SYSTEMATIC MARINE CONSERVATION PLANNING IN THE SCOTIAN SHELF BIOREGION

By

Adrian Gerhartz Abraham

Submitted in partial fulfillment of the requirements for the degree
Of
Master of Marine Management
At

Dalhousie University
Halifax Nova Scotia

December 2015

Contents

List of Figures

List of Tables

List of Abbreviations Used

SCP: Systematic conservation planning

CBD: Convention on Biological Diversity

CP: Conservation planning

DST: Decision Support Tools

GIS: Geographic Information Systems

IUCN: International Union for Conservation of Nature

PAs: Protected Areas

SS: Scotian Shelf

SSB: Scotian Shelf Bioregion

MPA: Marine Protected Area

MCP: Marine Conservation Planning

MSP: Marine Spatial Planning

Acknowledgments

First of all, I would like to thank Maxine Westhead, who agreed to be my supervisor. Thanks Max for believing in me, and for your encouragement, patience and all the flexibility you provided to me during the most critical time.

I also want to thank Rosaline Canessa for agreeing to be my second reader.

I must also thank Marty King, as well as the staff of the Ecosystem Management Branch of DFO for whom I had the wonderful opportunity to work with during my internship. The ideas and knowledge gained with you were invaluable for the successful fulfilment of my project. This project would not have been possible without your support.

I want to thank Ian Ball and Hugh Possingham, the creators of MARXAN, thanks for making this software open to any interested user. Also, I would like to thank Heather Coleman for her ideas and experiences shared during the PacMARA training.

A big thank to all my classmates. You guys were so important to me! I'm the only luckiest guy of the MMM 14/15 class.

Thank you Becky Field, for all your advice, support, and for being there every time I needed. A special thanks to Lucia Fanning and Claudio Aporta.

I must also thank Vanesa and Daniel. You guys were my family here. I will be always appreciative of your encouragement.

Last but not least, I would like to thank my mother, father, and all my family and friends. I Love you and miss you all every single day.

Abstract

The Scotian shelf bioregion constitutes an area of intense socio-economic activity. Key activities in the bioregion include fisheries, oil and gas, shipping, and aquaculture. However, Canada's commitment to protect at least 10% of the bioregion through networks of marine protected areas (MPAs) will require trade-offs between conservation and other human economic and social activities. This project draws on the principles of systematic conservation planning to explore and assess alternative designs of networks of marine protected area for the Scotian shelf, trying to achieve results that are: 1) effective in meeting conservation goals and 2) efficient in minimizing potential sea-use conflicts among stakeholders. In order to accomplish the former objectives, the project follows a systematic planning approach that allows for the selection of conservation features, the setting of goals and targets and the application of a selection process of conservation sites using Marxan software package and ArcGIS. To minimize cost among other sea uses, spatial distribution of socio-economic activities (fisheries) are used and a reverse Marxan was performed. The selection frequency of the reverse Marxan was used as a cost layer and this enabled avoiding areas that are frequently used for other activities in the bioregion. Results first indicate that the current network is ineffective in terms of representation and adequacy. Second, it identifies new areas that would complement the MPA system and improve the network's adequacy. Finally, it demonstrates how incorporating socio-economic costs can undermine some of the properties of MPA network design, particularly, spatial configuration (size, shape, spacing), and could increase the potential of conflicts with other marine activities not taken into account in the definition of costs.

1. Introduction

1.1 Overview

The number of protected areas has dramatically increased since the late 70s (Chape *et al*., 2008). Paradoxically, biodiversity has continued to decline over the past four decades (Rodrigues *et al*., 2003). The rate of biodiversity extinction is 100-1000 times greater than pre-human rates (Jérôme Cimon-Morin *et al.,* 2013). This clearly relates to the ineffectiveness of many protected areas worldwide. The ad hoc approach to site conservation areas, commonly implemented in the past, may be one of the reasons of why protected areas are claimed to contain a biased sample of biodiversity (Margules & Pressey, 2000). In such approaches, the scientific analysis on the conservation priorities is recurrently ignored, so site selection responds to the ease of choice, and evades politically and economically costly areas (Ardron *et al.*, 2010). In other words, some of them may either be in the wrong places or are poorly managed. Therefore, it is imperative that protected areas provide sufficient coverage to key biodiversity features so that ecosystems can maintain essential processes and functions that provide the so-called ecosystem services to humans.

Marine spatial planning is recognized a key tool in making ecosystem based management a reality (Douvere, 2008). It provides an integrated framework that can deal with multiple and conflicting users, creating and establishing 'a more rational organization of the use of the marine space and the interactions between its uses, to balance demands for development with the need to protect the environment, and to achieve social and economic objectives in an open and planned way' (Ehler & Douvere, 2009). In this sense, MSP is key to reducing sea use conflict and the guarantee of resource sustainability (Foley *et al.*, 2010). Overall, it looks for preserving the health of the relevant marine ecosystems, balancing biodiversity conservation with human use to achieve ecosystem-based management in the oceans (Craig, 2012). It is also important to bear in mind that most of the examples (implemented practices) of MSP are primarily inspired by driving forces related to nature conservation issues, and only more recently by considerations related to the general management of conflicts among uses or users. Furthermore, effective MSP should not only consider the current status of the issues but it should anticipate possible factors that might generate a different picture of the current situation. Climate Change and changes in land use patterns may trigger potential conflicts and displacement of current human activities on the sea (Craig, 2012). These two variables are emerging threats that complicate decision-making regarding resource use management.

Similarly, the successful development and implementation of MSP requires the use of the best available science and tools. Geographic information systems (GIS) and decision support systems (DSS), are among the most used scientific tools to solve coastal-marine issues (Katsanevakis *et al,.* 2011). However, GIS per se has limited capabilities to support the design and choice phases of the decision-making process that are essential component in marine spatial planning (Crosetto & Tarantola 2001). In this regard, computational models are often linked with GIS databases and employed in a variety of decision-making contexts such as MSP (Crosetto & Tarantola 2001).

1.2 Systematic Marine Conservation Planning

Marine protected areas (MPAs) are acknowledged as an effective instrument for improved ocean management (Osmond *et al.*, 2010). They are also recognized as one of the most powerful conservation tools aiming at protecting marine biodiversity from ocean management-related problems. Modern discourse in this field of knowledge speaks to the necessity of networks of marine protected areas as a fundamental ingredient to achieving conservation objectives. It has been argued that networks of MPAs are more effective and comprehensive in terms of protection in comparison with any single site (White *et al.*, 2005).

Also, it has been stated that MPA goals must lead to sustainability (Ervin *et al*., 2010). This implies that MPAs are no longer seen as isolated areas that are set aside strictly for a biodiversity protection purpose. Developing networks of MPAs can be arguably one of the most contentious issues of marine spatial planning. Frequently, areas of high importance for conservation (especially when they are areas of exceptional biodiversity and high biological productivity) coincide with areas that are of great interest for socioeconomic development. Therefore, while the scientific evidence about the benefits of MPAs and particularly marine reserves grows, they are still perceived as a threat to development, in particular by some stakeholders that completely depend on marine resources for their livelihood, e.g., fishers. Unfortunately, in practice, MPA designations tend to avoid such high conflict areas, even though, this may not only compromise fulfillment of a particular conservation goal but the success of an entire conservation network. In this sense, systematic marine conservation planning provides the scientific methods and tools to support MPA network planning and can be key in achieving conservation goals while being efficient in minimizing the impacts of different stakeholders that might potentially be affected in this process.

This new field of conservation science is a departure from ad-hoc, site-by-site approaches that have been used to select protected areas in the past. It draws on the principles of network design which includes efficiency, representativity, adequacy, complementarity, compactness and connectedness, to create a protected area network, which as a whole must achieve explicitly defined conservation targets for an entire planning region; while being broadly representative of the biodiversity of each region. Lastly, systematic conservation planning may be very complex when dealing with multiple objectives and design criteria. Therefore, a number of specialised methodologies and tools have been developed. Evans *et al.* (2004), and Margules and Sarkar (2007) provide reviews of such tools. Marxan is the most widely used of these decision-support tools for MPA network design.

Nevertheless, the success in achieving MPA network conservation objectives cannot be accomplished solely by undertaking a systematic conservation planning approach. Lessons from marine conservation planning (Osmond *et al.*, 2014) suggest four components of marine management that are fundamental for embarking on MPA network development: adequate governance structure and mandates; a well thought-out planning framework; dedicated and adequate funding; and a fundamental role for science to underpin the entire process. These elements directly affect the success of conservation efforts. Ultimately, systematic conservation planning can only be successful as long as such management components are well defined from the outset.

1.3 Context

An international commitment to effectively conserve at least 10% of coastal and marine areas by 2020 was agreed to by all nations in the COP 10 of the Convention on Biological Diversity, Japan, 2010. This target, known as Aichi target 11, represents specific, time-bound drivers for governments to safeguard both marine and coastal biodiversity. Accordingly, the number of the world's marine protected areas has noticeably increased since 2012 (Thomas *et al.*, 2014). However, this contribution has not followed an equally regional distribution. As a result, there are yet many countries that are very far from making a significant contribution to meeting the global target.

Although Canada has not set a national target, it is committed to reaching the global Aichi 11 by substantially increasing the number of marine protected areas. However, this is a huge challenge for the country given that the current national system of marine protected areas barely accounts for 1% of Canada's waters. Fisheries and Oceans Canada, the leading agency for MPA planning and designation process, is working towards effective MPA network development through marine spatial planning in five of the 13 marine bioregion identified in Canada. It is therefore critical that such planning and conception of the future network of MPAs is based on the principles of systematic conservation planning and that it incorporates forefront knowledge of the modern conservation science.

1.4 Problem statement

The Scotian shelf is one of Canada's marine bioregions committed to integrated ocean management. This region is home to some of the most biologically diverse areas in Atlantic Canada. Some of the most valuable areas include the Bay of Fundy, the eastern Gully, the slopes, western bank, and the northeastern shelf (Breeze *et al.* 2013). Particularly, the Gully is one of the most prominent undersea features on the east coast of Canada. Overall, a wide variety of habitats can be found in the bioregion, from kelp beds that support large populations of sea urchins to bedrock outcrops with a diversity of corals and sponges to deep waters of the open ocean where anglerfish and other rarely seen species live (Breeze *et al.* 2013).

Three marine protected areas make up the current network. The Gully, St Anns bank, and Musquash. These three areas only represent 1.2% of the bioregion. While this number is far behind the amount needed for an effective contribution to the Aichi target, it also indicates that the Scotian shelf may have a significant gap in terms of representativity and adequacy, two of the fundamental properties of reserve network design. Hence the urgency to moving forward the establishment of a network of marine protected areas for the region.

In addition, the Scotian Shelf is an intensely used ocean area with a number of user groups competing for space and resources. Some of the key activities in the area such as fishing, aquaculture, oil and gas exploration and extraction, shipping, and tourism, constitute an important source of income to the regional and national economy. Thus, the development of an MPA network in the Scotian shelf can certainly create dispute by stakeholders over the use of the maritime space.

1.5 Research objectives and questions

Drawing on the principles of systematic conservation planning, this project intends to explore and assess alternative designs of networks of marine protected area for the Scotian shelf, trying to achieve results that are: 1) effective in meeting conservation goals and 2) efficient in minimizing potential sea-use conflicts among stakeholders.

This assessment will therefore explore how effective the current network is in meeting conservation objectives, what would be the most effective network alternative from the conservation point of view, what stakeholders might potentially be affected by the MPA network design, to what extent SCP can minimize this impact while ensuring long term conservation objectives and to what extent the efficiency of the resulting network is undermined when costs are taken into account in order to minimize the direct impacts of the MPA network on fisheries.

The project will provide recommendations to DFO to support the making of informed decisions, which should lead to successful outcomes in the implementation of a MPA network in the Scotian Shelf.

2. Research theoretical framework

2.1 Paradigm of protected areas

The practice of setting aside natural or semi natural areas for protection is not novel. Historians have claimed that some protected areas date back as far as two millennia ago (Chape *et al.,* 2008). Around the 20 -21 Century, several countries in Europe, Africa, and Asia designated some type of protected areas (Dudley, 2008), mainly for sport hunting purposes, religious reasons or for spiritual recreation of the elites (Chape *et al.*, 2008; Ervin, 2010). Nevertheless, it was not until the mid-1800s where a more contemporary approach emerged, particularly with the creation of protected areas in the form of national parks (Phillips, 2003; Ervin, 2010). However, the actual conception of protected areas differs significantly from what was thought to be in the past. Ervin (2010) highlights that some drivers that influenced the conceptual development of protected areas were: increased scientific sophistication and understanding of ecology and biodiversity, an intensified awareness of human rights, a greater move toward democratization and the role of civil society, and technological advances, particularly geographic information systems (GIS), remote sensing, and spatial modeling tools. These factors were key in transitioning from an old narrow narrative to a more comprehensive and modern view of what protected areas represent for society. Internationally, a series of events that happened between 1970s and 1990s were decisive and critical in the transition to what Phillips (2003) call the ‘new paradigm’ of PAs. Amongst the most important are the United Nations Conference on the Human Environment held in Stockholm as well as the adoption of the Convention concerning the Protection of the World's Cultural and Natural Heritage both in 1972, the World Conservation Strategy that was launched in 1980 (it set out fundamental principles and objectives for conservation worldwide), the United Nations Conference on Environment and Development (UNCED), also known as the Rio Summit, Rio Conference, 1992 and the adoption on the Convention on Biological Diversity the same year, the outputs from

World Park Congress 1972, 1982, 1992 and 2003, the expansion of the world commission on protected areas networks. In this new paradigm, the concept of protected areas was subsequently redefined and mainstreamed into the concept of sustainable development. Some key arguments derived from these events that are at the forefront of this paradigm are:

- *The formulation of specific protected area management categories that recognize the scope and values of different approaches to conserving natural areas*
- *Mainstreaming of conservation concerns into development agendas*
- *Rethinking the role of protected areas vis-à-vis conservation and sustainable human use*
- *Recognition of the importance of cultural values*
- *Recognition of the role of PAs as key indicators for assessing achievement of global sustainable development objectives, and as contributing measures for combating desertification, climate change and loss of genetic diversity.*

Phillips (2003), a major advocate and promoter of such 'paradigm' also backed up the idea of having a broad range of actors involved in PAs, promoting working to a much wider scale while highlighting the importance of connectivity between seascapes/landscapes at all scales (locally, regionally, and globally). A major change in this new view is the idea of creating protected areas beyond the 'wild', to include parts of the transformed landscapes/seascapes by human activities, particularly with a renewed application of the management categories V and VI (See management categories 1994). Such development of management categories V and VI were in part a recognition of the necessity for a more active role of social sciences in conservation as well as reconciliation of community rights to sustainable resource use (Brown, 2002). However, this received a strong criticism from part of some conservationists who were pleading that this modern 'paradigm', and particularly the classification of categories V and VI did not fit neither the IUCN definition of PAs at that time nor the accorded conceptions in the Convention of Biological Diversity, which explicitly regarded PA main objective as the conservation of wildlife biodiversity and natural function of ecosystems. Furthermore, Locke & Dearden (2005) claimed that the promotion of humanized seascapes/landscapes in PAs under the new paradigm would be destructive and confusing. Particularly, Locke & Dearden (2005) argued that this new paradigm ignored some of the findings of conservation biology and that the embracement of it would undermine the creation of real protected areas by eroding the funding base for true conservation. Such reluctance to the new paradigm of PA were merely a reflection of a prevailing traditional approach to conservation in which 'local community welfare and development are viewed as directly conflicting with the objectives and practice of biodiversity conservation' (Brown, 2002).

However, despite Locke & Dearden lack of recognition of the 'boundary effect' of PAs (See McNeely, 1990, and Martino, 2005), which ignores the past experiences in PA management for years, one of Locke & Dearden (2005) main ideas that conservationists and PA managers should put more efforts on 'good management of the world's existing PAs' while 'ensuring connectivity among them', is still a remarkable and valid argument, especially when it is known that the so-called 'paper parks' which still exists and have existed for many years undermine the effectiveness of the world protected areas (Martino, 2005).

Such controversy around defining the global image of the world's protected areas led to a deeper analysis of their role as well as a revision of the different management categories associated with it. This resulted in a new definition of protected area as well as the development of international guidelines for the proper implementation and designation of the management categories. In this new approach, the notion of protected areas as a system that contributes to broader conservation objectives is underscored (Box 1). Therefore, protected areas are viewed as a set of management practices rather than isolated, closed and restricted areas. Also, it is important to note that the only principle that should be applied when assigning categories is the appropriateness of the management assigned objective to the protected area within the system in relation to the ecological needs and threats to the species or ecosystem in the full context of the territory where biodiversity occurs (Dudley, 2008).

Box 1: Protected area definitions according of IUCN:

Previous protected area definition (in Dudley & Stolton, 2008)
Area of land and/or sea especially dedicated to the protection and maintenance of biological diversity, and of natural and associated cultural resources, and managed through legal or other effective means

Current protected area definition (in Dudley, 2008)
A clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values.

More recently, Ervin, *et al.* (2010) describes three models that characterize how societal views towards protected areas have evolved during the last 150 years (Table 1). Some key themes that reflected the changing view of PAs throughout this period include: Design, Governance, Planning, and Financing. A major distinction in Ervin's view is the recognition of an emerging model of protected areas in which not only the importance of protecting biodiversity at all levels is recognized but the primacy of maintaining ecosystem processes and functions that support life. Climate change plays a defining role as well.

