Identifying potential spatial use conflicts between the commercial fishing industry and offshore wind development in the Scotian Shelf-Bay of Fundy planning area

By

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TABLE OF CONTENTS

TABLES

FIGURES

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

ABSTRACT

Offshore wind (OSW) is beginning to emerge as a major player within the Nova Scotia renewables sector as the province moves to fulfil its commitment of net-zero emissions by 2050. The addition of OSW as a new use in the ocean introduces a risk of spatial conflict with the various pre-existing uses including commercial fishing, shipping, and aquaculture. Ocean planning tools such as Marine Spatial Planning (MSP) seek to consider the needs and requirements of the various users so that potential spatial conflicts can be identified and proactively avoided. Using a two-staged approach this study sought to effectively integrate tools within the greater MSP process to address the potential spatial conflict between future fixed-base OSW development in Nova Scotia's offshore and the commercial fishing industry. The first stage of this project used a case study analysis to glean insights related to the OSW planning and siting process of other national jurisdictions. The second stage of this study was a spatial analysis that used the software Marxan to identify areas with high or low potential for spatial conflict between future OSW development and the commercial fishing industry. This study provides a framework for how the decision support tool Marxan can be used to highlight potential spatial overlap and conflict between future fixed-base OSW development and existing ocean uses in the Scotian Shelf-Bay of Fundy planning area. The results of this study were used to develop a series of recommendations that can inform future research examining potential conflicts between offshore wind and other ocean uses.

Keywords: offshore wind energy; marine spatial planning (MSP); commercial fishing industry; Marxan; spatial conflict; Nova Scotia; Canada

ABBREVIATIONS

AoS	Areas of Search
BOEM	Bureau of Ocean Energy Management
BLM	Boundary length modifier
CA	Characterisation areas
C-NLOPB	Canada-Newfoundland and Labrador Offshore Petroleum Board
C-NSOPB	Canada-Nova Scotia Offshore Petroleum Board
CSAS	Canadian Science Advisory Secretariats
DFO	Fisheries and Oceans Canada
DPO	Draft plan option
EA	Environmental Assessment
IAAC	Impact Assessment Agency of Canada
IMO	International Maritime Organization
LFA	Lobster Fishing Areas
MMO	Marine Management Organisation
MPA	Marine protected area
MSP	Marine spatial planning
NRCan	Natural Resources Canada
NGO	Non-government organization
NUMREPS	Number of repeat runs
OCS	Outer Continental Shelf
OSW	Offshore wind
OECM	Other effective area-based conservations measures
RA	Regional Assessment
RFI	Request for Interest
SA	Sustainability Appraisal
UK	United Kingdom
US	United States
VMS	Vessel Monitoring System
WEA	Wind Energy Area

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1. CHAPTER ONE: INTRODUCTION

1.1. Offshore Wind – A brief history

The increasing threat of global climate change has resulted in a trend of moving away from traditional energy sources such as fossil fuels to more renewable and environmentally friendly energy sources (Bhattacharya, 2019). As a result, in the late 20th century modern wind turbines were developed as a renewable energy source to generate electricity from the kinetic energy of wind (Bhattacharya, 2019). Advancements in turbine technology have led to the expansion from onshore areas to offshore areas for wind energy generation. Offshore wind (OSW) energy generation refers to the generation of electricity by wind turbines located in any body of water (Ng & Li, 2016). The generation of OSW energy has grown in popularity since the early 2000s as offshore areas have been found to have higher and more consistent wind speeds leading to increased energy generation when compared to onshore areas (The Crown Estate, 2021a).

One of the major advancements required to transition from onshore areas to offshore areas was the development of a foundation system that allowed for turbines to be anchored to the seabed. Two different types of turbine technologies have been developed and are currently used for generating OSW energy (Figure 1).

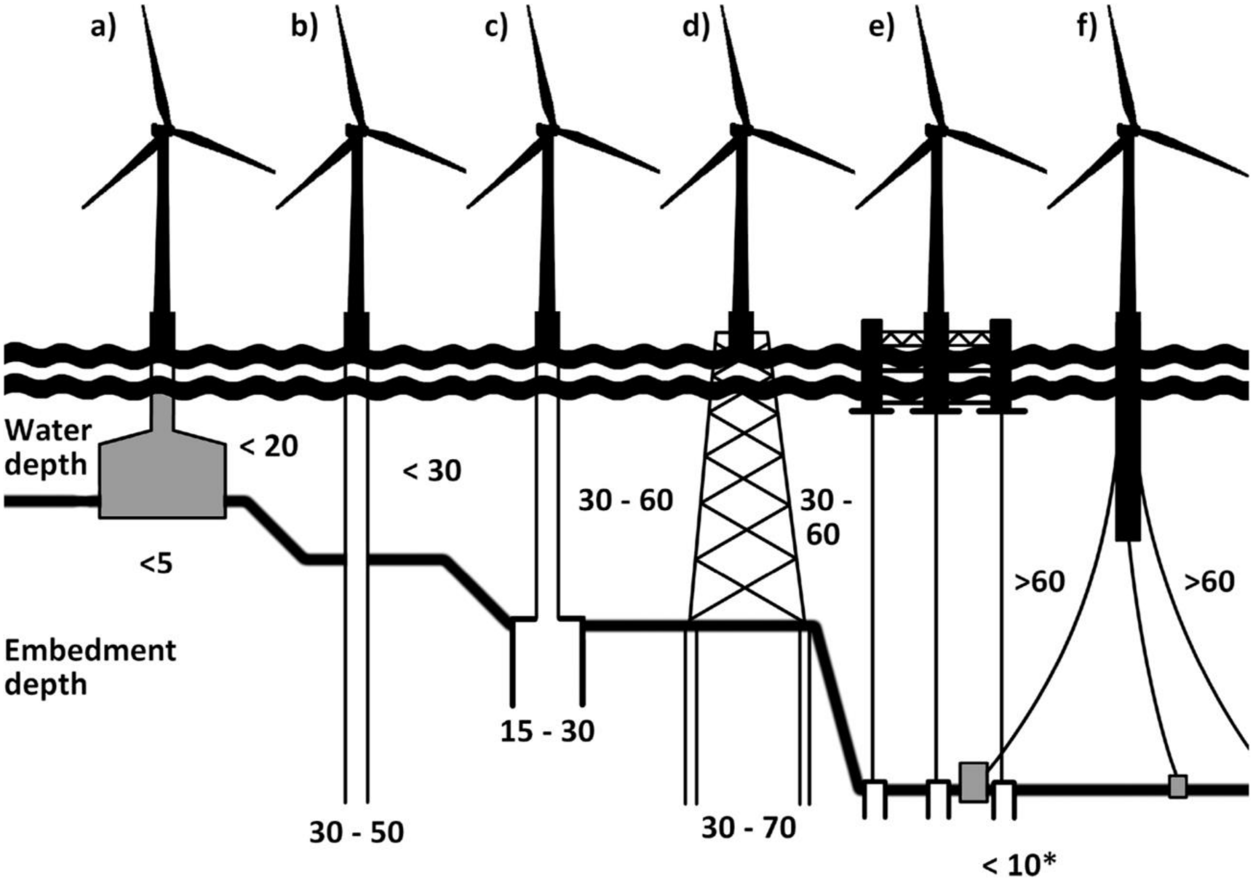

Figure 1. Types of OSW foundation technologies with water and embedment depths in metres. a) Gravity base b) monopile c) suction caisson d) multi-pile (jacket) e) floating – semi-submersible f) floating – spar buoy (Eamer et al., 2021).

The first is commonly referred to as a fixed-base or fixed-foundation turbine, which uses a support structure that is physically anchored to the seabed (Figure 1a-d). Fixed-base OSW turbines are the most common type of turbine accounting for 99.8% of the installed global capacity (Musial et al., 2022). Fixed-base OSW turbines can be classified into four main categories: gravity-based, monopiles, suction caissons, or multi-piles. Gravity-based foundations consist of a large heavy structure that rests on the seabed providing support for the turbine to prevent uplifting or overturning. Gravity-based foundations are typically installed in water between 5-20 m in depth and require a marine soil with high bearing capacity (Eamer et al., 2022; Ng & Li, 2016). Monopile foundations consist of a single large steel pile that is driven 30-50 metres (m) into the seabed to support the turbine. Monopile foundations are typically installed in water depths of less than 30 m and require thick deposits (>25 m) of silt or sand (Eamer et al., 2022; Ng & Li, 2016). Suction caisson foundations consist of a large open bottom cylinder that is attached to monopile or multi-pile turbines to act as an additional anchor through negative pressure. Suction caissons are typically installed in water between 30-60 m in depth in areas with low wave action due to the risk of uplifting (Eamer et al., 2022). Multi-piles (also referred to as jacket foundations) consist of multiple large steel piles that are driven 30-70 m into the seabed to support the turbine (Ng & Li, 2016). Multi-piles are typically installed in water depths of 30-60 m and require thick deposits of sand or silt (Eamer et al., 2022).

The second type of turbine foundation is commonly referred to as a floating foundation turbine where the turbine floats on the surface of the water column while anchored to the seabed through a mooring system (Figure 1e-f) (Ng & Li, 2016). Floating foundation OSW turbines are generally considered a pilot or demonstration technology with limited use globally (Eamer et al., 2022). As floating foundation OSW turbines are still a pilot technology the suitability constraints are not yet as defined as fixed-based OSW turbines. However, floating foundation OSW turbines can be installed within an estimated depth range of 35 – 1000 m depending on the technology (Carbon Trust, 2015).

OSW has become one of the fastest-growing sources of renewable energy around the globe with an estimated total energy generation capacity of 48.2 gigawatts (GW) as of 2021 (The Crown Estate, 2021a). The rapid growth seen within the OSW industry can be associated with various technological advancements that have increased the feasibility and capability of OSW turbines (Musial et al., 2022; O’Sullivan et al., 2021). Over the last 20 years, there has been a trend of increasing both the rotor diameter and hub height of OSW turbines leading to increased generation capacity defined as maximum electrical output per turbine (Musial et al., 2022). As of 2021, the average generation capacity per turbine was 7.4 MW with an average rotor diameter of 156.1 m and a hub height of 99.6 m (Musial et al., 2022). Additionally, over the last 20 years, various technological advancements have led to increasing both the distance from shore and the depth of OSW turbine development sites (Musial et al., 2022). OSW turbines around the globe were located on average 60 km from shore at a depth of 40 m in 2021 (Musial et al., 2022).

1.2. The Canadian Context

In Canada, various federal and provincial commitments have been made to reduce greenhouse gas emissions to help combat global climate change. The Government of Canada has committed to reducing the country's greenhouse gas emissions to 40% below the 2004 emission levels by 2030 (Government of Canada, 2022). On a provincial level, Nova Scotia has committed to having 80% of the province's electrical needs supplied by renewable sources by 2030 and attaining net zero emissions by 2050 (Environment and Climate Change, 2021). As of 2019, only 25% of energy generation within Nova Scotia is from renewable sources with coal accounting for 51% of the total energy generation (Canada Energy Regulator, 2022). To meet provincial and federal commitments the renewable energy sector needs to see substantial growth in the near future. Due to Nova Scotia's large coastline and ideal wind conditions (defined as average wind speeds greater than 7 m/s at 100 m above sea level), OSW offers an opportunity for Nova Scotia to generate significant amounts of renewable energy to help meet its renewable energy commitments and targets (Tang & Kilpatrick, 2021).

To achieve net zero emission goals and stimulate economic growth the Government of Canada developed the Hydrogen Strategy for Canada as a framework to prioritize the production and international export of green hydrogen as an alternative fuel source (NRCan, 2020). Hydrogen as a compressed gas or liquid contains a high amount of energy per mass making it an ideal fuel source to be generated for export (NRCan, 2020). Green hydrogen differs from conventional hydrogen generation as it is produced using electricity generated by renewable sources such as OSW energy instead of traditional greenhouse gas-emitting energy sources (NRCan, 2020). Globally the market for green hydrogen is rapidly expanding and is expected to be worth an estimated 2.5 trillion dollars by 2030 (NRCan, 2020). As a result, in addition to contributing to net-zero emission goals, OSW provides economic opportunities through its role in contributing to the international export of green hydrogen (Canada Energy Regulator, 2022).

Currently, there are no active OSW operations in Nova Scotia or Canada. However, recent federal and provincial announcements signal that OSW development in Atlantic Canada is being explored. Among these is the planned expansion of the Canada-Nova Scotia Offshore Petroleum Board's (C-NSOPB) mandate to include OSW by becoming the Canada-Nova Scotia Offshore Energy Board (C-NSOEB), an announcement made by the federal and provincial governments in April 2022 (NRCan, 2022). The announcement to transition the C-NSOPB to the C-NSOEB would expand the board's authority into the role of renewable energy regulator within the Nova Scotia offshore Accord Area (NRCan, 2022). The second key announcement, made in

April 2022, by the Impact Assessment Agency of Canada (IAAC), was the intent to conduct a Regional Assessment (RA) to evaluate OSW development in Newfoundland and Labrador and Nova Scotia (IAAC, 2022a). The goal of the RA is “to provide information, knowledge and analysis regarding future offshore wind development activities … to inform and improve future planning, licencing, and impact assessment processes (IAAC, 2022b).” Finally, in September 2022, the province of Nova Scotia announced a target to offer leases for 5 GW of OSW energy generation capacity by 2030 (Province of Nova Scotia, 2022).

As mentioned previously, OSW development in Nova Scotia will be regulated by the C-NSOPB once the board’s mandate is expanded to include the regulation of offshore renewable energy development. The C-NSOPB is an independent joint agency of the Government of Canada and the Government of Nova Scotia established through the Canada – Nova Scotia Offshore Petroleum Resources Accord Implementation Act (1988) and the Canada-Nova Scotia Offshore Petroleum Resources Accord Implementation (Nova Scotia) Act (1987). Natural Resources Canada (NRCan), through the arm of the Canada Energy Regulator, regulates offshore renewable energy projects within federal jurisdiction (Canadian Energy Regulator Act, 2019). The Government of Nova Scotia through the Department of Natural Resources and Renewables, regulates energy resource projects within provincial jurisdiction (Marine Renewable Energy Act, 2015). Under the Accord Implementation Acts, the governments of Canada and Nova Scotia publish mirrored regulations to further define requirements specific to oil and gas activity in the Canada-Nova Scotia offshore area.

1.3. Marine Activities in Nova Scotia

Nova Scotia is one of five provinces located on the Atlantic coast of Canada. As of 2021, approximately 80% of Nova Scotia’s population lived within 10 km of the coast (Ganter et al., 2021). As a result, the offshore and coastal areas of Nova Scotia have become spatially busy with a variety of user groups (Maclean et al., 2013). Nova Scotia has a substantial marine sector that employs over 60,000 people across various industries contributing upward of six billion dollars to the Nova Scotian gross domestic product (Ganter et al., 2021). The marine sector of Nova Scotia is diverse with various contributors including commercial fishing, aquaculture, offshore oil and gas, ports and shipping, ocean and coastal tourism, maritime defence, ship and boat building, and submarine cables (Ganter et al., 2021; Maclean et al., 2013). In addition to the marine sector, there are various other uses of the coastal and offshore marine space including recreational fishing, sailing, boating, surfing, snorkelling, scuba diving, research and monitoring, and areas designated for conservation (Breeze et al., 2005; Maclean et al., 2013).

The introduction of new ocean uses or users can result in spatial conflict with these pre-existing activities. The introduction of offshore energy industries such as OSW due to their relatively large spatial footprints presents a challenge when considering issues such as spatial conflict (De Groot et al., 2018). For example, the largest OSW farm (Hornsea 2) located in the North Sea off the United Kingdom, became operational in 2022 with 163 turbines, a generation capacity of 1.2 GW, and a spatial footprint of approximately 460 km^2 (Orsted, 2022). Additionally, due to the high costs associated with operating in the marine space, energy projects such as OSW tend to develop in the nearshore areas close to city centres to reduce transmission and operation costs (De Groot et al., 2018). These areas, although perceived as ideal for development, tend to be areas with the highest density of existing ocean users increasing the likelihood of issues such as spatial conflict (De Groot et al., 2018).

The commercial fishing industry is a key group of existing ocean users in Nova Scotia with livelihoods that are directly dependent on access to large ocean areas. As a result, it has been suggested that commercial fishing is the user group that is most likely to be negatively impacted by OSW development (De Groot et al., 2018; Gray & Haggett, 2005; Yates & Schoeman, 2013). Impacts may be felt through loss of access to important fishing grounds, reduced catch during construction and operation phases, negative impacts on fish and fish habitat, and loss or damage of fishing gear (De Groot et al., 2018). In some cases, a lack of acceptance and social licence among the commercial fishing industry can negatively impact development through organized protests and legal action (De Groot et al., 2018). For example, new ocean industries (such as tidal energy) have faced legal opposition from some fishing groups due to potential spatial conflict (De Groot et al., 2018). Therefore, the commercial fishing industry is of particular interest when evaluating how the introduction of OSW could impact existing ocean users in Nova Scotia.

1.4. Commercial Fishing Industry

The establishment of a commercial fishing industry is thought to have occurred in the mid-1500s after European settlers became aware of Atlantic fish stocks. By the early 1700s, a substantial commercial fishery primarily exporting cod, mackerel, and herring was established with participation from various international fleets such as Spain, France, Portugal, and England (Lear, 1998; Maclean et al., 2013). The value of this resource eventually led to various European settlements in Atlantic Canada (Lear, 1998). Total commercial fishing landings from the area peaked in 1973 exceeding over 750,000 tonnes from the Scotian Shelf alone (Maclean et al., 2013). However, in September 1993 region-wide fisheries closures were implemented for many of the commercially important groundfish species including cod and haddock due to major stock collapses (Maclean et al., 2013). Despite the closures, the commercial fishing industry has since diversified and now targets over 30 species and continues to play an important economic and cultural role within the region (Maclean et al., 2013). Nationally, Nova Scotia has the single highest value of commercial landings of all provinces accounting for approximately 38% of Canada's total value landed in 2019 (DFO, 2022a).

Within Nova Scotia, the commercial fishing industry is a major source of both direct and indirect employment and income which is of particular importance to the province due to the rural nature of the industry (Gardner et al., 2005). As of 2019, the province had nearly 6000 licence holders with the total value of commercial landings being upwards of 1.5 billion dollars (DFO, 2021a, 2022a). Shellfish accounted for nearly 88% of the total value of commercial landings for the province primarily from lobster (67%), snow crab (13%), and scallop (11%) (DFO, 2022a). Groundfish and pelagic species accounted for approximately 12% of the total value of commercial landings including species such as halibut, haddock, herring and swordfish (DFO, 2022a).

There are two main categories of fishing gear currently used by the Nova Scotia commercial fishing industry. The first category referred to as mobile gear includes fishing gear that is towed to catch the targeted species. The mobile gear classification encompasses trawls (side, otter, bottom, or beam) certain types of seines (Danish, Scottish, or purse), or dredges (DFO, 2018a, 2021b; Rozalska & Coffen-Smout, 2020). In Nova Scotia, the mobile gear commercial fishing fleet primarily targets various species of groundfish (halibut, haddock, pollock, cod, flatfish, redfish, silver hake, and others), shrimp, scallop, mackerel, and herring (DFO, 2018a, 2021b; Rozalska & Coffen-Smout, 2020). The second category often referred to as fixed gear includes fishing gear that is set in a stationary position to catch the targeted species (DFO, 2018a). The fixed gear classification encompasses certain types of seine (beach, bar, or tuck), gillnet, traps (all varieties), pots, rod and reel, harpoon, spear, and handline (DFO, 2018a, 2021b; Rozalska & Coffen-Smout, 2020). In Nova Scotia, the commercial fixed-gear fishing fleet primarily targets groundfish (halibut, haddock, cod, pollock, hake), crab, lobster, tuna, and swordfish (DFO, 2018a, 2021b; Rozalska & Coffen-Smout, 2020).

1.5. Marine Spatial Planning

Marine space in Canada is regionally diverse with varying ecological, social, and political considerations resulting in a complex ocean management process (Chircop & O'Leary, 2012). Additionally, within Canada jurisdiction is highly fragmented with various federal agencies, provincial governments, and indigenous groups asserting claims related to ocean management (Chircop & O'Leary, 2012). As a result, in the absence of a defined spatial planning process, the addition of new ocean activities can result in conflicting spatial overlap. For example, in 2017 the Northeastern Newfoundland Slope Closure was established as a marine refuge with the conservation objective of "protecting corals and sponges and contributing to the long term conservation of biodiversity (DFO, 2019b)." However, in September 2019, the Canada-Newfoundland and Labrador Offshore Petroleum Board (C-NLOPB) published a call for nominations for oil and gas exploration within the geographical boundaries of the marine refuge (WWF, 2019). The decision to release a call for nominations within the boundaries of a marine refuge was met with various voices of opposition with many claiming incompatibility between these ocean uses (WWF, 2019).

Effective planning of the marine space is a strategy to address potential spatial overlaps and conflicts associated with the addition of new ocean uses and users. For example, multi-objective planning is being used by DFO Maritimes region as a strategy to plan and implement a marine protected area (MPA) network plan for the Scotian Shelf-Bay of Fundy bioregion (King et al., 2021). The multi-objective planning process has included various stages of inter-departmental coordination, spatial planning, and stakeholder and public engagement (King et al., 2021). The process has also included an intensive spatial analysis component that was designed to select areas that meet conservation objectives while considering various human use activities to design a network plan that reflects a balance between conservation targets and socioeconomic objectives (Serdynska et al., 2021). Human use activities included in the spatial analysis component were commercial fishing, shipping, and oil and gas exploration and development (King et al., 2021; Serdynska et al., 2021).

Marine spatial planning (MSP) is another ocean management strategy with international recognition that can be used to accomplish transparent, inclusive, and sustainable ocean planning (DFO, 2021c). The Government of Canada has committed to advancing MSP across the country (DFO, 2019a). MSP is being co-developed by various federal and provincial agencies, with Fisheries and Oceans Canada (DFO) occupying the lead role (DFO, 2019a). MSP is an approach to ocean management that seeks to consider Canada's vast ocean space, jurisdictional complexity, and the rights and interests of rightsholders, stakeholders and partners (DFO, 2023). MSP can be used to guide the sustainable use of the ocean to achieve shared ecological, economic, cultural and social objectives (DFO, 2023). With the rapid growth of the OSW industry MSP has been applied in many jurisdictions around the world to address some of the complications and potential issues associated with new ocean uses (European Commission, 2022). As the likelihood of OSW development increases in Nova Scotia, an MSP approach can be used to address some of the potential concerns by reducing spatial conflict between activities, increasing transparency for the private sector, and continuing to advance conservation objectives (DFO, 2018b).

1.6. Management Problem

As the world transitions away from non-renewable energy sources to help combat global climate change the renewable energy sector is expected to see substantial growth. OSW energy generation appears to be a likely candidate for significant expansion within the coastal and offshore areas of Nova Scotia over the foreseeable future. In the absence of a defined planning process, the addition of OSW as a new use of marine space is likely to result in spatial overlap and conflict with the various pre-existing ocean activities including the commercial fishing industry. Therefore, the potential spatial conflict between the existing commercial fishing industry and future OSW development in Nova Scotia presents a key management problem. To address this management problem, this project sought to answer the following research question:

What areas of the Scotian Shelf-Bay of Fundy planning area have a low versus a high likelihood of spatial conflict between future OSW development and the existing commercial fishing industry?

Ocean planning tools such as MSP or multi-objective planning have been demonstrated to be effective to help address complex marine management issues such as spatial conflict associated with new ocean uses. Therefore, this project sought to answer the proposed research question using a two-staged approach that effectively integrated tools within the greater MSP and multi-objective process. The first stage of this project consisted of a case study analysis to review the planning and siting processes of multiple national OSW projects. The cases considered were Scotland's ScotWind Project, the United Kingdom's Round 4 OSW Leasing Project, and the Massachusetts OSW leasing process for Bay State Wind and Vineyard Wind. The purpose of this analysis was to gain insights related to the OSW planning and siting processes that have been used in other jurisdictions. The focus of this case study analysis was guided by four main questions.

1) What process was used during the planning and siting stages of OSW development?
2) What spatial analysis tools were used, if any?
3) What commercial fishing data were used to inform the decision-making process?
4) How were commercial fishing data incorporated into the decision-making process?

The second stage of this approach was the design and execution of a novel spatial analysis using the decision support tool Marxan. The Marxan spatial analysis was designed to highlight areas with low or high potential for spatial conflict between future fixed-base OSW development and the commercial fishing industry in the Scotian Shelf-Bay of Fundy planning area. Additionally, the spatial analysis process sought to provide a methodological framework for how the decision support tool Marxan could be used to integrate principles of MSP and multi-objective planning into a complex marine management problem such as OSW planning and siting.

2. CHAPTER TWO: CASE STUDY ANALYSIS

2.1. United Kingdom

The United Kingdom (UK) is a global leader in the offshore wind sector with the second-largest global operating capacity behind only China (The Crown Estate, 2021a). In 2021, the UK had 42 fully operational OSW farms with a total of 2,387 installed turbines and a generation capacity of 11.3 GW (The Crown Estate, 2021a). The UK has committed to increasing its OSW generation capacity by 65-140 GW by 2050 (The Crown Estate, 2021a).

Through the Crown Estate Act (1961), the Crown Estate was established as an independent commercial business by parliament with ownership rights to the seabed within the territorial waters around England, Wales, and Northern Ireland. It is the Crown Estate’s responsibility to award seabed rights for the development of offshore renewable energy, marine mining, carbon capture, cables, and pipelines (The Crown Estate, 2021b). The Scottish Crown Estate Act (2019), established the Crown Estate Scotland as a separate public corporation and the permanent manager of Scotland’s assets (Scottish Government, 2020a). Assets held by the Crown Estate Scotland include the role of awarding seabed leasing rights for Scottish territorial waters and the Scottish zone extending to the 200-nautical mile (M) limit (Scottish Government, 2020b).

2.1.1. Scotland – ScotWind Project

In 2017, the Crown Estate Scotland announced the ScotWind Project as a new round of seabed leasing for the development of OSW projects in Scottish waters (Scottish Government, 2020c). Using a MSP approach the ScotWind Project identified twenty development projects that that have been offered option agreements with an expected generation capacity of nearly 28 GW (The Crown Estate Scotland, 2022). The ScotWind Project process included a spatial analysis, various stages of refinement, and consultation with a target of leasing up to 10 GW of OSW generation capacity (Scottish Government, 2020c).

2.1.1.1. Spatial Analysis

The first step of the ScotWind Project was the identification of Areas of Search (AoS) through a spatial analysis process named the opportunity and constraint analysis (Marine

Scotland, 2018). The opportunity and constraint analysis combined an exclusion model and a constraint model to spatially visualize the cumulative obstacles related to new OSW development. The exclusion model was a single data layer containing the spatial footprint of activities that were identified to be incompatible with OSW development. Activities that were identified as incompatible included existing OSW lease areas, hydrocarbon activity and infrastructure, aquaculture sites, International Maritime Organization (IMO) ship routing and offshore shipping traffic control zones, offshore dumping zones, and mapped ship anchorages (Marine Scotland, 2018).

The constraint model was a single data layer that combined environmental, industrial, socio-cultural, and technical constraints to produce an output that displayed cumulative constraints (Marine Scotland, 2018). The environmental constraints included data layers such as marine protected areas, species density, and seabird vulnerability (Marine Scotland, 2018). The industrial constraints included data layers related to commercial fishing, shipping, aviation, and military (Marine Scotland, 2018). The socio-cultural constraints included recreational and leisure data layers. Finally, technical constraints included depth, slope, wind resource, distance from shore, and sediment layers (Marine Scotland, 2018). All data layers were reclassified into three levels of constraint, assigned a weighting score, and combined using a weighted overlay that produced an overall constraint score for each spatial unit (Marine Scotland, 2018). The constraint model output was combined with the exclusion model output so that any areas included in the exclusion model were removed. Polygons were manually drawn around areas with similarly low levels of constraint and were used as the AoS.

2.1.1.2 Refinement

The second step of the ScotWind Project was the refinement of the AoS through a consultation process and a sustainability appraisal. The initial round of consultation was held for the purpose of identifying single-issue interactions that were more likely to create barriers if OSW development were to take place (Marine Scotland, 2018). To identify single-issue interactions, sectoral engagement workshops were held with key stakeholders that included the OSW industry, non-government organizations (NGOs), the Royal Yachting Associating, and the fishing industry (Marine Scotland, 2018). Additionally, this stage included an open comment session with Scottish Ministers, the Sectoral Marine Plan Project Board, and the two Project

Steering Groups (Scottish Government, 2019a). Single-issue interactions representing a significant barrier to OSW development were identified as specific fishing activities, shipping traffic, nature-protected sites, and oil and gas installations. The AoS were refined so that areas of overlap with single-issue interactions were removed (Marine Scotland, 2018).

The revised AoS were finalized as Draft Plan Options (DPOs) to be used in the public consultation stage. The public consultation process included seventeen public events (Scottish Government, 2020d). The process was open to the public with various stakeholders and sub-groups participating including government officials, members of the general public, NGOs, and various sectors including energy, commercial fisheries, ports and harbors, tourism and recreation, military, oil and gas, and shipping (Scottish Government, 2020d).

