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

By

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Abstract

In a marine environment of competing human uses and objectives, Marine Protected Areas (MPAs) and marine renewable energy like offshore wind (OSW) fight for space. OSW has been internationally accepted as an economically viable green energy alternative to conventional carbon-emitting sources, with the long-term goal of aiding to slow global warming. Although OSW is posed as a green energy source, questions continually arise regarding the environmental impacts of the technology and its compatibility with marine conservation initiatives, including MPAs. MPAs have gained global support via the International Convention on Biological Diversity which targets protection for 30% of coastal and marine areas by 2030. This study aims to evaluate the compatibility of OSW and future MPAs in Scotian Shelf-Bay of Fundy bioregion using a novel environmental risk assessment (ERA) method. The ERA uses a case study of Canso and Middle Banks, a site for future marine conservation, to investigate the spatial compatibility of OSW and an *Oceans Act* MPAs. The environmental risk assessment of Canso and Middle Banks will estimate the magnitude of OSWs impacts to conservation priorities to discern suitability and gaps in knowledge. Overall, OSW site selection, construction and operation pose a moderate threat to the conservation priorities of Canso and Middle Bank. Therefore, it is unclear if OSW and MPAs are spatially compatible due to gaps in the literature, a limited understanding of ecosystem wide effects, and the lack of decommissioning ecological knowledge. This project will help managers understand the potential compatibility between OSW and MPAs and provide direction for future studies that explore beyond ecological components to safeguard marine ecosystems and advance decarbonization for generations to come.

Keywords:

Offshore wind – Environmental Risk Assessment – Marine Protected Areas

Acronyms

AC	Alternating Current
AOI	Area Of Interest
BOEM	Bureau Of Ocean Energy Management
CBD	Convention On Biological Diversity
CO	Conservation Objective
COSEWIC	Committee On the Status of Endangered Wildlife in Canada
CP	Conservation Priority
CSA	Continental Shelf Association
DFO	Fisheries and Oceans Canada
DC	Direct Current
EBSA	Ecologically and Biologically Significant Areas
ECCC	Environment And Climate Change Canada
EEZ	Exclusive Economic Zone
EMF	Electromagnetic Field
ERA	Environmental Risk Assessment
EU	European Union
GIS	Geographic Information System
GOC	Government of Canada
GW	Gigawatt
GWEC	Global Wind Energy Council
HVDC	High Voltage Direct Current
IAAC	Impact Assessment Agency of Canada
IR	Impact Risk
IRENA	International Renewable Energy Agency

ISO	International Organization for Standardization
IUCN	International Union for the Conservation of Nature
MPA	Marine Protected Area
MRE	Marine Renewable Energy
MSP	Marine Spatial Planning
NOAA	National Oceanic and Atmospheric Administration
NRCAN	Natural Resources Canada
NS	Nova Scotia
OECM	Other Effective Area-Based Conservation Measure
ODEMM	Options for Delivering Ecosystem-Based Marine Management
OSW	Offshore Wind
OSPAR	Oslo And Paris Convention for the Protection of the Marine Environment of the North-East Atlantic
OWF	Offshore Wind Farm
RA	Regional Assessment
RL	Recovery Lag
SEER	U.S. Offshore Wind Synthesis of Environmental Effects Research
SSIP	Scotian Shelf Ichthyoplankton Program
TLP	Tension Leg Platform
UK	United Kingdom
WWF	World Wildlife Fund

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1. Introduction

With continued climate change, Canadian and provincial governments are under pressure to achieve climate conscious goals in a highly political atmosphere (Stephenson 2022). Federal commitments to protect marine biodiversity and provincial interests to meet renewable energy targets (Nova Scotia Power 2022) compete for limited space in the Scotian Shelf-Bay of Fundy bioregion, a region with historic rightsholder and stakeholder conflicts. For both governance bodies to achieve their goals while advancing socio-economic interests of the region, exploring the possibilities to limit cumulative impacts of anthropogenic marine activities is imperative.

As presented in the *Oceans Act* (1996), Marine Protected Areas (MPAs) are legally-defined oceanographic regions established for the long-term conservation and protection of biodiversity by limiting harmful human activities and providing a haven for important species. Although they promise economic benefit from “spill-over” effects[1] (McClanahan and Mangi 2000, Di Lorenzo et al. 2020), MPAs have been controversial with harvesters in the region (Moreland et al. 2021) as they can interfere with their catch efforts. With new government mandates to conserve 25% of Canada’s oceans by 2025, working toward 30% by 2030, the drive for environmental protection is high and attempting to do so equitably is a challenge (CBD 2022; Government of Canada, 2019b). In 2019 the Federal government created Protection Standards that prohibit harmful human activities in all new federally designated MPAs including oil and gas activity, mining, dumping, and bottom trawling (Government of Canada 2023). The standards and the establishment process of MPAs focus on ecological components of site establishment with conservation is the main goal, but it is unclear what trade-offs could be made with rightsholders, and other industries such as fisheries, and renewable energy.

The Nova Scotia government plans to develop the Offshore Wind (OSW) industry to achieve its renewable energy targets of 80% of total provincial energy consumption by 2030 (Premier’s Office 2018, Nova Scotia Power 2022). Due to the infrastructure required to construct and operate OSW, it too will require a spatial trade-off with user groups like fish harvesters and rightsholders (Gee and Burkhard 2010, Hooper and Austen 2014, Stelzenmüller et al. 2016,

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[1] The spill-over effect is the phenomenon when fish stocks reach carrying capacity within an MPA, causing adults to emigrate outside of the boundary to adjacent fishing grounds (Di Lorenzo et al. 2020).

2021). For example, fishing gear can become entangled in windmill foundations and be lost, turbines could alter navigation and act as potential hazards, and falling debris from turbines could be a safety risk during winter months (Biswas et al. 2012). Generally, OSW limits mobile gear types and long-lines, while putting those with compatible gear who might remain in the area at potential physical risk. Although some fisheries have found success in co-location with OSW (Hooper & Austen, 2014,; Stelzenmüller et al., 2016), it is still unclear how conservation initiatives, like MPAs, are compatible with windfarm sites (Ashley et al. 2014).

To ensure that conservation goals and renewable energy targets are met and inform marine planning, the concept of spatial compatibility should be understood. In Canada, the majority of studies have researched wind resource availability, feasibility, and benthic suitability for OSW construction (Nichol et al. 2021, Dong et al. 2021, Eamer et al. 2022, AEGIR 2023), but no studies have investigated OSW and marine conservation. This novel study will explore the ecological compatibility of fixed-based offshore wind farms (OWF) and future *Oceans Act* MPAs in the Scotian Shelf – Bay of Fundy Bioregion. The work will contribute to an understanding of how protection standards could apply to OSW, the ecological risks that OSW poses, and how a novel environmental risk methodology for MPAs in Canada could apply to OSW (DFO 2023). As there is yet to be an example of OSW in Canada, a case study approach is used to investigate a real-world example of a potential MPA and OSW spatial conflict (Government of Canada 2019a, Serdynska et al. 2021, AEGIR 2023). The results of the environmental risk assessment can guide decision making on how tolerable the ecological risks of OSW are to an *Oceans Act* MPA, or if its impacts on conservation are too great and conflict with the ethos of MPAs. The environmental risk assessment conclusion will lead to potential management recommendations and identify areas of study required for informed decision making.

2. Scan of OSW and MPAs

Marine spaces continue to grow in complexity as new ecosystem services are relied upon, and users compete to achieve economic, social, and environmental objectives. Two of these uses are MPAs that seek protection for biodiverse and productive ecosystems, and marine renewable energy (MRE) devices such as OSW turbines that convert wind into green energy. Both activities have political drivers, rightsholders, and stakeholders that are looking to accomplish their set goals of protection or production respectively. The purpose of this literature review is to provide background knowledge on MPAs, environmental risk assessments, OSW, and the marine spatial planning (MSP) of OSW and MPAs in Canada versus Europe, the global leader in OSW.

2.1 Marine Protected Areas in Canada

MPAs are an international concept that can be traced back to the first World Congress on National Parks in 1962 and has continued to develop into MPAs that we think of today (Humphreys & Clark, 2020). The International Union for the Conservation of Nature (IUCN), an international organization that is a global authority on conservation and the natural world, defines the modern MPA as; “a clearly defined geographical space that is dedicated and managed through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values” (Day et al. 2012). To quantify achieving long-term conservation goals, the percentage of a nation's exclusive economic zone (EEZ) comprising MPAs has been used as a metric of success. The development of marine protection targets by the United Nations Convention on Biological Diversity (CBD) began at 10% by 2010 at the Rio “Earth Summit” in 1992 (Humphreys & Clark, 2020), replaced by Aichi Target 11 striving for 10% coverage by 2020 (CBD, 2011), and has now increased to 30% coverage by 2030 under the Kumming-Montreal Global Biodiversity Framework (CBD, 2022). In December of 2022, 196 countries, including Canada, adopted the updated framework and with it the race to achieve 30% protection.

Marine conservation is managed across federal agencies, with the Department of Fisheries and Oceans (DFO) as the greatest contributor. Due to the CBD agreements, Canada has a mandated target to protect 30% of Canada’s EEZ by 2030. The three federal agencies that can create MPAs are the DFO, Environment and Climate Change Canada (ECCC), and Parks

Canada. Currently, 14.66% of Canada's marine and coastal areas are protected through MPAs and marine refuges (Government of Canada 2019c). The spatial protection measures managed by DFO are *Oceans Act* (1996) MPAs under Section 35 and *Fisheries Act* (1985) Marine Refuges. *Oceans Act* MPAs can limit all anthropogenic activities, while *Fisheries Act* marine refuges can only limit fisheries. The focus of this study is on MPAs as they have greater legal power and level of protection.

In Canada, an *Oceans Act* MPA is a clearly defined geographical space that is managed to achieve long-term conservation of nature while providing environmental, social, and cultural benefits (Government of Canada 2019d). Like protected areas on land, an MPA has boundaries and management plans to conserve the ecosystem by limiting harmful human activities. The management plan and regulations of the site are created to protect the conservation objectives (COs)[2] and conservation priorities (CPs)[3] of the site. MPAs are designated in five steps (Government of Canada 2019e):

1. Pre-planning: Ecologically and biologically significant areas, or sites from a conservation network, are identified to potentially become an MPA. Information is then gathered on the site and dialogue begins with rightsholders, stakeholders and partners. Step one concludes with area of interest (AOI) selection and announcement.
2. Feasibility assessment and policy development: Conduct biophysical, socio-economic, and traditional knowledge studies to create an overview of site knowledge. Establish an intersectoral advisory committee and perform environmental risk assessment in consultation with interested and affected parties.
3. Regulatory development: A draft of MPA regulations is pre-published for public commentary. The regulations are then edited to reflect feedback, and a final regulatory document is made. The creation of the final regulations marks the legal establishment of an MPA.
4. MPA Management: Once the MPA is legally designated, plans for MPA management, compliance, enforcement, and education and outreach are established.

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[2] Conservation objectives are the general overarching ecological goals of an MPA.

[3] Conservation priorities are specific ecological or geographical features that an MPA is protecting.

Monitoring and management plans including surveillance and enforcement approaches.

5. Ongoing management: Management plans are continually developed and updated to achieve conservation objectives. The site is continually studied and monitored.

2.1.1 Environmental Risk Assessment

As mentioned, environmental risk assessments are used to support evidence-based decision making for MPA regulations. In its essence, risk assessments estimate the probability of anthropogenic activities impacting ecological receptors, and the magnitude and nature of the risk to the environment. Risk is a combination of the consequences of an event and the likelihood it will occur (ISO 2018). A risk assessment provides a structured and evidence-based process for decision-making. Although there are varying methodologies, all risk assessments inform managers when determining what level of risk is acceptable to achieve their goal, and mitigation measures that could be implemented to reduce risks.

DFO has implemented several risk methodologies to assess ecological risk from various human impacts. Recently, a new MPA Environmental Risk Assessment framework has been developed for the Marine Planning and Conservation program to support decision-making on allowable activities for all new *Oceans Act* MPAs. This study was the first to use the novel internal framework and assess the risks of OSW to conservation priorities within a potential future MPA in Canada (DFO 2023).

2.1.2 Protection Standards

The Government of Canada has created MPA protection standards to ensure that environmental protection is harmonious across the country by providing greater consistency and clarity on the compatibility of human activities and MPAs (Government of Canada 2023). These standards prohibit oil and gas activity, mineral exploration, and exploitation, dumping of waste, fill, and other deleterious matter, and mobile bottom contact fishing gear in all new MPAs. This new federal baseline will act as the starting point for activity limitations within MPA boundaries, however, there is no mention of marine renewable energy.

It is speculated that the ‘dumping of fill’ restriction could limit the dumping of clast [4] or scour protection [5], a common step in creating strong foundations for OSW (Matutano et al. 2014, Wang et al. 2017, Deltares 2017). Scouring of the seabed at pile-type foundations is well documented (Matutano et al. 2013, Asgarpour 2016, Wu et al. 2019, Fazeres-Ferradosa et al. 2021), but based on environmental conditions engineers may choose to mitigate scour by elongating the pile to account for loss of sediment, therefore the protection standards would not apply (Deltares 2017). Further, methods of anchoring floating wind farms may not require scour protection due to the anchors ability to be buried beneath the sediment itself to prevent erosion (Sumer and Kirca 2022). Therefore, it is inconclusive whether OSW construction based on dumping provisions will be incompatible with the MPA Protection Standards.

2.2 Offshore Wind Energy

Climate change has been recognized as a global threat to biodiversity, human safety, and economic prosperity. One way to address this threat is converting more of the global energy supply to renewable sources. A driver of climate change is the warming of the atmosphere due to the emission of carbon from human activities like agriculture, transportation, industrial manufacturing, and domestic energy consumption. To tackle climate change, world leaders signed the Paris Climate Agreement to reduce global greenhouse gas emissions to limit global temperature increase this century to 1.5 degrees Celsius (“The Paris Agreement | United Nations” 2015).

Renewable energy sources have become viable alternatives to fossil fuels and are central for decarbonization (deCastro et al. 2019). Currently, wind energy is one of the most widely used forms of renewable energy globally and technologies have expanded to generate substantial amounts of energy from turbines out at sea (Sadorsky 2021). Engineering OWFs has allowed wind turbines to become significantly larger and be placed offshore where wind speed is

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[4] Clast is fragmented rock of varying sizes used to protect OSW foundations from erosion.

[5] Scour protection is the placement of materials around the base of a structure in an aquatic ecosystem to prevent the erosion of sediment that leads to structural instability. Materials used for scour protection include rock dumping (most common), gravel dumping, concrete mattresses, fabric bags filled with gravel or sand, tires, or a combination of methods, with new approaches suggested in the literature regularly (El-Reedy 2012, Esteban et al. 2015, Asgarpour 2016, Fazeres-Ferradosa et al. 2021).

approximately 20% higher than on land; allowing for 70% higher power generation than onshore (Polinder et al. 2013, Li et al. 2020). The advantages of offshore wind are that noise pollution is lower near communities, the possible development area is larger, the industry creates green jobs, and cost-efficient energy for consumers (Virtanen et al. 2022). The limitations of offshore wind are that it can: negatively impact wildlife; compete for space and access with fisheries; conflict with other industries like oil and gas and shipping; and spatially interfere with conservation measures like MPAs (Ashley et al. 2014, Karlõševa et al. 2016, Virtanen et al. 2022, Püts et al. 2023).

2.2.1 OSW Internationally

Offshore wind (OSW) is a rapidly expanding global industry and is expected to continue an unwavering growth trajectory over the next decade (GWEC 2023). The market has historically been dominated by European countries, like Denmark and the UK, with approximately 84% of all OWFs operating in the EU in 2017 (deCastro et al. 2019). The UK was historically the most important OSW market in the world, with 36% of the global capacity in 2017. At the end of 2022, China surpassed the UK with 44% of the world's total OSW capacity in its waters (Buljan 2023). As technology continues to spread internationally, new countries are showing interest in developing an OSW industry themselves.

2.2.2 OSW on the Scotian Shelf

Nova Scotia has moved towards procuring OSW, announcing a five-gigawatt (GW)GW leasing target by 2030. Canada is pursuing a net zero carbon emissions by 2050, sparking governance processes for OSW, like a regional assessment and policy changes, and partnerships for future green hydrogen exports. Nova Scotia is a key component to achieving these goals as it is considered to have world-class offshore wind resources due to its unique shelf with shallow water areas and relatively high mean wind speeds ranging from 9-11 m/s (i.e., 32-40 kph) (AEGIR, 2023). The most promising areas for production appear to be the Sable Island Bank and Middle Bank as they are less than 60 metres deep and ice-free (Public Policy Forum, 2023). With these sites, it could be possible to develop 1000s of turbines with the capacity to generate 15 MW each, enough to supply 6.5 million average Canadian homes. This potential is driving the government and industry to the region, and with additional promises of green jobs, reduction in cost for the consumer, and export opportunities, there are hopes that rightsholders and stakeholders will support these ambitions as such key players are imperative to OSWs success.

In the spring of 2022, the Impact Assessment Agency of Canada (IAAC), in partnership with Nova Scotia and Newfoundland and Labrador, launched a large regional assessment (RA) of offshore wind development in hopes of beginning to permit OSW in the coming years (I.A.A. of Canada, 2022). The RA was split by province after its announcement, leading to the Scotian Shelf regional assessment for OSW. The assessment will engage the public, Indigenous Peoples, academics, and environmental, fishing, and industry organizations. The information will be analyzed and prepared into a draft report of potential areas for development, known impacts, and mitigation and monitoring recommendations for public review to be then submitted to the federal and provincial Ministers for approval. The report should address the future of OSW developments in NS and the potential environmental, health, social and economic effects, positive and negative, in the study area. The RA is crucial as it will inform planning and decision-making for future wind projects on the Scotian Shelf and sets the tone for how the public might respond to projects moving forward.

Currently, it is known that NS and the federal government will co-regulate OSW through the rebranded Canada-Nova Scotia Offshore Energy board to manage leasing and bids for construction (Communications Nova Scotia 2018). Similarly, the Nova Scotia Department of Energy and Mines is rebranding to the Department of Natural Resources and Renewables which will be responsible for the business and economic development of the sector (Communications Nova Scotia 2022). Other departments that will play a role in management will be Environment and Climate Change Canada, responsible for terrestrial environmental quality, migratory birds, and avian species listed under the *Species at Risk Act* (2002) that could be impacted by OSW, and DFO who is responsible for *Oceans Act* (1996) MPAs, protection of fish and fish habitat under the *Fisheries Act* (1985), and aquatic species listed under *Species at Risk Act* (2002). This crossing of provincial and federal authorities and complexity of roles and responsibilities makes the management of this industry complex.

2.2.3 Green Hydrogen and OSW

In Canada, OSW has been identified as a mechanism to generate exportable renewable energy in the form of green hydrogen acting as a motivator for development. In August of 2022, Canada and Germany signed a declaration of intent to enhance Canadian green hydrogen to cooperatively address climate change, accelerate the global energy transition to renewables, and improve international energy security (N.R.Can, 2021). Green hydrogen or low-carbon hydrogen is a gas alternative that does not emit pollutants during combustion or production when the facility is powered by renewable sources (CORPORATIVA n.d.). The agreement is in line with the G7 Hydrogen Action Plan which hopes to tackle the climate crisis as well as the energy crisis resulting from the war in Ukraine by supporting the development of green hydrogen for industrial use (Parkes 2022). The Canada-Germany hydrogen alliance will collaborate on aspects necessary to kick-start the hydrogen economy and transatlantic trade, aiming for first deliveries by 2025 (N.R.Can, 2022). Currently, the alliance focuses on Newfoundland and Labrador, with the intent to build 164 wind turbines along the Port au Port peninsula to fuel a green hydrogen facility (Moore 2022). The Government of NS has been advertising itself as open for business in the offshore wind and green hydrogen sector, with the excitement of a new export for the province (Communications Nova Scotia 2018). Nova Scotia hopes to join this regional hydrogen hub in Point Tupper where a facility is being constructed to generate renewable hydrogen and ammonia from the future development of offshore wind (IRENA 2022). Therefore, the budding hydrogen economy and international energy agreements are intricately linked to the development of offshore wind in Nova Scotia.

2.2.4 The Making of an Offshore Wind Farm

The life cycle of an OSW farm occurs in four steps: site selection, construction, operation, and decommissioning. Each comes with its own challenges and environmental impacts. On average, it takes 9 years to begin construction, three to build, and they will operate for 20-40 years (Mooney et al. 2020). There are few examples of decommissioning OSW and limited information on the environmental impacts. Therefore, this study will focus on the first three stages – locations selection, construction, and operation – and their environmental effects.

The following section will be an overview of the three phases covering technology, actions, environmental impacts, and mitigation measures.

2.2.4.1 Location Selection

Selecting an appropriate location to construct and operate a farm is the first phase. The site should have high-quality wind energy, consider actual and potential human activities like fish harvesting, tourism, and shipping, and consider environmental aspects like predominant wave direction, benthic structure, currents, and ecological impacts. Suitability models for site selection should jointly consider societal, environmental, and economic impacts (Asgarpour 2016, Lo et al. 2021, AEGIR 2023). The data used in the models are often collected from vessel traffic data, environmental data from fisheries surveys, government and academic researchers, passive acoustic monitoring of marine life, satellite imagery, and seismic surveys.

Reflective seismic exploration, also known as seismic surveys, is the main technique used to map the structure underneath the seafloor to determine where foundations may be constructed. Prefereable substrates include sand or gravel, as shallow bedrock increases costs during foundation construction (Deltares 2017). It uses sound waves that penetrate the seabed and reflect to the surface where they are processed to create seismic profiles (Hazlegreaves 2020). This technique has been used for oil exploration and geological research purposes in the past but is now used for preliminary site assessments of OSW.

Noise from reflective seismic exploration has been shown to have negative environmental impacts. Fish can experience delays in development, slower growth rates, hearing damage, increased stress levels, and behaviour changes like a reduction in predator evasion, schooling, and mating (Weilgart 2018). Invertebrates, like zooplankton, suffer high mortality rates in the presence of noise due to cellular damage (McCauley et al. 2017). Lastly, marine mammals can experience masking of communication, changes to diving and feeding patterns, hearing damage, and avoidance of key habitat (Di Iorio and Clark 2010, Thomas et al. 2016, Kavanagh et al. 2019). The severity of the impacts is contingent on the proximity of the receptor to the noise; therefore, mitigation measures have been developed. Mitigation measures may include visual and acoustic observations to ensure that vulnerable species are not present, shutdown and low-power zones in critical habitats, soft-starts or ramp-ups that give species an opportunity to vacate the area prior to the testing, and general avoidance of biologically important areas and times (Przeslawski et al. 2018).

2.2.4.2 Construction

Building OSW is complex as turbines are large and construction occurs in challenging environments (Sánchez et al. 2019). The main categories of construction correspond with the three main elements: foundations, turbines, and cables (Figure 2.2.1). The installation of each category requires specialized equipment and vessels, each with respective environmental risks. Additionally, preinstallation activities like onshore assembly and offshore transportation, are construction components central to the OSW construction process. Construction has been broken down into three stages: foundation installation, turbine installation, and cable installation.

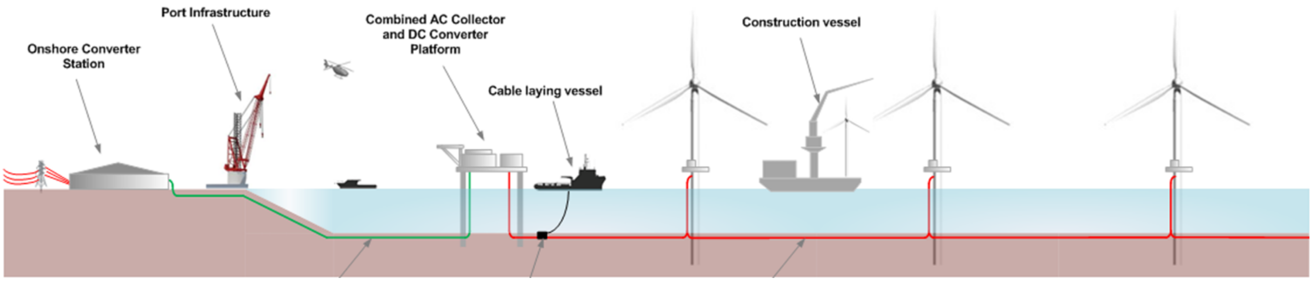

Figure 2.2.1 The structures and infrastructure required for a fixed-based OWF including foundations, turbines, inter-array cables, supporting structures, and vessels used (Baring-Gould 2014).

2.2.4.2.1 Foundations

The construction for OSW begins with its foundation. There are two foundation styles, fixed or floating, that secure the turbines to the seafloor. The foundation serves a critical role, supporting the integrity and stability of the turbine structures (Wu et al. 2019, Guo et al. 2022). The foundation style is selected for each site based on its depth, hydrodynamic regime, and substrate (Sánchez et al. 2019). Fixed base styles are gravity base, monopile, tripod, and jacket foundations which have a maximum depth of 60 metres (Figure 2.2.2) (Wu et al. 2019, Guo et al. 2022). For many countries, including Canada, there are limited coastal territorial waters with a depth less than 50m (Guo et al. 2022, Cerfontaine et al. 2023). Consequently, floating structures have garnered more attention as a solution to depth limitations. Floating systems are anchored, like floating oil and gas platforms. The three common floating structures are tension leg platforms (TLPs), semisubmersibles, and spars (Guo et al. 2022).

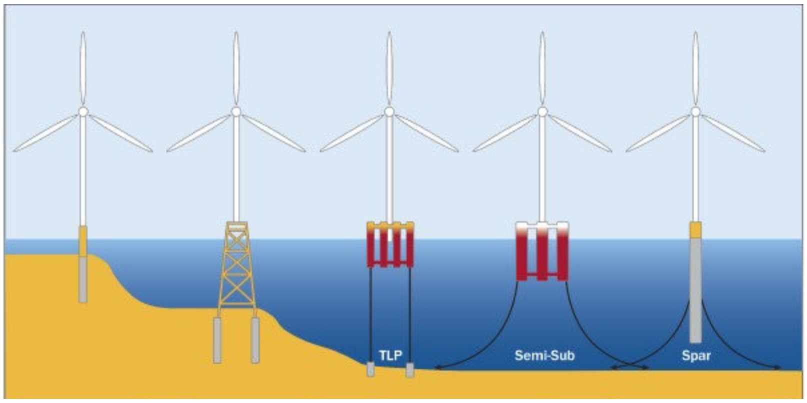

Figure 2.2.2 Examples of fixed and floating foundations (Bailey et al. 2014).