Table 1: *Paradigms of Protected Areas*[a]

PAs	Classic model (MID-1800s-1970s)	Modern model (1970s- MID-2000s)	Emerging model (MID 2000s and beyond)
Societal notions	- PAs viewed as existing independently from their nearby environment (landscape/seascape)	- PAs more as social enterprises and managed with the needs of local communities in mind (often in partnership with social scientists and local communities)	- PAs are viewed as a critical component of a life support system (recognition of ecological, economic and social benefits of PAs) - Pas linked to Sustainable development - PAs networks as for strengthening resilience to climate change
Objectives	- Established mainly for scenic protection (ecosystem function and processes are overlooked)	- Established for scientific, economic and cultural purposes - Conservation is focus on ecological and cultural importance of wilderness and large intact areas	- Established to support ecosystem services, and promote climate change adaptation, resilience and mitigation - Conservation is focus on intact areas as well as restoration of degraded areas to maintain ecosystem functioning
Governance	- PAs are run by governments (national and subnational)	- Recognition of governance models beyond government-run national parks (e.g., governments, local communities)	- Managed by many partners with many governance models
Design	- Developed in an ad hoc manner usually placed in areas with low economic and ecological value	- First attempts to protected area network design - The need for more systematically and comprehensively designed PAs networks is recognized	- Protected area network design is supported by a numerous of GIS-based tools - Consolidation of systematic conservation planning as key tool in PA network design (Space, Size)
Planning	- No consultation with local community (exclude local people)	- Local people are included	- Conducted by several different stakeholders across different sectors and levels
Financing	- Funded by a central government (annual government allocations)	- Funded by many partners (e.g., foundations, bilateral donors, government, NGOs)	- Financed by mainstreaming PAs into national and local economies - It looks at sustainable finance mechanisms

[a] Adapted from Ervin *et al.*., 2010 and Phillips, 2003.

2.2 Marine protected areas and network design

For years, conservationists have been more focused on land-based environmental problems than marine-related issues. Agardy (1999) argued that the fluid nature of the marine environment and the dim character of ecological boundaries are obstacles that contributed to the lag in marine conservation development. Roff & Zacharias (2011) also claim that this delay is exacerbated by the fact that ‘most marine environments are viewed as a global common resource where there is little incentive to any one nation to address these issues, as problems must be solved at an international level’. These have also affected the number of marine protected areas worldwide. Protected areas cover around 18% of the world surface, but only 3.4% accounts for oceanic area (Juffe-Bignoli *et al*., 2014). A smaller number of MPAs could also indicate less experience in designing and implementing marine protected areas if compared to terrestrials (Dudley, 2010). There is a global momentum towards designing marine protect areas, therefore the number of MPAs is expected to rise. Increased ocean environmental awareness has resulted in an international commitment to protect at least 10% of the ocean through networks of MPAs by 2020. This is known as the Aichi target 11 (CBD, 2011).

The Network approach is at the forefront of the paradigm of protected areas. It emerged as a promising solution to single reserves that failed to comprehensively mitigate the threats to biodiversity and to minimizing the negative, socioeconomic and cultural impacts of large reserves (Gaines *et al.*, 2010; Claudet, 2011). Despite the growing scientific information on MPA benefits to fisheries, such as increased species density, biomass, age and size composition, spawning stock biomass (Claudet *et al.* 2008; McClanahan *et al.*, 2006; Gerber *et al.*, 2007; Molloy *et al.*, 2009), it is argued that networks of MPAs are the long-sought solution to ecological integrity (Roff, 2009). Ecological integrity refers to the auto-capacity of life to organize, regenerate, reproduce, sustain, adapt, and evolve over time at a specific location so that the evolutionary and biological process can persist naturally (Roff & Zacharias, 2011). A single reserve may fail to attain ecological integrity because it is not 'self-sufficient as a location and will depend on its connectivity to other parts of the ocean for recruitment of its component species' (Roff & Zacharias, 2011). Therefore, protected areas should be designed in ways that guarantee the continued functioning of natural biophysical processes.

A Network of Marine Protected Areas is 'a collection of individual marine protected areas (MPAs) or reserves operating co-operatively and synergistically, at various spatial scales and with a range of protection levels that are designed to meet objectives that a single reserve cannot achieve' (IUCN-WCPA, 2008).

Roff & Zacharias (2011) argue that a set of protected areas can be only considered a network as long as the components of such system (the individual MPAs) are oceanographically connected on a time frame consistent with the life cycles and dispersal abilities of the associated flora and the fauna. They claim that connectivity should be a driving objective of any MPA network. However, the IUCN network definition, arguably one of the most recognized, does not explicitly declare neither connectivity nor ecological integrity and biodiversity persistence as the primary goal. One reason might be associated with the fact that most of the existing MPAs networks are seldom designed to be ecologically connected and therefore only few would categorically be considered a network. Concepts such as 'cooperatively' and 'synergistically' need to be further developed. Lastly, in practice, the desired goal of a given set of MPAs will depend on the environmental, socio-economic and cultural context in which such system is established (Grorud-Colvert *et al.*, 2011).

Most MPA network goals have targeted biodiversity conservation, fishery management, climate change adaptation, and preservation of natural and cultural heritage (Grorud-Colvert *et al.*, 2011). An ideal network would be one that embraces all of the four aforementioned goals.

However, this might be one of the most challenging tasks to accomplish in MPA network design, since planning for a specific objective may compromise the ability of the network to effectively fulfill the others (Almany *et al*., 2009; Green, *et al.*,2014; McInerney, *et al.*, 2012; Gaines *et al.*, 2010). For instance, in networks that are designed for a specific purpose, such as fisheries management, connectivity becomes the objective that drives the network design. In contrast, those in which biodiversity conservation is a major aim, representation tends to drive the design (Almany *et al*., 2009). Thus, connectivity and representation have a direct effect on network configuration, specifically, location, size, and space of and between reserves.

2.2.1 Connectivity

Connectivity refers to the demographic exchange between individuals of local populations through the dispersal of planktonic larvae, juveniles or adults (Almany *et al.*, 2009; Green *et al.*, 2014). Thus if reserves are to be connected they need to be placed in areas that either act as receptors or as sources of export through larval dispersal. Besides, reserves need to protect juvenile and adult life history phases which will ultimately allow maintenance of spawning stock by allowing individuals to grow to maturity and therefore increased species biomass and reproductive potential (Green, *et al.*, 2014). Although many papers discuss the importance of connectivity for reserve network design, this review found that few have explored practical ways to introduce robust connectivity indicators in systematic conservation planning approaches. Jones *et al.* (2007) summarized the findings on locating MPAs for connectivity suggesting three critical areas that should be protected 1) areas occupied by source populations 2) areas of isolated populations 3) spawning aggregation sites. Beside location, size and spacing and between reserves are also affected when planning for connectivity to improve fisheries. Ideally, reserves should be self-sustained (Gaines *et al.*, 2010) which implies that reserves need to be large enough to retain larvae within their boundaries. However, the variability of the traveled distance by larvae varies among species, from a few kilometers to up to large distances of hundreds of kilometers (Jones *et al.*, 2007; Green *et al.*, 2014). Thus it is sometimes unlikely to set aside large reserves (a diameter of more than 100km) given the potential socioeconomic costs associated with its implementation. Nonetheless, Lockwood *et al.* (2002) suggest that reserve size should be about two times the mean dispersal distance, especially for isolated reserves that are dependent on self-replenishment. Furthermore, and very importantly, size is strongly reliant on the spatial scale of movement of the target species, which also differs significantly along their different life stages (Almany *et al.*, 2009, Gaines *et al.* 2010). In this sense, knowledge about movement patterns of species is critical which highlights the need of studies about species home range. Finally, reserve size and larval dispersal must be considered when determining the optimal space between protected areas. The magnitude of dispersal is inversely proportional to the distance from the source population (Green *et al.*, 2014). Thus, a strategy might be to distribute reserves close enough to each other to allow considerable larval movement amongst them. This rule of thumb should be reinforced particularly when reserve size is thought to be small in the network design. Some studies show that reserves that are close together can lead to increased recruitment subsidies from other reserves (Roberts *et al.*, 2006).

2.2.2 Representativeness

When reserves are designed to meet a ‘representation’ objective, the network will attempt to represent or sample the full variety of biodiversity (ideally all levels of biodiversity) (Margules & Pressey, 2000). The rationale behind this objective is associated with the fact that marine species tend to segregate by habitat (e.g., depth, substrate, salinity, etc.) and use distinct habitat throughout their life stages (Gaines *et al.*, 2010), thus protection of all species and preservation of ecosystem health and integrity can be achieved by adequately capturing a proportion of each habitat across seascape. However, what an adequate proportion means, is a difficult question to answer that remains a central topic of debate in MPA network design.

Decisions support algorithms are typically used in the design of representative networks (Watts *et al.* 2009; Delavenne *et al.*, 2012; Breen, 2007). They use explicit quantitative targets and integrate spatial information to assist in building the conservation system (MPA network). Therefore, in this approach the network configuration is the product of design criteria (such as location, size, and space between reserves) the input data, the targets set (proportion of the habitat desired to be part of the network), and the software settings). Almany *et al.*, (2009) claimed that when the representation objective is met by means of the systematic target-driven approach, reserve configuration outputs tend to produce large and widely spaced reserves. Consequently, when this approach is used to build representative networks, connectivity is likely to be undermined.

Because data on connectivity is usually scarce, representativeness has been traditionally a major conservation objective incorporated in reserve network design. Biodiversity persistence and connectivity are often assumed to be guaranteed through representative networks, especially, if replication criterion is considered in the design. When multiple reserves are placed in each habitat (replicability criterion), biodiversity persistence is expected to be ensured by potential demographic connectivity among reserves and increasing the network resilience (Gaines *et al.*, 2010). However, as previously argued, some authors claim that biodiversity persistence can be only achieved if networks are ecologically connected (Roof & Zacharias, 2011). Specifically, if the network aims at enhancing fishery resources, then, specific criteria based on connectivity should lead the design of the network.

It is important to bear in mind that comprehensiveness is often used to substitute the term representativeness (See concept in Table 2). When this happens, the term representativeness is understood as the abundance and variability of each conservation feature on the network. Thus, it is more focused on determining the adequate proportion required for a particular feature to be representative of that feature. The need to replicate features is also fundamental to capture variability and comply with representativeness.

Another factor that plays an important role in network design is the total area under protection (Jones *et al.*, 2007). This number comes from international and national conservation policies and because it attempts to minimize political and socio-economic conflicts it is usually a small percentage (e.g. 10% to 12%) of the total region. Therefore, most of the time, this number is not ecologically suitable. Though this variable may have an effect on the network configuration, it can be seen more as a restriction to biodiversity conservation than a design driver. A commonly used strategy to address this issue is through the help of decision support tools (DST). DST such as Marxan can optimize the network solution by minimizing the cost of the area or through the incorporation of socio-economic costs. The incorporation of socio economic factors in reserve network design has received growing attention in the scientific literature (Klein *et al.*, 2008; Ban & Klein, 2009; Scholz *et al.*, 2010; Adams *et al.*, 2011; Yates *et al.*, 2015).

2.2.3 Incorporation of costs in network design

It is argued that addressing the needs of stakeholders can substantially improve user compliance on marine protected areas (Klein, 2006; see also Moore *et al.*, 2004, and Richardson *et al.*, 2006). One way to include stakeholder's needs is through the incorporation of costs. In conservation planning there are different kinds of costs. Most of them include acquisition costs, management costs, transaction costs and opportunity costs (Ban & Klein, 2009). In the marine conservation realm the opportunity costs typically influence site selection (Ban & Klein, 2009). Opportunity costs of conservation are associated with forgone revenues (Adams *et al.*, 2010). Inclusion of opportunity costs in MPA planning is critical since it can demonstrate how conservation costs are distributed between different stakeholders groups (Adams *et al.*, 2010). Klein *et al.* (2008) used opportunity costs for the California reserve network design in order to reduce social conflicts and economic costs of conservation. However, Adams *et al.* (2010) argue that most of the studies have considered partial estimates in opportunity costs and therefore, fail to adequately account for full opportunity costs.

The use of opportunity costs in marine conservation planning has been chiefly oriented towards the fishery industry (Adams *et al.*, 2011) and have failed to comprehensively address the variety of socioeconomic interest that usually takes place in the marine environment. Sometimes, even within the fishery (the socioeconomic activity most frequently addressed) socio economic considerations in network design may be biased towards a particular sector, for example commercial fishing (Ban & Klein, 2009). Fish landings or fishing effort is typically the metric used for analysis of opportunity costs (Adams *et al.*, 2011).

Overall, there is a need to developing frameworks that integrate multiple costs so that overall impact on marine users can be minimized. By incorporating socioeconomic costs into systematic conservation planning approaches costly conservation mistakes are likely to be avoided.

2.3 Systematic conservation planning

Systematic conservation planning is acknowledged worldwide as an effective method for conservation planning (Margules & Pressley, 2000; Groves, 2003; Noss, 2003; Lesslie, 2005). One of the major goals of this target driven-process is the location and design of a system of protected areas that work in combination to achieve conservation goals defined for the region in question (Delavene, 2010). Conservation planning is therefore inherently spatial. Countries in North America, South America, Europe, Asia, Africa, and Australia have used this approach to either design or redesign, complement or assess their respective marine/terrestrial conservation system (Stewart & Possingham, 2002; Balmford, 2003; Alonso *et al.*, 2010; Aridas, 2009; Metcalfe *et al.*, 2013, Zhang *et al.*, 2010). Systematic conservation planning offers a framework to account for two of the most important principles of any protected area system: representativeness and persistence. What these two terms mean and what the implications are for conservation have been widely discussed in the scientific literature of conservation planning (Marguless and Pressey, 2000; Margules *et al.*, 2002; Pressey, 2007; Ardron *et al.*, 2010). The first term, representativeness, was explained in the former section. On the other hand, persistence refers to the capacity of any conservation network to maintain ecosystem processes and functions (Margules and Pressey, 2000). Therefore, it 'promotes the vast ecological and evolutionary process that maintain and generate biodiversity' (Pressey *et al.*, 2007). Persistence has been interchangeably used as adequacy (Wilson *et al.*, 2009). Both adequacy and persistence can be linked to connectivity (see 2.2.1 and 2.2.2 before). The intrinsic relationship between these two principles is evident (connectivity and adequacy/persistence) and the accomplishment of these two depends on how effective are size, spacing, shape, and location in the network design.

Overall systematic conservation planning comprises a series of key stages (Margules and Pressey, 2000; Ardron *et al*., 2010): 1. Identify and involve stakeholders. 2. Identify goals and objectives. 3. Compile Data. 4. Setting conservation targets for each conservation feature. 5. Review existing protected areas and identify network gaps 6. Select new protected areas/propose modifications of current boundaries 7. Implement conservation action. 8. Maintain and monitor the protected area network. Systematic conservation planning usually adopts quantitative methods to go through some of these stages. Particularly, the use of decision support tools is a major distinction in conservation planning approaches.

2.3.1 Conservation objectives and targets

Definition of conservation goals and objectives are a distinctive characteristic of systematic conservation planning (Ardron *et al.*, 2010) and certainly one that should be set from the outset.

Having explicitly conservation goals and objectives is crucial if desirable outcomes are expected. They lay the groundwork to determine conservation features.

Overall, conservation targets are ‘interpretations of broad conservation goals set by experts and stakeholders’ (Rondinini & Chiozza, 2010). They are often used to determine gaps in MPA networks. Therefore, they may be useful as an indicator to measure conservation effectiveness. Targets explicitly state how much of each of the conservation feature is to be included in a reserve network. In other words, the amount of a feature required for meeting ecological goals.

In most of the conservation planning exercises, the scientific basis that supports target setting is usually weak, setting fixed targets across features (Chan *et al.*, 2006), and sometimes the importance of having a comprehensive rationale for those numbers is underestimated or overlooked. This is one of the reasons why quantitative target setting are still a controversial and widely discussed subject among the nature conservation scientists (Tear *et al.*, 2005; Svancara *et al.*, 2006; Rondinini & Chiozza, 2010; Harris *et al.*, 2014).

Consequently, understanding the underlying meaning of this concept is essential when applying SCP for MPA network design. In conservation planning, the concept of target is intrinsically linked to biodiversity persistence (Rondinini & Chiozza, 2010). Long term conservation will be achieved if there is sufficient space for species to maintain critical life stages such as reproduction and juvenile development. However, how much is enough is a difficult question that many conservationists still struggle to answer. In theory, the more habitat area a species has in a given network the more the likelihood of maintaining a viable population in the long term.

Types of targets

Two approaches have been documented in the literature to set targets for biodiversity features, the fixed target and the flexible target (evidence based) approach (Svancara *et al.*, 2006; Rondinini & Chiozza, 2010; Harris *et al.*, 2014). Fixed targets are principally policy driven (international agreements, national conservation policy). Thus, conservation targets are set as a percentage of a region, country or other area before the requirements of particular biodiversity features have been identified. The most common example is the international call to protect at least 10% of the oceans (CBD, 2011). The evidence-based approach to target setting is founded on an adequate understanding and mapping of the distribution and viability of the conservation features identified. According to Rondinini and Chiozza (2010) there are four evidence-based methods that can be used to determine targets: species–area relationship; habitat-specific species–area relationship; heuristic principles; and spatially-explicit population viability analysis (PVA). (See Appendix A for more information about of these methods).

