch probability (based on landings of georeferenced data). Non-georeferenced landings for each port were randomly distributed in the hexagonal cells within their respective fishing area. Additional depth and distance from port criteria from DFO Fisheries Management were used to develop indexes for sea scallop and Atlantic Rock Crab.

For species with non-georeferenced data (American Lobster, Atlantic Herring, and American Mackerel), proxy models were developed using M4 based on depth, Traditional Ecological Knowledge (TEK), Traditional Fisheries Knowledge (TFK), distance from landing port, and competition (Table 6).

Table 6. Proxy mapping model criteria for Atlantic Herring, American Lobster and Atlantic Mackerel.

Species	Habitat (depth)	TEK-TFK	Distance from landing port	Competition
Atlantic Herring	Yes – Fall spawning grounds	No	No	No
American Lobster	Yes – 2-40 m	Yes	Yes – 20 nm (37 km)	Yes
Atlantic Mackerel	No	Yes	No	No

For American Lobster, more weight was assigned to the human criteria (58%; 50% TEK-TFK, distance from landing port and competition) as opposed to habitat criteria (25%; depth and 50% TEK-TFK), as they were deemed to better represent actual fishing activities (D. Roy and D. Bourque, DFO, pers. comm.). The habitat index was calculated using depth. More weight was assigned to certain depth ranges to take into consideration the likelihood of finding lobster, as suggested by McKee, Grant, and Barrell (2020) for use in MSP. The TFK from 1994-97 were used to calculate the human and habitat index, to account for the lack of spatial landings data.

[8] Another method (M2) was developed by DFO Quebec Region for species where most of the planning units had more than 70% georeferenced logbook data. The ones less than 70% georeferenced only received treatment if there was more than $75,000 of landing value, in which case M1 was applied. In this study, only winter flounder could have been modelled using M2 but M1 was applied instead as the overall georeferencing percentage was close to 70%. The landing value in the fishing areas was also deemed above $75,000.

Distance from landing port was used to develop an index for this consideration. The other constraint considered was the fishing area that limits where fishers can fish. For example, landings with Summer-Fall licenses were distributed within LFA 25 of which the LFA boundary acts as hard constraint. Competition was modeled using buffers between landings ports. The distance to landing port index and competition index were then used to calculate the human index.

Proxy maps for Atlantic Herring and Atlantic Mackerel were created using fewer criteria compared to American Lobster (Table 6). For Atlantic Herring, landings were distributed in the respective herring fishing areas (HFA) within 50 NM from landing ports using an index. This indicator was calculated using the habitat index generated from fall spawning grounds data where areas with higher spawning density were favored (DFO 2022b). Logbook data which were georeferenced for the 2012-2021 period and 2022 were implemented in the model as a complementary variable to calculate a distribution index.

For Atlantic Mackerel, only TFK data was implemented in the model to identify the potential fishing areas. Unlike lobster, fishing intensity was not considered due to data gaps. An index was created using the TFK data and a random index. Landings were distributed accordingly in mackerel fishing area 16 using the index.

4.4.2 Marine transportation

Marine transportation was represented by two input data layers: vessel traffic density and vessel traffic routes. Anchorages were not included as a cost or exclusion layer, as these areas were substantially smaller than the 10 km^2 planning units used in this analysis. Vessel traffic density based on Automatic Identification System (AIS) records for the year 2019 (Vienot et al. 2023) were used as a feature layer, and a target was set for 90% of vessel traffic within the top decile (Figure 11). Vessel traffic routes (CHS 2019) were used in the multi-sector scenarios as exclusion areas for the OWE zone to demonstrate how scenarios can be set up to avoid overlap with these areas. Other options that could be considered in future analyses for considering vessel traffic and vessel traffic routes are described in section 6.4.

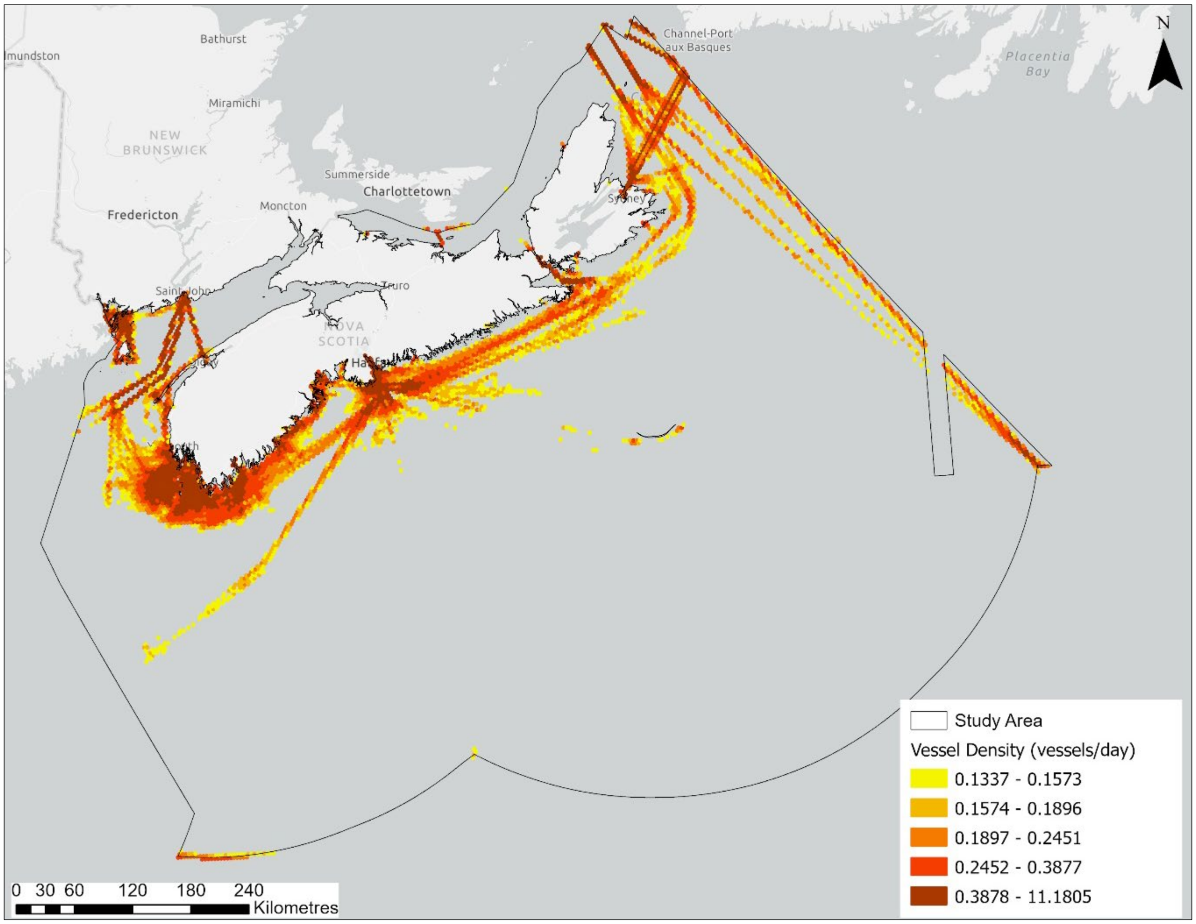


Figure 11. Top decile of vessel traffic density based on Automatic Identification System (AIS) records for the year 2019 based on data from Vienot et al. 2023.

4.5 Ecological data

4.5.1 Area-based conservation measures and ecologically important areas

Area-based conservation measures with legal designations, including *Oceans Act* MPAs (DFO 2021), *Fisheries Act* marine refuges (DFO 2022c), and *Species at Risk Act* critical habitat were excluded from the wind zone in some scenarios due to their legal status and purpose for conservation. Critical habitat for Species at Risk included aquatic species (DFO 2022d), as well as aerofauna (ECCC 2023a). Areas identified for future conservation measures, including Area of Interest (AOI) *Oceans Act* MPAs and Scotian Shelf and Bay of Fundy marine conservation network sites, were excluded from the wind zone for certain conservation focused scenarios. The marine conservation network plan incorporated coastal and offshore conservation priorities, as well as human uses (King et al. 2021, Serdynska et al. 2021). The marine conservation network plan design is subject to change (DFO 2024) and does not include any portion of DFO Gulf Region.

Targets were set within the existing-use zone for areas identified as ecologically important which may interact with OWE. In the absence of a formal conservation network in the DFO Gulf

Region portion of the study area, ecologically and biologically significant areas were used to represent additional ecological importance in the existing-use zone (DFO 2007). Other ecologically important areas included in the analysis were significant benthic areas (Kenchington et al., 2016) and important habitat for species designated as Endangered under Schedule 1 of the *Species at Risk Act*. This was chosen as a cautionary approach as there is uncertainty as to how OWE will interact with the species which use these areas.

Significant benthic areas for sponges, large gorgonian corals, small gorgonian corals, and sea pens (Kenchington et al., 2016) were included as these areas have been recognized as ecologically important regional habitats that are sensitive and susceptible to various anthropogenic activities (DFO 2010; Gullage et al., 2022). An example of how these data were summarized to the planning unit grid is shown in Figure 12 for large gorgonian corals.

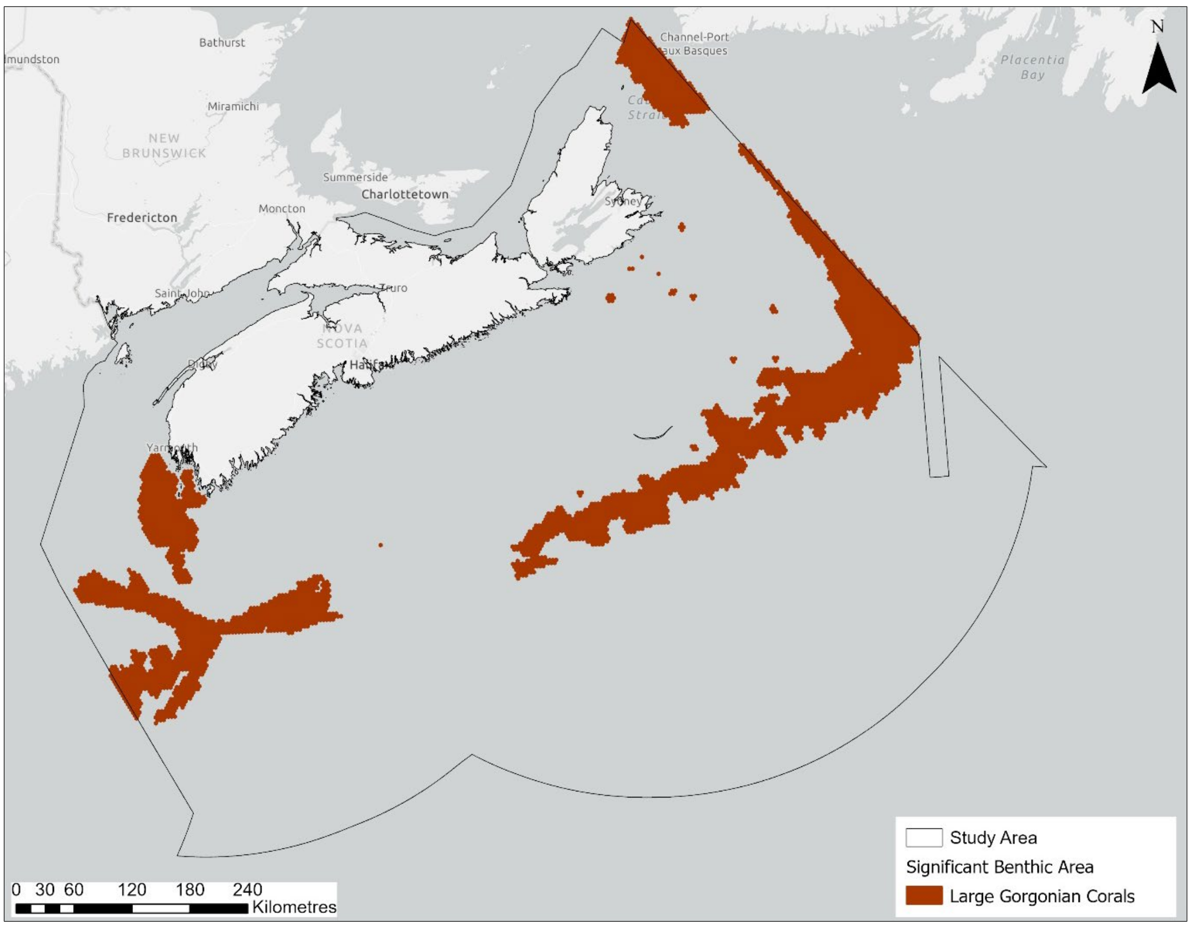


Figure 12. Significant benthic areas for large gorgonian corals based on data from Kenchington et al. (2016), summarized to the 10 km^2 resolution planning unit grid.

Offshore wind energy construction may change habitat characteristics such as sediment properties, and directly affect sessile benthic invertebrates (Kleinknecht 2023). Important habitat for Blue Whale (*Balaenoptera musculus*; DFO 2018), Leatherback Sea Turtle (*Dermochelys coriacea*; DFO 2020b), and Northern Bottlenose Whale (*Hyperoodon ampullatus*, Stanistreet et al. 2021) were included as these areas are defined as habitat that is important for the species survival (e.g., spawning, rearing areas, overwintering areas, migratory corridors) that is not yet identified as critical habitat in a federal Species at Risk recovery strategy or action plan. Each planning unit that intersected these features was assigned values of 1, and 90% targets were set for each category in the feature as described in Table 7.

Table 7. Data used to represent ecologically important areas and the separation of targets.

Ecological Feature	Separation for targets
Significant Benthic Area	Large gorgonian corals, small gorgonian corals, Sponges, sea pens
Important Habitat for Species at Risk	Blue Whale (*Balaenoptera musculus*), Leatherback Sea Turtle (*Dermochelys coriacea*), Northern Bottlenose Whale (*Hyperoodon ampullatus*)
Ecologically and Biologically Significant Areas (Gulf Region)	St. Georges Bay, Western Cape Breton, Laurentian Channel

4.5.2 Important areas for birds

Ecologically important areas for birds were included in some scenarios as feature layers to achieve targets within the existing use zone. Data included sea duck key habitat, important marine areas (IMAs) for migratory bird species at risk, seabird sightings, and areas of breeding seabird foraging.

Sea duck key habitat and important marine area data were available as vector polygons. Planning units that intersected with these areas were assigned equal values of 1, and 90% targets for these areas were set within the existing-use zone. Sea duck key habitat data were available from the Sea Duck Key Habitat Sites Atlas (Bowman et al. 2022).

Important marine areas were delineated by Environment and Climate Change Canada (ECCC) for 4 species listed as Endangered under Schedule 1 of the *Species at Risk Act*: Roseate Tern (*Sterna dougallii*); Piping Plover (*Charadrius melodus melodus*); Bank Swallow (*Riparia riparia*); and Red Knot (*Calidris canutus*). These areas include critical habitat identified in the species' recovery strategies (ECCC 2010; 2021; 2022; 2023b), colony and nest locations, or identified priority sites by the Canadian Wildlife Service (CWS 2024). Bank swallow IMA included a 10 km buffer around identified critical habitat, which includes nesting and foraging habitat (ECCC 2022). The area for Roseate Tern (ECCC 2010) included 50 km buffers around colony locations along the coast and 20 km buffers extending into the offshore. Buffers were based on foraging ranges informed by Very High Frequency (Rock et al. 2007) and Global Positioning System (GPS) (Pratte et al. 2021) tracking data. Piping Plover important areas were identified using a 10 km buffer around critical habitat (ECCC 2021) and observations of Piping Plover both outside the breeding season and at breeding locations recorded between 2017 and 2022 (CWS 2024). Red Knot priority stopover sites were identified by CWS-Atlantic based on Atlantic Canada Shorebird Survey data (ECCC 2023b), and 10 km buffers were applied around these sites (CWS 2024).

Seabird density was represented using Eastern Canada Seabirds at Sea (ECSAS) survey data from 2006-2020 (ECCC 2023c). Data were resampled to 50 km width hexagons and provided as 3 seasonal layers with mean seabird density values (number of birds km^{-2}) with all species aggregated (M. Beaumont, ECCC, pers. comm.). The maximum of the seasonal values was taken to develop an annual maximum seabird density layer. The 'summarize within' tool was used to calculate the mean area-weighted value per planning unit. A 90% target was set for the sum of these values within the existing-use zone.

Foraging distributions of colonial seabirds were developed for species where tracking data were available (per Ronconi et al. 2022), except for Leach's Storm Petrel as models did not capture foraging levels of smaller colonies (ECCC 2023d; 2023e). Models were developed using tracking data (GPS and Platform Transmitter Terminal) from 2005-2016, as well as colony data from the Atlantic seabird colony database (ECCC 2023d; 2023e, CWS 2024). Each input raster was standardized to be between 0-1 to allow for comparability between species, and each raster was resampled to equal resolutions of 2000 m. Each raster was then summarized using zonal statistics within the planning units. Individual species were combined based on foraging guild, and 90% targets were set for the sum of these values for each foraging guild (Table 8).

Table 8. Data used to represent marine bird ecological features and the separation of targets.

Ecological Feature	Separation for targets
Sea duck key habitat	N/A
Important marine areas for migratory birds Species at Risk	Roseate Tern (*Sterna dougallii*), Piping Plover (*Charadrius melodus melodus*), Bank Swallow (*Riparia riparia*), Red Knot (*Calidris canutus*),
Seabird density	All species grouped together
Breeding seabird foraging distributions	Benthic foraging divers, surface feeding piscivores, pursuit diving piscivore, plunge diving piscivore[9]

4.6 Scenarios

Eighteen scenarios with different configurations of targets and costs were developed to demonstrate the utility of MarZones as a flexible decision-support tool. For each scenario, 100 individual solutions were produced based on best practices, and then combined into summed solutions (Serra-Sogas et al. 2020). Four categories of scenarios were developed, 2 single-sector scenario categories (A, B) and 2 multi-sector scenario categories (C,D). These groups of scenarios are summarized in Table 9.

[9] Species composing each foraging guild are described in Ronconi et al. (2022).

Table 9 Summary of the A, B, C, and D groups of multi-sector and single sector scenarios.

Scenario group	Type	Existing Human-uses	Existing Conservation Areas	Additional Ecological Features
A	Single-sector	Commercial fishing	-	-
B	Single-sector	-	Existing Conservation Areas	Additional ecological features and marine conservation network plan
C	Multi-sector	Commercial fishing, transportation, oil & gas, aquaculture	Existing conservation areas	-
D	Multi-sector	Commercial fishing, transportation, oil & gas, aquaculture	Existing conservation areas	Additional ecological features and marine conservation network plan

Single-sector scenarios were developed to provide information on where OWE could be located to avoid spatial overlap with either commercial fishing features or conservation features alone. These included "A" scenarios which assessed a range of targets for commercial fishing, and "B" scenarios which assessed existing conservation areas, important habitat and critical habitat for Species at Risk, additional ecological features, and areas for potential future marine conservation from the marine conservation network plan (Table 9).

Multi-sector scenarios were developed which combined data from commercial fishing, conservation, transportation, oil & gas, and aquaculture sectors. The "C" scenarios assessed these uses as well as existing conservation areas (MPAs and marine refuges). The "D" scenarios expanded on the C scenarios by included additional ecological considerations including the marine conservation network plan, to have a greater ecological focus (Table 9). The multi-sector scenarios represent examples of how MSP or OWE planning can include considerations for other ocean uses simultaneously, to avoid spatial overlap with existing ocean uses and ecological features.

Commercial fishing single-sector scenarios are described in Table 10. These scenarios explored 3 different targets to avoid specific percentages of each fishery feature: 80% (A1), 90% (A2.1 and A2.2), and 100 % (A3). A1, A2.1 and A3. These scenarios were restricted by depth (< 70 m) and surficial geology to focus on areas where fixed foundation OWE was feasible (Figure 13). Scenario A2.2 represented a modified version of scenario A2.1, which was not limited by depth or surficial geology to represent areas where floating OWE could occur in addition to fixed OWE (Table S1, Figure S1; see Appendix 1).

Table 10. Feature layers, costs, and targets included in the commercial fishing single-sector scenarios.

Scenario	A1 Low target	A2.1 Baseline target, fixed	A2.2 Baseline target, fixed & floating	A3 High target
Commercial fishing target (separated by species and management unit)	80%	90%	90%	100%
OWE Technology	Fixed	Fixed	Fixed & floating	Fixed
Wind zone target (planning units)	170	170	170	170
Cost layers	Depth, distance to coast, wind speed, surficial geology, sea ice	Depth, distance to coast, wind speed, surficial geology, sea ice	Depth, distance to coast, wind speed, surficial geology, sea ice	Depth, distance to coast, wind speed, surficial geology, sea ice

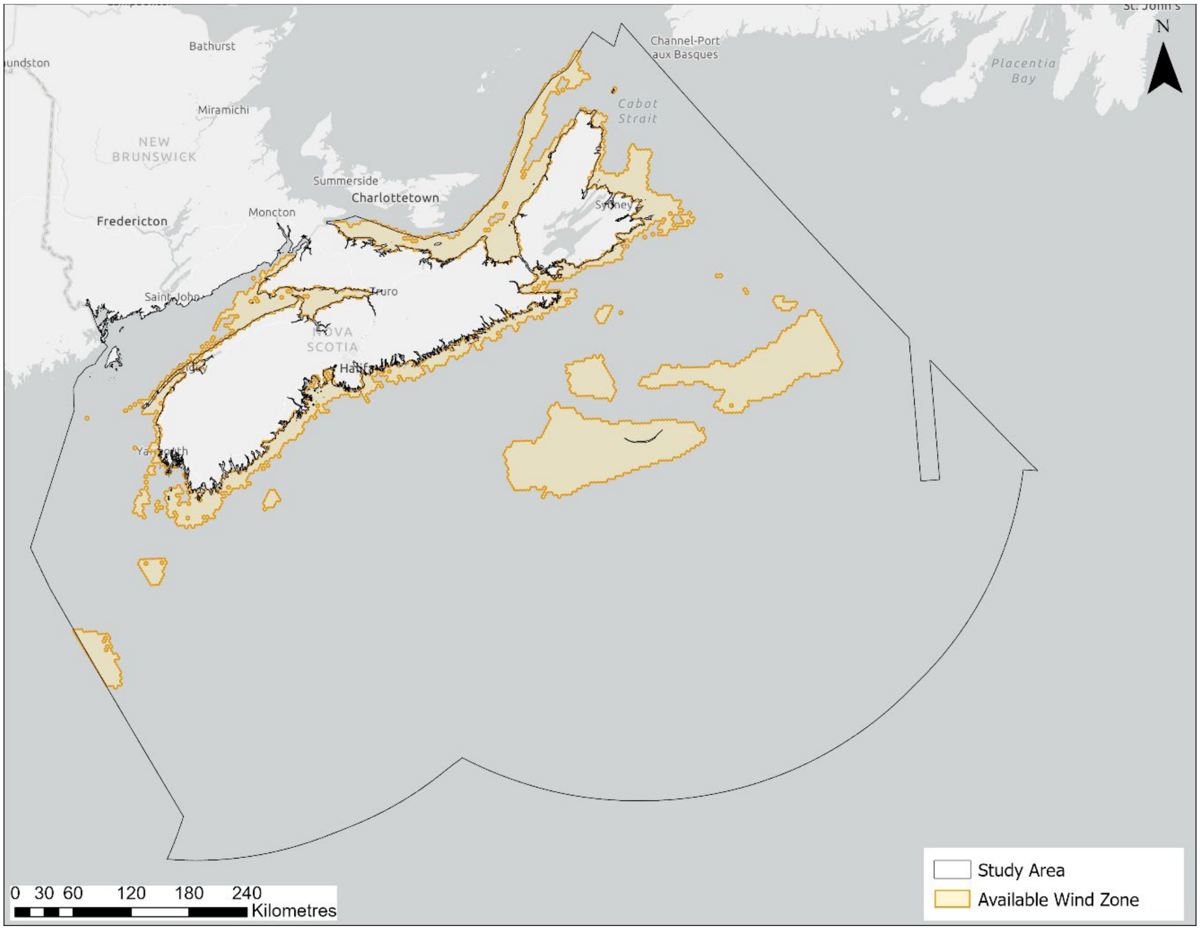


Figure 13. Planning units available to be selected for the wind zone for fixed foundation OWE. This extent was used to limit the wind zone in the commercial fishing single-sector scenarios A1, A2.1, and A3.

Conservation single-sector scenarios are described in Table 11. In scenario B1 MPAs were considered exclusion areas, which resulted in the wind zone not including any planning units falling within MPAs. Conservation scenarios ranged from least constrained for OWE in scenario B1 where only MPAs were excluded from the wind zone, to most constrained in scenario B4 where MPAs, marine refuges, existing conservation areas, critical habitat, and the marine conservation network plan were excluded from the wind zone (Table 11).