The focus of this study will be on the monopile foundation as it is suitable for the study area and is the most popular and well-understood method (AEGIR 2023). Monopiles are cylindrical steel structures driven into the seabed using pile-driving by hydraulic hammers (Asgarpour 2016). The pile is embedded 30m into the substrate depending on its composition (Arshad and O'Kelly 2013). The ideal substrates for a monopile are sand and gravel and could be installed on mud or till (Tang and Kilpatrick 2021). Monopiles cannot be constructed on cobble or boulder sized clasts. The average water depth for monopile foundations is 0-40m, beyond this depth the foundation is less stable and expensive to construct (Wang et al. 2018, Sánchez et al. 2019, Eamer et al. 2022).

Depending on the site's hydrography, installation of scour protection could be required to ensure the structure's stability. To account for risk of the windmill structure toppling failure due to scour, engineers have three solutions: (1) allowing scour to develop and fill with substrate; (2) lay scour protection prior to installation and add additional layer after embedment; (3) elongate the pile to cope with changing seabed levels (Deltares 2017). The materials used for scour protection include rock dumping (most common), gravel dumping, concrete mattresses, fabric bags filled with gravel or sand, tires, or a combination of methods, with novel approaches suggested in the literature regularly (El-Reedy 2012, Esteban et al. 2015, Asgarpour 2016, Fazeres-Ferradosa et al. 2021). It is unclear if scour protection is always necessary and if upkeep is required during operation.

Foundation installation impacts the pelagic and benthic ecosystems due to sediment disruption and noise. Pile-driving and drilling for monopiles can release fine particles into the water column, decreasing clarity, and changing the overall sediment structure by introducing new particulate matter into benthic ecosystems (Wilson et al. 2010). Further, the noise emitted can impact cetacean communication and fish behaviour like predator evasion, foraging, and reproduction (Madsen et al. 2006, Popper and Hastings 2009, Bailey et al. 2014). There are mitigation measures that can be implemented like bubble curtains that buffer noise by creating a ring of rising air bubbles that encircle the pile (Tsouvalas and Metrikine 2016, Peng et al. 2021). This measure has been found successful in reducing habitat loss of cetaceans (Dähne et al. 2017) and is a proven technique implemented for all OSW construction in Germany (Juretzek et al. 2021).

2.2.4.2.2 Turbines

Turbines are comprised of multiple parts assembled both onshore and onsite (Asgarpour 2016). First, a transition piece connecting the foundation to the turbine is installed (Sánchez et al. 2019). The transition piece is used as a work platform, a location for boat landings, ladder placement, and a tube that guides the cables from the tower to the seabed (Asgarpour 2016). Atop the transition piece, the turbine is installed beginning with the tower which is transported by a jack-up barge and lifted into place by a crane. Then the nacelle is lifted and placed on the top of the tower, with each blade lifted separately, and connected to the nacelle hub (Figure 2.2.3). As described, construction requires numerous support vessels to install foundations and turbines, as well as transport personnel to and from the site (Mooney et al. 2020). This influx of people and vessels brings pollutants to offshore sites through fossil fuel emissions and debris left by construction, and a threat of vessel collision to cetaceans (Wilson et al. 2010). Ways to mitigate impacts could be monitoring for cetaceans in the area and avoiding times of biological importance for slow moving marine mammals vulnerable to vessel strikes.

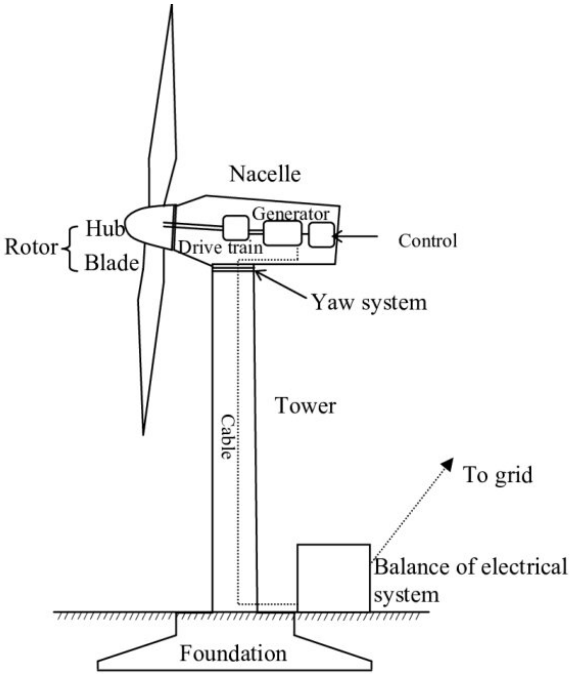

Figure 2.2.3 Wind turbine parts (Khodabux et al. 2022).

2.2.4.2.3 Cables and Supporting Structures

OSW requires submarine cables and co-located support structures like transformer stations to transfer energy to the shore. The turbines are connected through inter-array cables that carry energy to the offshore transformer station, which then is connected to land via export cables (Rodrigues et al. 2016). Cables run within the sea floor in trenches dug by vessels (Lozano-Minguez et al. 2011). The offshore substation prepares generated energy to travel to the shore by increasing the voltage or converting AC to DC (Rodrigues et al. 2016). On smaller developments, only one substation could be required, but it has become customary practice for large projects to include two substations. The substation platform sits atop a supporting foundational structure, which is installed like the previously described foundations with comparable environmental impacts.

The environmental impacts of supporting structure installation are like foundations; however, the cable trenching is an additional source of underwater noise during construction and introduces electromagnetic fields into benthic ecosystems (Öhman et al. 2007). Further, trenching can damage sessile species and cause a disturbance to sediments in its path. Impacts can be mitigated by choosing a route that avoids sensitive benthic habitat, keeping it short in length, strategically choosing times of year that avoid key biological processes, and burying the cables to reduce the magnetic fields (OSPAR 2012).

2.2.4.3 Operation

As mentioned, OWFs have a life expectancy of 20-40 years. The structures remain in the ecosystem for this time and are continually worked on by vessels. Operational ecosystem impacts are complex as OSW can provide biodiversity benefits while degrading the ecosystem in other capacities.

A positive impact to the ecosystem is the potential for structures to act as artificial reefs, providing new habitats for sedimentary flora and fauna to grow (Degraer et al. 2020). Vertical zonation has been observed along structures similar to the intertidal zone along coastlines (De Mesel et al. 2015). It is separated into splash, intertidal, shallow, and deep subtidal zones (Figure 2.2.4). For example, along structures in Belgian marine waters of the North Sea, researchers have identified this clear vertical zonation with barnacles in the splash zone, followed by mussels in the shallows, with filter-feeding anemones amphipods in the deep zone. Interestingly, all of these species are filter feeders or passive suspension feeders, picking their food particles from the water column, and acting as a biofilter that lowers turbidity and increases light penetration in the water column (Reichart et al. 2017). The filter feeders remove large sediments that would have settled along the sea floor and replace them with finer sediments rich in organic matter from suspension feeder fecal pellets. Changes to benthic sediments and an influx of organic matter can support higher-trophic-level fish species like Atlantic cod and black sea bass (Bergström et al. 2013, Reubens et al. 2014). As these fish enter the ecosystem, they attract larger predators like seals and herring gulls that forage around the windmills (Degraer et al. 2020). Over time, the foundation transforms into a diverse artificial reef community (Coolen et al. 2020). Although this potential reef could increase biodiversity, the composition may not be of native species.

Similarly, in benthic communities the rock clast acting as scour-protection has been shown to support communities of invertebrates and benthic fish. In the UK, it was found that European lobster (*Homarus gammarus*) display high residency within the habitat surrounding turbines (Thatcher et al. 2023). Further Atlantic Cod have been found to use clast as valuable complex habitat in European waters (Hammar et al. 2014, Schwartzbach et al. 2020, Degraer et al. 2020).

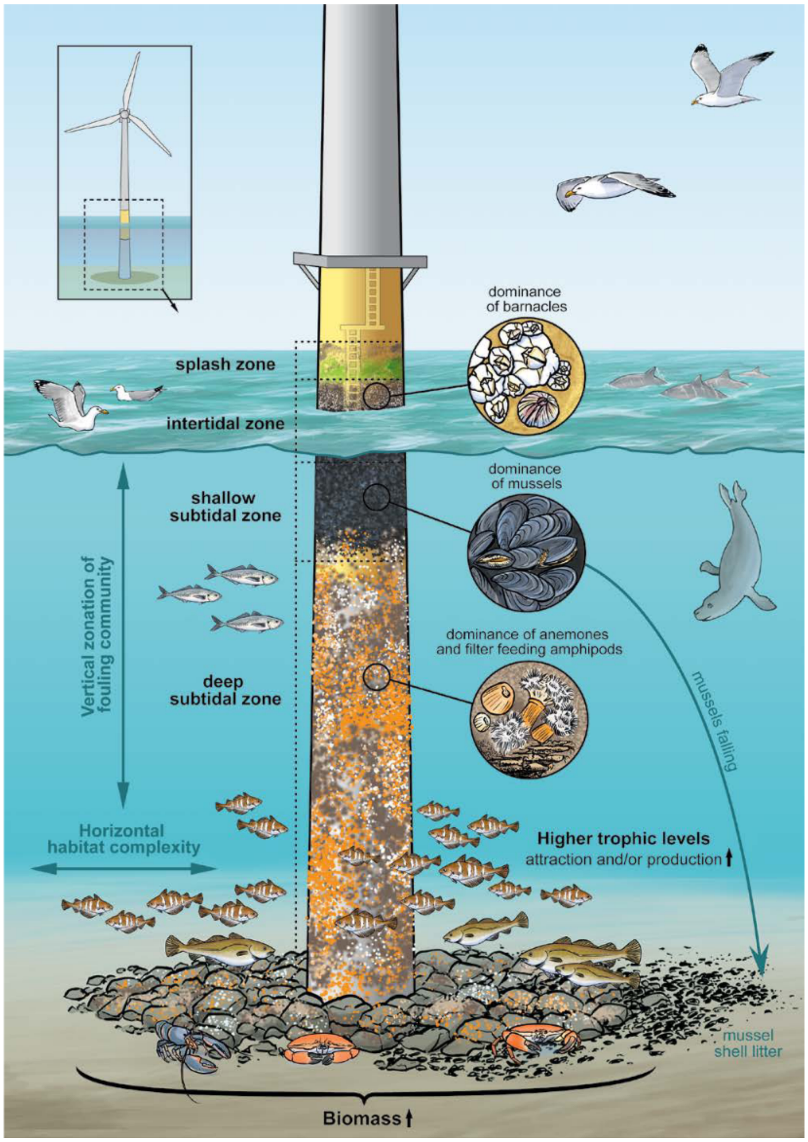

Figure 2.2.4 The vertical zonation and horizontal habitat changes of artificial reefs on monopile OSW foundations (Degraer et al. 2020).

The negative impacts during operation are noise and contaminants from turbines and maintenance vessels. Operational noise is less than that of a passing shipping vessel but can have cumulative impacts with other sources due to the noise's ability to permeate tens of kilometres distances (Tougaard et al. 2020, Mooney et al. 2020). Operational noise does not have physical harm implications to fish but can induce some behavioural changes. Background noise could interfere with mate selection, and continuous noise sources could cause higher levels of the stress hormone cortisol (Mooney et al. 2020). The sound generated during operation is low frequency, impacting some marine mammal species more than others. Baleen whales are affected most by low-frequency noise as they communicate at lower frequencies than other cetaceans, hindering species communication and navigation, which are both critical for migration success (Thomsen et al. 2015). It is thought that species can acclimate to some level of environmental noise in ecosystems, but the ability for sound to travel in water is a critical factor in understanding the cumulative and long-reaching environmental noise impacts of offshore wind farms. Further, the OWF structures require continual upkeep meaning that greenhouse gas emissions are unavoidable, generated by burning diesel for service vessels that clean, repair, and replace turbine components (Ren et al. 2021).

2.3 The Co-Existence Dilemma

Offshore wind farms and marine protected areas are distinct mechanisms that contribute to marine climate resilience. Marine protected areas safeguard ecosystems, enabling biomass to increase. Although ecological benefits of MPAs have been demonstrated by research, it is likely that climate change will alter the efficacy of some stationary protection measures depending on their conservation objectives as species compositions will shift over time (Bruno et al. 2018). Thus, to mitigate climate change and its negative impact on the ocean, renewable energy is integral to the long-term success of marine conservation initiatives. OSW is part of this energy transition, working to reduce the volume of carbon emitted into the atmosphere that causes ocean warming and acidification. Therefore, in planning the nascent offshore wind industry in Canada, managers should ensure that the goals of designating pristine and well protected ecosystems that are climate resilient can be met while transitioning away from fossil fuels. The link between MPAs and OSW has led to divided opinions among decision makers and other experts about the co-location of these activities due to spatial constraints, rightsholder and stakeholder needs, positive and negative biodiversity impacts, and the current environmental uncertainty of OSW.

Internationally, nations have approached the perceived link between OSW and MPAs differently when exploring their spatial compatibility. In the UK, territorial waters are limited, with human activities and marine conservation competing for little space, leading to the decision to co-locate MPAs and industrial OSW activity (Ashley et al. 2014). Across the Mediterranean, compatibility of these two spatial ocean endeavours is unclear as projects have not reached an industrial scale, thus infringing minimally on conservation (Defingou et al. 2019, Lloret et al. 2023). In response to this lack of clarity and the growth of the blue economy, researchers have suggested that depending on the purpose of designation, and the conservation priorities of the MPA, OSW could occasionally be co-located with IUCN category IV, V, and VI which are considered lightly protected MPAs (Day et al. 2012, Defingou et al. 2019). These categories of MPAs aim to protect species or habitats, seascapes in coastal areas, and the sustainable use of natural resources (Day et al. 2012). On the contrary, the IUCN views that MPAs and industrial activities or infrastructure developments should not coexist when they have adverse ecological impacts. Due to uncertainty, regulators, ENGOs, and academics continue to present new arguments on co-locating OSW and MPAs which have been grouped by positive and negative attributes as follows.

The positive attributes of co-location are that OSW can increase local biodiversity and reduce impacts to other rightsholders and stakeholders like fish harvesters. OSW farms limit fishing gear like an MPA would, potentially creating a similar haven for biodiversity. Hammer et al. (2016) suggest that OSW fisheries closures are equally effective at conserving marine biodiversity as MPAs due to the reef effect increasing biomass, however, this aptitude depends on the conservation priorities of the site as birds and whales potentially negatively impacted by OSW. The reef effect stems from complex habitat created by scour protection and foundations that increases the biomass and diversity of invertebrates along the faux intertidal and rocky benthic scour that leads to aggregation of top-trophic level species like large finfish and marine mammals (Raoux et al. 2017, Degraer et al. 2020, Wang et al. 2023). Like MPAs, economically important species that inhabit the windfarm can "spill-over" to support commercial and recreation fisheries around the site (Hammar et al. 2016, Gill et al. 2020). Further, co-location could alleviate pressure placed on available fishing grounds as effort is displaced into increasingly small areas, further degrading unprotected areas (Ashley et al. 2014, The Wildlife Trust 2020). Co-location allows the harvesters further access to historic fishing ground where livelihoods and identity are tied (Ashley, 2014), while reducing the overharvest of remaining grounds (Püts et al. 2023).

Conversely, the negative aspects of combining OWF infrastructure and MPAs are that conservation sites would be unnatural, foundations can spread invasive species, and there is general uncertainty of environmental impacts. OSW in MPAs could reduce ecological integrity as the MPAs would not be protecting naturally occurring habitats or species aggregations (Ashley et al., 2014). Assemblages at OSW sites are unnatural as endemic soft-sediment habitats are converted to synthetic rocky habitats, introducing novel habitat and niches that benefit novel species (Heery et al. 2017). Further, the structures can act as a stepping stone for invasive species, propagating the spread of alien species (Ashley et al. 2014, De Mesel et al. 2015). Additionally, for MPAs designated for seabirds, conservation is likely incompatible as wind farms can have negative impacts for several species as they could avoid preferred feeding or wintering grounds (Hammar et al. 2016). Lastly, limited longitudinal monitoring of ecological impacts of OSW (Wilson et al. 2010) and studies that mainly focus on the North Sea mark a gap in our understanding of risks posed to the natural world, particularly in new regions to the industry (Lloret et al. 2022). Therefore, the precautionary approach would suggest that due to uncertainty, caution should be taken in the spatial management of OSW and MPA co-location.

Overall, the international MPA community is unclear on how to proceed, giving Canada the opportunity to set a precedent for conservation and determine what is best for its marine users. The GOC has a unique approach to conservation with protection standards that prohibit four environmentally harmful activities (Government of Canada 2023). Highly protected areas serve greater conservation value then lightly protected areas as it results in an increase in local biomass, biodiversity, and large individuals of species represented which benefits reproductive output (Edgar et al. 2014).

Although this novel approach was applauded by environmentalists, the standards fail to mention MRE in any capacity. This oversight at the time of its creation has led to uncertainty among practitioners, rightsholders, and stakeholders due to this pressing policy gap and the target of 30% ocean protection by 2030. This study aims to shed light on this gap and answer the question of ecological compatibility between OSW and MPAs.

3. Case Study of Canso and Middle Banks AOI

A case study was used to approach the compatibility of MPAs and OSW in a real-world setting. The qualifications used for case study selection were that the area must be identified for future conservation efforts and have high suitability for OSW development. By using the draft conservation network designed by the DFO Maritimes and the AEGIR suitability survey (AEGIR 2023), the site “Canso and Middle Banks” was selected. The site is approximately 45 km southeast of Canso, Nova Scotia. The specific boundaries are not set and are subject to change as it is not currently under consideration by DFO for designation (Figure 3.1.1). It is an area of high biodiversity and is an important habitat for several depleted groundfish species. The Canso Bank portion of this site also supports high primary productivity and is considered relatively natural because it has not been trawled to the extent of adjacent banks. Further, Middle Bank was historically an important cod spawning and nursery area.

This chapter will introduce the site and its conservation priorities, and the mock windfarm that has been created based on suitability studies and industry best practices.

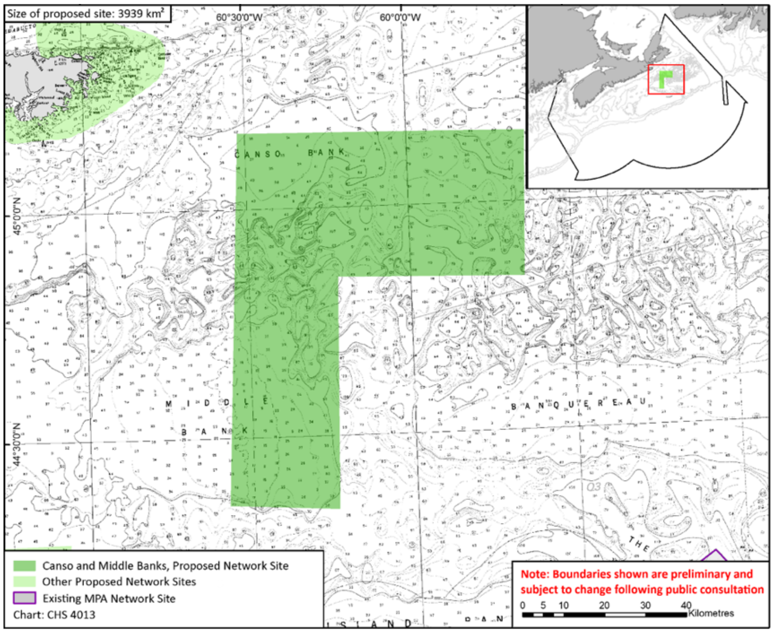

Figure 2.3.1 Map of Canso and Middle Banks hypothetical network site.

3.1 Proposed Conservation Priorities

The draft CPs were identified for the site in the conservation network (Serdynska et al. 2021). The CPs of Canso and Middle Banks include its diversity of habitat types, high primary productivity, ichthyoplankton diversity, benthic invertebrate diversity, sand dollar beds, sensitive benthic sponges, depleted groundfish, and seabirds. For this study, sand dollars were grouped with benthic invertebrates, Atlantic cod represent depleted groundfish, and sponges were removed from the analysis since they do not overlap with the projected OSW sites in the MPA (AEGIR 2023). Lastly, for interest, Blue Whales were added as a hypothetical conservation priority for the site as cetaceans are a topic of interest relating to OSW.

3.1.1 Primary producers

Phytoplankton is the main source of primary production in Canso and Middle Banks. They are the base of the marine food web and set the upper limit of productivity across trophic levels (Worcester and Parker 2010). Canso and Middle Banks are most productive during the spring and fall (King et al. 2016). During the winter months, upwelling by passing storms increases nutrients at the surface (MacLean et al. 2013). This upwelling of nutrients, increased sunlight that warms surface temperatures, and water stabilization create ideal conditions for phytoplankton to bloom in spring. Over the summer, plankton use nutrients regenerating within the ecosystem to reproduce. As the water temperatures reach their maximum in fall, a second bloom of small phytoplankton occurs. The blooms in all seasons vary temporally and spatially, with a trend of blooming earlier in the recent decades compared to the 1960s and 1970s (Worcester and Parker 2010). Although blooms may be changing, the persistence of chlorophyll a indicates that phytoplankton have remained abundant within the AOI (MacLean et al. 2013).

3.1.2 Ichthyoplankton species diversity

The areas around Canso and Middle Bank have high larval fish genus richness as determined from an analysis of the Scotian Shelf Ichthyoplankton Program (SSIP) survey results (1978-1982) (Shackell & Frank, 2000). The genus richness analysis was repeated for conservation network planning to identify areas of high larval richness, finding that both Canso and Middle Banks support diverse larval communities. SSIP surveys are relatively dated but are the only shelf-wide larvae dataset available for the region which was required for network analysis and the creation of this site.

3.1.3 Invertebrate species diversity

Overall, Canso and Middle Banks are high in invertebrate species richness and diversity (Bundy et al. 2017, Serdynska et al. 2021). In general, benthic invertebrates reproduce regularly and are important prey for higher trophic levels. Additionally, they are ecosystem engineers, predators, detritivores, and are bioturbators mixing sediments to aid nutrient cycling, to filter water of toxins and to incorporate new biogenic material up trophic levels (Kenchington 2014).

3.1.4 Atlantic cod (COSEWIC - Endangered)

Atlantic Cod (*Gadus morhua*) are listed as Endangered by COSEWIC and have remained under a fishing moratorium since 1993 (COSEWIC 2010), and they are a well-studied species with DFO Research Vessel Survey data collected over time. They are known to breed in distinct groups[6] across the bioregion (Serdynska et al., 2021). Atlantic cod are a demersal species generally found within 2 m of the sea floor. They are known to use Middle Bank throughout their life cycle year-round as feeding adults, and as a spawning and nursery areas (King et al., 2016). Cod eggs are buoyant and float to the surface where larvae hatch and live in the top 10-15 m of the water column feeding on plankton before settling into benthic habitats (COSEWIC, 2010). The greatest threats to Atlantic cod are commercial and recreational fishing, fisheries bycatch, illegal fishing, climate related changes to ecosystem, and habitat alterations (COSEWIC, 2010). Although fisheries have been limited, there continues to be a decline due to increased natural mortality and small catches.

3.1.5 Blue Whale (COSEWIC, Species at Risk – Endangered)

Blue whales are a baleen whale and are the largest animal known to have lived on earth (Beauchamp et al. 2009). In Canada, Blue whales were listed as endangered under the *Species at Risk Act* and COSEWIC (Sears and Calambokidis 2002, Beauchamp et al. 2009). The northern blue whale (*Balaenoptera musculus musculus*) lives in the northern hemisphere in two

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[6] Atlantic cod breeding subpopulation 4VsW.

populations: the Pacific and Atlantic. The Atlantic population is found on the Scotian Shelf, the Gulf of St. Lawrence, and off the coast of Newfoundland. Blue whales inhabit coastal and pelagic waters year-round to feed on euphausiids, commonly known as krill (Beauchamp et al. 2009, Wingfield et al. 2022). This species is particularly vulnerable due to its life history, with a long gestation period of 11-months, 2 to 3-year care of a single calf, and sexual maturity at 5–15 years resulting in low population growth. Further, the dietary specialization can pose challenges as krill are rarely found in densities to support blue whale survival (Beauchamp et al., 2009). Although the Blue Whale is not a conservation priority for the site, for the sake of the case-study we will consider Canso and Middle Banks an ecologically important area for the species to include a cetacean.

3.1.6 Seabirds

Several seabird functional feeding guilds were identified as conservation priorities for the Canso and Middle Banks site. Allard et al. (2014) used a hotspot analysis to determine critical seabird habitat for eight functional groups using data from Environment and Climate Change Canada. Canso and Middle Banks contribute to seven of eight seabird functional group targets. The most notable functional group selected for the study are surface Shallow-Diving Piscivores/Generalists (Table 3.1.1) which includes several Gull and Tern species (Serdynska et al., 2021).

3.2 Mock Wind Farm Design

The AEGIR offshore wind resources assessment on the Scotian Shelf (AEGIR, 2023), industry best practices, and personal communications have informed the mock wind farm design for the risk analysis. In the assessment, Canso and Middle Banks have been recognized as potential sites for energy generation with two different approaches. Canso Bank has been identified as a site for a floating wind farm with the capacity of generating 1000 MWs, and Middle Bank as a site for a fixed foundation-based type to generate 2000 MWs. As monopiles are a well-established and researched foundation type they will be used in this study (Lozano-Minguez et al. 2011, Arshad and O’Kelly 2013, Wang et al. 2018, Oh et al. 2018, Wu et al. 2019, Sánchez et al. 2019, Mooney et al. 2020). To reflect conversations with regulators, the size of the monopile wind farm was reduced from AEGIRs estimates to 1000 MWs made up of 50 individual turbines as this is a more achievable development size (Table 3.2.1). Turbines of the mock farm are spaced by 1 nautical mile to discern the spatial use of the windfarm in the site (Figure 3.2.1), consistent with the United States identified criteria for ease of navigation.

Table 3.2.1 Characteristics the sample Middle Bank OSW site from AEGIR (2023) and regulator discussion.