2.3.2 Marxan in SCP

SCP is usually used to solve the minimum set problem of achieving some minimum representation of biodiversity features for the smallest possible cost (McDonnell *et al.* 2002), one of the most common expressions of the reserve design problem that results from the idea that biodiversity conservation must compete against social, economic and management constraints (Stewart & Possingham, 2002). Marxan software is intended to solve this particular problem. Based on an optimization algorithm, known as simulated annealing, Marxan answers the question of: what is the minimum number (and size) of sites that are needed to meet the targets (proportion of area assigned) for each biodiversity feature (Smith *et al.*, 2010; Stelzenmüller *et al.*, 2013). For this, the system requires that: conservation features identified for protection are mapped and cover the extent of the planning region; the study area is divided into a set of planning units (squares, hexagons or any spatial unit that one wants to consider appropriate); quantitative conservation targets are established for each conservation feature, and the abundance of features within each of the selected planning unit is calculated (Game and Grantham, 2008). Thus Marxan develops a selection routine of conservation portfolios that meets pre-set conservation targets. A portfolio or efficient solution would be one that meets the targets with the lowest cost as possible. This is achieved through the use of a mathematical objective function that gives a value for a collection of planning units based on the various costs of the selected set and the penalties for not meeting conservation targets (Ban & Possingham, 2000). Thus, a solution containing zero planning units, though cheap to implement (total cost equals zero), would not meet any biodiversity goal and so the objective function value will be zero (Game and Grantham 2008). Having an objective function which gives any possible reserve system a cost value, allows the user to automate the selection of good reserve networks (at least according to the objective function) (Ban & Possingham, 2000).

Marxan works simply by continually testing alternate selections of planning units, aiming at improving the whole reserve system value. The objective function's value must reflect the desirability of that particular reserve system (Game & Grantham 2008). The Marxan objective function (simplest form) is a combination of the total cost of the reserve system and a penalty for any of the ecological targets that are not met. This objective function is designed so that the lower the value the better the solution (Game & Grantham 2008).

Thus, the objective function in Marxan takes the form:

$$\sum_{Sites} \text{Cost} + BLM \sum_{Sites} \text{Boundary} + \sum_{ConValue} CFPF \times \text{Penalty}$$

It is important to bear in mind that most of the decision support systems (DSS) are computerized systems designed to provide a range of optimal solutions to a given problem according to prescribed rules. Consequently, a selection will be made by the user who determines which one is most appropriate. Also, the inability of Marxan to easily integrate stochastic or temporally dynamic data has been acknowledged (Martin *et al*. 2008).

Furthermore, like in many other tools, the quality of the solutions in Marxan is a reflection of the quality of the data used (Martin *et al.*, 2008).

Finally, using a systematic approach is considered a good practice because it promotes transparency, inclusiveness and defensibility in the planning process (Ardron *et al.*, 2010). A clear comprehension of core principles of systematic conservation planning is fundamental if robust and effective results are to be achieved (Watts *et al.*. 2009).

3. Study region profile and the context for MCP in the Scotian Shelf Bioregion.

Conservation planning requires an understanding of the natural and socio-economic context in where protection will be provided. This chapter provides an overview of the major physical, biological and socioeconomic characteristics of the Scotian Shelf Bioregion. It outlines the reasoning of further decisions in conservation planning.

3.1 The Scotian Shelf Bioregion Characterization

The Scotian Shelf Bioregion is located in the south portion of the Eastern Canada-Cold Temperate Northwest Atlantic, one of the three Canadian ocean provinces. From a planning and management perspective the SSB is divided in three subregions: The Bay of Fundy, the Atlantic coast of Nova Scotia, and Offshore Scotian Shelf (Appendix B).

3.1.1 Physical characteristics

The Scotian Shelf Bioregion represents the southernmost portion of Atlantic Canadian waters the shape of the sea bottom and the sediments overlying them are important to differentiate habitats and define the flora and fauna associated within each area.

Seafloor geomorphology of the SSB has been largely determined by the Last Glacial Maximum (LGM) along with the subsequent sea level rise (King & Fader, 1986), although currents, storms, and tides continue to shape the distribution of sediments (Breeze *et al.*, 2002).

According to King and MacLean (1976) the SS can be divided into the inner, middle and outer shelf areas. Rough topography and bedrock outcrops characterizes the inner shelf (Breeze *et al.*, 2013). Small banks such as St. Anns Bank and Scaterie Bank, off Cape Breton are distinctive features in the eastern portion of this area. The middle shelf is characterized by large deep basins (e.g., Emerald, LaHave and Roseway) and small banks in the central and western part while the east comprises a wide, complex network of valleys, ridges and small gravel- covered banks (Breeze *et al.*, 2013). Large shallow banks dominate the outer shelf i.e., Banquereau, Sable, Western, Emerald, LaHave, and Browns, and have been argued to function as a physical obstacle between the waters of the shelf and the deep waters of the ocean (Breeze *et al.*, 2002). It is also worth noting the only offshore island in the SS, Sable Island (exposed portion of Sable Island Bank), and its surrounding morphological features such as sand waves, sand ridges, ripples and mega ripples (Breeze *et al.*, 2013).

On the other hand, The Laurentian Channel, The North East Channel and the Continental Slope although they correspond to different geomorphological regions they are also important features that are part of the Scotian shelf bioregion.

The Slope spreads about 200m to 2000m deep along the outer edge of the shelf. A number of steep submarine canyons are found along the Slope. Relevant to mention from these features is the Gully with more than two kilometers deep and fifteen kilometers wide, making it the largest of these canyons. Beyond the slope is the continental rise (2000-5000m) and the abyssal plain (more than 5000m).

On the east of the Scotian Shelf bounds The Laurentian Channel. In particular, the Fan that is formed down the slope of the Channel, is a large delta-like deposition area. Some deep portions of the Channel carry water from the Atlantic Ocean into the Gulf of St, Lawrence (Breeze *et al.*, 2013).

The SS is bounded on the west by The Northeast Channel. This physiographic feature separates Browns Bank (part of the Scotian Shelf) from Georges Bank and the Gulf of Maine. In addition, this channel also connects the Bay of Fundy and the Gulf of Maine with the rest of the Northwest Atlantic (Breeze *et al.*, 2013).

Oceanographic characteristics are also an essential component of marine ecosystem dynamics. The oceanographic conditions in The SSB are dependent on large scale and complex atmospheric and oceanic interactions that happen over short and long terms. The North Atlantic Oscillation is the Scotian shelf most influential climatic process that affects water properties (i.e., temperature and salinity), vertical mixing, sea ice coverage, and circulation through air-sea heat exchange and wind stress (Hurrell & Deser 2009).

Circulation patterns are mainly influenced by three major currents, The Nova Scotia Current, the Labrador Current, and the Gulf Stream, and their influence vary both spatially and seasonally (King, 2004). The Nova Scotia current is a relatively fresh mass of cool water moving southwest along Nova Scotia's Atlantic coast. It is a result of the influence of both the Gulf of St. Lawrence outflow and the Labrador Current (Sutcliffe *et al.,* 1976). Likewise, the current turns near Halifax waters, crossing the shelf between Emerald and LaHave basins, then it joins Labrador Current and continue to move southwest along the edge shelf. The Gulf Stream flows northeastwards and it's warmer and saltier water that mixes with the cool Labrador Current forming the slope water (Breeze *et al.*, 2013). This also affects the shelf waters since it periodically drifts on to the shelf through the channels and other canyons. Largely, the cool waters form the Gulf of St. Lawrence and Newfoundland Shelf affects more the banks of the eastern Scotian Shelf whereas the Gulf Stream has more influence on the Slope and deep channels and basins of the shelf. Overall, the SSB is influenced by a general flow that comes from the northeast to the southwest across the shelf during the winter the flow is strong while summer is characterized by a weak pattern (Breeze *et al.*, 2013). (A map of the currents is showed in Appendix B)

Lastly, there are gyres that retain particles, such as plankton, for a period of time in one area, and may be important for larval (retention) stages of fish and invertebrates (see complete references and discussion in Breeze *et al.* 2002).

3.1.2 Biological characteristics

Eastern Canada (Atlantic) represents a unique large ecosystem that is home to various forms of marine life. Eastern Canada has the highest number of known benthic infaunal and fish species in Canada (Archambaul *et al.*, 2010). Also, the region ranks second in terms of phytoplankton diversity (with a total of 626 phytoplankton taxa) and marine mammal diversity with 30 species out of the 52 found in Canada (Archambaul *et al.*, 2010). The Scotian Shelf Bioregion contributes to the relative importance of the biodiversity found in Atlantic Canada.

The SSB may be considered a relatively productive bioregion compared to the rest of Canada. Phytoplankton blooms occur in the area during spring (Breeze *et al.*, 2002) and there is evidence of an increased intensity and duration of these events (Zwanenburg *et al.*, 2006). Phytoplankton is responsible for more than 45% of the annual net primary production of the planet (Archambaul *et al.*, 2010) and are the base of marine food web (i.e., the primary food source of zooplankton) (Breeze *et al.*, 2013). The zooplankton constitutes an important source of food for many species, and it is argued that all species of fish feed on zooplankton at some stage of their life cycle (Breeze *et al.*, 2002). In the Scotian shelf copepods and euphausiids comprise much of the zooplankton biomass (King, 2004).

Benthic invertebrates are important food source in shelf ecosystems and they can also occur in the form of biogenic habitat. Polychaete worms are common non-commercial invertebrates that are found on the Scotian Shelf. Moreover, echinoderms (starfish and sand dollars), anemones, corals, sponges, and tunicates represent the epifaunal community that can be found in the bioregion. On the other hand, structure-forming animals such as ascidians, bryozoans, corals, hydroids, and sponges can ‘create, modify and maintain habitat for other species by producing complex structures on top of sediments’ (Breeze *et al.*, 2013). Such biogenic habitats can provide space and shelter to animals as well as increased food supply (Breeze *et al.*, 2013).

Deep-sea corals and sponge aggregations are common in certain areas of the Scotian Shelf forming complex structures that bolster biodiversity compared to other benthic habitats (Breeze *et al.*, 2013). In addition, there are around 28 of invertebrate species on the SSB that are commercially important. Crustaceans (e.g., lobster, snow crab and northern shrimp), bivalves (e.g., sea scallop, Atlantic surf clam, and Iceland scallop), snails (e.g., periwinkle, whelk), cephalopods (squid), and echinoderms (e.g., sea cucumber, sea urchin) are examples of these species (Breeze *et al.* 2002). Contrary to the benthic invertebrates, little is known about the occurrence and distribution of pelagic invertebrates of the Scotian Shelf.

Fish are the most studied group of species in the Scotian shelf mainly due to extensive trawls surveys that have been carried out in the bioregion since 1950s (Doubleday & Rivard, 1981). There are demersal, pelagic and diadromous fish species on the waters off of Nova Scotia. Most groundfish (demersal) include gadoids (e.g., Atlantic cod, pollock, and haddock), flatfishes (e.g., Atlantic halibut) and elasmobranchs (e.g., smooth skate) (King, 2004). Pelagic fish is usually divided into two groups: small and large pelagics. Small pelagics (e.g., Herrings) can be widely distributed in the SSB and are important forage species to many others. Most large pelagic fish are highly migratory species (e.g., tuna, swordfish, and sharks) (Breeze *et al.*, 2002). From the nineteen species of sharks that inhabit the waters of Atlantic Canada only five species are considered common residents. They include the blue shark, porbeagle, shortfin mako, basking shark and the spiny dogfish (Zwanenburg *et al.* 2006). Finally, diadromous species (i.e., those that spend a portion of their lives in freshwater) of the SS include Atlantic salmon, gas pereau, sea lamprey, striped bass, Atlantic sturgeon and American shad (Breeze *et al.* 2002).

Migratory turtles such as leatherback can be found in the waters of the Scotian Shelf during the summer months when they are reported to be foraging for jellyfish (Breeze *et al.*, 2013).

Loggerhead and Kemp's ridley turtle can be spotted in the area as well. Important to note that Atlantic leatherback is registered as endangered since 2012 (COSEWIC, 2002).

SSB is home to a number of local and non-local pelagic seabirds. High concentrations of seabirds throughout the year can be found in Sable Island Bank and the Scotian Slope (Breeze *et al.*, 2013). Terns and large gulls are amongst the most abundant seabirds on the SS (Gaston *et al.* 2009). Particularly, Sable Island, a designated Migratory Bird Sanctuary, constitute an important tern nesting area (Breeze *et al.*, 2013).

Marine mammals inhabit the Scotian Shelf waters throughout the year, specifically, cetaceans (e.g., whales, dolphins) and pinnipeds (i.e., seals). Cetacean populations were intensely fished when commercial whaling was allowed. This has resulted in populations that have not been recovered yet. Large cetaceans (i.e., Baleen whales) feed form zooplankton or small schooling fish (King, 2004). Cetaceans identified on the Scotian Shelf include fin whale, minke whale, sperm whale, pilot whale, sei whale, Nothern bottlenose whale, blue whale, harbor porpoise, North Atlantic right whale, and killer whale (Breeze *et al.*, 2013). From this list two are listed as endangered species by COSEWIC, the North Atlantic right whale and the Nothern bottlenose whale (COSEWIC, 2002).

3.1.3 Socioeconomic characteristics

Ocean related activities in the SSB are a critical component of the regional economy. An overview of the Economic Value of the Ocean Sector in Nova Scotia: 2007 – 2011 (Gardner Pinfold, 2014). The Nova Scotia report (2011) stated that ocean activities accounts for 7% of the GDP in the province generate around 2.5 billion in GDP. As of 2011, Nova Scotia Ocean related activities direct impact was up to 2,547 millions in terms of GDP creating about 34,800 jobs (Gardner Pinfold, 2014).

It is important to bear in mind that not all of these marine activities represent a direct ocean use with an associated spatial attribute. DFO has underscored eight key ocean use sectors that are often considered in regional coastal and ocean management practices. To see more detail see Breeze *et al.* (2013) report. They are: Fishing (commercial and Aboriginal), Aquaculture, Offshore oil and gas, Ports and shipping, Ocean and coastal tourism, Maritime defense, and Submarine cables.

Nonetheless, some of them may have a more inshore influence than offshore. For instance, aquaculture and tourism though they are important for the local and regional economy in terms of revenues, they occur more on the coastal waters than offshore.

Nevertheless, from all of these ocean-related activities, fishing, shipping and oil and gas represent the most prominent offshore activities. At the same time, they occupy the top three industries that contribute the most to the regional economy (excluding the National Defense sector) (Gardner Pinfold, 2014). A brief description is presented below.

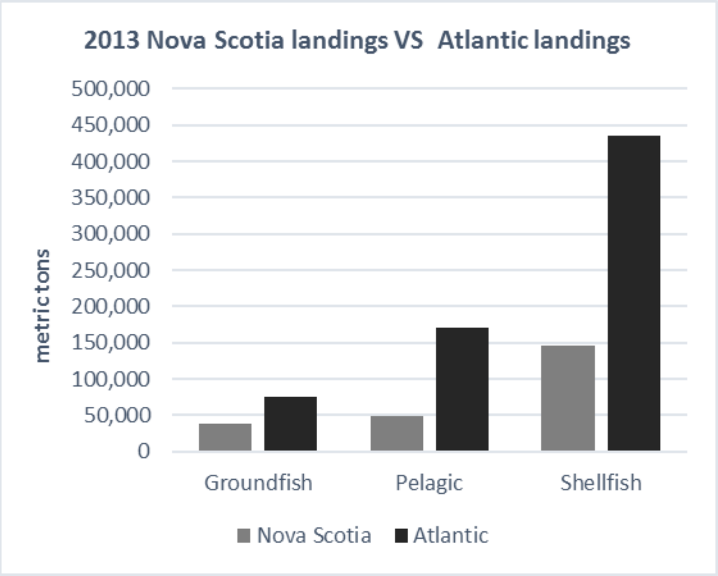
Fishing

Commercial fishing is considered the most extensive industry in the SSB with a history of nearly 500 years (Breeze *et al.*, 2013). There are three important commercial fisheries in the Scotian Shelf: groundfish, pelagic, and shellfish fisheries. Groundfish used to be one of the most important fisheries in the region, particularly the cod and haddock fisheries (Underwood, 1995; Breeze *et al.*, 2013). However, overfishing led to stock collapse in these species (Myers, 1997; Breeze *et al.*, 2013). Yet, in some areas of the SS, cod and haddock fisheries are still allowed at reduced levels. Key target groundfish species include, hake, haddock, redfish and pollock. Two major groups according to vessel size and gear type can be distinguished in this fishery: small inshore fixed gear vessels that use hook and line, and large offshore trawlers (King, 2004). On the other hand, pelagic fishes are the least important fishery in terms of regional revenues

(DFO, 2014). Important to note though is the position that the herring fishery occupies in the pelagic fishery, with landings quantities that represent more than 90% of the total fishery (DFO, 2014). However, the contribution in terms of profits barely accounts for the 30% (DFO, 2014), this can speak about the little value of the herring fishery in the region.

Furthermore, commercial fishing effort shifted to shellfish after the groundfish decline (Charles, 1997; Mather, 2013). At present, shellfish fisheries (i.e., lobster, crab, scallop, and shrimp) account for around 80% of the landed value (Gardner Pinfold, 2014) (Figure 1).