In scenario B4, 90% targets were set for other ecological features including important habitat, significant benthic areas, EBSAs (Estuary and Gulf of St. Lawrence planning area only), IMAs for seabirds, key habitat for sea ducks, and predictive foraging areas for seabirds. In contrast to setting areas as exclusions, setting targets allowed for overlap between the wind zone and ecological features. Scenarios B2-B3 represented a range of intermediate scenarios between B1 and B4 (Table 11).

Table 11. Feature layers, costs, and targets included in the conservation single-sector scenarios.

Scenario	B1 MPAs	B2 Conservation areas	B3 Additional ecological considerations	B4 Additional ecological considerations + network plan
MPAs	Exclusion	Exclusion	Exclusion	Exclusion
Marine refuges	-	Exclusion	Exclusion	Exclusion
Other existing conservation areas	-	Exclusion	Exclusion	Exclusion
Critical habitat	-	-	Exclusion	Exclusion
AOIs	-	-	Exclusion	Exclusion
Marine conservation network plan	-	-	-	Exclusion
Cetaceans and leatherback turtles: Important habitat	-	-	90% target for each species	90% target for each species
Significant Benthic Areas	-	-	90% target for each species	90% target for each species
Gulf Region EBSAs	-	-	90% target for each EBSA	90% target for each EBSA
Birds: IMAs, key habitat for sea ducks, sightings	-	-	90% target for each layer	90% target for each layer
Birds: predictive foraging	-	-	90% target for each foraging guild	90% target for each foraging guild
Technology	Fixed	Fixed	Fixed	Fixed
Wind zone target (planning units)	170	170	170	170
Cost layers	Depth, distance to coast, wind speed, surficial geology, sea ice	Depth, distance to coast, wind speed, surficial geology, sea ice	Depth, distance to coast, wind speed, surficial geology, sea ice	Depth, distance to coast, wind speed, surficial geology, sea ice

Baseline multi-sector scenarios are described in Table 12. C1.1 represented a baseline scenario where the ecological exclusions from scenario B2 (Table 11) applied, as this scenario excluded existing conservation areas from the wind zone. This represented a conservative assumption that OWE would not be permitted in existing conservation areas. Vessel traffic routes, oil & gas leases, and aquaculture leases were excluded from the wind zone to prevent overlap between OWE and these existing uses (Figure 14). Targets of 90% were set for commercial fishing and vessel traffic.

Table 12. Feature layers, costs, and targets included in the baseline multi-sector scenarios.

Scenario	C1.1 Baseline	C1.2 Baseline, floating	C2 Baseline, lower wind target	C3 Baseline, higher wind target	C4 Baseline, Regional Assessment study area	C5 Baseline, LCoE
Commercial fishing target (separated by species and management unit)	90%	90%	90%	90%	90%	90%
AIS vessel traffic target (top decile)	90%	90%	90%	90%	90%	90%
Vessel traffic routes, oil & gas leases, aquaculture leases	Exclusion	Exclusion	Exclusion	Exclusion	Exclusion	Exclusion
MPAs, marine refuges & other existing conservation areas	Exclusion	Exclusion	Exclusion	Exclusion	Exclusion	Exclusion
OWE Technology	Fixed	Fixed + floating	Fixed	Fixed	Fixed	Fixed
Wind zone target (planning units)	170	170	100	300	170	170
Cost layers	Depth, distance to coast, wind speed, surficial geology, sea ice	Depth, distance to coast, wind speed, surficial geology, sea ice	Depth, distance to coast, wind speed, surficial geology, sea ice	Depth, distance to coast, wind speed, surficial geology, sea ice	Depth, distance to coast, wind speed, surficial geology, sea ice	Levelized Cost of Energy

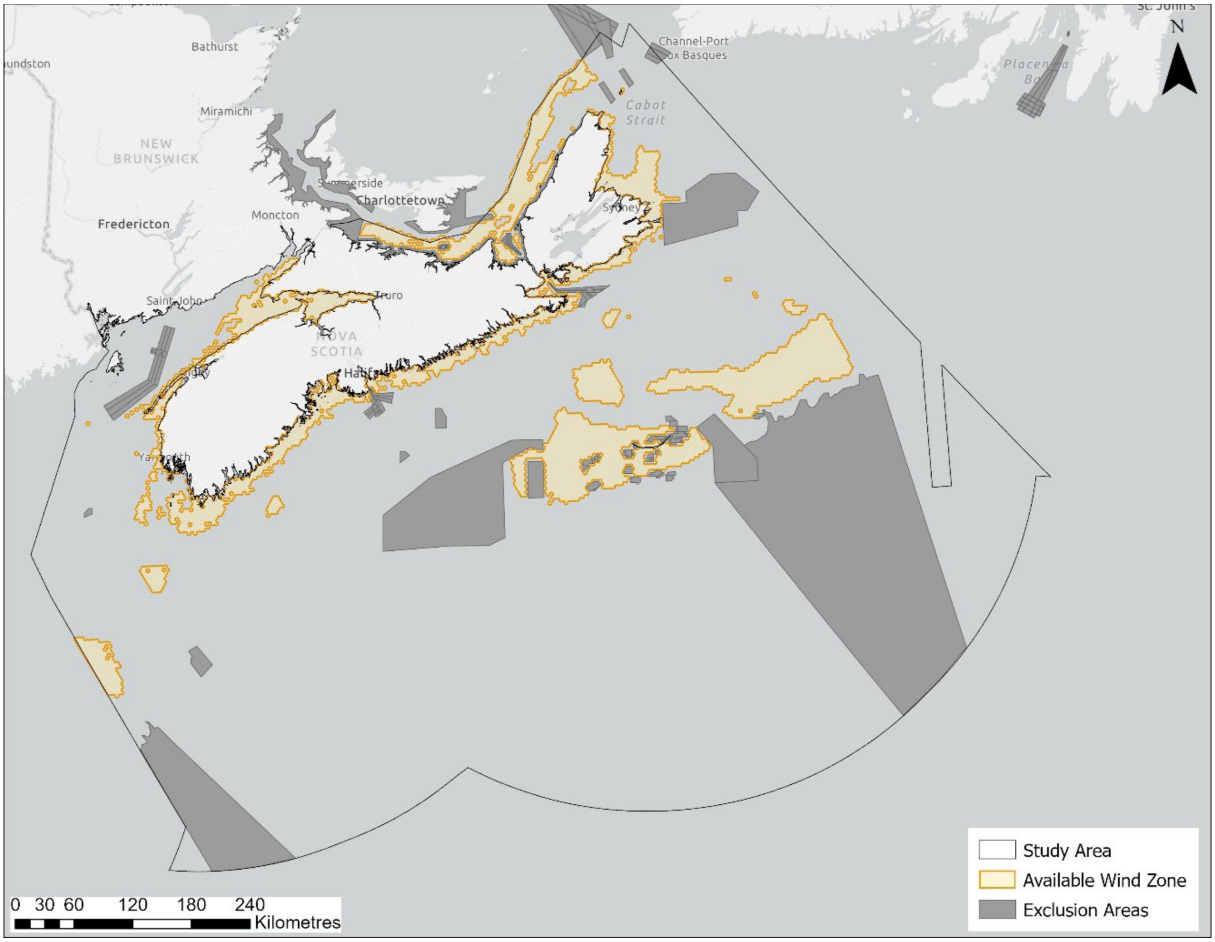


Figure 14. Planning units available to be selected for the wind zone for fixed foundation OWE. This extent was used to limit the wind zone in the multi-sector scenarios C1.1, C2, C3, and C5. Marine protected areas and marine refuges are shown as exclusion area which were unavailable for the wind zone.

Scenario C2 and C3 differed in that the wind area target was set at 100 planning units and 300 planning units respectively (see section 4.2.1). Scenario C5 used LCoE as the Marxan cost layer instead of the combined suitability layer (see section 4.2.2). Scenario C1.2 was similar to C1.1 with the difference that the wind zone was unconstrained by depth or surficial geology, to represent potential areas where floating OWE may be considered in addition to fixed OWE (Figure S3; see Appendix 1).

Ecologically restricted multi-sector scenarios are described in Table 13. Scenario D1.1 represented a multi-sector scenario where ecological considerations from scenario B3 (Table 11) were applied. D2.1 represented a multi-sector scenario where ecological considerations from scenario B4 were applied. Scenario D1.2 represented the fixed and floating-foundation version of D1.1. Scenario D2.2 represented the fixed and floating-foundation version of D2.1 (Table 13).

Table 13. Feature layers, costs, and targets included in the ecologically restricted multi-sector scenarios.

Scenario	D1.1 Ecologically restricted, fixed	D1.2 Ecologically restricted, fixed & floating	D2.1 Ecologically restricted + network plan, fixed	D2.2 Ecologically restricted + network plan, fixed & floating
Commercial fishing target (separated by species and management unit)	90%	90%	90%	90%
AIS vessel traffic (top decile)	90%	90%	90%	90%
Vessel traffic routes, oil & gas leases, aquaculture leases	Exclusion	Exclusion	Exclusion	Exclusion
MPAs, marine refuges & other existing conservation areas	Exclusion	Exclusion	Exclusion	Exclusion
Critical habitat	Exclusion	Exclusion	Exclusion	Exclusion
AOIs	Exclusion	Exclusion	Exclusion	Exclusion
Marine conservation network plan	-	-	Exclusion	Exclusion
Additional ecological considerations (described in scenario B3)	90% targets	90% targets	90% targets	90% targets
OWE Technology	Fixed	Fixed + floating	Fixed	Fixed + floating
Wind zone target (planning units)	170	170	170	170
Cost layers	Depth, distance to coast, wind speed, surficial geology, sea ice	Depth, distance to coast, wind speed, surficial geology, sea ice	Depth, distance to coast, wind speed, surficial geology, sea ice	Depth, distance to coast, wind speed, surficial geology, sea ice

5.0 RESULTS

MarZones produced 100 individual solutions for each scenario. The 100 solutions were combined spatially to produce summed solution maps for the existing-use zone and the wind zone for each of the 18 scenarios. The summed solution maps display the selection frequency for each planning unit for the wind zone or the existing-use zone. Summed solution selection frequency values indicate how many times planning units were selected across the 100 individual solutions for each scenario. For example, a summed solution value of 1 indicated a planning unit was only selected 1 time out of 100 solutions, and that planning unit was a less optimal area to meet targets.

In the wind zone summed solutions, the areas selected represent more than the area target (e.g., 1,700 km^2 for most scenarios) because different areas are sometimes selected across the individual 100 solutions. The summed solutions for each zone show areas that were more or less optimal for meeting the objectives compared to other areas. Summed solution maps for the wind zone do not depict an area of a specific size.

5.1 Marxan results interpretation

5.1.1 Existing-use zone

Existing-use zone selection frequency was visualized using a yellow-blue colour scheme where areas with low selection frequency appear as a lighter yellow colour and areas with higher selection frequency appear as a darker blue colour (e.g., Figure 15). planning units selected 10 or less times per 100 solutions had low selection frequency. Planning units selected 11-50 times per 100 solutions were considered to have moderate selection frequency, as they were selected in some of the 100 solutions. Planning units selected greater than 50 times out of the 100 scenarios were considered to have high selection frequency as they were selected in the majority of the 100 MarZones solutions. *The Marxan Good Practices Handbook* notes that for traditional Marxan, planning units selected greater than 50% of the time are important for efficiently meeting targets (Ardron et al. 2010). Areas of higher selection frequency in the existing-use zone were areas of high value for meeting existing-use feature (i.e., commercial fishing, vessel traffic, or ecological) targets in a spatially efficient manner.

5.1.2 Wind zone

Wind zone selection frequency was visualized using a yellow-red colour scheme where areas with low selection frequency appear as a lighter yellow colour and areas with higher selection frequency appear as a darker orange/red colour (e.g., Figure 15). As in the existing-use zone, planning units selected 10 or less times per 100 solutions had low selection frequency, 11-50 had moderate selection frequency, and >50 had high selection frequency.

Areas with the highest selection frequency were areas that were consistently chosen to meet the wind zone target while avoiding the features in the existing-use zone. When selecting between planning units in the wind zone where feature values were otherwise equal, MarZones selected planning units with higher OWE suitability (i.e., lower MarZones cost). Therefore, the wind zone planning units with higher selection frequency values represented areas with higher OWE suitability and lower spatial overlap with existing uses and ecological features.

5.1.3 Bivariate maps

For several scenarios, bivariate maps were also produced which identified areas where selection was moderate to high in both zones, indicating areas of potential overlap between OWE and existing human uses or ecological features. The areas in brown, dark blue, and black (e.g., Figure 23) on these maps represent areas of potential spatial conflict where more analysis is recommended to assess the activities or features which may overlap with OWE.

5.2 Single sector scenarios

Single sector scenarios were developed to illustrate the influence of a single sector on the area selected in the wind zone. Most scenarios were for fixed foundation OWE. These scenarios incorporated OWE suitability considerations (i.e., costs) in the wind zone.

5.2.1 Commercial fishing scenarios

Summed solution results for scenario A1 which utilized a lower target of 80% for the commercial fishing features (i.e., capture 80% of each commercial fishing feature within the existing-use zone) are shown in Figure 15. Results for scenario A2.1 (baseline target of 90% for commercial fishing features) are shown in Figure 16. Scenario A2.2 allowed the wind zone target to also be met at water depths greater than 70 m to consider fixed and floating foundation OWE (Figure S1; see Appendix 1). Results for scenario A2.2 are shown in Figure S2 (see Appendix 1). Results for scenario A3 (higher target of 100% for commercial fishing features) are shown in Figure 17.

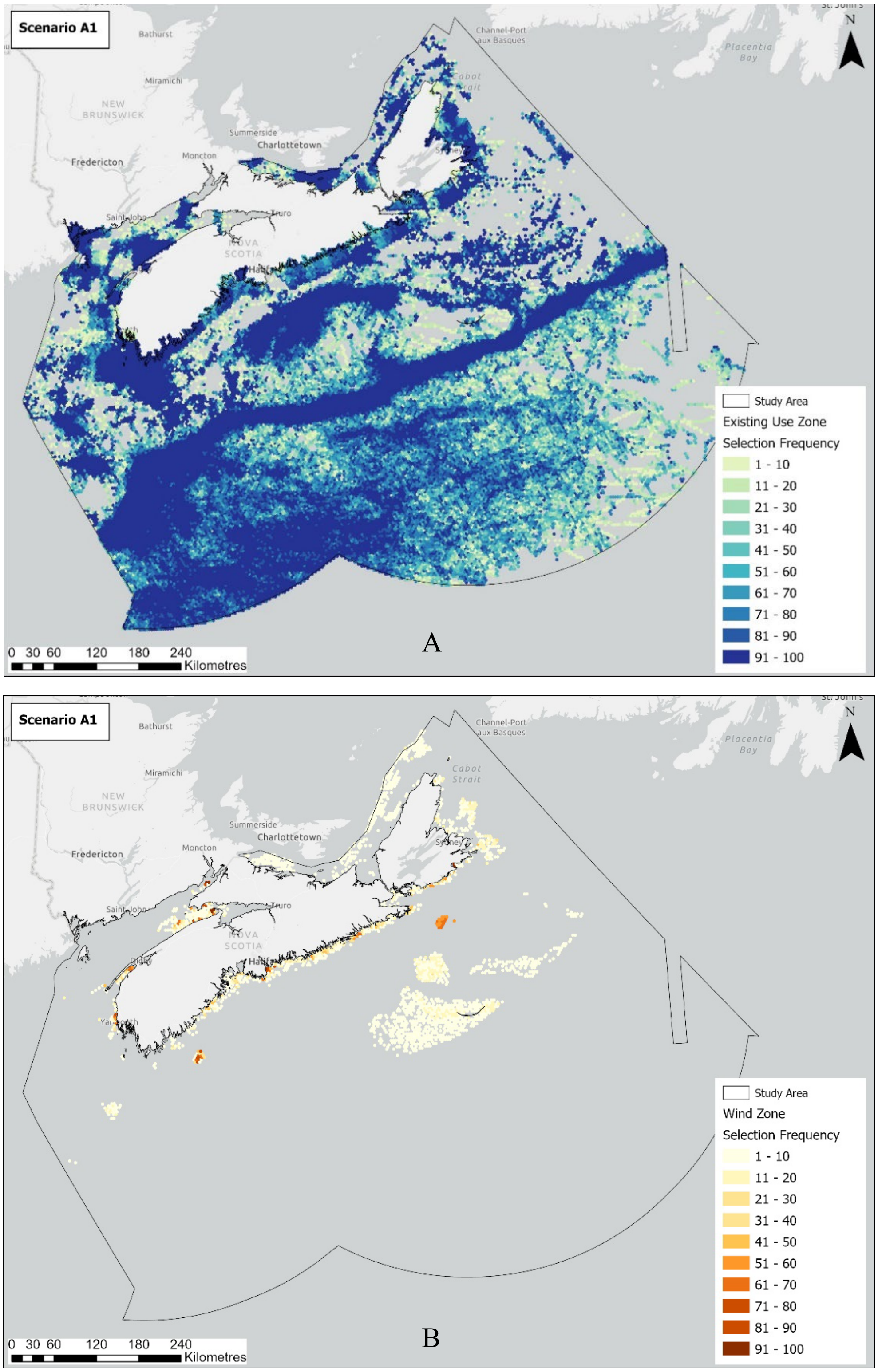


Figure 15. Scenario A1 summed solution selection frequency, n = 100 solutions. Existing-use zone (A): areas selected to meet 80% targets for commercial fishing features. Wind zone (B): areas selected to meet target of 170 planning units for fixed foundation OWE.

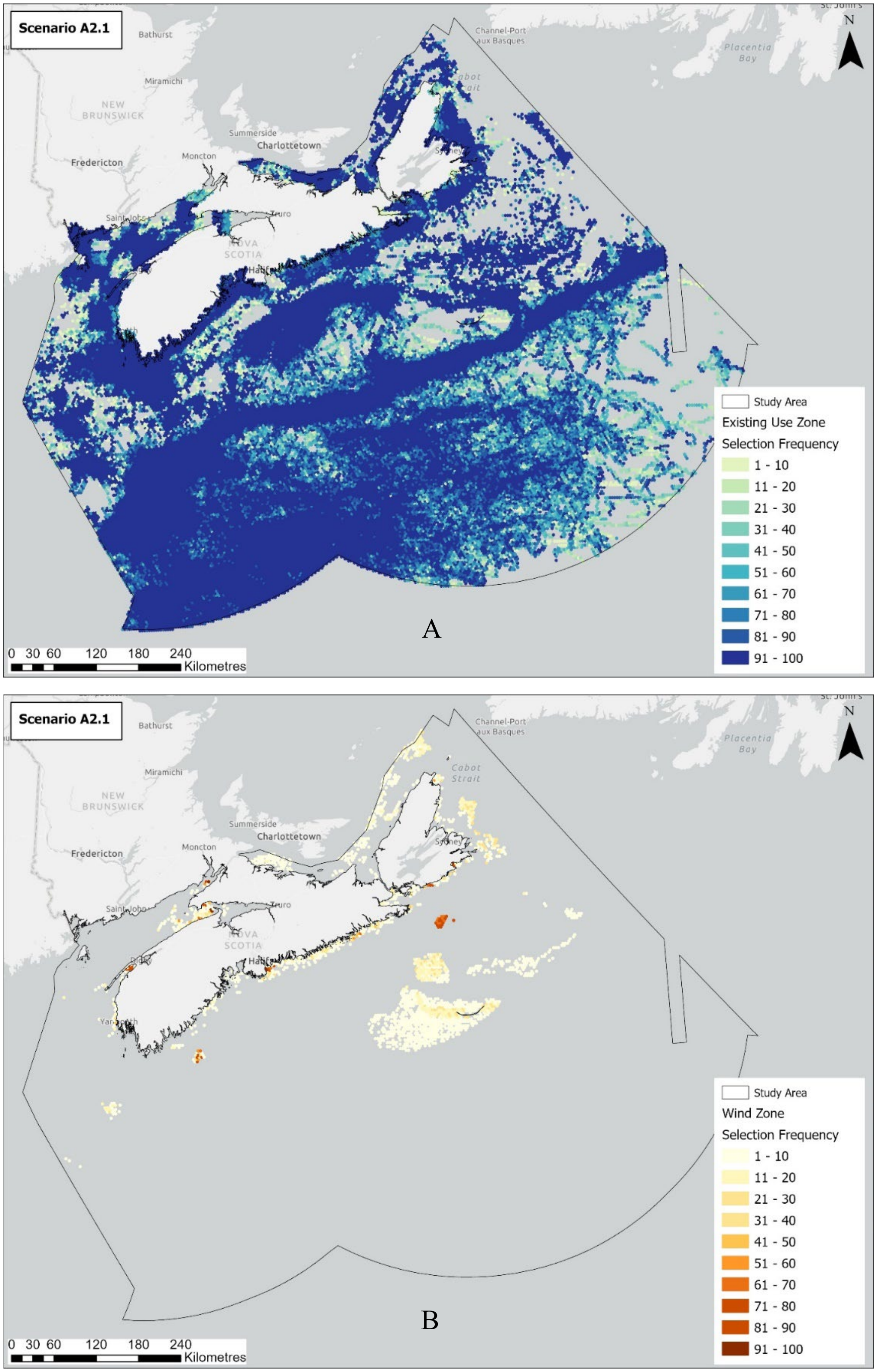


Figure 16. Scenario A2.1 summed solution selection frequency, n=100 solutions. Existing-use zone (A): areas selected to meet 90% for commercial fishing features. Wind zone (B): areas selected to meet the wind zone target of 170 planning units for fixed foundation OWE.

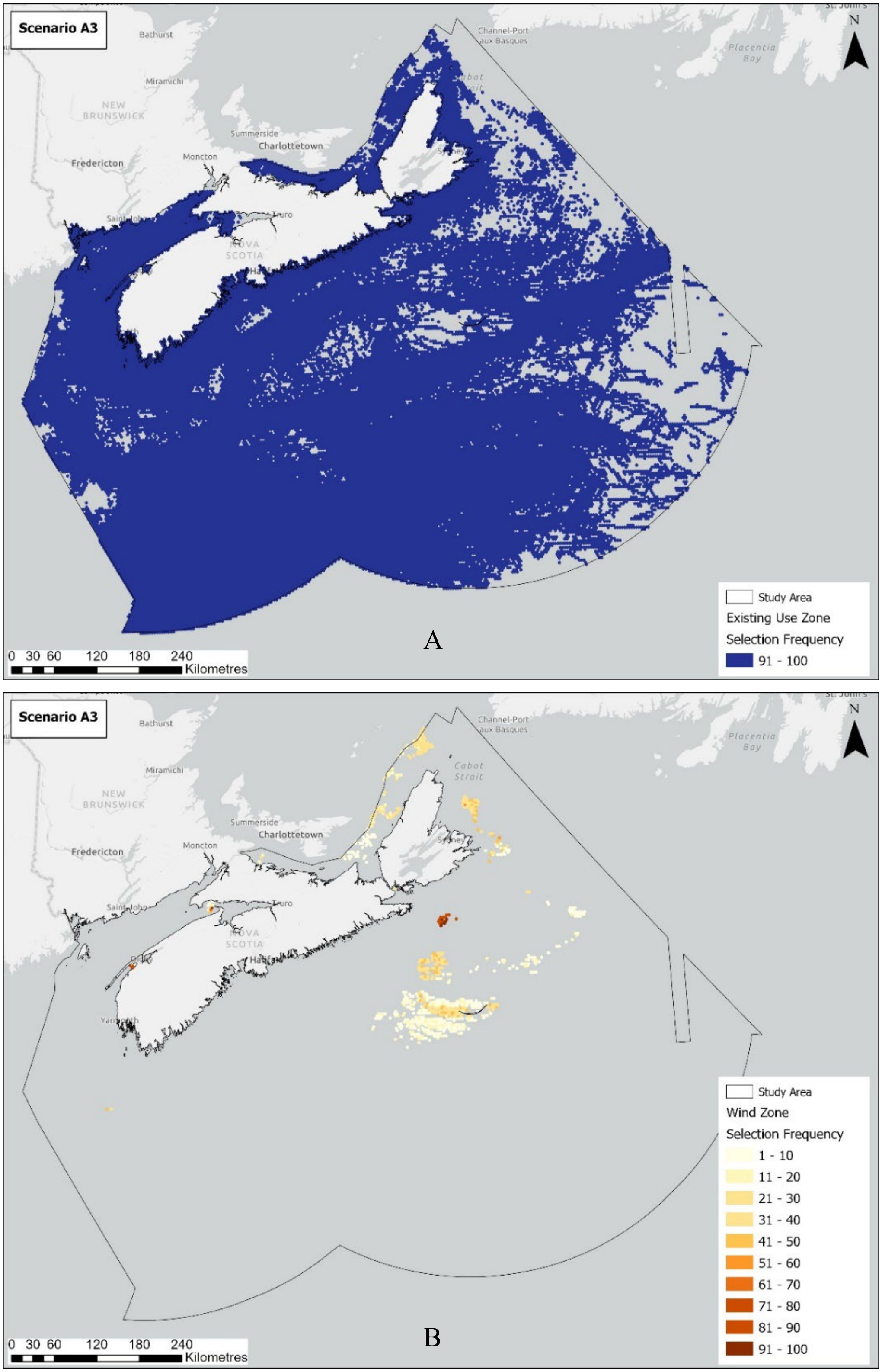


Figure 17. Scenario A3 summed solution selection frequency, n=100 solutions. Existing-use zone (A): areas selected to meet 100% targets for commercial fishing features. Wind zone (B): areas selected to meet target of 170 planning units for fixed foundation OWE.