A Sustainability Appraisal (SA) was conducted to evaluate the decision-making process used throughout the ScotWind Project to ensure that all relevant environmental and socio-economic information was included and informed the identification of DPOs (Scottish Government, 2019b). The final step in the ScotWind Project was the revision of the DPOs to mitigate various potential negative impacts highlighted by the public consultation process and the SA (Scottish Government, 2020c). As a result, the Sectoral Marine Plan for Offshore Wind Energy identified 15 final plan options for OSW development in Scottish waters (Scottish Government, 2020c).

2.1.1.3. Commercial Fishing Industry Considerations

A singular fisheries data layer mapping the monetary value of catch within the study area was used in the constraint model. The data layer was developed from information gathered through an in-depth interview process that included 1,090 interviews with harvesters (Kafas et al., 2014). Additional spatial considerations were provided to the commercial fishing industry through the identification and exclusion of single-issue interaction fishing activities. Fishing activities identified as single-issue interactions were scallop dredging, nephrops trawling and creeling, demersal trawling, pelagic trawling, and crab and lobster creeling (Marine Scotland, 2018).

The commercial fishing industry was actively involved in the engagement process with various issues, concerns, and opinions related to commercial fishing being highlighted (Scottish

Government, 2020d). Representatives from the commercial fishing industry on many occasions raised concerns related to the impact that OSW development would have on the commercial fishing industry (Scottish Government, 2020d). Concerns were raised related to the loss of access to fishing grounds, lack of clarity surrounding co-location, impact on fish and fish habitat, and the potential for the emotional attachment associated with fishing to outweigh the economic benefit of OSW development (Scottish Government, 2020d). Additional concerns were highlighted specific to the spatial analysis process that was conducted. One common concern among commercial fishing representatives was that the commercial fishing datasets that were used in the spatial analysis only considered 5 years of catch data which was not an accurate representation of the dynamic and fluctuating nature of the commercial fishing industry (Scottish Government, 2020d).

2.1.1.4. Analysis

There are various limitations associated with the use of a weighted overlay as a spatial analysis method to identify OSW site locations for the ScotWind Project. The first and major limitation of a weighted overlay is that individual data layers have a relatively small amount of influence on the overall results. The analysis considered 20 data layers and assigned each data layer a weighting score (Marine Scotland, 2018). Based on the assignment of weighting scores a single data layer could only be provided with a maximum impact of eight percent on the total constraint score (Marine Scotland, 2018). Additionally, another issue that can be associated with a weighted overlay is that the weighting scores and overall influence of each data layer are determined by user-defined weights. The process of defining weighting scores for each data layer can introduce a certain amount of user bias and make it difficult to demonstrate the logic that was applied when assigning the weightings for each data layer. Therefore, an important lesson learned from the ScotWind Project is that the use of a weighted overlay as a spatial analysis process for OSW planning and siting has various limitations which may lower the overall effectiveness of the outcome.

Information gathered during the various stages of consultation in the ScotWind Project had a direct and defined impact on the final OSW leasing areas. The Post Adoption Statement that accompanied the published sectoral marine plan provided an in-depth description of the consultation feedback that was incorporated into the revision process (Scottish Government, 2020e). For example, the Post Adoption Statement described how multiple DPOs were revised to avoid important commercial fishing grounds identified during the consultation process (Scottish Government, 2020e). The inclusion of a document like the Post Adoption Statement provides transparency and accountability related to the decision-making process. Transparency has been identified by multiple guidelines as a key principle for achieving effective MSP (Gopnik et al., 2012; Iglesias-Campos et al., 2021; Yates, 2018). Transparency is central to the development of trust between stakeholders which can encourage and provide a foundation for meaningful engagement (Kerr et al., 2014; Yates, 2018). Additionally, transparency through its connection with accountability plays an integral role in garnishing support and legitimacy related to the eventual outcome of MSP (Gilliland et al., 2008; Gopnik et al., 2012). Therefore, the development of a document that clearly describes what information was gathered from the consultation process and how that information impacted the final outcome can be used as a strategy to increase the effectiveness of the MSP process.

2.1.2. England, Wales and Northern Ireland – Round 4 OSW Leasing Project

In 2017, the Crown Estate announced its intention to award seabed rights for Round 4 of OSW development in the waters of England, Wales, and Northern Ireland (The Crown Estate, 2021b). The Round 4 OSW Leasing Project identified six development projects that are currently in the final lease agreement stage representing nearly 8 GW of generation capacity (The Crown Estate, 2021b). The process of identifying sites for the Round 4 OSW Leasing Project included spatial analysis, stakeholder engagement, and refinement (The Crown Estate, 2021b).

2.1.2.1. Spatial Analysis

The first step of the Round 4 OSW Leasing Project was the identification of characterisation areas (CA) through a resource and constraint analysis (The Crown Estate, 2019a). Similar to the ScotWind Project, the constraint analysis combined a technical resource model with a constraint analysis to identify areas for potential OSW development. The technical resource model was a single data layer used to identify areas of the seabed that had the appropriate technical conditions to support OSW development. Within the technical resource model areas were classified as either favorable, limited, or marginal based on water depth, quaternary sediment thickness, bedrock lithology, accessibility due to wave climate, and other considerations (The Crown Estate, 2019a). Only areas that received a classification of favorable were investigated for potential OSW leasing sites. Areas were considered favorable if water depth was between 5 and 50 m and if access to the site was possible (e.g., wave height less than 2.5 m) for more than 80% of the year (The Crown Estate, 2019a).

The second portion of the resource and constraint analysis was the completion of a constraint analysis for areas that received a technical resource classification of favorable. The constraint analysis combined an exclusion model and a restriction model. The exclusion model was a single data layer that includes the spatial footprint of features that could prevent OSW development from taking place. The exclusion model included safety and navigation zones, shipping routes, existing infrastructure, and existing seabed leases (The Crown Estate, 2019a). The restriction model was a single data layer that used a weighted overlay process to combine various economic, environmental, and social activities that may provide some level of constraint on the development of fixed-base OSW (The Crown Estate, 2019a). Economic activities included navigation and shipping, subsurface activity, and fishing activity (The Crown Estate, 2019a). Environmental activities included designated areas and nursery and spawning grounds (The Crown Estate, 2019a). Social activities included recreational vessel traffic and visibility from designated areas (e.g., National Parks) (The Crown Estate, 2019a). An analytical hierarchical process was used to assign weighted values across the various activities to provide additional transparency in the decision-making process (The Crown Estate, 2019a).

The constraint model was combined with the exclusion model so that any areas included in the exclusion model were removed. The output of combining the models displayed relative constraint values for areas that are favorable for OSW development. The top 50% least constrained areas of the combined model were taken and split into 18 CA by existing MSP boundaries (The Crown Estate, 2019a). A separate document was developed for each of the 18 identified CA. These documents described the various constraining activities and mitigation measures that would need to be considered for OSW development.

2.1.2.2 Refinement

The second step of the Round 4 OSW Leasing Project was the refinement of the CA using information gathered through the consultation process (The Crown Estate, 2019b). The first stage of the consultation process involved 30 statutory stakeholders from 15 organizations including the Marine Management Organisation (MMO), the Welsh Government, National Resources Wales, and the Northern Ireland Department of Environment, Agriculture and Rural Affairs (The Crown Estate, 2019b). The second stage of the consultation process included a series of engagement events between statutory, non-statutory, and industry stakeholders (The Crown Estate, 2019b). The purpose of this stage of engagement was to collect feedback on the 18 CA that were identified by the spatial analysis. During the stakeholder engagement stage, written responses were received from various national departments, commercial fishing agencies, county councils, and conservation agencies (The Crown Estate, 2019b).

Information from the consultation process was compiled and used for regional refinement of the CA (The Crown Estate, 2019c). The first stage of the regional refinement process was the removal of areas that contained activities that were highlighted as incompatible or highly constraining with OSW development during the consultation process. Incompatible or highly constraining activities were identified as Ministry of Defence Practice and Exercise Areas, visually sensitive areas (i.e., areas within 13 km of the coast), and major shipping routes (areas with over 1000 ships per year) (The Crown Estate, 2019c). The second stage of the regional refinement included the modification of the CA to reflect specific stakeholder feedback. The first major modification to the remaining eight CA was extending the regions to include 60 m water depth (The Crown Estate, 2019c). Upon engagement with relevant market stakeholders, it was stressed that due to technological and operational advancements fixed-base OSW turbines are likely to be economically feasible at depths up to 60 m. The second component of site-specific refinement was based on feedback received from other stakeholders during the consultation process. As a result, eight CA were selected from the refinement process to move forward as bidding areas for the Round 4 OSW Leasing Project (The Crown Estate, 2019c).

2.1.2.3. Commercial Fishing Industry Considerations

A singular fisheries data layer mapping fishing intensity in total kilowatt hours was used in the restriction model (The Crown Estate, 2019a). This layer was developed using Vessel Monitoring System (VMS) data from the MMO (The Crown Estate, 2019a). Additional commentary was provided by the Chair of the Fisheries Liaison with Offshore Wind and Wet Renewables. Within the weighted overlay process, the commercial fishing data layer was assigned a lower weighting score when compared to the other economic activities (The Crown

Estate, 2019a). As a result, commercial fishing had a lower overall influence on the output compared to other activities. The lower influence score was deliberate, resulting from the fishing dataset having contained only information on vessels greater than 12 m (The Crown Estate, 2019a).

Commercial fishing including the representation of fishing activity in the spatial analysis was one of the most commonly raised topics across engagement sessions (The Crown Estate, 2019b). The use of historic and long-term fishing data sets rather than a single-year data set was suggested as a more accurate representation of spatial importance for the fishing industry. Additionally, the impact of OSW development on the commercial fishing industry, specifically cumulative impacts on fish and shellfish species, was raised as an issue of concern (The Crown Estate, 2019b). As a result, the fishing industry requested an additional engagement session dedicated to discussing spatially important fishing areas (The Crown Estate, 2019b).

Feedback related to the fishing industry appeared to have little to no impact during the regional refinement process. For example, of the four CA that were modified during the regional refinement only “The Wash” mentions the commercial fishing industry as a constraint (The Crown Estate, 2019c). However, modifications to the boundaries of The Wash were a result of other constraints including oil and gas, navigation, and environmental sensitivities (The Crown Estate, 2019c). The well-established inshore fishing industry did not appear to have any influence on the refinement of the area.

2.1.2.4. Analysis

The temporal scale of the commercial fishing data was a point of contention throughout the consultation process of the Round 4 OSW Leasing Project (The Crown Estate, 2019b). Many commercial fishing representatives highlighted that the temporal scale of the fishing layer used was not long enough to accurately reflect long-term distribution changes seen in commercial fish stocks (The Crown Estate, 2019b). Similar concerns were raised by commercial fishing representatives during the ScotWind Project (Scottish Government, 2020d). Various published studies support this claim providing evidence of long-term changes in the spatial distribution of various commercial fish stocks (Nye et al., 2009; Rose et al, 2000; Walsh et al., 2015). During the consultation process, it was recommended that long-term or historic data sets be used to help account for natural population distribution dynamics in commercial fish stocks. Therefore, an important lesson learned from this case study would be looking into the inclusion of long-term or historic fishing data sets for future OSW planning and siting projects to increase accuracy and reduce potential conflict.

The spatial analysis used during the Round 4 OSW Leasing Project was designed to identify large areas to consider for OSW development rather than small discrete areas (The Crown Estate, 2019a). The resource and constraint analysis selected a total of 50% of the area that met the OSW technical requirements as CA. As a result, much larger areas were used throughout the various stages of stakeholder engagement when compared to other OSW planning processes. The use of larger areas for the various stages of consultation could have benefits related to improving stakeholder engagement. Active and impactful engagement is a key principle associated with achieving effective MSP which can help address issues such as perceived conflict (Iglesias-Campos et al., 2021; Yates, 2018). The identification of small discrete areas for OSW development may be considered a top-down approach where information delivery is one-directional. A top-down approach to engagement may eliminate some opportunities for refinement and reduce the likelihood of impactful engagement (Reilly et al., 2016; Yates, 2018). In contrast, larger areas may be better suited to a bottom-up approach that encourages stakeholder participation resulting in impactful engagement which may play a role in reducing conflict (Yates, 2018). Moving forward, the identification of large broad areas for OSW development may allow for a consultation process that fosters and encourages more meaningful stakeholder engagement.

2.2. United States

The United States (US) is in the process of developing its wind portfolio having set a national target of 30 GW of OSW generation capacity by 2030 (Musial et al., 2022). Across the US, the total current generation capacity for OSW is only 42 MW. However, the regulatory and development process is well underway with the OSW pipeline having an estimated capacity of 40 GW which is representative of leased and unleased wind energy areas and all projects that have been installed, approved, or are in the permitting process (Musial et al., 2022).

The Department of the Interior’s Bureau of Ocean Energy Management (BOEM) is responsible for sustainably managing the development of offshore energy and mineral resources within the US Outer Continental Shelf (OCS) (BOEM, 2022a). The OCS often referred to as federal waters are defined as all submerged lands lying seaward of state coastal waters (3 miles) which are under U.S. jurisdiction (BOEM, 2017a). Waters within 3 miles of shore are referred to as state coastal waters and are governed by the respective state governments (BOEM, 2017a).

2.2.1. Massachusetts OSW Leases– Bay State Wind and Vineyard Wind

2.2.1.2. Site Identification

The process of identifying the Massachusetts OSW leases of OCS-A 0500 (Bay State Wind) and OCS-A 0501 (Vineyard Wind) began in 2010 and was part of the initial round of OSW leasing conducted by BOEM. The Massachusetts OSW leases of Bay State Wind and Vineyard Wind included a series of engagement and refinement sessions to identify the final lease areas. BOEM’s first step in identifying areas for potential offshore wind development was the publication of a Request for Interest (RFI) in the Federal Register to gauge commercial interest in OSW development (BOEM, 2010). The publication of the RFI to the Federal Register invited all interested and affected parties including the general public to provide comments on the area (BOEM, 2010). The initial RFI area was identified through consultation with the Massachusetts Renewable Energy Task Force which is composed of federal, state, tribal, and industry representatives (BOEM, 2018).

Comments and nominations from the comment period were reviewed and the RFI area was refined to a call area (BOEM 2012a). The size reduction was based on comments received from the commercial fishing industry, the Massachusetts Executive Office of Energy and Environmental Affairs, and the Massachusetts congressional delegation (BOEM, 2012a). A Call for Information and Nominations (Call) was published for the call area in the Federal Register. The Call provides an opportunity for interested parties to confirm, revise, or withdraw their nominations from the RFI and provides another opportunity for public comment (BOEM, 2012a). Comments received from the Call were revised and a Wind Energy Area (WEA) was selected from the CA (BOEM, 2012b). Major changes from the call area to the WEA were the exclusion of an area with high sea duck occurrence and the exclusion of an area with high value to the commercial fishing industry (BOEM, 2012b). The WEA was divided into four separate Lease Areas with a sale notice being published in the Federal Register (BOEM, 2014a).

An Environmental Assessment (EA) was conducted by BOEM to evaluate the potential impacts OSW development would have on the WEA (BOEM, 2014b). The EA reviewed both environmental and socioeconomic consequences of routine and non-routine events related to OSW installation and operation within the WEA (BOEM, 2014b). Routine events included the installation of meteorological towers and buoys within the WEA and displacement related to survey activities. Non-routine activities included water quality events such as oil spills that could be associated with installation and operation. Overall, it was concluded that these activities would have a non-measurable impact on commercial fishing within the WEA (BOEM, 2014b).

2.2.1.3. Spatial Analysis

BOEM commissioned a socio-economic impact analysis of OSW development on fisheries for the first eight WEAs that were identified for the Atlantic coast of the US (Kirkpatrick et al., 2017a). This report combined the results of two spatial analysis models (exposure and impact analysis) to quantify the potential impacts of OSW development within WEAs would have on the fishery industry. The exposure analysis quantified the total amount of fishing that occurred near or within each WEA to represent the total fishing activity that may be impacted should OSW development occur (Kirkpatrick et al., 2017a). Exposure included total revenue for the WEA, commercial revenue by ports, commercial revenue by fisheries management plans, commercial revenue by permit and gear type, total recreation expenditures, and recreation expenditures by port. Minimum exposure thresholds were set for each category so that subgroups that were highly impacted could be identified and included in the impact analysis. The threshold for the commercial fishing categories were an annual revenue of more than US$1 million sourced from the WEA and/or more than 2 percent of the annual revenue sourced from a WEA with a total exposure revenue of greater than US$1,000 (Kirkpatrick et al., 2017a).

The impact analysis was designed to examine the cumulative impacts of OSW development across all WEAs on commercial fisheries and their shoreside dependents (Kirkpatrick et al., 2017a). The impact analysis involved the development and combination of clusters, scenarios, and a location choice model (Kirkpatrick et al., 2017a). Four clusters were identified representing fishing permit groups that are most likely to experience the greatest impact from the development of the WEAs (Kirkpatrick et al., 2017a). Cluster 1 was identified as pot and gillnet permits in Rhode Island and Massachusetts South Coast. Cluster 2 was identified as scallop vessels across the study area. Cluster 3 was identified as surf clam and ocean quahog permits in New Jersey, Massachusetts, and Rhode Island. Cluster 4 was identified as permits landing on Roanoke Island. The four clusters represent 82.5% of total exposed revenue across all of the WEAs. Four scenarios were developed to represent likely exclusion situations that could arise within WEAs if they were to be developed (Kirkpatrick et al., 2017a). Scenarios considered the impacts of increasing or decreasing catch, gear type closures, and weather-based closures. A location choice model was developed to produce an estimate for the probability of fishing trip location for each of the four clusters (Kirkpatrick et al., 2017a). Using trip probability, the expected change in revenue was calculated for each cluster and scenario.

2.2.1.4. Commercial Fishing Industry Considerations

The primary avenue for input from the commercial fishing industry was through the various public comment sessions held during the development of the Massachusetts WEA. During the first comment session, a large number of comments were received from various stakeholders including fisheries organizations, local government, environmental advocates, and individuals related to the commercial fishing industry (BOEM, 2012a). Some of the major themes of these comments included the concern that commercial harvesters were not provided with a sufficient opportunity to provide comments about the potential impact that OSW development within the WEA would have on the industry (BOEM, 2012a). Additional research was requested surrounding the potential impact of OSW development on various fish stocks (BOEM, 2012a). It was recommended that areas of high value to the fishery industry be excluded from the WEA (BOEM, 2012a). Concerns related to the potential interference with vessel radar systems and issues surrounding vessel insurance if operating within a wind farm were highlighted (BOEM, 2012a). As a result, commercial fishing was recognized as one of two competing uses within the proposed WEA and the area was reduced in size to reflect this (BOEM, 2012a; BOEM, 2012b).

The spatial analysis that was conducted by BOEM focused on the potential socio-economic impacts of OSW development on the fishing industry (Kirkpatrick et al., 2017a). A fishing activity model was developed to be used as the spatial data for this analysis (Kirkpatrick et al., 2017a). The fishing activity model used VMS and fishery observer data to supplement point data from vessel trip reports to develop a predictive spatial footprint of fishing around actual fishing locations (Kirkpatrick et al., 2017a). Using dealer reports this model was transformed to represent revenue generated for gear type, species, or port of landings (Kirkpatrick et al., 2017a).

2.2.1.5. Analysis

The socio-economic impact analysis had little to no influence on the selection of Massachusetts OSW lease areas. The spatial analysis completed by BOEM evaluated the socio-economic impacts of OSW development and highlighted potential issues associated with OSW development. The conclusion from the analysis was that the impact of the development of the various WEAs on the commercial fishing industry would be minimal in all of the WEAs except for the pot and gillnet fisheries within the Massachusetts and Rhode Island WEAs (Kirkpatrick et al., 2017a). The maximum estimated impact of OSW development on pot and gillnet fisheries was US$517,000 (Kirkpatrick et al., 2017a). However, the recognition that the development of the Massachusetts WEA could negatively impact the commercial pot and gillnet fisheries did not appear to influence the leasing process in any capacity. The two leases for the Massachusetts WEA were signed prior to the publication of this report in 2015 (BOEM, 2015a; BOEM, 2015b). The site assessment plans for each of the leased areas make little to no mention of the results of the socio-economic analysis and do not provide any method of mitigation related to the impacts on the identified trap and gillnet fisheries (Daniels & Lavellee, 2017; Vinyard Wind, 2017). An integral principle of effective ocean planning is the inclusion of the best available information (Iglesias-Campos et al., 2021). The Massachusetts WEA process does not appear to have been inclusive of all of the available information and as a result, OSW development in these areas could harm pre-existing pot and gillnet fisheries. An important lesson learned from the Massachusetts OSW leasing process is that available information needs to be provided with a clear and well-communicated pathway for inclusion in the decision-making process. The final outcomes of the process should be reflective of the analyses and information gathering that has been conducted.

The BOEM OSW leasing process considered the co-location of specific commercial fishing gear types within OSW farms. The complete exclusion of commercial fishing activities from OSW sites has been found to have various negative economic, social, and environmental effects on harvesters, the commercial fishing industry, coastal communities, and the wider society (Kafas et al., 2018). Multi-use or co-location of various ocean uses and users has been identified as a potential mitigation strategy to reduce the potential impacts of spatial conflict associated with an increasingly busy ocean space (Schupp et al., 2021). One of the exclusion scenarios that was developed for the socio-economic analysis conducted by BOEM included considerations related to the co-location of commercial fishing and OSW development through gear-based closures (Kirkpatrick et al., 2017a). This scenario considered potential OSW sites as closed to mobile gear fishing activity, but fixed gear fisheries were assumed to operate at full capacity and with no impact on catch within OSW lease areas (Kirkpatrick et al., 2017a). The development of this scenario was based on the cumulative results of different consultation and engagement sessions with commercial fishing industry representatives around the world (Kirkpatrick et al., 2017b). For example, fixed gear commercial fishing fleets from the UK have been found to operate within operational OSW farms with little impact on operating patterns (Kirkpatrick et al., 2017b). Therefore, an effective strategy to identify potential spatial conflict mitigation strategies for OSW development could be the exploration of co-location and multi-use with the commercial fishing industry.

3. CHAPTER THREE: SPATIAL ANALYSIS

3.1. Context

Marxan (Ball et al., 2009) is a software designed to act as a decision support tool to aid in conservation and other spatial planning issues. Marxan uses a suite of algorithms to find a solution that selects areas to be included in a reserve system that meets user-defined targets for each input feature and minimizes the cost or impact of the system on other users (Serra et al., 2020). The Canadian Science Advisory Secretariat (CSAS) conducted an in-depth review of various decision-support tools and identified Marxan as the optimal tool to be used by DFO for achieving its MPA percentage coverage targets (DFO, 2004). As a result, Marxan has contributed to DFO Maritimes Region's ongoing process of developing a conservation network design for the Scotian Shelf-Bay of Fundy Bioregion (King et al., 2021; Serdynska et al., 2021). Although originally developed for the purpose of conservation network design, Marxan has been used internationally to assist in various other spatial planning issues including both onshore and offshore wind planning (Elgi et al.,2017; Goke et al., 2018). As a result of the CSAS recommendations, DFO's past experience, and cited use within the published literature Marxan was selected to be used as a decision-support tool for this study.

Two different types of Marxan analyses have been identified and described in past work by DFO (DFO, 2017).

1. Marxan Analysis: The standard or basic Marxan analysis was originally developed for conservation in which the user defines protection targets for various conservation features with the software producing a series of solutions to meet these targets while minimizing the total cost (DFO, 2017). The standard Marxan analysis allows for the addition of multiple conservation features but only allows for a singular socio-economic cost layer to be considered.

2. Reverse Marxan: The reverse Marxan analysis is an adaptation to the basic Marxan analysis to allow for the consideration of more than one socio-economic feature using either one or two phases (DFO, 2017). Socio-economic layers are used instead of conservation features with the solution of the first phase identifying planning units that

meet the objective of preserving economic features instead of areas for conservation (DFO, 2017). The output from the first phase can be used as a cost layer for the optional second phase which is a standard or basic Marxan analysis where the solution is selecting areas to conserve ecological features (DFO, 2017).

The objective of the Marxan analysis used in this study was to highlight areas that had a high likelihood versus a low likelihood of spatial conflict with the commercial fishing industry if fixed-base OSW development were to take place. To accomplish this objective a variation of a reverse Marxan analysis was designed with commercial fishing spatial data being used as the socio-economic features to be preserved in the final solution of the Marxan analysis.

Three different exercises were designed with the goal of demonstrating how the Marxan cost layer can be used to include multiple sector considerations and objectives within a complex MSP issue such as OSW siting and planning in the Scotian Shelf-Bay of Fundy planning area.

3.2. Methodology

Marxan read five specific input files to produce a user-defined number of solutions. Each solution selected a number of planning units that contained enough of the features to meet the user-defined targets. The five input files that were required were the planning unit file, feature file, planning unit vs. feature file, boundary file, and the input parameter file. The five files were read by Marxan and a variety of different outputs including the Marxan summed solution and the summary information file were produced (Figure 2).

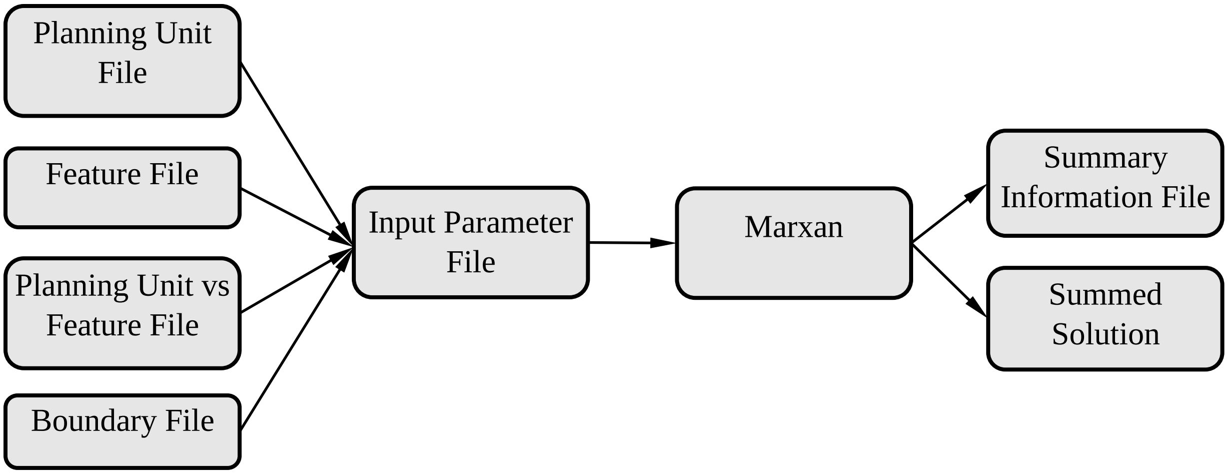

Figure 2. Marxan analysis process diagram.

The spatial analyses required to create these files were carried out using ArcGIS Pro version 2.8.3 and ArcMap version 10.8.2 (ESRI, 2021a; ESRI, 2021b). All spatial analysis was completed using the projection NAD 1983 UTM Zone 20. Conversion of the shapefiles into the correct file format for Marxan was completed using ArcMarxan Toolbox version 2.0.2 (Apropos Information Systems Inc, 2020). The Marxan analyses were completed using Marxan version 4.0.6 (Ball, 2009).

3.2.1. Marxan Input Files

3.2.1.1. Planning Unit File

The planning unit file described the planning units within the study area including the location, size, unique identification code, cost, and status. The focus of this study was to evaluate potential spatial conflicts between the commercial fishing industry and OSW development. As a result, the 10 km^2 transverse hexagonal grid for Northwest Atlantic Canada and Central & Arctic Region developed by DFO for commercial fishing catch atlases was selected to be used as the planning units for this study (DFO, 2019c). This study contributed to the efforts of the DFO Maritimes Region Marine Spatial Planning program to better understand the potential impacts of future OSW development. As a result, the spatial extent of the 10 km^2 transverse hexagonal grid was restricted to the Scotian Shelf-Bay of Fundy planning area to create the planning unit shapefile and study area (DFO, 2022b) (Figure 3).