Overall, the fishing industry has experienced ups and downs in terms of quantity and value of the landings (Gardner Pinfold, 2014). Since 2008, commercial fishing landings have been declining, this is primarily attributed to the reduced abundance of pelagic and demersal fish species.



.

Figure 1*: Commercial landings for Nova Scotia and all Atlantic provinces (2013)*

Shipping

International and national commercial shipping traffic occurs on the SSB. According to Gardner Pinfold (2014) the shipping industry generates direct revenues that are estimated at $500-600 million annually. Around 8000 fulltime jobs are created from the shipping industry (Gardner Pinfold, 2014).

Marine transportation comprises marine towing, ship chartering, cargo handling, harbours and port operations, ferries, pilotage and shipping agencies (Breeze *et al.*, 2013). In addition some of the commodities that are commonly moved in the area consist of crude oil and gas, minerals and chemicals, paper and forest products, etc.

Offshore Oil and Gas

Oil and gas has been occurring in the region since 1967 when the first exploration well was drilled on Sable Island (Breeze *et al.*, 2013). After that, many important discoveries were made in the area (Breeze *et al.*, 2013) unveiling the abundance of this resource and prompting a more firm establishment of the industry in the region. Offshore exploration comprises seismic surveys and exploratory drilling. Amongst the most important areas for hydrocarbon reserves are: the deep water of the Scotian Slope, the Laurentian Sub-basin and the Shelburne sub-basin (i.e., Goerges Bank) (Breeze and Horsman, 2005). Petroleum exploration and development are managed by Canada Nova Scotia Offshore Petroleum Board (CNSOPB). For instance Georges Bank is subject to a moratorium and only offshore exploration is permitted.

Currently, there are two petroleum projects in production over the waters of Nova Scotia. First, the Sable Offshore Energy Project (made up of six production platforms taping natural gas fields nearby Sable Island) that is expected to cease production by 2020. The second project is the Deep Panuke (250 km southeast of Halifax), which started production in 2013.

3.2 Framework for Canada's MPA planning and implementation

3.2.1 Policy framework

In accordance with its long and strong maritime traditions, Canada has made a commitment to developing and establishing an effective network of marine protected areas (MPAs) (DFO, 2012; DFO, 2013).

At the international level, the 2010 Conference of the Parties to the Convention on Biological Diversity (CBD) reaffirmed the commitment to the implementation of a global network of MPAs, this time with a 2020 timeline and a global target of ‘10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well-connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscape and seascape’ (Lopoukhine, 2013). At the national level, commitments have been made through the Oceans Act and Canada's Federal Marine Protected Areas Strategy. In addition, The National Framework for Canada's Network of MPAs constitute a policy document which provides strategic direction for the planning and design of a national network of MPAs (Westhead, 2012). The network is to be planned and implemented using bioregions as a common foundation.

3.2.2 Legislative framework

There are approximately eight federal and 40 provincial/territorial legislative or regulatory tools in Canada for establishing protected areas with a marine component (Lopoukhine, 2013). Fisheries and Oceans Canada operating under the *Oceans Act* is responsible for the establishment and designs of marine protected areas ‘to protect and conserve important fish and marine mammal habitats, endangered marine species, unique features and areas of high biological productivity or biodiversity (DFO, 2005). Also, DFO along with federal and provincial agencies and departments is responsible for leading and coordinating the development and implementation of the national network of MPAs.

Parks Canada operating under the *National Marine Conservation Areas Act* has the mandate to establish at least one Canada National Marine Conservation Area (NMCA) in each of Canada’s 29 distinct marine regions. NMCAs are marine are areas managed for sustainable use (Lopoukhine, 2013).

Environment Canada establishes Marine Wildlife Areas under the *Canada Wildlife Act* and the *Migratory Birds Convention Act* to protect unique, critical and productive terrestrial, wetland and marine habitats/ecosystems for wildlife in Canada (Lopoukhine, 2013).

3.3 Goals, objectives, priorities and targets for MPA network design in SS

3.3.1 Conservation objectives and priorities

The National Framework for Canada’s Network of Marine Protected Areas outlines the overarching vision and goals for Canada’s MPA network.

Vision:

An ecologically comprehensive, resilient, and representative network of marine protected areas that protects the biological diversity and health of the marine environment for present and future generations (Government of Canada, 2011)

Goals:

1. To provide long-term protection of marine biodiversity, ecosystem function and special natural features;
2. To support the conservation and management of Canada’s living marine resources and their habitats, and the socio-economic values and ecosystem services they provide; and

3. To enhance public awareness and appreciation of Canada's marine environments and rich maritime history and culture.

The planning process for MPAs in the Scotian shelf is mainly guided by the CBD guidelines on the design of MPA networks. For the definition of the conservation objectives in this region, the experiences from the planning process of the existent management regimes in the area such as integrated ocean management (IOM) were fundamental (DFO, 2013).

In 2012, DFO Maritimes defined two overarching conservation objectives for the Scotian shelf network of MPAs (DFO, 2012):

1. Protect Ecologically or Biologically Significant Areas and other special natural features in the Scotian Shelf Bioregion that benefit from long-term, year-round, spatial management; and
2. Protect representative examples of all marine ecosystem and habitat types in the Scotian Shelf Bioregion based on coastline, coastal subtidal, and offshore classifications, along with their associated biodiversity and ecological processes

However, an updated version of proposed strategic objectives for the Scotian Shelf bioregional MPA network was recently developed. The provisional strategic objectives for the SS bioregion are:

1. Protect unique, rare, or sensitive ecological features in the bioregion;
2. Protect representative examples of identified ecosystem and habitat types in the bioregion;
3. Help maintain ecosystem structure, functioning and resilience within the bioregion;
4. Contribute to the recovery and conservation of depleted species; and

5. Help maintain healthy populations of species of commercial, recreational and/or Aboriginal importance.

Setting conservation objectives when planning for conservation is essential for an effective network. Likewise, DFO is working towards developing measurable conservation objectives and identifying the appropriate indicators, monitoring protocols and strategies to evaluate the effectiveness of MPA networks. Its actual conception has different levels of specificity. It goes from the overarching conservation goals to the more specific strategic conservation objectives and to the operational conservation objectives (DFO, 2013).

Another key component in MPA planning in the Scotian shelf is in regard of the design properties of the network. The MPA network design for the Scotian shelf includes: Ecologically and Biologically Significant Areas (EBSAs); 'Representativity' (Representativeness); Connectivity; Replicated of ecological features; Adequate and viable sites. This indicates that 'networks should protect EBSAs and representative examples of all ecosystem or habitat types through individual MPAs that are connected through ecological processes and of sufficient size and protection level' (Gromack & Allard, 2013).

4. Research Methodology

This chapter describes the procedures taken in each major step of the investigation. The general approach undertaken in the research is illustrated below (Figure 2). Overall, the methodology follows the general sequence pursued in most conservation planning exercises: Definition of conservation goals and objectives, selection of conservation features, target setting, and scenario analyses and network design.

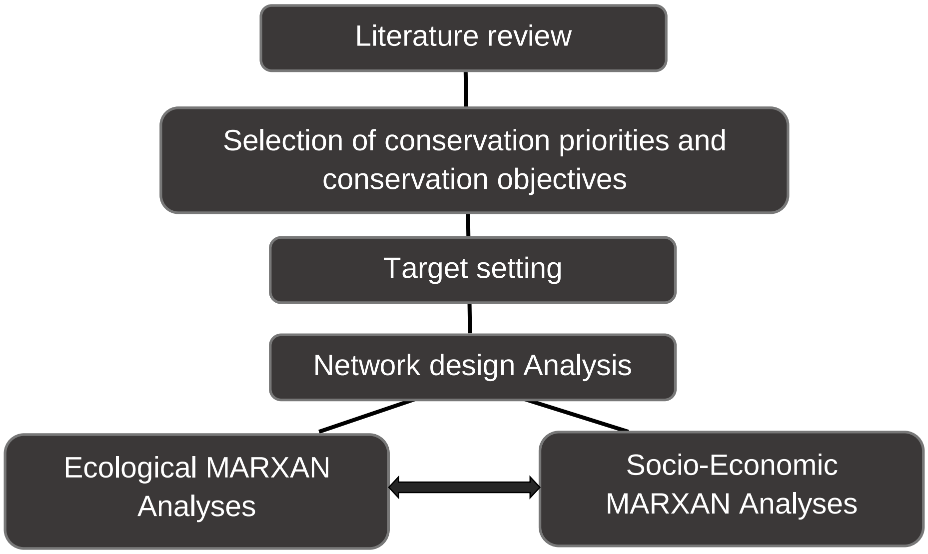


Figure 2: *Methodological structure of the paper.*

4.1 Literature review

An extensive literature review was conducted as first step in the research. Modern discourses in the literature of conservation planning and particularly protected area network design were brought together and critically analyzed. In addition, a characterization of natural diversity of the Scotian shelf bioregion coupled with a socio-economic description was conducted as well.

4.2 Selection of conservation objectives and conservation priorities for MPA network design in the SSB.

The overarching conservation goals and the strategic conservation objectives previously defined and agreed upon by DFO were used for the analysis of the investigation. They represent the building blocks of the MPA network design in the Scotian shelf bioregion. An analysis of both conservation objectives (overarching goals and strategic conservation objectives) was conducted to determine gaps and weaknesses as well as implications for network effectiveness.

A number of conservation priorities were selected for the analysis as well. However, although most of them might potentially make the list of definite priorities, they do not represent the DFO official list of biodiversity features for the SSB. Expert opinion, as well as previous MARXAN analyses (See Horsman *et al*., 2011) were key in selecting the conservation priorities.

Finally, the relationship between conservation priorities and conservation goals and objectives was analyzed and compared to the modern theory of network design.

It is important to mention that despite the fact that terms such as conservation goals and objectives, and conservation features, have become customary concepts within the conservation community, their meaning as well as their name (terminology) varies depending on the level or scale in which they operate as well as the community of people that make use of it. For instance, The Nature Conservancy interprets goals not as part of their conservation objectives but as what the literature of SCP regard as target.

For clarification purposes the conceptual terminology used in this paper is presented (**Table 2**):

Table 2: *Terminology used for conservation objectives*

Commonly named in the Conservation planning literature	**Name adopted in the paper**	**Explanation**
Conservation objectives	Conservation objectives	General term that do not specify which kind of conservation objective we are referring to.
Conservation goals	Overarching conservation goals	The desired or final end purpose of the MPA network (Rupp et al, 2013)
Conservation objectives	Strategic conservation objectives	Specify the desired state of ecosystem features in order to have a high likelihood of achieving the overarching goal (DFO, 2013)
Conservation features	Either conservation priorities or features. Also biodiversity features.	The biodiversity features that the network will aim to protect
Target	Target	The amount (area) of conservation feature that the network will aim to protect.

4.3 Target setting

Targets were set at each of the conservation priorities listed. Expert opinion and previous Marxan analyses (See Horsman *et al.*, 2011) were key in determining the amount of area that each biodiversity feature needs for protection. Conservation status, vulnerability, rarity, and uniqueness were among the criteria used to set different levels of priority. This allows one to determine which features will receive a high target (e.g. a very unique and rare feature would get a high target) and which ones will get a low target. However, adjustments to the targets assigned to some priorities were made.

Overall, the following guiding principles were applied to determining the final targets

1. <u>That none of the conservation priorities are assigned targets less than 10% of its</u>

distribution. This is a precautionary measure supported by the international call to protect at least 10% of the world's oceans. (CBD, 2011)

2. That larger conservation features are assigned smaller targets and vice versa. This was brought up by the author's concern about the size (spatial distribution) of the conservation features, which was not taken into account in the DFO approach for setting targets. The main reason is that smaller features are also vulnerable to any changes and therefore should get a high target.

3. That as a starting point in determining the targets conservation features can be grouped by categories, then targets can be assigned in proportion to the size of its distribution. This will only apply to coarse filters features (e.g. representative features). The criterion described in Ardron *et al.* (2010) was applied in order to scale proportional targets based on the overall abundance of the conservation features. In this approach conservation priorities targets are scaled in proportion to the square-root of the ratio of representative features' overall areas (equation 1).

Equation 1.

$$(x_p / y_p) \approx (x_t / y_t)^{0.5}$$

Where the subscript "p" represents the protected area of a given feature and the subscript "t" represents the total area of a given feature in the network.

4. That the target be consistent with the degree of conservation importance (rareness, sensitivity, uniqueness, etc.) and threat to the feature in question. This is basically the approach DFO undertook to setting the targets. Therefore, features that are unique or rare will get a high target.

4.4 Network design analysis

The conservation network that DFO aims to design is formulated on the minimum set problem. Since Marxan was designed to solve this conservation problem (See Chapter 2 section 2.3), it was the tool used for the analysis.

4.4.1 Data preparation

In order to design a network that embodies the goals and objectives it is necessary to map all conservation features. Assembling all spatial information required for robust results is certainly one of the most time demanding steps in conservation planning. However, for this project, all ecological and socio-economic data used were provided by DFO. The ecological layers represent the potential list of conservation priorities identified by DFO. The socio-economic layers were used to describe the human activities in the study region, the SSB. Only fisheries data were used as part of the incorporation of socio-economic criteria for the network design.

Spatial and cartographic coherence is necessary when spatial analyses are planned to be performed. Geographic data layers, both ecological and socioeconomic, were normalized. This encompassed projecting all layers to the same spatial reference (UTM NAD 83 Zone 20), repairing the geometry for all features, standardizing the database design (deleting and creating new fields) and removing all small objects, less than 1ha (this is a cartographic generalization process to determine the minimum work unit). Normalization, despite being time consuming, is crucial to guarantee a standard quality of the information and allow further complex geoprocessing that is required to generate Marxan input files.

The analysis of this project was limited to the region known as the DFO Maritimes administrative area, which was determined by DFO as one of the 13 marine regions that aims to develop a network of MPAs. Consequently, all data layers were clipped to this area.

As previously mentioned, Marxan requires that the study region is divided into planning units. Decision about the type and size of the planning unit is a critical step to attaining adequate results in Marxan. Types of planning units can include grids, hexagons and even natural units such as watersheds (in terrestrial conservation). This study opted to subdivide the region into hexagons as it produces more efficient and less fragmented portfolios than squares (Nhancale and Smith, 2010). Planning unit resolution (size) should be one that is not too coarse so that spatial variation of individual features are captured or too fine which can considerably slow the optimization process. Previous Marxan studies for the Scotian Shelf have used grids of approximately 10Km^2. However, Horsman *et al.*, (2011) explain that the two by two arc minutes size of the planning unit was selected as a matter of being consistent with GISMO, a geospatial database compiled for internal use by the Oceans and Coastal Management Division (Horsman *et al.*, 2011). In order to maintain consistency with previous work, hexagons of approximately 11km^2 were determined as the appropriate size. Hexagons were generated using Protected Area Tool (PAT), a GIS-based tool that support MPA network design developed by The Nature Conservancy.

4.4.2 Input file preparation

Marxan requires at least five text files containing data in order to run (Table 3). All the input files for Marxan were generated with the help of ArcGIS 10.2 as well as the Protected Area Tool. Some post processing was carried out in Excel.

Table 3: *Marxan minimum required input files.*

Input file	Description	Software used
input.dat	The input parameter file used to set values for all the main parameters (BLM, Number of runs, iterations, etc.) that control the way Marxan works.	Input generator
spec.dat	The conservation feature file contains information about each of the conservation features being considered, such as their name, targets and representation requirements, and the penalty that should be applied if these representation requirements are not met.	Excel; PAT
pu.dat	The planning unit file contains information such as costs as well as the status of some planning units.	PAT
puvsr.dat	The planning unit versus conservation feature file (puvsr.dat) contains information on the distribution of conservation features in each of the planning units.	PAT, geoprocessing in ArcGIS
bound.dat	The Boundary Length File contains information about the length of shared boundaries between planning units.	PAT

4.4.3 Marxan Calibration

In order to get efficient portfolios, it is necessary to balance the Marxan objective function through a series of experimental runs. This process ensures that solutions generated by Marxan are close to the lowest cost or optimum. For this analysis, Marxan calibration process encompassed the checking and setting of the number of runs and iterations as well as Species Penalty Factor (SPF)[1] and Boundary Length Modifier (BLM)[2]. Aspects such as efficiency and boundary length were compared and final parameters were decided when efficient solutions both in terms of overall cost of the objective function and spatial configuration (visual) were found to be appropriate.

---

[1] The SPF is a weighting factor defined by the user that applies when a conservation feature target is not met. Depending on the value assigned, the SPF intends to put more emphasis on the last component (cost for not meeting the targets) of the Marxan objective function, which forces Marxan to find solutions that meet the targets.

[2] The BLM controls the clustering of the solutions by increasing the cost of reserves with high boundary-area ratio. This way Marxan intends to select more compact solutions. (See Game, & Grantham, 2008).

4.4.4 Conservation network design analysis: Scenario comparison

Two different approaches were followed for the analysis of the network design: Analysis not considering economic costs and analysis considering economic costs.

4.4.4.1 Marxan analysis not considering economic costs

The first approach aims at understanding the ideal network to achieve conservation targets. One important thing about this step is that it provides a sort of baseline or reference portfolio of “highest” efficiency, against which one can compare any other portfolio to assess efficiency. It also explores some of network design principles that are widely cited in the literature such as connectivity, replicability, representativity, etc. Therefore, it does not include any socio-economic cost. Area is used as cost, a value of 1119 (the area of a planning unit in hectares) was used for all planning units. Therefore, the problem is restricted to find reserves that are efficient in meeting conservation targets and minimizing the boundary length and the network total area as much as possible.