In comparing results from scenarios A1, A2.1, and A3, shallow offshore areas such as Canso Bank, Roseway Bank, Middle Bank, Sable Island Bank and Sydney Bight emerged as common large contiguous areas selected in the wind zone across the single-sector commercial fishing scenarios (Figures 15-17). Of the offshore areas, selection frequency was consistently highest on Canso Bank across all single-sector fixed foundation commercial fishing scenarios (Figures 15-17). Selection frequency values were highest on Canso Bank in scenario A3 with the 100% target set for fishing features. Scenario A3 also showed more constrained selection on the offshore banks, Sydney Bight, and areas in the Northumberland Strait compared to scenarios A1 and A2.1. In the floating scenario (A2.2) the pattern of areas selected was similar to the other single-sector commercial fishing scenarios, however with lower wind zone selection frequency on the offshore banks such as Canso Bank, Middle Bank, and Sable Island Bank (Figure S2; see Appendix 1).

Across these scenarios, moderate to high wind zone selection frequency was also seen in several coastal areas including the Eastern Shore of Nova Scotia, parts of the Minas Channel, outside of the Halifax Harbour, and in the Northumberland Strait (Figures 15-17). For scenarios A1, A2.1, and A2.2, all 80% and 90% targets for features in the existing-use zone were exceeded, meaning that for each scenario the wind zone avoided more than 80% or 90% of every individual feature. For scenario A3 the 100% target was met in all 100 MarZones solutions for 44 of the 80 features included in the existing-use zone. Potential overlap between features and the wind zone was quantified by assessing the percentage of the feature value occurring within the wind zone across all 100 solutions. Across the commercial fishing scenarios, the mean overlap for all features with the wind zone across the 100 solutions was between 0.03-0.45% (Table 14). The influence on the wind zone by increasing the target for commercial fisheries from 80% to 100% was most evident in nearshore areas where suitable wind areas are no longer identified along much of the Nova Scotia coastline (Figure 17).

Table 14. Mean percentage overlap (± standard deviation) of all features with the wind zone for the commercial fishing single-sector scenarios.

Scenario	**Mean feature overlap (% ± SD) with wind zone**
A1	0.45 ± 0.75
A2.1	0.25 ± 0.43
A2.2	0.43 ± 0.83
A3	0.03 ± 0.07

The highest overlap between the wind zone and individual commercial fishing features across the 100 MarZones solutions for each A scenario ranged from 0.34% to 3.18% (Table 15). These features were inshore lobster (LFAs 31B and 32), herring (fixed), and sea cucumber (4W midshore).

Table 15. Individual commercial fishing features with the highest mean percentage overlap (± standard deviation) with the wind zone for each commercial fishing single-sector scenario.

Scenario	Feature	Individual feature overlap (% ± SD) with wind zone
A1	American Lobster, inshore, LFA 32	3.18 ± 0.68
A2.1	American Lobster, inshore, LFA 31B	2.09 ± 0.65
A2.2	Atlantic Herring, fixed	3.59 ± 1.24
A3	Sea cucumber, 4W midshore	0.34 ± 0.16

5.2.2 Conservation and ecological feature scenarios

Scenario B1 excluded only MPAs from the wind zone, and summed solution results are shown in Figure 18. Results for scenario B2, which excluded conservation areas (MPAs and marine refuges) from the wind zone are shown in Figure 19. The areas selected more frequently in scenarios B1 and B2 reflect OWE physical suitability data as the sole driver, as no feature targets were set for the existing-use zone in these scenarios. Therefore, the existing-use zone is not shown for scenarios B1 and B2. Summed solution results for scenario B3 which excluded existing conservation areas and AOIs for future conservation areas from the wind zone and incorporated ecological features in the existing-use zone, are shown in Figure 20. Results for scenario B4 which included the same ecological features and exclusions as scenario B3, plus the exclusion of the marine conservation network plan for the Scotian Shelf and Bay of Fundy bioregion, are shown in Figure 21.

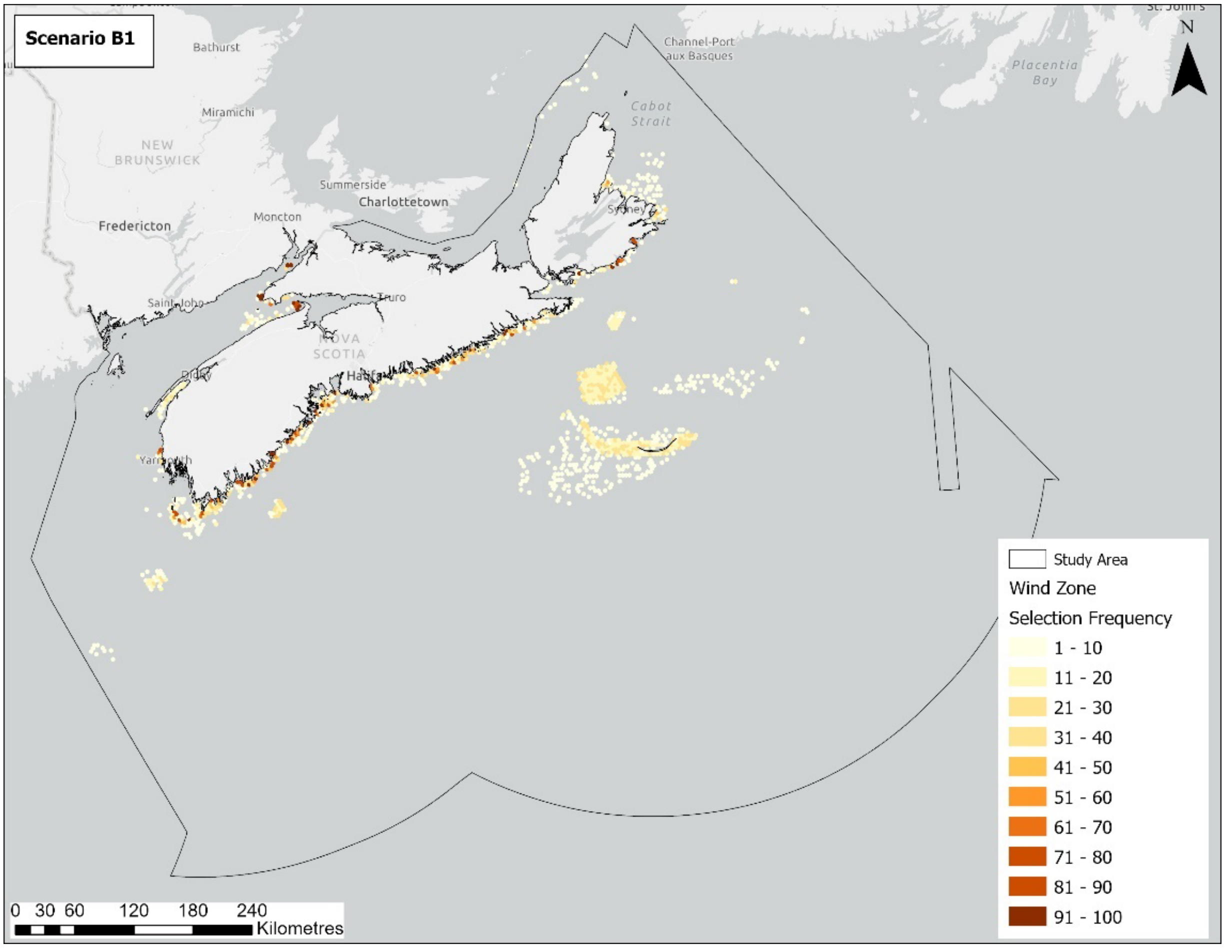


Figure 18. Scenario B1 wind zone summed solution selection frequency, n=100 solutions. Areas selected to meet the target of 170 planning units for fixed foundation OWE that do not overlap with existing MPAs.

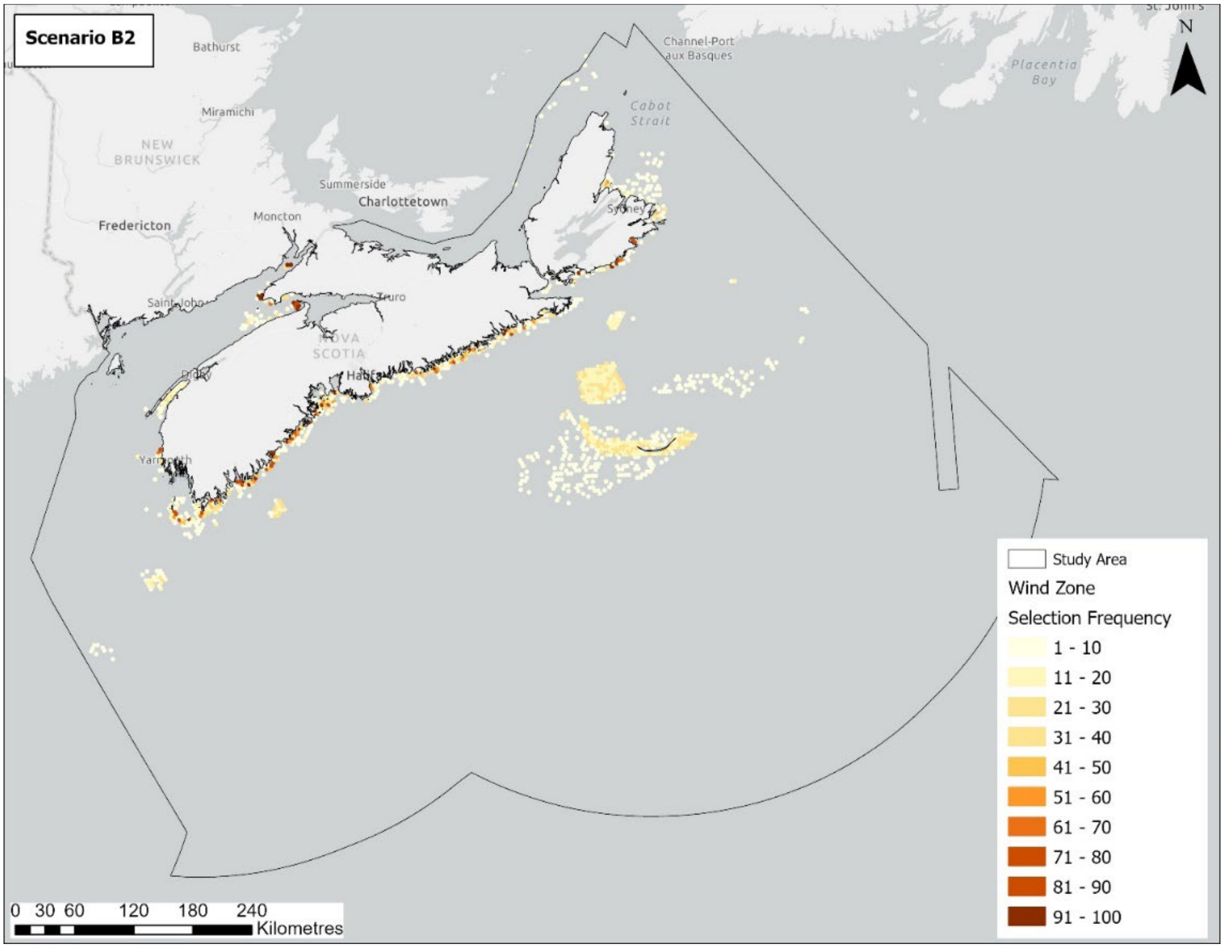


Figure 19. Scenario B2 wind zone summed solution selection frequency, n=100 solutions. Areas selected to meet target of 170 planning units for fixed foundation OWE that do not overlap with existing conservation measures (i.e., MPAs and marine refuges).

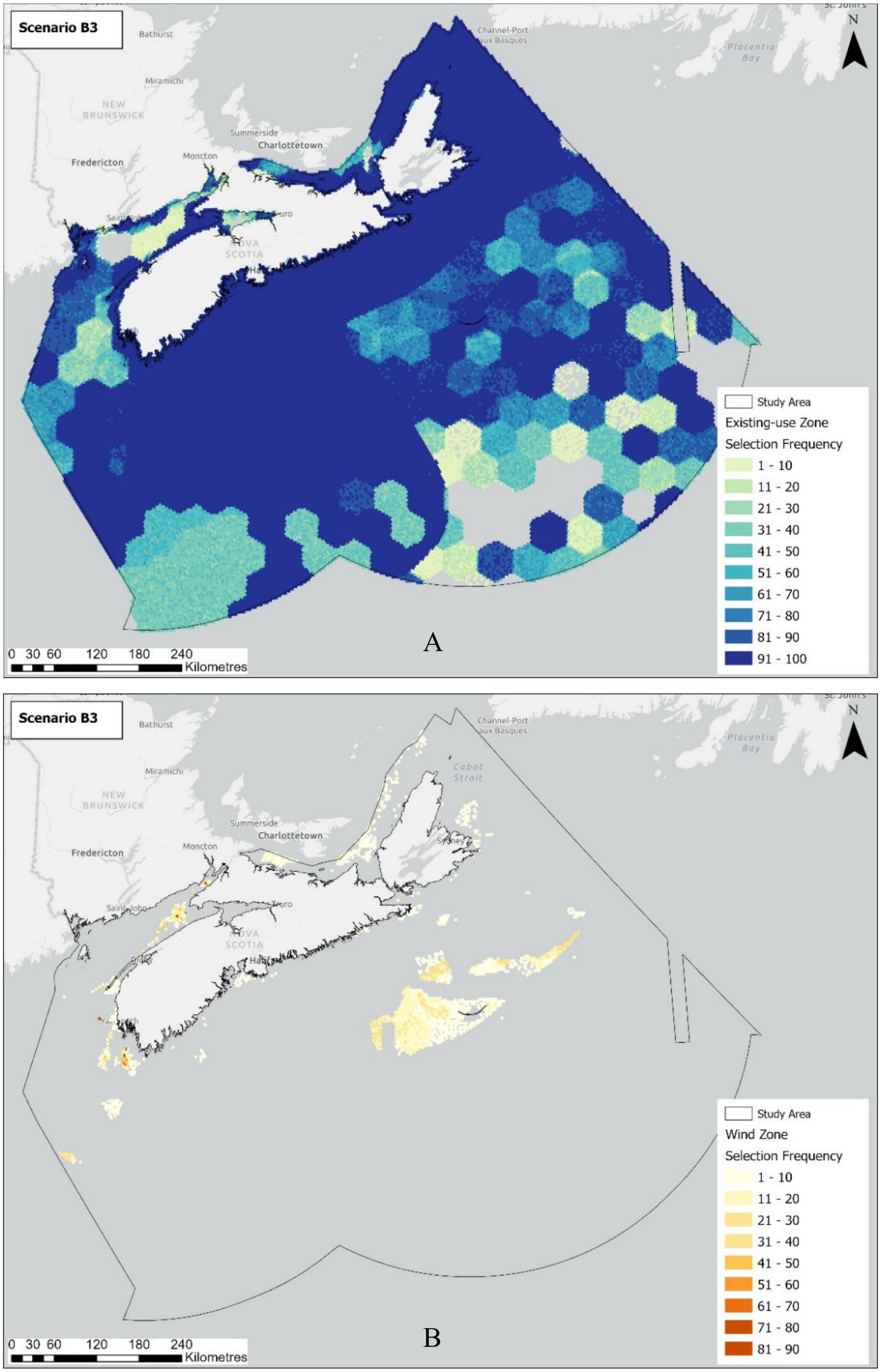
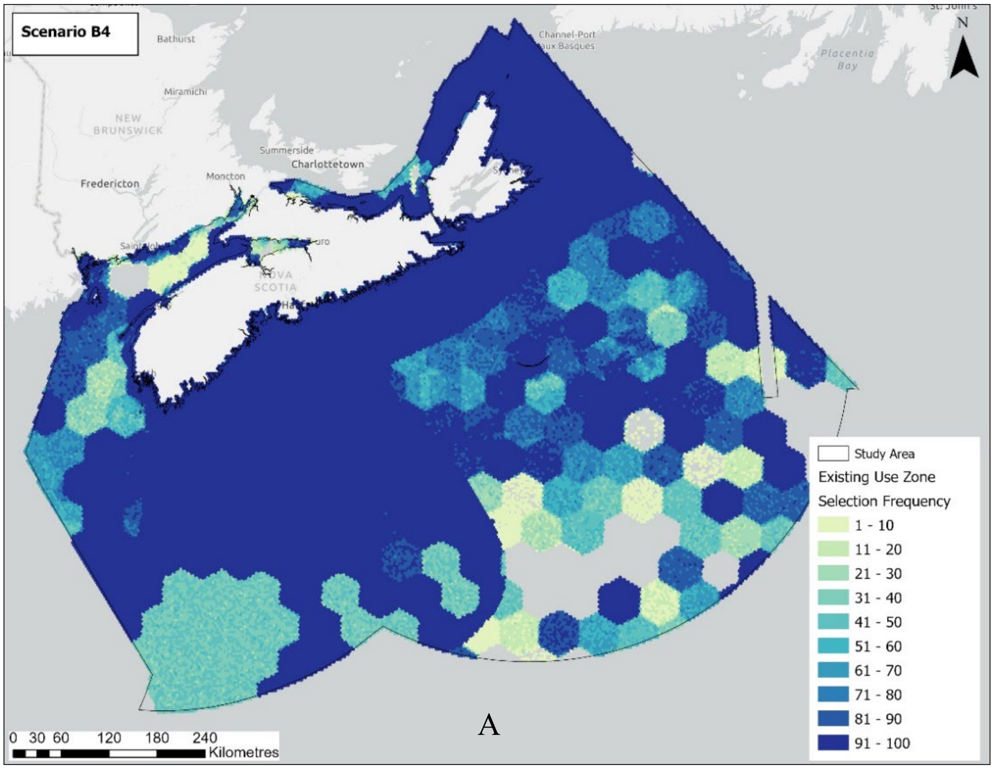


Figure 20. Scenario B3 summed solution selection frequency, n=100 solutions. Existing-use zone (A): areas selected to meet 90% target for ecological features. Wind zone (B): areas selected to meet target of 170 planning units for fixed foundation OWE and do not overlap with existing conservation measures and AOIs.



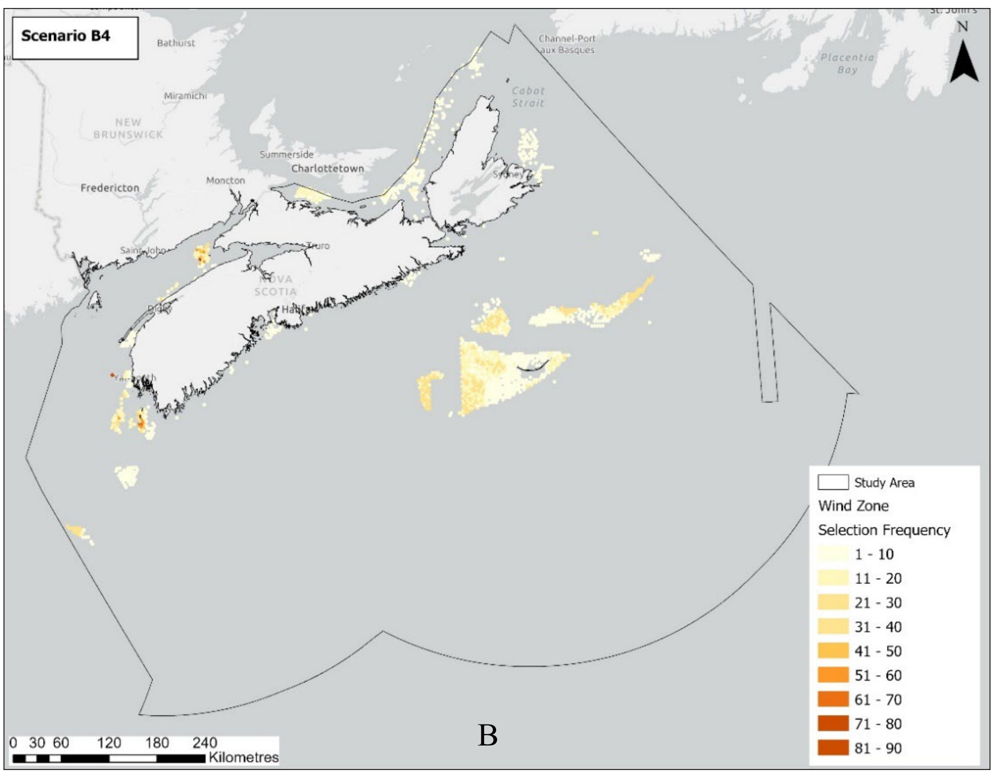


Figure 21. Scenario B4 summed solution selection frequency, n=100 solutions. Existing-use zone (A): areas selected to meet 90% target for ecological features. Wind zone (B): areas selected to meet target of 170 planning units for fixed foundation OWE and do not overlap with existing conservation measures, AOIs, and marine conservation network sites.

Across the single-sector conservation scenarios B1, B2, B3, and B4, shallow offshore banks including Canso Bank, Roseway Bank, Middle Bank, and Sable Island Bank emerged as common large contiguous areas with low to moderate selection frequency (Figures 18-21). Sydney Bight showed lower selection frequency in the wind zone in the B scenarios compared to A1, A2.1, and A3. In scenario B4, Roseway Bank and Canso Bank overlapped with the marine conservation network plan and as a result were not available to be selected in wind zone in this scenario (Figure 21).

Several nearshore areas emerged as small hotspots of high wind zone selection frequency in scenarios B1 and B2 including areas of the Eastern Shore of Nova Scotia, Southern Shore of Nova Scotia, and the Minas Channel (B1 Figure 18, B2 Figure 19). For the single-sector conservation scenarios that included ecological features in the existing use zone (i.e., scenarios B3 and B4) wind zone selection frequency differed in the nearshore areas with low to moderate wind zone selection frequency in the Minas Chanel and the Southern Shore of Nova Scotia (off the coast of Barrington Passage) and no wind zone selection frequency around the Eastern Shore of Nova Scotia (B3 Figure 20, B4 Figure 21). The pattern of selection in the existing-use zone in scenarios B3 and B4 was substantially different than in the A-series scenarios, and the pattern of selection frequency in some areas visually aligned with the pattern of the ECSAS 50 km-width hexagons.

Across the single-sector conservation and ecological scenarios B3 and B4 all 90% targets for features in the existing-use zone were exceeded, meaning that for each scenario the wind zone avoided more than 90% of every individual conservation and ecological feature. Potential overlap between features and the wind zone was quantified by assessing the percentage of the feature value occurring within the wind zone across all 100 solutions. Across these scenarios, the mean overlap for all features with the wind zone across the 100 solutions was 0.24% in scenario B3 and 0.27% in scenario B4 (Table 16).

Table 16. Mean percentage overlap (± standard deviation) of all features with the wind zone for the conservation and ecological feature scenarios.

Scenario	Mean feature overlap (% ± SD) with wind zone
B1	NA
B2	NA
B3	0.24 ± 0.24
B4	0.27 ± 0.29

In the B scenarios where targets were set in the existing-use zone, the highest overlap between the wind zone for any individual feature across the 100 solutions was with the IMA for Roseate Tern in both scenario B3 (0.96%) and scenario B4 (1.06%) (Table 17).

Table 17. Individual features with the highest mean percentage overlap (± standard deviation) with the wind zone for each conservation and ecological feature scenario.

Scenario	Feature	Individual feature overlap (% ± SD) with wind zone
B1	NA	NA
B2	NA	NA
B3	IMA Roseate Tern	0.96 ± 0.18
B4	IMA Roseate Tern	1.06 ± 0.19

5.3 Multi-sector scenarios

Multi-sector scenarios identified potential areas for OWE when multiple oceans uses and conservation or ecological features were incorporated as exclusion areas or as target features within the existing-use zone. These scenarios incorporated OWE suitability considerations (i.e., costs) in the wind zone. Scenarios C1.2, D1.2, and D2.2 allowed the wind zone target to be met at depths greater than 70 m.