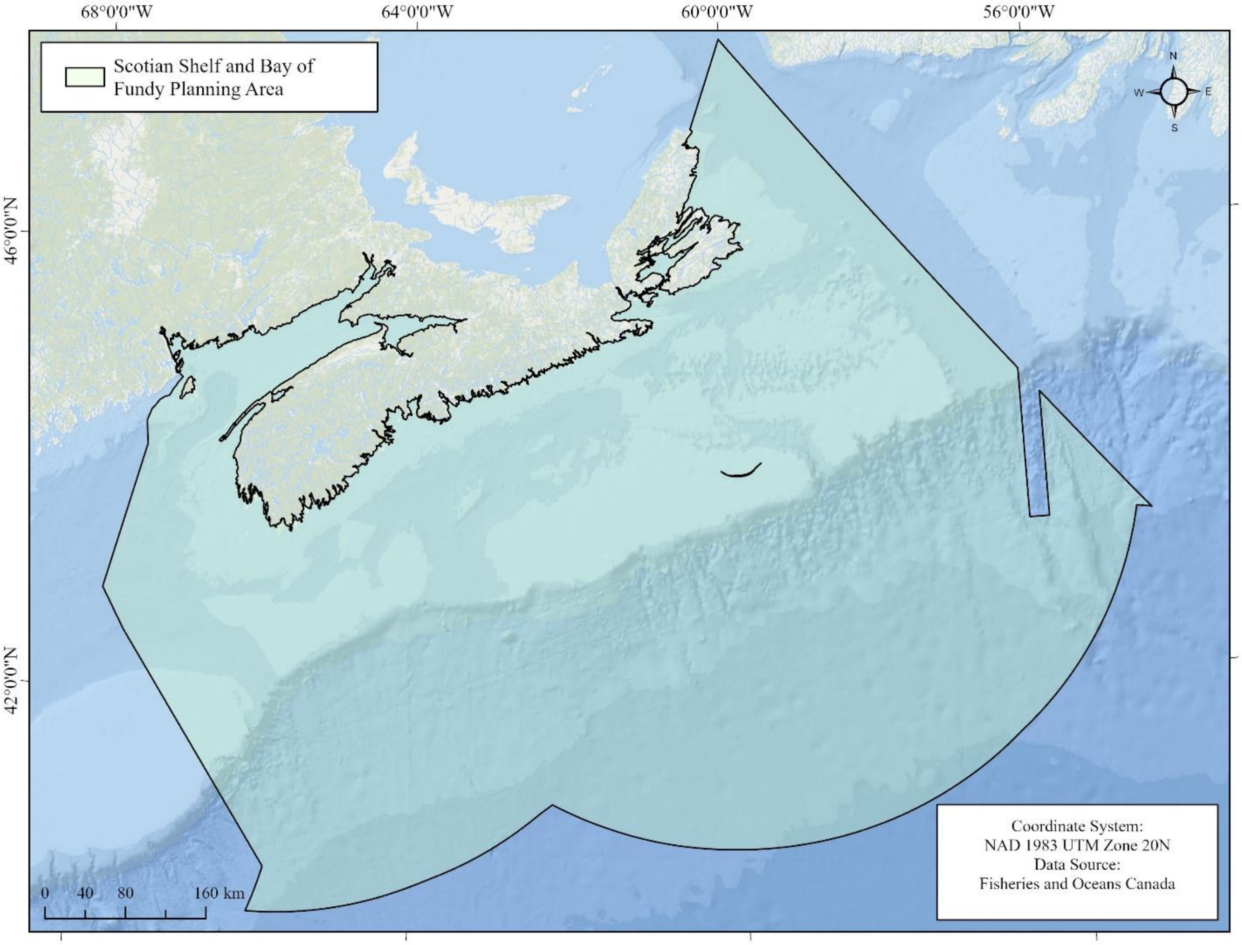

Figure 3. Scotian Shelf-Bay of Fundy planning area.

The geographical extent of Oceans Act MPAs (DFO, 2021d) and Marine Refuges (other effective area-based conservation measures or OECMs) (DFO, 2022c) found within the study area were deemed to be important areas to exclude from consideration for OSW development due to their legal status and purpose for conservation (Figure 4).

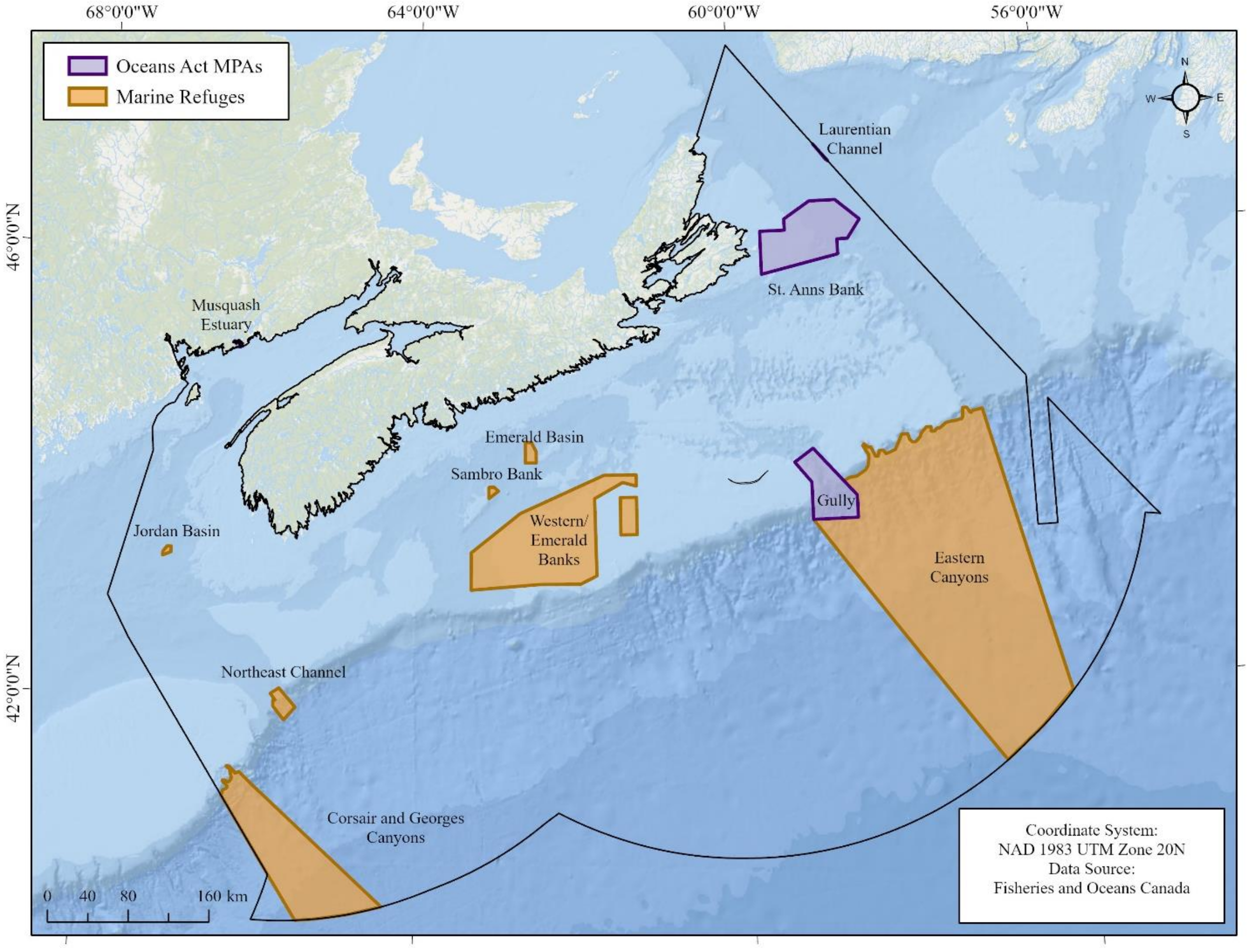

Figure 4. Oceans Act Marine Protected Areas (MPAs) and Marine Refuges within the study area.

New fields named "PUID", "Status", and "Cost" were added to the planning unit file. A unique identification code was assigned to the PUID field for each planning unit ranging from 1 to 42,340.

Marxan uses status as a field to define if a planning unit is available to be selected as part of the final solution. For this analysis, the status field was used to limit the planning units that were available to be selected by Marxan to areas that contained the potential for spatial conflict between the commercial fishing industry and fixed-base OSW development. There were three options for planning unit status. A status value of 0 indicated the planning unit was available to be selected in the solution. Areas that were considered suitable for fixed-base OSW and that contained potential for spatial conflict between the commercial fishing industry and fixed-base OSW development were assigned a status of available. A status value of 2 indicated a planning unit could not be selected but was “locked in” and would always be included in the final solution. Areas that were considered unsuitable for fixed-base OSW and that contained no potential for spatial conflict between the commercial fishing industry and fixed-base OSW development were assigned a status value of locked in. A status value of 3 signified that a planning unit could not be selected but was “locked out” and would never be included in the final solution.

Depth has been recognized as a technical constraint associated with fixed-base OSW development and was used to define suitability for this analysis (The Crown Estate, 2019c; Eamer et al., 2022). Areas with a mean depth of less than 60 m were considered suitable for fixed-base OSW and areas with a mean depth greater than 60 m were considered unsuitable (The Crown Estate, 2019c; Eamer et al., 2022). A raster file containing depth (m) for the study area was downloaded from the General Bathymetric Chart of the Oceans (GEBCO Compilation Group, 2022) and the mean depth for each planning unit in the study area was calculated. The status field of planning units with a depth greater than 60 m was set to equal 2 representing that these planning units would be “locked in.” The status field of all planning units with a depth of less than 60 m was set to equal 0 representing these planning units were “available” (Figure 5).

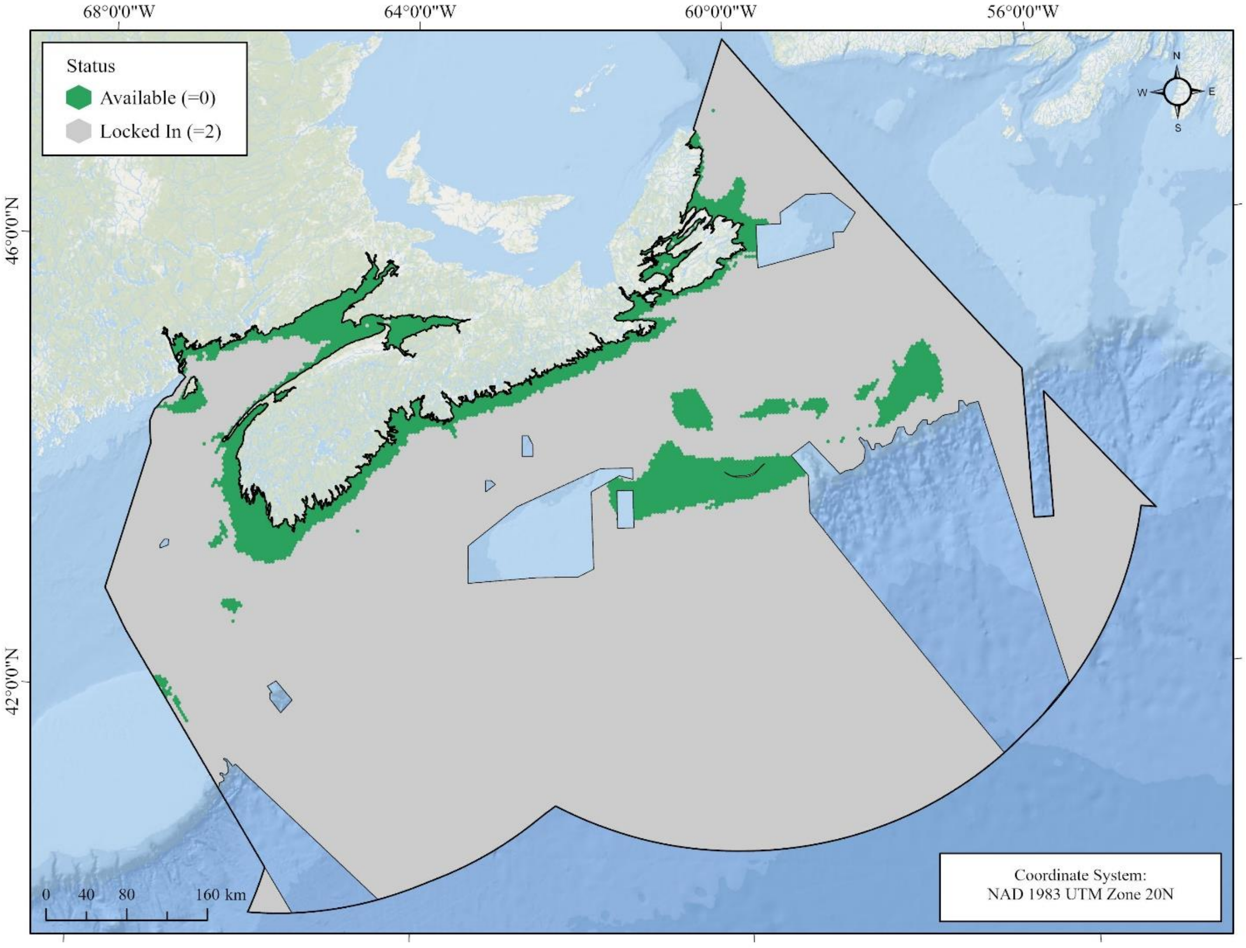

Figure 5. Marxan status per 10 km^2 hexagonal planning unit.

Marxan uses cost as a numerical field to represent how much it would cost to include each planning unit in the final solution. Three different exercises were designed for this study that used a different cost layer to represent different considerations that may be relevant when addressing complex issues such as future OSW development. The first exercise was named the baseline exercise did not use the cost layer to represent any additional consideration for OSW development and was designed to be used as a control point for comparison with the other two exercises. The second exercise was named the multi-objective exercise and was designed to represent a potential compromise between the commercial fishing industry and fixed-base OSW development. The multi-objective exercise analysis highlighted areas of high fisheries catch weight while favoring areas that were less suitable for fixed-base OSW development. The third exercise was named the conflict identification exercise and was designed to select areas with the highest likelihood of spatial conflict between fixed-base OSW development and commercial fishing catch weight. The conflict identification exercise analysis highlighted areas with high contributions to commercial catch weight targets while favoring areas that were more suitable for fixed-based OSW development.

Baseline Cost Layer

The baseline cost layer assigned an equal cost value (i.e. Cost = 1) to each planning unit (Figure 6).

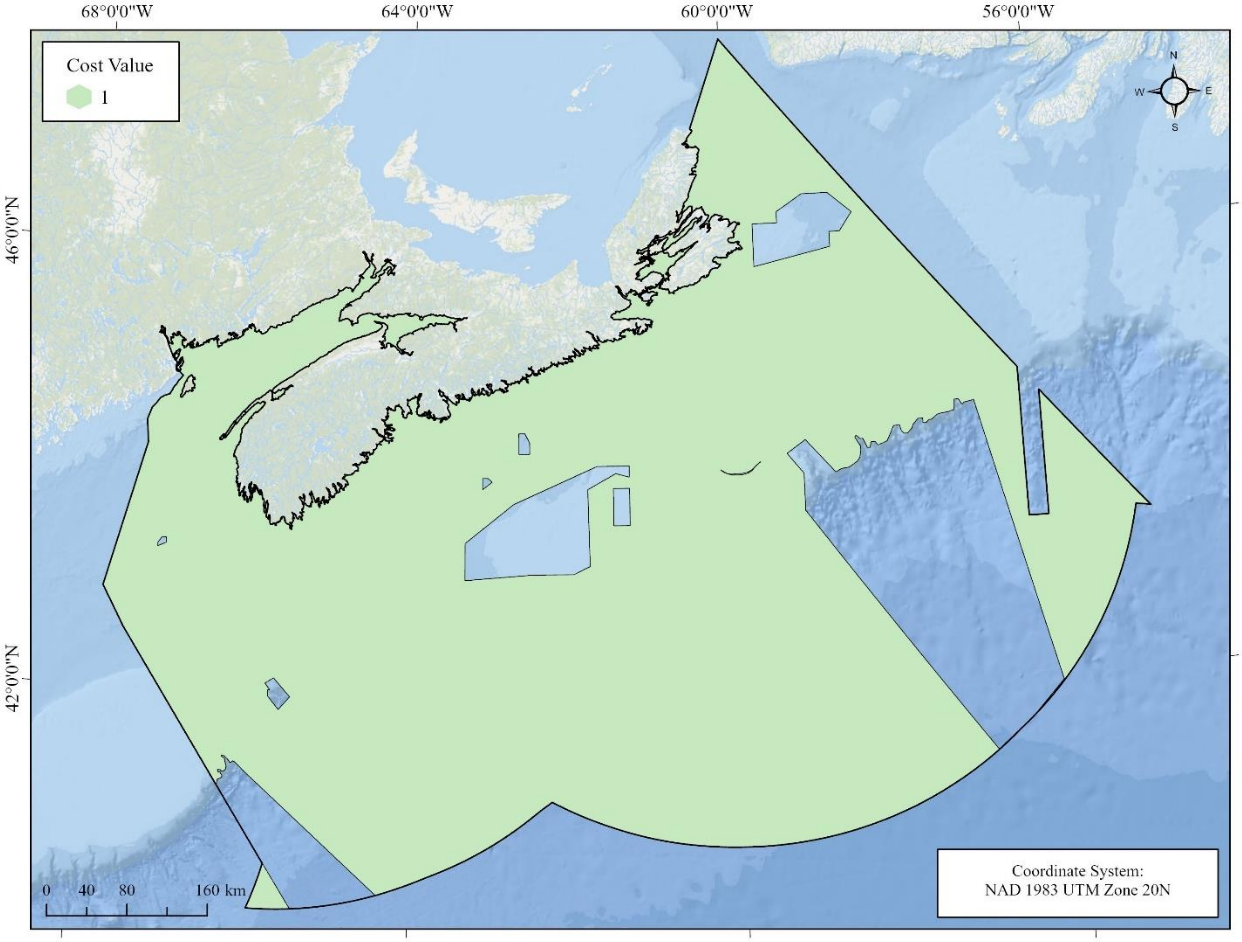

Figure 6. Cost per 10 km^2 hexagonal planning unit for the baseline exercise.

Multi-Objective Cost Layer

Distance from shore has been found to be a strong indicator of the cost of OSW development. As the distance from shore increases the cost of development increases as well due to accessibility, cables, infrastructure, and labour (Johnston et al., 2020). The multi-objective cost layer reversed the cost relationship associated with OSW development so that cost decreased as distance from shore increased. To accomplish this the distance (km) to the closest point of the shoreline was calculated for each planning unit. The distance from shore values were reclassified into 109 classes by 5-km intervals in descending order. The new classes were set to equal the Cost field resulting in cost decreasing in value by 5-km increments from shore with the highest cost value of 109 being assigned to the planning units closest to shore (1-5 km) and the lowest cost value of 1 being assigned to planning units furthest from shore (540-545 km) (Figure 7).

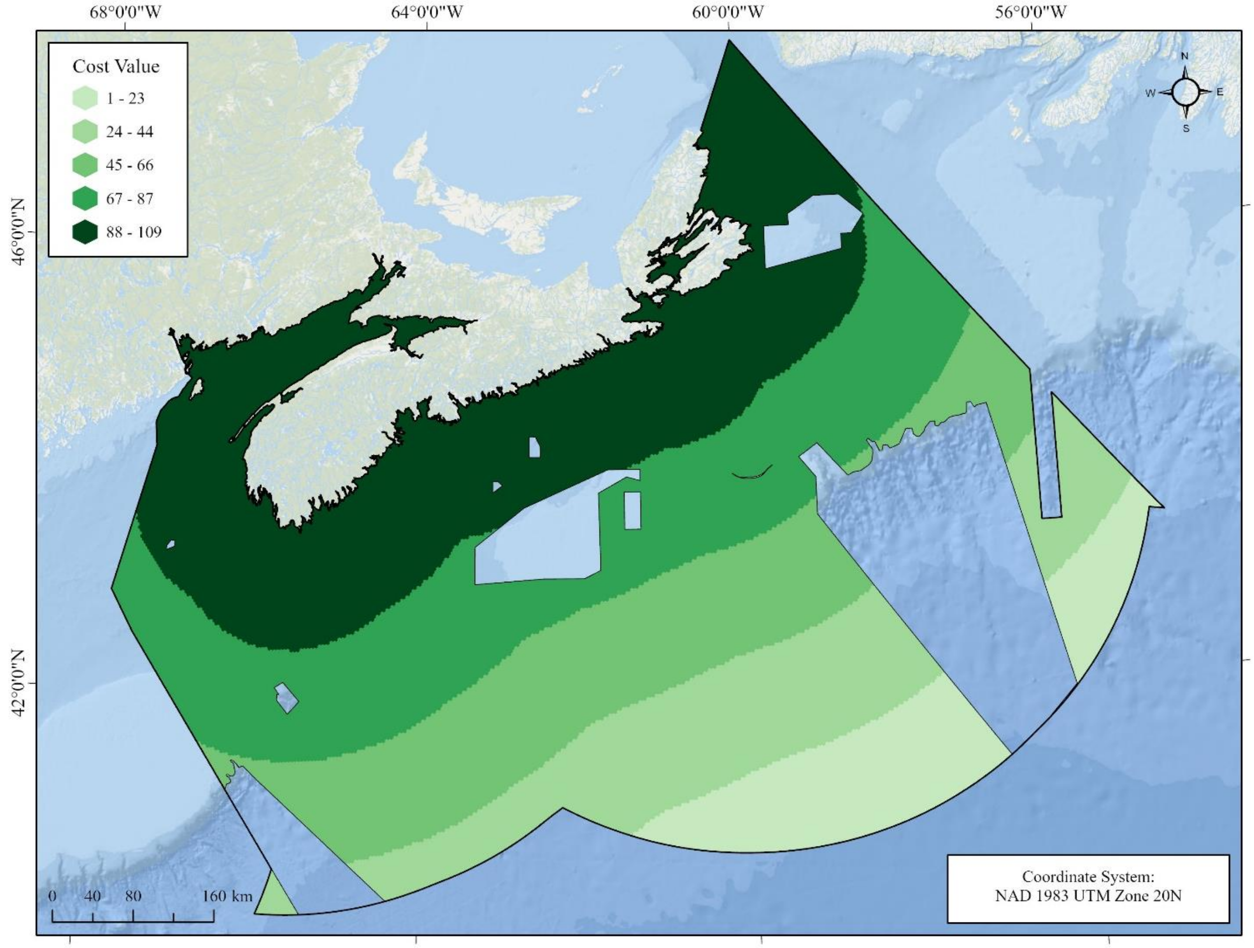

Figure 7. Cost per 10 km^2 hexagonal planning unit for the multi-objective exercise.

<u>Conflict Identification Cost Layer</u>

The conflict identification cost layer used the traditional relationship of increasing cost of OSW development as the distance from shore increased, providing a lower cost to areas more suitable for OSW development. To accomplish this the distance to the closest point of the shoreline was calculated for each planning unit. Distance from shore values were reclassified into 109 classes by 5-km intervals in ascending order. The new classes were set to equal the Cost field resulting in the cost value of planning units increasing by 5-km increments from shore with the lowest cost value of 1 being assigned to the planning units closest to shore (1-5 km) and the highest cost value of 109 being assigned to planning units furthest from shore (540-545 km) (Figure 8).

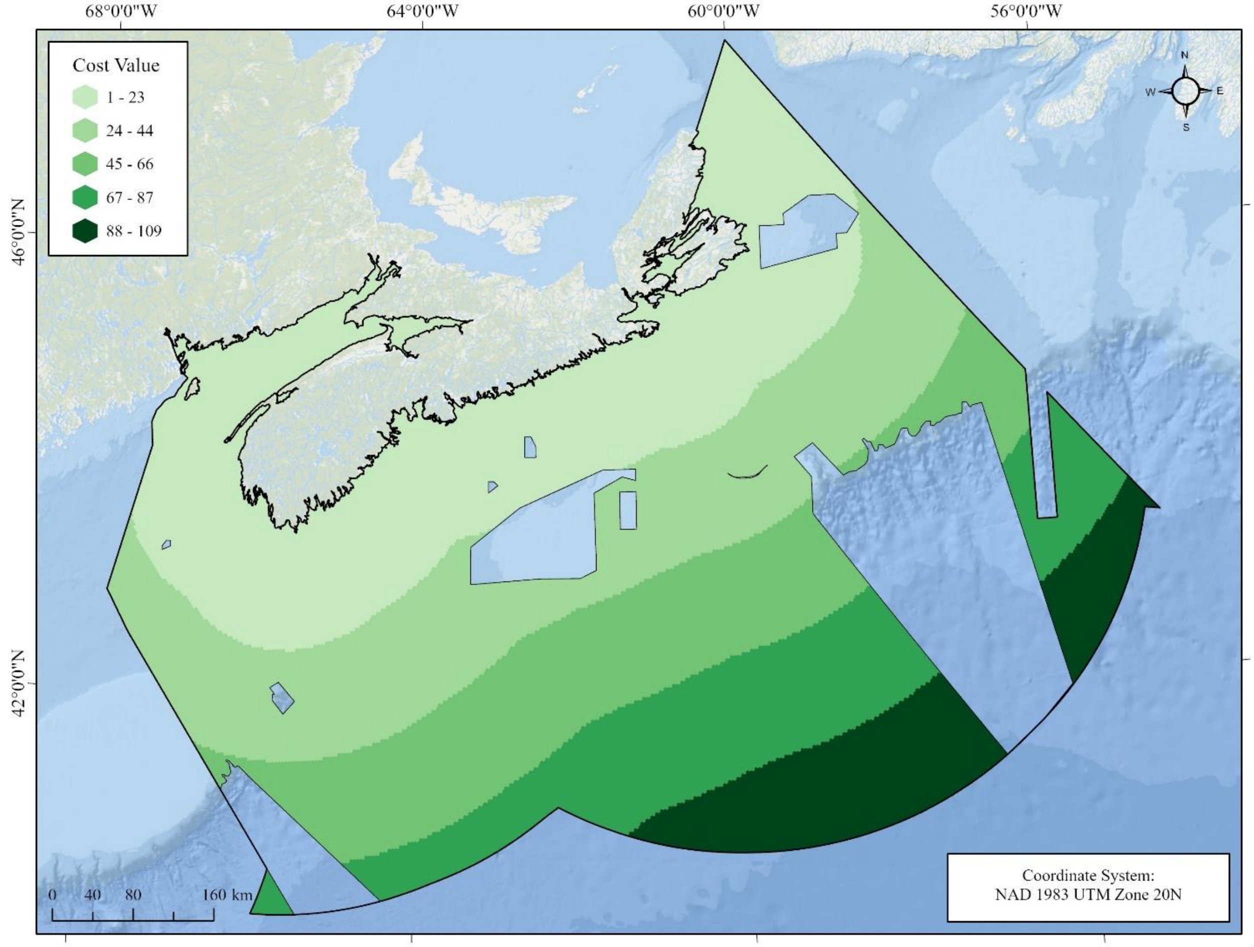

Figure 8. Cost per 10 km^2 hexagonal planning unit for the conflict identification exercise.

Using the ArcMarxan Toolbox the planning unit shapefile was converted to the format required for the Marxan analysis.

3.2.1.2. Planning Unit vs Feature File

Marxan selected planning units to meet user-defined targets based on the amount of a feature found within each planning unit. The planning unit vs feature file was a shapefile that contained the amount of each feature within each planning unit of the study area. The feature classes in this analysis were inshore lobster, mobile gear, and fixed gear commercial fishing catch weights. Data from the planning unit file were extracted to a new layer to be used as the planning unit vs feature file. The fields “Mobile”, “Fixed” and “Lobster” representing the three feature classes were added to this shapefile.

Mobile Gear Feature Layer:

The “Gear Type Mobile” data layer from the Eastern Commercial Fishing Database was used to represent commercial catch weight for the mobile gear fishing fleet (DFO, 2021b). This data layer included catch weight in kilograms (kg) from all Canadian vessels greater than 35 feet that used mobile fishing gear within the Maritimes, Gulf, Quebec, Newfoundland and Labrador, and Eastern Arctic DFO regions from 2009-2018 on a 10 km^2 hexagonal grid. Mobile fishing gear included bottom otter trawl (side), bottom otter trawl (stern), bottom pair trawl, Danish seine, dredge (boat), purse seine, Scottish seine, shrimp beam trawl, shrimp trawl, and troller lines (DFO, 2021b). Catch weight from the “Gear Type Mobile” data layer was joined to the mobile field for each of the planning units within the study area (Figure 9).