ASPECT	**MIDDLE BANK FEATURES**
Foundation Type	Fixed – bottom (monopile)
Capacity	1000 MW
Water depth	46 m
Distance to port	140 km (Port of Sheet Harbour)
Distance to grid connection	112 km (Goldboro)
Transmission system	HVDC (two cables)
Turbine rating	20 MW
Number of turbines	50

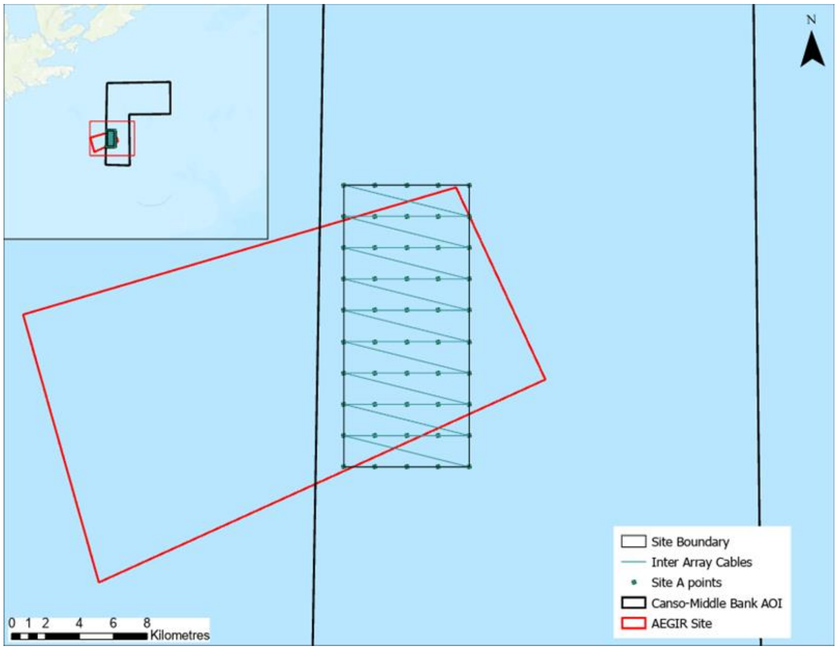

Figure 3.2.1 Map of the Canso and Middle Bank proposed network site outlined in black, the AEGIR suitable area for OSW development in red, and the mock windfarm design used in the study in green.

3.2.1 Characterization of Wind Farm Sub-Activities

Construction and operation of OSW occurs through a variety of sub-activities as described in section 2.2.4. To identify the environmental pressures of OSW, these sub-activities were defined as follows:

- **Seismic Surveys:** Actions that use sound blasting of high-powered airguns to map the sea floor prior to construction.
- **Foundation Installation:** All actions required for the installation of monopiles and substation piles including the removal of obstructions to construction, pile-driving with hydraulic hammers and the dumping or construction of scour protection.
- **Tower:** The physical mounting of a turbine tower, nacelle, rotor blades, and gearbox atop the foundation.
- **Cable installation:** The trenching, laying, and burial of subsea cables and the installation of scour protection where required (clast or concrete mattresses).
- **Active Turbines:** The actions associated with an active turbine above water including the turning of rotor blades, the vibration of the tower, and the working gearbox.
- **Foundation:** The underwater structures associated with the foundations of the turbine and substation comprising piles transecting the water column and scour protection at the base.
- **Active Cables:** The underwater structures associated with active cables such as scour protection, exposed cables, and the electromagnetic emissions.

4. Method: Environmental Risk Assessment

An environmental risk assessment (ERA) of the Canso and Middle Banks AOI case study was conducted to explore ecological compatibility of OSW and MPAs. The methodology was provided by the DFO, in order to test a new framework guidance (DFO 2023) adopted from Robinson et al. (2014). The analysis occurred in four steps: 1) Defining the case study area (Chapter 3); 2) Risk identification; 3) Risk analysis; 4) Risk evaluation.

4.1 Risk Identification

The purpose of risk identification is to determine all pressures associated with OSW activities and whether they will impact conservation priorities of the AOI. To begin to understand the interaction between sub-activities and the risk to conservation objectives, a brief scan of potential sensitivities was conducted (Table 4.1.1). The purpose is to highlight where actions could pressure conservation priorities.

Table 4.1.1 Identifying the interaction between OSW actions and conservation priorities based upon literature review. Potential interactions are denoted with an "x".

		CONSERVATION PRIORITIES					
		Primary production	Ichthyoplankton	Benthic invertebrates	Atlantic cod	Seabirds	Blue whales
CONSTRUCTION	Seismic surveys		x	x	x		x
	Foundation installation		x	x	x		x
	Tower installation					x	
	Cable installation			x	x		
OPERATION	Active turbines		x	x	x	x	x
	Foundations	x					

	Active cables/ substation		**x**	**x**	**x**		

4.1.1 Environmental Pressures

For each conservation priority and sub-activity of OSW, the pressures to the environment were identified and defined (Appendix 1). Using these pressures, draft risk statements for all potential activity-pressure-receptor occurrences were identified using a literature review. Not all risk statements were used in the risk analysis for reasons described in Appendix 2.

4.2 Risk Analysis

The purpose of the risk analysis is to evaluate the risks of potential interactions between human activities and conservation priorities with qualitative descriptors and associated risk scores. These risk scores are then evaluated to determine the likely compatibility or incompatibility between an activity and achievement of the proposed MPA conservation priorities. The qualitative descriptors and their respective numerical scores are derived from an adaptation of the ODEMM risk assessment methodology (Robinson et al. 2014, DFO 2023). The method is more stringent of environmental risks as the tolerance of negative environmental impacts is lower in conservation areas.

4.2.1 Search of the Literature

The scores were assigned by thoroughly reviewing the available and relevant literature of pressures to the receptors. The search engines used to find peer reviewed literature were Novanet and Google Scholar, and the search terms consisted of a combination of a pressure and a receptor, with “offshore wind” or “offshore wind farm.” For example, searching “Atlantic cod pile driving noise” and “Pile driving noise offshore wind Atlantic cod.” This process was repeated until the literature was repetitive and the search became exhausted.

4.2.2 Methodology Criteria

The methodology involves assessment of five “criteria” or parameters: spatial overlap, temporal overlap, severity, persistence, and resilience (Figure 4.2.1). The scores of these five parameters are combined to give Impact Risk (IR) and Recovery Lag (RL) which are calculated as follows:

Impact Risk (IR) = ***spatial overlap*** × ***temporal overlap*** × ***severity***

= the likelihood of an adverse ecological impact following an activity-pressure introduction, where the greater the Impact Risk score, the greater the threat to that conservation priority

Recovery Lag (RL) = ***persistence & resilience***

= a relative indication of the time it takes for an impacted conservation priority to return to pre-impacted condition after the activity stops, where the greater the Recovery Lag value, the longer time is required for a conservation priority to recover to its pre-impacted state

As suggested by the equations above, there are numerical scores assigned to all five criterium which are determined using binning tables from the DFO method and a resilience scoring table from the Options for Delivering Ecosystem-Based Marine Management (ODEMM) risk assessment framework (DFO 2023, Pedreschi et al. 2023) (Appendix 3). Scores were reviewed by five DFO staff members to validate the assignment of scores and accompanying rationales.

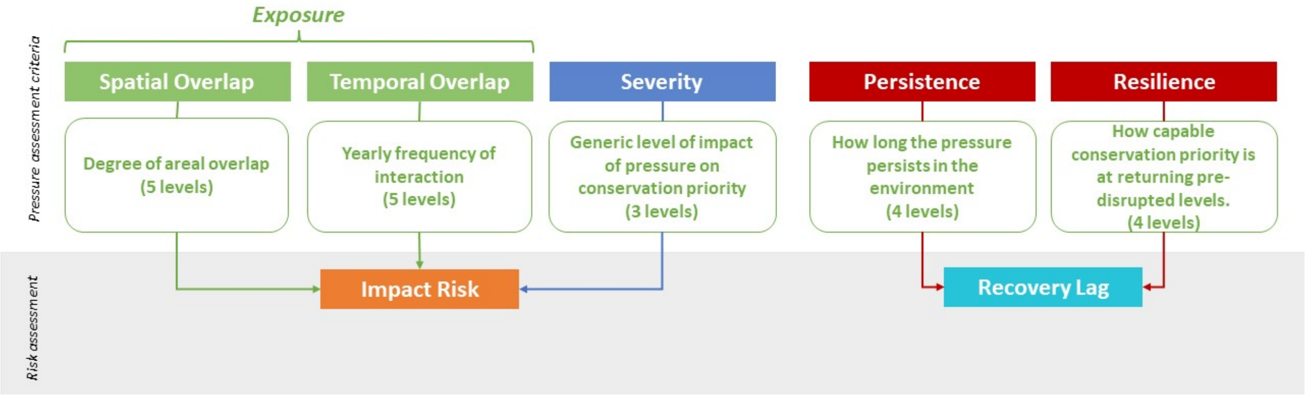

Figure 4.2.1 Modified ODEMM Pressure Assessment Parameters (criteria) (Robinson et al. 2014).

4.2.3 Uncertainty Assessment

The level of uncertainty in the assessment of the IR and RL parameters for each risk event were determined by assigning a *low, moderate,* or *high* rating according to the criteria shown in Table 4.2.1. The assessment is based on the availability and quality of data and references, whether the literature is peer reviewed, and whether the information is current. This is consistent with the precautionary approach that requires decisions to be made in the face of scientific uncertainty erring on the side of caution to prevent undue risk. Although the uncertainty levels are not as formally estimated as other parameters, they are critical in interpreting the risk and making recommendations of risk tolerance.

Table 4.2.1 Uncertainty level descriptions from Phase 1 Risk Guidance (DFO, 2023).

UNCERTAINTY LEVEL	DESCRIPTION
Low uncertainty	Widely accepted information, applicable to study area, and supported by peer reviewed, science-based literature. No, or minimal, additional data collection needed.
Moderate uncertainty	Limited/non-peer-reviewed literature and/or partial data available. Science-based evidence available but potentially requiring updating or validation for specific location or time frame.
High uncertainty	Little to no science-based data and/or published material available. Some general knowledge and/or data may exist but would require validation.

4.3 Risk Evaluation

The purpose of the risk evaluation is to evaluate all risk events based on the determined scores to conclude whether a given risk is *acceptable, may be tolerable,* or *intolerable* to conservation priorities by using a heat map (Figure 4.3.1). The three categories are defined as:

- **Acceptable:** The risk associated with an activity is likely compatible with MPA conservation priorities and requires no further treatment.
- **May be tolerable:** The activity is likely somewhat compatible with MPA conservation priorities, but risk should be reduced in the MPA as much as possible through design and consideration of other risks.

- **Intolerable:** The activity is likely not compatible with MPA conservation priorities and requires treatment or elimination.

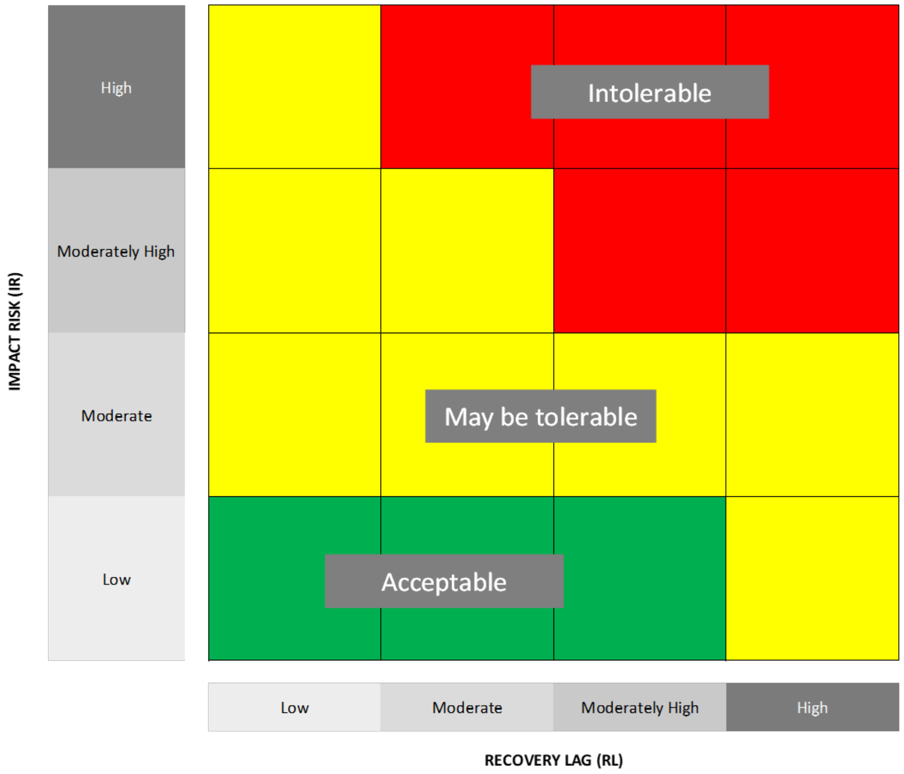

Figure 4.3.1 Heat map with risk tolerance based on IR and RL.

5. Results

In this chapter, the results of the risk analysis are presented by planning phase and element of OSW construction. Each section contains the analysis by pressure and conservation priority, which are summarized in a final table in subsection 5.6.

5.1 Seismic Surveys

5.1.1 Noise (underwater or other)

Risk Assessment – Seismic Survey Noise and Ichthyoplankton

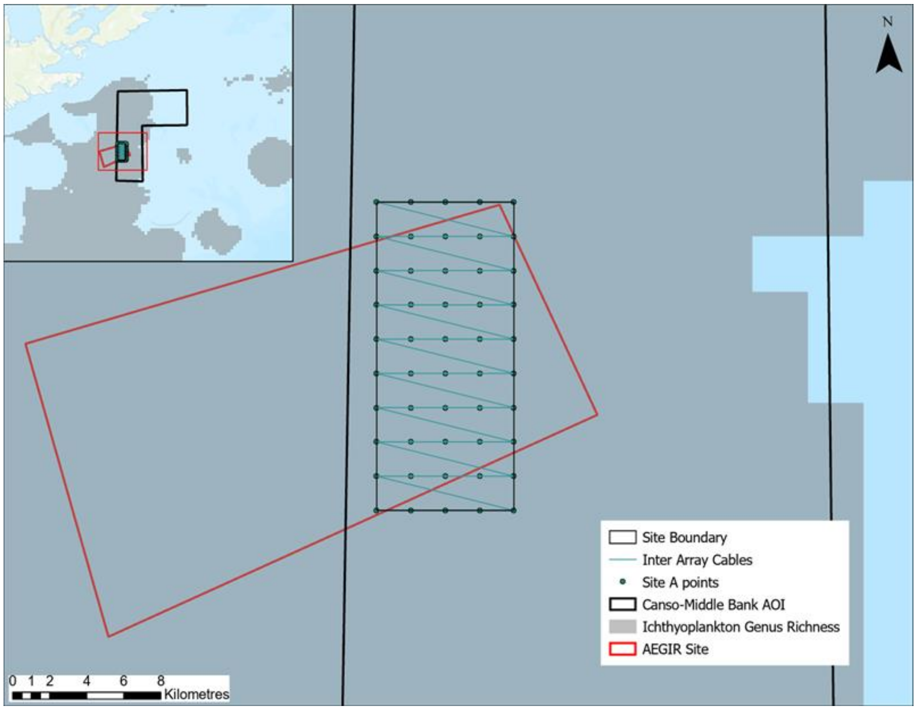

Figure 5.1.1 Seismic survey noise overlap with ichthyoplankton within the AOI.

Risk statement: If an interaction occurs involving ichthyoplankton and noise (underwater and other) due to seismic testing, the consequence could result in damage and behavioural changes (Wilkens et al. 2012, Pine et al. 2016, Jolivet et al. 2016, Lecchini et al. 2018, Anderson et al. 2021).

Table 5.1.1 Scoring for the risk posed by seismic survey noise to ichthyoplankton within the AOI.

Risk factor	Score	Rationale
Impact Risk	Low (binned)	IR = Spatial x Temporal x Severity = 0.03 x 0.08 x 0.1 = 0.00024
Spatial	Site (0.03)	Overlap = 100*(Area of ichthyoplankton layer that overlaps with windfarm site/ Area of ichthyoplankton within AOI) = 3.1% The activity will cover the entire offshore wind farm site to map locations for construction. The activity overlaps with 3.1% of the area that the CP occupies in the AOI.
Temporal	Rare (0.08)	Seismic testing consists of loud blasts every 10 seconds for less than a month.
Severity	Moderate (0.1)	The impacts of noise produced by seismic surveys on ichthyoplankton are species-dependent and influenced by the distance the individual is from the source. Seismic blasts within 5 metres have been shown to damage shellfish eggs and larvae (Dalen et al., 2007; Payne, 2004), but have no impact to quantity or quality of spiny lobster larvae in the wild (Day et al. 2016b). Larval snow crabs experience slower development rates and higher mortality or abnormalities when exposed to seismic blasts (Christian et al. 2003). Similarly, scallop larvae exposed to playbacks of seismic pulses experienced significant developmental delays and 46% of the brood developed body abnormalities (de Soto et al. 2013). Lastly, experimental seismic air gun sounds in-situ led to a two- to threefold increase in dead zooplankton, within which ichthyoplankton are classified, in a 1.2 km range of the blast (McCauley et al. 2017). Although these studies show evidence of a loss of fitness, it is unclear if seismic surveys lead to recruitment declines that impact species at a population level. Carroll et al. (2017) suggests that some fish whose larvae lose swim-bladders with maturity (e.g., flounders, cod, flatfish) are more vulnerable in early life stages to noise versus later in life. Although there is a threat of mortality and injury to ichthyoplankton due to seismic surveys, the proximity to seismic blasts that can cause this level of damage is unlikely. Therefore, the impacts are not expected to have local population level effects.
Recovery Lag	Moderate	RL = Persistence & Resilience
Persistence	Low	Noise pressure dissipates instantly after noise omitting activities conclude.

Resilience	Moderate	COSEWIC status varies across this group as it is composed of various species with different life histories. Early life history stage is highly vulnerable.
Overall Risk	Low	If an interaction occurs involving ichthyoplankton and noise due to seismic surveys, the consequences could result in behavioural changes and potential injuries. **The risk is tolerable.**
Uncertainty	High uncertainty	There is limited and conflicting literature on the impacts of seismic surveys on ichthyoplankton. Generally, there are few studies published that use in-situ methods and limited literature focused on North America.

Risk Assessment – Seismic Survey Noise and Benthic Invertebrates

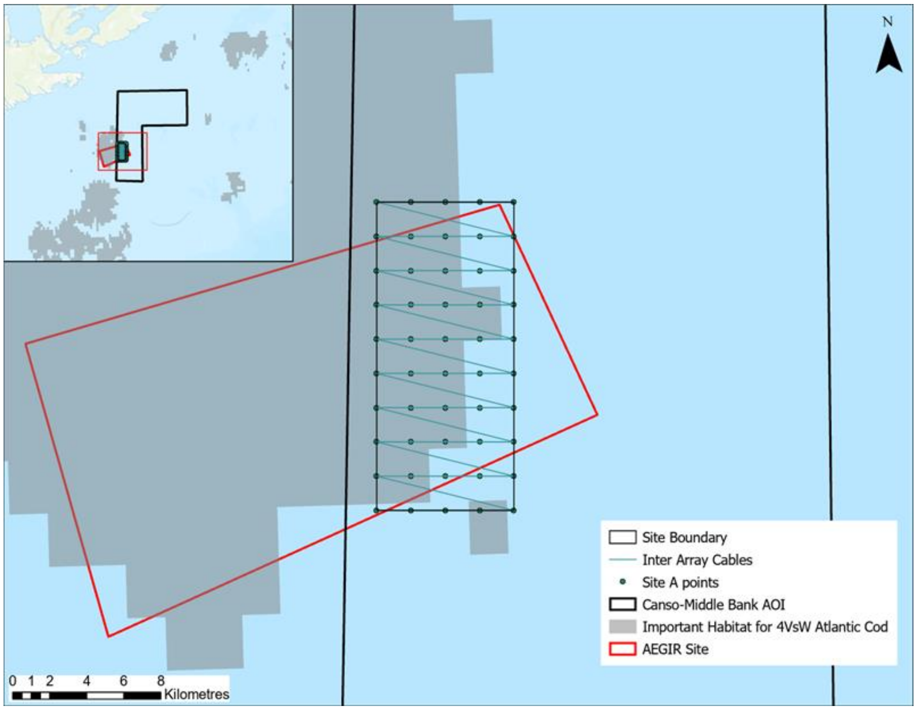

Figure 5.1.2 Seismic survey noise overlap with benthic invertebrates within the AOI.

Risk statement: If an interaction occurs involving benthic invertebrates and noise (underwater and other) due to seismic testing, the consequence could result in impaired foraging and predator evasion behaviours (Hutchison et al. 2020, Solé et al. 2023).

Table 5.1.2 Scoring for the risk posed by seismic survey noise to benthic invertebrates within the AOI.

Risk factor	Score	Rationale
Impact Risk	Low (binned)	IR = Spatial x Temporal x Severity = 0.03 x 0.08 x 0.01 = 0.00024
Spatial	Site (0.03)	Overlap = 100*(Area of benthic invertebrate layer that overlaps with windfarm site/ Area of benthic invertebrate within AOI) = 3.00% The activity will cover the entire offshore wind farm site to map locations for construction. The activity overlaps with 3.00% of the area occupied by the conservation priority in the AOI.
Temporal	Rare (0.08)	Seismic testing consists of loud blasts every 10 seconds for less than a month.
Severity	Moderate (0.1)	Seismic surveys impact benthic invertebrates differently by species and distance from noise blasts. For bivalves, larvae have been shown to be damaged or experience mortality when proximal to sound blasts (Christian et al., 2003; Dalen et al., 2007; Day et al., 2016b; de Soto et al., 2013; Payne, 2004). Further, adult scallops in field experiments experienced increased mortality and abnormal reflexes, suggesting damage to mechanosensory organs (Day et al., 2016a, 2017). Decapod crustaceans exposed to seismic sounds exhibited alarm behaviour responses which increases individual energy expenditure (Goodall et al. 1990, Christian et al. 2003). Lobster (*Homarus americanus*) exposed to both high and low seismic sound levels experienced no damage to mechanosensory systems associated with animal equilibrium, or a delayed mortality events, but lobsters did increase food intake after (Payne et al., 2007, 2008). Contrarily, exposed snow crabs experienced bruised ovaries, and injuries to the equilibrium receptor system (DFO 2004). Another study on adult snow crab found bruising of the hepatopancreas and ovaries, causing the eggs of a female exposed to produce larva smaller than controls (Christian et al. 2004). Although there are physiological and behavioural changes to snow crabs, these effects did not impact the catch rate of snow crabs after seismic surveys, suggesting that noise does not impact at a population level (Morris et al. 2018).
Recovery Lag	Low (binned)	RL = Persistence & Resilience
Persistence	Low	Noise pressure dissipates instantly after noise omitting activities conclude.
Resilience	High	Various life stages are impacted, some invertebrates are slow maturing, like snow crabs, and others that are not like lobsters, sand

		dollars, and bivalves (Silva et al. 2012, MacLean et al. 2013, DFO 2022). Generally, highly fecund with success varying by species.
Overall Risk	Low	If an interaction occurs involving benthic invertebrates and noise due to seismic surveys, the consequences could result in minor behavioural changes. **The risk is acceptable.**
Uncertainty	High	Limited peer-reviewed literature on adults and limited understanding of seismic noise impacts overall. Can identify a common theme of a stress response, physiological or behavioural, but there are few details on species native to the area of study. Further, a challenge is that many studies are performed in lab rather than in situ. Largely identified gap in the literature (Mooney et al. 2020, Solé et al. 2023).

Risk Assessment – Seismic Survey Noise and Atlantic Cod

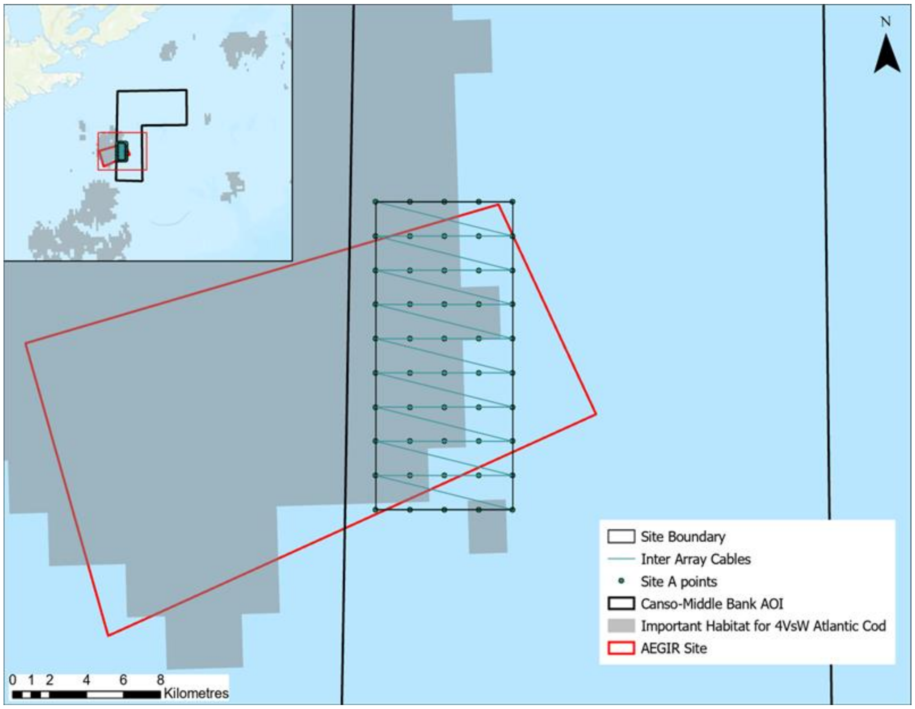

Figure 5.1.3 Seismic survey noise overlap with Atlantic cod within the AOI.

Risk statement: If an interaction occurs involving Atlantic cod and noise (underwater and other) due to seismic testing, the consequence could result in hearing loss, impaired foraging and predator responses, and swim bladder injuries (Popper and Hastings 2009, Bailey et al. 2014, Thomsen et al. 2015, Hawkins et al. 2015, 2020).

Table 5.1.3 Scoring for the risk posed by seismic survey noise to Atlantic cod within the AOI.