5.3.1 Baseline multi-sector scenarios

The summed solution maps for baseline scenario C1.1 are shown in Figure 22. The summed solutions were combined to also show bivariate results, identifying areas selected in both zones across the 100 individual solutions (Figure 23). Scenario C1.2 allowed the wind zone target to be met in areas greater than 70 m depth to consider both fixed and floating OWE (Figure S3, Figure S4; see Appendix 1). Scenario C2 used a lower wind area target of 100 planning units (Figure 24), scenario C3 used a higher wind energy area target of 300 planning units (Figure 25), and scenario C4 constrained the wind zone to the Nova Scotia *Regional Assessment* study area (Figure 26). Scenario C5 used LCoE as the sole cost layer for the wind zone, instead of the suitability layers (Figure 27, Figure 28).

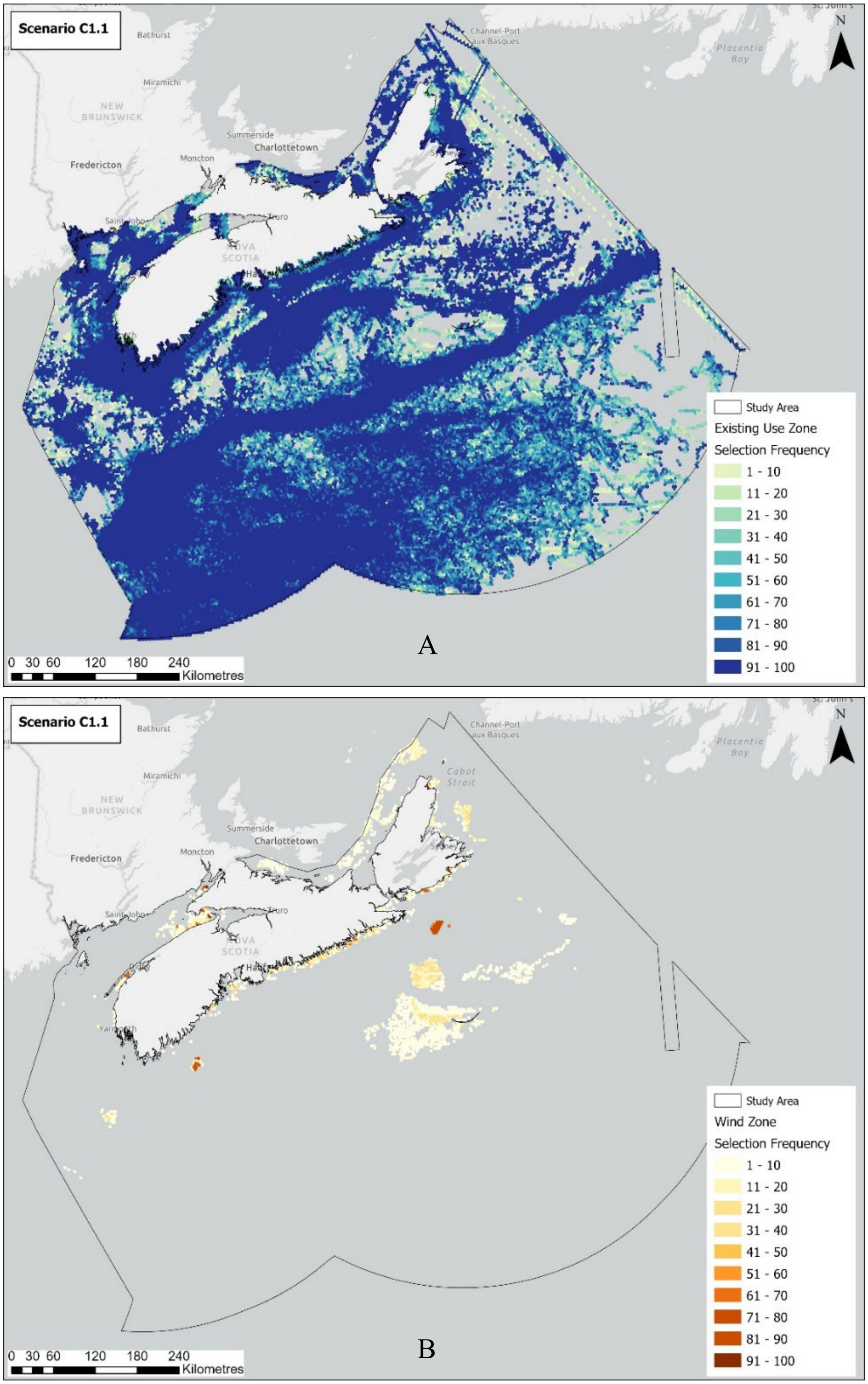


Figure 22. Scenario C1.1 summed solution selection frequency, n=100 solutions. Existing-use zone (A): areas selected to meet 90% targets for commercial fishing and vessel traffic features. Wind zone (B): areas selected to meet target of 170 planning units for fixed foundation OWE excluding existing conservation measures, lease areas, and vessel traffic routes.

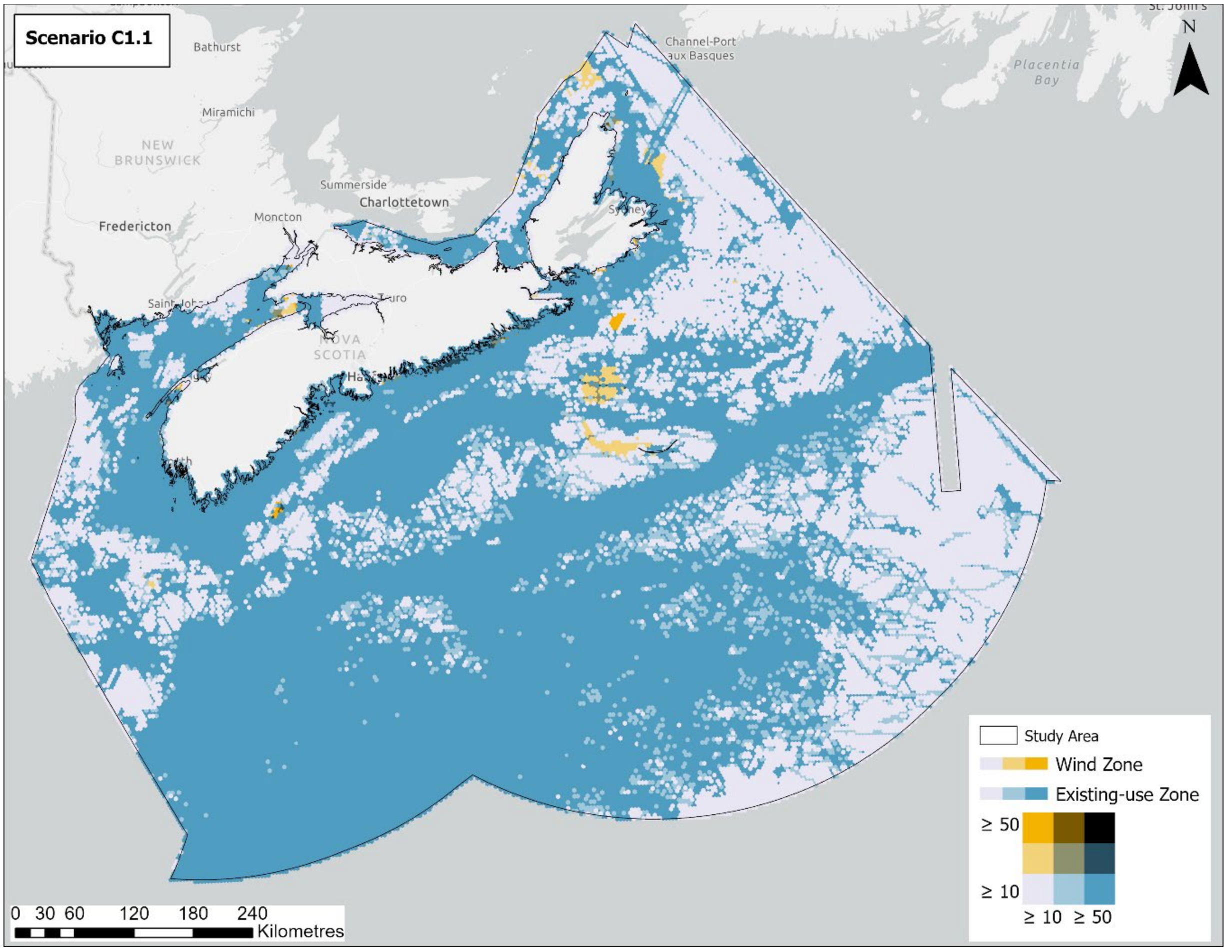


Figure 23. Scenario C1.1 bivariate selection frequency for the wind zone and existing-use zone summed solutions n=100 solutions. Bivariate symbology highlights areas of lower and higher overlap between the two summed solutions.

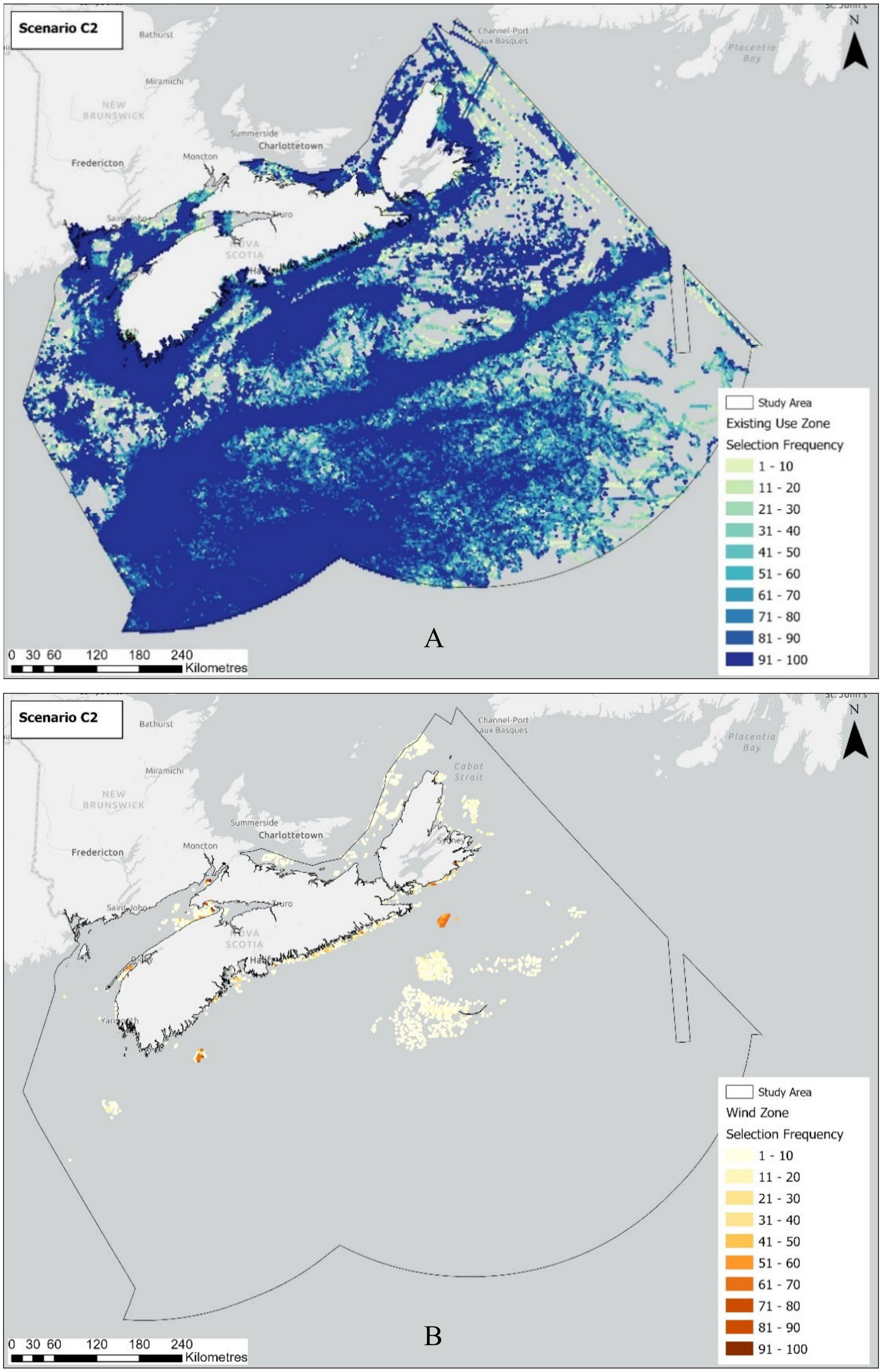


Figure 24. Scenario C2 summed solution selection frequency, n=100 solutions. Existing-use zone (A): areas selected to meet 90% targets for commercial fishing and vessel traffic features. Wind zone (B): areas selected to meet target of 100 planning units for fixed foundation OWE excluding existing conservation measures, lease areas, and vessel traffic routes.

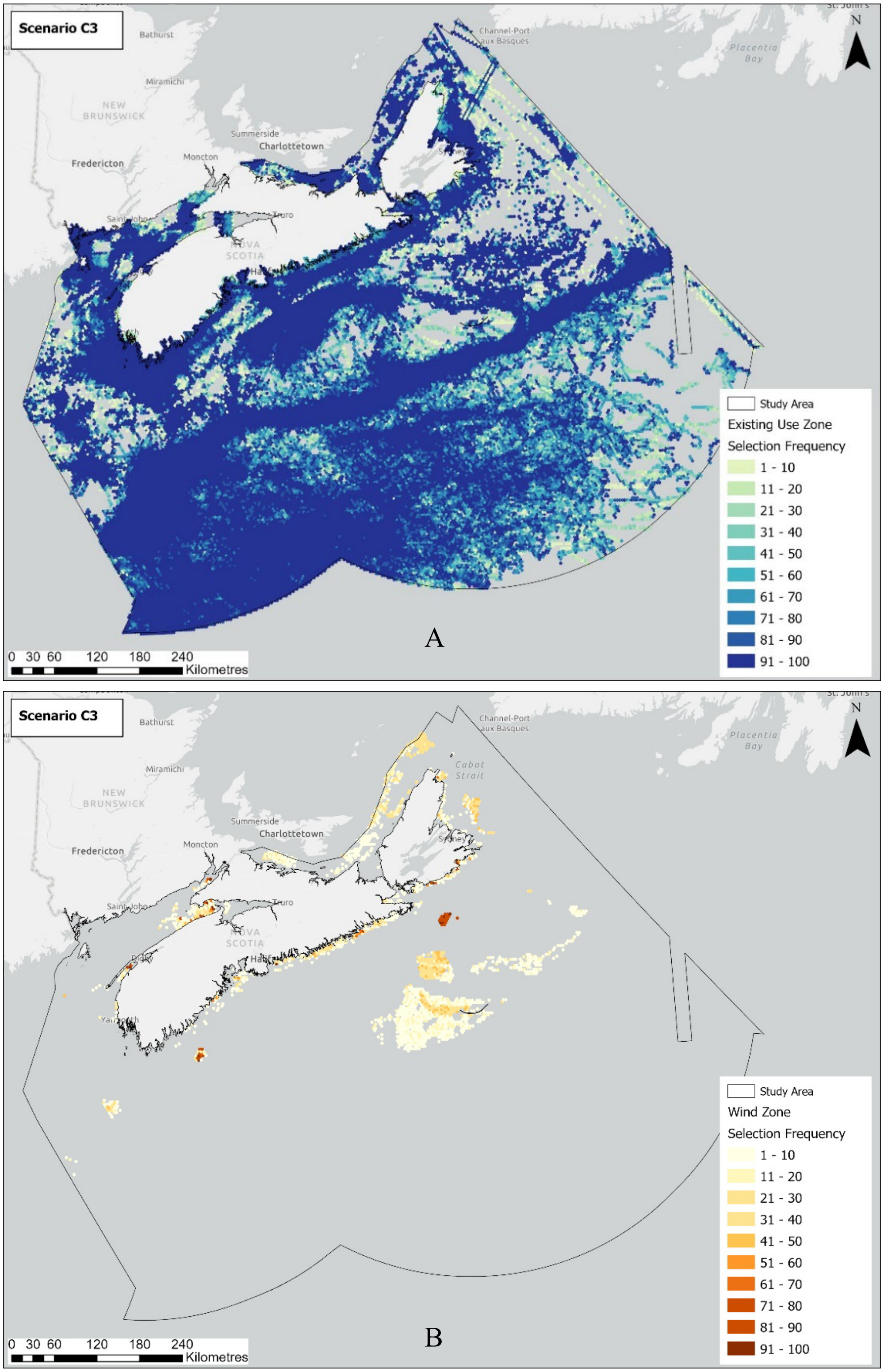


Figure 25. Scenario C3 summed solution selection frequency, n=100 solutions. Existing-use zone (A): areas selected to meet 90% targets for commercial fishing and vessel traffic features. Wind zone (B): areas selected to meet target of 300 planning units for fixed foundation OWE excluding existing conservation measures, lease areas, and vessel traffic routes.

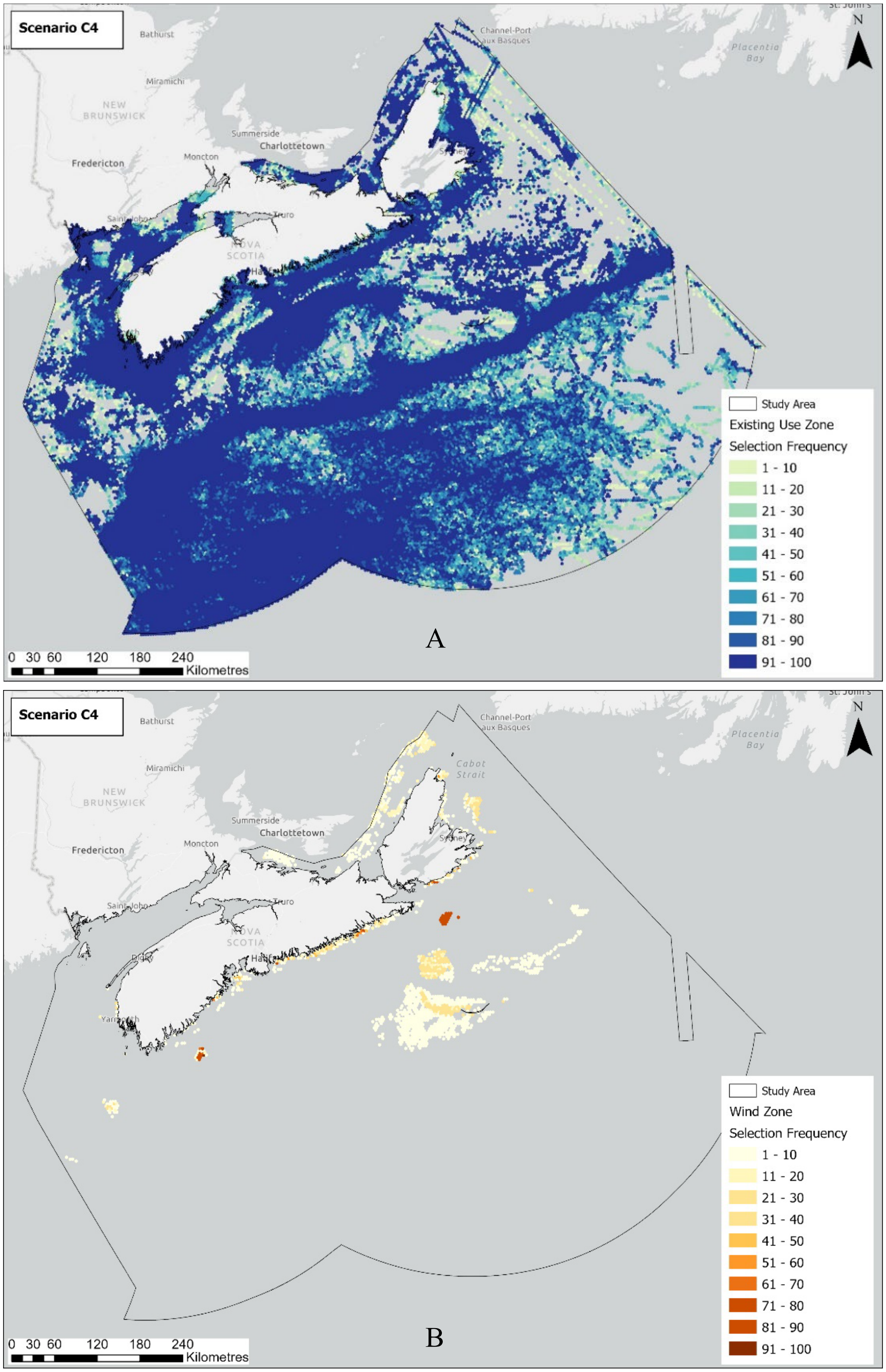


Figure 26. Scenario C4 summed solution selection frequency, n=100 solutions. Existing-use zone (A): areas selected to meet 90% targets for commercial fishing and vessel traffic features. Wind zone (B): areas selected to meet target of 170 planning units for fixed foundation OWE, restricted to the Regional Assessment study area excluding existing conservation measures, lease areas, and vessel traffic routes.

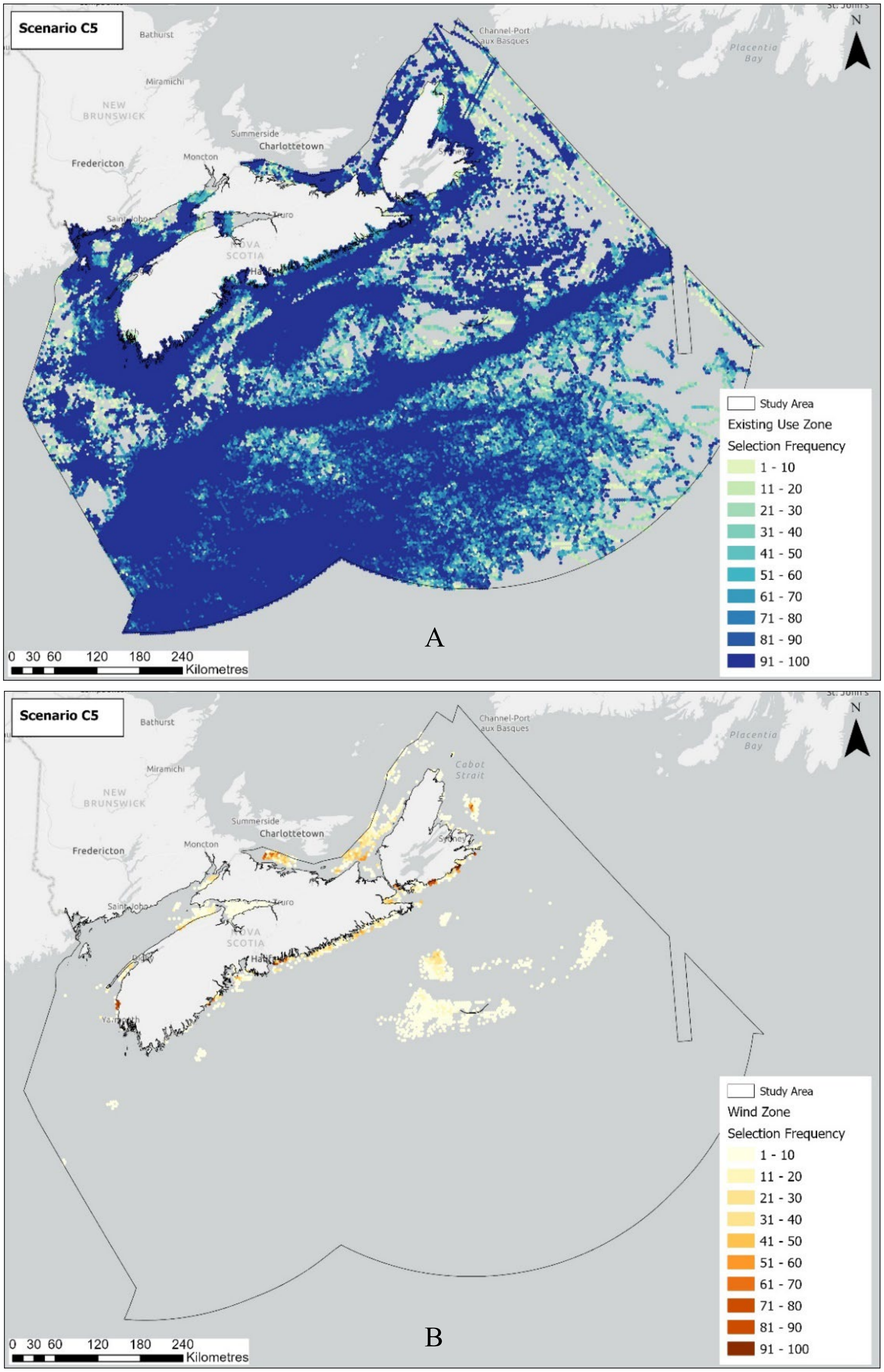


Figure 27. Scenario C5 summed solution selection frequency, n=100 solutions. Existing-use zone (A): areas selected to meet 90% targets for commercial fishing and vessel traffic features. Wind zone (B): areas selected to meet target of 170 planning units for fixed foundation OWE, minimize LCOE, excluding existing conservation measures, lease areas, and vessel traffic routes.