The first approach looked at five different scenarios. They are defined as follows:

1. ***Most suitable network scenario:*** This is a Marxan scenario that represents the baseline for comparison. It is made up by the most efficient solution resulted from running Marxan with no restriction or consideration of any existing marine protected area. All planning units have an equal opportunity to be selected in the final portfolio, which will depend on the contribution each planning unit has to the targets and to the portfolio final cost. This yields a network design that is most suitable in terms of spatial efficiency and compactness. One that would be ideal to implement if no conservation measure exists in place.
2. ***Current MPA network scenario***: It represents the current network of marine protected areas, which is made up by two offshore MPAs, St Anns bank (considered as a MPA for the purpose of this project despite the fact that is officially an area of interest) and the Gully

(Musquash MPA is not included because the analysis is limited to offshore marine protected areas and no coastal). Marxan was only used to calculate the parameters (see below) that are analyzed, but no target was set whatsoever.

3. ***MPA network scenario***: In this scenario all planning units that contain the current network (The Gully and St Anns bank) were locked in. It is therefore a restricted scenario where the current system of MPAs becomes the starting point in the search for efficient networks. Thus, it is a more realistic output from a management perspective since it complements the existing conservation system by finding new efficient areas that meet all conservation targets.
4. ***Complemented comprehensive Scenario***: In this scenario, not only are MPAs are locked in, but other conservation measures already in place such as critical habitats and sponge areas as well. Marxan is run to create a portfolio that complements the network that is made by current MPAs and other conservation measures.

All these scenarios were analyzed and compared according to the following variables:

- *Efficiency*: Percentage of efficiency compared to the most suitable scenario. The percentage that the inverse of the total cost in each scenario represents of the efficiency in the most suitable portfolio. This can better be expressed in the form of an equation:

  Equation 2. $\frac{x-(y_i-x)}{x} * 100$

  Equation 3. $\left(2-\frac{y_i}{x}\right) * 100$ ------ Equation 2 in its simplest form.

  Where x is always the efficiency value of the most suitable network scenario (The first of the 5 scenarios before explained) and y_i the efficiency value of the different scenarios, with the subscript "i" varying from scenario 2 to 5.
- *Comprehensiveness*: Percentage of conservation features contained in each scenario (Regardless of whether or not the targets are met) respect to the total number of

conservation priorities.

- *Representativity*: Proportion of represented features. The percentage of conservation priorities that are represented (If a conservation priority meets the target then such feature is considered represented by the network) compared to the total. Features with a met target at 99% were considered represented by the network. In addition, the coverage of all features were compared to two a 10% target (the minimum level considered) and a 30% target, as a more adequate basis for well representation.
- *Compactness*: Measured by the relationship between the boundary length and the area of the solution in question.
- *Size*: The average size of all individual areas that form the network in each scenario was calculated.
- *Spacing*: The average space between reserves was measured.

4.4.4.2 Marxan analysis considering economic costs (Reverse Marxan)

The second Marxan analysis did address socio economic costs. For this, a reverse Marxan (RM) using information about fishery landings was performed. A reverse Marxan is merely a Marxan analysis but instead of dealing with conservation features or priorities it deals with economic information or layers. Importantly to understand is that the fish data used were all points feature representing the catch in tons.

A number of target species from pelagic, shellfish, and groundfish fisheries were selected for this analysis. The list represents some of the most important offshore fisheries for the Scotian shelf. Targets of 70, 80 and 90% of landings in weight tons were set for each fishery feature.

Most of the previously created Marxan input files were also used in this analysis, specifically, the bound.dat, input.dat, and the pu.dat file. The sepc.dat was recreated in excel. The planning unit versus species file was created through a series of spatial joins between each layer representing the fish distribution and the planning unit layer (hexagons). Then, a matrix of each planning unit containing the landing info of each fishery was put together and converted to Marxan original input format. Finally, Marxan was run three times, for each target set, 70%, 80%, and 90%. However, the run with the 70% target was selected as the cost layer for this analysis.

In order to truly incorporate socioeconomic costs from the outputs of the reverse Marxan into the regular Marxan analysis, the planning unit file (pu.dat) to rerun Marxan was created. The values of the sum solution output was used as the cost.

However, it was necessary to alter the value of the cost in order to make this analysis comparable with the first regular Marxan (ecological analysis). Consequently, all values were multiplied by 1119 (the cost value that was used in the first analysis). This way the cost of the planning units ranged from a value of 1119 (the same cost weight used in first analysis) to 111900 (resulted from multiply 1119 by the highest value of the sum solution, 100).

Lastly, results from both Marxan analyses (ecological versus socioeconomic) were compared, analyzed and discussed based on the same parameters that were earlier explained.

5. Results

5.1 Conservation objectives and proposed priorities

The relationship between Canada's overarching conservation goals, the Scotian Shelf strategic objectives, and the proposed conservation priorities derived from the Scotian Shelf strategic objectives is shown in Table 4. In terms of consistency, all of the five proposed conservation objectives for the Scotian Shelf are directed to fulfill the first two national overarching conservation goals outlined in the MPA National Framework (**Table 4**).

A number of conservation priorities were defined from the proposed strategic conservation objectives for the Scotian Shelf. They comprise seven broad categories, although some may contain sub-categories (**Table 5**). Each category and subcategory comprises a number of layers. A total of 114 layers make the list of all conservation features that were selected for the MPA network development in the Scotian Shelf (Appendix C).

Table 4: *Overarching conservation goals, objectives and proposed priorities for the Scotian Shelf.*

Scotian Shelf Strategic Objectives	Conservation priorities Categories	All conservation features	No. of layers	Canada overarching goals for MPA network 1	2	3
Objective 1	**Special features**	Unique & rare features. Vulnerable and limited distribution. High importance for Conservation. Generally fine filter		To provide long-term protection of marine biodiversity, ecosystem function and special natural features.	To support the conservation and management of Canada's living marine resources and their habitats, and the socio-economic values and ecosystem services they provide.	To enhance public awareness and appreciation of Canada's marine environments and rich maritime history and culture.
Protect unique, rare, or sensitive ecological features in the bioregion	*Biogenic habitats*	Sponge aggregations	1	✓	✓	-
		Coral aggregations	1	✓	✓	-
		Horse mussel reefs	1	✓	✓	-
	Areas of high biodiversity	Fish species diversity (hot spots)	3	✓	✓	-
		Invert species diversity (hot spots)	2	✓	✓	-
		SSIP diversity larvae	9	✓	✓	-
		Stomachs diversity small fishes	2	✓	✓	-
		Stomachs diversity small inverts	2	✓	✓	-
Objective 2	**Representative features**	Broad distribution, coarse filter, critical for capturing samples of all ecosystems and with that species that are not otherwise included in the network.				
Protect representative examples of identified ecosystem and habitat types in the bioregion	*Seabed*	Seabed types	28	✓	✓	-
Objective 3						
Help maintain ecosystem structure, functioning and resilience within the bioregion	*Functional groups*	F.G Fish	16	✓	✓	-
		F.G Inverts	12	✓	✓	-
		F.G Seabirds	8	✓	✓	-
	Areas of High Biological Productivity	Areas of persistent high chlorophyll concentrations	4	✓	✓	-
		Biomass	3	✓	✓	-
Objective 4	**Depleted species**	Fine filter, limited distribution, species associated with a certain level of threat due to overfishing, bycatch or poor management.				
Contribute to the recovery and	*Fish habitat distribution*	Atlantic cod	3	✓	✓	-
		Redfish (Unit 2)	1	✓	✓	-

Scotian Shelf Strategic Objectives	Conservation priorities Categories	All conservation features	No. of layers	Canada overarching goals for MPA network		
				1	2	3
conservation of depleted species		Winter skate (ESS)	2	✓	✓	-
		American plaice	2	✓	✓	-
		Cusk	1	✓	✓	-
		White hake	2	✓	✓	-
		Smooth skate	2	✓	✓	-
		Atlantic wolfish	1	✓	✓	-
		Thorny skate	2	✓	✓	-
		Redfish (Unit 3)	1	✓	✓	-
		Spiny dogfish	1	✓	✓	-
	Cetaceans distribution	Cetaceans (hot spots)	2	✓	✓	-
	Turtles distribution	Leatherback turtle	2	✓	✓	-
Objective 5	**Commercial fishes**					
Contribute to the recovery and conservation of depleted species	*Pelagic fish distribution*	Haddock	-	✓	✓	-
		Longhorn sculpin	-	✓	✓	-
		Pollock	-	✓	✓	-
		Silver hake	-	✓	✓	-
	Groundfish distribution	Atlantic halibut	-	✓	✓	-
	Shellfish distribution	American lobster	-	✓	✓	-
		Snow crab	-	✓	✓	-

Table 5: *Groups of proposed conservation features*

Conservation Priorities Categories	***Sub-Categories***
Biogenic habitats	
Areas of high biodiversity	
Seabed	
Functional groups	*Fish, Birds, and Inverts*
Areas of High Biological Productivity	
Depleted Species	*Fish, Cetaceans, and Turtles*
Commercial Species	*Pelagic, Groundfish, and Shellfish*

Table 6 *Direct and indirect contribution of each priority to the representation or connectivity objective. (Red means a primary contribution)*

Conservation priorities Categories	All conservation features	Representation	Connectivity	Replication
Biogenic habitats	Sponge aggregations	✓	✓	-
	Coral aggregations	✓	✓	-
	Horse mussel reefs	✓	✓	-
Areas of high biodiversity	Fish species diversity (hot spots)	✓	✓	✓
	Invert species diversity (hot spots)	✓	✓	✓
	SSIP diversity larvae	✓	✓	-
	Stomachs diversity small fishes	✓	✓	✓
	Stomachs diversity small inverts	✓	✓	✓
Seabed	Seabed types	✓	✓	-
Functional groups	F.G Fish	✓	✓	✓
	F.G Inverts	✓	✓	✓
	F.G Seabirds	✓	✓	✓
Areas of High Biological Productivity	Areas of persistent high chlorophyll concentrations	✓	✓	✓
	Biomass	✓	✓	✓
Fish habitat distribution	Atlantic cod	✓	✓	✓
	Redfish (Unit 2)	✓	✓	-
	Winter skate (ESS)	✓	✓	✓
	American plaice	✓	✓	✓
	Cusk	✓	✓	✓
	White hake	✓	✓	✓
	Smooth skate	✓	✓	✓
	Atlantic wolfish	✓	✓	-
	Thorny skate	✓	✓	✓
	Redfish (Unit 3)	✓	✓	-
	Spiny dogfish	✓	✓	-
Cetaceans distribution	Cetaceans (hot spots)	✓	✓	✓
Turtles distribution	Leatherback turtle	✓	✓	✓
Pelagic commercial fish species distribution	Haddock	✓	✓	No layer
	Longhorn sculpin	✓	✓	No layer
	Pollock	✓	✓	No layer
	Silver hake	✓	✓	No layer
Groundfish commercial species distribution	Atlantic halibut	✓	✓	No layer
Shellfish commercial species distribution	American lobster	✓	✓	No layer
	Snow crab	✓	✓	No layer

Analysis of the SS conservation priorities revealed a lack of biodiversity features specifically aiming at improving the biological connectivity amongst potential reserves (**Table 6** Direct and indirect contribution of each priority to the representation or connectivity objective. (Red means a primary contribution)). Although all priorities can somehow contribute to the connectivity objective, only one of the conservation priorities explicitly represent a spatial indicator of connectivity. (**Table 6**) SSIP's[3] larval diversity, is directly linked to connectivity since it has been proved that areas with high larval diversity (genus richness was one of the indices used to measure larval diversity), are positively related to abundance (Shackell & Frank, 2000), which can also be an indicator of important spawning sites or retentions areas in the region. Nevertheless, the validity of using SSIP data in the SS network design can be questioned, since the data in which the maps are based were collected more than 30 years ago (DFO, 2007). On the other hand, it's important to mention that other features may be playing an indirect role in contributing to an enhanced connectivity of the MPA network. Biogenic habitats, such as sponge and coral aggregations, might be the most obvious example. The distribution of these habitats can be a limiting factor for populations of certain species (Breeze *et al.*, 2002), which in turn can be associated with the possibility of existing isolated populations. Therefore, it is important to protect such habitats as a measure to maintain local connectivity.

5.2 Target setting

Targets, derived from applying the criteria outlined in the methodology, ranged from 5 to 100% (Appendix C). Although 10% was thought to be the minimum target, when applying the method described in Ardon *et al.* (2010) for representative habitats (seabed) it was evident that setting a

---

[3] (SSIP) The Scotian Shelf Ichthyoplankton Program collected temporal and spatial information about fish eggs and larvae and associated environmental data across the Scotian Shelf (from 1978 to 1982). A related goal of the SSIP was to characterize the distribution, abundance, mortality, and growth rates of various ichythyoplankton species (Shackel and Frank, 2000)

10% target for the largest feature (The Scotian Rise, with an area that covers 17% of the bioregion) would imply very high targets for the rest of the seabed layers. Consequently, the adopted alternative was to set a 5% for the largest feature.

Figure 3 shows the distribution of the number of conservation priorities by target. It is clear that most priorities (100) were allocated a target ranging from 10 to 25 percent of their distributions. Only seven conservation priorities received targets below 10%. Ten percent of the conservation priorities received a target above 30% (green zone in **Figure 3**), which is what the scientific community (National and internationally) recommends for long term conservation purposes (Jessen *et al.*, 2011). Furthermore, just one priority was targeted at 100% (*Lophelia pertusa*), which is a very small critical habitat that already protects the only species in the genus *Lophelia*, a deep cold-water coral.

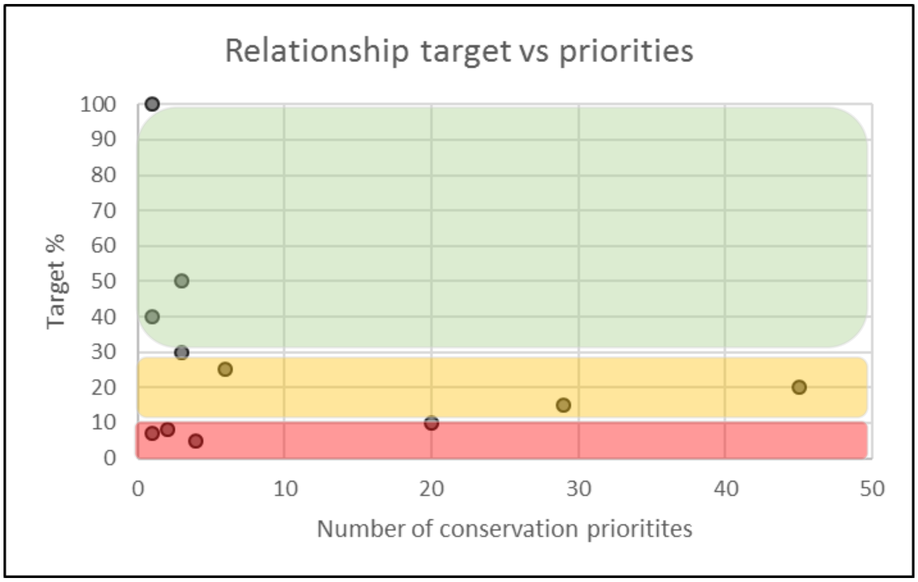


Figure 3 *Number of conservation priorities by the target assigned. Colors refer to three groups of targets (0-10%-poorly represented; 10-30%-represented; greater than 30%-well represented)*

5.3 Marxan Calibration

Marxan calibration consumed considerable time during the course of this investigation. However, this step is critical if robust results to support decision making are to be achieved.

More than 25 rounds of Marxan running were necessary to calibrate the parameters. The number of iterations was one of the first parameters tested. The number of iterations was set to 100,000,000 (10^8) after consecutively increasing it from 1 million (10^6). Although each execution took approximately 90min, 10^8 iterations produced more efficient solutions and clumping effect than when performed with 10^6 iterations. Higher numbers of Iterations (up to 10^9) were dismissed due to time limitation.

For all executions during the calibration process, the number of runs was set to 10. However, unlike previous Marxan analysis for the region where 10 was the determined number (Horsman *et al.*, 2011), this project tested other alternatives, comparing results of 10, 50 and 100 runs. When increasing the number of runs, Marxan produced less costly solutions in terms of area and boundary length (Table 7). Having 100 repetitions also allowed to boost the spectrum of efficient solutions. The best solution may not be the most effective in minimizing conflicts among interested parties. Consequently, having a wide range of efficient solutions may be a more useful and practical way of communicating results to stakeholders, as it creates a negotiation space. Additionally, a reduction of 1,000 km2 in the total area under protection is achieved in the solution with 100 runs, an amount which although might be seem negligible, can make a difference when dealing with spatial conflicts amongst stakeholders.

Table 7: Comparison of best solution outputs for scenarios with 10 and 100 runs.

Number of runs	***Cost***	***Boundary***	***Missing Values***	***Area km^2***	***% of Bioregion***
100	4860936	4513146.1	0	48,218.4	10.13
10	4969479	5368443.2	2	49,295.1	10.36

Figure 4 shows the spatial solution of both outputs previously discussed. As can be seen, 10 runs resulted in a more dispersed and fragmented network. With 100 runs, the number of polygons (blue) that make up the network was reduced from 30 to 20 polygons. While there is no scientific evidence over the minimum number of area required for a marine protected area to be effective, it has been claimed about the role of larger MPAs in meeting conservation goals and objectives (Green *et al*., 2010). A small number of relatively large areas forming a cohesive and adequate network of marine protected areas may perhaps be the most suitable scenario for the bioregion from a management perspective.