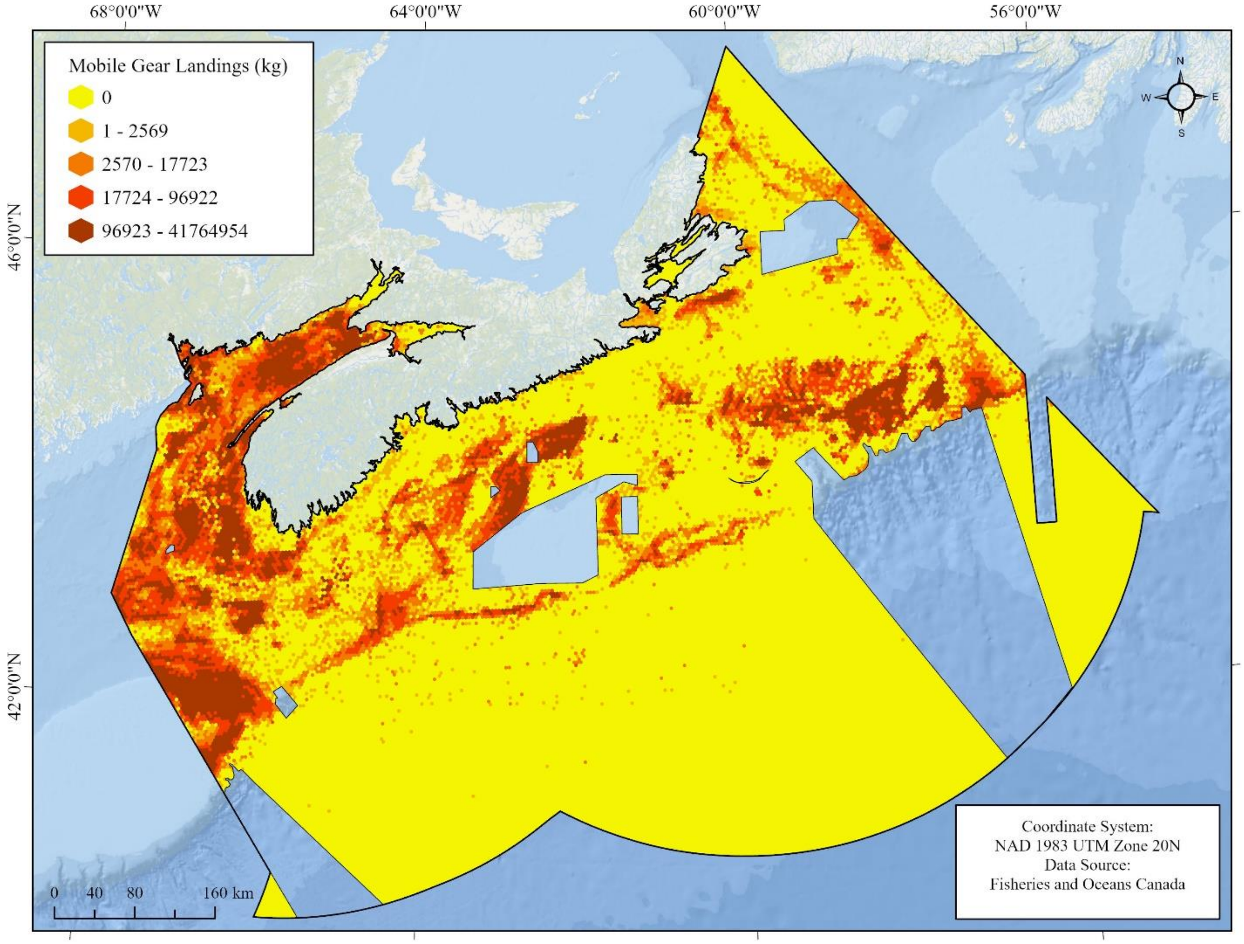

Figure 9. Mobile gear composite landings (catch weight kg) from 2009-2018 per 10 km^2 hexagonal planning unit.

Fixed Gear Feature Layer:

The “Gear Type Fixed” data layer from the Eastern Commercial Fishing Database was used to represent commercial catch weight for the fixed gear commercial fishing fleet. This data layer included catch weight (kg) from all Canadian vessels greater than 35 feet that used fixed fishing gear within the Maritimes, Gulf, Quebec, Newfoundland and Labrador, and Eastern Arctic DFO regions from 2009-2018 on a 10km^2 hexagonal grid (DFO, 2021b). Fixed fishing gear included angling, beach and bar seine, conical trap, conical trap – 4 feet, diving with a hand tool, electric harpoon, gillnet (drift), gillnet (set or fixed), handline (baited), harpoon and spear, Japanese trap, longline, mixed trap – crab, pot, pyramidal trap, rectangular trap, rod and reel (chumming), rope, trap net, and tuck seine (DFO, 2021b). Catch weight from the “Gear Type

Fixed" data layer was joined to the Fixed field for each of the planning units within the study area (Figure 10).

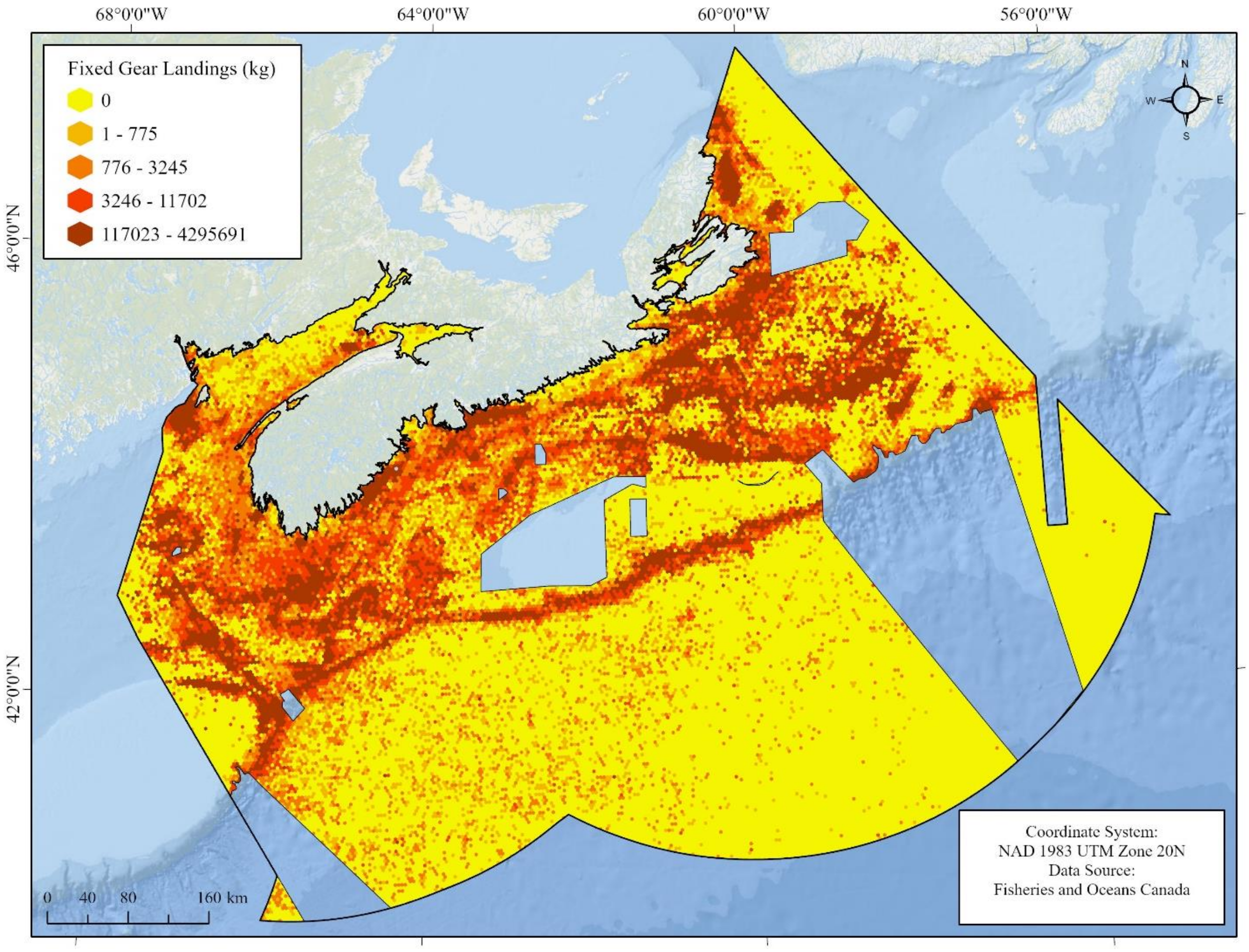

Figure 10. Fixed gear composite landings (catch weight kg) from 2009-2018 per 10 km^2 hexagonal planning unit.

Inshore Lobster Feature Layer:

Inshore lobster catch weight standardized by area (kg/km^2) on a nonuniform statistical grid from 2012 to 2014 for the DFO Maritimes region was used to represent commercial catch weight for the inshore lobster fishing fleet (DFO, 2020a) (Figure 11).

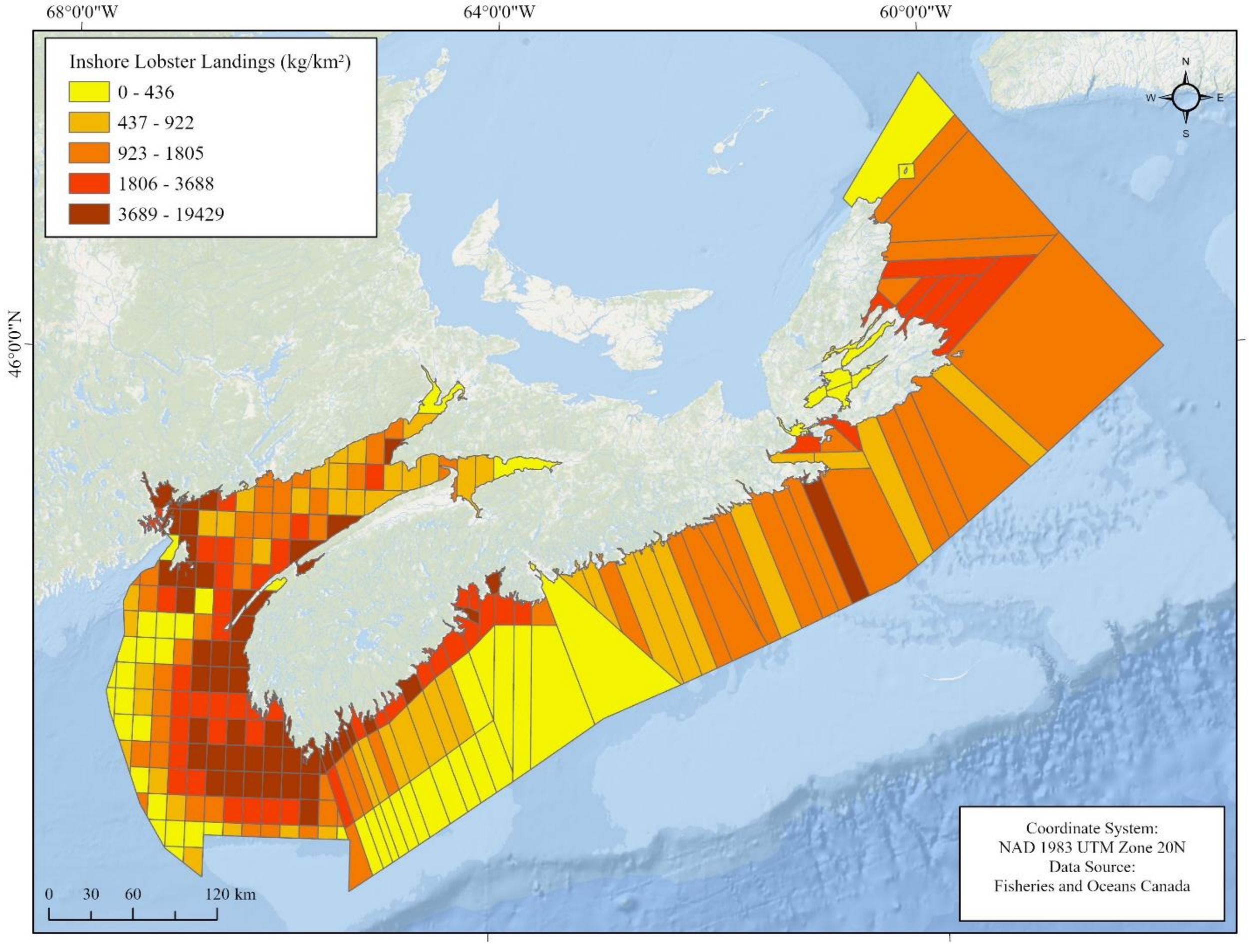

Figure 11. Inshore lobster catch weight standardized by area (kg/km^2) from 2012 - 2014 on a nonuniform statistical grid.

Based on active fishing areas and lobster research surveys the extent of the nonuniform statistical grid was modified to accurately reflect the distribution of commercial fishing activity (Coffen-Smout et al., 2013). This modification was consistent with the modification of the published 2008 - 2011 inshore lobster statistical grid and included the reduction of Lobster Fishing Areas (LFAs) east of Halifax (LFAs 32 – 27) to the 100m depth contour (Coffen-Smout et al., 2013). LFAs west of Halifax (i.e., LFAs 33 – 38) were left unmodified as the statistical grid boundaries better reflected the distribution of lobster fishing activity (Coffen-Smout et al., 2013).

Additionally, to avoid data duplication catch weight (kg) was converted to catch weight standardized by area (kg/km^2) due to the nonuniform statistical grid cells being larger than the 10 km^2 hexagonal planning units. Catch weight and area were used to calculate inshore lobster catch weight standardized by area (kg/km^2) for each of the modified nonuniform statistical grid cells. The mean inshore lobster catch weight standardized by area (kg/km^2) was then calculated for the Lobster field of each planning unit (Figure 12).

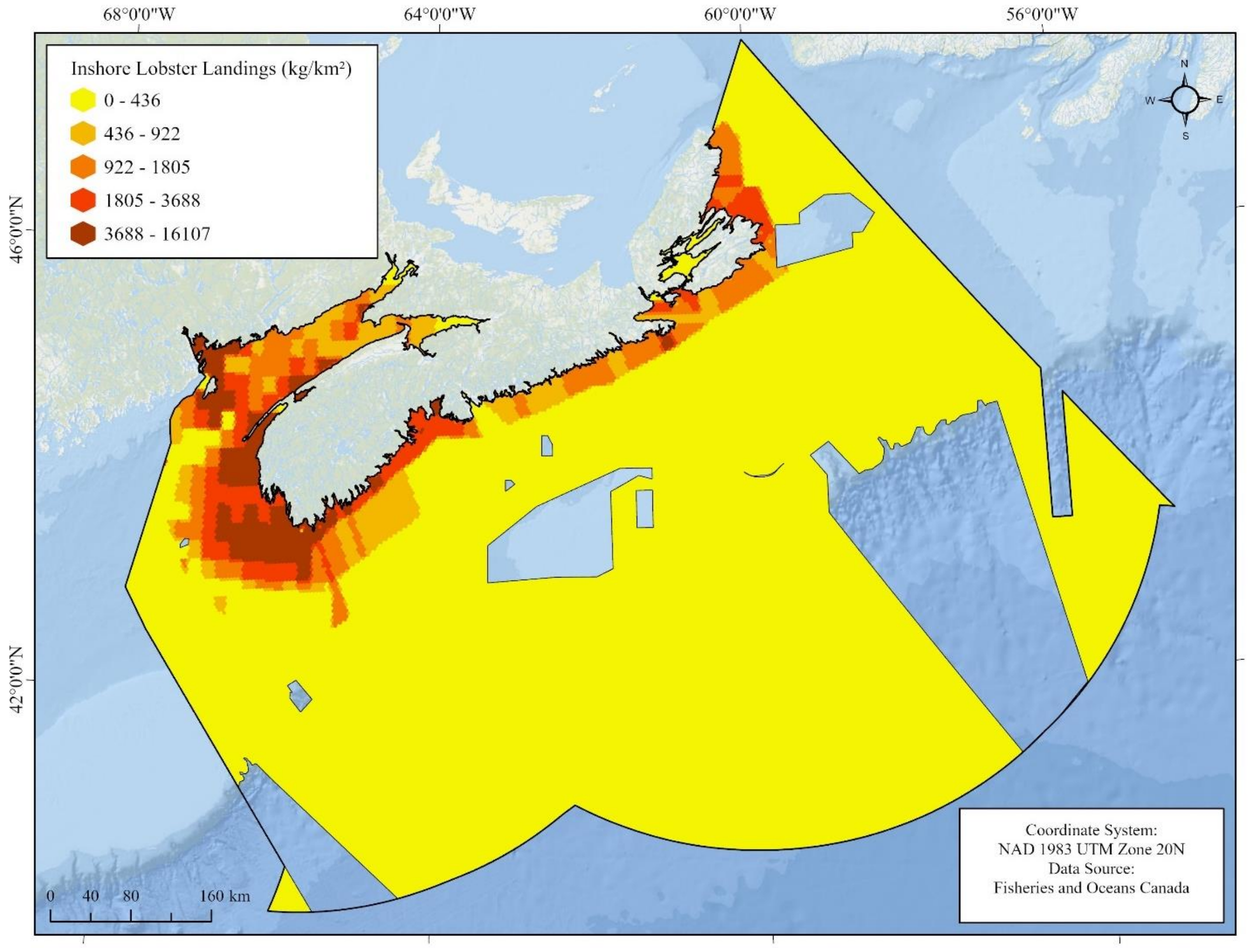

Figure 12. Inshore lobster catch weight standardized by area (kg/km^2) from 2012-2014 per 10 km^2 hexagonal planning unit.

The ArcMarxan toolbox was used to convert the planning unit vs feature file shapefile to the format required for the Marxan analysis.

3.2.1.3. Feature File

The "Export Feature Files" tool from the ArcMarxan toolbox was used to create the feature file. The feature file contained the user-defined targets for each of the features included in the analysis. The user-defined target represented the amount of each feature that Marxan must include within the final solution of selected planning units. This analysis utilized the feature target field named “proportion” or “prop” which is a decimal value that represents the percentage of the feature class that must be included in the Marxan solution. The prop value for the feature classes was set to equal 0.95 meaning 95% of the feature must be included in the Marxan solution.

3.2.1.4. Boundary File

Using the Export Boundary File tool from the ArcMarxan toolbox the planning unit file was converted to the boundary file format required for the Marxan analysis. The method variable was set to measured and the boundary treatment variable was set to full. The boundary file is an optional file that contains information related to the length of the shared boundaries between planning units.

3.2.1.5. Input Parameter File

The input parameter file contains the parameters related to the Marxan analysis allowing for a degree of user customization. The input parameter file contains fields such as the number of repeat runs (NUMREPS) and the boundary length modifier (BLM). Using the Create Input File and Folders tool from the ArcMarxan toolbox the input parameter file was created. The field “BLM” was set to zero and the field “NUMREPS” was set to 100 for each scenario.

3.2.2. Scenarios

Using the three cost layers and the three feature classes six different scenarios were developed to demonstrate how Marxan can be configured to consider various objectives in a complex MSP issue. The scenarios were split into three different exercises depending on the cost layer that was used. The parameters of each scenario are described in Table 1.

Table 1. Marxan parameters for the six scenarios.

Exercise	Scenario	Feature Layers	Target	Cost Layer
Baseline	BL-MF	Mobile Gear Fixed Gear	Prop=0.95 Prop=0.95	No Cost (Cost = 1 for each planning unit
	BL-MFL	Mobile Gear Fixed Gear Inshore Lobster	Prop=0.95 Prop=0.95 Prop=0.95	No Cost (Cost = 1 for each planning unit
Multi-Objective	MO-MF	Mobile Gear Fixed Gear	Prop=0.95 Prop=0.95	Multi-objective (Distance from shore – High to Low)
		Mobile Gear	Prop=0.95	

Exercise	Scenario	Feature Layers	Target	Cost Layer
	MO-MFL	Fixed Gear Inshore Lobster	Prop=0.95 Prop=0.95	Multi-objective (Distance from shore – High to Low)
Conflict Identification	CI-MF	Mobile Gear Fixed Gear	Prop=0.95 Prop=0.95	Conflict Identification (Distance from shore – Low to High)
	CI-MFL	Mobile Gear Fixed Gear Inshore Lobster	Prop=0.95 Prop=0.95 Prop=0.95	Conflict Identification (Distance from shore – Low to High)

3.2.3. Marxan Output Files

3.2.3.1. Summary Information File

For each scenario, Marxan created an output summary information file containing the Marxan score, cost, and the number of planning units included in the solution for each of the 100 repeat runs completed by Marxan for each scenario. Marxan score is a numerical value that represents the efficiency of each run by accounting for the total cost, boundary length, and target penalties of the solution. The number of planning units included in the solution of each run is the number of planning units with a status of locked in (n = 37,758) plus the number of planning units Marxan selected to reach the user-defined targets

3.2.3.2. Marxan Summed Solution

For each scenario, Marxan created a Marxan summed solution file that contained a value ranging from 1 to 100 that represented the number of times a planning unit was selected as part of the solution across all 100 repeat runs. The Marxan summed solution file was joined to the planning unit and feature file for each scenario. A new field named SSOLN was created. The SSOLN field was set to equal the status value plus the Marxan selection frequency value for each planning unit. SSOLN values except for a value of 102 represent how many times a planning unit was selected across all Marxan runs in that scenario. A SSOLN value of 102 represented a planning unit that had a status value of 2 or “locked in” and was considered unsuitable for OSW development due to having a depth greater than 60 m. The mean, SD, maximum, and sum of the area (km^2), distance from shore (km), mobile gear catch weight (kg), fixed gear catch weight (kg), and inshore lobster catch weight standardized by area (kg/km^2) for planning units with a SSOLN value of 0 and a SSOLN value of 100 were calculated. Adjacent planning units with the same SSOLN value were aggregated into clusters .

3.3. Results

The study area had a total size of 405,903.82 km^2 and was divided into 42,340 ten square kilometer hexagonal planning units. The average planning unit size was 9.6 km^2 due to the planning units being clipped to align with the boundaries of the Scotian Shelf-Bay of Fundy planning area, Oceans Act MPAs, and Marine Refuges. A total of 37,758 planning units had a mean depth greater than 60 m and were assigned a status of locked in, meaning that these planning units were automatically included as part of the solution for each Marxan run. The remaining 4,582 planning units had a mean depth of less than 60 m and were assigned a status of available.

Table 2 includes the total catch weight found in the study area for the mobile, fixed, and lobster feature classes and the proportion of landings found within planning units with a status of locked in. The fixed gear feature class had the highest proportion at 71.9% of catch contained within locked in planning units. The inshore lobster feature class had the lowest proportion at 43.7% of catch contained within locked in planning units (Table 2).

Table 2. Amount and percent of the total mobile gear catch weight (kg), fixed gear catch weight (kg), and inshore lobster catch weight standardized by area (kg/km^2) found within the study area and within planning units assigned a status of locked in.

	Catch weight in	**Catch Weight Locked In**	
Feature Class	**Study Area**	**Sum**	**% of Total**
Mobile Gear (kg)	1,755,378,177.0	1,238,325,798.0	70.5%
Fixed Gear (kg)	286,712,897.0	206,331,667.0	71.9%
Inshore Lobster (kg/km^2)	14,479,167.2	6,330,953.6.0	43.7%

3.3.1. Marxan Analysis

Table 3 includes the mean Marxan score and the mean number of planning units selected in addition to the locked in planning units per solution for each scenario. The MO-MFL scenario had the highest mean Marxan score with a score of 2,628,820.00 ± 588.26. The mean number of planning units selected within the CI-MFL scenario was 2,081.46 ± 11.68 which was the highest when compared to all other scenarios.

Table 3. Mean (±SD) Marxan score and the number of planning units selected per solution for each scenario in addition to locked in planning units.

Scenario	**Mean Marxan Score**			**Mean Planning Units Selected**			**Planning Units Locked in**
BL-MF	38,213.6	±	8.8	455.4	±	8.8	37,758
BL-MFL	39,742.3	±	8.2	1,984.1	±	8.2	37,758
MO-MF	2,462,683.0	±	737.1	442.7	±	7.3	37,758
MO-MFL	2,628,820.0	±	588.3	1,942.9	±	6.1	37,758
CI-MF	1,735,954.0	±	70.4	641.3	±	15.9	37,758
CI-MFL	1,737,569.0	±	100.4	2,081.5	±	11.7	37,758

3.3.2. Marxan Summed Solution

Marxan summed solution results display the number of times a planning unit was selected (SSOLN) across all repeat runs for each scenario. Planning units that received a SSOLN value of 100 indicate that these planning units had a high contribution to commercial catch weight targets as they were selected to meet the class targets in every run (100%) within a scenario. These planning units would therefore represent areas with a high potential for spatial conflict between the commercial fishing industry and future fixed-base OSW development. Planning units that received a SSOLN value of 0 indicate that these planning units had a low contribution to commercial catch weight targets as they were not selected to meet the feature class targets for any run (0%) within a scenario. These planning units would therefore represent areas with a low potential for spatial conflict between the commercial fishing industry and future fixed-base OSW development.

Figure 13 displays the Marxan summed solution result for the BL-MF scenario. Planning units selected by Marxan to meet the mobile gear and fixed gear feature class targets were located primarily around the offshore bank areas, in the Bay of Fundy, and off the South shore of Nova Scotia.

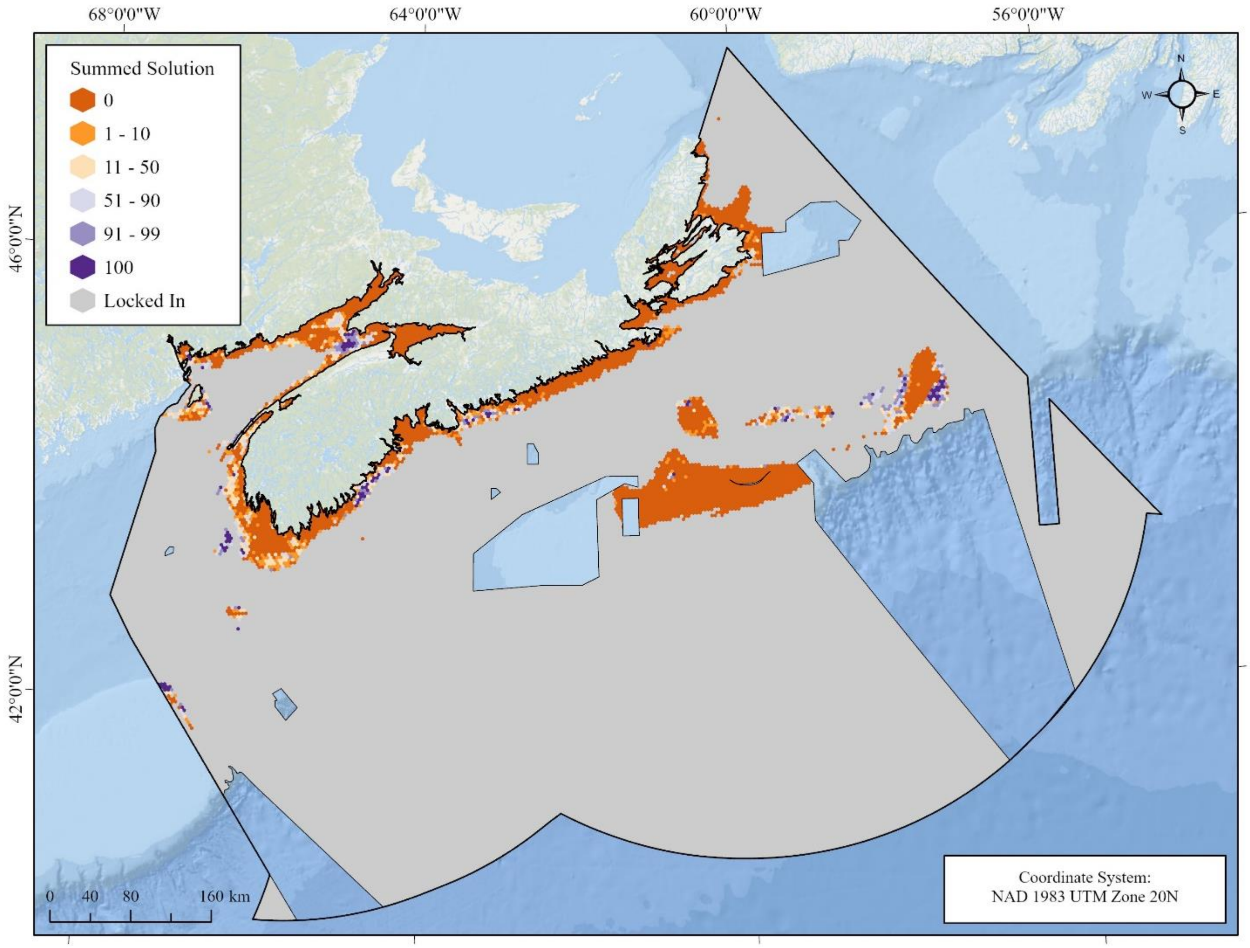

Figure 13. Marxan analysis summed solution result for the Baseline - Mobile + Fixed (BL-MF) scenario.

Figure 14 displays the five largest clusters of planning units that received a SSOLN value of 100 or 0 for the BL-MF scenario. The five largest clusters of planning units receiving a SSOLN value of 100 by area (km^2) in descending order were identified as northeast Banquereau, outer Minas Basin, Georges Bank, the southern shore of Nova Scotia near Port Mouton, and German Bank. The five largest clusters of planning units receiving a SSOLN value of 0 by area (km^2) in descending order were identified as Sable Island Bank and Western Bank, the eastern coast of New Brunswick from St. Andrews to Chignecto Bay, the eastern shore of Nova Scotia from Halifax to Guysborough, Sydney Bight, and southwest Nova Scotia from Yarmouth to Barrington.