Risk factor	Score	Rationale
Impact Risk	Low (binned)	IR = Spatial x Temporal x Severity = 0.37 x 0.08 x 0.01 = 0.000296
Spatial	Local (0.37)	Overlap = 100*(Area of Atlantic cod layer that overlaps with windfarm site/ Area of Atlantic cod within AOI) = 26.9% The activity will cover the entire offshore wind farm site to map locations for construction. The activity overlaps with 26.9% of the area occupied by the conservation priority in the AOI.
Temporal	Rare (0.08)	Seismic testing consists of loud blasts every 10 seconds for less than a month.
Severity	Low (0.01)	Noise blasts from seismic surveys elicit physical and behavioural responses in Atlantic cod. Novel sound blasts can alter heart rates of cod, change swimming direction and depth, and trigger predatory evasion responses in adults and larvae (Nedelec et al. 2015, Davidsen et al. 2019). However, adults habituate physiologically and behaviourally with repeated exposure. The startled larvae use yolk reserves which can result in a lower width-length ratio, limiting motility and lowering survivorship of the larvae (Fuiman and Magurran 1994). Researchers have identified that noise of seismic surveys overlap with cod communication ranges used for breeding (Codarin et al. 2009), but it has not been found to substantially alter cod behaviour during the spawning period (McQueen et al. 2023). Anthropogenic noise in general could increase energy expenditure and indirectly affect the age of maturity, survival, and fecundity of cod (Soudijn et al. 2020). Overall, the literature suggests potential for injury in close range, severity is assigned across the entire impacted area opposed to few in immediate proximity and is therefore low. The most likely impacts are behavioural and will not have population level impacts.
Recovery Lag	High (binned)	RL = Persistence & Resilience
Persistence	Low	Noise pressure dissipates instantly after noise omitting activities conclude.
Resilience	None	This species is endangered, a critical stock, with a low natural mortality used in assessments, noise impacts all stages, and the crossbreeding of populations is unlikely (COSEWIC 2010).
Overall Risk	Moderate	If an interaction occurs involving groundfish and noise due to seismic surveys, the consequences could result in behavioural changes. **The risk may be tolerable.**
Uncertainty	Moderate	Science-based evidence available is limited and requires updating or validation for specific locations.

Risk Assessment – Seismic Survey Noise and Blue Whales

Risk statement: If an interaction occurs involving blue whales and noise (underwater and other) due to seismic testing, the consequence could result in the masking of baleen whale calls, auditory injury, increased stress levels and avoidance of critical habitat (Madsen et al. 2006, Wilson et al. 2010, Bailey et al. 2014, Slabbekoorn et al. 2018, CSA Ocean Sciences Inc 2021).

Table 5.1.4 Scoring for the risk posed by seismic survey noise to blue whales within the AOI.

Risk factor	Score	Rationale
Impact Risk	Low (binned)	IR = Spatial x Temporal x Severity = 0.37 x 0.08 x 0.01 = 0.000296
Spatial	Local (0.37)	The activity overlaps with 10.00% of the hypothetical area occupied by the conservation priority.
Temporal	Rare (0.08)	Seismic testing consists of loud blasts every 10 seconds or so for weeks to months at a time.
Severity	Low (0.01)	Seismic surveys emit sound blasts below vessels which can interfere with blue whale communication and cause behavioural changes. The noise from seismic surveys is of a similar frequency of vocalizations, leading to disruption of communication (Thomas et al. 2016). Thomas et al. (2016) found that distant seismic survey activity increases background noise to levels that could potentially reduce blue whales' ability to communicate by 29-40%. As a result, blue whales can try to compensate by calling more frequently (Di Iorio and Clark 2010), or vacating the area causing displacement from potentially important breeding and feeding habitats (Castellote and Llorens 2016, Kavanagh et al. 2019). Although behavioural changes could potentially impact breeding, the magnitude of impact is unclear and is thought not to interfere at a population level.
Recovery Lag	High (binned)	RL = Persistence & Resilience
Persistence	Low	Noise pressure dissipates instantly after noise omitting activities conclude.
Resilience	None	Blue Whales are endangered, low reproduction, late maturity, impacts all stages of life history (Beauchamp et al. 2009).
Overall Risk	Moderate	If an interaction occurs involving blue whales and noise due to seismic surveys, the consequence could result in behavioural changes and **the risk may be tolerable.**
Uncertainty	Moderate	The moderate uncertainty score reflects that there is literature exploring impacts to cetaceans and other baleen whales available

		but few focus specifically on blue whales. Further, local validation is required.

5.2 Foundation Installation

5.2.1 Abrasion/damage

Risk Assessment – Foundation Installation Abrasion/damage and Benthic Invertebrates

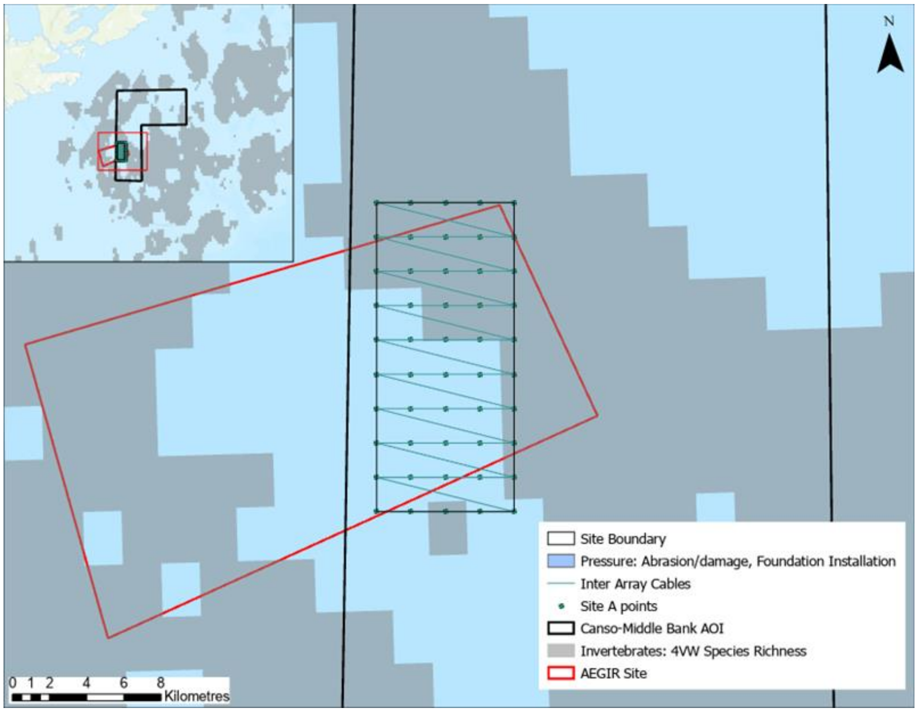

Figure 5.2.1 Foundation installation abrasion/damage overlap with benthic invertebrates within the AOI.

Risk statement: If an interaction occurs involving benthic invertebrates and abrasion/damage due to foundation installation the consequences could result in damage or destruction of sand dollar beds, and injury or death by crushing of bivalves and crustaceans (Petersen and Malm 2006, Bernier et al. 2018, Rosellon-Druker and Stokesbury 2019, Bureau of Ocean Energy Management Office of Renewable Energy Programs 2022).

Table 5.2.1 Scoring for the risk posed by foundation installation abrasion/damage to benthic invertebrates within the AOI.

Risk factor	Score	Rationale
Impact Risk	Moderately High (binned)	IR = Spatial x Temporal x Severity = 0.03 x 1 x 0.1 = 0.003
Spatial	Site (0.03)	Overlap = 100*(Area of benthic invertebrates that overlaps in a 12m radius from the base / Area of benthic invertebrate layer within AOI) = 0.000615% The activity overlaps with 0.000615% of the area occupied by the conservation priority in the AOI (Bureau of Ocean Energy Management Office of Renewable Energy Programs 2018).
Temporal	Frequent (1)	Piling one monopile typically lasts 1.5–4.5 h, depending on the density of the sediment (Lacal-Arántegui et al. 2018, van der Knaap et al. 2022). Total turbine installation time takes 5.9 days. There will be 50 turbines, therefore it can be assumed 300 workdays.
Severity	Moderate (0.1)	Although no studies have specifically investigated the damage of fixed foundation construction on benthic invertebrates, research from other industries suggest potential injury and mortality, mainly to sessile species. Studies investigating fisheries have found that crabs, sand dollars, and other sessile benthic dwelling invertebrates are vulnerable to crushing during harvest, potentially making them vulnerable to crushing during foundation construction (Jenkins et al. 2001, MacLean et al. 2013, Bernier et al. 2018, Rosellon-Druker and Stokesbury 2019, Bureau of Ocean Energy Management Office of Renewable Energy Programs 2022). Overall, the localized pressure of abrasion/damage is not likely to have local population impacts.
Recovery Lag	Moderate (binned)	RL = Persistence & Resilience
Persistence	Low	Pressure dissipates once the activity has concluded.
Resilience	Moderate	Various life stages are impacted, some invertebrates are slow maturing, like snow crabs, and others that are not like lobsters, sand dollars, and bivalves (Silva et al. 2012, MacLean et al. 2013, DFO 2022). Generally, highly fecund with success varying by species. Studies have shown that benthic communities can rebound within 1-10 years depending on the ecosystem (Taormina et al. 2018, Copping et al. 2021).
Overall Risk	Moderate	If an interaction occurs involving benthic invertebrates and abrasion/damage due to foundation installation, the consequences could result in minimal injury or mortality. **The risk may be tolerable**

Uncertainty	High	No peer-reviewed literature available on this topic, so had to extrapolate from other damaging benthic activities.

5.2.2 Noise (underwater or other)

Risk Assessment – Foundation Installation Noise and Ichthyoplankton

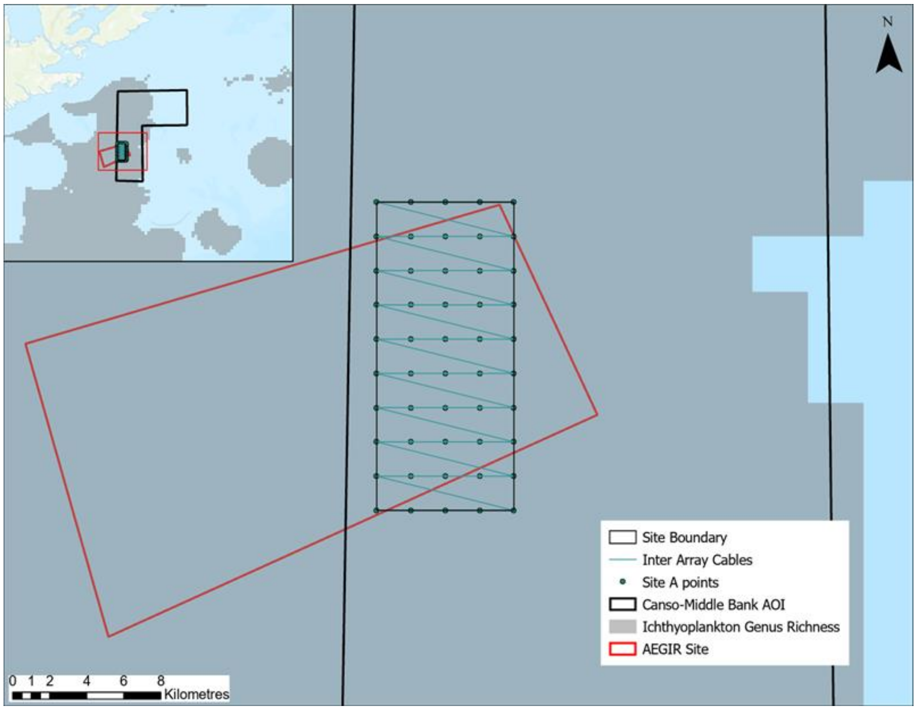

Figure 5.2.2 Foundation installation noise overlap with ichthyoplankton within the AOI.

Risk statement: If an interaction occurs involving ichthyoplankton and noise (underwater and other) due to foundation installation, the consequence could result in a change in larval settling behaviours (Wilkens et al. 2012, Pine et al. 2012, Jolivet et al. 2016, Anderson et al. 2021).

Table 5.2.2 Scoring for the risk posed by foundation installation noise to ichthyoplankton within the AOI.

Risk factor	Score	Rationale
Impact Risk	Moderate (binned)	IR = Spatial x Temporal x Severity = 0.03 x 1 x 0.01 = 0.0003
Spatial	Site (0.03)	Overlap = 100*(Area of ichthyoplankton layer that overlaps with windfarm site/ Area of ichthyoplankton within AOI)

		= 3.1% The activity overlaps with 3.1% of the area that the CP occupies in the AOI.
Temporal	Frequent (1)	Piling one monopile typically lasts 1.5–4.5 h, depending on the density of the sediment (Lacal-Arántegui et al. 2018, van der Knaap et al. 2022). Total turbine installation time takes 5.9 days. There will be 50 turbines, therefore it can be assumed 300 workdays.
Severity	Low (0.01)	The impacts of noise due to foundation installation, more specifically pile-driving, are dependent on species, ranging from no impact to behavioural changes. Generally, finfish larvae such as sole, European sea bass, and herring larvae were found to have no significant impact resulting from noise generated by pile driving (Bolle et al. 2012, 2016). A different study found that pile-driving noise impairs the predatory escape response of seabass larvae, increasing the likelihood of capture compared to natural conditions (Cervello et al. 2023), which has been suggested broadly as an impact of acute noise on finfish larvae (Nedelec et al. 2015). Invertebrate larvae rely on acoustic cues to settle out of the water column, and it has been found that pile-driving enhanced larval recruitment of blue mussels and great scallops (Cervello et al. 2023, Gigot et al. 2023). It is unclear if this is a positive or negative impact and is likely dependent on ideal substrate availability in proximity to the noise. Further, the impact to local populations is unclear, with potential for competition to increase, however this is unlikely.
Recovery Lag	Moderate	RL = Persistence & Resilience
Persistence	Low	Noise pressure dissipates instantly after noise omitting activities conclude.
Resilience	Moderate	COSEWIC status varies across this group as it is composed of various species with different life histories. Early life history stage is highly vulnerable.
Overall Risk	Moderate	If an interaction occurs involving foundation installation and ichthyoplankton, the consequences could result in behavioural changes and **the risk may tolerable.**
Uncertainty	High	Limited and conflicting literature. The novel field has limited studies, with the majority in laboratory settings.

Risk Assessment – Foundation Installation Noise and Benthic Invertebrates

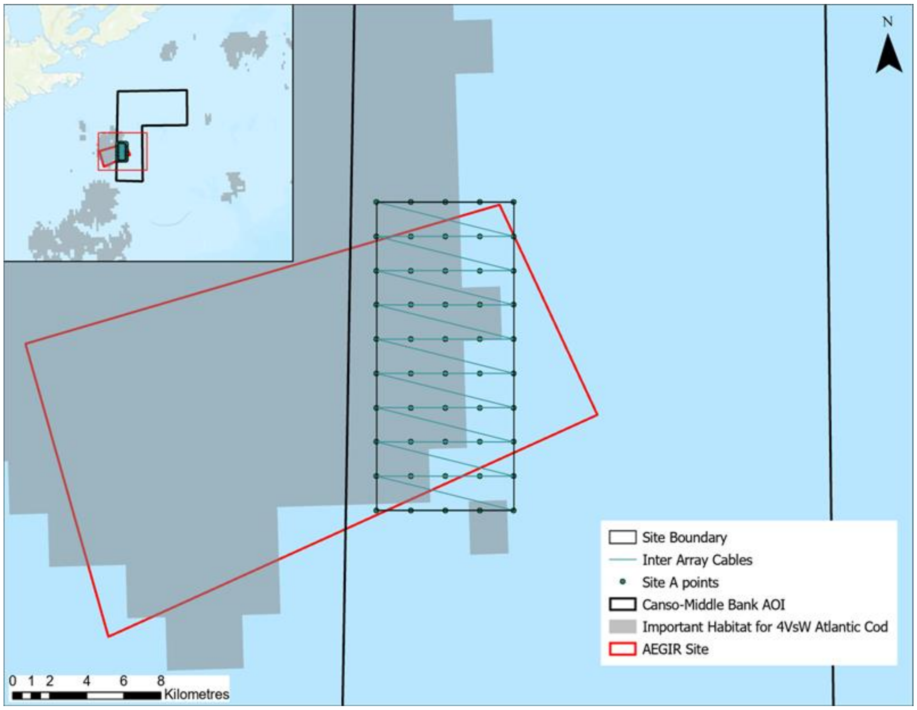

Figure 5.2.3 Foundation installation noise overlap with benthic invertebrates within the AOI.

Risk statement: If an interaction occurs involving benthic invertebrates and noise (underwater and other) due to foundation installation, the consequence could result in bivalves increasing or decreasing filtration as a stress response and behaviour changes in decapods (Wale et al. 2013, Roberts et al. 2015, Spiga et al. 2016, Popper and Hawkins 2018, Jézéquel et al. 2022).

Table 5.2.3 Scoring for the risk posed by foundation installation noise to benthic invertebrates within the AOI.

Risk factor	Score	Rationale
Impact Risk	Moderate (binned)	IR = Spatial x Temporal x Severity = 0.03 x 1 x 0.01 = 0.0003
Spatial	Site (0.03)	Overlap = 100*(Area of benthic invertebrate layer that overlaps with windfarm site/ Area of benthic invertebrate within AOI) = 3.00% The activity overlaps with 3.00% of the area occupied by the conservation priority in the AOI.
Temporal	Frequent (1)	Piling one monopile typically lasts 1.5–4.5 h, depending on the density of the sediment (Lacal-Arántegui et al. 2018, van der

		Knaap et al. 2022). Total turbine installation time takes 5.9 days. There will be 50 turbines, therefore it can be assumed 300 workdays.
Severity	Moderate (0.1)	Noise emitted from foundation installation has various impacts to both adult and juvenile bivalves and crustaceans. Bivalves like blue mussels and giant scallops experience physiological stress responses to pile-driving like increasing clearance rate and valve movement and increased valve closure (Spiga et al. 2016, Jézéquel et al. 2022). In larvae, it causes local recruitment of blue mussels to increase by 22% as noise triggers settlement (Cervello et al. 2023), and it triggers growth and metamorphosis in scallops (Gigot et al. 2023). Further, crustaceans experience stress responses and behavioural changes. Norwegian lobsters experience adult mortality, larval mortality, and physiological delays to larval development and swimming behaviour in juveniles during pile-driving depending on proximity to the source (Stenton et al. 2022). Lastly, noise negatively impacts hermit crab searching behaviour, hindering their ability acquire necessary resources like shells (Roberts and Laidre 2019), but will overall unlikely impact the local population of invertebrates in the AOI.
Recovery Lag	Low (binned)	RL = Persistence & Resilience
Persistence	Low	Noise pressure dissipates instantly after noise omitting activities conclude.
Resilience	High	Various life stages are impacted, some invertebrates are slow maturing, like snow crabs, and others that are not like lobsters, sand dollars, and bivalves (Silva et al. 2012, MacLean et al. 2013, DFO 2022). Generally, highly fecund with success varying by species.
Overall Risk	Moderate	If an interaction occurs involving benthic invertebrates and noise due to foundation installation, the consequences could result in minor behavioural and physical changes and **the risk may be tolerable.**
Uncertainty	High	Majority of studies occur in environments different than in the study area and majority in a laboratory setting versus in-situ. Further, scholars emphasize impacts of noise on benthic invertebrates for OSW are poorly understood (Mooney et al., 2020; Solé et al., 2023).

Risk Assessment – Foundation Installation Noise and Atlantic Cod

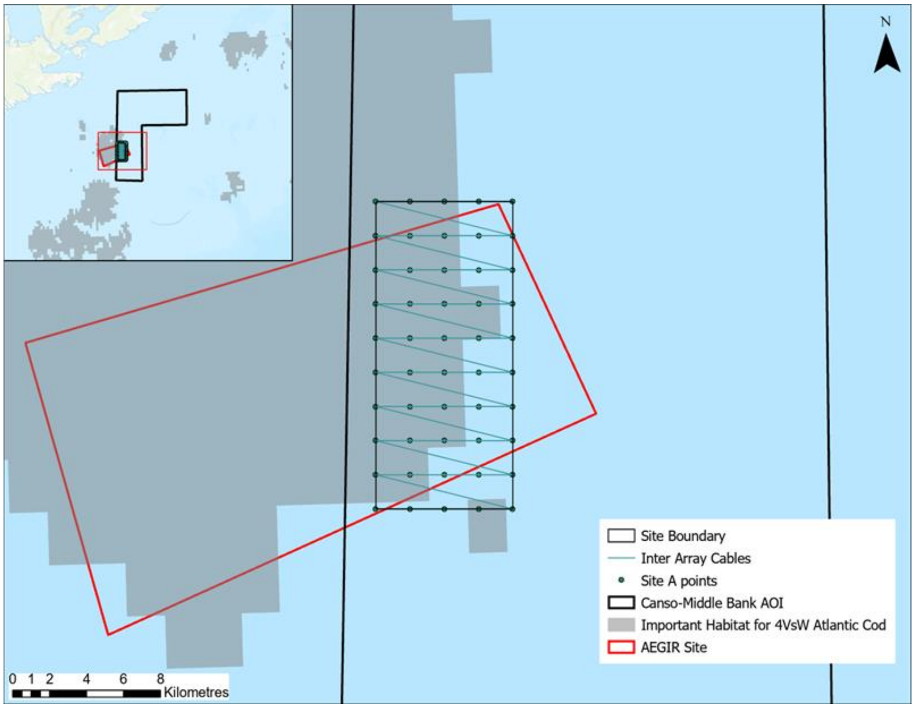

Figure 5.2.4 Foundation installation noise overlap with Atlantic cod within the AOI.

Risk statement: If an interaction occurs involving Atlantic cod and noise (underwater and other) due to foundation installation, the consequence could result in hearing loss, impaired foraging and predator responses, and disruptions to intraspecies communication (Bailey et al., 2014; Popper & Hastings, 2009; Siddagangaiah et al., 2022; Thomsen et al., 2015).

Table 5.2.4 Scoring for the risk posed by foundation installation noise to Atlantic cod within the AOI.

Risk factor	Score	Rationale
Impact Risk	Moderate (binned)	IR = Spatial x Temporal x Severity = 0.37 x 1 x 0.01 = 0.0037
Spatial	Local (0.37)	Overlap = 100*(Area of Atlantic cod layer that overlaps with windfarm site/ Area of Atlantic cod within AOI) = 26.9% The activity overlaps with 26.9% of the area occupied by the conservation priority in the AOI.
Temporal	Frequent (1)	Piling one monopile typically lasts 1.5–4.5 h, depending on the density of the sediment (Lacal-Arántegui et al. 2018, van der

		Knaap et al. 2022). Total turbine installation time takes 5.9 days. There will be 50 turbines, therefore it can be assumed 300 workdays.
Severity	Low (0.01)	Pile-driving to install foundations could have physiological and behavioural impacts on Atlantic cod which vary with life stage. Larvae expend greater energy as noise elicits a startle response, leading to increased yolk consumption, resulting in a lower width-length ratio (Nedelec et al. 2015). It is hypothesized that it makes the larvae weaker and more vulnerable to predation. Depending on proximity to the protrusion, the swim bladder of juvenile and adult cod could rupture or bruise (CSA Ocean Sciences Inc, 2021; Hernandez et al., 2021; Popper & Hastings, 2009). Furthermore, behaviourally, noise can elicit startle responses or cause cod to seek shelter which could change energy expenditure of the fish, impacting growth rate, maturity and fecundity (Soudijn et al. 2020). Although there are impacts to cod during foundation installation, it does not substantially alter habitat ranges (van der Knaap et al. 2022), and there is no evidence of mortality with fish returning to the wind farm site after installation has concluded (Lindeboom et al. 2011, Bergström et al. 2013, Reubens et al. 2014, van Hal et al. 2017, Degraer et al. 2018, 2020, Hutchison et al. 2020, Wilber et al. 2022). Therefore, it is unlikely that noise from foundation installation will have local population effects.
Recovery Lag	High (binned)	RL = Persistence & Resilience
Persistence	Low	Noise pressure dissipates instantly after noise omitting activities conclude.
Resilience	None	This species is endangered, a critical stock, with a low natural mortality used in assessments, noise impacts all stages, and the crossbreeding of populations is unlikely (COSEWIC 2010).
Overall Risk	Moderate	If an interaction occurs involving groundfish and noise due to seismic surveys, the consequences could result in behavioural changes and **the risk may be tolerable.**
Uncertainty	Moderate	The effects of noise from construction are well researched and documented in the literature. Majority of studies in Europe, limited knowledge on impacts of particle motion.

Risk Assessment – Foundation Installation Noise and Blue Whale

Risk statement: If an interaction occurs involving cetaceans and noise (underwater and other) due to foundation installation, the consequence could result in temporary displacement and auditory injury (Madsen et al. 2006, Bailey et al. 2014, Mooney et al. 2020, CSA Ocean Sciences Inc 2021).

Table 5.2.5 Scoring for the risk posed by foundation installation noise to blue whales in the AOI.

Risk factor	Score	Rationale
Impact Risk	Moderate (binned)	IR = Spatial x Temporal x Severity = 0.37 x 1 x 0.01 = 0.0037
Spatial	Local (0.37)	The activity overlaps with 10.00% of the hypothetical area occupied by the conservation priority.
Temporal	Frequent (1)	Piling one monopile typically lasts 1.5–4.5 h, depending on the density of the sediment (Lacal-Arántegui et al. 2018, van der Knaap et al. 2022). Total turbine installation time takes 5.9 days. There will be 50 turbines, therefore it can be assumed 300 workdays.
Severity	Low (0.01)	Foundation installation, specifically pile-driving, produces a repetitive low frequency sound that overlaps with blue whale communication (Madsen et al. 2006, Bailey et al. 2014). Pile-driving is hypothesized to be the underwater noise source with the worst impacts to baleen whales due to the low frequency, making them more vulnerable than other cetaceans (Madsen et al. 2006, Thomsen et al. 2015). Depending on distance from the source, there is potential the noise could cause hearing damage or loss, but this is yet to be studied and is inconclusive (Theriault and Moors-Murphy 2015). Overall, there is potential that pile-driving noise could mask communication and potentially damage the hearing of blue whales. Like seismic surveys, the avoidance of noise could result in a loss of food and breeding habitat, but it is unlikely this will occur at a scale that has population effects.
Recovery Lag	High (binned)	RL = Persistence & Resilience
Persistence	Low	Noise pressure dissipates instantly after noise omitting activities conclude.
Resilience	None	Blue Whales are endangered, low reproduction, late maturity, impacts all stages of life history (Beauchamp et al. 2009).
Overall Risk	Moderate	If an interaction occurs involving blue whales and noise due to foundation installation, the consequences could result in behavioural changes and injury and **the risk could be tolerable.**
Uncertainty	Moderate	Limited data available. Science-based evidence requires updating and validation for location and for species.