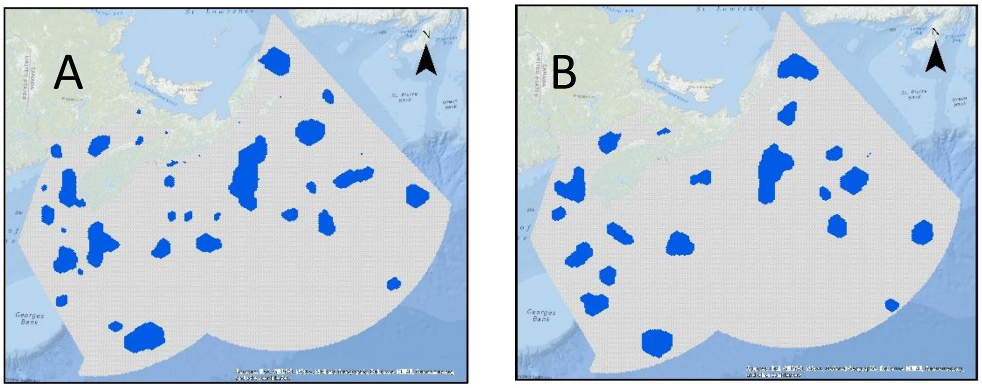


Figure 4: *Best solutions A) No. of runs set to 10. B) No. of runs set to 100.*

As mentioned earlier, the species penalty factor (SPF) controls the cost that is added to the objective function when conservation targets are not met. The SPF value was mostly set according to methods suggested in the literature (Ardron *et al.,* 2010). With a SPF value of 1, a number of 10 conservation features did not meet their targets. An SPF value of 4 was chosen as the most suitable number, since was the starting point from where the number of missing values (this refers to the number of conservation features that did not meet their targets) approached zero (**Figure 5**)

Figure 6 shows the boundary length modifier testing graph that was constructed to determine the desired level of spatial compactness for the solutions. Changes in the BLM affected the spatial configuration of the identified areas. When the BLM was increased the cost of the Marxan solution (which is directly proportional to total area) increased while the boundary length cost decreased. Therefore, an ideal BLM is one that trades off cost (in terms of area) and boundary length to achieve reasonably compact MPA networks. For this analysis BLM equal 1 was determined to be the desired number.

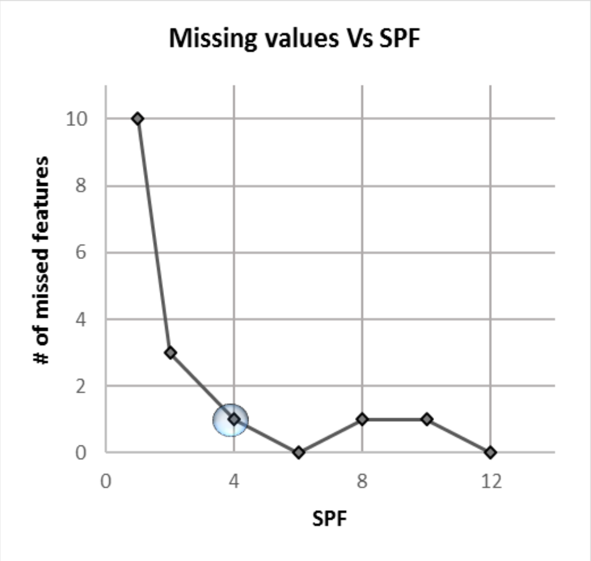


Figure 5 *SPF values, testing results*

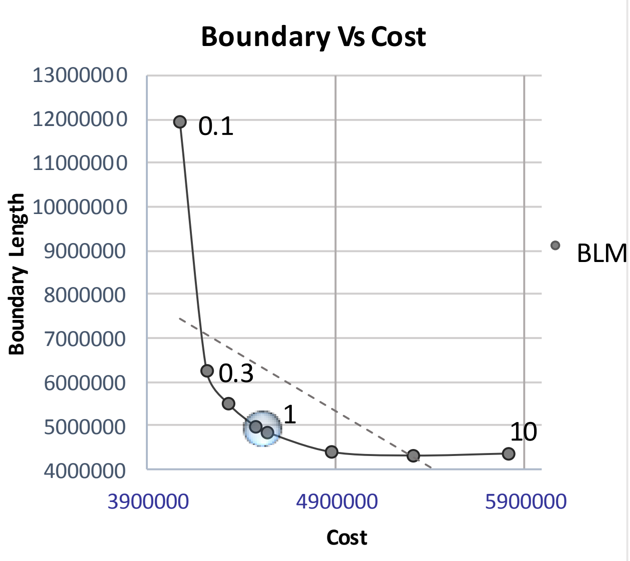


Figure 6 *Relationship between boundary and planning unit cost*

5.4 Conservation network design analysis: Scenario comparison

A quick inspection of the results indicates that there were no major differences between scenarios 1, 3, and 4 with respect to the first four variables analyzed (Efficiency, Comprehensiveness, Representativity and Compactness) (Table 8). Scenarios 3 and 4 obtained a good level of efficiency because they still meet the targets at the expense of a small increase in area. However, overall, efficiency decreases as it moves away from scenario 1. It is obvious the inefficiency of the current MPA network scenario, with less than 1% of the efficiency of the most suitable one (scenario 1). This is because the fact that the current MPA network is only composed by two reserves (The Gully and St. Anns Bank) that fail being ecologically representative and comprehensive of the SS biodiversity.

Furthermore, all network scenarios, except the number 2 (Current MPA system), met the targets, which mean there is no gap in terms of representativity or comprehensiveness for the priorities analyzed. However, although this was likely because Marxan is designed for this particular propose, the idea was to show how ineffective the current network of marine protected areas is in the Scotian Shelf. For instance, around 60% of the proposed conservation priorities are not covered whatsoever in the current network. Among them, seabed features and areas of high biodiversity have the most significant gaps, with almost 21 seabed features and 4 out 5 layers representing biodiversity hot spots without any level of representation in the network (Figure 7). Depleted fish species also have a low level of representation, with 10 fish species that are not protected by the current two MPAs.

The compactness of the different possible networks was primarily homogenous across scenarios. Nonetheless, this indicator decreased by 16% in scenario 5 (Socioeconomic costs incorporated). The most rational explanation is the highly increased boundary length of this scenario.

Table 8: Scenario comparison

	1	2	3	4	5
Scenarios ***Variable***	***Most suitable network scenario***	***Current MPA network scenario***	***MPA network scenario***	***Complemented comprehensive scenario***	***Scenario with Socioeconomic costs incorporated***
Efficiency	*100%*	*0.0002%*	*96.50%*	*94.00%*	*26%*
Comprehensiveness	*100%*	*41%*	*100%*	*100%*	*100%*
Representativity	*100%*	*1.70%*	*100%*	*100%*	*100%*
Compactness	*100%*	*100%*	*94.00%*	*93.00%*	*84%*
% of the Bioregion	*9.5*	*1.2*	*9.6*	*10.0*	*11.8*
MPA average size(km2)	*2430.8±1607.3*	*3374.4± 1006.15*	*1838.33 ± 1733*	*2435.02 ± 1972.1*	*1054.1 ± 1376.6*
Minimum patch area (km2)	*347*	*2368.246354*	*22.4*	*22.393*	*11.20*
Maximum patch area (Km2)	*7434*	*4380.548454*	*6270*	*6438.12*	*7345.06*
MPA spacing (km)	*77± 58.9*	*180*	*95.21 ± 105.039*	*106 ±60.74*	*43.75 ±31.14*
No. of reserves	*20*	*2*	*26*	*20*	*54*

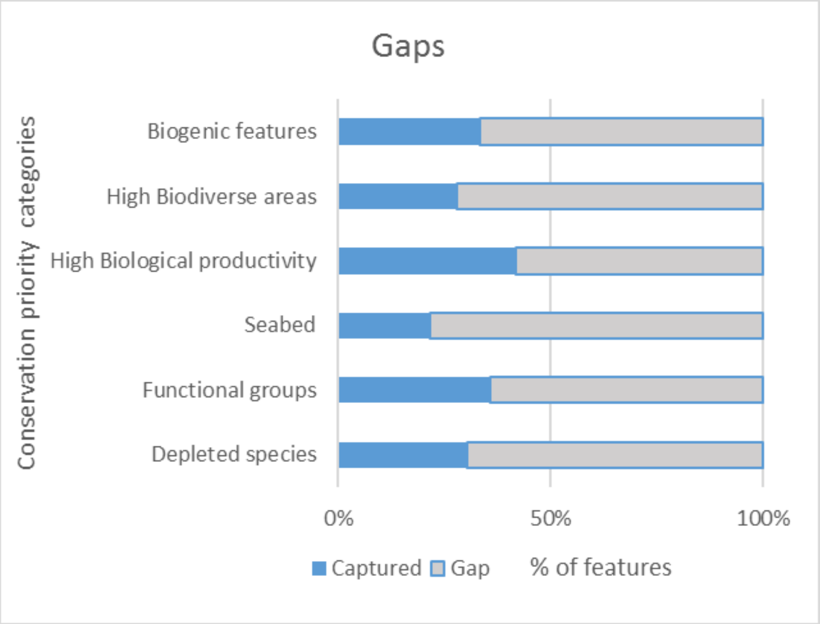


Figure 7: *Biodiversity features Gaps for the current MPA network*

All spatial outputs of the different scenarios are shown below (Figure 9-13).

Interestingly, the percentage of area occupied for each solution, ranged around 10% of the area of the bioregion. However, the difference in terms of area between scenario 5 (representing 11.8 % of the bioregion) and 1 (9.5 %) was approximately 7,688.6 km^2, which is more than the area occupied by the two offshore MPAs that form the current network. This provides an idea of how big the SSB is and that every single planning unit counts as important.

The average size of patches varied between scenarios (Table 8). For instance, scenario 5 yielded a network with an average size of up to 1,054 km^2, the smallest number of all scenarios. (See **Figure 13**). Conversely, scenarios 1 and 4 comprised similar average patch size, 2,430 and 2,435 km^2 respectively. Yet, despite this similarity, scenario 4 had more variability in the size of MPAs (see standard deviation), patches varied from a minimum of 22 km^2 to a maximum of 6,438 km^2. Scenario 2 had the highest average size, and largest space between patches. However, because this scenario is made up of only two patches, the analysis of the design criteria does not make much sense in this particular case.

MPA spacing also showed interesting results. Scenario 1 achieved a moderate average distance (77 km) compared to the rest of scenarios (Scenario 5, an average of 43 km; Scenario 4, an average of 106 km) (Table 8).

In terms of the total number of potential reserves, all scenarios with the exception of the current system (1, 3, and 4), contained a number of patches that ranged from 20 (scenarios 1 and 4) to 25 (scenario 3). Not surprisingly, a total of 54 patches are included in the network of scenario 5, which visually shows a scattered patterned (**Figure 13**).

As discussed earlier (Chapter 2), these last variables (spacing, size and number of patches) are interrelated. Results revealed an inverse correlation (r = -0.975) between the number of patches and size of reserves (**Figure 8** A). Likewise, an inverse correlation was observed between the patch spacing and No. of patches (r = -0.89). On the other hand, space and size correlated in a positive way (r = 0.9) (**Figure 8** B)

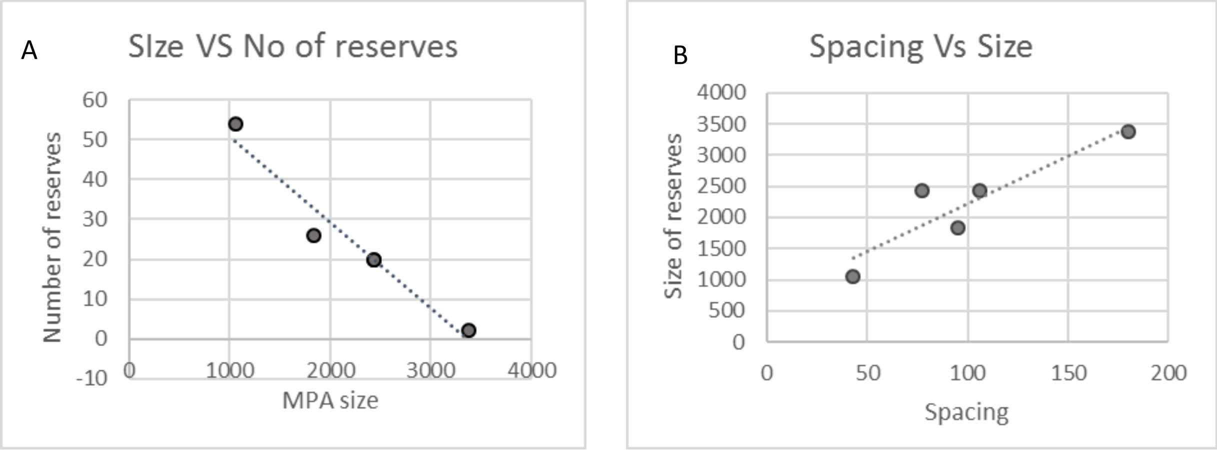


Figure 8 *A) Relationship between Size and No. of patches B) Relationship between MPA spacing and size*

Although all variables explained in the table are reflected in the maps, other results can be unfolded by simply inspecting the spatial outputs of the scenarios. For instance, the spatial pattern is kept for the scenarios 1, 3, and 4 even despite scenarios 3 and 4 were built considering different areas as starting point (Current MPAs in scenario 3, and current MPAs plus other conservation areas in scenario 4). This provides clues about the importance in meeting conservation targets and being efficient of those areas repeated among scenarios. Overall, the observed pattern is consistent with previous Marxan analysis in the SSB (See Horsman *et al.*, 2013) (Appendix D) even when less data and fixed targets were set for that exercise. The spatial pattern of reserves obtained also favors connectivity, since currents in the region are usually southwestern.

Surprisingly, the area of St. Anns Bank, did not come out of the solution neither of the most suitable network scenario (**Figure 9**) nor in the solution when running Marxan with socioeconomic data (**Figure 13**). This is a clear indication of the low contribution that this area is making to protecting various conservation priorities and to meeting multiple targets.

Finally, solutions of each scenario showed a gap in the central and southern portion of the Scotian Shelf, off continental slope which confirms the lack of biophysical data about these zones of the SSB.