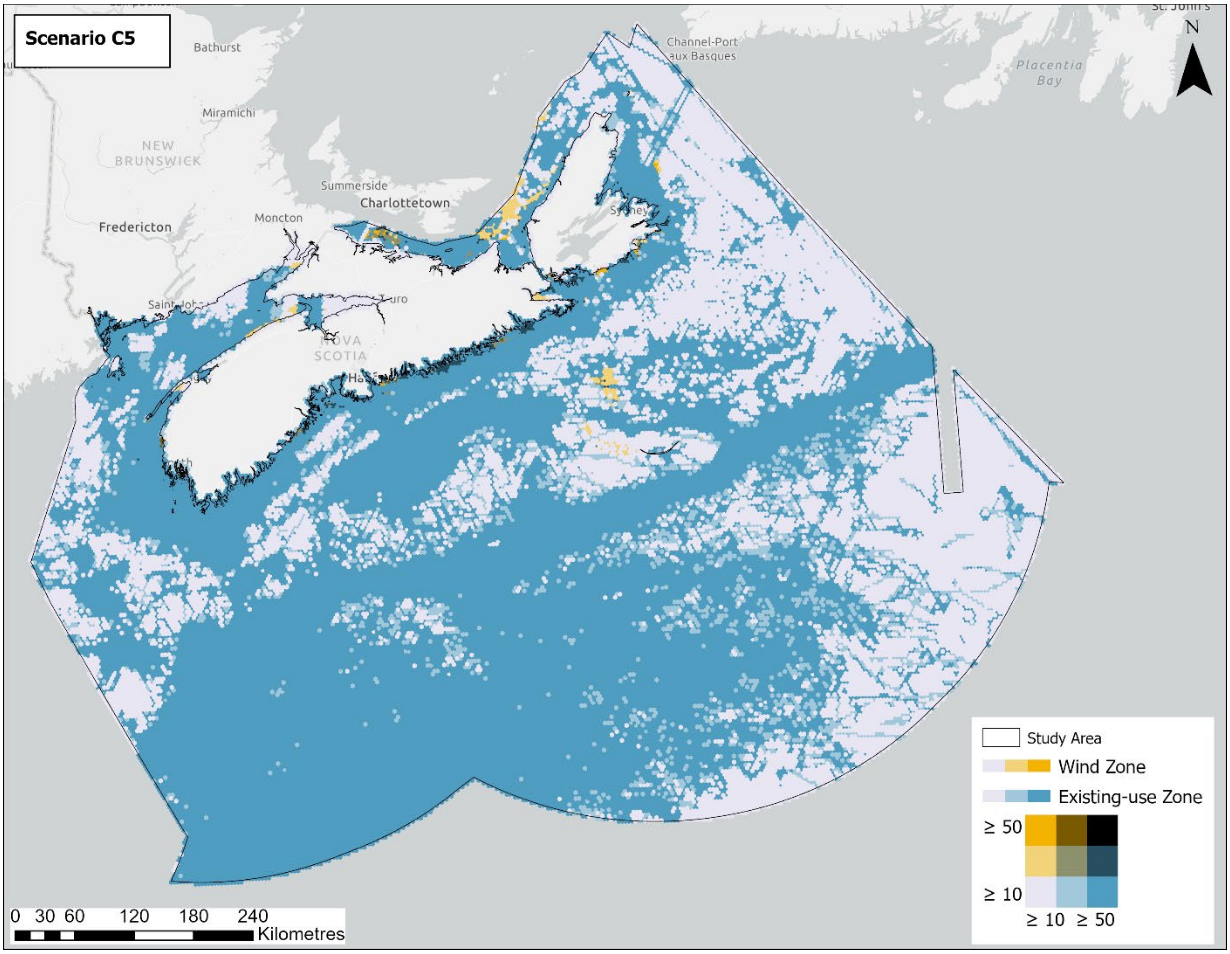


Figure 28. Scenario C5 bivariate selection frequency for the wind zone and existing-use zone summed solutions, n=100 solutions. Bivariate symbology highlights areas of lower and higher overlap between the two summed solutions.

Across all the fixed foundation multi-sector baseline scenarios (C1.1, C2, C3, C4, C5) common areas with moderate to high selection in the wind zone included Canso Bank, Sydney Bight, Middle Bank, parts of Sable Island Bank, and parts of the Northumberland Strait (Figures 22-28). The addition of a target for vessel traffic resulted in higher existing-use zone selection frequency in areas closer to the coast, as well as areas such as ferry routes compared to the A and B group scenarios.

In scenario C1.1, shallow offshore areas such as Canso Bank, Roseway Bank, Middle Bank, Sable Island Bank and Sydney Bight emerged as large contiguous areas selected in the wind zone (Figure 22). Of the offshore areas, selection frequency was highest on Canso Bank and Roseway Bank in this scenario, likely a result of low existing-use activity and higher suitability for OWE. Smaller areas of low to moderate wind zone selection frequency was also seen in several coastal areas including the Eastern Shore of Nova Scotia, parts of the Minas Channel, outside of Halifax Harbour, and in the Northumberland Strait (Figure 22). The bivariate symbology for scenario C1.1 showed several areas of moderate to high selection frequency in both zones, including a small section on Middle Bank and along the Eastern Shore (Figure 23).

In the floating multi-sector baseline scenario (C1.2) lower wind zone selection frequency was seen on shallow offshore areas (Figure S4; see Appendix 1) compared to the fixed foundation scenario C1.1 (Figure 22).

Higher wind zone selection frequency was seen in coastal areas in C1.2 (Figure S5; see Appendix 1) compared to the fixed foundation scenario C1.1. This pattern was likely due to other variables in the suitability layer (e.g., distance to shore, wind speed, and sea ice) having greater influence over the distribution of wind zone selection frequency than in the fixed foundation scenario where surficial geology and water depth constrained the wind zone and were more restrictive cost considerations.

In the two scenarios with modified wind zone area targets (i.e., C2 = 100 planning units, C3 = 300 planning units) the pattern of areas selected remained consistent with the multi-sector baseline scenario (C1.1). Generally, most selection frequency values decreased with the lower wind zone target scenario C2 (Figure 24), and increased with the higher wind zone target scenario C3 (Figure 25). In the lower target scenario C2, the wind zone summed solution conveyed less information about which areas were more or less optimal compared to others; for example, selection frequency on Sable Island Bank was very low and some areas on this bank disappeared, because other areas closer to shore were more optimal to meet the lower wind zone target (Figure 24). The scenario C3 wind zone summed solution had higher contrast in the selection frequency values between areas – for example the areas of moderate vs. low selection frequencies in the Northumberland Strait, Sydney Bight, Middle Bank, and Sable Island Bank were more apparent (Figure 25) compared to scenario C1.1 (Figure 22).

Scenario C4 restricted the study area to the extent of the Nova Scotia Regional Assessment (Figure 26). The selection frequency patterns were consistent with C1.1 (Figure 22), with the key difference being that the wind zone was not able to select areas within the Bay of Fundy or other bays.

In scenario C5 which used the LCoE layer in substitution for the suitability layer higher wind zone selection frequency was seen closer to shore (Figure 27). This was likely due to the LCoE cost layer incorporating both distance to port and distance to grid, with lower LCoE values closer to shore. Moderate and high wind zone selection frequencies were seen in the Northumberland Strait in this scenario (Figure 27), likely due to the LCOE layer not including both sea ice and surficial geology considerations (Aegir Insights 2023). Some selection for the wind zone was seen on shallow offshore banks (Figure 27). Canso Bank and Roseway Bank had very low selection frequency in this scenario compared to other scenarios, likely because surficial geology was not a consideration in this scenario (Figure 27). Moderate to high selection frequency was seen in both zones along the Eastern shore of Nova Scotia and the western Northumberland Strait (Figure 28).

Across the baseline multi-sector scenarios all 90% targets for features in the existing-use zone were exceeded, meaning that for each scenario the wind zone avoided more than 90% of every individual feature. Potential overlap between features and the wind zone was quantified by assessing the percentage of the feature value occurring within the wind zone across the individual 100 solutions. Across the baseline multi-sector scenarios the mean overlap for all features with the wind zone across the solutions was between 0.17-0.53% (Table 18).

Table 18. Mean percentage overlap (± standard deviation) of all features with the wind zone for the baseline multi-sector scenarios.

Scenario	Mean feature overlap (% ± SD) with wind zone
C1.1	0.25 ± 0.51
C1.2	0.38 ± 0.76
C2	0.17 ± 0.39
C3	0.41 ± 0.36
C4	0.23 ± 0.52
C5	0.53 ± 1.02

The highest overlap between the wind zone for any individual feature across the 100 solutions for each scenario ranged from 2.36% to 4.20% and included inshore lobster (LFAs 31B and 32) and Atlantic Rock Crab (RCFA 26a) (Table 19).

Table 19. Individual features with the highest mean percentage overlap (± standard deviation) with the wind zone for each baseline multi-sector scenario.

Scenario	Feature	Individual feature overlap (% ± SD) with wind zone
C1.1	Lobster, inshore, LFA 32	2.80 ± 0.68
C1.2	Lobster, inshore, LFA 32	3.92 ± 0.77
C2	Lobster, inshore, LFA 32	2.36 ± 0.59
C3	Lobster, inshore, LFA 31B	3.31 ± 0.68
C4	Lobster, inshore, LFA 32	3.02 ± 0.70
C5	Atlantic Rock Crab, RCFA 26a	4.20 ± 0.71

5.3.2 Ecologically restricted multi-sector scenarios

Scenario D1.1 expanded on scenario C1.1 by incorporating ecological considerations for the existing-use zone, and excluded critical habitat for Species at Risk, AOIs, and existing conservation areas from the area available for selection in the wind zone. The summed solutions and bivariate summed solutions for scenario D1.1 are shown in Figure 29 and Figure 30. Floating scenarios were developed to consider fixed and floating OWE, allowing the wind zone target to be met in areas greater than 70m depth (see Appendix 1). Scenario D1.2 represented the fixed and floating version of scenario D1.1 (Figure S6, Figure S7; see Appendix 1).

Additional ecological restricted multi-sector scenarios (D2.1 and D2.2) included Scotian Shelf and Bay of Fundy marine conservation network sites as exclusions. Scenario D2.1 results are shown in Figure 31. Scenario D2.2 represented the fixed and floating version of D2.1, and results are shown in Figure S8 (see Appendix 1).

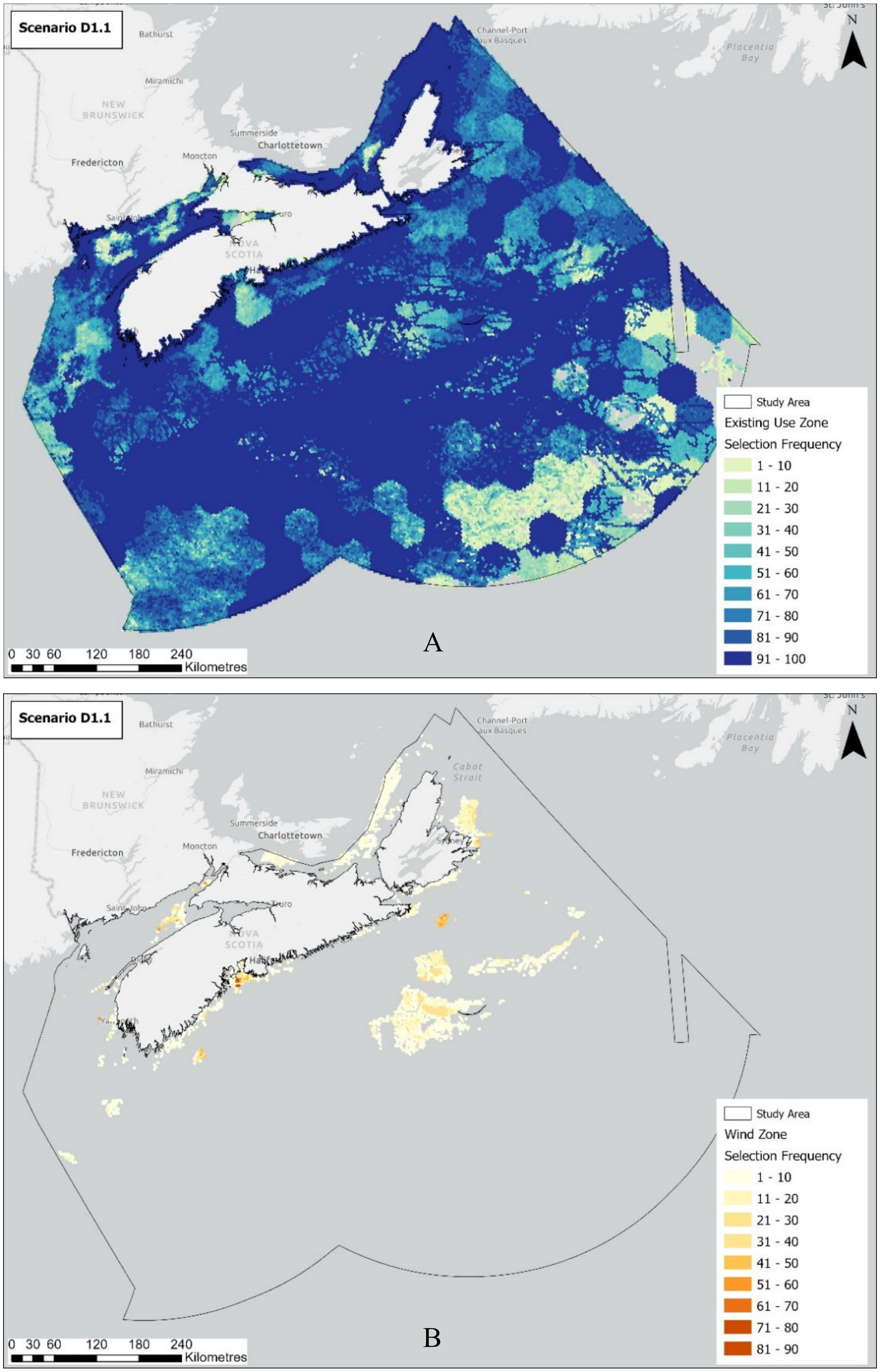


Figure 29. Scenario D1.1 summed solution selection frequency, n=100 solutions. Existing-use zone (A): areas selected to meet 90% targets for commercial fishing, vessel traffic, and ecological features. Wind zone (B): areas selected to meet target of 170 planning units for fixed foundation OWE and do not overlap with existing conservation measures, lease areas, and vessel traffic routes.

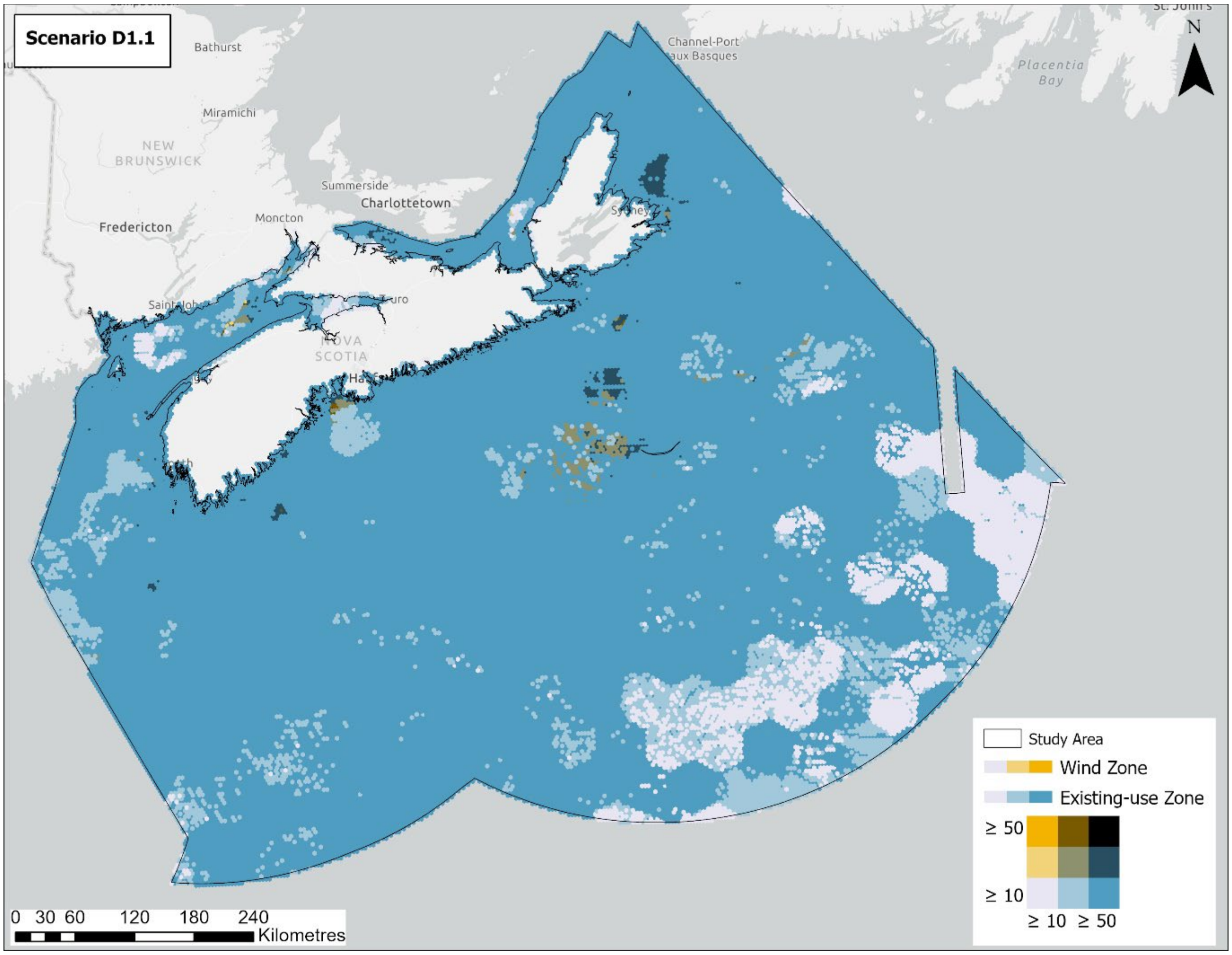


Figure 30. Scenario D1.1 bivariate selection frequency for the wind zone and existing-use zone summed solutions, n=100 solutions. Bivariate symbology highlights areas of lower and higher overlap between the two summed solutions.

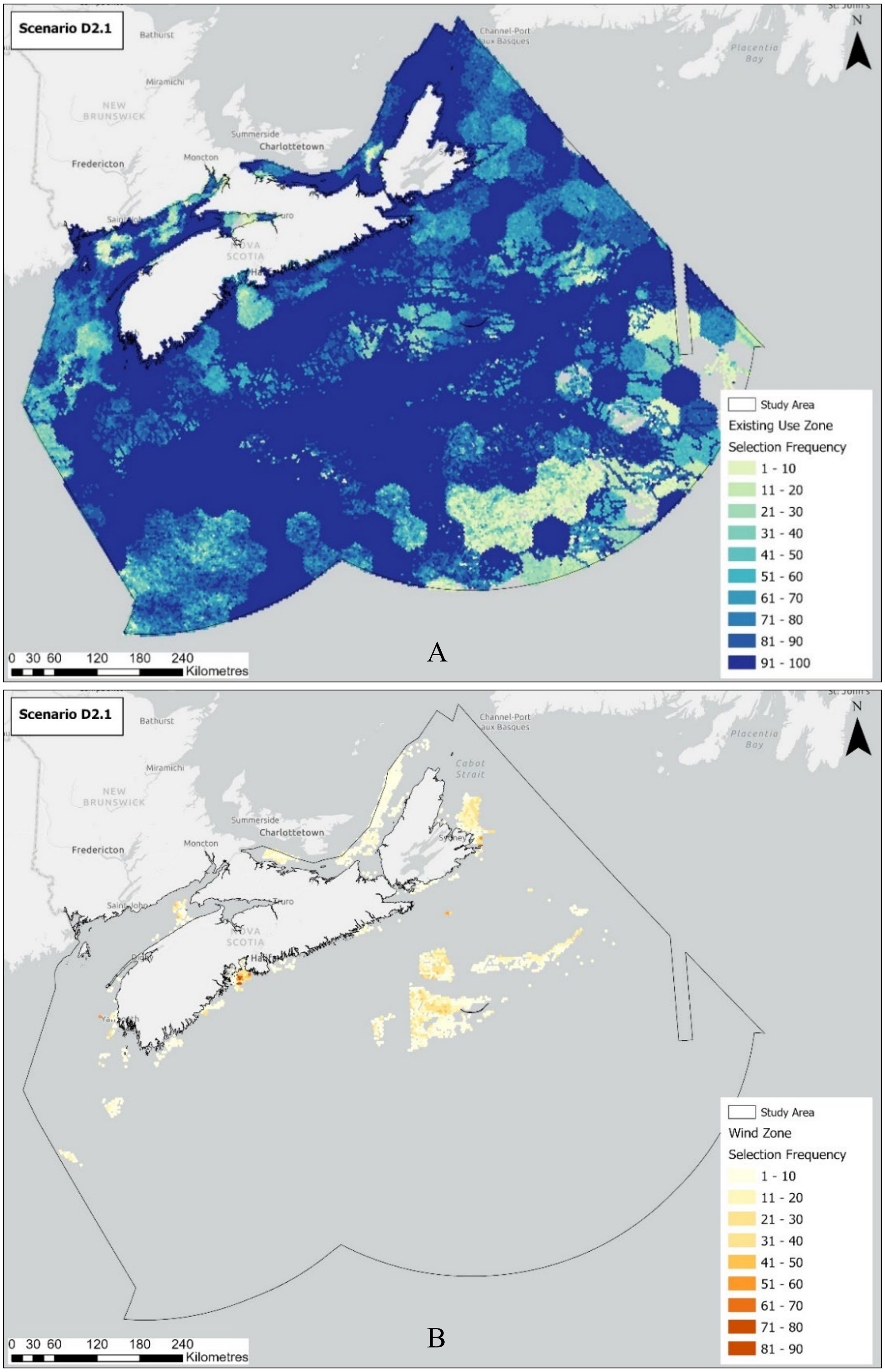


Figure 31. Scenario D2.1 summed solution selection frequency, n=100 solutions. Existing-use zone (A): areas selected to meet 90% targets for commercial fishing, vessel traffic features, and ecological features. Wind zone (B): areas selected to meet target of 170 planning units for fixed foundation OWE and do not overlap with existing conservation measures, marine conservation network sites, lease areas, and vessel traffic routes.

In the fixed foundation multi-sector ecologically restricted scenarios, shallow offshore areas including Middle Bank, Sable Island Bank, and Sydney Bight emerged as large contiguous areas with low to moderate wind zone selection frequency (Figure 29, Figure 31). Canso Bank and Roseway Bank emerged as areas of moderate wind zone selection frequency in scenario D1.1 (Figure 29); however, these areas overlapped with marine conservation network plan sites and as a result were not available to be selected in the wind zone in scenario D2.1 (Figure 31). Many of these offshore areas, specifically Sydney Bight, Middle Bank, Canso Bank, and Roseway Bank also emerged as areas of high existing-use zone selection frequency in these scenarios, indicating the potential for spatial overlap with the existing-use features included in this analysis (Figure 30). In the floating foundation ecologically restricted scenarios (D1.2 Figure S6, D2.2 Figure S8; see Appendix 1), lower wind zone selection frequency was seen on shallow offshore areas compared to the fixed foundation scenarios likely a result of the reduced influence of depth and surficial geology in the floating suitability cost layer.

The near shore area around St. Margaret's Bay emerged as an area of high wind zone selection frequency in both of the fixed foundation multi-sector ecologically restricted scenarios (Figure 29, Figure 31). Low to moderate wind zone selection frequency was also seen in several other coastal areas including parts of the Minas Channel and in the Northumberland Strait. Similar patterns including high selection frequency in the near shore area around St. Margaret's Bay were seen in the floating foundation multi-sector ecologically restricted scenarios (D1.2 Figure S6, D2.2 Figure S8; see Appendix 1).

Across the ecologically restricted multi-sector scenarios all 90% targets for human use and ecological features in the existing-use zone were exceeded, meaning that for each scenario the wind zone avoided more than 90% of every individual feature. Potential overlap between features and the wind zone was quantified by assessing the percentage of the feature value occurring within the wind zone across the 100 individual solutions. Across the ecologically restricted multi-sector scenarios the mean overlap for all features with the wind zone across the solutions was between 0.43-0.48% (Table 20).

Table 20. Mean percentage overlap (± standard deviation) of all features with the wind zone for the ecologically restricted multi-sector scenarios.