5.2.3 *Changes in Siltation*

Risk Assessment – Foundation Installation Changes in Siltation and Benthic Invertebrates

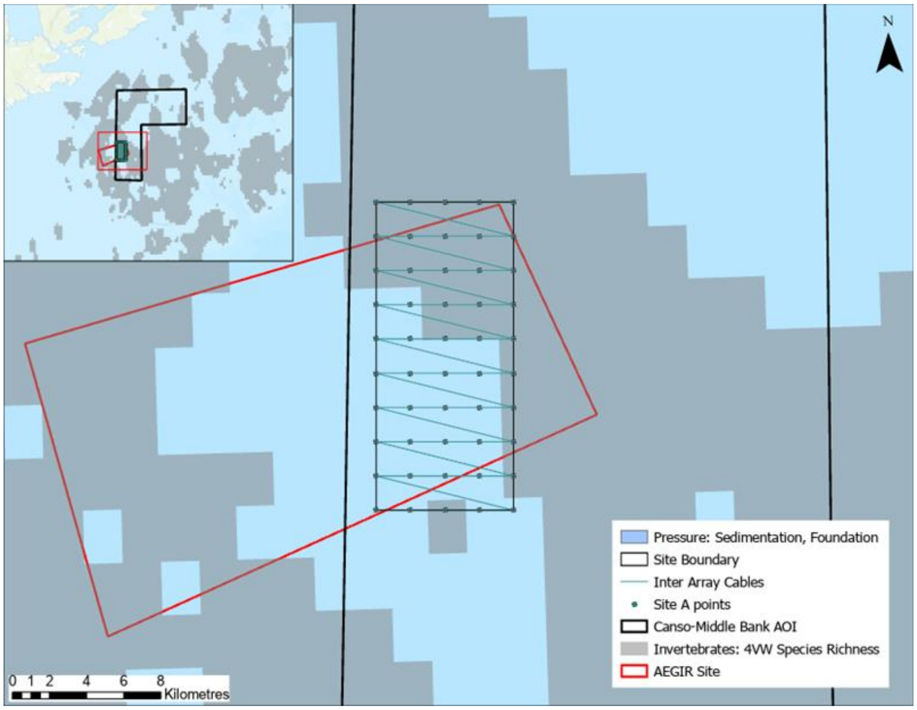

Figure 5.2.5 Foundation installation changes in siltation overlap with benthic invertebrates within the AOI.

Risk statement: If an interaction occurs involving benthic invertebrates and changes in siltation due to foundation installation, the consequences could result in reduced oxygen consumption, complete burial, or limited vision (Bernier et al., 2018; Bureau of Ocean Energy Management Office of Renewable Energy Programs, 2022; Wilber & Clarke, 2001).

Table 5.2.6 Scoring for the risk posed by foundation installation changes in siltation to benthic invertebrates in the AOI.

Risk factor	Score	Rationale
Impact Risk	Moderate (binned)	IR = Spatial x Temporal x Severity = 0.03 x 1 x 0.01 = 0.0003
Spatial	Site (0.03)	Overlap = 100*(Area of benthic invertebrates that overlaps in a 91m buffer around foundation (NOAA 2023)/ Area of benthic invertebrate layer within AOI)

		= 0.0285% The activity overlaps with 0.0285% of the area occupied by the conservation priority in the AOI.
Temporal	Frequent (1)	Piling one monopile typically lasts 1.5–4.5 h, depending on the density of the sediment (Lacal-Arántegui et al. 2018, van der Knaap et al. 2022). Total turbine installation time takes 5.9 days. There will be 50 turbines, therefore it can be assumed 300 workdays.
Severity	Moderate (0.1)	Changes in siltation can result in behavioural and physiological changes to benthic invertebrates. Mobile species of benthic invertebrates are likely to avoid deposition areas and gills can become damaged by resuspension of sediments in the water column (Messieh et al. 1991, Bureau of Ocean Energy Management Office of Renewable Energy Programs 2022). Sessile species are more vulnerable to turbidity and sedimentation as sediment plumes can result in reduced fitness or mortality (Wilber and Clarke 2010, Berry et al. 2011). In general, bivalves experience reduced feeding and reparatory rates from deposition (Wilber and Clarke 2010). While sessile species can handle some degree of sediment deposition due to naturally occurring turbidity on the seafloor, the impacts during pile driving are greater and could smother these species causing mortality at depths greater than 20 millimeters (Messieh et al. 1991, Epsilon 2020). Overall, the foundation installation could cause behavioural changes and major physiological damage to benthic invertebrates, but it is unlikely to occur at a level that will impact the local population.
Recovery Lag	Low (binned)	RL = Persistence & Resilience
Persistence	Low	Sediment changes last from minutes to hours, dissipating shortly after activities conclude or foundations are removed.
Resilience	High	Various life stages are impacted, some invertebrates are slow maturing, like snow crabs, and others that are not like lobsters, sand dollars, and bivalves (Silva et al. 2012, MacLean et al. 2013, DFO 2022). Generally, highly fecund with success varying by species.
Overall Risk	Moderate	If an interaction occurs involving benthic invertebrates and changes in siltation due to foundation installation, the consequences could result in behavioural changes, injury, and mortality. **The risk may be tolerable**.
Uncertainty	Moderate	Changes in siltation are relatively well understood but data is incomplete and limited in the study area.

Risk Assessment – Foundation Installation Changes to Siltation and Atlantic Cod

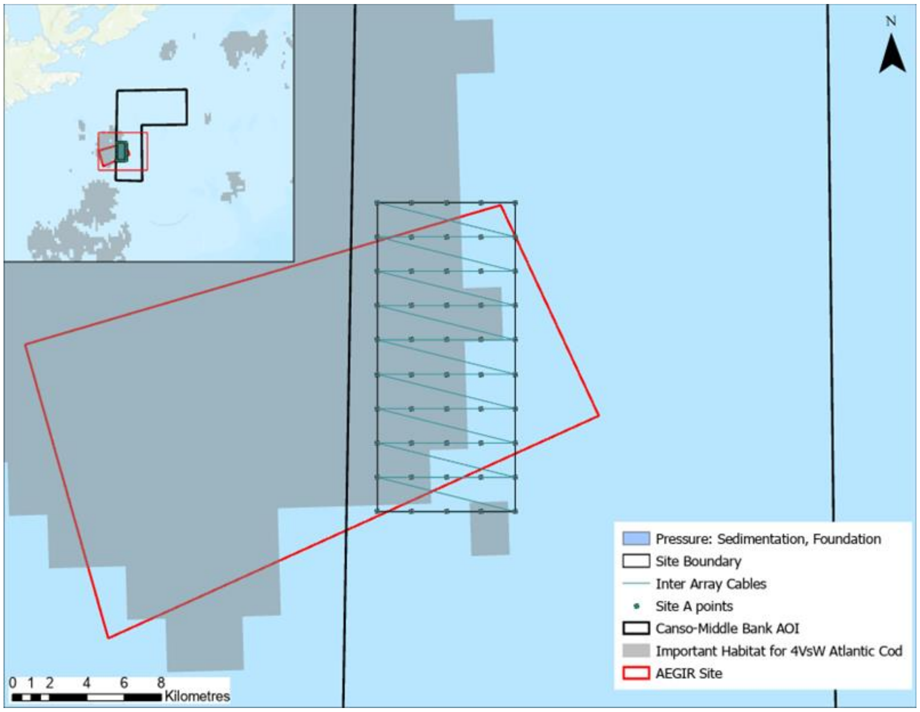

Figure 5.2.6 Foundation installation changes to siltation overlap with Atlantic cod within the AOI.

Risk statement: If an interaction occurs involving Atlantic cod and changes in siltation due to foundation installation, the consequence could result in a greater vulnerability to predation, a reduction in feeding, or the avoidance of habitat potentially resulting in higher energetic costs (Bureau of Ocean Energy Management Office of Renewable Energy Programs, 2018).

Table 5.2.7 Scoring for the risk posed by foundation installation changes in siltation to Atlantic cod in the AOI.

Risk factor	Score	Rationale
Impact Risk	Moderate (binned)	IR = Spatial x Temporal x Severity = 0.37 x 1 x 0.01 = 0.0037
Spatial	Local (0.37)	Overlap = 100*(Area of Atlantic cod that overlaps in a 91m buffer around foundation (NOAA 2023)/ Area of Atlantic cod layer within AOI) = 0.285%

		The activity overlaps with 0.285% of the area occupied by the conservation priority in the AOI.
Temporal	Frequent (1)	Piling one monopile typically lasts 1.5–4.5 h, depending on the density of the sediment (Lacal-Arántegui et al. 2018, van der Knaap et al. 2022). Total turbine installation time takes 5.9 days. There will be 50 turbines, therefore it can be assumed 300 workdays.
Severity	Low (0.01)	The impacts siltation to Atlantic cod due to foundation installation could result in behavioural changes. Turbidity is known to displace mobile juvenile and adult finfish during dredging and pile-driving (Utne-Palm 2002, Bureau of Ocean Energy Management Office of Renewable Energy Programs 2022). Turbidity can cause fish to become more vulnerable to predation and reduce prey availability, resulting in a greater energetic demand. In general, siltation changes will cause Atlantic cod to undergo sublethal stress as they are able to move away from the area (Kjelland et al. 2015). Overall, behavioural changes are not expected to have population level impacts.
Recovery Lag	High (binned)	RL = Persistence & Resilience
Persistence	Low	Sediment changes last from minutes to hours, dissipating shortly after activities conclude or foundations are removed.
Resilience	None	This species is endangered, a critical stock, with a low natural mortality used in assessments, noise impacts all stages, and the crossbreeding of populations is unlikely (COSEWIC 2010).
Overall Risk	Moderate	If an interaction occurs involving Atlantic cod and changes in siltation due to foundation installation, the consequences could result in behavioural changes. **The risk may be tolerable**.
Uncertainty	High	There are very few studies that investigate the impacts of sedimentation to Atlantic cod, necessitating extrapolation of potential impacts to adults from other studies on visual finfish. Further, data should be verified for the area of study.

5.3 Cable Installation

5.3.1 Abrasion/damage

Risk Assessment – Cable Installation Abrasion/damage and Benthic Invertebrates

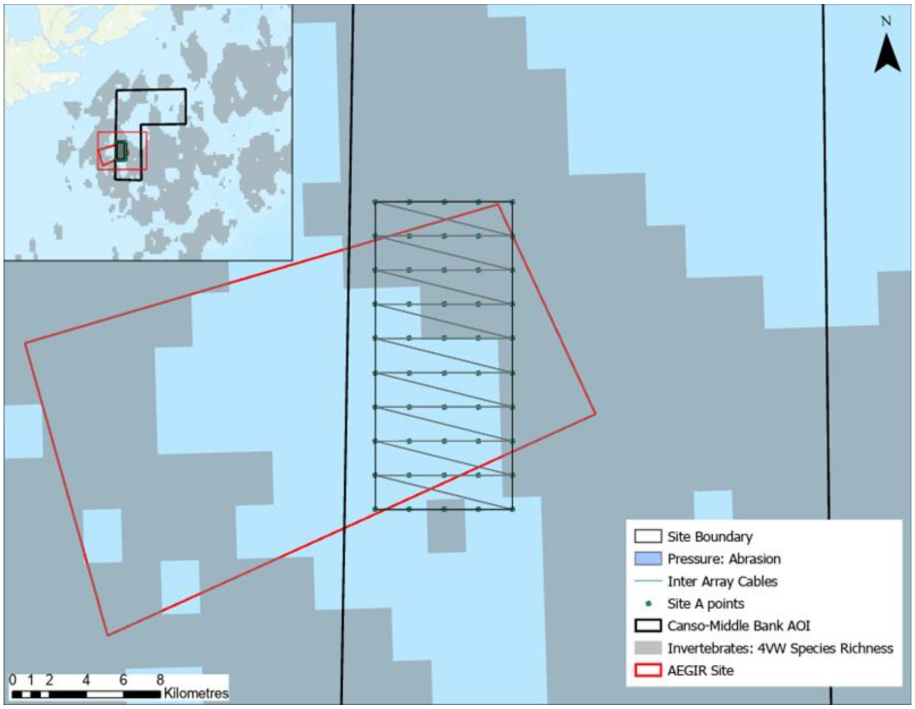

Figure 5.3.1 Cable installation abrasion/damage overlap with benthic invertebrates within the AOI.

Risk statement: If an interaction occurs involving benthic invertebrates and abrasion/damage due to cable installation the consequences could result in damage or destruction of sand dollar beds, and injury or death by crushing of bivalves and crustaceans (Bernier et al. 2018, Bureau of Ocean Energy Management Office of Renewable Energy Programs 2022).

Table 5.3.1 Scoring for the risk posed by cable installation abrasion/damage to benthic invertebrates in the AOI.

Risk factor	Score	Rationale
Impact Risk	Moderately High (binned)	IR = Spatial x Temporal x Severity = 0.03 x 1 x 0.1 = 0.003

Spatial	Site (0.03)	Overlap = 100*(Area of benthic invertebrates that overlaps in a 2m buffer around inter array cables (Vineyard Wind 2022)/ Area of benthic invertebrate layer within AOI) = 0.0465% The activity overlaps with 0.0465% of the area occupied by the conservation priority in the AOI.
Temporal	Frequent (1)	Assume dredging and cable laying to take 8 months to a year based on BOEM approved projects.
Severity	Moderate (0.1)	Submarine cables at windfarms are buried in the seafloor. This is done by dragging heavy objects along the seafloor to clear obstructions from the route for trenching and cable insertion. Direct impacts of cable installation are damage or crushing of sessile benthic organisms (Dunham et al. 2015, Taormina et al. 2018). Studies investigating fisheries have found that crabs, sand dollars, and other sessile benthic dwelling invertebrates are vulnerable to crushing during harvest, potentially making them vulnerable to crushing during cable installation (Jenkins et al. 2001, MacLean et al. 2013, Bernier et al. 2018, Rosellon-Druker and Stokesbury 2019, Bureau of Ocean Energy Management Office of Renewable Energy Programs 2022). Across the AOI, burial damage is likely to not impact benthic invertebrates at a population level.
Recovery Lag	Moderate (binned)	RL = Persistence & Resilience
Persistence	Low	Pressure dissipates once the activity has concluded.
Resilience	Moderate	Various life stages are impacted, some invertebrates are slow maturing, like snow crabs, and others that are not like lobsters, sand dollars, and bivalves (Silva et al. 2012, MacLean et al. 2013, DFO 2022). Generally, highly fecund with success varying by species. Although the installation can be damaging unless cables are laid on slow growing taxa, overall, the re-colonization of the area is rapid by encrusting organisms and may lead to a full recovery of the seafloor in a few years (Dunham et al. 2015, Copping et al. 2021).
Overall Risk	Moderate	If an interaction occurs involving benthic invertebrates and abrasion/damage due to cable installation, the consequences could result in minimal injury or mortality. **The risk may be tolerable**.
Uncertainty	Moderate	Peer-reviewed literature investigating the physical and direct damage of benthic organisms from cable installation is limited.

5.3.2 Changes in Siltation

Risk Assessment – Cable Installation Changes to Siltation and Benthic Invertebrates

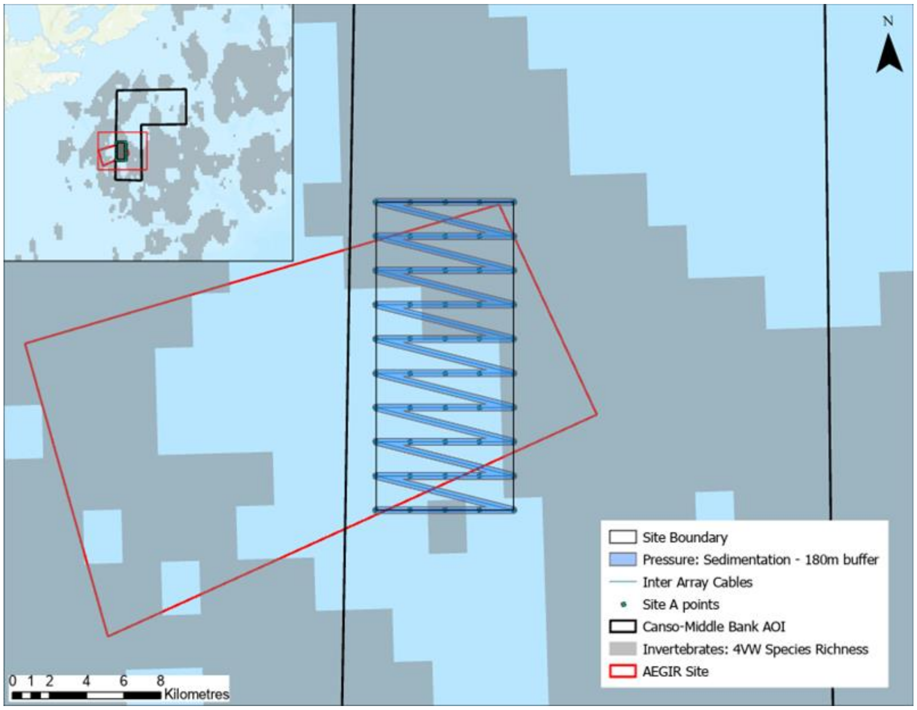

Figure 5.3.2 Cable installation changes to siltation overlap with benthic invertebrates within the AOI.

Risk statement: If an interaction occurs involving benthic invertebrates and changes in siltation due to foundation installation, the consequences could result in reduced oxygen consumption, complete burial, or limited vision (Wilber and Clarke 2010, Bernier et al. 2018, Bureau of Ocean Energy Management Office of Renewable Energy Programs 2022).

Table 5.3.2 Scoring for the risk posed by cable installation changes in siltation to benthic invertebrates in the AOI.

Risk factor	Score	Rationale
Impact Risk	Moderate (binned)	IR = Spatial x Temporal x Severity = 0.03 x 1 x 0.01 = 0.0003
Spatial	Site (0.03)	Overlap = 100*(Area of benthic invertebrates that overlaps in a 180m buffer around inter array cables (AECOM 2021)/ Area of benthic invertebrate layer within AOI)

		=1.2% The activity overlaps with 1.2% of the area occupied by the conservation priority in the AOI.
Temporal	Frequent (1)	Assume dredging and cable laying to take 8 months to a year based on BOEM approved projects.
Severity	Moderate (0.1)	Changes in siltation can cause physiological and behavioural impacts to benthic invertebrates. The plumes of sediment can result in smothering or burial of sessile organisms, clogging of filtration systems and gills, and decreased visibility reducing the ability of visual predators to find prey (Messieh et al. 1991, SEER 2022). Further, early life history stages are most vulnerable due to smothering and the inability to settle upon required benthic habitat (Wilber and Clarke 2010, Magris and Ban 2019). Overall, impacts are likely to not have local population level effects.
Recovery Lag	Moderate (binned)	RL = Persistence & Resilience
Persistence	Low	Sediment changes last from minutes to hours, dissipating shortly after activities conclude or foundations are removed.
Resilience	Moderate	Various life stages are impacted, some invertebrates are slow maturing, like snow crabs, and others that are not like lobsters, sand dollars, and bivalves (Silva et al. 2012, MacLean et al. 2013, DFO 2022). Generally, highly fecund with success varying by species. It is unlikely that cable installation will cause long-term impacts, as examples have shown that sediment dispersion during cable installation causes little to no change in diversity, abundance, or biomass around cable routes within the first few years following construction (Andrulewicz et al. 2003, SEER 2022).
Overall Risk	Moderate	If an interaction occurs involving benthic invertebrates and changes in siltation due to cable installation, the consequences could result in behavioural and physiological changes including injury and mortality across life history stages. **The risk may be tolerable**.
Uncertainty	Moderate	Changes in siltation are relatively well understood but data is incomplete and limited in the study area.

Risk Assessment – Cable Installation Changes to Siltation and Atlantic Cod

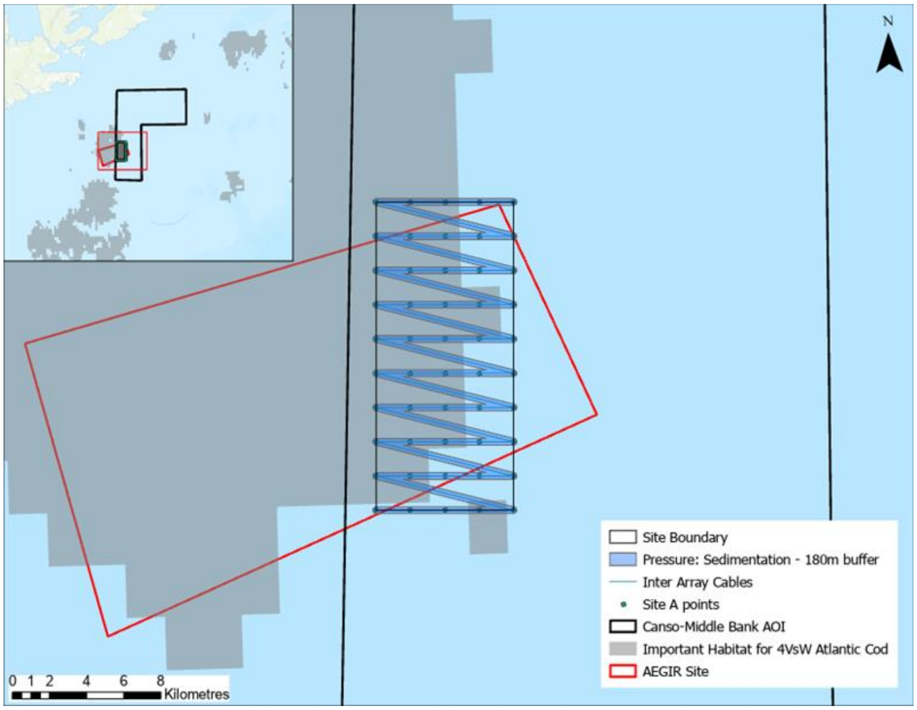

Figure 5.3.3 Cable installation changes to siltation overlap with Atlantic cod within the AOI.

Risk statement: If an interaction occurs involving Atlantic cod and changes in siltation due to cable installation, the consequence could result in a greater vulnerability to predation, a reduction in feeding, or the avoidance of habitat potentially resulting in higher energetic costs (Bureau of Ocean Energy Management Office of Renewable Energy Programs, 2018).

Table 5.3.3 Scoring for the risk posed by cable installation changes in siltation to Atlantic cod in the AOI.

Risk factor	Score	Rationale
Impact Risk	Moderate (binned)	IR = Spatial x Temporal x Severity = 0.37 x 1 x 0.01 = 0.0037
Spatial	Local (0.37)	Overlap = 100*(Area of Atlantic cod that overlaps in a 180m buffer around inter array cables (AECOM 2021)/ Area of Atlantic cod layer within AOI) = 16.7% The activity overlaps with 16.7% of the area occupied by the conservation priority in the AOI.

Temporal	Frequent (1)	Assume dredging and cable laying to take 8 months to a year based on BOEM approved projects.
Severity	Low (0.01)	Cable installation can cause changes in siltation that are likely to result in behavioural changes in adult Atlantic cod, and physiological damage to larval cod. Adults react to the plumes created during cable trenching by moving from the disturbed area (Hammar et al. 2014). This could result in a reduction in foraging behaviour as they are visual predators (Utne-Palm 2002) and overall increased stress levels (Kjelland et al. 2015). It is hypothesized that sediment plume particles can weigh down eggs floating in the water column and clog the gills of larvae, potentially resulting in mortality during cods' early life history (Hammar et al. 2014, Wenger et al. 2017). Models suggest that concentrations of fine-grain sediment particles could damage eggs as far as 0.3 km^2 from the source (Westerberg et al. 1996, Jiang et al. 2007). Overall, the threat is not likely to have population level impacts.
Recovery Lag	High (binned)	RL = Persistence & Resilience
Persistence	Low	Sediment changes last from minutes to hours, dissipating shortly after activities conclude and cables are removed.
Resilience	None	This species is endangered, a critical stock, with a low natural mortality used in assessments, noise impacts all stages, and the crossbreeding of populations is unlikely (COSEWIC 2010).
Overall Risk	Moderate	If an interaction occurs involving Atlantic cod and changes in siltation due to cable installation, the consequences could result in behavioural changes and mortality in early life history stages. **The risk may be tolerable**.
Uncertainty	High	There are very few studies that investigate the impacts of changes in sedimentation to Atlantic cod, so it required extrapolation of potential impacts to adults from other studies on visual finfish. Further, data should be verified for the area of study.

5.4 Active Turbines

5.4.1 Artificial Light

Risk Assessment – Active Turbine Artificial Light and Seabirds

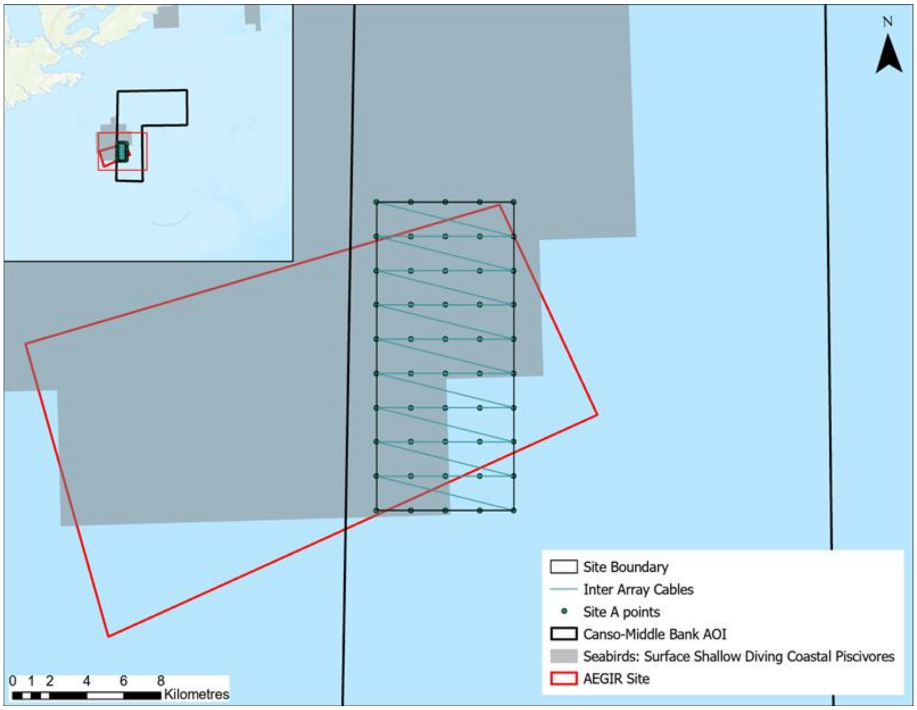

Figure 5.4.1 Active turbine artificial light overlap with seabirds in the AOI.