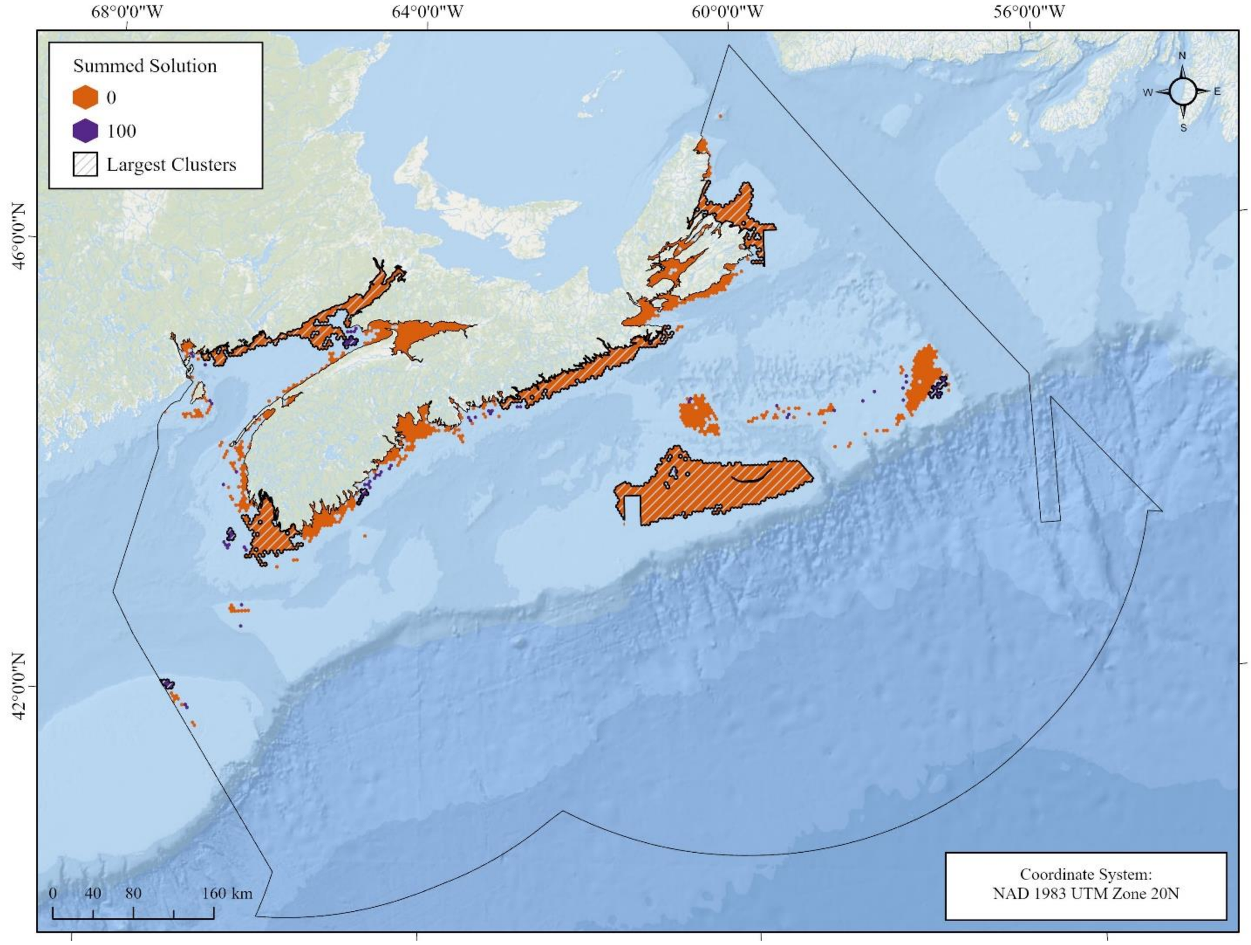

Figure 14. Planning units with a SSOLN value of 100 or 0 for the Baseline - Mobile + Fixed (BL-MF) scenario. The five largest clusters of planning units with a SSOLN value of 100 or 0 are labelled as largest clusters.

Figure 15 displays the Marxan summed solution result for the BL-MFL scenario. Planning units selected by Marxan to meet the mobile gear, fixed gear, and inshore lobster feature class targets were located primarily near the coast including the southern shore of Nova Scotia and New Brunswick, the Bay of Fundy, and Sydney Bight.

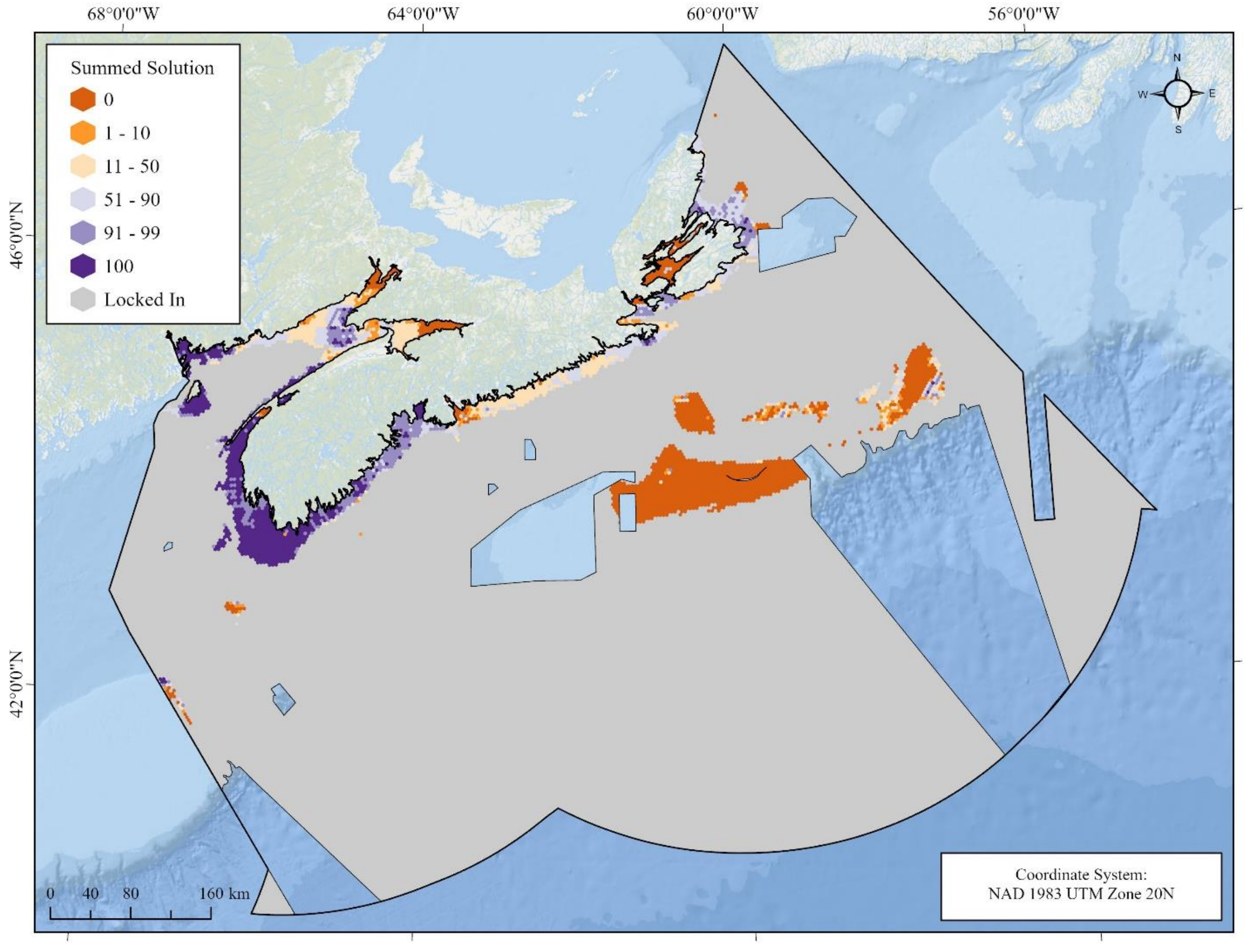

Figure 15. Marxan analysis summed solution result for the Baseline - Mobile + Fixed + Lobster (BL-MFL) scenario.

Figure 16 displays all planning units and the five largest clusters of planning units that received a SSOLN value of 100 or 0 for the BL-MFL scenario. The five largest clusters of planning units receiving a SSOLN value of 100 by area (km^2) in descending order were identified as the southern shore of Nova Scotia from Yarmouth to Barrington, the southern shore of Nova Scotia from Digby Neck to Yarmouth, nearshore St. Andrews, nearshore Grand Manan, and the western shore of Nova Scotia from Annapolis Royal to Margaretsville. The five largest clusters of planning units receiving a SSOLN value of 0 by area (km^2) in descending order were identified as Sable Island Bank and Western Bank, Banquereau, Middle Bank, Bras d'Or Lake, and Cobequid Bay.

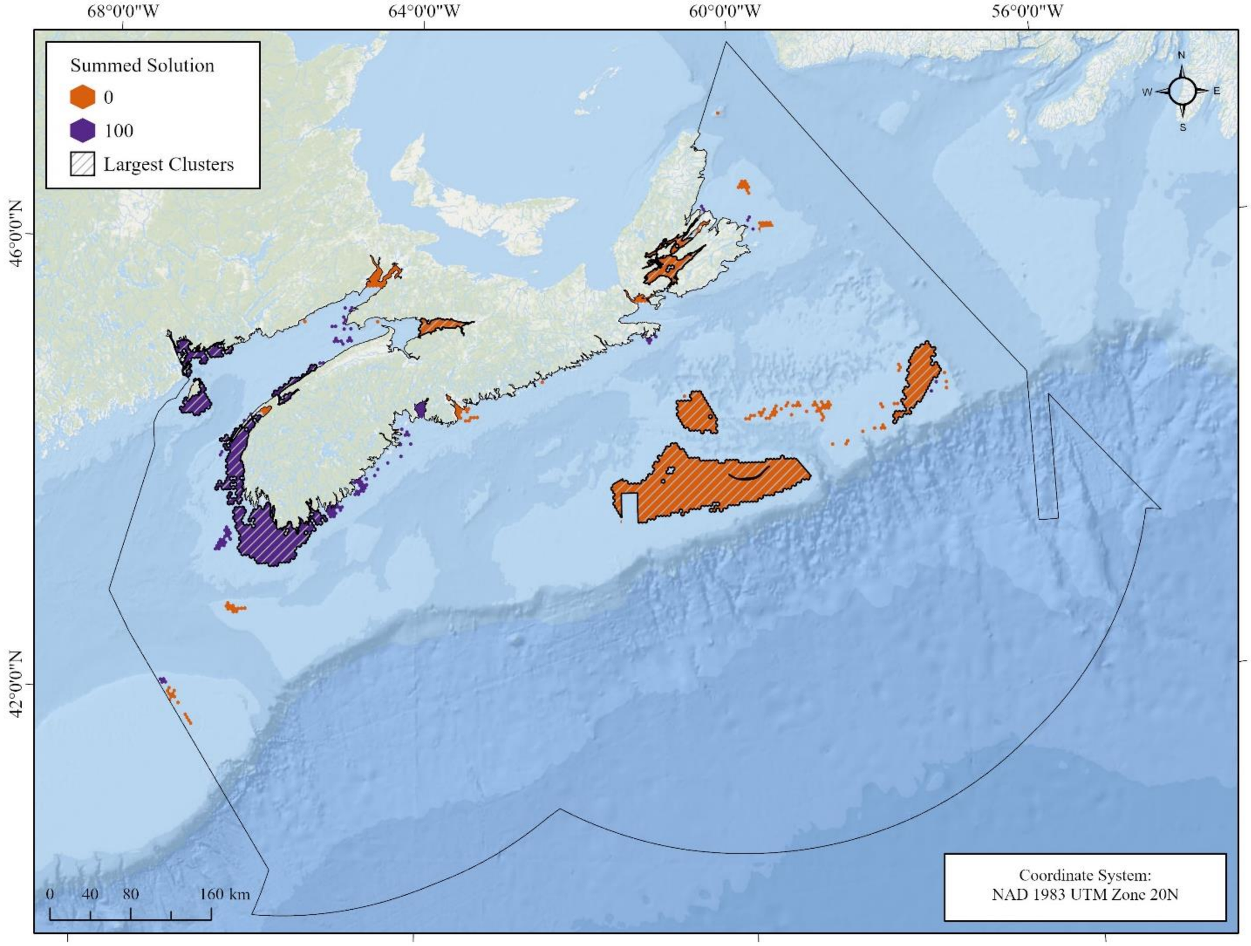

Figure 16. Planning units with a SSOLN value of 100 or 0 for the Baseline - Mobile + Fixed + Lobster (BL-MFL) scenario. The five largest clusters of planning units with a SSOLN value of 100 or 0 are labelled as largest clusters.

Figure 17 displays the Marxan summed solution result for the MO-MF scenario. Planning units selected by Marxan to meet the mobile gear and fixed gear feature class targets were located around the offshore bank areas, in the Bay of Fundy, and off the eastern shore of Nova Scotia.

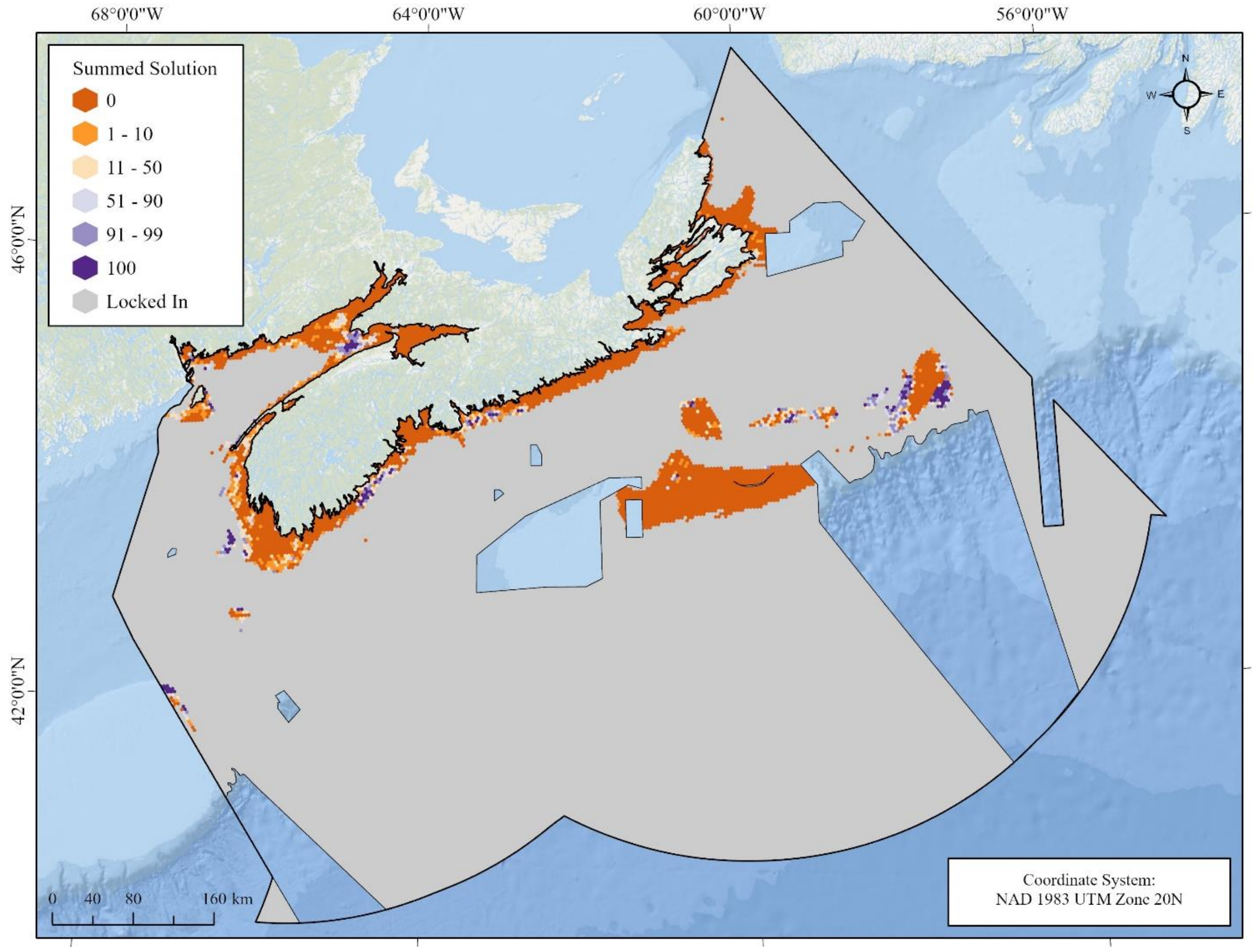

Figure 17. Marxan analysis summed solution result for the Multi-Objective - Mobile + Fixed (MO-MF) scenario.

Figure 18 displays all planning units and the five largest clusters of planning units that received a SSOLN value of 100 or 0 for the MO-MF scenario. The five largest clusters of planning units receiving a SSOLN value of 100 by area (km^2) in descending order were identified as north east Banquereau, the southern shore Nova Scotia near Port Mouton, outer Minas Basin, German Bank, and Georges Bank. The five largest clusters of planning units receiving a SSOLN value of 0 by area (km^2) in descending order were identified as Sable Island Bank and Western Bank, the southern shore of Nova Scotia from Digby Neck to Port Mouton, the Fundy shore of New Brunswick from St. Andrews to Chignecto Bay, the eastern shore of Nova Scotia from Halifax to Guysborough, and Sydney Bight.

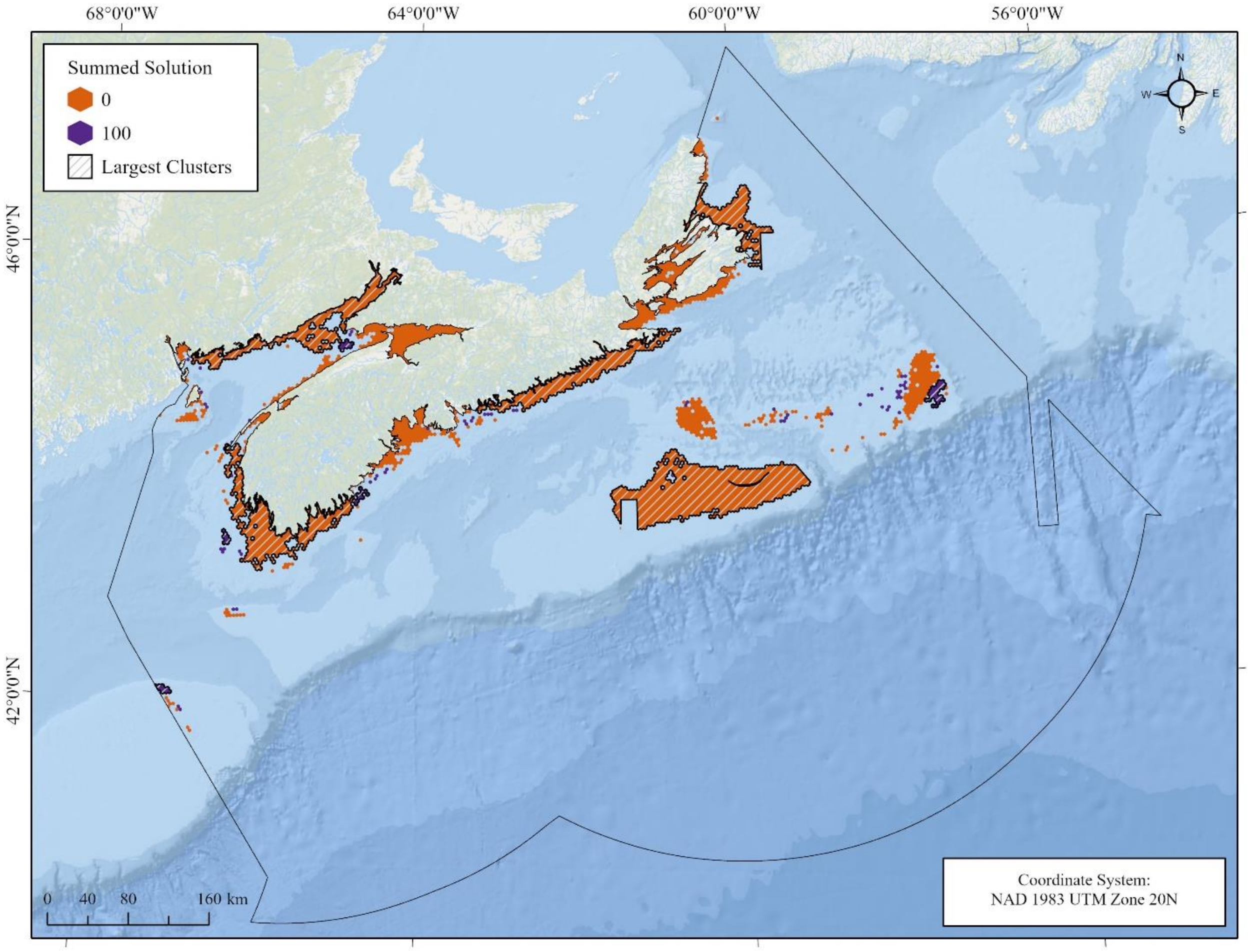

Figure 18. Planning units with a SSOLN value of 100 or 0 for the Multi-Objective - Mobile + Fixed (MO-MF) scenario. The five largest clusters of planning units with a SSOLN value of 100 or 0 are labelled as largest clusters.

Figure 19 displays the Marxan summed solution result for the MO-MFL scenario. Planning units selected by Marxan to meet the mobile gear, fixed gear, and inshore lobster feature class targets were located primarily near the coast including the southern shore of Nova Scotia and New Brunswick, the Bay of Fundy, and Sydney Bight.

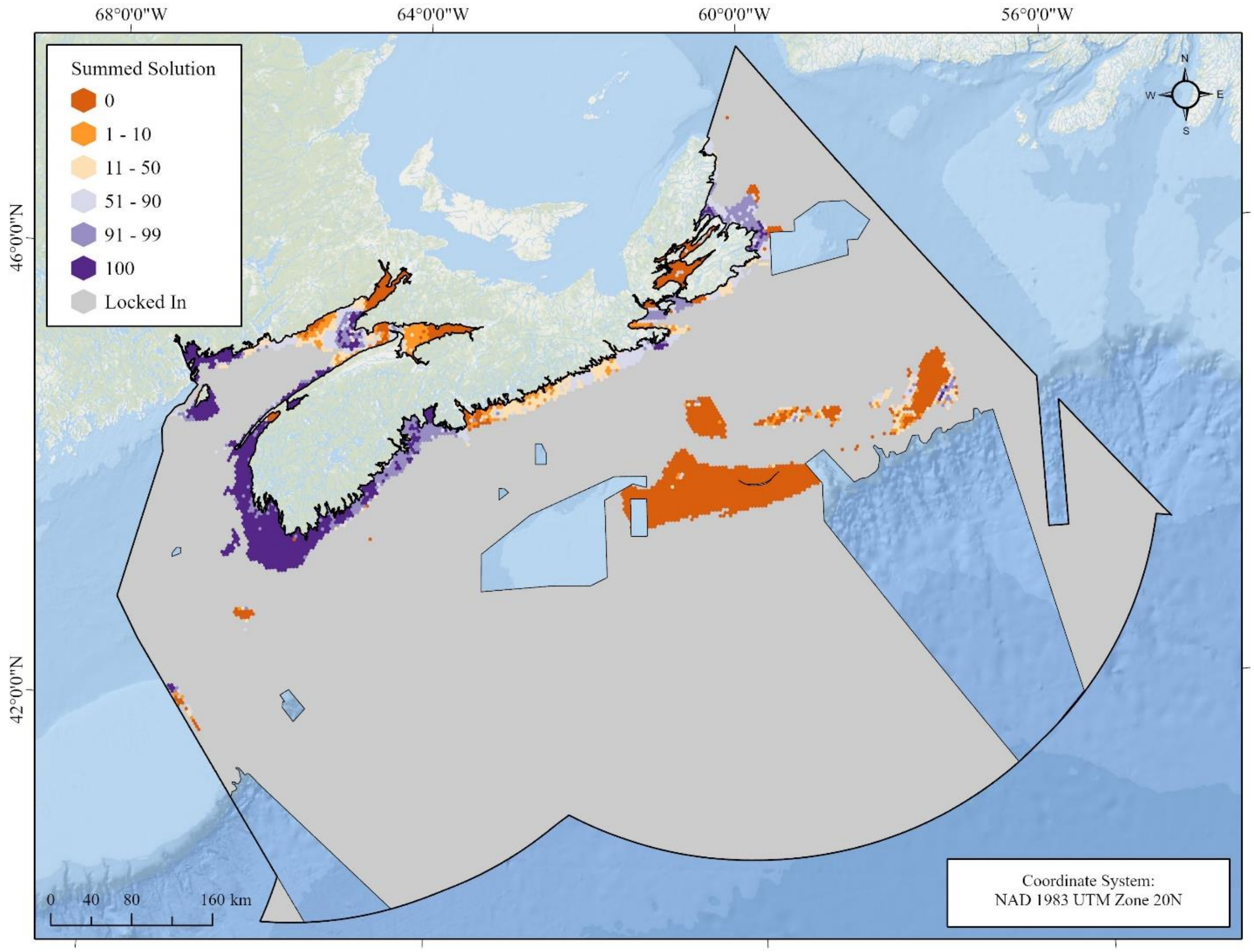

Figure 19. Marxan analysis summed solution result for the Multi-Objective - Mobile + Fixed + Lobster (MO-MFL) scenario.

Figure 20 displays all planning units and the five largest clusters of planning units that received a SSOLN value of 100 or 0 for the MO-MFL scenario. The five largest clusters of planning units receiving a SSOLN of 100 by area (km^2) in descending order were identified as the southern shore of Nova Scotia from Digby Neck to Shelburne, the nearshore of St. Andrews, the nearshore of Grand Manan, the west coast of Nova Scotia from Annapolis Royal to Youngs Cove, and the nearshore of Port Mouton. The five largest clusters of planning units receiving a SSOLN of 0 by area (km^2) in descending order were identified as Sable Island Bank and Western Bank, Banquereau, Middle Bank, Bras d'Or Lake, and Chignecto Bay.

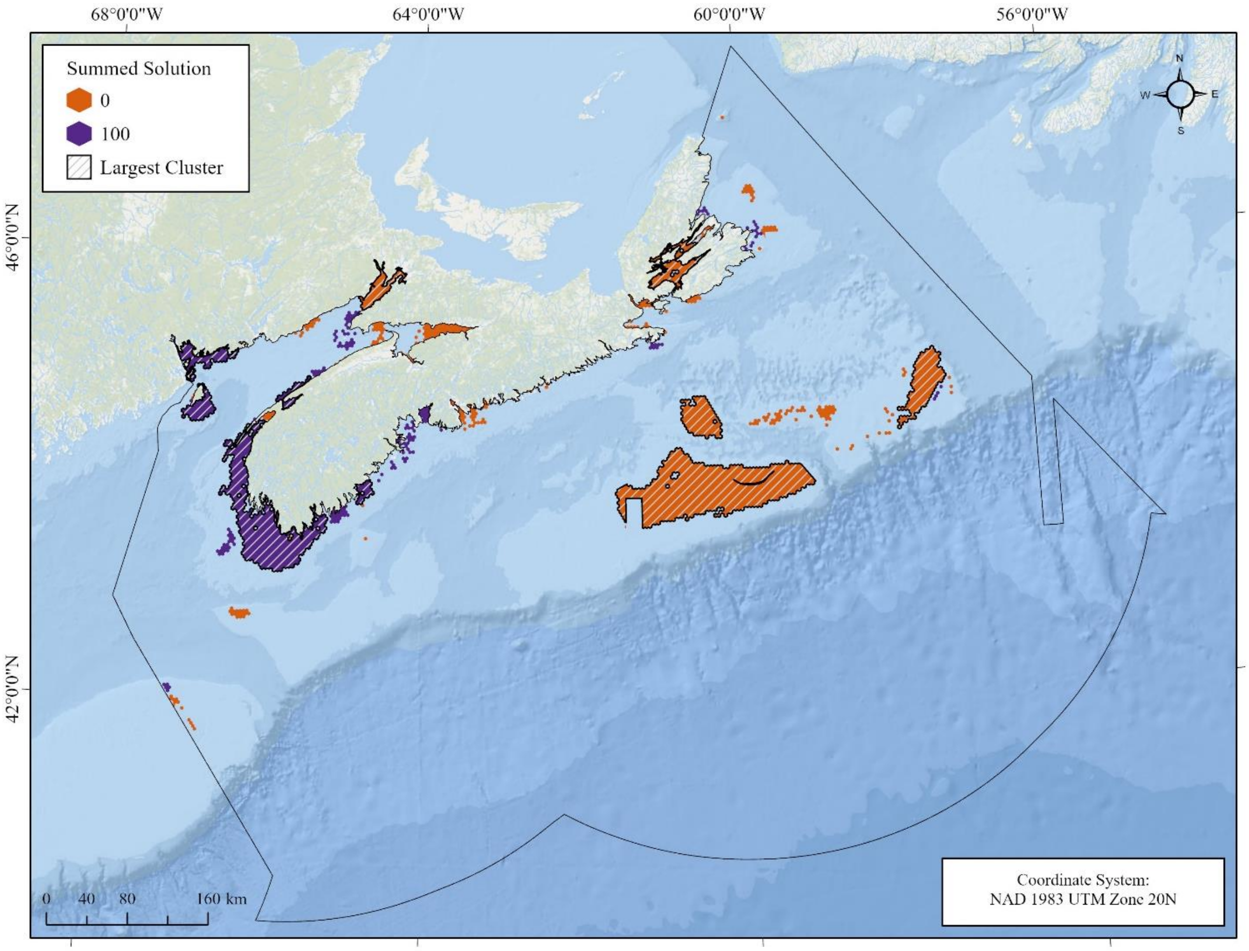

Figure 20. Planning units with a SSOLN value of 100 or 0 for the Multi-Objective - Mobile + Fixed + Lobster (MO-MFL) scenario. The five largest clusters of planning units with a SSOLN value of 100 or 0 are labelled as largest clusters.