Scenario	Mean feature overlap (% ± SD) with wind zone
D1.1	0.43 ± 0.62
D1.2	0.48 ± 0.73
D2.1	0.42 ± 0.65
D2.2	0.43 ± 0.58

The highest overlap between the wind zone for any individual feature across the 100 solutions for each scenario ranged from 2.78% to 3.29% (Table 21).

Table 21. Individual features with the highest mean percentage overlap (± standard deviation) with the wind zone for each ecologically restricted multi-sector scenario.

Scenario	Feature	Individual feature overlap (% ± SD) with wind zone
D1.1	Sea cucumber, 4W midshore	3.03 ± 3.59
D1.2	Bluefin Tuna	3.29 ± 1.43
D2.1	American Lobster, inshore, LFA 27	3.29 ± 0.56
D2.2	IMA Roseate Tern	2.78 ± 0.27

6.0 DISCUSSION

6.1 Decision support and MSP

The decision-support tool described by this study represents a combination of methods adapted from existing modeling approaches (Göke et al. 2018, Kilpatrick et al. 2023, Randall et al. 2024). The results from this study demonstrate that MarZones is a flexible and customizable tool, which can incorporate cost layers, suitability layers, exclusion areas, and targets. Results of this study demonstrate how MarZones can be configured to explore a range of spatial scenarios to support planning for new ocean activities such as OWE. This study sought to address several knowledge gaps for OWE planning identified by Kilpatrick et al. (2023); primarily, commercial fishing in the DFO Gulf Region portion of the study area that includes inshore lobster landings, and additional ecological considerations such as the marine conservation network plan for the Scotian Shelf and Bay of Fundy bioregion.

This decision-support tool demonstrates how MarZones can produce outputs to satisfy specific objectives. These objectives can be translated into specific targets for existing human use activities or ecological features. Setting clear targets is key, as this increases the transparency of the Marxan analysis (King et al. 2021). Marxan targets can be adapted over time as planning objectives evolve. As scenarios are developed and evaluated, targets can be readjusted to develop additional scenarios that reflect tradeoffs or specific planning priorities. As the OWE regulatory regime evolves and proposed wind energy areas are identified, this tool can provide additional decision support to explore different planning scenarios. Similarly, as data on human use activities and/or ecological features improves or is updated these also can be explored in future analyses using this tool.

This study did not assess the potential for co-location. However, co-location may be possible between OWE and other activities (such as commercial fishing, vessel traffic, oil & gas, and aquaculture) if they are deemed to be compatible. This analysis also did not consider mitigation measures or tradeoffs, as this generally occurs later in the planning and decision-making processes (King et al. 2021). This tool could be adapted in the future to develop co-location scenarios for use by regulators and decision makers.

6.2 Interpretation of results

Eighteen spatial scenarios were developed using the most representative regional data currently available, which reflect outputs from the 102 feature targets, 6 cost layers, and exclusions described in this study. The wind zone did not represent any allocation of marine space in a management context, it only represented planning units selected by MarZones. Summed solution maps do not depict areas of any particular size for the wind zone, as they are a combination of the 100 individual MarZones solutions which each selected a slightly different configuration of either 100, 170, or 300 planning units.

The wind zone summed solutions identified potentially suitable areas for OWE which avoided overlap with existing human uses and/or ecological features. Across the scenarios, all 90% targets were exceeded in the existing-use zone, as the wind zone overlapped with less than 10% of each individual feature. The highest percentage overlap with any individual feature was 4.2%, observed in scenario C5. Scenario A3 was the only scenario where the existing-use zone targets were not met across all 100 MarZones solutions due to existing-use targets being set at 100%. However, in scenario A3 the mean overlap for all features with the wind zone across the 100 MarZones solutions was only 0.03% and the maximum overlap with a single feature was 0.34%. All targets were still met when the wind zone target area was increased in scenario C3 to 300 planning units, or 3,000 km^2.

Comparing the multi-sector baseline scenarios with the ecologically restricted scenarios also identified some areas that have ecological features present which overlap with suitable areas for OWE. For example, Canso Bank and Roseway Bank both had high wind zone selection frequency in the commercial fishing single sector scenarios and in the baseline multi-sector scenarios, but lower selection frequency in the conservation single sector scenarios and ecologically restricted multi-sector scenarios. This indicated these banks may avoid overlap with areas of high commercial fishing and vessel traffic, but that there is potential for overlap with ecological features. Parts of Middle Bank, Sable Island Bank, Sydney Bight, the Northumberland Strait, and some nearshore areas emerged across multiple scenarios with moderate wind zone selection frequency.

6.3 Marxan with Zones configuration

Marxan and MarZones are flexible tools with additional options not utilized in this analysis. These options include adjusting the boundary length modifier and introducing minimum patch size, which would result in larger clusters of contiguous planning units being selected for the wind zone. These parameters could be added to analyses where the objective includes finding areas of a specific minimum size for OWE or other ocean uses. Depending on the minimum area needed for an OWE farm (or multiple OWE farms together) to be viable, different minimum contiguous patch sizes could be explored in future analyses.

The large geographic area of this analysis and the size of the planning units (10 km^2) were selected to provide a broad overview of activities that have potential to overlap with OWE development in DFO's Maritimes Region and Gulf Region within Nova Scotia coastal and offshore waters. The 10 km^2 planning unit resolution was selected to align with the standardized grid for aggregating fisheries landings in Eastern Canada (DFO 2022a; DFO 2023c). This planning unit resolution does not represent any specific distances or buffers related to OWE turbines or OWE farms. One limitation of the results is that the resolution of planning units summarizes the features within a 10 km^2 area, which provides general information appropriate for a regional analysis but may not provide the level of detail needed for finer-scale analyses. Another limitation of this resolution was that smaller features such as cables, pipelines, and anchorages, were not included as they were significantly smaller than the planning unit size. In future applications of this decision-support tool, using smaller planning unit sizes could allow for fine-scale data to be analyzed. Future analyses could also focus on smaller areas of interest, such as sites that are identified as potential wind energy areas.

The relative scaling of cost layers in this analysis resulted in selection of areas for the OWE zone with relatively lower depth, distance to shore, and sea ice cover, suitable wind speeds, and more suitable surficial geology. These cost layers were normalized relative to each other, similarly to the approach taken by Kilpatrick et al. (2023). Scenario C5 also demonstrated how OWE cost layers such as LCoE can be substituted for suitability layers. In future analyses, applying different cost values or scaling factors could result in different patterns of selection for the wind zone. Kilpatrick et al. (2023) has also demonstrated that adjusting the weighting of suitability layers relative to each other can result in different patterns of suitability for OWE.

Scenario results demonstrated how targets can be assigned to features for the purpose of conflict avoidance and how exclusions can be applied to areas to prevent all overlap. Feature layers were incorporated to broadly represent the footprint of existing uses and ecological features. Exclusions could be applied to additional features in future analyses. For example, IMAs or important habitat for marine and aerofauna Species at Risk could be exclusion layers if the objective of the analysis was to avoid all overlap with those areas. For transportation, the wind zone avoided areas of high AIS vessel traffic and was excluded from defined vessel traffic routes to avoid direct overlap with this existing use; however, alternative planning approaches could be explored such as including corridors for vessel traffic within OWE farm designs. It is recommended that future research identify appropriate buffers and setback distances between OWE and other ocean uses for the Atlantic Canadian context. For example, in Europe safety zones are typically applied between OWE farms and vessel routes (European MSP Platform 2024).

6.4 Limitations and data gaps

This study incorporated regional and inter-regional scale data that were broadly representative of human use and ecological features, although there are known limitations and data gaps which could be considered for future analyses.

6.4.1 Physical & Economic data

To identify areas which may be suitable for OWE, this analysis used the suitability data layers first described in Kilpatrick et al. (2023) with updated scoring. Suitability scores were based on international experiences and literature and do not constitute guidance or direction for OWE development in Canada. These suitability scores, their intervals, and the parameters assessed could be updated in future analyses based on parameters of interest and planning objectives, and further exploration of these parameters is recommended for the Atlantic Canadian context. Freezing spray and ice accretion are two such parameters affecting siting suitability that can be incorporated into future analyses. Additional scientific knowledge on seabed geology is also required to inform OWE site selection (Eamer et al. 2023). Additional geological data beyond surficial geology could be considered in future analyses, such as depth of sediment, geohazards, or sediment mobility (Eamer et al. 2023).

Economic data associated with OWE were limited to those included in the Aegir Insights LCoE layer. In future analyses, suitability or cost layers could be included to represent other factors of interest for OWE development. This could include proximity to transmission infrastructure or port facilities, which were factored into the LCoE layer used in scenario C5 but were not represented in the other scenarios. Socio-economic considerations such as viewsheds or minimum distances from shore could also be incorporated into future analyses.

6.4.2 Indigenous use

This analysis included landings from Indigenous Communal Commercial fisheries but did not include other information on other Indigenous fisheries (e.g., Food, Social, and Ceremonial fisheries) or areas of cultural importance as these data were not available at a regional scale. Direct engagement with First Nations and Indigenous organizations would be the most appropriate method to explore how Indigenous use data could be included in future applications of this tool or other planning exercises related to OWE. Future analyses (in collaboration with Indigenous organizations) could incorporate relevant data to examine planning objectives and scenarios relevant to that community. Analyses using Indigenous data must respect data sovereignty and use scales and locations appropriate to the data and community need.

6.4.3 Commercial fishing data

Commercial fisheries represent a major source of data in this analysis, based primarily on the most recently available 10 years (2012-2021) of commercial catch weight data in DFO Maritimes Region (including inshore lobster), VMS tracks for pelagic longline fisheries, and newly developed landings models in DFO Gulf Region. One limitation for inshore lobster landings data in Maritimes Region was the aggregation of landings by statistical grid. Additional information and considerations for these data are described in Serdynska and Coffen-Smout (2017) and Serdynska et al. (2022).

Individual targets were set for each fishery species and management unit, which allowed for equal treatment regardless of economic value. This analysis did not assess potential compatibility between OWE and specific commercial fishing activities/gear types, and instead focused on avoidance of areas of high fishing. This resulted in the wind zone avoiding areas where fishing activity has occurred in the 10 years of the commercial fisheries dataset. The analysis did not consider areas that have been fished before the 2012-2021 period or where fishing effort may be focused in the future (e.g., due to shifts in fishery resources associated with climate change). However, data representing historic fisheries landings and models of where fishing may occur in the future could be incorporated into this type of analysis, but their importance compared to current fishing trends and uncertainty in predictive modelling would warrant a discussion around their relative weighting within such analyses.

Commercial fisheries data included in this analysis did not include exploratory fisheries. If new commercial fisheries emerge from existing exploratory fisheries, additional analysis will need to be conducted to ensure such fisheries were adequately considered when identifying areas of lower potential overlap between OWE and commercial fishing activity.

6.4.4 Ecological data

Ecological considerations were a major driver in this analysis through the inclusion of conservation and ecological data layers as features and exclusions across the different scenarios. Data layers selected represented features such as aerofauna, species at risk, and sessile benthic species, as these may interact with various phases of OWE. As more information becomes available on where OWE may be located in the waters surrounding Nova Scotia, additional research is recommended such as risk assessments (e.g., Kleinknecht 2023).

There are known data gaps related to ecological features in this analysis, including but not limited to: information on migratory movement, seasonality, and spawning of marine species, connectivity for aerofauna and marine species (e.g., flight paths, migration corridors), and important habitat and updated critical habitat for North Atlantic Right Whales. The seabird data also did not include areas of use by Leach's Storm Petrel where updated data are forthcoming. Research is underway to further examine collision and displacement vulnerability for seabird species (P. Knaga, ECCC, pers. comm). Survey effort can also be examined further to determine whether gaps exist in surveys. These data gaps would likely be important for informing the timing or location of OWE and should be integrated into future planning and decision making processes. Future research could include developing design strategies for specific ecological targets related to OWE planning which could be assessed using Marxan, similarly to the marine conservation network analysis (King et al. 2019).

6.5 Future assessment of compatibility and coexistence

This analysis focused on conflict avoidance by minimizing overlap between the wind zone and other features, and by setting exclusion areas. Exclusion areas were applied where the potential for coexistence is currently uncertain due to lack of regulatory guidance – for example between existing lease areas and OWE. Potential compatibility between OWE and other human uses (e.g., aquaculture, oil & gas, commercial fishing) could be explored further in future research or in discussions with federal and provincial regulators. Tools such as the Ocean Use Compatibility Analysis (Serdynska et al. 2024) can provide starting points for examining potential for coexistence. This tool characterized ocean uses occurring in the Scotian Shelf and Bay of Fundy planning area and provided preliminary assessments of spatial compatibility, and could be expanded upon to examine which types of management measures could allow for coexistence between uses (Serdynska et al. 2024). If uses are determined to be compatible with OWE, this MarZones tool could be configured to address planning questions around optimizing spatial use with compatibility in mind.

This analysis could also be configured using additional zones beyond just an existing-use zone and a wind zone. For example, the analysis could incorporate a conservation zone, which was used while designing the marine conservation network plan (DFO 2024, King et al. 2021). This would allow for a more diverse and complex number of management objectives to be examined. For example, potential impacts on existing uses such as commercial fishing from both offshore wind and conservation management measures could be examined holistically.

7.0 CONCLUSION

The methods outlined in this study represent one potential approach to exploring planning objectives using MarZones, but other approaches and modeling tools exist. Existing approaches such as those developed in Europe or the US could be adapted or combined with this approach. A key benefit of MarZones as a spatial planning tool is that it provides quantifiable information about potential overlap between ocean uses and can identify multiple optimized solutions for planners to explore and discuss with stakeholders. The decision-support tool described in this study represents a transparent and repeatable methodology to apply marine spatial planning to identify potential areas for ocean uses. Offshore wind energy was used as a case study, and other ocean sectors and uses could be assessed in the future using this same tool. The inputs to this tool can be adjusted based on the purpose, scale, and input data available for the specific planning exercise.

The areas identified through this analysis represent potential areas where OWE may be feasible and may pose lower risk of conflict with the human uses and ecological features assessed. Other areas not identified in this study may also be feasible for OWE and could be identified by adjusting the parameters of this MarZones tool (e.g., by using different suitability layers or increasing the wind zone area target). This study did not examine all marine or aerofauna species present within the study area, and the tool could be modified in the future to examine potential overlap with specific species of interest. Similarly, the influence of data gaps should be recognized and considered in interpreting the results. As such, further engagement may play a key role in verifying scenario results if such tools are used for OWE planning purposes.

The intent of this study was to demonstrate a data-driven, quantitative methodology that can develop spatial scenarios based on defined targets, costs, and exclusions, which could be modified as more information becomes available on viable areas for OWE. As such, results of this study should be interpreted as potential areas which may be suitable for OWE that may warrant further exploration. Additional areas for OWE could be identified using this methodology by adjusting the wind zone target parameter or using different suitability or cost layers (as discussed in section 6.3).

This study is not Government of Canada direction on OWE development, rather, the methods and results can be used to inform future research and discussions around OWE siting, alongside other research published on this topic (i.e., Kilpatrick et al. 2023). It is recommended that the areas identified be studied further (using desktop analysis or in-situ research and data collection) to determine their suitability for OWE. It is also recommended that regulators further assess and develop guidance on the potential for compatibility and coexistence between OWE and other ocean uses.

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9.0 REFERENCES

Aegir Insights. 2023. Value mapping Nova Scotia's offshore wind resources. NetZero Atlantic. Available from https://netzeroatlantic.ca/research/value-mapping-nova-scotias-offshore-wind-resources

Ardron, J., A., Possingham, H.P., and Klein, C.J. 2010. Marxan Good Practices Handbook. Available from https://marxansolutions.org/wp-content/uploads/2020/04/Marxan-Good-Practices-Handbook-v2-2013.pdf

Ball, I. R., Possingham, H. P., & Watts, M. E. 2009. Marxan and relatives: Software for spatial conservation prioritization. In A. Moilanen, K. A. Wilson, & H. P. Possingham (Eds.), Spatial conservation prioritisation: Quantitative methods and computational tools (pp. 185–210). Oxford University Press.

Bates, E., Gianou, K., Hennessey, J., Lassiter, K., McCord, A., Niles, C., Doerpinghaus, D., Culver, M., Whiting, L. 2017. Marine Spatial Plan for Washington's Pacific Coast. Publication no. 17-06-027 Revised June 2018. Available from https://apps.ecology.wa.gov/publications/SummaryPages/1706027.html

Bennour L., O. Parent, S. Pereira, D. Dorion and G. Cantin. In prep. Methodology for the Development of a Marine Protected Area Network. Can. Manuscr. Rep. Fish. Aquat. Sci.

BOEM. 2021. Vineyard Wind 1 Offshore Wind Energy Project Final Environmental Impact Statement Volume I. OCS EIS/EA BOEM 2021-0012. U.S. Department of the Interior Bureau of Ocean Energy Management Office of Renewable Energy Programs. Available from https://www.boem.gov/sites/default/files/documents/renewable-energy/state-activities/Vineyard-Wind-1-FEIS-Volume-1.pdf

BOEM. 2022. Supporting National Environmental Policy Act Documentation for Offshore Wind Energy Development Related to High Voltage Direct Current Cooling Systems. OCS Study BOEM 2022-023. Available from https://www.boem.gov/sites/default/files/documents/renewable-energy/state-activities/HVDC%20Cooling%20Systems%20White%20Paper.pdf

BOEM. 2023a. Draft Wind Energy Areas – Commercial Leasing for Wind Power Development on the Gulf of Maine Outer Continental Shelf (OCS). Available from https://www.boem.gov/sites/default/files/documents/renewable-energy/state-activities/Notice%20for%20Comment%20for%20Gulf%20of%20Maine%20Draft%20WEAs_0.pdf

BOEM. 2023b. Gulf of Maine Draft WEA NEFMC Habitat Committee [presentation]. Available from https://www.boem.gov/sites/default/files/documents/renewable-energy/state-activities/BOEM_Draft-GOM-WEAs.pdf

BOEM. 2023c. New York Bight – Lease Area Descriptions [accessed November 29, 2023]. Available from https://www.boem.gov/renewable-energy/state-activities/new-york-bight

BOEM. 2023d. Environmental Impact Statements; Availability, etc.: Future Floating Wind Energy Development Related to 2023 Leased Areas Offshore California. 2023-27930. Available from https://www.regulations.gov/document/BOEM-2023-0061-0001

Bowman, T.D., Churchill, J.L., Lepage, C., Badzinski, S.S., Gilliland, S.G., McLellan, N.R., and Silverman, E. 2022. Atlas of Sea Duck Key Habitat Sites in North America. Available from https://seaduckjv.org/atlas/pdf/Sea%20Duck%20Atlas%20all%20lowres%203-21-22.pdf

BVG Associates. 2019. Guide to an offshore wind farm, updated and extended. Published on behalf of The Crown Estate and the Offshore Renewable Energy Catapult. Available from https://www.thecrownestate.co.uk/media/2861/guide-to-offshore-wind-farm-2019.pdf

Canadian Ice Service. 2021. Archive Search. Available from https://iceweb1.cis.ec.gc.ca/Archive/page1.xhtml

CHS 2019. Vessel Traffic Routes [dataset]. Available from https://open.canada.ca/data/en/dataset/6ab2803a-aace-4e60-83ed-44a7e0ccd1d8

COWI. 2021. Study on criteria and regulatory setup for efficient and sustainable offshore wind market in Vietnam. Danish Energy Agency, Royal Danish Embassy in Vietnam Electricity and Renewable Energy Authority. Available from https://ens.dk/sites/ens.dk/files/Globalcooperation/report_on_density_and_definition_2021.pdf

CWS. 2024. Aerofauna Data Products in Support of the Regional Assessments for Offshore Wind in Nova Scotia and Newfoundland and Labrador. 62pg.

Davis, N.N., Badger, J., Hahmann, A.N. Hansen, B.O, Mortensen, N.G., Kelly, M., Larsén, X.G., Olsen B.T., Floors, R., Lizcano, G., Casso, P., Lacave, O., Bosch, A., Bauwens, I., Knight, O.J., Potter van Loon, A., Fox, R., Parvanyan,T., Hansen, S.B.K., Heathfield, D., Onninen, M., Drummond, R. 2023. The Global Wind Atlas: A high-resolution dataset of climatologies and associated web-based application; Bulletin of the American Meteorological Society, Volume 104: Issue 8, Pages E1507-E1525, https://doi.org/10.1175/BAMS-D-21-0075

Deutsche WindGuard GmbH. 2018. Capacity Densities of European Offshore Wind Farms. Interreg Baltic Sea Region – Project Baltic LINes. Available from https://vasab.org/wp-content/uploads/2018/06/BalticLINes_CapacityDensityStudy_June2018-1.pdf

DFO. 2007. Ecologically and Biologically Significant Areas (EBSA) in the Estuary and Gulf of St. Lawrence: identification and characterization. DFO Can. Sci. Advis. Sec., Sci. Adv. Rep. 2007/016. https://publications.gc.ca/collections/collection_2011/mpo-dfo/Fs70-6-2007-016-eng.pdf

DFO. 2010. Occurrence, susceptibility to fishing, and ecological function of corals, sponges, and hydrothermal vents in Canadian waters. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2010/041. https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/341630.pdf

DFO. 2017. Guidance on incorporating economic use information into marine protected area network design. Available from https://www.dfo-mpo.gc.ca/ea-ae/economic-analysis/incorporating-economic-information-mpa-network-integration-renseignements-economiques-reseaux-amp-eng.htm

DFO. 2018a. Design Strategies for a Network of Marine Protected Areas in the Scotian Shelf Bioregion. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2018/006. https://publications.gc.ca/collections/collection_2018/mpo-dfo/fs70-6/Fs70-6-2018-006-eng.pdf

DFO. 2018b. Identification of habitats important to the blue whale in the western North Atlantic. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2018/003.

DFO. 2020a. Mapping inshore lobster landings and fishing effort on a Maritimes Region statistical grid (2012–2014). https://open.canada.ca/data/en/dataset/64f741d7-1129-49dd-9e5c-2b1de79024f0/resource/e3fb2352-1163-4d40-ab7d-105adb44f008

DFO. 2020b. Using Satellite Tracking Data to Define Important Habitat for Leatherback Turtles in Atlantic Canada: 2019 Update. DFO Can. Sci. Advis. Sec. Sci. Resp. 2020/041.

DFO. 2021. *Oceans Act* marine protected areas. Available from https://open.canada.ca/data/en/dataset/a1e18963-25dd-4219-a33f-1a38c4971250

DFO. 2022a. Hexagon Grid for Northwest Atlantic, and Central & Arctic Region, 10km^2 [dataset]. Available from https://gcgeo.gc.ca/geonetwork/metadata/eng/572f6221-4d12-415e-9d5e-984b15d34da4

DFO. 2022b. Assessment of the southern Gulf of St. Lawrence (NAFO Division 4TVn) spring and fall spawner components of Atlantic Herring (*Clupea harengus*) with advice for the 2022 and 2023 fisheries. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2022/021.