Risk statement: If an interaction occurs involving seabirds and input of light due to active turbines, the consequence could result in seabirds altering feeding behaviours and migration patterns or could cause seabirds to become disoriented and collide resulting in injury or death (Kingsley and Whittam 2001, Gaston et al. 2014).

Table 5.4.1 Scoring for the risk posed by active turbine artificial light to seabirds in the AOI.

Risk factor	Score	Rationale
Impact Risk	Moderate (binned)	IR = Spatial x Temporal x Severity = 0.37 x 1 x 0.01 = 0.0037 (raw score)
Spatial	Local (0.37)	Overlap = 100*(Area of seabirds that overlap with site boundary/ Area of seabird layer within AOI) = 14.0%

		The activity overlaps with 14.0% of the area occupied by the conservation priority in the AOI.
Temporal	Frequent (1)	Wind turbines will be in operation for 20-40 years.
Severity	Low (0.01)	Structures are required to have lighting for navigation. The lighting associated with wind turbines and the substations may result in attraction of birds and increase the risk of collision and alterations to behaviour, but few studies on the impacts of light from OSW have been undertaken (Burke et al. 2012, Ronconi et al. 2015, Fox and Petersen 2019). Artificial light has been linked to mortality and alterations to migration paths around offshore oil and gas platforms (Montevecchi 2006) as nocturnal seabirds are attracted to light as they hunt bioluminescent prey. Light caused mortality occurs through collision with structures mainly and the potential to become fatigued from light attraction that causes birds to circle platforms for hours (Wiese et al. 2001, Burke et al. 2005). Generally, offshore turbines are using flashing lights over bright steady lights for shipping navigation as steady lights attract more nocturnal migrants, therefore reducing risk of artificial light (Gauthreaux and Belser 2006, Gehring et al. 2009, Rebke et al. 2019). As explored in the collision risk assessment, collision impacts are not a local population threat.
Recovery Lag	Low (binned)	RL = Persistence & Resilience
Persistence	Low	Pressure dissipates instantly when the turbine is removed.
Resilience	Moderate	Generally, seabirds have a low fecundity and high success of recruitment. Natural mortality rate is low and mainly mature life stages impacted. Some species of this functional group are COSEWIC listed.
Overall Risk	Moderate	If an interaction occurs involving seabirds and barrier to species movement due to active turbines, the consequences could result in behavioural changes and **the risk may be tolerable.**
Uncertainty	High	Highly under-researched field with outdated literature. Very few studies investigate light from OSW directly, rather more general light houses, offshore oil and gas platforms, and vessel navigation lights.

5.4.2 Barrier to species movement

Risk Assessment – Active Turbine Barrier to Species Movement and Seabirds

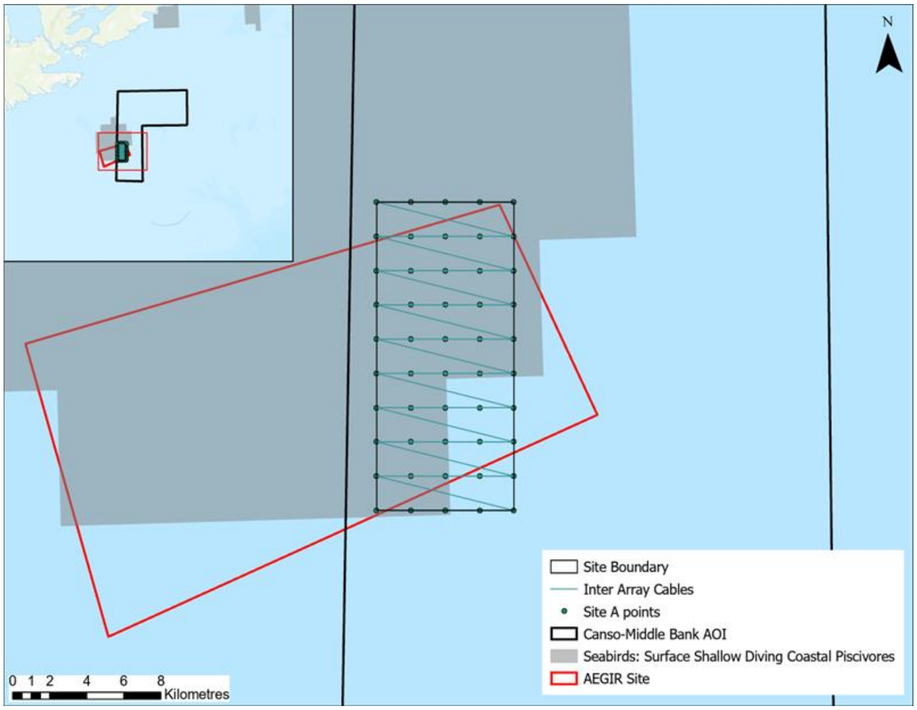

Figure 5.4.2 Active turbine barrier to species movement overlap with seabirds in the AOI.

Risk statement: If an interaction occurs involving seabirds and a barrier to species movement due to active turbines, the consequence could result in seabird displacement from optimal breeding, wintering, migratory or foraging habitats due to an obstacle to natural movement and behaviour (Bennun et al., 2021; Humphreys, 2015; Hüppop et al., 2016).

Table 5.4.2 Scoring for the risk posed by active turbine barrier to species movement to seabirds in the AOI.

Risk factor	Score	Rationale
Impact Risk	Moderate (binned)	IR = Spatial x Temporal x Severity = 0.37 x 1 x 0.01 = 0.0037
Spatial	Local (0.37)	Overlap = 100*(Area of seabirds that overlap with site boundary/ Area of seabird layer within AOI) = 14.0%

		The activity overlaps with 14.0% of the area occupied by the conservation priority in the AOI.
Temporal	Frequent (1)	Wind turbines will be in operation for 20-40 years.
Severity	Low (0.01)	Offshore wind turbines are known to create a barrier to seabirds with evidence showing several bird species completely avoid the windfarm area itself along with a buffer zone (Mendel et al. 2014, Garthe et al. 2023). The barrier effect has the potential to alter the migration flyways or local flight paths of seabirds to avoid turbines (Drewitt & Langston, 2006; Garthe et al., 2023; Larsen & Guillemette, 2007). Avoiding turbine arrays can increase energy expenditure, potentially disturbing the linkages between distant feeding, roosting, moulting, and breeding areas not directly impacted by the turbine (Drewitt & Langston, 2006). Although some species avoid OSW farms, others are attracted (Dierschke et al. 2016, Vanermen et al. 2020). During operation of European wind farms, most of the birds observed within the turbines were gulls with preference for the edges of the farm (Vanermen et al. 2015, 2020). Observational studies show that even gulls which are most attracted are found in highest abundances outside the windfarm (Mendel et al. 2014). In conclusion there is evidence of habitat loss and barrier to movement, but we lack understanding of the impacts of barrier effects at a population level as it is thought to impact a relatively small number of birds (Fox and Petersen 2019).
Recovery Lag	Moderate (binned)	RL = Persistence & Resilience
Persistence	Low	Pressure dissipates instantly when the turbine is removed.
Resilience	Moderate	Generally, seabirds have a low fecundity and high success of recruitment. Natural mortality rate is low and mainly mature life stages are impacted. Some species of this functional group are COSEWIC listed.
Overall Risk	Moderate	If an interaction occurs involving seabirds and barrier to species movement due to active turbines, the consequences could result in behavioural changes. **The risk may be tolerable.**
Uncertainty	Moderate	Habitat loss due to the barrier is evident, but the impact on migrating species is unclear as mentioned. Overall, it is conclusive that there is some impact to species movement but highly dependent on species, time of year, and the individual.

5.4.3 Collision

Risk Assessment – Active turbine collision and seabirds

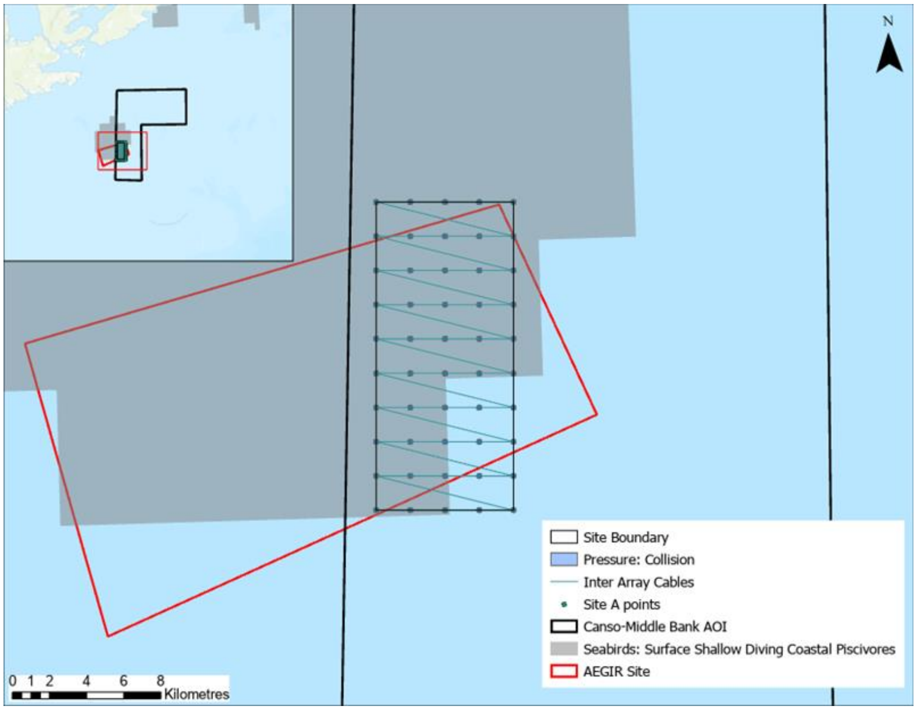

Figure 5.4.3 Active turbine collision overlap with seabirds in the AOI.

Risk statement: If an interaction occurs involving seabirds and death or injury by collision due to active turbines, the consequence could result in seabird mortality and reduced fitness of those injured (Bennun et al. 2021).

Table 5.4.3 Scoring for the risk posed by active turbine collision to seabirds in the AOI.

Risk factor	Score	Rationale
Impact Risk	Moderately high (binned)	IR = Spatial x Temporal x Severity = 0.03 x 1 x 0.1 = 0.003
Spatial	Site (0.03)	Overlap = 100*(Area of seabirds that overlap with turbines and blade buffer (Souza and Bachynski-Polić 2022)/Area of seabird layer within AOI) = 0.6% The activity overlaps with 0.6% of the area occupied by the conservation priority in the AOI.
Temporal	Frequent (1)	Wind turbines will be in operation for 20-40 years.

Severity	Moderate (0.1)	The risk of collision with man-made structures is thought to rank among the top threats to birds in terms of individuals killed (Loss et al. 2012), but the contribution of OSW to collision risk is moderate. Direct mortality or injury of birds can occur from collision with the rotors, towers, nacelles, and associated structures (Drewitt & Langston, 2006). Although it is possible, mortality levels are relatively low during the day (Drewitt & Langston, 2006; Furness et al., 2013). In general, studies show that average annual bird deaths from turbine accidents range between 0 and 50 globally (Thaxter et al. 2015, Cook et al. 2018, Martin and Banks 2023), while others suggest an average death of 150 dead birds per year conservatively and likely more as dead birds fall into the sea and are not counted (Hüppop et al. 2016). Behaviourally, seabirds respond differently from avoidance to attraction (Garthe et al. 2023), and will react differently within seasons, between individuals, and sexes (Thaxter et al. 2015). Evidence suggests seabirds are well equipped to avoid turbines during the day through species-specific adjustments of flight paths which vary by altitudes and direction (Cook et al., 2018). Contrarily, at night a migrating flock could be more likely to enter a wind farm resulting in a higher collision risk (Desholm & Kahlert, 2005), but few in-situ studies have investigated this relationship. Further, a gap in knowledge relevant to the study area is the risk of collision during unusual weather, storms, and snow due to limited post construction monitoring (Fox and Petersen 2019). Overall, there is a risk of collision, but gulls have been found to be attracted to windfarms due to increased boat traffic, new food resources, or new perches (Desholm et al. 2006, Vanermen et al. 2015). Seabirds could become habituated to take advantage of potential benefits from the new habitat, mainly food availability due to aggregating sea life around foundations (Leopold and Verdaat 2018). Overall, there is a low risk of mortality and few behavioural changes, likely not resulting in population level impacts to seabirds.
Recovery Lag	Moderate (binned)	RL = Persistence & Resilience
Persistence	Low	Pressure dissipates instantly when the turbine is removed.
Resilience	Moderate	Generally, seabirds have a low fecundity and high success of recruitment. Natural mortality rate is low and mainly mature life stages impacted. Some species of this functional group are COSEWIC listed.
Overall Risk	Moderate	If an interaction occurs involving seabirds and collision due to active turbines, the consequences could result in injury, mortality, and behavioural changes. **The risk may be tolerable.**

Uncertainty	Low	Collision with turbines is well researched and conclusive. These are European-based OSW research findings, however similar species to what are considered in this study.

5.4.4 Flow Rate Changes

Risk Assessment- Active turbine flow rate changes and primary producers.

Risk statement: If an interaction occurs involving primary producers and the water flow rate changes due to foundations, the consequence could result in an increase of dead phytoplankton and organic material sinking to the sediment in deep water which could result in hypoxia (Dorrell et al. 2022, Daewel et al. 2022).

Table 5.4.4 Scoring for the risk posed by active turbine flow rate changes and primary producers within the AOI.

Risk factor	Score	Rationale
Impact Risk	Moderate (binned)	IR = Spatial x Temporal x Severity = 0.03 x 1 x 0.01 = 0.0003
Spatial	Site (0.03)	Overlap = 100*(Area of productivity that overlaps with site boundary/ Area of productivity layer within AOI) = 3.1% The activity overlaps with 3.1% of the area occupied by high concentrations of chlorophyll A in the AOI.
Temporal	Frequent (1)	Wind turbines are operational for 20-40 years, disturbing water flow.
Severity	Low (0.01)	There are two mechanisms in which flow rate impacts primary production: changes to flow rate of water around the pile in the water column and atmospheric effects due to wind extraction (Hogan et al. 2023). Energy extraction creates upwelling/downwelling dipoles in the surface mixed layer (Brostrom 2008, Floeter et al. 2017, 2022), impacting the transportation of nutrients from the seabed. Further, the change in mixing impacts thermodynamics and the thermocline (Daewel et al. 2022), which has been found to be of particular concern in seasonally stratified shelf seas where growth is dependent on seasonal changes (Dorrell et al. 2022). This increase in thermocline mixing will drive more nutrients from the bottom to the subsurface, potentially supporting increased growth of primary producers and zooplankton, but not necessarily in the original composition of the

		ecosystem (van der Molen et al. 2014, Dorrell et al. 2022). On the contrary, others have found decreases in chlorophyll a in their models, suggesting a decrease in primary production (Maar et al. 2009, Slavik et al. 2019). A recent literature review by Wang et al. (2023) somewhat addressed this contradiction, suggesting that phytoplankton and zooplankton can be positively or adversely affected by these changes to water flow, shade, oxygen depletion, and predation pressure leading to a fluctuation in biomass. Overall, field, laboratory, and modeling studies have shown that phytoplankton and zooplankton growth and diversity could be impacted by flow rate changes which could impact the entire marine trophic web (Lévy et al. 2018). Although primary producers serve an invaluable ecosystem function, there is little evidence to suggest that OSW will impact their local productivity.
Recovery Lag	Low (binned)	RL = Persistence & Resilience
Persistence	Low (0.01)	Flow rate changes will stop once the pile is removed, allowing surface winds and currents to mix as normal.
Resilience	High (1)	The composition of phytoplankton that bloom interannually is variable over time but are predictably at highest productivity in the spring and fall with large blooms (Song et al., 2011). Population growth depends on light, nutrient availability, and oceanographic conditions. Overall, phytoplankton have short generation times and dynamic ocean conditions in the AOI will bring an influx of organisms to the site, resulting in a high resilience.
Overall Risk	Moderate	If an interaction occurs involving primary producers and flow rate changes, the consequence could result in positive or negative biomass changes and **the risk may be tolerable.**
Uncertainty	Moderate	The literature focuses on models rather than in situ studies, are all based in Europe, and emphasizes that this field of study is novel.

5.4.5 Noise (underwater or other)

Risk Assessment – Active Turbine Noise and Ichthyoplankton

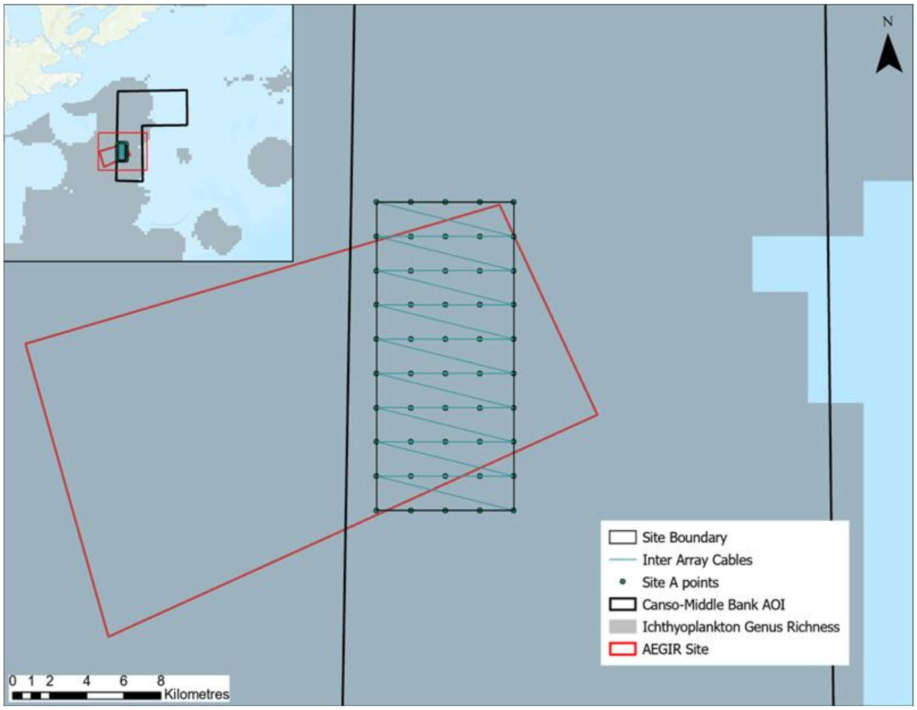

Figure 5.4.4 Active turbine noise overlap with ichthyoplankton within the AOI.

Risk Statement: If an interaction occurs involving ichthyoplankton and noise (underwater and other) due to active turbines, the consequence could result in settlement changes of larvae and larval attraction (Jeffs et al. 2003, Montgomery et al. 2006, Radford et al. 2007, Anderson et al. 2021).

Table 5.4.5 Scoring for the risk posed by active turbine noise to ichthyoplankton within the AOI.

Risk factor	Score	Rationale
Impact Risk	Moderate (binned)	IR = Spatial x Temporal x Severity = 0.03 x 1 x 0.01 = 0.0003
Spatial	Site (0.03)	Overlap = 100*(Area of ichthyoplankton layer that overlaps with windfarm site/ Area of ichthyoplankton within AOI) = 3.1% The activity overlaps with 3.1% of the area that the CP occupies in the AOI.

Temporal	Frequent (1)	Wind turbines will be in operation for 20-40 years.
Severity	Low (0.01)	The impact of the low frequency noise generated by active turbines is likely to result in behavioural changes to larvae. Numerous experimental studies indicate that ambient underwater noise plays an important role in the orientation and settlement of pelagic invertebrate larvae and of economically important finfish, bivalves, and crabs (Jeffs et al. 2003, Montgomery et al. 2006, Radford et al. 2007, Lillis et al. 2013, Anderson et al. 2021, Williams et al. 2022, Cresci et al. 2023). Generally, anthropogenic noise has been found to reduce feeding which can impact the larvae's ability to escape predation (Gendron et al. 2020). As mentioned, invertebrate larvae rely on acoustic cues to settle. The increased noise could be beneficial for species to settle out of the vulnerable larval stage, but only if the ideal substrata is available. Overall, the behavioural changes caused by active turbines are likely to not have population level impacts.
Recovery Lag	Moderate (binned)	RL = Persistence & Resilience
Persistence	Low	Noise pressure dissipates instantly after noise emitting activities conclude.
Resilience	Moderate	COSEWIC status varies across this group as it is composed of various species with different life histories. Early life history stage is highly vulnerable.
Overall Risk	Moderate	If an interaction occurs involving ichthyoplankton and noise due to foundation installation, the consequences could result in behavioural changes and **the risk may be tolerable.**
Uncertainty	High	Limited to no literature on the impacts of operational noise of OSW on ichthyoplankton; rather used sources investigating vessel noise.

Risk Assessment – Active Turbine Noise and Benthic Invertebrates

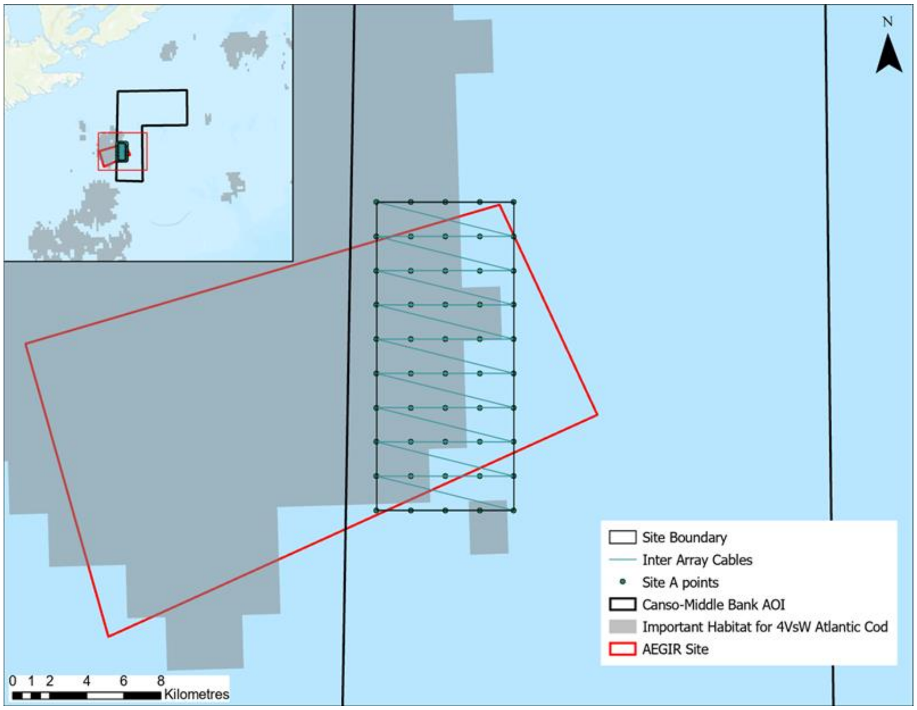

Figure 5.4.5 Active turbine noise overlap with benthic invertebrates within the AOI.

Risk Statement: If an interaction occurs involving benthic invertebrates and noise (underwater and other) due to active turbines, the consequence could result in bivalves increasing or decreasing filtration as a stress response, and behaviour changes in decapods (Popper & Hawkins, 2018; Roberts et al., 2015; Solé et al., 2023).

Table 5.4.6 Scoring for the risk posed by active turbine noise to benthic invertebrates within the AOI.

Risk factor	Score	Rationale
Impact Risk	Moderate (binned)	IR = Spatial x Temporal x Severity = 0.03 x 1 x 0.01 = 0.0003
Spatial	Site (0.03)	Overlap = 100*(Area of benthic invertebrate layer that overlaps with windfarm site/ Area of benthic invertebrate within AOI) = 3.00% The activity will cover the entire offshore wind farm. The activity overlaps with 3.00% of the area occupied by the conservation priority in the AOI.

Temporal	Frequent (1)	Wind turbines will be in operation for 20-40 years.
Severity	Low (0.01)	The impacts of active turbine noise on benthic invertebrates are poorly understood and vary by species. Active turbines could impact the settlement of various crab species as noise could delay the metamorphosis of megalopa (Pine et al. 2012, Mooney et al. 2020), impacting recruitment by changing settlement processes (Stanley et al. 2012). Generally, the impacts of operational noise are unknown to adults and thought to be non-damaging (Solé et al. 2023). Overall, it is unlikely that operational noise will have local population level impacts on benthic invertebrates in the AOI.
Recovery Lag	Low (binned)	RL = Persistence & Resilience
Persistence	Low	Noise pressure dissipates instantly after noise omitting activities conclude.
Resilience	High	Various life stages are impacted, and some invertebrates are slow maturing, like snow crabs, and others that are not like lobsters, sand dollars, and bivalves (Silva et al. 2012, MacLean et al. 2013, DFO 2022). Generally, highly fecund with success varying by species.
Overall Risk	Moderate	If an interaction occurs involving benthic invertebrates and noise due to active turbines, the consequences could result in minor behavioural changes and **the risk may be tolerable.**
Uncertainty	High	Limited peer-reviewed sources and a general lack of understanding of noise impacts on benthic invertebrates (Mooney et al. 2020, Solé et al. 2023).