Figure 21 displays the Marxan summed solution result for the CI-MF scenario. Planning units selected by Marxan to meet the mobile gear and fixed gear feature class targets were located in the Bay of Fundy area and the southern shore of Nova Scotia and New Brunswick.

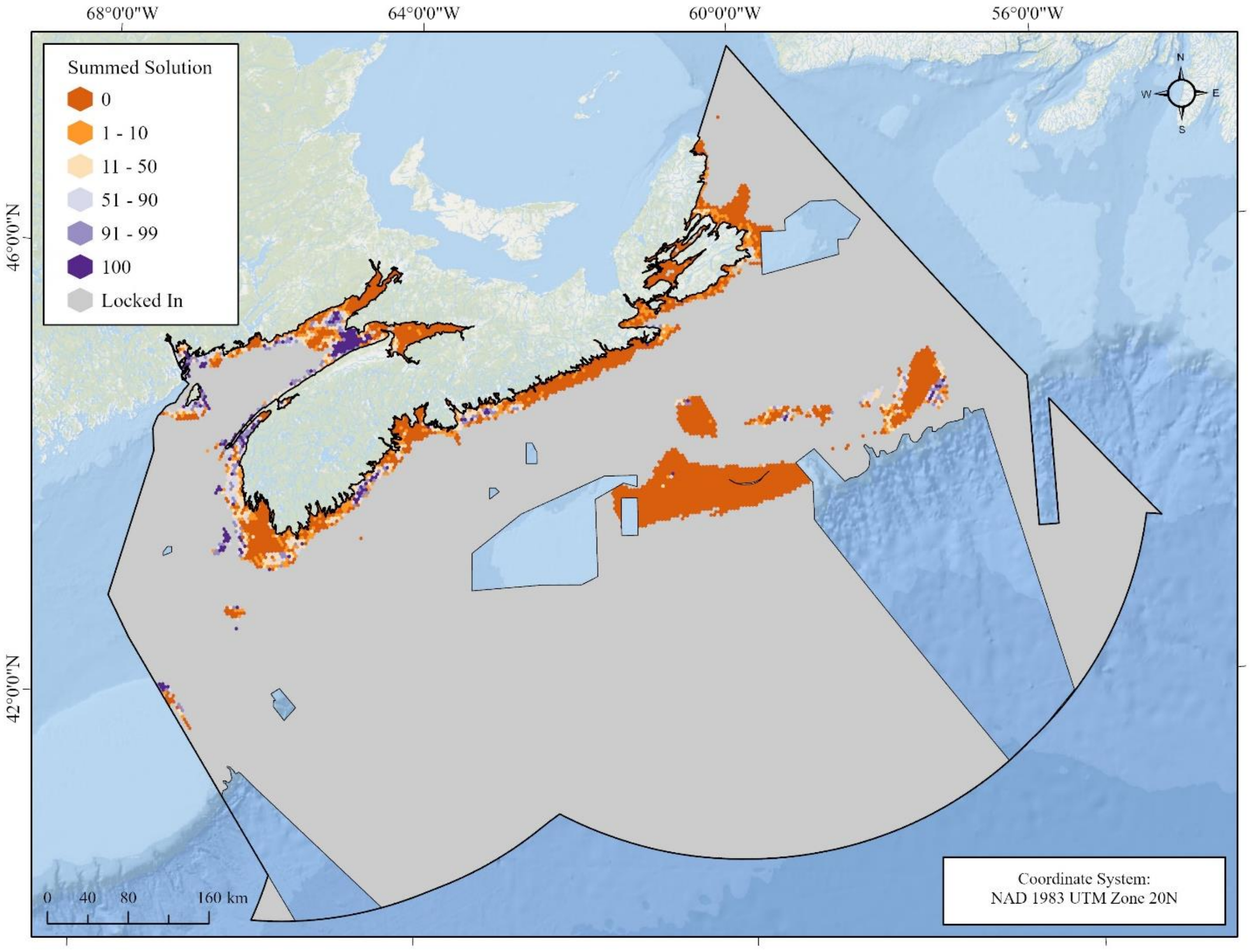

Figure 21. Marxan analysis summed solution result for the Conflict Identification - Mobile + Fixed (CI-MF) scenario.

Figure 22 displays all planning units and the five largest clusters of planning units that received a SSOLN value of 100 or 0 for the CI-MF scenario. The five largest clusters of planning units receiving a SSOLN value of 100 by area (km^2) in descending order were identified as the outer region of Minas Basin, the nearshore of Port Mouton, German Bank, the outer region of Chignecto Bay, and Georges Bank. The five largest clusters of planning units receiving a SSOLN value of 0 by area (km^2) in descending order were identified as Sable Island Bank and Western Bank, the eastern shore of Nova Scotia from Owls Head to Guysborough, Banquereau, the southern shore of Nova Scotia from Yarmouth to Barrington, and Sydney Bight.

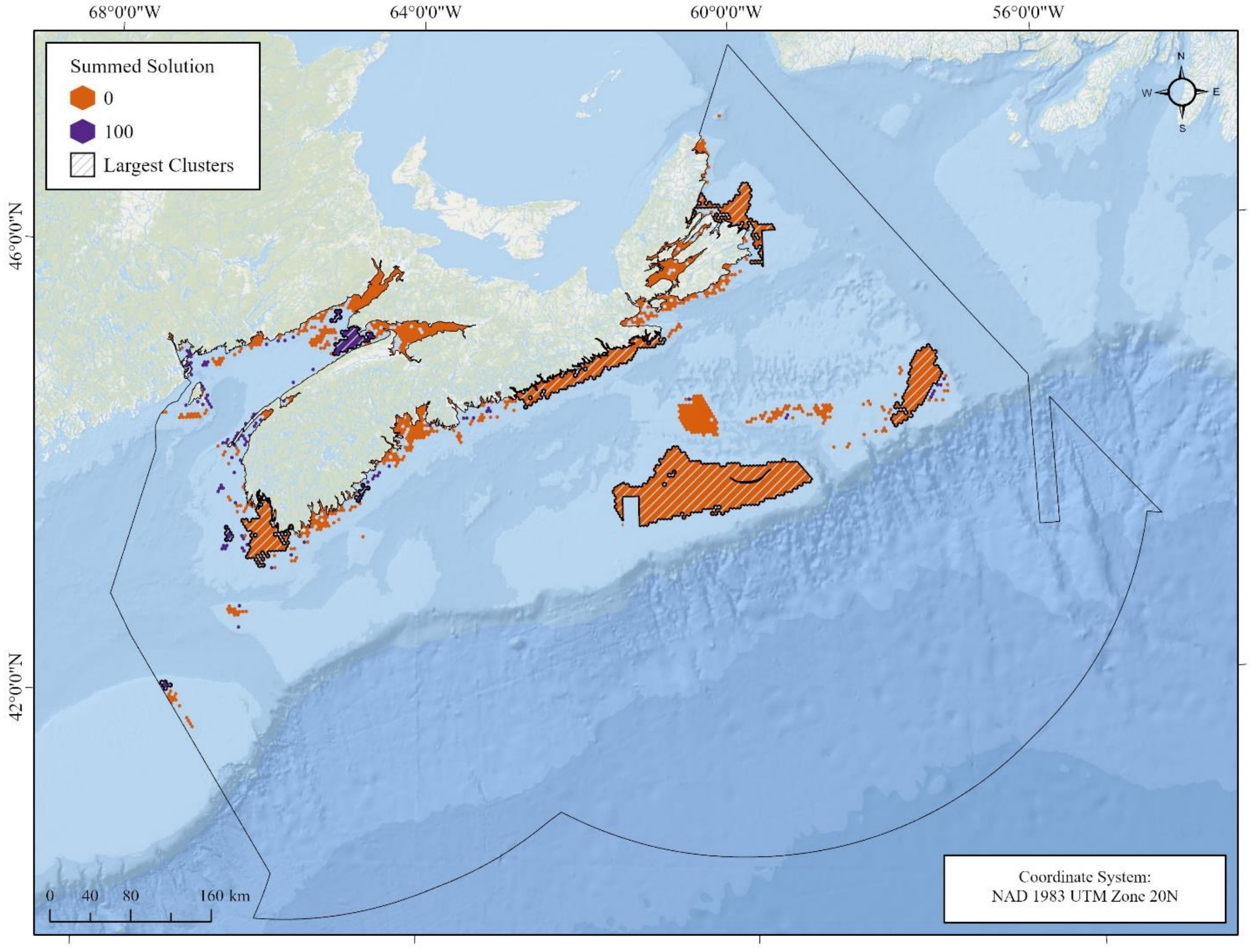

Figure 22. Planning units with a SSOLN value of 100 or 0 for the Conflict Identification - Mobile + Fixed (CI-MF) scenario. The five largest clusters of planning units with a SSOLN value of 100 or 0 are labelled as largest clusters.

Figure 23 displays the Marxan summed solution result for the CI-MFL scenario. Planning units selected by Marxan to meet the mobile gear, fixed gear, and inshore lobster feature class targets were located primarily near the coast including the southern shore of Nova Scotia and New Brunswick and the Bay of Fundy.

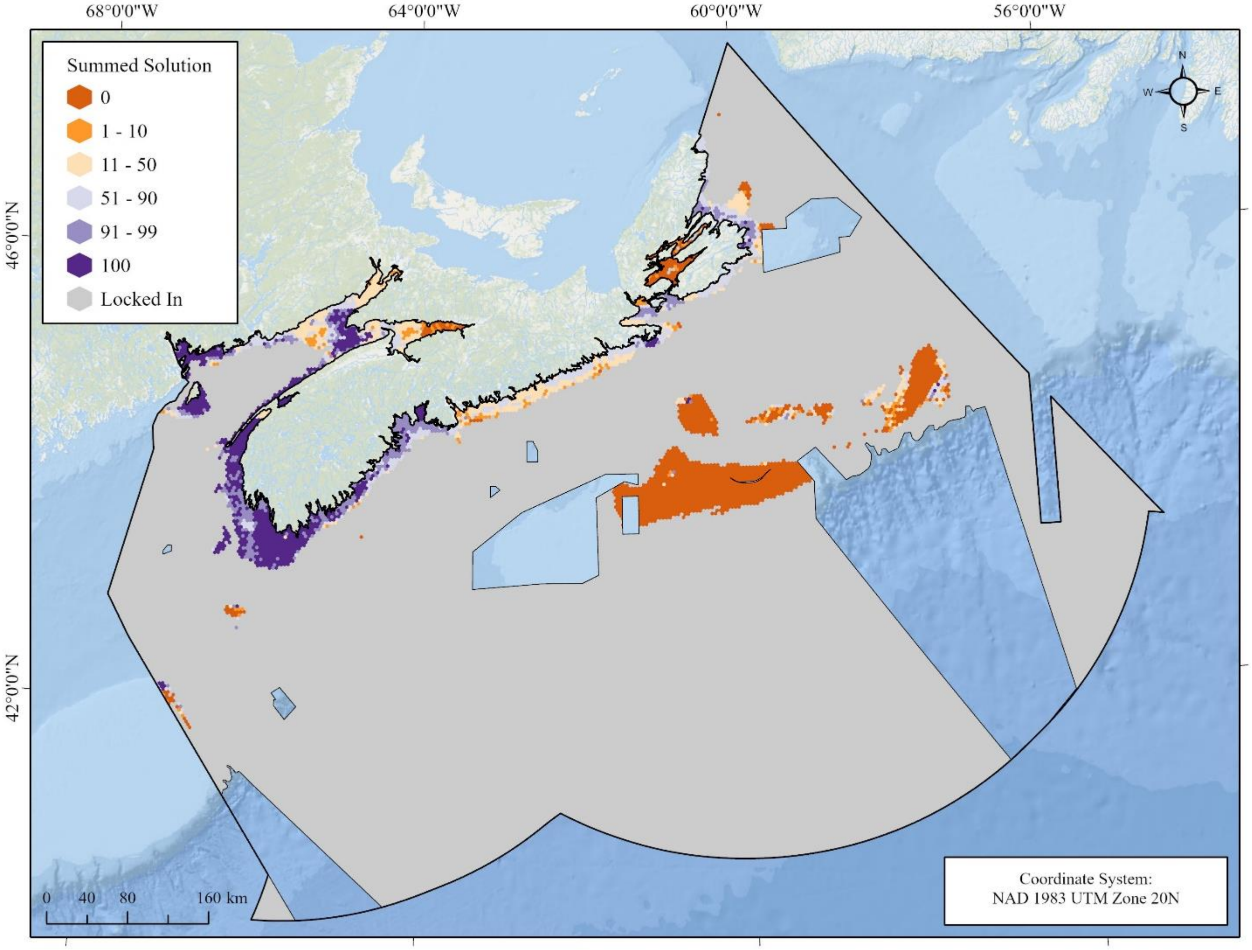

Figure 23. Marxan analysis summed solution result for the Conflict Identification - Mobile + Fixed + Lobster (CI-MFL) scenario.

Figure 24 displays all planning units and the five largest clusters of planning units that received a SSOLN value of 100 or 0 for the CI-MFL scenario. The five largest clusters of planning units receiving a SSOLN value of 100 by area (km^2) in descending order were identified as the southern shore of Nova Scotia from Yarmouth to Shelbourne, the southern shore of Nova Scotia from Digby Neck to Yarmouth, the outer area of Minas Basin, the nearshore of St. Andrews, and the nearshore of Grand Manan. The five largest clusters of planning units receiving a SSOLN value of 0 by area (km^2) in descending order were identified as Sable Island Bank and Western Bank, northern Banquereau, Middle Bank, Bras d'Or Lake, and southern Banquereau.

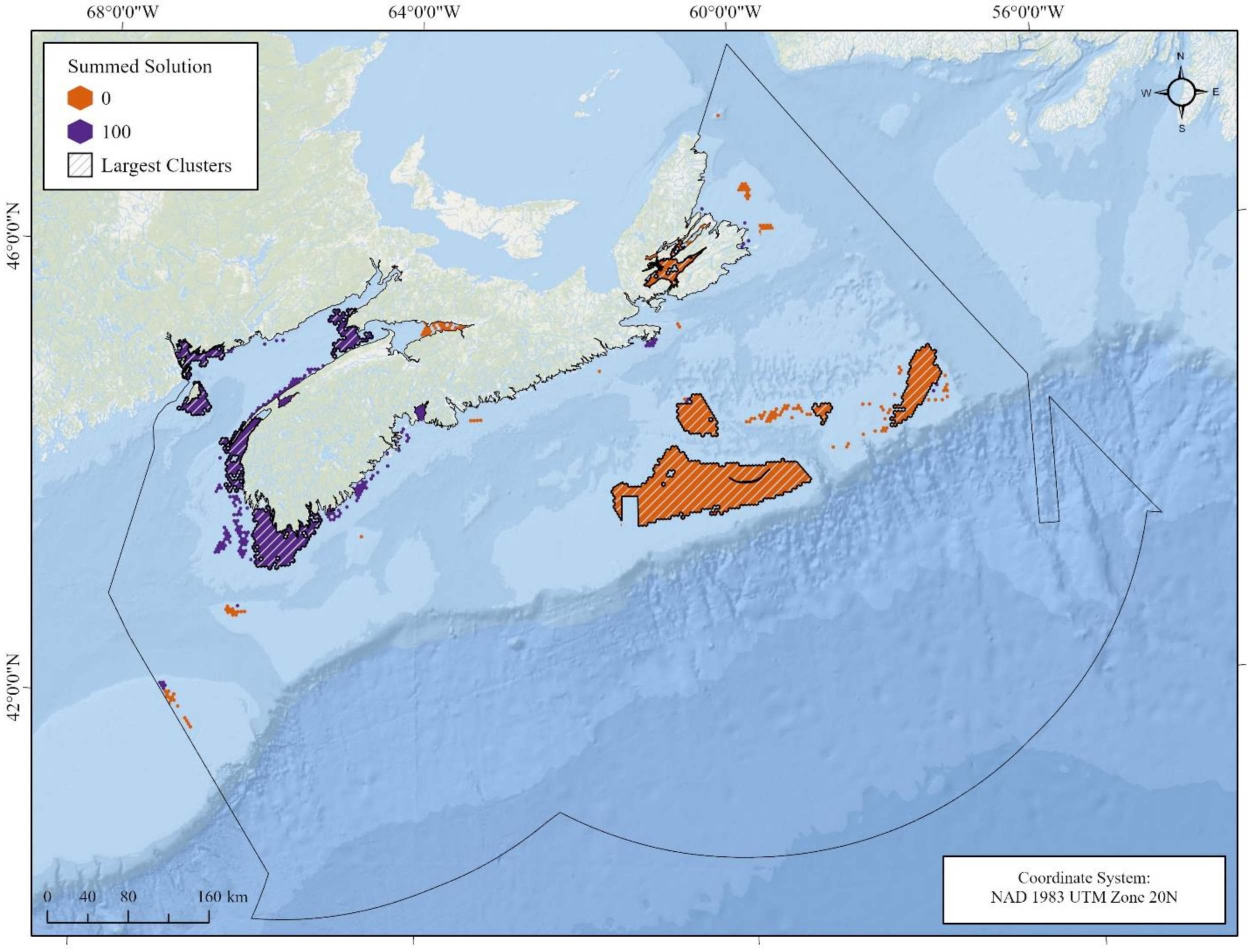

Figure 24. Planning units with a SSOLN value of 100 or 0 for the Conflict Identification - Mobile + Fixed + Lobster (CI-MFL) scenario. The five largest clusters of planning units with a SSOLN value of 100 or 0 are labelled as largest clusters.

3.3.3. Summed Solution Value 100 and 0

Table 4 includes the number of planning units, the total area (km^2), and the distance from shore for planning units that received a SSOLN value of 100 and 0 for each scenario. The number and area of planning units receiving a SSOLN value of 100 was larger in the three MFL scenarios when compared to the MF scenarios. The MO-MFL scenario had the largest (110.3 km ± 95.5) and the CI-MFL had the smallest (8.2 ± 20.5km) mean distance from shore for planning units with a SSOLN value of 100. The CI-MFL scenario had the largest (121.3 ± 72.6 km) and the MO-MF scenario had the smallest (48.2 ± 72.4 km) mean distance from shore for planning units with a SSOLN value of 0 (Table 4).

Table 4. Number of planning units and area of planning units that received a SSOLN value of 100 and 0 for each scenario.

	SSOLN = 100			**SSOLN = 0**		
Scenario	**Planning Unit Count**	**Area (km^2)**	**Mean Distance from Shore (km)**	**Planning Unit Count**	**Area (km^2)**	**Mean Distance from Shore (km)**
BL-MF	103	1018.2	83.1 ± 91.0	3488	27084.3	50.3 ± 73.6
BL-MFL	783	6737.5	9.1 ± 19.5	1723	13684.7	103.2 ± 78.7
MO-MF	129	1275.6	110.3 ± 95.5	3632	28353.5	48.2 ± 72.4
MO-MFL	934	7998.9	9.0 ± 21.5	1896	14870.6	95.3 ± 80.3
CI-MF	192	1788.1	22.6 ± 51.8	3123	24324.7	61.4 ± 77.8
CI-MFL	794	6864.8	8.2 ± 20.5	1537	13069.7	121.3 ± 72.6

Figure 25 shows the mean distance from shore (km) for planning units with a SSOLN of 100 for each of the six scenarios. The distance from shore for planning units that received a SSOLN value of 100 was on average 8 times larger in the MF scenarios compared to the MFL scenarios.

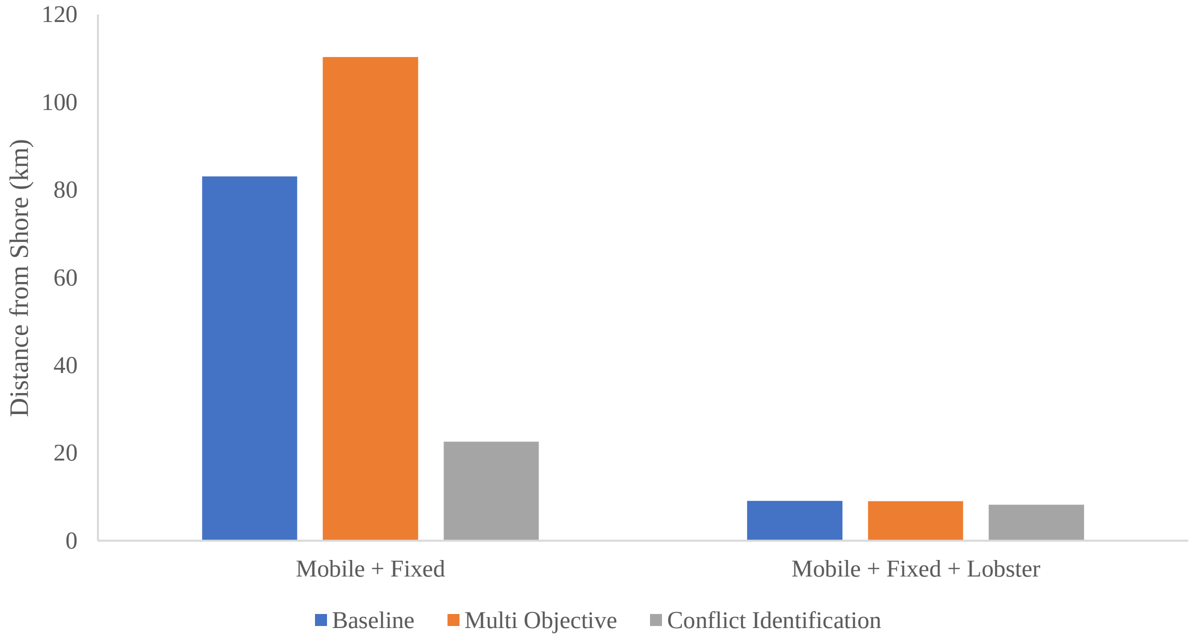

Figure 25. Mean distance from shore (km) for planning units with a SSOLN value of 100 for each scenario.

Figure 26 shows the mean distance from shore for planning units with a SSOLN value of 0 for each of the six scenarios. The mean distance from shore for planning units with a SSOLN value of 0 was on average 2 times larger in the MFL scenarios compared to the MF scenarios.

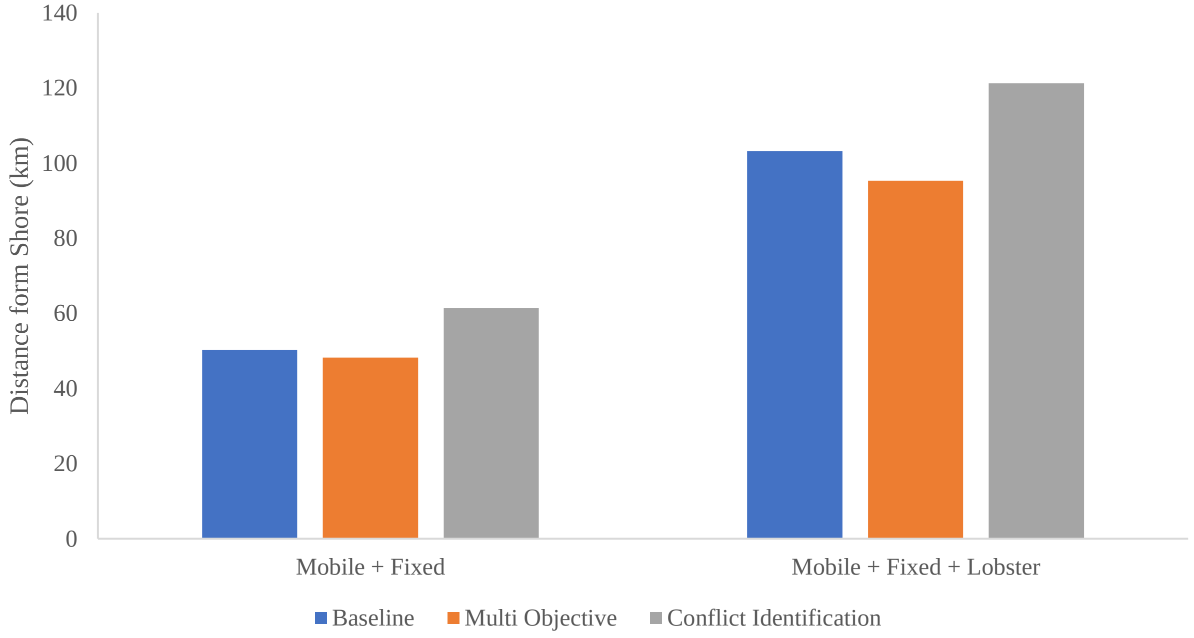

Figure 26. Mean distance from shore (km) for planning units with a SSOLN value of 0 for each scenario.

Table 5 includes the amount and the percent of the total catch of each feature class that was captured by planning units with a SSOLN value of 100. The amount of mobile gear and fixed gear catch weight contained within planning units that received a SSOLN value of 100 was relatively consistent across the six scenarios ranging from 14.8% to 17.9% and 12.7% to 15.8% respectively.

Table 5. Amount and percent of total mobile gear catch weight (kg), fixed gear catch weight (kg), and inshore lobster catch weight standardized by area (kg/km^2) within planning units that received a SSOLN value of 100 for each scenario.

	Mobile Gear		**Fixed Gear**		**Inshore Lobster**	
Scenario	**Sum (kg)**	**% of Total**	**Sum (kg)**	**% of Total**	**Sum (kg/km^2)**	**% of Total**
BL-MF	267,237,108	15.2	45,348,533	15.8	203,139.7	1.4
BL-MFL	259,592,904	14.8	36,424,099	12.7	5,278,196.6	36.5
MO-MF	292,023,437	16.6	44,917,872	15.7	199,441.9	1.4

Scenario	Mobile Gear Sum (kg)	Mobile Gear % of Total	Fixed Gear Sum (kg)	Fixed Gear % of Total	Inshore Lobster Sum (kg/km^2)	Inshore Lobster % of Total
MO-MFL	284,329,843	16.2	41,040,731	14.3	5,755,578.9	39.8
CI-MF	295,235,609	16.8	44,738,029	15.6	684,121.6	4.7
CI-MFL	315,650,440	17.9	38,202,381	13.3	4,963,837.3	34.3

Figure 27 shows the percentage of each feature class that was captured by planning units with a SSOLN value of 100. The amount of the inshore lobster feature class that was captured by planning units with a SSOLN value of 100 was lower in the scenarios that did not include a target for the inshore lobster feature class (MF scenarios) when compared to the scenarios that did (MFL scenarios). The amount of inshore lobster feature class captured by planning units with a SSOLN value of 100 for the MF scenarios ranged from 1.4% to 4.7% compared to 34.3% - 39.6% for the MFL scenarios.

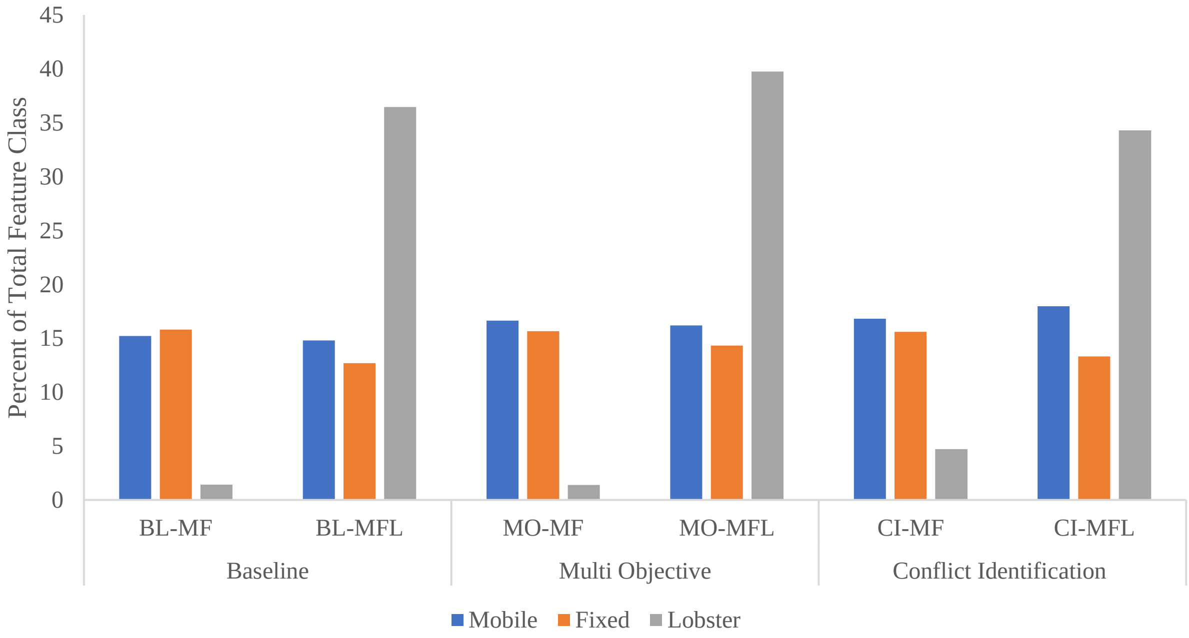

Figure 27. Percent of mobile gear catch weight (kg), fixed gear catch weight (kg), and inshore lobster catch weight standardized by area (kg/km^2) contained within planning units that received SSOLN value of 100 for each scenario.