DFO. 2022c. Other effective area-based conservation measures. Available from https://open.canada.ca/data/en/dataset/44769543-7a23-4991-a53f-c2cf7c7a946f

DFO. 2022d. Critical Habitat of Species at Risk. Available from: https://open.canada.ca/data/en/dataset/db177a8c-5d7d-49eb-8290-31e6a45d786c

DFO. 2023a. About marine spatial planning. Available from https://www.dfo-mpo.gc.ca/oceans/planning-planification/about-au-sujet-eng.html

DFO. 2023b. Canada Marine Planning Atlas. Available from https://www.dfo-mpo.gc.ca/oceans/planning-planification/atlas/index-eng.html

DFO. 2023c. Eastern Canada Commercial Fishing [Open Canada dataset]. Available from https://open.canada.ca/data/en/dataset/502da2ef-bffa-4d9b-9e9c-a7425ff3c594

DFO. 2023d. Mapping Inshore Lobster Landings and Fishing Effort on a Maritimes Region Statistical Grid (2015–2019). Available from https://open.canada.ca/data/dataset/123d6569-b879-4203-9e22-c8b65c05a09e

DFO. 2024. Approach for creating the marine conservation network plan for the Scotian Shelf-Bay of Fundy. Available from https://www.dfo-mpo.gc.ca/oceans/networks-reseaux/scotian-shelf-plateau-neo-ecossais-bay-baie-fundy/development-developpement-eng.html

Dogger Bank Wind Farm. 2024. The world's largest offshore wind energy farm – Dogger Bank wind farm. Available from https://doggerbank.com/

Eamer, J.B.R., Shaw, J., King, E.L., and MacKillop, K. 2021. The inner shelf geology of Atlantic Canada compared with the North Sea and Atlantic United States: Insights for Atlantic Canadian offshore wind energy. Cont. Shelf Res. 213: 104297. https://doi.org/10.1016/j.csr.2020.104297

Eamer, J.B., Levisky, Z., and MacKillop, K. 2022. Geotechnical parameters important for offshore wind energy in Atlantic Canada. Geological Survey of Canada Open File, 8873, 1-41. https://doi.org/10.4095/329688

Eamer, J.B.R., Greaves, C., and King, E.L., 2023. The science questions underpinning the potential for offshore wind turbines on Atlantic Canada's continental shelves; Geological Survey of Canada, Scientific Presentation 158, 1 poster. https://doi.org/10.4095/331697

ECCC. 2010. Amended Recovery Strategy for the Roseate Tern (*Sterna dougallii*) in Canada. *Species at Risk Act* Recovery Strategy Series. Environment Canada. Ottawa. vii + 36 pp. Critical Habitat for Species at Risk National Dataset - Canada: https://open.canada.ca/data/en/dataset/47caa405-be2b-4e9e-8f53-c478ade2ca74

ECCC. 2021. Recovery Strategy (Amended) and Action Plan for the Piping Plover melodus subspecies (*Charadrius melodus melodus*) in Canada. *Species at Risk Act* Recovery Strategy Series. Environment and Climate Change Canada, Ottawa. ix + 125 pp. Critical Habitat for Species at Risk National Dataset - Canada: https://open.canada.ca/data/en/dataset/47caa405-be2b-4e9e-8f53-c478ade2ca74

ECCC. 2022. Recovery Strategy for the Bank Swallow (Riparia riparia) in Canada. *Species at Risk Act* Recovery Strategy Series. Environment and Climate Change Canada, Ottawa. ix + 125 pp. Critical Habitat for Species at Risk National Dataset - Canada: https://open.canada.ca/data/en/dataset/47caa405-be2b-4e9e-8f53-c478ade2ca74

ECCC. 2023a. Critical Habitat for Species at Risk National Dataset – Canada [Open Data dataset]. Available from https://open.canada.ca/data/en/dataset/47caa405-be2b-4e9e-8f53-c478ade2ca74

ECCC. 2023b. Red Knot Priority Sites in Atlantic Canada. Internal unpublished data.

ECCC. 2023c. Atlas of Seabirds at Sea in Eastern Canada 2006 – 2020 [Open Canada dataset]. Available from https://open.canada.ca/data/en/dataset/f612e2b4-5c67-46dc-9a84-1154c649ab4e

ECCC. 2023d. Banque informatisée des oiseaux de mer au Québec (BIOMQ: ECCC-CWS Quebec Region). Unpublished internal data.

ECCC. 2023e. Atlantic Colonial Waterbird Database (ACWD: ECCC-CWS-ATL). Internal unpublished data

Enevoldsen P. and Jacobson M. 2020. Data investigation of installed and output power densities of onshore and offshore wind turbines worldwide, Energy for Sustainable Development. Available from web.stanford.edu/group/efmh/jacobson/Articles/I/WindSpacing.pdf

European Commission. 2019. Study on Baltic offshore wind energy cooperation under BEMIP, final report. ENER/C1/2018-456. Available from https://op.europa.eu/en/publication-detail/-/publication/9590cdee-cd30-11e9-992f-01aa75ed71a1/language-en

European MSP Platform. 2024. Offshore Renewable Energy & Maritime transport [accessed April 25, 2024]. Available from https://maritime-spatial-planning.ec.europa.eu/msp-resources/co-existence-and-multi-use-activities/offshore-renewable-energy-maritime-transport

ESMAP. 2019. Going Global: Expanding Offshore Wind to Emerging Markets. Washington, DC: World Bank. Available from https://esmap.org/going_global_offshore_wind

Farmer, N.A., Garrison, L.P., Litz, J.A., Ortega-Ortiz, J.G., Rappucci, G., Richards, P.M., Powell, J.R., Bethea, D.M., Jossart, J.A., Randall, A.L., Steen, M.E., Matthews, T.N., and Morris, J.A. 2023. Protected species considerations for ocean planning: A case study for offshore wind energy development in the U.S. Gulf of Mexico. Mar. Coast. Fish. 15(3). https://doi.org/10.1002/mcf2.10246

GEBCO. 2023. Gridded bathymetry data. Available from https://www.gebco.net/data_and_products/gridded_bathymetry_data/

Global Wind Energy Council. 2023. Global offshore wind report 2023. Available from https://gwec.net/wp-content/uploads/2023/08/GWEC-Global-Offshore-Wind-Report-2023.pdf

Göke, C., Dahl, K., and Mohn, C. 2018. Maritime spatial planning supported by systematic site selection: Applying marxan for offshore wind power in the western baltic sea. PLoS One 13(3): 1–13. https://doi.org/10.1371/journal.pone.0194362

Gordon, K. 2022. Identifying potential spatial use conflicts between the commercial fishing industry and offshore wind development in the Scotian Shelf-Bay of Fundy planning area [graduate project]. Halifax, NS: Dalhousie University. https://dalspace.library.dal.ca/handle/10222/82609

Gullage, L., Hayes, V., Neves, B.M., Wells, N., Cyr, F., and Murillo, F.J. 2022. Avoidance and Mitigation of Coral and Sponge Species During Exploratory Drilling Activities Offshore Newfoundland and Labrador. DFO Can. Sci. Advis. Sec. Res. Doc. 2022/059. vii + 141 p. https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/41087033.pdf

IAAC. 2023. Regional Assessment of Offshore Wind Development in Nova Scotia. Available from https://iaac-aeic.gc.ca/050/evaluations/proj/83514

ICF. 2018. Assessment of the Potential for High-Voltage Direct Current Transmission to Mitigate Impacts of Non-Dispatchable Generation Technologies. Fairfax, VA, USA: United States Energy Information Administration. Retrieved February 1, 2022, from https://www.eia.gov/analysis/studies/electricity/hvdctransmission/pdf/transmission.pdf

Jiang, Z. 2021. Installation of offshore wind turbines: A technical review. Renew. Sustain. Energy Rev. 139(April 2020): 110576.

Kenchington, E., L. Beazley, C. Lirette, F.J. Murillo, J. Guijarro, V. Wareham, K. Gilkinson, M. Koen Alonso, H. Benoît, H. Bourdages, B. Sainte-Marie, M. Treble, and T. Siferd. 2016. Delineation of Coral and Sponge Significant Benthic Areas in Eastern Canada Using Kernel Density Analyses and Species Distribution Models. DFO Can. Sci. Advis. Sec. Res. Doc. 2016/093. vi + 178 p. https://publications.gc.ca/collections/collection_2016/mpo-dfo/Fs70-5-2016-093-eng.pdf

Kilpatrick, R.J., Wakim, C., and Caesar, G. 2023. Preliminary considerations analysis of offshore wind energy in Atlantic Canada. Natural Resources Canada, GEOSCAN ID 331855, 65p. https://doi.org/10.4095/331855

King, M., Pardy, G., Lieberknecht, L., Serdynska, A., & Ardron, J. 2017. MPA Network Design Analysis for the Offshore Scotian Shelf Bioregion. Unpublished internal report.

King, M., Koropatnick, T., Gerhartz Abraham, A., Pardy, G., Serdynska, A., Will, E., Breeze, H., Bundy, A., Edmondson, E., and Allard, K. 2021. Design Strategies for the Scotian Shelf Bioregional Marine Protected Area Network. DFO Can. Sci. Advis. Sec. Res. Doc. 2019/067. vi + 122 p.

Kleinknecht, C. 2023. Exploring the Compatibility of Offshore Wind Farms and Marine Protected Areas in the Scotian Shelf-Bay of Fundy Bioregion: A Case Study of Canso and Middle Banks [graduate project]. Halifax, NS: Dalhousie University. https://dalspace.library.dal.ca//handle/10222/83655

Kranck, K. 1971. Surficial Geology of Northumberland Strait. Geological Survey of Canada, Paper 71-53, 1971, 10 p. https://doi.org/10.4095/102409

Loring, D.H., and Nota, D.J.G. 1973. Benthic substrates of the Saguenay fjord, the St. Lawrence lower estuary and Gulf [Open Canada dataset]. Available from https://open.canada.ca/data/en/dataset/8c269a91-d3a2-4f49-943d-6b2401c42cba

Marxan. 2022. What is Marxan? Available from https://marxansolutions.org/what-is-marxan/

McKee, A., Grant, J., and Barrell, J. 2021. Mapping American lobster (*Homarus americanus*) habitat for use in marine spatial planning. Can. J. Fish. Aquat. Sci. 78(6): 704–720. https://doi.org/10.1139/cjfas-2020-0051

Murphy, G., and Kelly, N. 2023. Cumulative human impact maps for the Bay of Fundy and Scotian Shelf. Published September 2023. Coastal Ecosystems Science Division, Fisheries and Oceans Canada, Dartmouth, N.S. https://open.canada.ca/data/en/dataset/37b59b8b-1c1c-4869-802f-c09571cc984b

Musial, W., Elliott, D., Fields, J., Parker, Z., Scott, G., and Draxl, C. 2013. Assessment of Offshore Wind Energy Leasing Areas for the BOEM Maryland Wind Energy Area. National Renewable Energy Laboratory. Available from https://www.nrel.gov/docs/fy13osti/58562.pdf

Musial, W., Spitsen, P., Duffy, P., Beiter, P., Marquis, M., Hammond, R., & Shields, M. 2022. Offshore wind market report: 2022 edition. U.S. Department of Energy Office of Energy

Efficiency and Renewable Energy. Available from https://www.energy.gov/sites/default/files/2022-09/offshore-wind-market-report-2022-v2.pdf

Musial, W., MacDonald, S., Fuchs, R., Zuckerman, G. R., Carron, S., Hall, M., Mulas Hernando, D., Sathish, S., and Fan, K. 2023. Considerations for Floating Wind Energy Development in the Gulf of Maine. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5000-86550. https://www.nrel.gov/docs/fy23osti/86550.pdf

Northeast Regional Planning Body. 2016. Northeast Ocean Plan. Available from https://neoceanplanning.org/plan/

NRCan. 2019. Atlantic Canada and US Eastern Seaboard, 1:50000, WGS84. Ottawa, ON. Available from https://open.canada.ca/data/en/dataset/b3fdcd34-4533-415f-8f83-68f17f9d5d68

NRCan. 2023. The Offshore Renewable Energy Regulations Initiative. Available from https://natural-resources.canada.ca/public-consultations-and-engagements/the-offshore-renewable-energy-regulations-initiative/25006

Oh, K.Y., Nam, W., Ryu, M.S., Kim, J.Y., and Epureanu, B.I. 2018. A review of foundations of offshore wind energy convertors: Current status and future perspectives. Renew. Sustain. Energy Rev. 88(February): 16–36. https://doi.org/10.1016/j.rser.2018.02.00

Ørsted. 2023. Block Island Wind Farm – America's starting five. Available from https://us.orsted.com/renewable-energy-solutions/offshore-wind/block-island-wind-farm

Philibert, G., Todd, B.J., Campbell, D.C., King, E.L., Normandeau, A., Hayward, S.E., Patton, E.R., and Campbell, L., 2022. Updated surficial geology compilation of the Scotian Shelf bioregion, offshore Nova Scotia and New Brunswick, Canada; Geological Survey of Canada, Open File 8911, 1 .zip file. https://doi.org/10.4095/330474

Pratte I., Ronconi R. A., Craik S. R. and McKnight, J. 2021. Spatial Ecology of Endangered Roseate Terns and Foraging Habitat Suitability Around a Colony in the Western North Atlantic. Endangered Species Research 44: 339–350. https://doi.org/10.3354/esr01108

Province of Nova Scotia. 2022. Province Sets Offshore Wind Target [press release]. Available from https://novascotia.ca/news/release/?id=20220920003

Pryor, S.C., Barthelmie, R.J, and Shephard, T.J. 2021. Wind power production from very large offshore wind farms. Joule 5(10): 2663–2686. doi:10.1016/j.joule.2021.09.002.

Randall, A.L., Jylkka, Z.E, Jossart, J.A., O'Brien, B.R, Carlton, J.L., Shamaskin, A.C., Feinberg, L.B., Jensen, B.M., Theuerkauf, S., J., and Morris, J.A. 2024. A Wind Energy Area Siting Analysis for the Gulf of Maine Call Area. NOAA NCCOS.

Rhode Island Coastal Resources Management Council (RI CRMC). 2010. *Rhode Island Ocean Special Area Management Plan: Ocean SAMP - Volume 1.* Available From https://seagrant.gso.uri.edu/oceansamp/pdf/samp_crmc_revised/RI_Ocean_SAMP.pdf

Rock J., Leonard M. and Boyne, A. 2007. Foraging habitat and chick diets of Roseate Tern, *Sterna dougallii*, breeding on Country Island, Nova Scotia. Avian Conservation and Ecology 2(1). http://www.ace-eco.org/vol2/iss1/art4

Ronconi, R.A., Lieske, D.J., McFarlane Tranquilla, L.A., Abbott, S., Allard, K.A., Allen, B., Black, A.L., Bolduc, F., Davoren, G.K., Diamond, A.W., Fifield, D.A., Garthe, S., Gjerdrum, C., Hedd, A., Mallory, M.L., Mauck, R.A., McKnight, J., Montevecchi, W.A., Pollet, I.L., Pratte, I., Rail, J.F., Regular, P.M., Robertson, G.J., Rock, J.C., Savoy, L., Shlepr, K.R., Shutler, D., Symons, S.C., Taylor, P.D., and Wilhelm, S.I. 2022. Predicting seabird foraging habitat for conservation planning in Atlantic Canada: integrating telemetry and survey data across thousands of clonies. Front. Mar. Sci. 9(July): 1–18. https://doi.org/10.3389/fmars.2022.816794

Serdynska, A., and S. Coffen-Smout. 2017. Mapping Inshore Lobster Landings and Fishing Effort on a Maritimes Region Statistical Grid (2012–2014). Can. Tech. Rep. Fish. Aquat. Sci. 3177: 28 pp.

Serdynska, A.R., Pardy, G.S., and King, M.C. 2021. Offshore Ecological and Human Use Information considered in Marine Protected Area Network Design in the Scotian Shelf Bioregion. Can. Tech. Rep. Fish. Aquat. Sci. 3382: xi + 100 p.

Serdynska, A., Rozalska, K. and Coffen-Smout, S. 2022. Mapping Inshore Lobster Landings and Fishing Effort on a Maritimes Region Statistical Grid (2015–2019). Can. Tech. Rep. Fish. Aquat. Sci. 3509: vii + 51 p.

Serdynska, A.R., Nagel, E.J., Kleinknecht, C., Baxter, L.N., and Dykun, L. 2024. Ocean Use Compatibility Analysis for the Scotian Shelf and Bay of Fundy Planning Area. Can. Tech. Rep. Fish. Aquat. Sci. 3613: v + 40 p.

Serra-Sogas N., Kockel A, Williams, B., Watts, M., Klein, C., Stewart, R., Ball, I., Game, E., Possingham, H., & McGowan J. 2020. Marxan with Zones User Manual. For Marxan with Zones version 2.0.1 and above. The Nature Conservancy (TNC), Arlington, Virginia, United States and Pacific Marine Analysis and Research Association (PacMARA), Victoria, British Columbia, Canada.

Stanistreet, J.E., Feyrer, L.J., and Moors-Murphy, H.B. 2021. Distribution, movements, and habitat use of northern bottlenose whales (Hyperoodon ampullatus) on the Scotian Shelf. DFO Can. Sci. Advis. Sec. Res. Doc. 2021/074. vi + 34 p. https://publications.gc.ca/collections/collection_2022/mpo-dfo/fs70-5/Fs70-5-2021-074-eng.pdf

Tang, G., and Kilpatrick, R. 2021. Offshore wind technology scan, a review of offshore wind technologies and considerations in the context of Atlantic Canada. GEOSCAN ID 329349. Available from https://doi.org/10.4095/329349

United States Department of Energy. 2015. Wind vision: a new era for wind power in the United States. Available from https://www.energy.gov/sites/prod/files/wv_appendix_final.pdf

U.S. Department Of Energy. 2023. Offshore Wind Market Report: 2023 Edition. DOE/GO-102023-6059. Available from https://www.energy.gov/sites/default/files/2023-09/doe-offshore-wind-market-report-2023-edition.pdf

Veinot, T., Nicoll, A., Rozalska, K. and Coffen-Smout, S. 2023. Vessel Density Mapping of 2019. Automatic Identification System (AIS) Data in the Northwest Atlantic. Can. Tech. Rep. Fish. Aquat. Sci. 3520: vi + 29 p.

Yang, B., Liu, B., Zhou, H., Wang, J., Yao, W., Wu, S., Shu, H., and Ren, Y. 2022. A critical survey of technologies of large offshore wind farm integration: summary, advances, and perspectives. Prot. Control Mod. Power Syst. 7(1). Springer Singapore. doi:10.1186/s41601-022-00239-w.

Yeter, B., and Garbatov, Y. 2022. Structural integrity assessment of fixed support structures for offshore wind turbines: A review. Ocean Eng. 244(December 2021): 110271.

10.0 APPENDIX 1: SUPPLEMENTARY TABLES AND FIGURES

Table S1. Combined fixed and floating-foundation scenario descriptions and data layers.

Scenario	A2.2 Commercial fishing, fixed & floating	C1.2 Baseline, fixed & floating	D1.2 Ecologically restricted, fixed & floating	D2.2 Ecologically restricted + network plan, fixed & floating
Commercial fishing (separated by species and management unit)	90% target	90% target	90% target	90% target
AIS vessel traffic (top decile)	-	90% target	90% target	90% target
Vessel traffic routes, oil & gas leases, aquaculture leases	-	Exclusion	Exclusion	Exclusion
MPAs, marine refuges, & other existing conservation areas	-	Exclusion	Exclusion	Exclusion
Critical habitat	-	-	Exclusion	Exclusion
AOIs	-	-	Exclusion	Exclusion
Additional ecological considerations (described in scenario B3)	-	-	90% targets	90% targets
Marine conservation network plan	-	-	-	Exclusion
OWE technology	Fixed & floating	Fixed & floating	Fixed & floating	Fixed & floating
Wind zone target (planning units)	170	170	170	170
Cost layers	Depth, distance to coast, wind speed, surficial geology, sea ice	Depth, distance to coast, wind speed, surficial geology, sea ice	Depth, distance to coast, wind speed, surficial geology, sea ice	Depth, distance to coast, wind speed, surficial geology, sea ice

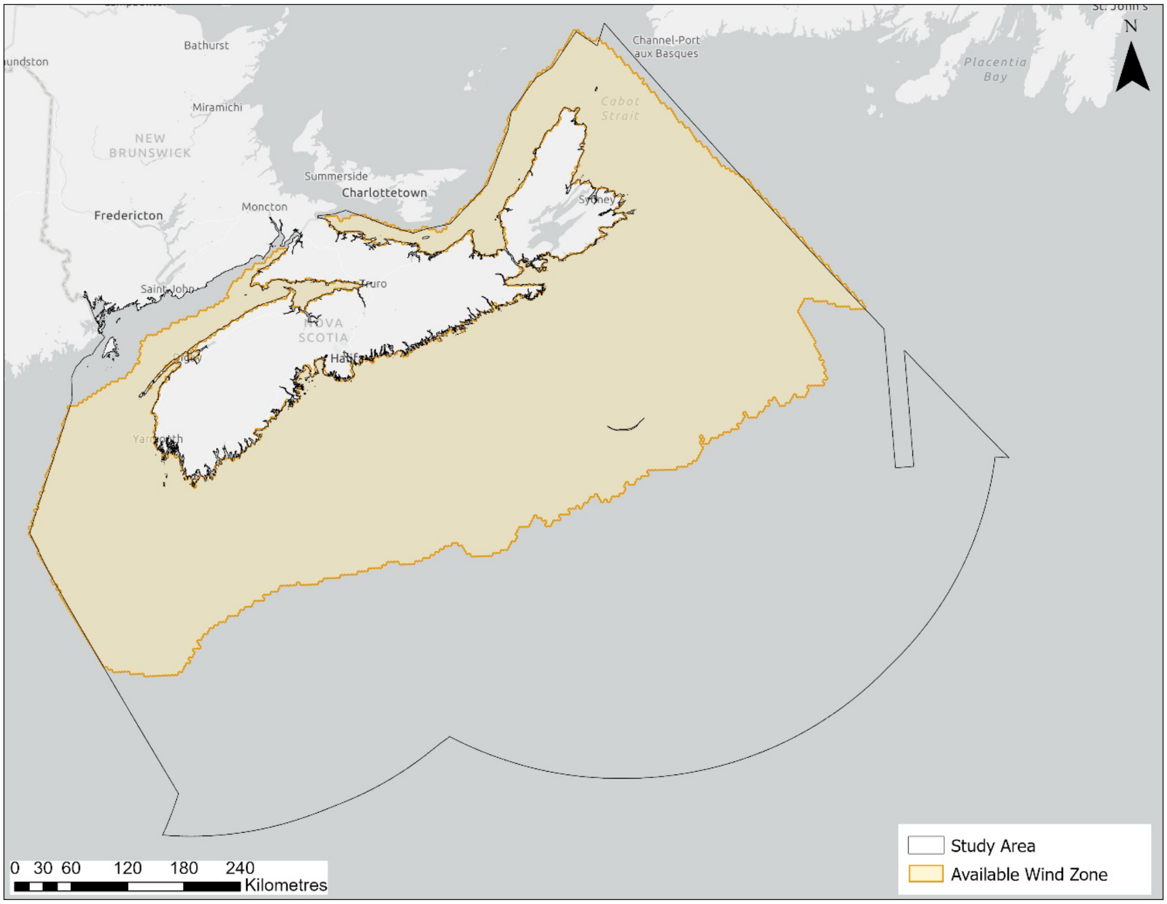

Figure S1. Planning units available to be selected in the wind zone for fixed and floating foundation OWE. This extent was used to limit the wind zone in the multi-sector baseline scenario A2.2.

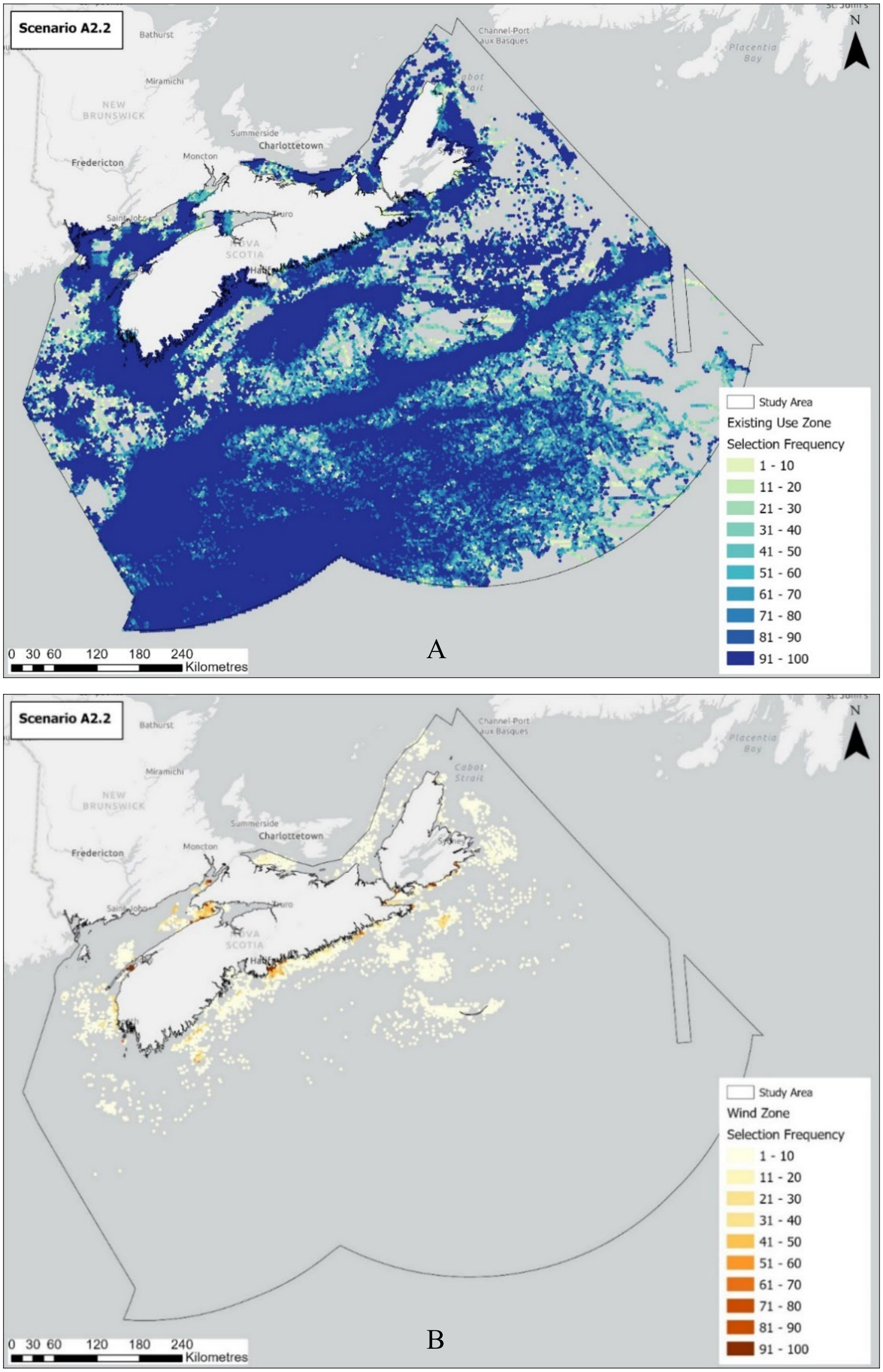

Figure S2. Scenario A2.2 summed solution selection frequency, n=100 solutions. Existing-use zone (A): areas selected to meet 90% for commercial fishing features. Wind zone (B): areas selected to meet the wind zone target of 170 planning units for fixed and floating foundation OWE.