Risk Assessment – Active Turbine Noise and Atlantic Cod

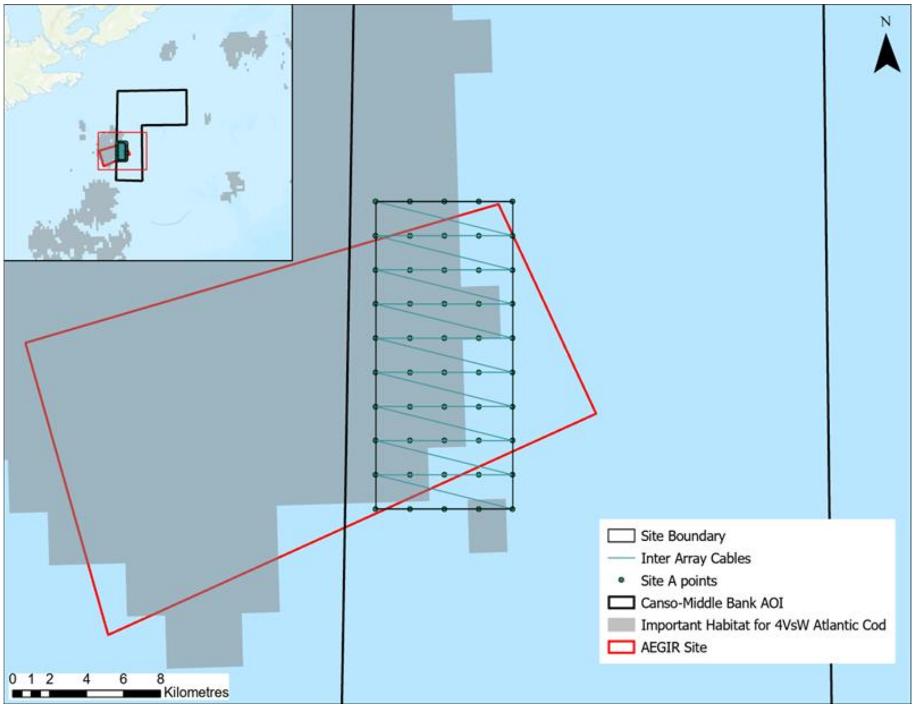

Figure 5.4.6 Active turbine noise overlap with Atlantic cod within the AOI.

Risk Statement: If an interaction occurs involving Atlantic cod and noise (underwater and other) due to active turbines, the consequence could result in a reduction in intraspecific communication and changes to foraging, predatory evasion, and reproductive behaviour (Bailey et al., 2014; Hernandez et al., 2021; Mooney et al., 2020; Popper & Hawkins, 2018; Thomsen et al., 2015).

Table 5.4.7 Scoring for the risk posed by active turbine noise to Atlantic cod within the AOI.

Risk factor	Score	Rationale
Impact Risk	Moderate (binned)	IR = Spatial x Temporal x Severity = 0.37x 1 x 0.01 = 0.0037
Spatial	Local (0.37)	Overlap = 100*(Area of Atlantic cod layer that overlaps with windfarm site/ Area of Atlantic cod within AOI) = 26.9% The activity will cover the entire offshore wind farm. The activity overlaps with 26.9% of the area occupied by the conservation priority in the AOI.

Temporal	Frequent (1)	Wind turbines will be in operation for 20-40 years.
Severity	Low (0.01)	The noise emitted from active turbines will likely cause minor behavioural changes. It has been found the Atlantic cod are attracted to foundations of OSW turbines regardless of noise (Lindeboom et al. 2011, Bergström et al. 2013, Reubens et al. 2014, van Hal et al. 2017, Degraer et al. 2018, 2020, Hutchison et al. 2020, Wilber et al. 2022). They may benefit energetically from access to complex rocky habitat created by scour protection that could provide shelter and increase prey availability (Schwartzbach et al. 2020). Although there could be benefits, noise could still have some negative long-term energetic impacts (Soudijn et al. 2020). Particle sensors found that operational sound particles have levels comparable to Atlantic cod hearing ability within the first 10m of a turbine (Sigray and Andersson 2012, Thomsen et al. 2015). These low frequency sounds could mask adult communication used for mating (Finstad & Nordeide, 2004; Midling et al., 2002). Further, low frequencies attract cod larvae, causing an orientation change towards the source which could impact the dispersal of this species (Cresci et al. 2023). Overall, there is no evidence of hearing loss, and it has been thought to pose an insignificant risk to Atlantic cod and will not cause local population impacts (Wahlberg and Westerberg 2005, Hammar et al. 2014).
Recovery Lag	High (binned)	RL = Persistence & Resilience
Persistence	Low	Noise pressure dissipates instantly after noise omitting activities conclude.
Resilience	None	This species is endangered, a critical stock, with a low natural mortality used in assessments, noise impacts all stages, and the crossbreeding of populations is unlikely (COSEWIC 2010).
Overall Risk	Moderate	If an interaction occurs involving Atlantic cod and noise due to active turbines, the consequences could result in minor behavioural changes and **the risk may be tolerable.**
Uncertainty	Low	The effects of OSW operational noise on Atlantic cod are well understood in the literature, however, it would benefit from North American studies.

Risk Assessment – Active Turbine Noise and Blue Whale

Risk Statement: If an interaction occurs involving cetaceans and noise (underwater or other) due to active turbines, the consequence could result in the masking of baleen whale communication and increased stress (Madsen et al. 2006, Wilson et al. 2010, Bailey et al. 2014, Tougaard et al. 2020, CSA Ocean Sciences Inc 2021).

Table 5.4.8 Scoring for the risk posed by active turbine noise to blue whales within the AOI.

Risk factor	Score	Rationale
Impact Risk	Moderate (binned)	IR = Spatial x Temporal x Severity = 0.37 x 1 x 0.01 = 0.0037
Spatial	Local (0.37)	The activity overlaps with 10.00% of the hypothetical area occupied by the conservation priority.
Temporal	Frequent (1)	Wind turbines will be in operation for 20-40 years.
Severity	Low (0.01)	During operation, the spinning turbines generate a low-frequency vibrational noise. The underwater noise levels emitted during operation is not expected to cause physiological injury as it is less than that of a passing vessel but could impact behaviour in its immediate vicinity (Tougaard et al. 2020). Blue whales communicate at frequencies between 8-35 Hz (Mellinger and Clark 2003), which overlaps with the frequency range generated by active turbines. A masking effect could occur, where arrays of turbines could act as acoustic barriers to long-range communication (Thomsen et al. 2015). Limited studies have explicitly investigated the relationship between operational noise and OSW, but studies on vessel noise show that large vessels can reduce communication for baleen whales by as much as 87.4% (Putland et al., 2018), while vessel traffic in the Gulf of St. Lawrence masks blue whale calls (Aulanier et al. 2016). It is of particular concern for blue whales as they are solitary and rely on long distance communication with conspecifics for reproductive efforts (Payne and Webb 1971, Oleson et al. 2007). Noise from active turbines could result in behavioural and communication changes, but it is likely not to impact the Atlantic population of blue whales.
Recovery Lag	High (binned)	RL = Persistence & Resilience
Persistence	Low	Noise pressure dissipates instantly after noise omitting activities conclude.
Resilience	None	Blue Whales are endangered, low reproduction, late maturity, impacts all stages of life history (Beauchamp et al. 2009).
Overall Risk	Moderate	Therefore, if an interaction occurs involving baleen whales and noise due to active turbines, the consequences could result in long-term behavioural changes and **the risk may be tolerable.**
Uncertainty	Moderate	Limited peer-reviewed sources available on this species; would benefit from in-situ experimentation in the study area.

5.5 Active Cables

5.5.1 Electromagnetic changes

Risk Assessment – Active Cable Electromagnetic Changes and Ichthyoplankton

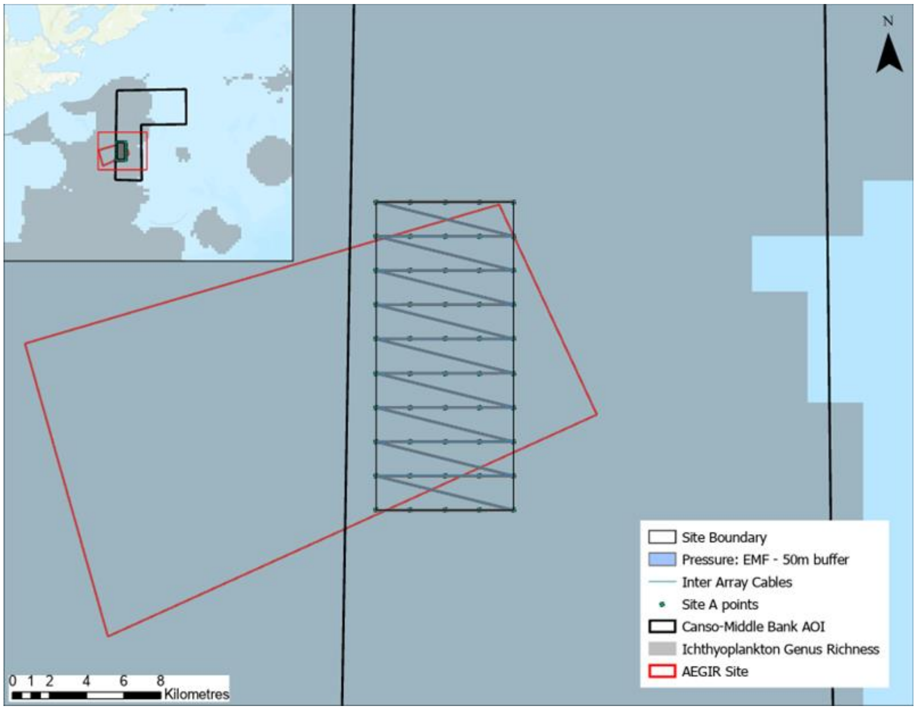

Figure 5.5.1 Active cable electromagnetic changes overlap with ichthyoplankton within the AOI.

Risk Statement: If an interaction occurs involving ichthyoplankton and electromagnetic changes due to active cables, the consequence could result in impacts to behaviour, development, and/or size of newly hatched fish (Levin and Ersnt 1995, 1997).

Table 5.5.1 Scoring for the risk posed by active cables electromagnetic fields to ichthyoplankton within the AOI.

Risk factor	Score	Rationale
Impact Risk	Moderate (binned)	IR = Spatial x Temporal x Severity = 0.03 x 1 x 0.01 = 0.0003
Spatial	Site (0.03)	Overlap = 100*(Area of ichthyoplankton layer that overlaps with 50m buffer around cables (Gill and Desender 2020)/ Area of ichthyoplankton within AOI)

		= 0.5% The activity overlaps with 0.5% of the area occupied by the conservation priority in the AOI.
Temporal	Frequent (1)	Wind turbines will be in operation for 20-40 years.
Severity	Low (0.01)	Electromagnetic changes are suggested to have minor impacts to development and behaviour of ichthyoplankton. Sea urchin embryos experience changes to cell division timing, development, and size at hatch due to DC currents (Levin and Ersnt 1995, 1997). Additionally, magnetic fields produced by subsea cables used to transport energy in OSW farms has been found to alter the orientation of haddock larvae that rely on Earth's magnetic field to orient themselves in the water column, but response varied by individual (Cresci et al. 2019, 2022a). In contrast, lesser sand eel larvae have been shown to experience no impact from DC cables (Cresci et al. 2022b). Overall, Freshwater species like rainbow trout and northern pike experienced changes in size at hatch but there is no mortality effect found (Fey et al. 2019a, 2019b). Overall magnosensitivity in marine larvae is poorly understood but is not likely to have population level impacts or cause mortality.
Recovery Lag	Moderate (binned)	RL = Persistence & Resilience
Persistence	Low	EMF pressure dissipates instantly after the cables are removed and energy generation has concluded.
Resilience	Moderate	COSEWIC status varies across this group as it is composed of various species with different life histories. Early life history stage is highly vulnerable.
Overall Risk	Moderate	If an interaction occurs involving ichthyoplankton and electromagnetic changes due to active cables, the consequences could result in minor behavioural and developmental changes and **the risk may be tolerable.**
Uncertainty	High	Effects of electromagnetic fields is an underdeveloped research area (Thomsen et al. 2015, Cresci et al. 2022b).

Risk Assessment – Active Cable Electromagnetic Changes and Benthic Invertebrates

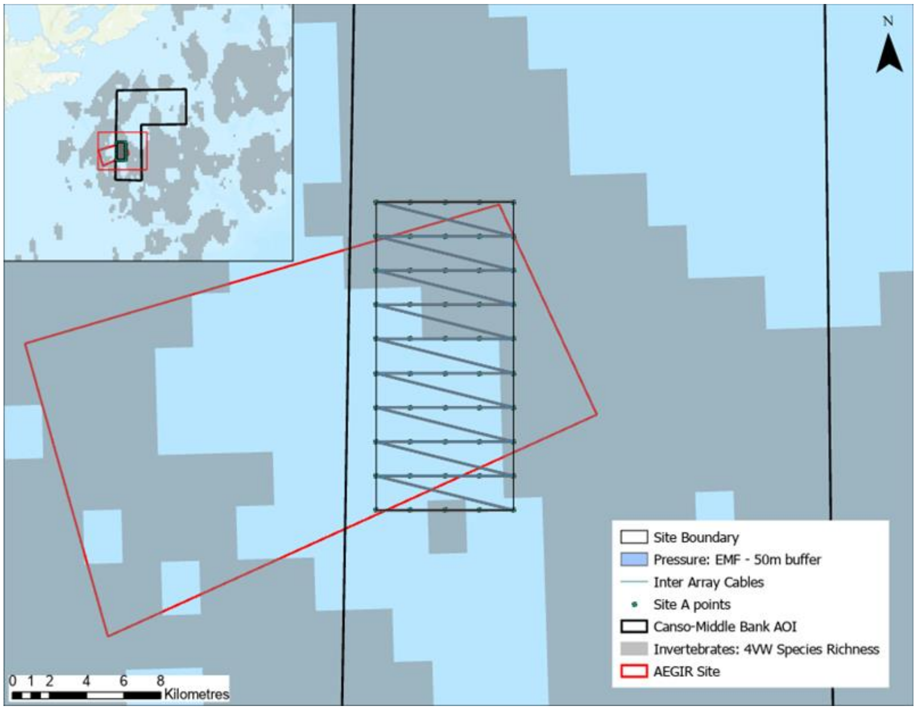

Figure 5.5.2 Active cable electromagnetic changes overlap with benthic invertebrates within the AOI.

Risk Statement: If an interaction occurs involving benthic invertebrates and electromagnetic changes due to active cables, the consequence could result in species can experiencing repulsion or attraction to a site and can impact physiological processes like cell division in early life (Gill & Desender, 2020; Hutchison et al., 2018).

Table 5.5.2 Scoring for the risk posed by active cables electromagnetic fields to benthic invertebrates within the AOI.

Risk factor	Score	Rationale
Impact Risk	Moderate (binned)	IR = Spatial x Temporal x Severity = 0.03 x 1 x 0.01 = 0.0003
Spatial	Site (0.03)	Overlap = 100*(Area of benthic invertebrate layer that overlaps with 50m buffer around cables (Gill and Desender 2020)/ Area of benthic invertebrates within AOI) = 0.3%

		The activity overlaps with 0.3% of the area occupied by the conservation priority in the AOI.
Temporal	Frequent (1)	Wind turbines will be in operation for 20-40 years.
Severity	Low (0.01)	Impacts of magnetic fields to benthic invertebrates are species specific (Albert et al. 2020). A literature review of behavioural impacts found that half the papers suggested attraction, 30% found no effect, and one paper found repulsion (Albert et al. 2020). American lobster exhibits exploratory response when exposed to high voltage DC cables (Hutchison et al., 2020), but juveniles appear to have no behavioural response (Taormina et al. 2020). In situ choice experiments allowing two crab species (*Metacarcinus anthonyu, Cancer productus*) to choose traps with or without EMFs revealed no preference (Love et al. 2015), and crossed cables to enter traps (Love et al. 2017b, 2017a). In contrast, *Cancer pagurus* reduced roaming behaviour and sought shelter during exposure (Scott et al. 2018). Fewer studies have been focused on bivalves, but these have found a cellular response that is not stress related (Malagoli et al. 2004, Bochert and Zettler 2006, Stankevičiūtė et al. 2019). Further long-term exposure is not shown to alter valve activity or filtration rates of blue mussels (Albert et al. 2022). Lastly a study of coastal sea urchins, periwinkles, common starfish and velvet crabs (*Asterias rubens, Echinus esculentus, Necora puber,* and *Littorina littorea*) found that EMFs had no physiological or behavioural impact to righting reflex of all four species (Chapman et al. 2023). Overall, impacts to benthic invertebrates are minimal and are not likely to have population or community level impacts (Albert et al., 2020; Boehlert & Gill, 2010).
Recovery Lag	Low (binned)	RL = Persistence & Resilience
Persistence	Low	EMF pressure dissipates instantly after the cables are removed and energy generation has concluded.
Resilience	High	Various life stages are impacted, some invertebrates are slow maturing, like snow crabs, and others that are not like lobsters, sand dollars, and bivalves (Silva et al. 2012, MacLean et al. 2013, DFO 2022). Generally, highly fecund with success varying by species.
Overall Risk	Moderate	If an interaction occurs involving benthic invertebrates and electromagnetic changes due to subsea cables, the consequences could result in minor behavioural and development changes and **the risk may be tolerable.**
Uncertainty	High	Effects of electromagnetic fields is an underdeveloped research area and little is known about the impacts to benthic invertebrates even though some decapods and crustaceans are magnosensitive (Gill & Desender, 2020).

Risk Assessment – Active Cable Electromagnetic Changes and Atlantic Cod

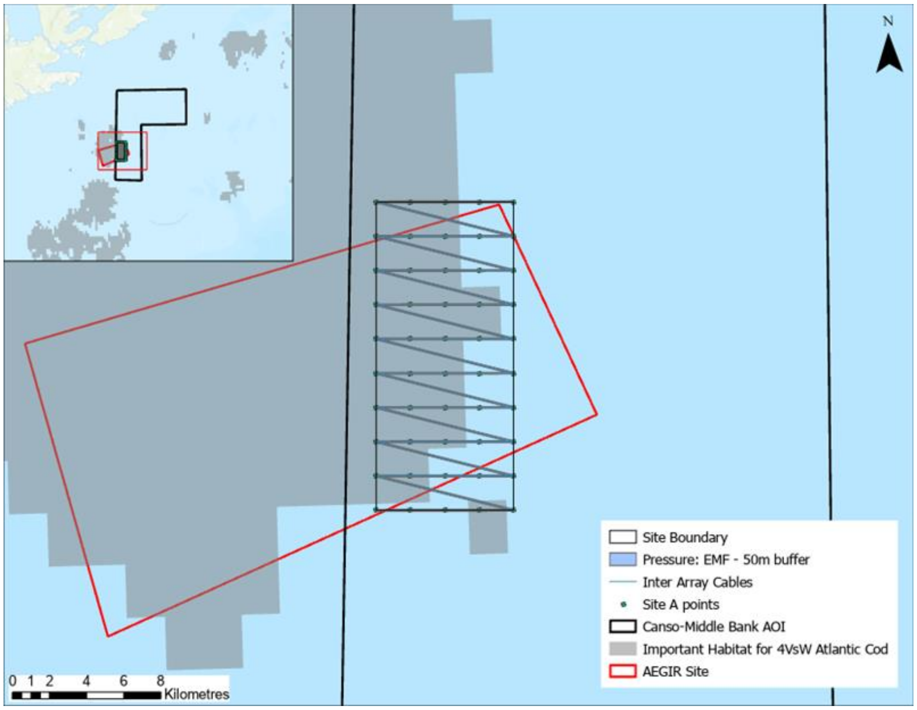

Figure 5.5.3 Active cable electromagnetic changes overlap with Atlantic cod within the AOI.

Risk Statement: If an interaction occurs involving Atlantic cod and electromagnetic changes due to active cables, the consequence could result in elasmobranchs exerting excessive energy foraging for prey when no prey is available due to the electric signals (Hutchison et al., 2018).

Table 5.5.3 Scoring for the risk posed by active cables electromagnetic fields to Atlantic cod within the AOI.

Risk factor	Score	Rationale
Impact Risk	Moderate (binned)	IR = Spatial x Temporal x Severity = 0.03 x 1 x 0.01 = 0.0003
Spatial	Site (0.03)	Overlap = 100*(Area of Atlantic cod layer that overlaps with 50m buffer around cables (Gill and Desender 2020)/ / Area of Atlantic cod within AOI) = 4.8% The activity overlaps with 4.8% if the area occupied by the conservation priority in the AOI.
Temporal	Frequent (1)	Wind turbines will be in operation for 20-40 years.

Severity	Low (0.01)	Deep sea cables that carry the collected energy from turbine, to substation, to shore, generate electromagnetic fields (EMFs) in the environment. It is not understood if cod can sense and respond to magnetic fields (Gill, 2005), but it is generally accepted that levels of EMFs from marine renewable energy are unlikely to significantly affect fish (Gill et al., 2014). Cod are known to regularly aggregate around transmission cables, but it is not thought to be due to EMFs as aggregation persists when power transmission is shut off (Pedersen and Leonhard 2006). Overall, EMFs are not likely to have population level impacts.
Recovery Lag	High (binned)	RL = Persistence & Resilience
Persistence	Low	EMF pressure dissipates instantly after the cables are removed and energy generation has concluded.
Resilience	None	This species is endangered, a critical stock, with a low natural mortality used in assessments, noise impacts all stages, and the crossbreeding of populations is unlikely (COSEWIC 2010).
Overall Risk	Moderate	If an interaction occurs involving Atlantic cod and electromagnetic changes due to subsea cables, the consequences could result in minor behavioural changes and **the risk may be tolerable.**
Uncertainty	High	No studies focused on Atlantic cod; the uncertainty of this score is high as the literature is general to benthic fish.

5.6 Summary of Analysis

The results of the risk analysis vary by species, activity, and pressure with most of the relationships causing moderate risk to CPs (Table 5.6.1). None of the activities resulted in an intolerable risk (represented by red), and a few resulted in a tolerable impact. The complete summary can be seen below.

Table 5.6.1 A summary table of all CPs, pressures, and activity scores from the risk analysis in Canso and Middle Banks AOI. Green represents tolerable risk, yellow represents a moderate risk to CPs, and grey are pressures and CPs not analyzed in this study.

	Seismic Surveys	**Foundation Installation**			**Cable Installation**		**Active Turbines**					**Active Cables**
	Noise	Abrasion	Noise	Sediment	Abrasion	Sediment	Barrier	Collision	Flow Rate	Light	Noise	EMFs
Primary Producers	▨	▨	▨	▨	▨	▨	▨	▨	🟨	▨	▨	▨
Ichthyo - plankton	🟩	▨	🟨	▨	▨	▨	▨	▨	▨	▨	🟨	🟨
Benthic Inverts	🟩	🟨	🟨	🟨	🟨	🟨	▨	▨	▨	▨	🟨	🟨
Atlantic Cod	🟨	▨	🟨	🟨	▨	🟨	▨	▨	▨	▨	🟨	🟨
Blue Whales	🟨	▨	🟨	▨	▨	▨	▨	▨	▨	▨	🟨	▨
Seabirds	▨	▨	▨	▨	▨	▨	🟨	🟨	▨	🟨	▨	▨

6. Discussion

This study examined the compatibility of *Oceans Act* MPAs and OSW through a case study of a potential AOI – Canso and Middle Banks – and a hypothetical fixed-based OSW farm. An environmental risk assessment analyzed the risk of offshore wind activities with the site's conservation priorities to provide a preliminary understanding of the compatibility of the emerging industry and marine conservation in Canada. Overall, offshore wind construction is most impactful to the CPs as it relates to mortality risks to marine life. Generally, the environmental risks posed are moderate across CPs and activities. These findings align with previous risk assessments performed in the US and literature reviews of the environmental impacts of OSW (Bureau of Ocean Energy Management Office of Renewable Energy Programs 2018, Defingou et al. 2019), however, a single impact chain risk method may not be the ideal tool to analyze activity compatibility across MPAs.

6.1 Site Surveys

The site survey activities elicit a moderate noise risk to Atlantic cod and blue whales, and an acceptable low risk to ichthyoplankton and benthic invertebrates. Seismic noise can cause an array of behavioral or physiological impacts to ichthyoplankton and Atlantic cod depending on their distance from seismic noise blasts. Similarly, blue whales may experience ear trauma depending on proximity to blasts, but this phenomenon is yet to be studied in full and likelihood remains unclear. While physiological eardrum damage is hypothesized due to noise and particle motion associated with seismic blasting, it has yet to be observed. This has led to a conclusion drawn upon current literature which mainly indicates behavioral changes of blue whales occurring at a distance.

Atlantic cod and blue whales both rely on auditory communication with conspecifics during mating, which can be masked by low frequency blasts. Furthermore, as auditory communication is used by both species during aggregating events, such as spawning or feeding, the implications of seismic surveying may have a direct consequence to individual fitness. As such, continued research on the impacts of noise from seismic blasts on benthic invertebrates and blue whales is recommended as these CPs were limited in literature availability. It is further recommended that potential OSW sites be screened with respect to their uses in key life history events, such as spawning or feeding for conservation priorities to reduce impacts. Overall, site selection surveys may not cause population level damage to species in the AOI but can cause marine life to avoid the area. Site avoidance in this case could lead CPs to avoid the MPA, thus losing protection and access to important breeding and foraging habitats, rendering the site temporarily ineffective.

6.2 Construction

It was found that OSW construction activities are the most impactful to CPs in the AOI, and thus pose the greatest conservation risk. Foundation and cable installation are likely to cause changes to sediment properties, generate noise, and directly damage marine life. Benthic invertebrates experienced the greatest impact across all construction activities, undergoing mortality, injury, and physiological changes. Further, ichthyoplankton were found to be vulnerable to noise and sediment changes, eliciting behavioural and physiological responses which increase the risk of mortality. As the planktonic stage is vulnerable, there is potential for downstream population impacts, however, the gravity of this relationship is poorly understood. Atlantic cod and blue whales experience moderate effects from noise, with the greatest impact experienced during mating seasons as conspecific communication could be masked. Across CPs, noise impacts to species within the AOI are poorly understood, marking a major gap in knowledge. Current literature suggests construction of OSW poses a moderate risk, with the need for mitigation measures in place. Mitigation measures should reduce noise impacts through methods like bubble curtains and temporal avoidance of life history events for sensitive species. Construction could cause key species to avoid critical habitats and the protected area, negatively impacting the success of the potential future MPA.

6.3 Operation

During operation, noise, abrasion, and sedimentation pressures are found to subside, and seabirds experience the greatest threat across CPs. Seabirds are at the greatest risk due to collision potential with turbines and the potential threat of artificial light induced mortality. The relationship between seabirds and OSW is poorly understood over time and within the bioregion. Although noise is less impactful during operation than seismic surveys and construction, the low frequency noise could mask communication in both Atlantic cod and blue whale species.