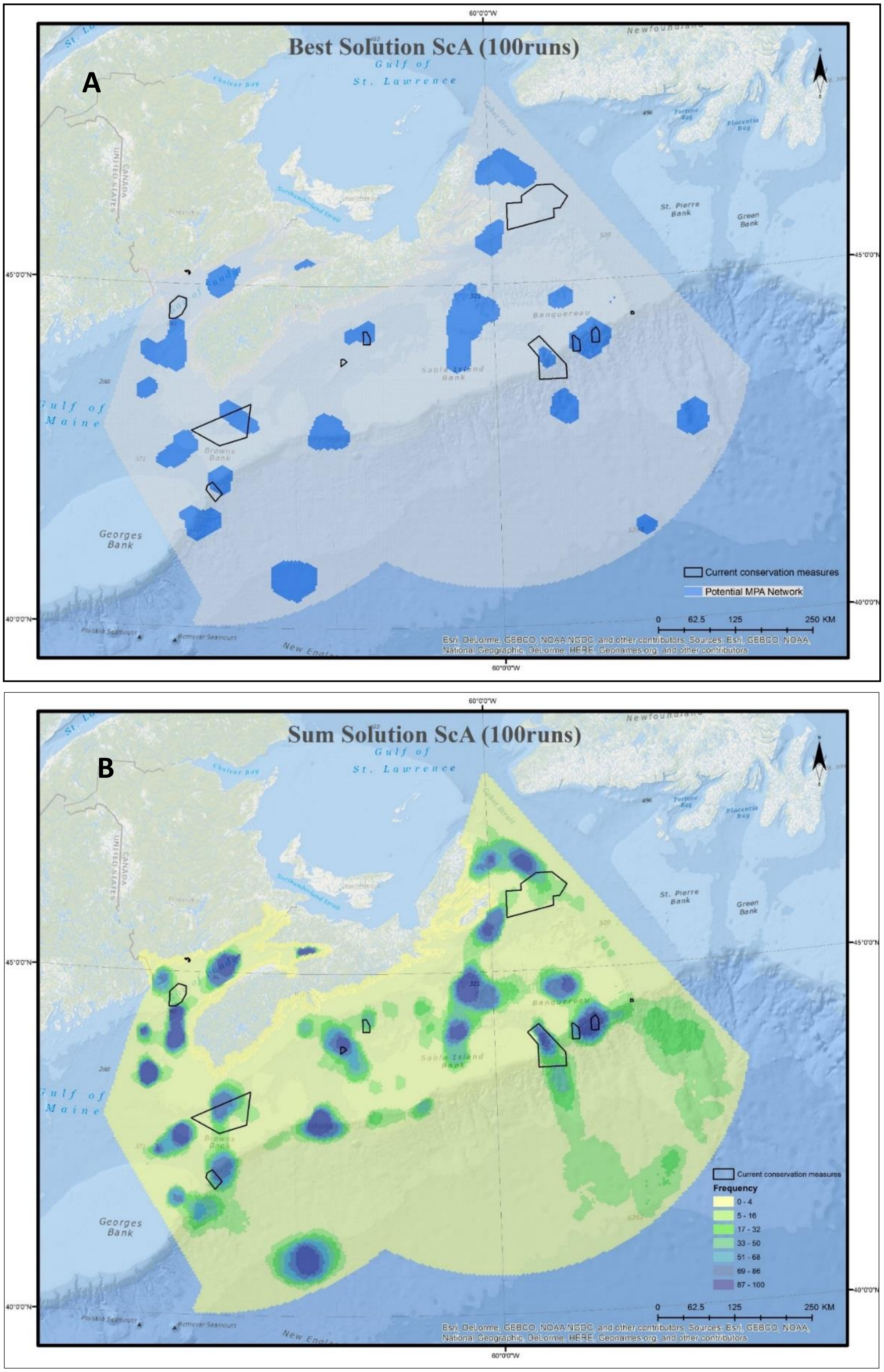


Figure 9: *Most suitable network scenario. A) Best solution. B) Sum solution*

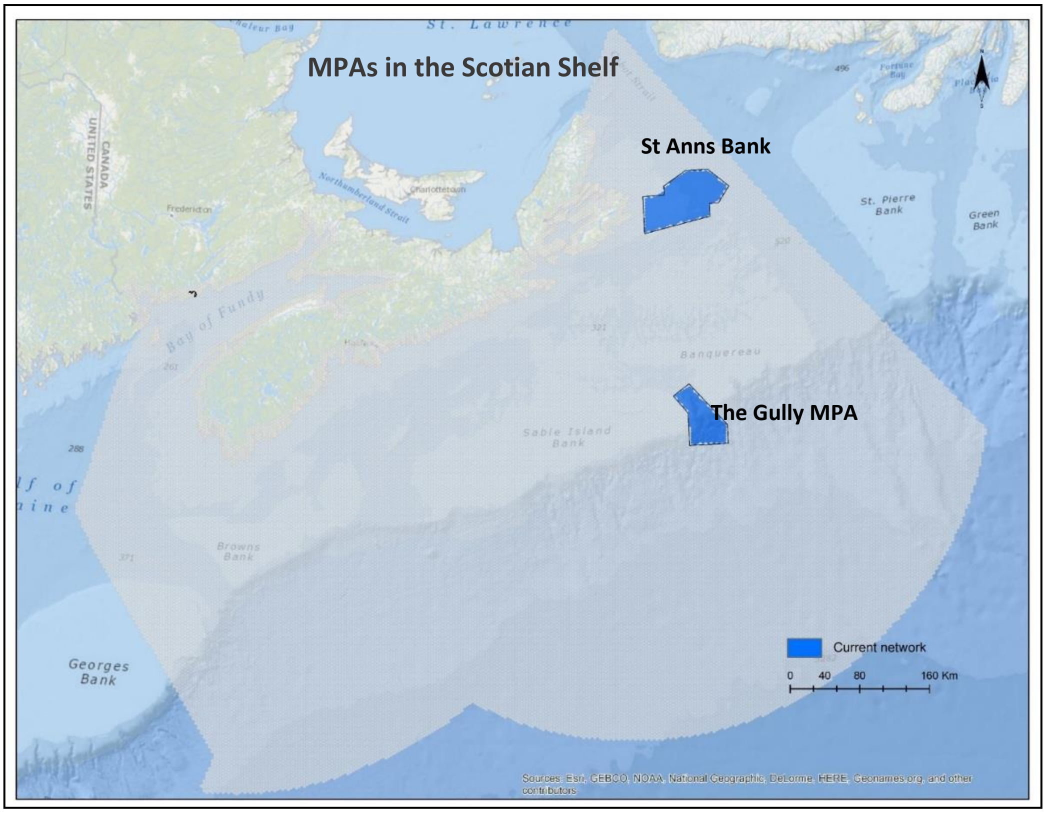


Figure 10: *Current MPA network*

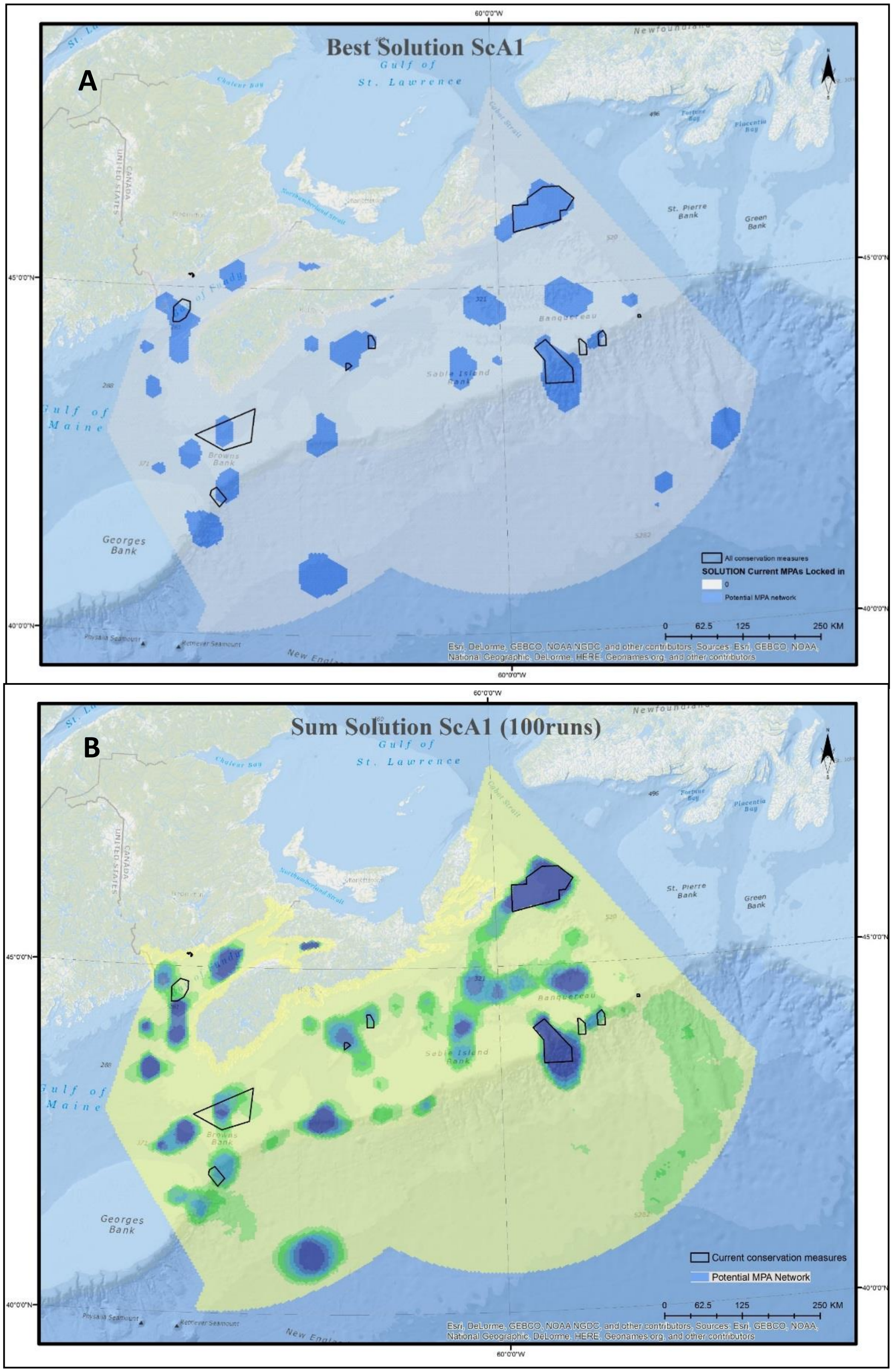


***Figure 11**. MPA network scenario. A) Best solution. B) Sum Solution*

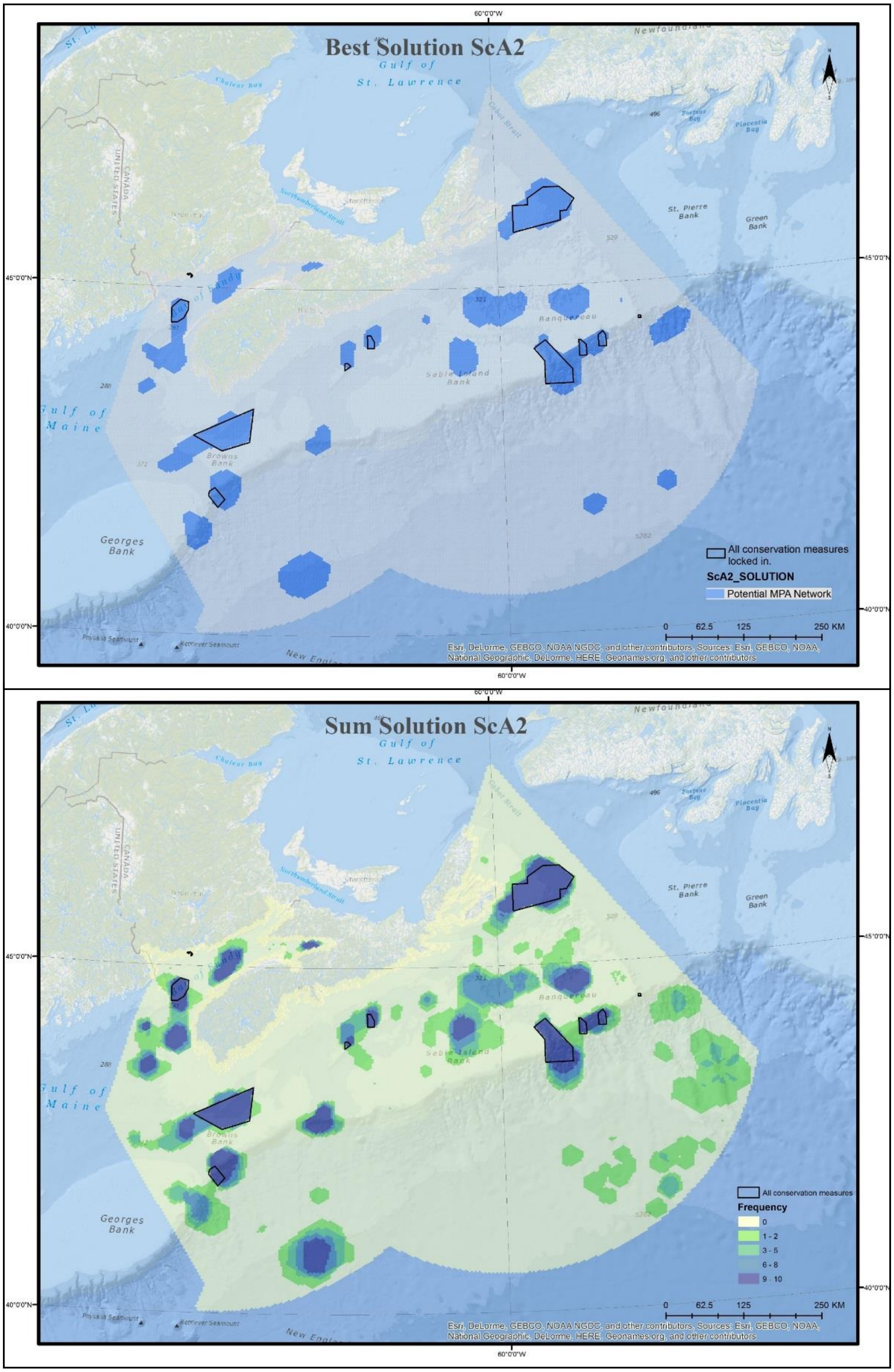


__Figure 12.__ Complemented comprehensive scenario. A) Best solution B) Sum solution

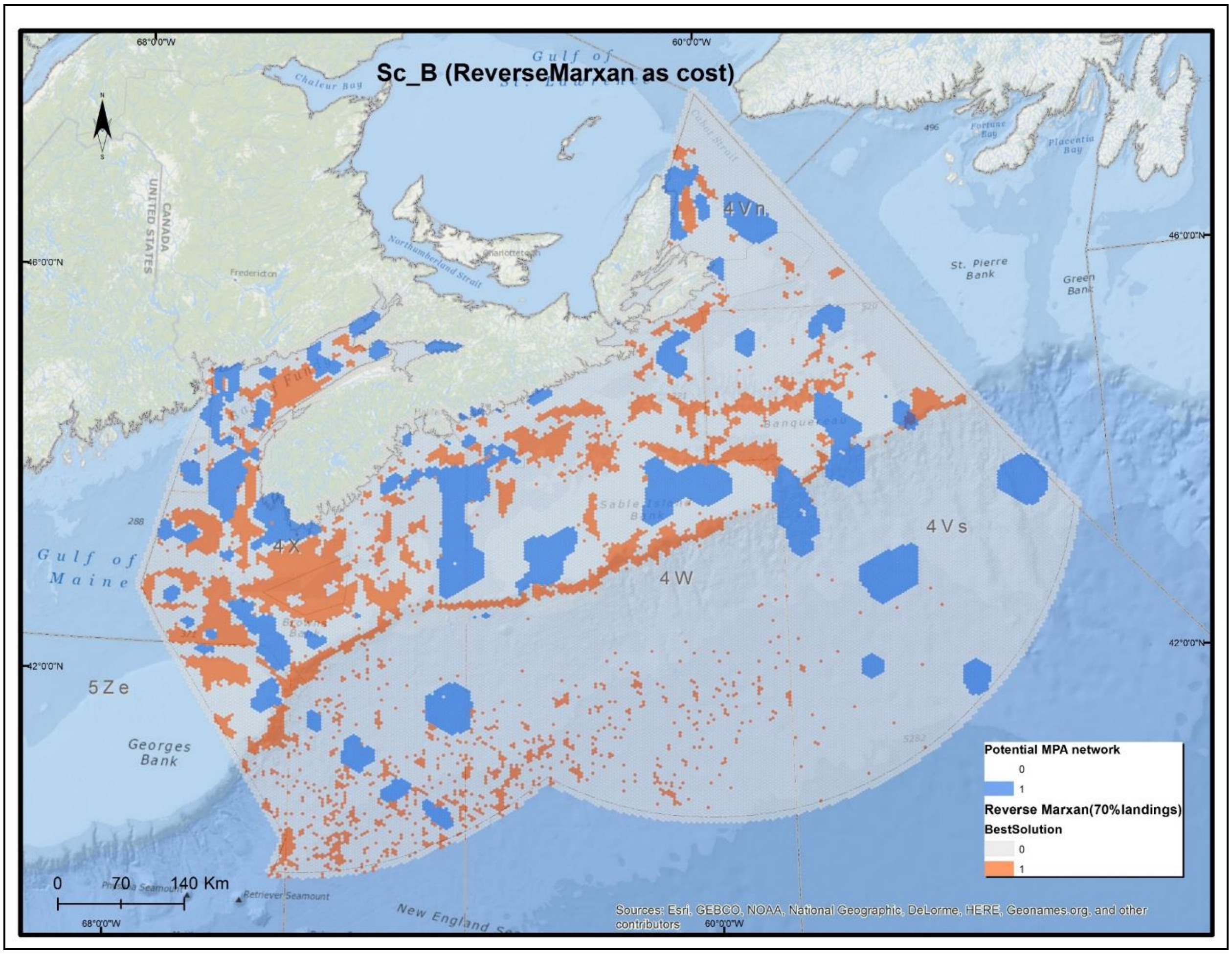


***Figure 13**. Scenario with socioeconomic cost incorporated*

6. Discussion

6.1 Design of the Marine Protected Area Network of the Scotian Shelf

As previously discussed in Chapter 2, defining clear and coherent conservation objectives is fundamental if a successful network of marine protected areas is desired. It requires a hierarchical process, from general to more specific objectives, and plays a central role in applying science to policy and translating policy into action (Tear *et al.*, 2005).

DFO Maritimes have not stated any goal for the Scotian Shelf network of MPAs, and is not planning to do so. The national guidelines for the formulation of conservation objectives (DFO, 2012) explicitly states that each bioregion should adopt Canada's national goals as their bioregional goals. It may be questionable whether such statement is appropriate or not. Canada, the second largest country in the world, has the longest coastline of all countries and has access to three oceans, the Atlantic, Artic, and Pacific Ocean. Therefore, the ecology, physical environment and socioeconomic characteristics vary throughout each oceanic region. Each bioregion should develop their own MPA network goals in consistency with the national overarching goals. The development of bioregional goals is the guarantee of an adequate and effective planning at the regional level. There are a significant number of examples in conservation planning worldwide where goals have been defined at the regional level (for instance in California). However, it is not clear yet how the SSB will contribute to meet the last of the three outlined goals. Perhaps, the development of a strategic conservation objective that aims at improved recreational and educational opportunities from the MPA network could outweigh such gap.

Furthermore, the development of more specific objectives is required for a better transition to conservation priorities/features. For example, from the strategic objective 3 and 4, the following sub-objectives could be unfolded:

Objective 3. Help maintain ecosystem structure, functioning and resilience within the bioregion:

- **3.1** Protect natural size, age structure and genetic diversity of populations in representative habitats
- **3.2** Protect areas of high species diversity and maintain species diversity and abundance of populations
- **3.3** Protect areas of high biological productivity in representative habitats

Objective 4. Contribute to the recovery and conservation of depleted species:

- **4.1** Help protect/rebuild populations of threatened, endangered, or depleted, where identified, and the habitats and ecosystem functions upon which they rely.
- **4.2** Protect larval sources and restore reproductive capacity of species that are most likely to benefit from MPAs through retention of large, mature individuals.