Table 6 includes the amount and the percent of the total catch for each feature class that was captured by planning units with a SSOLN value of 0. The percent of the total mobile gear and fixed gear catch weight contained within planning units that received a SSOLN value of 0 was relatively consistent across the six scenarios ranging from 0.4% to 1.2% and 0.6% to 1.5% respectively.

Table 6. Amount and percent of total mobile gear catch weight (kg), fixed gear catch weight (kg), and inshore lobster catch weight standardized by area (kg/km^2) within planning units that received a SSOLN value of 0 for each scenario.

	Mobile Gear		**Fixed Gear**		**Inshore Lobster**	
Scenario	**Sum (kg)**	**% of Total**	**Sum (kg)**	**% of Total**	**Sum (kg /km^2)**	**% of Total**
BL-MF	13,714,333	0.8	3,174,072	1.1	5,168,391.1	35.7
BL-MFL	7,241,661	0.4	2,403,532	0.8	68,259.6	0.5
MO-MF	20,793,349	1.2	4,336,066	1.5	5,738,186.4	39.6
MO-MFL	10,889,981	0.6	2,837,140	1.0	152,612.1	1.1
CI-MF	17,457,635	1.0	3,221,956	1.1	3,753,066.6	25.9
CI-MFL	15,824,865	0.9	1,748,083	0.6	13,975.8	0.1

Figure 28 shows the percentage of each feature class that was captured by planning units with a SSOLN value of 0. The amount of the inshore lobster feature class that was captured by planning units with a SSOLN value of 0 was higher in scenarios that did not include a target for the inshore lobster feature class (MF scenarios) compared to the scenarios that did (MFL scenarios). The amount of the inshore lobster feature class captured by planning units with a SSOLN value of 0 for the MFL scenarios ranged from 0.1% to 1.1% compared to 25.9% - 39.6% for the MF scenarios.

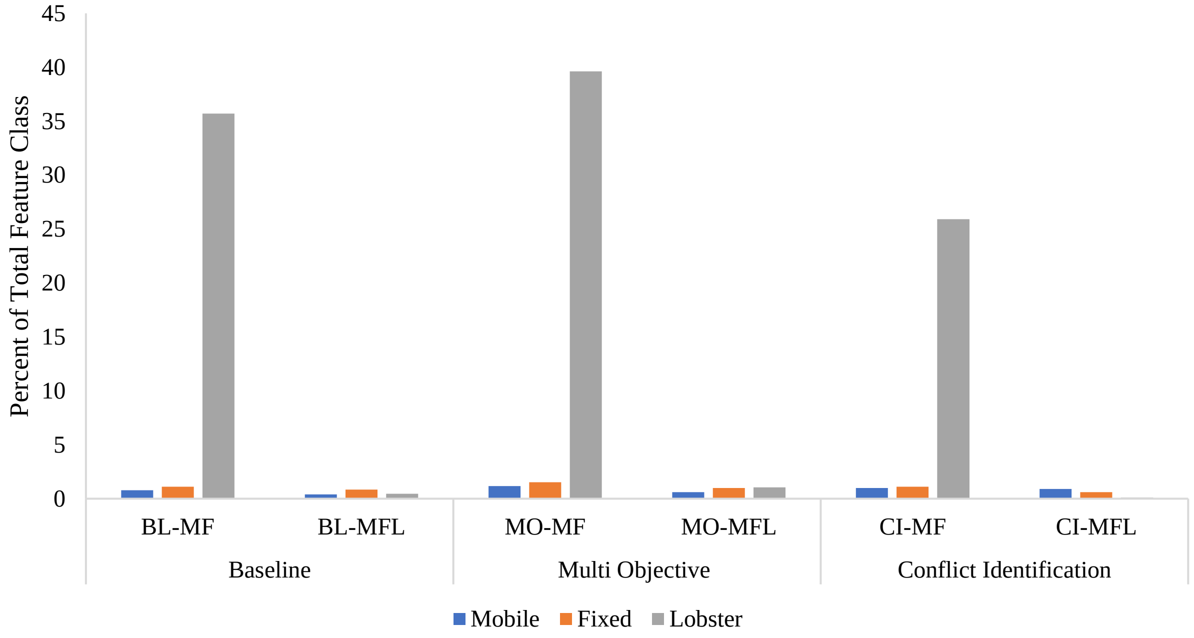

Figure 28. Percent of mobile gear catch weight (kg), fixed gear catch weight (kg), and inshore lobster catch weight standardized by area (kg/km^2) contained within planning units that received a SSOLN value of 0 for each scenario.

4. CHAPTER FOUR: DISCUSSION

In this study, a reverse Marxan analysis was conducted to highlight potential spatial overlap between future fixed-base OSW development and the commercial fishing industry. The purpose of this study was to develop a methodology to support future MSP and multi-objective planning in the Scotian Shelf-Bay of Fundy planning area. Multiple Marxan scenarios were designed to consider various Marxan configurations and objectives such as cost, the existing commercial fishing industry, and suitable areas for fixed-base offshore wind development. The results of the Marxan analyses selected areas that were considered suitable for fixed-base OSW development and that were important to maintaining commercial fishing catch targets. Results identified areas of increased potential for spatial conflict between industries should OSW development take place. Additionally, areas that were not selected represented areas with less contribution to commercial catch targets and that were suitable for fixed-base OSW development indicating a lower likelihood of spatial conflict should OSW development take place.

This analysis was not inclusive of all constraints and objectives that exist within the Scotian Shelf-Bay of Fundy planning area and therefore should not be used for fixed-base OSW siting and planning. Areas identified by this study should be viewed as an indicator of potential spatial conflict and therefore should be evaluated to a greater extent in future OSW planning and siting exercises conducted for the Scotian Shelf-Bay of Fundy planning area. However, this study achieved its main objective of providing an initial framework for the methodology that can be used for future spatial analyses using the decision-support tool Marxan.

The Marxan analysis used in this study was designed to include three different exercises to demonstrate how the selection preferences of Marxan can be modified to solve for different outcomes. The baseline exercise was designed so that the Marxan analysis selected areas that contributed to commercial catch targets with no additional considerations related to the OSW industry. The multi-objective exercise was designed to demonstrate how Marxan can be used to select areas that would represent a compromise between the commercial fishing industry and the OSW industry. Finally, the conflict identification exercise was designed so that the Marxan analysis selected areas with the highest likelihood of spatial conflict between commercial fishing and the OSW industry. Each exercise was comprised of two scenarios based on the feature classes that were included in the Marxan analysis. The first scenario of each exercise included the mobile gear and fixed gear feature classes and the second scenario of each exercise included the mobile gear, fixed gear, and inshore lobster feature classes. The combination of the exercises and feature classes resulted in six different scenarios.

4.1. Exercise Comparison

4.1.1. Marxan Analysis Results

Marxan scores differed between the three exercises with the baseline exercise scenarios receiving the lowest overall Marxan scores and the multi-objective exercise scenarios receiving the largest overall Marxan scores. The baseline exercise receiving the lowest overall Marxan score is likely a result of the low cost value assigned to planning units in the baseline exercise compared to the other two exercises. The baseline exercise assigned a cost value of 1 to each planning unit whereas the cost layers used for the multi-objective and conflict identification exercises assigned cost values to planning units that ranged from 1 to 109. The multi-objective exercise receiving the highest overall Marxan score is likely the result of two factors within the Marxan analysis design. First, the cost layer used in the multi-objective exercise assigned larger cost values to planning units closer to shore when compared to the cost layer used in the conflict identification exercise. Second, planning units that were available to be included in the Marxan analysis tended to be closer to shore due to the 60 m depth restriction that was implemented using the status variable. As a result, planning units that were available to be included in the final solution tended to have a higher cost value in the multi-objective exercise when compared to the conflict identification exercise which resulted in a higher overall Marxan score in the multi-objective exercise.

4.1.2. Marxan Summed Solution Results:

The results of this study identified the same four areas as suitable for fixed-base OSW development while contributing highly to commercial catch weight targets within each of the mobile gear plus fixed gear (MF) scenarios. These areas included Georges Bank, German Bank, the eastern shore of Nova Scotia near Port Mouton, and the nearshore area of Minas Basin. These areas should be examined further as they have a high potential for spatial conflict between the mobile and fixed gear commercial fishing fleets and future fixed-base OSW development in the

Scotian Shelf-Bay of Fundy planning area. The results of this study also identified the same four areas that were suitable for fixed-base OSW development and contributed less to commercial catch weight targets within each of the three MF scenarios. These areas included Sable Island Bank and Western Bank, the eastern shore of Nova Scotia from Halifax to Guysborough, the southern shore of Nova Scotia near Yarmouth, and Sydney Bight. These areas may have a lower potential for spatial conflict between the mobile and fixed gear commercial fishing fleets and future fixed-based OSW development in the Scotian Shelf-Bay of Fundy planning area. It is important to note that these scenarios did not consider the inshore lobster fishing fleet in any capacity and as a result are not representative of spatial importance to this industry.

Some differences were observed across the summed solution results of the MF scenarios between the three exercises. The main differences between exercises can mainly be seen in the location of planning units that received an SSOLN value of 100 or 0 and can likely be associated with the different cost layers that were used between exercises. The cost layer used for the baseline exercise was designed to act as a reference point by providing each planning unit with the same cost value. Therefore, the results from the baseline scenario can be used to compare how the cost layers of the other two exercises affected the location of planning units that received a SSOLN value of 100 or 0.

The multi-objective exercise was designed so that the Marxan analysis would consider the objectives of both the commercial fishing and OSW industry while selecting planning units to meet the commercial fishing targets. Higher cost values were assigned to areas closer to shore as these areas were assumed to be more economically feasible for the development of fixed-base OSW turbines. Planning units receiving a SSOLN value of 100 had a larger mean distance from shore in the multi-objective exercise when compared to the baseline and conflict identification exercises. Planning units receiving a SSOLN value of 0 had a lower mean distance from shore in the multi-objective exercise when compared to the baseline and conflict identification exercises. Therefore, the results from the MO-MF scenario indicate that the objectives of multiple industries were integrated into the Marxan analysis so that the areas that were highlighted with high contributions to catch weight targets favored locations that were less ideal for OSW development. Alternatively, areas that were highlighted by the MO-MF scenarios with low contributions to catch weight targets favored locations that were more ideal for OSW development. Therefore, a cost layer representing the objectives of multiple industries could be used in future spatial analyses so that the final outputs represent a compromise between industries.

The conflict identification exercise was designed so that the Marxan analysis would select areas that were favorable to both the commercial fishing and OSW industry to indicate a higher or lower likelihood of spatial conflict related to future fixed-base OSW development. Lower cost values were assigned to areas that were closer to shore as these areas were assumed to be more economically feasible for the development of fixed-base OSW turbines. Planning units receiving a SSOLN value of 100 had a lower mean distance from shore in the conflict identification exercise when compared to the baseline and multi-objective exercises. Planning units receiving a SSOLN value of 0 had a higher mean distance from shore in the conflict identification exercise when compared to the baseline and multi-objective exercises. Therefore, the CI-MF scenario tended to select planning units closer to shore as areas with a higher likelihood of spatial conflict due to higher contributions to catch weight targets and increased economic feasibility for the OSW industry. Alternatively, the CI-MF scenario tended to select planning units further from shore as areas with a lower likelihood of spatial conflict due to lower contributions to catch weight targets and decreased economic feasibility for the OSW industry.

The summed solution results of the MFL scenarios were relatively consistent across the three exercises. The results of the MFL scenarios identified the same four areas that were classified as suitable for fixed-base OSW development and with higher contributions to catch weight targets. These areas included southern Nova Scotia from Yarmouth to Barrington, southern Nova Scotia from Digby Neck to Yarmouth, the nearshore area of Grand Manan, and the nearshore area of St. Andrews. These areas may have a higher potential for spatial conflict between the mobile gear, fixed gear, and inshore lobster commercial fishing fleets and future fixed base OSW development in the Scotian Shelf-Bay of Fundy planning area. The results of the MFL scenarios also identified the same four areas that were classified as suitable for fixed-base OSW development and with lower contributions to catch weight targets. These areas included Sable Island Bank and Western Bank, Banquereau, Middle Bank, and Bras d’Or Lake. These areas may have a lower potential for spatial conflict between the mobile gear, fixed gear, and inshore lobster commercial fishing fleets and future fixed-base OSW development in the Scotian Shelf-Bay of Fundy planning area.

The marginal differences between the MFL scenarios would suggest that the different cost layers of the three exercises had little influence on the selection of planning units by Marxan. The inshore lobster feature class is unique as this fishing fleet has a much smaller spatial extent when compared to the fixed gear and mobile gear fishing fleets. The inshore lobster fishing fleet can only operate within 50 M of the coast whereas the mobile and fixed gear fleets can operate up to 200 M from the coast (DFO, 2020b). Additionally, only planning units with a depth of less than 60 m were available to be selected by Marxan restricting available planning units to the nearshore and the shallow offshore banks of the study area. However, offshore bank areas are typically located further than 50 M from the coast and therefore did not contain any inshore lobster fishing fleet activity. As a result, regardless of the cost value, planning units close to shore were selected to reach the inshore lobster feature class target, reducing the overall influence of the various cost layers.

4.2. Scenario Comparison

4.2.1. Marxan Summed Solution Results:

A larger area of high potential for spatial conflict was identified by the Marxan summed solutions in the three MFL scenarios compared to the MF scenarios. Additionally, a smaller area of lower likelihood for spatial conflict was identified by the Marxan summed solution in the MFL scenarios compared to the MF scenarios. This relationship is likely due to the inshore lobster feature class having a larger amount of spatial overlap with potential fixed-base OSW development when compared to the mobile and fixed gear feature class. The inshore lobster feature class had 56.1% of its catch sourced from areas that were considered suitable for fixed-base OSW development compared to 29.5% for fixed gear and 28.1% for mobile gear. The differences in spatial overlap between the various fishing fleets highlight the importance of including the inshore lobster fishing fleet in OSW planning exercises for the Scotian Shelf-Bay of Fundy planning area.

The location of areas that were identified as having a higher likelihood of spatial conflict between the commercial fishing industry and fixed-base OSW development differed between the

MFL scenarios and the MF scenarios. In the three MF scenarios, the southern shore of Nova Scotia, the eastern shore of Nova Scotia, and Sydney Bight were identified as areas containing a low likelihood of spatial conflict with future OSW development. However, in the three MFL scenarios, these three areas were not consistently identified to be areas of low likelihood of spatial conflict. Additionally, the results of the three MFL scenarios were conflicting with the MF scenario results as the southern shore of Nova Scotia was identified as the largest area containing a high likelihood of spatial conflict between the commercial fishing industry and future fixed-based OSW development. This result would indicate that inshore lobster is a key consideration for the southern shore of Nova Scotia, the eastern shore of Nova Scotia and Sydney Bight.

The MF scenarios did not include the inshore lobster feature class within the analyses resulting in little representation of the fleet across the various solutions. In the MF scenarios, the planning units that were identified to have a high contribution to catch weight targets contained a small amount of the inshore lobster feature class (1.4% - 4.7% of total catch). Additionally, in the MF scenarios, the planning units that were identified to have a low contribution to catch weight targets contained a large amount of the inshore lobster feature class (25.9% - 35.7% of total catch). These results demonstrate that when the inshore lobster feature class was not included in the spatial analysis the areas that were identified to have a high or low likelihood of spatial conflict were not representative of potential conflict with the inshore lobster commercial fishing fleet. Therefore, if the entire fishing fleet is not adequately considered during the planning stages future commercial developments such as OSW could result in significant conflict with existing activities.

4.3. Analysis and Recommendations

The purpose of this study was to develop methodology for spatial analyses that can be used to effectively inform MSP within the Scotian Shelf-Bay of Fundy planning area. From the results of the case study analysis and spatial analysis a suite of lessons learned related to the commercial fishing industry, the OSW industry, and other ocean uses was developed to inform future research.

4.3.1. Commercial Fishing Industry

For the mobile and fixed gear feature classes, catch weight was used to represent spatial importance. There are two major issues of representation that can be associated with the use of catch weight as an indicator of spatial importance. The first issue is that using catch weight to represent all commercial fishing activity provides the landed weight of each species with the same value resulting in equal influence across species. However, within the Scotian Shelf-Bay of Fundy planning area, there is a large diversity of species caught with a wide range of value per unit of catch weight. For example, from the mobile gear fishing fleet, the average price of herring was $0.39/kg compared to $24.15/kg for scallops in 2015 (DFO, 2018c, 2021e). Therefore, the catch weight of landed scallops would have a considerably higher monetary value than the catch weight of landed herring. However, the results from this study do not consider the difference in catch value between species such as scallops and herring within the mobile gear feature layer. This issue could be addressed by considering each species individually when setting Marxan targets, or through the use of a different data layer to represent spatial importance to the commercial fishing industry. As demonstrated through various other existing OSW spatial analysis projects such as the three case studies evaluated in this study, other data layers can be used to represent spatial importance to the commercial fishing industry (The Crown Estate, 2019a; Kirkpatrick et al., 2017; Marine Scotland, 2018). For example, Scotland's ScotWind Project used the monetary value of catch to represent spatial importance to the commercial fishing industry addressing the issue of representation by providing species with higher economic value with increased influence on the spatial analysis (Marine Scotland, 2018).

The second issue associated with using catch weight to represent spatial importance to the commercial fishing industry is the generalization of the spatial footprint of fishing activities. The Eastern Commercial Fishing Database reports catch weight on a 10km^2 grid using point data from commercial fishing logbooks (DFO, 2021b). Due to the dynamic nature of many fishing activities, the use of point data may lead to the generalization of the commercial fishing industry's spatial footprint (Lee et al., 2010). For example, Atlantic swordfish and other tuna are fished in the Scotian Shelf-Bay of Fundy planning area using pelagic longlines which can range from 18 km – 90 km in length and can drift for several hours (DFO, 2016; Domingo et al., 2014). As discussed in Chapter Two, the issue of generalization associated with the use of logbook data can be addressed through either supplementation or replacement with more accurate data sources. The socio-economic impact analysis commissioned by BOEM for OSW planning in the US supplemented catch weight data from vessel logbooks with a fishing activity model and dealer reports (Kirkpatrick et al., 2017). As a result, a data layer was developed that mapped the predictive spatial footprint around actual fishing locations and the generated revenue of the activity (Kirkpatrick et al., 2017). Additionally, the UK's Round 4 OSW Leasing Project used VMS data to develop a data layer that used fishing intensity in kilowatt-hours to represent spatial importance to the commercial fishing industry (The Crown Estate, 2019a). The use of VMS data to develop a fishing activity layer has been found to provide higher-resolution estimates of commercial fishing spatial effort distributions and footprint when compared to standard catch weight logbook entries (Lee et al., 2010). Moving forward, future research could look to replace or supplement catch weight data with a predictive model, monetary value, or VMS data to increase the representation of spatial importance to the commercial fishing industry.

The potential impact of fixed-based OSW development on commercial fishing activity was treated equally across the three commercial fishing fleets evaluated within this study. However, there is growing evidence and examples that the development of OSW farms may not impact all fishing activities equally. For example, from Scotland's ScotWind project through consultation with industry five commercial fishing activities were highlighted to have higher levels of constraint related to OSW development (Marine Scotland, 2018). These fishing activities were identified as scallop dredging, nephrops trawling and creeling, demersal trawling, pelagic trawling, and crab and lobster creeling (Marine Scotland, 2018). Additionally, with OSW development growing around the globe opportunities for joint or shared use of the marine space with certain fishing activities are being explored (Schupp et al., 2021). For example, in the UK the fixed gear lobster pot fishery has remained operational within the Westermost Rough offshore wind farm (Roach et al., 2022). This is a successful example of co-existence between OSW development and the commercial fishing industry with both catch per unit effort and landings per unit effort being unaffected after the development of the OSW farm (Roach et al., 2022). Consideration for potential compatibility with specific fishing activities can be seen in the socio-economic impact analysis used during OSW planning in the US (Kirkpatrick et al., 2017). The gear-based closure scenario of the impact analysis used a model that considered OSW farms to be open to fixed gear fishing activities and closed to mobile gear fishing activities (Kirkpatrick et al., 2017). Therefore, future assessments related to OSW planning in the Maritimes region should consider specific fishing activities individually to provide a more accurate estimation of impacts on the commercial fishing industry.

4.3.2. Offshore Wind Industry

In this study, areas that were less than 60 m in depth were considered suitable and areas that were deeper than 60 m in depth were considered unsuitable for fixed-base OSW development (The Crown Estate, 2019b). The inclusion of only one layer to represent suitability is likely an oversimplification with various other considerations being important for fixed-base OSW suitability mapping (The Crown Estate, 2019a; Marine Scotland, 2018).

The spatial analysis used during the Round 4 OSW Leasing project in the UK considered three suitability requirements in addition to depth to determine if an area was technically favorable for fixed-base OSW development (The Crown Estate, 2019b). The first two additional suitability requirements were quaternary sediment thickness and bedrock lithography which are both related to the geological condition of the seabed (The Crown Estate, 2019b). Areas with a thin quaternary sediment thickness and/or hard bedrock lithology (Igneous, Palaeozoic, or Metamorphic) were not considered favorable for fixed-base OSW development (The Crown Estate, 2019b). The geological condition of the seabed is likely an important consideration for this analysis as the study area has been found to have a highly variable substrate with many areas of hard bedrock which would likely impact the suitability of fixed-base OSW development (Eamer et al., 2022).

The third additional suitability requirement considered was accessibility due to wave height (The Crown Estate, 2019b). Accessibility for the operation and maintenance of OSW turbines was determined to have a working limit of 2.5 m wave height (The Crown Estate, 2019b). As a result, regions were not considered favorable for OSW development if they had wave heights of over 2.5 m for more than 20% of the year (The Crown Estate, 2019b). The Scotian Shelf-Bay of Fundy planning area has consistently high wind speeds resulting in relatively rough wave conditions. For example, the mean significant wave height for the middle Scotian Shelf and Slope was found to range from 1.13 m in the summer months to 2.8 m in the winter months (Stantec Consulting Ltd, 2019). Due to the relatively rough conditions mean wave height is a suitability requirement that might influence where OSW development can take place within the Scotian Shelf-Bay of Fundy planning area and therefore should be considered during future suitability mapping research.

The status of planning units for this study was determined using mean depth to account for the suitability constraints related to fixed-base OSW development. The use of this suitability requirement heavily influenced the results of the analyses as a total of 89.2% of the study area had a mean depth greater than 60 m and was not available to be selected by Marxan. Depth as a major suitability restriction is unique to fixed-base OSW turbines, and recent floating foundation OSW turbines have been installed at depths of 200 m (Musial et al., 2022). The decision to restrict the scope of this study to only consider fixed-base OSW technology was due to the fact that floating foundation OSW turbines are still considered a pilot or demonstration technology and are not readily employed across the industry (Eamer et al., 2022; Musial et al., 2022).

Recent forecasts are predicting that the deployment of floating OSW technologies will rapidly grow to an estimated 10 GW of generation capacity by 2030 and 234 GW by 2050 (Musial et al., 2022). Current market forecasts paired with the province of Nova Scotia targeting 2030 for a first call for bids for offshore wind leases (Province of Nova Scotia, 2022) may result in floating foundation OSW technology being a realistic option for the region. Therefore, moving forward limiting the scope of the study area for OSW planning and siting spatial analyses to fixed-base OSW technologies may not be an accurate representation of the state of the industry when deployment begins in the Scotian Shelf-Bay of Fundy planning area. Countries such as Scotland with their ScotWind project have already taken a proactive approach and included floating foundation OSW technologies in their latest spatial analysis project (Marine Scotland, 2018). The inclusion of floating OSW technologies had a large influence on this ScotWind spatial analysis as the study area was not restricted by any depth limitations, with depth being considered as one of the several constraint layers (Marine Scotland, 2018).

The relationship between distance from shore and the monetary cost of development was used in this study to develop multiple spatial analysis exercises in an effort to support MSP and multi-objective planning in the Scotian Shelf-Bay of Fundy planning area. However, the use of distance from shore is likely an oversimplification of the various factors that can influence the cost and overall viability of an OSW project (ARUP, 2022; Johnston et al., 2020). To effectively conduct multi-objective planning exercises accurate indicators of development costs and overall project viability are essential especially when considering large commercial developments such as OSW. Across the renewable energy sector levelized cost of energy (LCOE) production has been developed as a variable to more accurately represent the spatial considerations relevant to project viability. LCOE is a single data layer that is representative of the total lifetime costs of a project relative to the amount of energy that is produced (Johnston et al., 2020). For OSW projects various factors and parameters such as water depth, number and size of turbines, grid connection costs, equipment costs, revenue from the wholesale market price of electricity, and operation and maintenance costs can influence LCOE (Johnston et al., 2020). The development of an LCOE data layer for the Scotian Shelf-Bay of Fundy planning area to be used in future OSW planning and siting projects would increase the representation of relevant considerations for the OSW industry and contribute to effective MSP and multi-objective planning.

4.3.3. Other Ocean Uses

The spatial analysis conducted in this study only considered the commercial fishing industry when highlighting areas with low or high potential for spatial conflict with future OSW development, as an initial test for this Marxan analysis methodology. As a result, the various other activities and industries that exist within the Scotian Shelf-Bay of Fundy planning area were not included in this analysis and did not influence the overall results. Activities other than the commercial fishing industry can both influence and be impacted by OSW development to varying degrees and therefore an in-depth process that identifies and considers all activities within the region would need to be conducted to allow for an effective OSW planning and siting exercise.

Other OSW planning processes such as the UK OSW Round 4 Leasing project and the ScotWind project have identified other activities through the consultation process that contain some degree of constraint related to OSW development (The Crown Estate, 2019b; Marine Scotland, 2018). The identified activities include military practise areas, high traffic (1,000 ships per year) shipping lanes, a 13 km buffer from shore due to the visual appearance of offshore wind farms, aviation, recreation and leisure activities, oil and gas development, and nature protected sites (The Crown Estate, 2019b; Marine Scotland, 2018). Similarly, it could be useful to conduct a consultation process with the purpose of identifying ocean use activities within the Scotian Shelf-Bay of Fundy planning area with high levels of constraint towards future OSW development. Activities identified through the consultation process could be used in future OSW planning and siting projects to allow for a better and more holistic view of potential spatial conflict across the Scotian Shelf-Bay of Fundy planning area.

4.4. Recommendations for Future Research

Moving forward three recommendations have been developed for future OSW spatial analyses for the Scotian Shelf-Bay of Fundy planning area.

First, it is recommended that future research focus on increasing the representation of industries across the region. A recurring theme from the analysis of this study was found to be the limitations and issues associated with the representation of the various user groups considered or not considered. Limitations that were identified included the representation of spatial importance to the commercial fishing industry, suitability for OSW development, feasibility of OSW development, and the inclusion of existing other ocean uses. In order for future research to effectively contribute to MSP and OSW planning within the region these issues of representation should be an area of focus moving forward.

Second, it is recommended that study areas for future research be expanded to include floating foundation OSW turbines. Technology advancements and trends in the OSW industry paired with Nova Scotia’s development timeline suggest that floating foundation OSW turbines may be a realistic option for OSW development in the Scotian Shelf-Bay of Fundy planning area. Exclusion of this technology from consideration within research increases the risk of the analysis not being representative of the industry, which may reduce the applicability of results. The scope of future research should be expanded to include relevant considerations for floating OSW technology to ensure it can effectively contribute to MSP in the Maritimes region.

Third, it is recommended that future research explore the use of the software Marxan with Zones. The basic Marxan software was an effective decision-support tool for the limited scope of this initial OSW analysis for the region. Moving forward, spatial analysis related to MSP should be expanded to include a more holistic view of the entire Scotian Shelf-Bay of

Fundy planning area. This expansion could include fixed and floating wind considerations, additional commercial fishing considerations, commercial shipping, aquaculture, conservation targets, and tourism and recreation, which would increase the number of planning objectives. Marxan with Zones allows for increased user customization when compared to the basic Marxan software, which could allow for more effective inclusion of these additional considerations. For example, a Marxan with Zones spatial analysis could be designed with multiple zones each selecting planning units to contribute to different user-defined targets. This analysis could include a wind energy zone selecting planning units to contribute to energy generation targets, a socio-economic activity zone selecting planning units to meet existing ocean use targets, and a conservation zone that selects planning units to contribute to existing conservation targets.

4.5. Data Limitations

The reporting of inshore lobster fishing effort on a non-uniform statistical grid in the data layer that was used to create the inshore lobster feature class creates a series of issues related to data resolution, representation, and generalization that have been recognized and discussed in previously published reports (Coffen-Smout et al., 2013; Serdynska & Coffen-Smout, 2017). Additionally, another issue was introduced by the inclusion of this data as catch weight standardized by area (kg/km^2) instead of catch weight (kg). Catch weight values were standardized to catch by area to account for the differences in grid cell sizes between the non-uniform grid and the 10 km^2 planning units used in the spatial analysis. However, the manipulation of the data creates an inconsistency in the spatial analyses as the three feature classes that were included used non-uniform units of measurement (kg and kg/km^2). To adequately address these issues catch reporting requirements would need to be changed across the inshore lobster fleet to include precise location data for catch and effort to allow for the development of higher-resolution spatial data products.