Additionally, EMFs are assumed to have limited impact on Atlantic cod and benthic invertebrates, but few studies have investigated this relationship (Copping et al. 2021). Active cables that emit EMFs are poorly monitored at operational wind farms and there is an extremely limited understanding of EMF impacts to endemic species in the AOI. Lastly, impacts to phytoplankton in the water column are site specific, vary by study, and not understood in the AOI, therefore the impacts should be further understood on the Scotian Shelf. Generally, longitudinal studies of impacts across researched pressures are minimal (Wilson et al. 2010), with longitudinal studies mainly focused on the reef effect (Westerberg et al. 2013, Glarou et al. 2020, Degraer et al. 2020, Reis et al. 2021) and invasive species (De Mesel et al. 2015). To mitigate impacts of OSW operation, implementing navigational light solutions like non-continuous signals and planning sites to avoid important migratory, foraging, and breeding grounds will reduce impacts to CPs. Operation is unlikely to damage the ecosystem but could alter the ecological community of the site.

6.4 Environmental Risk Assessment Methodology

The new draft risk assessment method tested in this study was adequate at assessing environmental risk of OSW to an MPA. As conservation is the purpose of an MPA, the environmental risk assessment method was developed to be less tolerable of adverse environmental impacts than methods for industrial activity. The low tolerance method generated a moderate range of impacts on CPs across trophic levels, and yielded comparable results to previous assessments of OSW projects in the US (Bureau of Ocean Energy Management Office of Renewable Energy Programs 2018, 2022).

Challenges with the method were its inability to capture variability in impacts experienced by CPs depending on distance from the pressure, population impacts, and cumulative impacts. The method struggled to capture pressures with nuance like noise which is experienced differently depending on distance. For example, a ruptured swim bladder of finfish in proximity to a pile driving activity versus a behavioural change experienced at a distance is vastly different in severity (Popper and Hastings 2009). Additionally, severity scores attempted to estimate the level of impact to the local population however, literature generally indicates individual impacts. This required expert opinion to estimate potential local population impacts. Lastly, the method did not explore cumulative impacts to the environment, which is difficult to assess and can become a point of contention with rightsholders and stakeholders (Willsteed et al. 2018). Single-impact chain assessments are only able to capture individualistic impacts of pressures that may not be cumulatively understood through simple score addition. Cumulative impacts of activities are a challenge across environmental risk assessments and would provide immense value to MPA zoning decisions.

In conclusion, the method is useful as it provides a uniform environmental risk approach across Canada but as it was created for MPA activity zoning, it is unable to capture whether an activity is compatible with the greater conservation objectives of the site. Generally, an activity would have to either conflict with a sensitive species found across the entire site, or all species would have to be impacted at a "non-tolerable" score. This is challenging for this study which is attempting to explore the compatibility of a large activity with the site as a whole.

6.5 Implications, Recommendations, and Future Areas of Study

The results of this study suggest that ecological impacts of offshore windfarms range from behavioural to physiological damage of marine life, and knowledge gaps in environmental understanding are an obstacle for decision making. The risks of OSW to CPs in the case study site are moderate, and not intolerable according to the single-chain risk assessment method. Ecological impacts of OWFs are increasingly studied, but the impacts over a farm's lifetime remain unclear, and some species in the potential MPA have yet to be mentioned in decommissioning literature. The greatest knowledge gaps are the impacts of noise, electromagnetic fields, and flow rate changes across CPs analyzed in this study. Future ecological studies should focus on detailed environmental monitoring of new OSW farms constructed on the Eastern coast of the United States as the environment is similar to the Scotian Shelf. Researchers should investigate the success of mitigation measures, perform in-situ monitoring studies of long-term impacts of noise and EMFs. Further efforts to understand the reef effect, its implications for invaders, and its success in promoting biodiversity on the Eastern seaboard are needed to explore these previous trends in Canada.

This study highlighted some environmental concerns of OSW for marine management, but it does not fully reveal the compatibility of OSW with MPAs across Canada. The results are a tool to support local decision making, provide knowledge for future studies, and begin the conversation surrounding the compatibility of the activities. The unclarity of ecological compatibility between MPAs and OSW demonstrates the potential for policy and planning solutions, like protection standards, MSP expansion, and inclusion in standards set by the regulators. In Canada, *Oceans Act* (1996) MPAs are designated for general reasons under section 35 like conservation of fishery resources, protection of endangered or threatened marine species, protection of unique habitats, conservation of areas of high biodiversity or biological productivity, and the maintenance of ecological integrity. These general concepts are difficult to capture with a single-impact chain risk assessment and are critical in understanding co-location. For example, construction of OSW could be incompatible with an MPA due to potential harm to a particular sensitive benthic species in the MPA designated under 35.1.b (*Oceans Act* 1996). During operation, which is less impactful to the environment, it is unlikely that OSW would reduce biodiversity of an site designated under 35.1.d, but foreign objects in a conservation area will reduce the sites ecological integrity under 35.1.f. Broader studies that expand on comprehensive ecological compatibility that relate to policy and planning, like the protection standards, are essential moving forward.

Currently the international community is divided on overall compatibility of MPAs and OSW. Those in favour cite biodiversity increases, spill-over, and a reduction of impacts to fish harvesters as pro-compatibility markers (Hammar et al. 2016, Raoux et al. 2017, Defingou et al. 2019, Gill et al. 2020, Wang et al. 2023). Those opposed suggest that limited environmental monitoring data and the incompatibility of the ethos of conservation should deter from co-location (Wilson et al. 2010, Ashley et al. 2014, De Mesel et al. 2015, Heery et al. 2017, Lloret et al. 2022, 2023). As Canada explores these options, DFO and the OSW regulators should include cumulative affects assessments of industries and conservation through MSP to reduce impacts to harvesters. MSP could be used to ensure that the conservation network, which will require 25% of the area in the bioregion, and offshore wind are able to accomplish their goals while reducing the economic burden that could be placed on harvesters.

Along with MSP and cumulative impacts assessments, the DFO and OSW regulators should continue to explore Indigenous perspectives in conservation, socio-economic dimensions of decision making and how other conservation tools and OWF styles could be compatible. Indigenous rights to access a moderate livelihood and harvest for food, social and ceremonial purposes must be integrated into planning (2.1) and should be at the forefront of future work on compatibility and cumulative impacts of industry on the Scotian Shelf (*Oceans Act* 1996). Government-to-government meaningful consultation and collaboration will help ensure that the burden of development is not placed on marginalized communities across the province and safeguard cultural values. Further, it is important that Canadians have a say in the planning of their common space, and for managers to promote transparency to prevent mistrust with rightsholders and stakeholders as decisions on compatibility are made (Devine-Wright 2009). Future surveys to rights- and stakeholders should explore how marine conservation is perceived, reactions to the co-location of OSW with MPAs or other conservation tools, and what should be done to preserve marine spaces.

6.6 Study limitations

A major limitation of this study is that it did not include vessels, nor the decommissioning phase of OSW, and the environmental impacts and the literature will continually require updating as research is an everchanging landscape. Vessel-related impacts were not included in this risk assessment as the DFO method requires marine transportation to be evaluated as a separate chapter and analysis, and therefore was deemed extraneous to the study. The decommissioning phase of offshore wind remains uncharted territory, and the phase is largely unexplored with uncertain environmental impacts (Topham et al. 2019, Lemasson et al. 2022, Spielmann et al. 2023). Studies have begun hypothesizing environmental impacts and determining the ideal avenue for decommissioning, but it is still unclear which is the ideal avenue forward (Lemasson et al. 2022). Some researchers recommend leaving structures in place for the reef effects to continue (Smyth et al. 2015), or complete or partial removal of the structure like cutting the foundation at various heights or excavating scour protection. Due to this uncertainty and lack of environmental studies at this time, speculating the future impacts of the decommissioning phase was deemed beyond the scope of the study as single-impact chains were unable to be assessed. Overall, there are numerous gaps in the literature across OSW activities and pressures, making these results a starting point for future studies and risk assessments that include all four phases.

7. Conclusion

The compatibility of conservation and renewable energy is exceedingly complex in the Scotian Shelf-Bay of Fundy bioregion as governments, rightsholders, and stakeholders that are uniquely motivated push to accomplish their respective, and often competing, goals. This study was the first in Canada to explore spatial compatibility of MPAs and OSW through a novel environmental risk assessment method to begin understanding the ecological conflicts of co-location. The results indicate that MPAs and OSW are not outright incompatible, but knowledge gaps and a lack of clarity on cumulative ecosystem impacts indicate the need for future studies. As conservation is the goal of an MPA, sustainable development and industry do not always fit within its bounds, but future studies that build upon this study will begin clarifying this relationship.

Moving forward, MSP is a useful tool to begin planning for conservation and the expansion of OSW to reduce impacts to rightsholders and stakeholders. This next step should involve knowledge from across Indigenous communities and stakeholders to understand the values of users in the study area before decisions can be made. This is an opportunity for innovation and understanding as both OSW and MSP are needed for climate resilience. Mitigating undue negative impacts between them is essential for a sustainable future and biodiversity in Atlantic Canada.

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Appendix 1: List of Pressures

Table 1: The pressures required for this study and their mechanism of impact to the environment.

Pressure	Definition
Abrasion/damage	The physical injury to marine life through benthic construction, dumping, dredging, and other industrial activity.
Artificialization of habitat	The alteration of habitat through the introduction of anthropogenic structures such as foundations through the water column and scour or cable protection.
Barrier to species movement	An anthropogenic structure that inhibits the normal migration or daily movement of marine life such as turbines and foundations.
Changes in siltation	The suspension of sediment into the water column increasing turbidity which limits visual acuity and when settles could smother benthic marine life.
Death or injury by collision	The mortality or injury of marine life because of anthropogenic structures such as moving turbines.
Electromagnetic change	The introduction of magnetic fields due to electric currents carried in underwater cables. As cables are buried, the electric fields will be shielded by the cable and the focus will be magnetic fields produced by AC currents in inter-array cables. The electromagnetic field can be detected10 – 50 m from the source (Gill & Desender, 2020; Hutchison et al., 2018).
Input of light	The introduction of light through navigational lights of turbine structures. Assumption that the lights are motion censored for vessel and air traffic (as is best practice) and the light travels up to 40 km from the wind turbine (Sullivan et al., 2013).

Introduction of non-indigenous species	The transportation and introduction of alien species to a new environment through ballast water or biofouling of vessels.
Introduction of synthetic compounds	A manufactured substance that is introduced to the environment through the leaking of mechanical fluids from turbines.
Noise (underwater or other)	The increase of environmental noise through anthropogenic activity. Assumption that noise from seismic testing covers the OSW farm area, pile-driving noise travels 2.5 km from the pile and damaging operational noise travels 10 m from the turbine (MacLean et al., 2013).
Salinity changes	The alteration of ocean salinity level through anthropogenic-induced mixing which increases upwelling in the wake of wind turbines (Dorrell et al., 2022; Floeter et al., 2017, 2022).
Secondary entanglement	The entanglement of marine debris on a foundation that could subsequently entangle marine life.
Thermal changes	The alteration of sea surface temperature and the thermocline due to anthropogenic-induced mixing which increases upwelling in the wake of wind turbines (Dorrell et al., 2022; Floeter et al., 2017, 2022).
Water flow rate changes	Changes in the movement of water because of the structures introduced to the ecosystem such as monopile foundations (Dorrell et al., 2022; Floeter et al., 2017, 2022).

Appendix 2: Draft Risk Statements

Appendix 2 includes all draft risk statements for potential activity-pressure interactions that were not included in the analysis. Justification is given in the subtext below each statement describing its exclusion, with reasonings such as unclear relationships to OSW, minimal impacts to CPs, and the use of proxies to estimate impacts. Statements are organized by OSW phase, the activity, and by pressure.

1. Construction

1.1 Tower installation

If an interaction occurs involving seabirds and death or injury by collision due tower installation, the consequence could result in seabird mortality and reduced fitness (Bennun et al., 2021).

- Collision risk assessed during active turbine operation.

2. Operation

2.1 Active turbines

2.1.1 Artificial light

If an interaction occurs involving biodiversity and artificial light due to active turbines, the consequence could result in influence on the behaviour of zooplankton, fish, and birds (Gaston et al., 2014).

- The amount of light is unlikely to interfere on a biodiversity scale.

2.1.2 Introduction of synthetic compounds

If an interaction occurs involving primary producers and the introduction of synthetic compounds, the consequence could result in changes to environmental conditions that limit growth or could cause toxicity (Kirchgeorg et al., 2018).

- Negligible risk according to research on synthetic compound leaks from OSW equipment (Kirchgeorg et al., 2018).

2.2 Foundations

2.2.1 Artificialization of habitat

If an interaction occurs involving primary producers, zooplankton, and ichthyoplankton and artificialization of habitat due to foundations, the consequence could result in an increased predation due to an influx of filter feeders (Maar et al., 2009).

- An environmental assessment on a young wind farm in the North Sea noted that there was no decline in phytoplankton after the construction of a wind farm (DONG Energy, 2006).

If an interaction occurs involving benthic invertebrates and artificialization of habitat due to foundations, the consequence could result in a change in the pelagic community due to benthic invertebrates creating an artificial reef on the foundation and an attraction to scour protection around the base (De Mesel et al., 2015; Degraer et al., 2020; Ivanov et al., 2021).

- Literature is inconclusive on how impactful this is.

If an interaction occurs involving Atlantic cod and artificialization of habitat due to foundations, the consequence could result in an increase in habitat for species that prefer rocky areas, like Atlantic cod, without reducing the number of sand dwelling residents (Bergström et al., 2013; Dannheim et al., 2020; Krone et al., 2013; Love et al., 2017; Stenberg et al., 2015; van Hal et al., 2017; D. H. Wilber et al., 2022).

- No clear negative impacts to conservation objectives.

2.2.2 Barrier to species movement

If an interaction occurs involving cetaceans and barrier to species movement due to foundations, the consequence could result in a change to cetacean habitat use, potentially avoiding key feeding and nursing environments (Beauchamp et al., 2009, 2009; Quintana-Rizzo et al., 2021).

- Cetaceans can avoid the foundations and have a wide habitat use, so it will not be impactful.

2.2.3 Flow rate changes

If an interaction occurs involving cetaceans and water flow rate changes due to foundations, the consequence could result in cetaceans, specifically baleen whales, to experience disruptions to food availability and habitat as there could be changes to primary productivity (Daewel et al., 2022; Dorrell et al., 2022; Floeter et al., 2017; Ivanov et al., 2021; Rivier et al., 2016; Vanhellemont & Ruddick, 2014).

- Considered the impact to primary producers as a proxy.

2.2.4 Introduction of non-indigenous species

If an interaction occurs involving benthic invertebrates and the introduction of non-indigenous species due to foundations, the consequence could result in increased competition for ideal habitat, food, or increased predation (De Mesel et al., 2015).

- Interaction facilitated through vessel ballast water exchange regulations which is extraneous to OSW and beyond the scope of the study.

2.2.5 Salinity change

If an interaction occurs involving primary production and salinity change due to foundations, the consequence could result in an increase in primary production due to the reduction in stratification and increased mixing changing the productivity in the upper portion of the water column (Daewel et al., 2022; Dorrell et al., 2022; Floeter et al., 2017; van Berkel et al., 2020).

- Literature is inconclusive whether this will increase or reduce primary production and what the impacts are.

2.2.6 Secondary entanglement

If an interaction occurs involving benthic invertebrates and secondary entanglement due to foundations, the consequence could result in injuries often leading to mortality for bivalves and crabs (Good et al., 2010).

- Secondary entanglement is highly unlikely and is not directly linked to OSW itself.

If an interaction occurs involving benthic Atlantic cod and secondary entanglement due to foundations, the consequence could result in compromised mobility and or vision, increasing the vulnerability to predation of fish (Good et al., 2010).

- Secondary entanglement is highly unlikely and is not directly linked to OSW itself.

If an interaction occurs with cetaceans and secondary entanglement due to foundations, the consequence could result in impaired feeding, lower fecundity, and mortality (Dolman & Brakes, 2018; Glass et al., 2008).

- Secondary entanglement is highly unlikely and is not directly linked to OSW itself.

2.2.7 Thermal changes

If an interaction occurs involving primary production and thermal changes due to foundations, the consequence could result in a reduction, increase, or temporal change to primary production (Daewel et al., 2022; Dorrell et al., 2022; Floeter et al., 2017; Ivanov et al., 2021).

- Literature is inconclusive whether this would increase or reduce primary production.

2.3 Active cables

2.3.1 Abrasion/damage

If an interaction occurs involving benthic invertebrates and abrasion/damage due to active cables, the consequences could result in injury or death by crushing (Petersen & Malm, 2006; Taormina et al., 2018).

- Cables are buried in the sediment, therefore there is no ongoing risk of abrasion/damage due to cable movement on seabed.

2.3.2 Artificialization of habitat

If an interaction occurs involving benthic invertebrates and artificialization of habitat due to active cables, the consequence could result in an increase in local invertebrate biodiversity due to attraction to clast or scour protection around the structure (Z. Hutchison et al., 2020; Thatcher et al., 2023).

- Literature is inconclusive of how impactful this is, either negatively or positively.

If an interaction occurs involving Atlantic cod and artificialization of habitat due to active cables, the consequence could result in an increase in habitat for species that prefer rocky areas, like Atlantic cod, without reducing the number of sand dwelling residents (Bergström et al., 2013; Dannheim et al., 2020; Krone et al., 2013; Love et al., 2017; Stenberg et al., 2015; van Hal et al., 2017; D. H. Wilber et al., 2022).

- No clear negative impacts to conservation objectives.

Appendix 3: Binning Tables for Assessing Risk Parameters

Note to readers:

The tables below are components of an ecological risk assessment method designed to support *Oceans Act* MPA establishment. In March 2023, this particular risk assessment method was approved for use by DFO's marine planning and conservation program. It has yet to be published because it is part of a larger guidance document that is currently still under development. Minor modifications that continue to align with the approved risk assessment method may be made to these tables as the guidance document is finalized. DFO aims to finalize the guidance document in 2024.

Impact Risk

Table 1: Spatial overlap categories (adapted from Borgwardt et al. 2019) calculated with GIS.

CATEGORY	SCORE	DESCRIPTION
Widespread – even	1	The activity-pressure overlaps with the conservation priority by **between 50 and 100%** of the area occupied by the conservation priority in the AOI, and is **evenly distributed** across that area
Widespread – patchy	0.67	The activity-pressure overlaps with the conservation priority by **between 50 and 100%** of the area occupied by the conservation priority in the AOI, but the distribution within that area is **patchy**
Local	0.37	The activity-pressure overlaps with the conservation priority by **between 5 and 50%** of the area occupied by the conservation priority in the AOI
Site	0.03	The activity-pressure overlaps with the conservation priority by up to **5% of the area** occupied by the conservation priority in the AOI
Exogenous	0.01	The activity-pressure occurs outside of the area* occupied by conservation priority, but one or more of its pressures would reach the conservation priority **through dispersal.** *The activity is still one that is within the AOI boundary

Table 2: Temporal overlap categories (adapted from Knights et al. 2015)

CATEGORY	SCORE	DESCRIPTION
Frequent	1	Where the activity and the conservation priority overlap: a. daily (throughout the year); or b. continuously for 9 months of the year or more and the probability of interaction between the pressure and the conservation priority is high (>50%).

Common	0.67	Where the activity and the conservation priority overlap: a. weekly to monthly (throughout the year); or b. continuously for 4 to 8 months of the year; and the probability of interaction between the pressure and the conservation priority is high (>50%). OR Where the activity and conservation priority overlap is *frequent*, but the probability of interaction between the pressure and the conservation priority is moderate (>20% and <50%).
Occasional	0.33	Where the activity and the conservation priority overlap: a. quarterly to annually; or b. continuously for less than 4 months of the year; or and the probability of interaction between the pressure and the conservation priority is high (>50%). OR Where the activity and conservation priority overlap is *frequent*, but the probability of interaction between the pressure and the conservation priority is low (<20%). OR Where the activity and conservation priority overlap is *common*, but the probability of interaction between the pressure and the conservation priority is moderate (>20% and <50%).
Rare	0.08	Where the activity and the conservation priority overlap: a. not every year, or b. continuously for less than 1 month, and the probability of interaction with the conservation priority is high (>75%) or moderate (>20% and <50%). OR Where the activity and conservation priority overlap is *common*, but the probability of interaction between the pressure and the conservation priority is low (<20%). OR Where the activity and conservation priority overlap is *occasional*, but the probability of interaction between the pressure and the conservation priority is low (<20%) or moderate (>20% and <50%).
*Very rare	0.01	Where the activity and the conservation priority overlap: a. every 5 years or less frequently, or

b. due to an accidental event or abnormal operations,

and the probability of interaction between the pressure and the conservation priority is high (>75%).

OR

Where the activity and conservation priority overlap is *rare*, but the probability of interaction between the pressure and the conservation priority is low (<25%).

Table 3: Exposure binning table.

SPATIAL OVERLAP DESCRIPTOR	**SPATIAL OVERLAP SCORE** [SO]	**TEMPORAL OVERLAP DESCRIPTOR**	**TEMPORAL OVERLAP SCORE** [TO]	**EXPOSURE SCORE** [SO X TO]	**BINNED EXPOSURE**
Exogenous	0.01	Very rare	0.01	0.0001	Very low
Site	0.03	Very rare	0.01	0.0003	
Exogenous	0.01	Rare	0.08	0.0008	
Site	0.03	Rare	0.08	0.0024	
Exogenous	0.01	Occasional	0.33	0.033	Low
Local	0.37	Very rare	0.01	0.0037	
Exogenous	0.01	Common	0.67	0.0067	
Widespread - patchy	0.67	Very rare	0.01	0.0067	
Site	0.03	Occasional	0.33	0.0099	Moderate
Exogenous	0.01	Frequent	1.00	0.0100	
Widespread - even	1.00	Very rare	0.01	0.0100	
Site	0.03	Common	0.67	0.0201	
Local	0.37	Rare	0.08	0.0296	
Site	0.03	Frequent	1.00	0.0300	Moderately high
Widespread - patchy	0.67	Rare	0.08	0.0536	
Widespread - even	1.00	Rare	0.08	0.0800	

Local	0.37	Occasional	0.33	0.1221	
Widespread - patchy	0.67	Occasional	0.33	0.2211	High
Local	0.37	Common	0.67	0.2479	
Widespread - even	1.00	Occasional	0.33	0.3300	
Local	0.37	Frequent	1.00	0.3700	
Widespread - patchy	0.67	Common	0.67	0.4489	
Widespread - patchy	0.67	Frequent	1.00	0.6700	
Widespread - even	1.00	Common	0.67	0.6700	
Widespread - even	1.00	Frequent	1.00	1.0000	

Table 4: Severity (adapted from Knights et al. 2015)

CATEGORY	SCORE	DESCRIPTION
HIGH	1	• The conservation priority (exposed individuals and populations) has low resistance to the pressure. • The pressure has been shown to cause mortality for a large proportion of exposed individuals and/or other severe perturbation, including after a single interaction or short duration exposure.
MODERATE	0.1	• The conservation priority (exposed individuals and populations) has moderate resistance to the pressure. • The pressure has been shown to cause severe perturbation after repeated interactions or sustained exposure at high enough levels.
LOW	0.01	• The conservation priority (exposed individuals and populations) has a high resistance to the pressure. • The pressure may in some cases cause some detrimental perturbation after very long-term exposure at high enough levels.

Table 5: IR binning table

BINNED EXPOSURE LEVEL	SEVERITY DESCRIPTOR	IMPACT RISK (IR) BINNED LEVEL
High	High	High
High	Moderate	
Moderately High	High	
Moderately High	Moderate	Moderately high
Moderate	High	
Moderate	Moderate	
Low	High	
High	Low	Moderate
Moderately High	Low	
Low	Moderate	
Very low	High	
Moderate	Low	Low
Low	Low	
Very low	Moderate	
Very low	Low	

Recovery Lag

Table 6: Persistence (adapted from Borgwardt et al. 2019)

CATEGORY	SCORE	*PERSISTENCE (YEARS)*	DESCRIPTION
CONTINUOUS	1	*10*	The pressure takes more than 10 years to disappear, or never leaves the system, after the activity stops.
HIGH	0.55	*5.5**	The pressure takes 1 to 10 years to disappear after the activity stops.
MODERATE	0.06	*0.6**	The pressure takes weeks to a year to disappear after the activity stops.
LOW	0.01	*0.1**	The pressure dissipates instantly or in less than a week after the activity stops.

Table 7: Resilience categories.

RESILIENCE				
	DESCRIPTIONS			
Categories	**High**	**Moderate**	**Low**	**None**
Score	1	0.55	0.06	0.01
COSEWIC status	No status / Not at Risk	Special Concern	Threatened	Endangered
Sustainable Fisheries Framework	fish stock in Healthy Zone	fish stock at or near Target Reference Point (TRP)	fish stock in Cautious Zone	fish stock in Critical Zone
Species Recovery Factors (adopted from O et al. 2015)				
Fecundity The population-wide average number of offspring produced by a female each year	>100,000	100-100,000	<100	
Breeding strategy Winemiller's index (1989) method	<1	1 to 3	>3	
Recruitment pattern success frequency	>75%	10-75%	<10%	
Natural mortality rate instantaneous mortality rate	>0.4	0.2-0.4	<0.2	
Age at maturity Age of sexual maturation (i.e., age at which reproduction may begin	<2 years	2-4 years	>4 years	
Life stage the life stage(s) affected by a stressor	Not affected or only mature stages	Only immature stages	All stages	
Population connectivity realized exchange with other populations	Regular (not a distinct DPS or ESU)	occasional	Negligible (DPS or ESU)	
Habitat recovery from bottom trawl and dredging **(CSAS 2006/057)**	Less consolidated coarse sediments in areas of high natural disturbance show fewer initial effects, recovery is also faster.		More stable biogenic, gravel, and mud habitats experience the greatest change and have the slowest recovery rates	

Table 8: Resilience binning table when information is available on recovery time (Pedreschi et al., 2023).

CATEGORY	SCORE	DESCRIPTION
NONE	1	Population expected to go locally extinct, or recovery expected to take over 100 years.
LOW	0.55	The population will take between 10-100 years to recover
MODERATE	0.06	The population will take between 2-10 years to recover.
HIGH	0.01	The population will take between 0-2 years to recover.

Table 9: Recovery lag binning table.

RESILIENCE DESCRIPTOR	PERSISTENCE DESCRIPTOR	RECOVERY LAG (RL) BINNED LEVEL
None	Continuous	High
None	High	
None	Moderate	
None	Low	
Low	Continuous	
Low	High	
Low	Moderate	Moderately High
Low	Low	
Moderate	Continuous	
Moderate	High	
High	Continuous	Moderate
High	High	
Moderate	Moderate	
Moderate	Low	
High	Moderate	Low
High	Low	