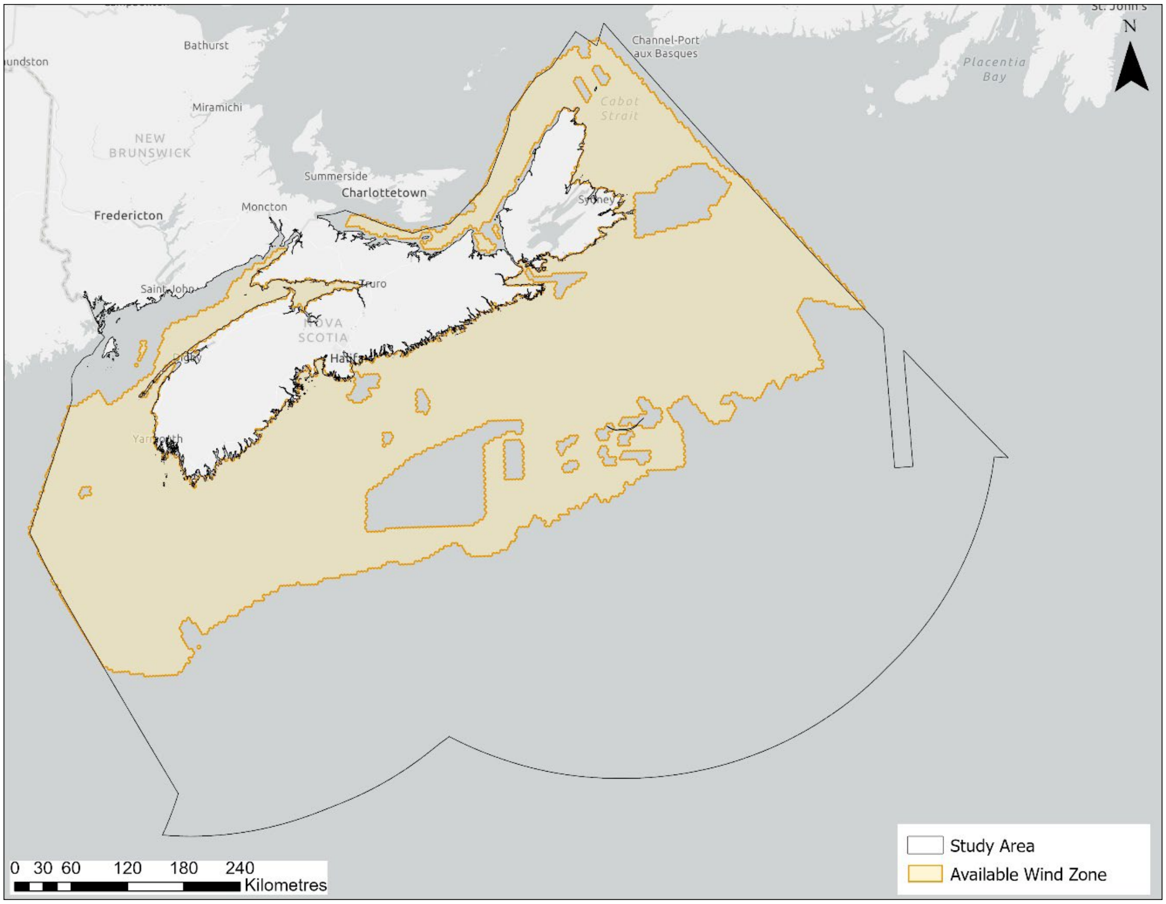

Figure S3. Planning units available to be selected for the wind zone for fixed and floating foundation OWE. This extent was used to limit the wind zone in the multi-sector baseline scenario C1.2.

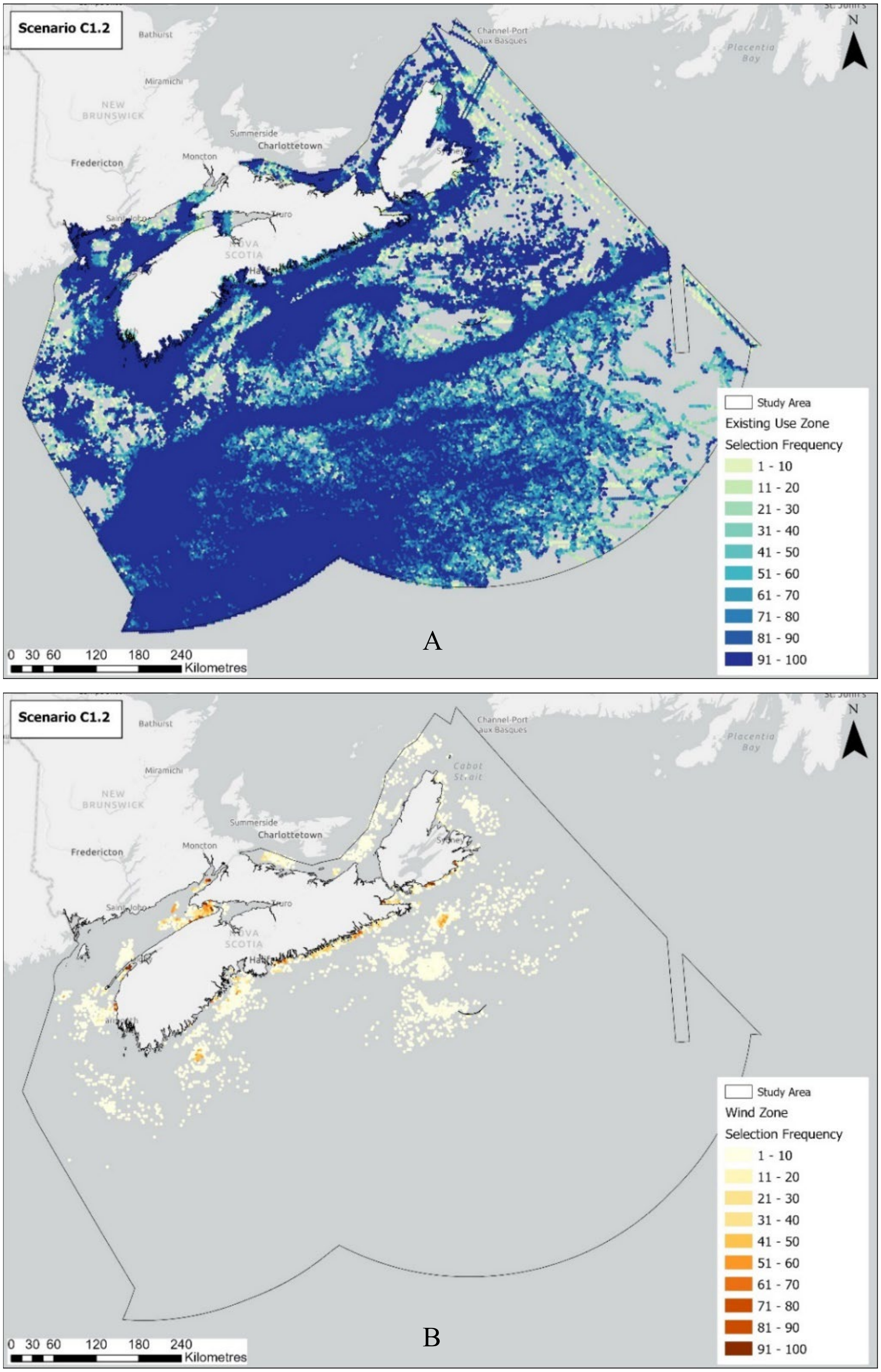

Figure S4. Scenario C1.2 summed solution selection frequency, n=100 solutions. Existing-use zone (A): areas selected to meet 90% targets for commercial fishing and vessel traffic features. Wind zone (B): areas selected to meet target of 170 planning units for fixed and floating foundation OWE excluding existing conservation measures, lease areas, and vessel traffic routes.

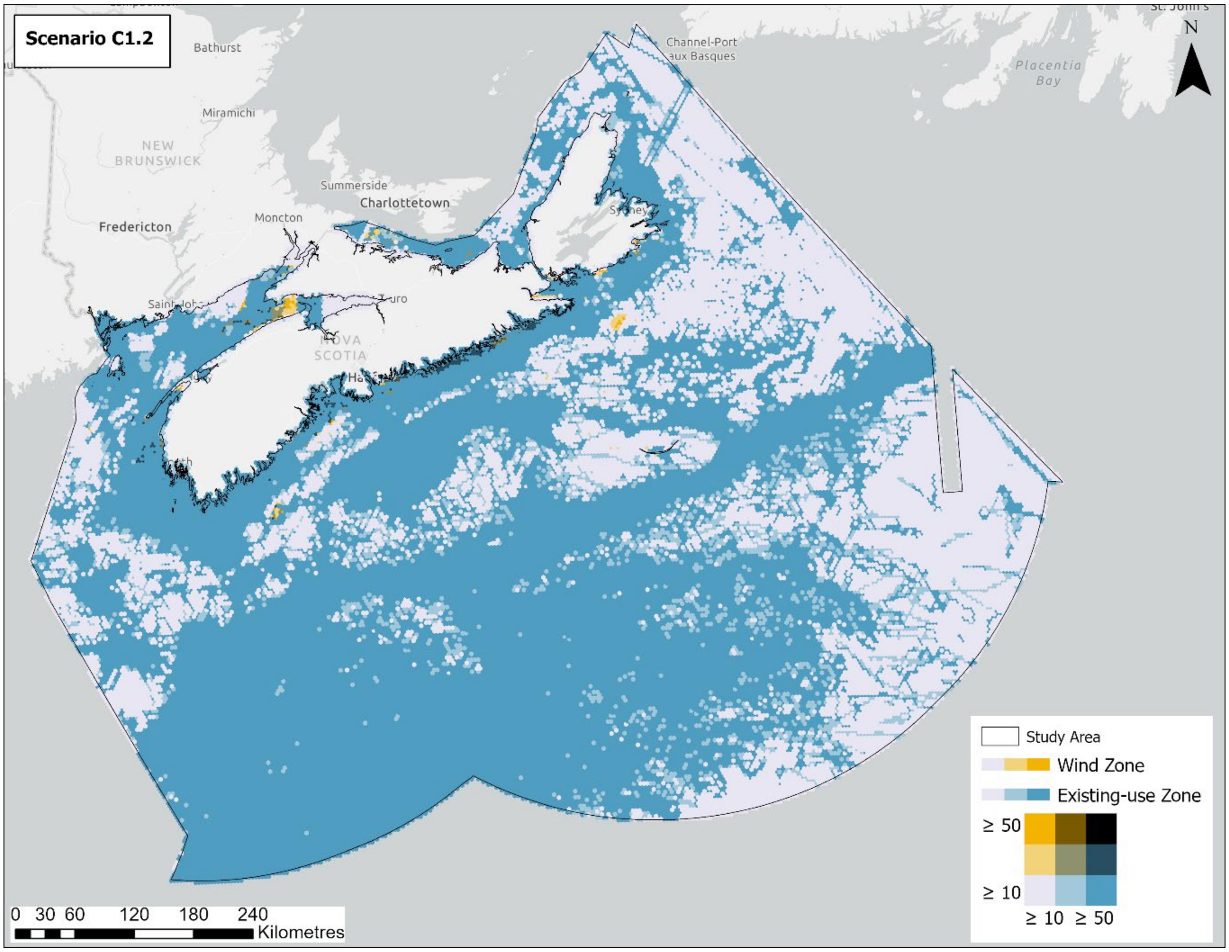

Figure S5. Scenario C1.2 bivariate selection frequency for the wind zone and existing-use zone summed solutions n=100 solutions. Bivariate symbology highlights areas of lower and higher overlap between the two summed solutions.

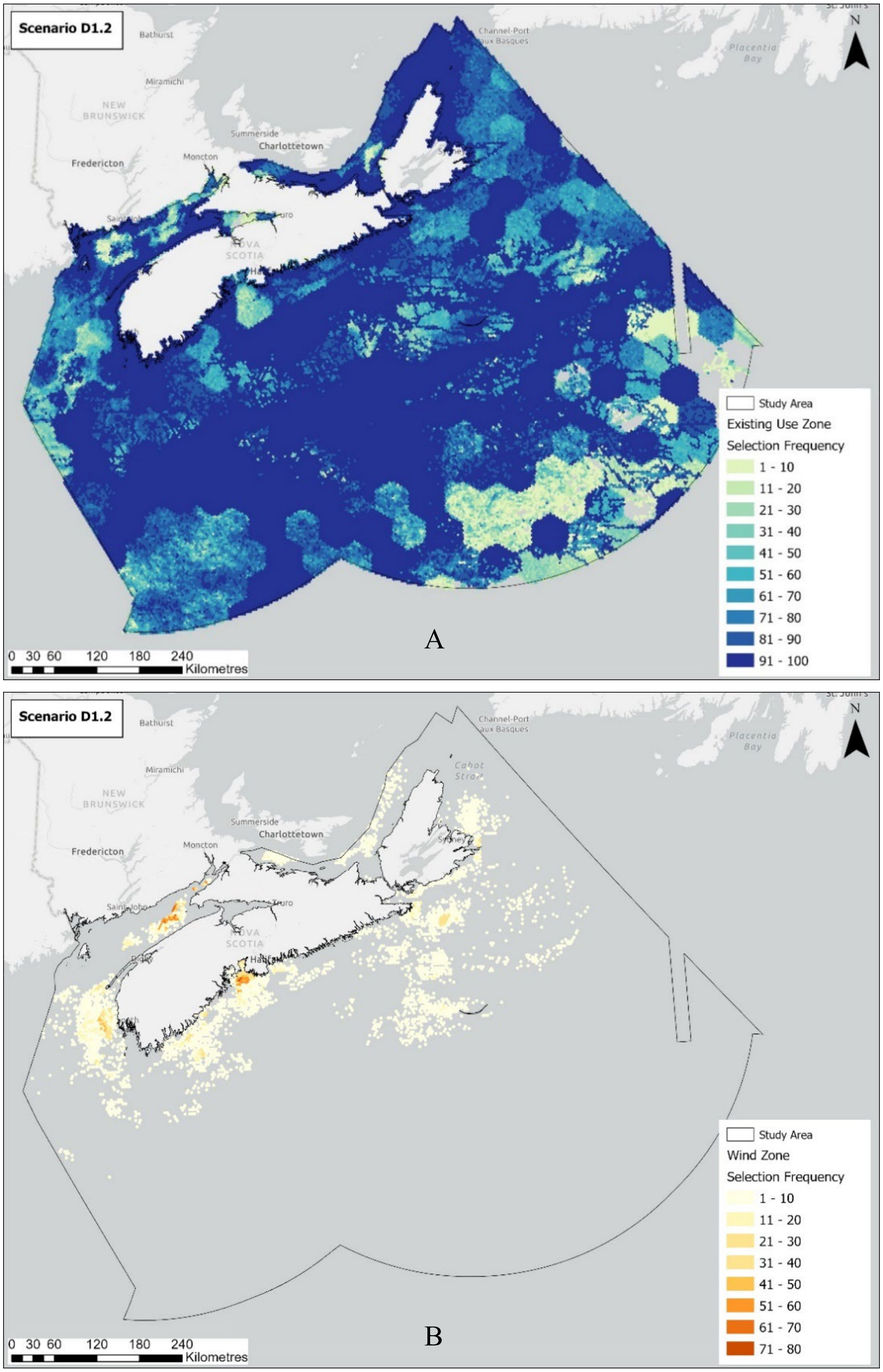

Figure S6. Scenario D1.2 summed solution selection frequency, n=100 solutions. Existing-use zone (A): areas selected to meet 90% targets for commercial fishing, vessel traffic features, and ecological features. Wind zone (B): areas selected to meet target of 170 planning units for fixed and floating foundation OWE and do not overlap with existing conservation measures, lease areas, and vessel traffic routes.

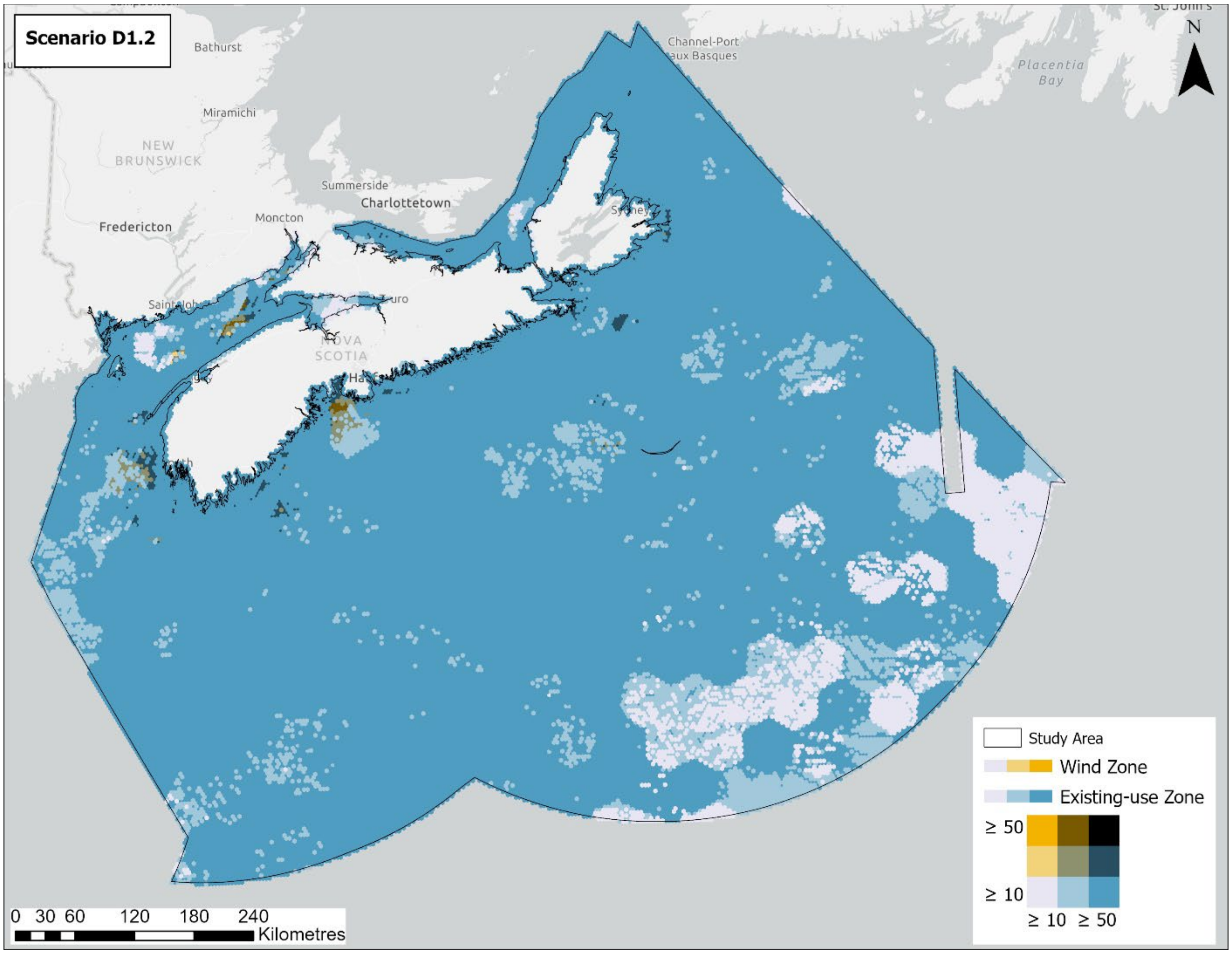

Figure S7. Scenario D1.2 bivariate selection frequency for the wind zone and existing-use zone summed solutions, n=100 solutions. Bivariate symbology highlights areas of lower and higher overlap between the two summed solutions.

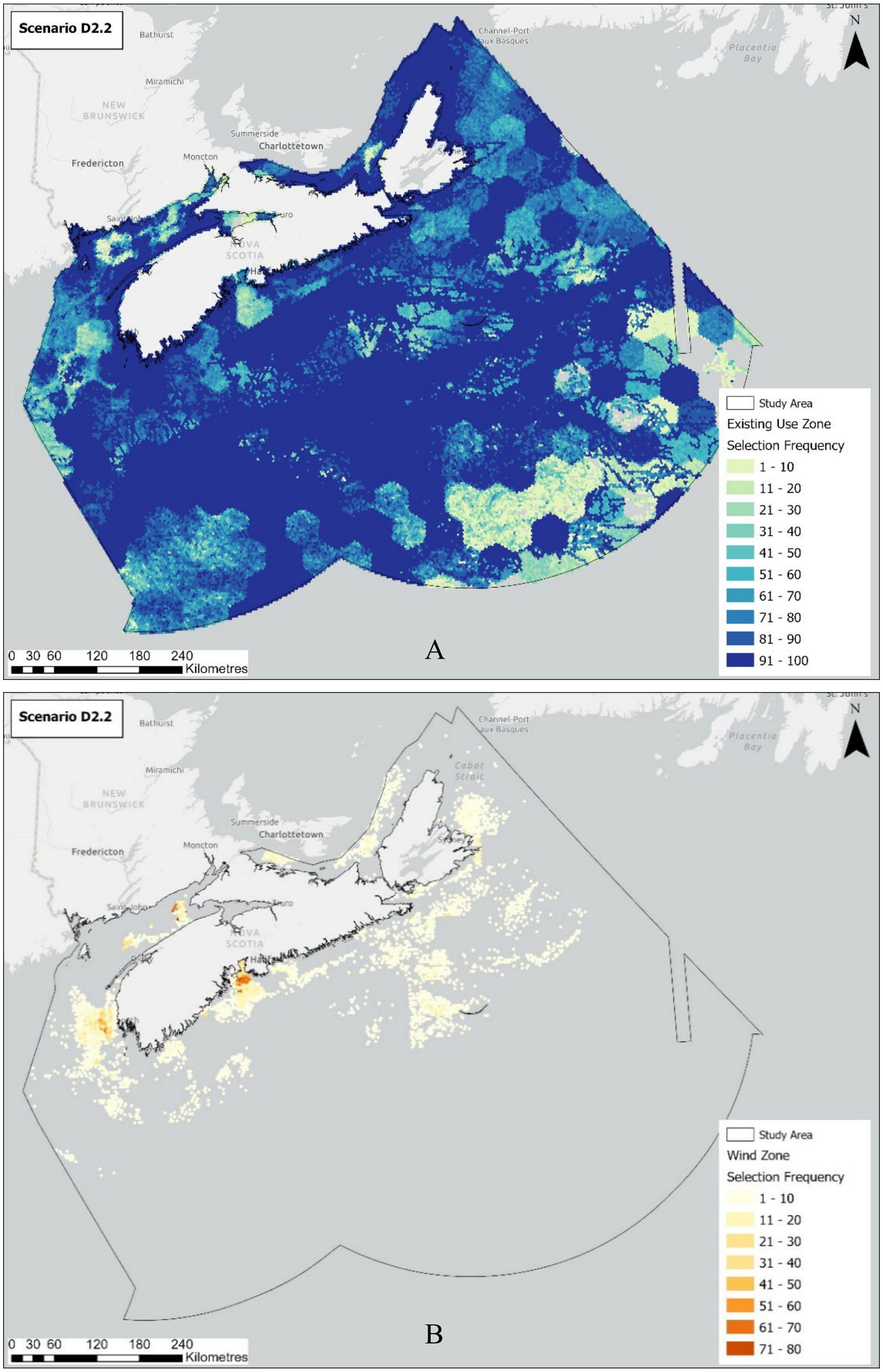

Figure S8. Scenario D2.2 summed solution selection frequency, n=100 solutions. Existing-use zone (A): areas selected to meet 90% targets for commercial fishing, vessel traffic features, and ecological features. Wind zone (B): areas selected to meet target of 170 planning units for fixed and floating foundation OWE and do not overlap with existing conservation measures, marine conservation network sites, lease areas, and vessel traffic routes.