4.6. Conclusion

As a strategy to combat global climate change, the federal and provincial governments have made several commitments to expand the offshore renewable energy sector. Due to regional conditions, OSW appears to be an ideal candidate to help meet these commitments as well as provide an economic opportunity through its potential for the international export of green hydrogen. The prospect of OSW development within the Scotian Shelf and Bay of Fundy raises concerns related to potential spatial conflict with existing important industries such as commercial fishing. Through various international examples, MSP has been found to be an effective tool that can proactively identify areas of potential spatial conflict between future OSW development and existing ocean users. Therefore, the main objective of this study was to demonstrate how MSP can be effectively used to assist in the planning of a new ocean use while including the considerations of multiple sectors in the Scotian Shelf-Bay of Fundy planning area. Specifically, this study sought to create a methodological framework outlining how the decision-support tool Marxan can be used to highlight various spatial interactions between potential OSW development and the commercial fishing industry. Results from this study can inform future research examining potential conflicts between offshore wind and other ocean uses.

5. REFERENCES

Apropos Information Systems Inc. (2020). *ArcMarxan Toolbox* (2.0.2) [Computer Software]. https://aproposinfosystems.com/

Arup. (2022). *Future offshore wind scenarios: An assessment of deployment drivers.* https://www.futureoffshorewindscenarios.co.uk/assets/report/20220421_FOW_Final_Report.pdf

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

Bhattacharya, S. (2019). Overview of a wind farm and wind turbine structure. In S. Bhattacharya (Ed.), *Design of foundations for offshore wind turbines* (pp. 1-50). John Wiley & Sons, Inc.

BOEM. (2010). Commercial leasing for wind power on the Outer Continental Shelf (OCS) offshore Massachusetts – Request for Interest (RFI). *Federal Register, 75*(249), 82055-82061. https://www.boem.gov/sites/default/files/uploadedFiles/BOEM/Renewable_Energy_Program/State_Activities/FederalRegisterMassachusettsRFI.pdf

BOEM. (2011). Commercial leasing for wind power on the Outer Continental Shelf (OCS) offshore Massachusetts—Request for Interest; reopening of the comment period. *Federal Register, 76*(52), 14381-14682. https://www.boem.gov/sites/default/files/uploadedFiles/BOEM/Renewable_Energy_Program/State_Activities/FRNoticeRFI.pdf

BOEM. (2012a). Commercial leasing for wind power on the Outer Continental Shelf offshore Massachusetts—Call for Information and Nominations. *Federal Registry, 77*(24), 5820-5830. https://www.boem.gov/sites/default/files/uploadedFiles/BOEM/Renewable_Energy_Program/Regulatory_Information/MA%20Call%20for%20Information%20and%20Nominations_Federal%20Register.pdf

BOEM. (2012b). *Announcement of area identification: commercial wind energy leasing on the Outer Continental Shelf Offshore Massachusetts.* https://www.boem.gov/sites/default/files/uploadedFiles/BOEM/Renewable_Energy_Program/State_Activities/MA_AreaID_Announcement_052412_Final.pdf

BOEM. (2014a). Atlantic Wind Lease Sale 4 (ATLW4) commercial leasing for wind power on the Outer Continental Shelf offshore Massachusetts—Proposed Sale Notice. *Federal Registry, 79*(117), 34771- 34781. https://www.boem.gov/sites/default/files/regulations/Federal-Register-Notices/2014/79-FR-34771.pdf

BOEM. (2014b). *Commercial wind lease issuance and site assessment activities on the Atlantic Outer Continental Shelf offshore Massachusetts revised Environmental Assessment.* https://www.boem.gov/sites/default/files/renewable-energy-program/State-Activities/MA/Revised-MA-EA-2014.pdf

BOEM. (2015a). *Commercial lease of submerged lands for renewable energy development on the Outer Continental Shelf – OCS-A 0501.*

https://www.boem.gov/sites/default/files/renewable-energy-program/State-Activities/MA/Lease-OCS-A-0501.pdf

BOEM. (2015b). *Commercial lease of submerged lands for renewable energy development on the Outer Continental Shelf – OCS-A 0500*. https://www.boem.gov/sites/default/files/renewable-energy-program/State-Activities/MA/Lease-OCS-A-0500.pdf

BOEM. (2017). *OCS Lands Act history*. https://www.boem.gov/oil-gas-energy/leasing/ocs-lands-act-history

BOEM. (2018). *Renewable Energy Task Force meetings*. https://www.boem.gov/renewable-energy/state-activities/renewable-energy-task-force-meetings

BOEM. (2021). *Wind energy commercial leasing process.* https://www.boem.gov/sites/default/files/documents/about-boem/Wind-Energy-Comm-Leasing-Process-FS-01242017Text-052121Branding.pdf

BOEM. (2022). *About BOEM fact sheet.* https://www.boem.gov/sites/default/files/documents/newsroom/fact-sheets/BOEM_About.pdf

Butler, S., Ibarra, D., & Coffen-Smout, S. (2019). Maritimes Region longline and trap fisheries footprint mapping for marine spatial planning and risk assessment. *Canadian Technical Report of Fisheries and Aquatic Sciences, 3293,* v-30. https://publications.gc.ca/collections/collection_2019/mpo-dfo/Fs97-6-3293-eng.pdf

Breeze, H., & Horsman, T. (2005). *The Scotian Shelf: an atlas of human activities*.https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/321387.pdf

Carbon Trust. (2015). *Floating offshore wind: market and technology review*. https://ctprodstorageaccountp.blob.core.windows.net/prod-drupal-files/documents/resource/public/Floating%20Offshore%20Wind%20Market%20Technology%20Review%20-%20REPORT.pdf

Canada – Nova Scotia Offshore Petroleum Resources Accord Implementation Act (S.C. 1988, c. 28). https://laws-lois.justice.gc.ca/eng/acts/C-7.8/index.html

Canada – Nova Scotia Offshore Petroleum Resources Accord Implementation (Nova Scotia) Act (S.N.S. 1987, c. 3). https://nslegislature.ca/sites/default/files/legc/statutes/canada-ns%20offshore%20petroleum.pdf

Canada Energy Regulator. (2022). *Provincial and territorial energy profiles – Nova Scotia*. https://www.rec-cer.gc.ca/en/data-analysis/energy-markets/provincial-territorial-energy-profiles/provincial-territorial-energy-profiles-nova-scotia.html

Canadian Energy Regulator Act (S.C. 2019, c 28). https://laws-lois.justice.gc.ca/eng/acts/c-15.1/page-2.html#h-1161684

Chircop, A., & O'Leary, R. (2011). Legal frameworks for integrated coastal and ocean management in Canada and the European Union: Some insights from comparative analysis. *Vermont Journal of Environmental Law, 13*, 425. https://heinonline.org/HOL/LandingPage?handle=hein.journals/vermenl13&div=22&id=&page=

Coffen-Smout, S., Shervill, D., Sam, D., Denton, C., and Tremblay, J. (2013). Mapping inshore lobster landings and fishing effort on a Maritimes Region modified grid system. *Canadian Technical Report of Fisheries and Aquatic Sciences, 3024,* i-33. https://publications.gc.ca/collections/collection_2013/mpo-dfo/Fs97-6-3024-eng.pdf

The Crown Estate. (2019a). *Resource and constraints assessment for offshore wind: methodology report.* https://www.thecrownestate.co.uk/media/3331/tce-r4-resource-and-constraints-assessment-methodology-report.pdf

The Crown Estate. (2019b). *Offshore wind leasing round 4: summary stakeholder report*. https://www.thecrownestate.co.uk/media/3332/tce-r4-summary-stakeholder-feedback-report.pdf

The Crown Estate. (2019c). *Offshore Wind Leasing Round 4: regions refinement report*. https://www.thecrownestate.co.uk/media/3330/tce-r4-regions-refinement-report.pdf

The Crown Estate. (2021a). *Offshore wind report.* https://www.thecrownestate.co.uk/media/4095/2021-offshore-wind-report.pdf

The Crown Estate. (2021b). *Offshore Wind Leasing Round 4 delivering a low carbon future.* https://www.thecrownestate.co.uk/media/3921/guide-to-offshore-wind-leasing-round-4.pdf

The Crown Estate Act (1961, c. 55). https://www.legislation.gov.uk/ukpga/Eliz2/9-10/55/contents

The Crown Estate Scotland. (2022). *ScotWind leasing round.* https://www.crownestatescotland.com/scotlands-property/offshore-wind/scotwind-leasing-round

Daniels, J. & Lavellee, J. (2017). Bay State wind offshore wind farm project site assessment plan. *Tetra Tech, Inc*. https://www.boem.gov/sites/default/files/renewable-energy-program/State-Activities/MA/Bay-State-MA-Wind-Offshore-Wind-Farm-Project.pdf

De Groot, J., Campbell, M., Reilly, K., Colton, J., & Conway, F. (2018). A sea of troubles? Evaluating user conflicts in the development of ocean energy. *Ocean Energy Governance Challenges for Wave and Tidal Stream Technologies*, 170-190.

DFO. (2016). *Canadian Atlantic swordfish and other tunas*. https://www.dfo-mpo.gc.ca/fisheries-peches/ifmp-gmp/swordfish-espadon/NEW-swordfish-2013-espado-eng.html#toc1.4.1

DFO. (2017). *Guidance on incorporating economic use information into marine protected area network design, 2017*. https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/40938943.pdf

DFO. (2018a). *4VWX5 groundfish - Maritimes Region*. https://www.dfo-mpo.gc.ca/fisheries-peches/ifmp-gmp/groundfish-poisson-fond/groundfish-poisson-fond-4vwx5-eng.html

DFO. (2018b). *Final evaluation report - evaluation of the ocean management program*. https://www.dfo-mpo.gc.ca/ae-ve/evaluations/16-17/6D014-eng.html#_Toc504556581

DFO. (2018c). *Offshore scallop - Maritimes Region*. https://www.dfo-mpo.gc.ca/fisheries-peches/ifmp-gmp/scallop-petoncle/2018/index-eng.html

DFO. (2019a). *Departmental plan 2019-20*. https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/40776542.pdf

DFO. (2019b). *Northeastern Newfoundland Slope Closure.* https://www.dfo-mpo.gc.ca/oceans/oecm-amcepz/refuges/northeastnewfoundlandslope-talusnordestdeterreneuve-eng.html

DFO. (2019c). *Hexagon grid for Northwest Atlantic Canada, and Central & Arctic Region, 10km*^{2}. https://gcgeo.gc.ca/geonetwork/metadata/eng/572f6221-4d12-415e-9d5e-984b15d34da4

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

DFO. (2020b). *Lobster Fishing Areas 27 – 38 integrated fisheries management plan*. https://www.dfo-mpo.gc.ca/fisheries-peches/ifmp-gmp/maritimes/2019/inshore-lobster-eng.html

DFO. (2021a). *Fisheries information: number of licence holders by province and region, 2019.* https://www.dfo-mpo.gc.ca/stats/commercial/licences-permis/fishers-pecheurs/fp19-eng.htm

DFO. (2021b). *Eastern Canada commercial fishing.* https://open.canada.ca/data/en/dataset/502da2ef-bffa-4d9b-9e9c-a7425ff3c594

DFO. (2021c). *Marine spatial planning*. https://www.dfo-mpo.gc.ca/oceans/management-gestion/msp-psm/index-eng.html

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

DFO. (2021e). *Atlantic herring in the Maritimes Region*. https://www.dfo-mpo.gc.ca/fisheries-peches/ifmp-gmp/herring-hareng/2020/index-eng.html

DFO. (2022a). *Seafisheries landed value by region, 2019.* https://www.dfo-mpo.gc.ca/stats/commercial/land-debarq/sea-maritimes/s2019pv-eng.htm

DFO. (2022b). *Eastern Canada Marine Spatial Planning areas.* https://gcgeo.gc.ca/geonetwork/metadata/eng/f089a3f3-45e9-47de-b1c4-170e9950d8e7

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

DFO. (2023). *Marine spatial planning.* https://www.dfo-mpo.gc.ca/oceans/planning-planification/index-eng.html

Domingo A., Forselledo R., Miller P., Jiménez S., Mas F. and M., Pons. (2014). *ICCAT Manual.* https://www.iccat.int/Documents/SCRS/Manual/CH3/CHAP_3_1_2_LL_ENG.pdf

Duc, T., Coupiac, O., Girard, N., Giebel, G., & Göçmen, T. (2019). Local turbulence parameterization improves the Jensen wake model and its implementation for power optimization of an operating wind farm. *Wind Energy Science, 4*(2), 287-302.

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

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

Egli, T., Bolliger, J., & Kienast, F. (2017). Evaluating ecosystem service trade-offs with wind electricity production in Switzerland. *Renewable and Sustainable Energy Reviews, 67*, 863-875. https://doi.org/10.1016/j.rser.2016.09.074

Energy Policy Act (2005, H. R. 6). https://www.govinfo.gov/content/pkg/BILLS-109hr6enr/pdf/BILLS-109hr6enr.pdf

ESRI. (2021a). *ArcGIS Pro* (2.8.3) [Computer Software]. Environmental Systems Research Institute Inc. https://pro.arcgis.com/en/proapp/2.8/get-started/download-arcgis-pro.htm

ESRI. (2021b). *ArcMap* (10.8.2) [Computer Software]. Environmental Systems Research Institute Inc.

European Commission. (2022). *Report from the Commission to the European Parliament and the Council outlining the progress made in implementing directive 2014/89/EU establishing a framework for maritime spatial planning*. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52022DC0185&from=EN

Evans, S. M. J., Jamieson, G., Ardron, J., Patterson, M., Jessen, S. (2004). Evaluation of site selection methodologies for use in marine protected area design. *Canadian Science Advisory Secretariat Research Document, 2004*(082), i-40. https://waves-vagues.dfo-mpo.gc.ca/Library/316630.pdf

Ganter, S., Crawford, T., Irwin, C., Robichaud, V., DeMaio-Sukic A., Wang, J., Andrews, J., & Larocque, H. (2021). Canada's oceans and the economic contribution of marine sectors. *Statistics Canada*, *16*(002), 1-16. https://www150.statcan.gc.ca/n1/pub/16-002-x/2021001/article/00001-eng.htm#at-4

Gardner, M., Fraser, R., & Miloy, M. (2005). *Economic value of the Nova Scotia ocean sector*. https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/314642.pdf

GEBCO Compilation Group. (2022). *GEBCO gridded bathymetry data download.* https://download.gebco.net/

Gilliland, P. M., & Laffoley, D. (2008). Key elements and steps in the process of developing ecosystem-based marine spatial planning. *Marine Policy, 32*(5), 787-796. https://doi.org/10.1016/j.marpol.2008.03.022

Gopnik, M., Fieseler, C., Cantral, L., McClellan, K., Pendleton, L., & Crowder, L. (2012). Coming to the table: early stakeholder engagement in marine spatial planning. *Marine Policy, 36*(5), 1139-1149. https://doi.org/10.1016/j.marpol.2012.02.012

Government of Canada. (2011). *National framework for Canada's network of marine protected areas.* https://www.dfo-mpo.gc.ca/oceans/publications/mpanf-cnzpm/page10-eng.html#c102

Government of Canada. (2022a). *2030 emissions reduction plan: clean air, strong economy*. https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/climate-plan-overview/emissions-reduction-2030.html

Government of Canada. (2022b). *Regional Assessment under the Impact Assessment Act.* https://www.canada.ca/en/impact-assessment-agency/services/policy-guidance/regional-strategic-assessments/regional-assessment-impact-assessment-act.html

Gray, T., Haggett, C., & Bell, D. (2005). Offshore wind farms and commercial fisheries in the UK: a study in stakeholder consultation. *Ethics place and environment, 8*(2), 127-140. https://doi.org/10.1080/13668790500237013

Iglesias-Campos, A., Rubeck, J., Sanmiguel-Esteban, D., & Schwarz, G. (2021*). MSPglobal International Guide on Marine/Maritime Spatial Planning.* https://unesdoc.unesco.org/ark:/48223/pf0000379196

Impact Assessment Agency of Canada. (2022a). *Regional Assessment of offshore wind development in Newfoundland and Labrador and Nova Scotia*. https://iaac-aeic.gc.ca/050/evaluations/proj/83514?culture=en-CA

Impact Assessment Agency of Canada. (2022b). *Draft agreement to conduct a regional assessment of offshore wind development in Nova Scotia*. https://iaac-aeic.gc.ca/050/documents/p83514/145235E.pdf

Johnston, B., Foley, A., Doran, J., & Littler, T. (2020). Levelised cost of energy, a challenge for offshore wind. *Renewable Energy, 160,* 876-885. https://doi.org/10.1016/j.renene.2020.06.030

Kafas, A., Donohue, P., Davies, I., & Scott, B. E. (2018). Displacement of existing activities. In *Offshore energy and marine spatial planning* (pp. 88-112). Routledge. https://www.taylorfrancis.com/chapters/edit/10.4324/9781315666877-7/displacement-existing-activities-andronikos-kafas-penelope-donohue-ian-davies-beth-scott

Kafas, A., McLay, A., Chimienti, M., & Gubbins, M. (2014). ScotMap Inshore Fisheries Mapping in Scotland: recording fishermen's use of the Sea. *Scottish Marine and Freshwater Science Report*, *5*(17), 1-32. https://data.marine.gov.scot/sites/default/files//Scottish%20Marine%20and%20Freshwater%20Science%20Vol%205%20No%2017.pdf

Kerr, S., Watts, L., Colton, J., Conway, F., Hull, A., Johnson, K., Jude, S., Kannen, A., MacDougall, S., McLachlan, C., & Vergunst, J. (2014). Establishing an agenda for social studies research in marine renewable energy. *Energy Policy, 67,* 694-702. https://doi.org/10.1016/j.enpol.2013.11.063

Kirkpatrick, A. J., Benjamin, S., DePiper, G. S., Murphy, T., Steinback, S., & Demarest, C. (2017a). Socio-economic impact of Outer Continental Shelf wind energy development on fisheries in the U.S. Atlantic. Volume I—report narrative. *OCS Study BOEM, 2017*(012), iv-150.

Kirkpatrick, A. J., Benjamin, S., DePiper, G. S., Murphy, T., Steinback, S., & Demarest, C. (2017b). Socio-Economic Impact of Outer Continental Shelf Wind Energy Development on Fisheries in the U.S. Atlantic. Volume II—appendices. *OCS Study BOEM, 2017*(012), ii-176.

Lear, W. 1998. History of Fisheries in the Northwest Atlantic: The 500-year perspective. *Journal of Northwest Atlantic Fishery Science, 23,* 41-73. https://doi.org/10.2960/J.v23.a4

MacLean, M., Breeze, H., Walmsley, J. & Corkum, J. (2013). State of the Scotian Shelf Report. *Canadian Technical Report of Fisheries and Aquatic Sciences*, *3074*, xvi-352. https://publications.gc.ca/collections/collection_2014/mpo-dfo/Fs97-6-3074-eng.pdf

Marine Renewable Energy Act (S.N.S. 2015, c. 32). https://nslegislature.ca/legc/bills/62nd_2nd/1st_read/b110.htm

Marine Scotland. (2018). *Scoping 'Areas of Search' study for offshore wind energy in Scottish Waters, 2018.* https://www.gov.scot/binaries/content/documents/govscot/publications/consultation-paper/2018/06/scoping-areas-search-study-offshore-wind-energy-scottish-waters-2018/documents/00536637-pdf/00536637-pdf/govscot%3Adocument/00536637.pdf

King, M., Koropatnick, T., Gerhartz Abraham, A., Pardy, G., Serdynska, A., Will, E., Breeze, H., Bundy, A., Edmondson, E., and Allard, K. (2021). Design strategies for the Scotian Shelf bioregional marine protected area network. *Canadian Science Advisory Secretariat Research Document, 2019*(067), vi-122. https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/40974625.pdf

Musial, W., Spitsen, P., Duffy, P., Beiter, P., Marquis, M., Hammond, R., & Shields, M. (2022). Offshore wind market report: 2022 edition. *U.S. Department of Energy Office of Energy Efficiency and Renewable Energy*. https://www.energy.gov/sites/default/files/2022-09/offshore-wind-market-report-2022-v2.pdf

Natural Resources Canada. (2020). *Hydrogen strategy for Canada: seizing the opportunities for hydrogen.* https://www.nrcan.gc.ca/sites/nrcan/files/environment/hydrogen/NRCan_Hydrogen%20Strategy%20for%20Canada%20Dec%2015%202200%20clean_low_accessible.pdf

Natural Resources Canada. (2022a). *Canada and Nova Scotia announce intent to expand the mandate of offshore energy regime to support the transition to a clean economy and create sustainable jobs.* https://www.canada.ca/en/natural-resources-canada/news/2022/04/canada-and-nova-scotia-announce-intent-to-expand-the-mandate-of-offshore-energy-regime-to-support-the-transition-to-a-clean-economy-and-create-sust.html

Natural Resources Canada. (2022b). *The offshore renewable energy regulations initiative.* https://www.rncanengagenrcan.ca/en/collections/offshore-renewable-energy-regulations-initiative#s1

Ng, C., & Li, R. (2016). Offshore wind farms: technologies, design and operation. *Woodhead Publishing*. https://www.sciencedirect.com/science/article/pii/B9780081007792000015?via%3Dihub#abs0015

Nye, J. A., Link, J. S., Hare, J. A., & Overholtz, W. J. (2009). Changing spatial distribution of fish stocks in relation to climate and population size on the Northeast United States continental shelf. *Marine Ecology Progress Series*, 393, 111-129. https://doi.org/10.3354/meps08220

Orsted. (2022). *Hornsea 2, the worlds largest windfarm, enters full operation.* https://hornseaprojects.co.uk/hornsea-project-two/news/2022/08/hornsea-2-enters-full-operation

O'Sullivan, R., Ramírez, L., Fraile, D., Brindley, G. (2021*). Offshore wind in Europe, key trends and statistics 2020*. https://windeurope.org/intelligence-platform/product/offshore-wind-in-europe-key-trends-and-statistics-2020/

Province of Nova Scotia. (2021). *Legislation to address climate crisis, guide province to cleaner, sustainable future*. Legislation to Address Climate Crisis, Guide Province to Cleaner, Sustainable Future - Government of Nova Scotia, Canada

Province of Nova Scotia. (2022). *Province sets offshore wind target*. https://novascotia.ca/news/release/?id=20220920003

Reilly, K., O'Hagan, A. M., & Dalton, G. (2016). Moving from consultation to participation: a case study of the involvement of fishermen in decisions relating to marine renewable energy projects on the island of Ireland. *Ocean & Coastal Management, 134*, 30-40. https://doi.org/10.1016/j.ocecoaman.2016.09.030

Roach, M., Revill, A., & Johnson, M. J. (2022). Co-existence in practice: a collaborative study of the effects of the Westermost Rough offshore wind development on the size distribution and catch rates of a commercially important lobster (Homarus gammarus) population. *ICES Journal of Marine Science, 79*(4), 1175-1186. https://doi.org/10.1093/icesjms/fsac040

Rose, G. A., DeYoung, B., Kulka, D. W., Goddard, S. V., & Fletcher, G. L. (2000). Distribution shifts and overfishing the northern cod (Gadus morhua): a view from the ocean. *Canadian Journal of Fisheries and Aquatic Sciences, 57*(3), 644-663. https://doi.org/10.1139/f00-004

Rozalska, K., & Coffen-Smout, K. (2020). Maritimes Region fisheries atlas: catch weight landings mapping (2014–2018) on a hexagon grid. *Canadian Technical Report of Fisheries and Aquatic Sciences, 3373*, vi-68. https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/40885690.pdf

Schupp, M. F., Kafas, A., Buck, B. H., Krause, G., Onyango, V., Stelzenmüller, V., Davies, I., & Scott, B. E. (2021). Fishing within offshore wind farms in the North Sea: stakeholder perspectives for multi-use from Scotland and Germany. *Journal of Environmental Management*, *279*, 111762. https://doi.org/10.1016/j.jenvman.2020.111762

The Scottish Crown Estate Act (2019, asp 1). https://www.legislation.gov.uk/asp/2019/1/contents

Scottish Government. (2019a). *Draft sectoral marine plan for offshore wind energy (2019).* https://www.gov.scot/publications/draft-sectoral-marine-plan-offshore-wind-energy/

Scottish Government. (2019b). *Sectoral Marine Plan for Offshore Wind Energy: Sustainability Appraisal.* https://www.gov.scot/publications/draft-sectoral-marine-plan-sustainability-appraisal/

Scottish Government. (2020a). *Scottish Crown Estate strategic management plan.* https://www.gov.scot/binaries/content/documents/govscot/publications/strategy-plan/2020/03/first-strategic-management-plan-scottish-crown-estate/documents/scottish-crown-estate-strategic-management-plan/scottish-crown-estate-strategic-management-plan/govscot%3Adocument/scottish-crown-estate-strategic-management-plan.pdf

Scottish Government. (2020b). *The Scottish Crown Estate.* https://www.gov.scot/policies/marine-planning/the-scottish-crown-estate/#:~:text=The%20Scottish%20Crown%20Estate%20Act%202019%20A%20public,analysis%20report%20was%20published%20on%2025%20January%202018.

Scottish Government. (2020c). *Sectoral marine plan for offshore wind energy.* https://www.gov.scot/publications/sectoral-marine-plan-offshore-wind-energy/documents/

Scottish Government. (2020d). *Draft sectoral marine plan for offshore wind energy (2019): consultation analysis report (December 2019 to March 2020).* https://www.gov.scot/publications/draft-sectoral-marine-plan-offshore-wind-energy-2019-consultation-analysis-report/documents/

Scottish Government. (2020e). *Sectoral marine plan for offshore wind energy (2020): post adoption statement*. https://www.gov.scot/publications/sectoral-marine-plan-post-adoption-statement/

Serdynska, A., & Coffen-Smout, S. (2017). Mapping inshore lobster landings and fishing effort on a Maritimes Region statistical grid (2012–2014). *Canadian Technical Report of Fisheries and Aquatic Sciences, 3177*, i-29. https://publications.gc.ca/collections/collection_2017/mpo-dfo/Fs97-6-3177-eng.pdf

Serdynska, A. R., Pardy, G. S., and King, M. C. (2021). Offshore ecological and human use information considered in marine protected area network design in the Scotian Shelf Bioregion. *Canadian Technical Report of Fisheries and Aquatic Sciences*, *3382*, xi-100. https://publications.gc.ca/collections/collection_2021/mpo-dfo/Fs97-6-3382-eng.pdf

Serra, N., Kockel, A., Game, E. T., Grantham H., Possingham H.P., & McGowan, J. (2020). *Marxan user manual: for Marxan version 2.43 and above.* https://marxansolutions.org/wp-content/uploads/2021/02/Marxan-User-Manual_2021.pdf

Stantec Consulting Ltd. (2019). *Middle Scotian Shelf and Slope strategic environmental assessment.* https://www.cnsopb.ns.ca/sites/default/files/resource/final_middle_scotian_shelf_sea_.pdf

Tang, G., & Kilpatrick, R. (2021). *Offshore wind technology scan: a review of offshore wind technologies and considerations in the context of Atlantic Canada*. https://geoscan.nrcan.gc.ca/starweb/geoscan/servlet.starweb?path=geoscan/fulle.web&search1=R=329349

Vineyard Wind. (2017). *Site Assessment Plan (SAP) Vineyard Wind Lease OCS-A 0501 Massachusetts Offshore Wind Energy Area.* https://www.boem.gov/sites/default/files/renewable-energy-program/State-Activities/MA/VW-Site-Assessment-Plan.pdf

Walsh, H. J., Richardson, D. E., Marancik, K. E., & Hare, J. A. (2015). Long-term changes in the distributions of larval and adult fish in the northeast US shelf ecosystem. *PLoS One, 10*(9), e0137382. https://doi.org/10.1371/journal.pone.0137382

World Wildlife Fund. (2019). *Northeast Newfoundland Marine Refuge should be exempt from oil and gas development –WWF-Canada*. https://wwf.ca/media-releases/northeast-newfoundland-marine-refuge-should-be-exempt-from-oil-and-gas-development-wwf-canada-2/#:~:text=Parts%20of%20the%20Northeast%20Newfoundland%20Slope%20Closure%2C%20a,it%20is%20open%20for%20oil%20and%20gas%20development

Yates, K. L. (2018). Meaningful stakeholder participation in marine spatial planning with offshore energy. In *Offshore Energy and Marine Spatial Planning* (pp. 169-188). Routledge. https://www.taylorfrancis.com/chapters/edit/10.4324/9781315666877-10/meaningful-stakeholder-participation-marine-spatial-planning-offshore-energy-katherine-yates

Yates, K. L., & Schoeman, D. S. (2013). Spatial access priority mapping (SAPM) with fishers: a quantitative GIS method for participatory planning. *PloS one, 8*(7), e68424. https://doi.org/10.1371/journal.pone.0068424