Having a more detailed list of conservation objectives would allow to broadening the possibilities, and eventually identifying information gaps. For instance, a map of areas with the location of source populations of larval export could represent a key conservation feature to fulfill the last sub-objective. Although such maps may not be available at the moment for the study region, knowing this sort of information needs will point out the road towards the filling of strategic information gaps and would eventually encourage future work towards filling them.

However, it is important to note that the concept of connectivity explained throughout this paper has been mainly limited to biological connectivity. At the land/seascape level, connectivity has also a lot to do with the transport of matter other than species in any stage of life cycle. The exchange of individuals is paramount in marine connectivity, but so it is the transport of sediments and nutrients other than plankton. If rivers and currents do not transport sediments, then blooming of plankton and formation/maintenance of ecosystems depending on sediments would never occur. Moreover, connectivity also has to do with energy exchanges through the food web.

Consequently, if connectivity is considered at its widest sense, other selected biodiversity features could be making the case for it. For instance, areas with persistent chlorophyll concentrations represent a priority with a great significance from a connectivity standpoint. Normally, such areas correlate with high primary or secondary productivity, which provides key ecosystem services that support critical life stages of species of higher trophic levels, particularly cetaceans (Smith *et al.*, 1986). Furthermore, incorporation of some spatial patterns of ocean circulation into the design should also be prioritized. Particularly, the protection of gyres, since it has been argued that these oceanographic patterns are associated with a physical retention process that can lead to increased larval fish diversity (Shackell & Frank, 2000).

Nonetheless, having these types of areas under protection goes beyond the merely protection of the marine life that is associated to them, they will ultimately have an impact in the maintenance of the natural process and ecosystem function that not only occur at local scales but at regional and even global scales.

Therefore, although the proposed conservation features do not fully reflect the intention of designing a connected network, they do comprise an important set of features that contributes to the achievement of ecological integrity.

Whilst the existing spatial, seasonal, temporal, and taxonomic data gaps in the region have been acknowledged (King *et al.*, 2013), the SSB may be generally considered data-rich if compared to other maritime regions. Therefore, the list of proposed priorities reflects the potential of DFO to create a comprehensive and representative network of marine protected areas for the Scotian Shelf.

However, efforts must still be in place to improve significant data gaps in poorly surveyed areas of the SSB, specifically the slope and abyssal areas where invertebrates and cetaceans have been poorly sampled as opposed to demersal fishes (King *et al.*, 2013).

A limitation worth mentioning is the stationary character of the fish distribution data, while many marine species that inhabit the Scotian Shelf migrate during the winter. This is expressed in the seasonality of the information gathered in some maps. For instance, from the list of proposed conservation priorities; the fish habitat maps available represent only the summer distribution of fish.

Another shortcoming of the network design is that, although a number of 26 features (mainly functional groups and depleted species) were replicated within the bioregion (using the NAFO regions), there are no depth variations, consequently failing in representing and replicating different depth zones.

6.2 Implications of target setting

The method used to determine targets in this exercise, though more factual founded than policy driven, is still rather weak. For instance, priorities with the same conservation status (endangered) received the same target even when other conservation measures are already in place for them. Factors such as the management effectiveness and existing conservation policies should be considered as well, although this could result in lower targets (if the current conservation measures are regarded as effective). So, a more comprehensive and systematic methodology should be developed to set targets for the conservation priorities in the SS.

Fisheries and Oceans Canada as well as other organizations have provided each bioregion with guidelines for the development of MPA networks. However, such guidelines are general in nature and do not address in detail some specific steps that are essential for guaranteeing long-term conservation objectives and goals. For instance, despite the argued importance of quantitative conservation targets and its impact in achieving conservation objectives (Vimal *et al*., 2011), DFO Canada has not provided any guidelines with the rationale to be followed for implementing this critical phase. Therefore, though common principles guide MPA network development across Canada, it is a regional responsibility to undertake specific methods and make sure all steps of this process (such as the setting of conservation targets) are carried out in the best way possible. DFO should explore methods in order to determining meaningful targets.

Furthermore, even though there are various methods for determining targets, the application of such methods requires a high level of knowledge of the species or any conservation feature in question. Thus, methods such as population viability analysis may be only applicable to those priorities with considerable amount of knowledge and data about their life history.

Setting targets in the SS is not an easy task because the setting of conservation objectives must compete with other goals and objectives that have a more powerful influence on public policy (e.g., economic growth). However, as a precautionary principle, targets for most of the species should be close to the 30%. It is important to understand that because it is impossible to spatially express the whole range of biodiversity, conservation priorities are expressed most of the time in terms of biodiversity surrogates. These usually include some of the better-known taxonomic groups, focal species, umbrella species, species assemblages, and various ecological classifications. Therefore it is even more urgent the need to set higher targets.

How conservation features are selected, and their targets set, will depend on the type, scale, quality and quantity of the available ecological datasets. In practice the availability of good quality spatial data will often limit what conservation features can be taken into account in the analysis.

6.3 Analysis of potential MPA network scenarios

Implementing entirely scenario 1 is unlikely. The SS has already in place two marine reserves. Therefore the most logical scenario would be No. 3 which attempts to build an efficient network from the existing MPAs. However, an assessment of the potential socio-economic impact derived from the new reserves should be carried out, because the SS is an intensely used maritime area (in terms of human activities). Also, it is essential to understand the relative importance of each of the patches that composes a network scenario, more specifically, each scenario should be asked: what are the biodiversity features that make such reserves to come out in the solution? If this is known, decision making may be directed to trying to implement those critical areas as MPAs.

Scenario 2 should never be an option; on the contrary, it must act as a trigger to rapidly move forward the establishment of a comprehensive and representative network of marine protected areas in the region.

Although it may be certain that incorporating other existing conservation measures on the network is ideal, it should be noted that most of these areas were not determined through a systematic approach, and having them as locked in areas in Marxan, can result in networks that are overrepresented.

Scenario 5, is perhaps the scenario most likely to be implemented in a context of multiple interests. The SSB has all the ingredients to meet the former criterion. Therefore, in theory, this could be a scenario that might accomplish a high level of social acceptability amongst potentially impacted parties. However, two main issues could be argued against the latter assertion. Firstly, scenario 5 only comprises commercial fishing as cost factor and therefore it is likely to fail in minimizing the potential impacts of the reserve network on other industries. As described in Chapter 3, there are other activities that are important for the regional economy and that also make use of the maritime space. Secondly, the spatial configuration of scenario 5 characterized by a large number of small reserves makes it the least feasible of all scenarios (See Figure 14), as dealing with 54 reserves would be very costly and challenging from the management point of view. Consequently, this seems to be an unfeasible network scenario. Nevertheless, it can always be useful for identifying less costly areas that, at the same time, are biodiversity-rich. This scenario should be assed in detail in order to identify potential and viable candidate's areas.

Conversely, results of network configuration in scenario 5 favor network biological connectivity. As discussed (Chapter 2), reserves in networks designed for improving connectivity are usually small in size, and close to each other. Scenario 5 showed the smallest average size and spacing of and between reserves. Interestingly, unlike other studies where size and space is determined by specific information about larval dispersal, in this case the result came from finding a way to minimizing costs. Halpern & Warner (2003) proposed that size of MPAs should encompass an area that ranges from 10 to 100 km2. Similarly, Roberts et al., (2010) recommended a space ranging 40 to 80 km, in order to assure sufficient ecological connectivity. Scenario 5 comprises a considerable number of patches under 100 km2, and has an average patch spacing of 43.75 km. Conversely, spatial configuration in scenario 1 is closer to the typical representative network with large and widely space reserves. However, asserting that connectivity is achieved in scenario 5 based on morphometric indicators (such as reserve size, number and separation) is not a guarantee that actual connectivity is achieved and that it is effective from the ecological point of view in order to sustain viable populations of target species or to maintaining ecological processes.

Furthermore, it is important to bear in mind that most of the studies in which a minimum size and space has been determined, have been focused on tropical marine systems, in particular reef fishes (Bode *et al*., 2006; Botsford *et al*., 2009). Little is known about larval dispersal of temperate species. Therefore, it may be questionable the application of such findings in temperate waters.

7. Conclusion

Establishing a conservation network in the Scotian Shelf Bioregion is an arduous task. Numerous challenges define the context in which MPA network development takes place. The most difficult of these challenges is the complex diversity of stakeholders that are affected, which puts the Scotian Shelf Bioregion in an unfavourable position from a conservation perspective. However, DFO has the potential to design a comprehensive and representative MPA network and contribute towards ecological integrity of the Scotian Shelf. Yet, trade-off assessments are required if informed decisions are to be made. As explored in this paper, systematic conservation planning can provide a framework and the necessary tools in order to support informed decision making.

Although guidelines for MPA network planning are provided, they are general in nature and do not address in detail some essential steps. For instance, more specific objectives must be developed, as they are required for a better and more precise identification of conservation priorities and for eventually identifying information gaps. On this regard efforts must still be in place to fill some significant data gaps in poorly surveyed areas of the SSB, specifically the slope and abyssal areas, as well as to overcome the current stationary character of the fish distribution data, which represent only the summer distributions. Additionally, a more comprehensive and systematic methodology should be developed to set targets for the conservation priorities and methods should be explored for determining meaningful targets. In any case, as a precautionary principle, targets for most of the priorities should be set close to the 30% of its current distribution.

From the scenario comparison, one thing is clear: keeping the status quo in marine conservation for the Scotian Shelf is no longer an option. The four variables assessed

(Efficiency, Representativity, Comprehensives and Compactness) confirmed that the current system of MPAs in the SS is very ineffective.

Having different scenarios can be critical to facilitate negotiation and evaluating potential trade-offs during the process to designate new MPAs. Also, DFO should use the indicators presented in this paper, since it can easily communicate how successful or unsuccessful the implementation of a network can be.

There is not a unique answer about which of the discussed scenarios is most appropriate to be implemented. Decision support tools such as Marxan provide a range of solutions but it does not make the decision of which network should be put in place. However, these results can aid the decision making process, which are based upon agreement between stakeholders.

An important conclusion derived from this project is that while incorporating socio-economic costs (in our case commercial fishing) can reduce potential conflicts amongst resource users, it can also undermine some of the properties of MPA network design, i.e. spatial configuration, as in order to reduce overall portfolio cost Marxan will prefer to select planning units of lowest cost, many times resulting in a more spread spatial pattern of reserves, which on the other hand could increase the risk of new conflicts with other marine activities not taken into account in the definition of costs.

Finally, although the inclusion of design criteria for spatial configuration is gaining interest, connectivity in particular requires understanding of spatial patterns of larval dispersal, which is are still poorly known. This paper argued that connectivity has often been few times used as input factor for reserve network design in most of the works reviewed. Although connectivity is important, when there is poor info about larval dispersal distances, reserve size and separation will ultimately depend on the types of conservation features that will be protected in a specific area.

Bibliography

Adams, Vanessa M., Pressey, Robert L., & Naidoo, Robin. (2010). Opportunity costs: Who really pays for conservation? *Biological Conservation, 143*(2), 439-448.

Adams, Vanessa M., Mills, Morena, Jupiter, Stacy D., & Pressey, Robert L. (2011). Improving social acceptability of marine protected area networks: A method for estimating opportunity costs to multiple gear types in both fished and currently unfished areas. *Biological Conservation, 144*(1), 350-361.

Agardy, T. (1999). Creating havens for marine life. *Issues in Science and Technology*, 16(1), 37.

Almany, G., Connolly, R., Heath, S., Hogan, D., Jones, J., McCook, P., . . . Williamson, H. (2009). Connectivity, biodiversity conservation and the design of marine reserve networks for coral reefs. *Coral Reefs, 28*(2), 339-351.

Alonso, D., Castillo, P., Segura, C., Gerhartz, J.L.. (2010). Diseño de una red de áreas marinas protegidas: estrategia de conservación para el norte del Caribe continental colombiano. *Bol. Invest. Mar. Cost.* 37 (1). Santa Marta, Colombia, 2008.

Ardron, J.A., Possingham, H.P., and Klein, C.J. (eds). (2010). *Marxan Good Practices Handbook, Version 2*. Pacific Marine Analysis and Research Association, Victoria, BC. Canada. 165 pages. Available at: www.pacmara.org

Archambault, Snelgrove, Fisher, Gagnon, Garbary, Harvey, . . . Romanuk, Tamara Natasha. (2010). From Sea to Sea: Canada's Three Oceans of Biodiversity (Marine Biodiversity in Canada). *PLoS ONE, 5*(8), E12182.

Aridas, Z. Estudio de Análisis de Omisiones y Vacíos de Representatividad en los Esfuerzos de Conservación de la Biodiversidad en Chile [GAP-Chile 2009].

Ball, I. R., & Possingham, H. P. (2000). *MARXAN (V1. 8.2). Marine Reserve Design Using Spatially Explicit Annealing, a Manual*.

Balmford, A. (2003). Conservation planning in the real world: South Africa shows the way. *Trends in Ecology & Evolution*, *18*(9), 435-438.

Ban, N., & Klein, C. (2009). Spatial socioeconomic data as a cost in systematic marine conservation planning. *Conservation Letters, 2*(5), 206-215.

Bode, M., Bode, L., & Armsworth, P. R. (2006). Larval dispersal reveals regional sources and sinks in the Great Barrier Reef. *Marine Ecology Progress Series*, *308*, 17-25.

Botsford, L., White, W., Coffroth, J., Paris, M., Planes, A., Shearer, C., . . . Jones, S. (2009). Connectivity and resilience of coral reef metapopulations in marine protected areas: Matching empirical efforts to predictive needs. *Coral Reefs, 28*(2), 327-337.

Breen, D. (2007). *Systematic conservation assessments for marine protected areas in New South Wales, Australia.* PhD thesis, James Cook University.

Breeze, H., & Horsman, T. (2005). *The Scotian Shelf: An atlas of human activities* /c[co-editors], Heather Breeze and Tracy Horsman. Dartmouth: Fisheries and Oceans Canada

Breeze, H., Fenton, D. G., Rutherford, R. J., & Silva, M. A. (2002). T*he Scotian Shelf: An ecological overview for ocean planning*. Can. Tech. Rep. Fish. Aquat. Sci./Rapp. Tech. Can. Sci. Halieut. Aquat., (2393), 269.

Breeze, H., MacLean, M., Walmsley, J. J. (Eds). (2013). *The state of the Scotian Shelf report*. *(Canadian technical report of fisheries and aquatic sciences; no. 3074)*. Report. Can. Tech. Rep. Fish. Aquat. Sci. 3074: xvi + 352 p.

Brown, K. (2002). Innovations for conservation and development. *The geographical journal*, 168(1), 6-17.

CBD. 2011. *Aichi Target 11. Decision X/2*. Convention on Biological Diversity.

Chan, K. M., Shaw, M. R., Cameron, D. R., Underwood, E. C., & Daily, G. C. (2006). Conservation planning for ecosystem services. *PLoS Biol*, *4*(11), e379.

Chape, S., Spalding, M., & Jenkins, M. (2008). *The world's protected areas: status, values and prospects in the 21st century*. Univ de Castilla La Mancha.

Charles, A. T. (1997). Fisheries management in Atlantic Canada. *Ocean & Coastal Management*, 35(2), 101-119.

Cimon-Morin, J., Darveau, M., & Poulin, M. (2013). Fostering synergies between ecosystem services and biodiversity in conservation planning: A review. *Biological Conservation*, 166, 144-154.

Claudet, Osenberg, Benedetti-Cecchi, Domenici, García-Charton, Pérez-Ruzafa, . . . Planes. (2008). Marine reserves: Size and age do matter. *Ecology Letters, 11*(5), 481-489.

Claudet, J. (2011). *Marine protected areas : A multidisciplinary approach* (Ecology, biodiversity and conservation). Cambridge ; New York: Cambridge University Press.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). (2002). *Canadian species at risk*. Online database. Last update 2015-01-08. Available at: http://www.cosewic.gc.ca/eng/sct1/searchresult_e.cfm.

Craig, R.K. 2012. Ocean Governance for the 21st century: Making marine zoning climate change adaptable. Harv. *Environ. Law Rev*. 36(2): 305–350.\

Crosetto, M., & Tarantola, S. (2001). Uncertainty and sensitivity analysis: tools for GIS-based model implementation. *International Journal of Geographical Information Science*, 15(5), 415-437.

Delavenne, J., Metcalfe, K., Smith, R., Vaz, S., Martin, C., Dupuis, L., . . . Carpentier, A. (2012). Systematic conservation planning in the eastern English Channel: Comparing the Marxan and Zonation decision-support tools. *ICES Journal of Marine Science*, 69(1), 75-83

DFO (Fisheries and Oceans Canada). 2014. Statistical Services, retrieved from:http://www.dfo-mpo.gc.ca/stats/commercial/land-debarq/sea-maritimes/s2012av-eng.htm (accessed 22 October 2015)

DFO. (2005). *Canada's Oceans Action Plan*. Communications Branch. DFO/ 2005-348.

DFO. (2012). Marine Protected Area Network Planning in the Scotian Shelf Bioregion: Objectives, Data, and Methods. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2012/064: 19 p.

DFO. (2013). Guidance on the formulation of Conservation Objectives and Identificatin of Indicators, Monitoring Protocols and Strategies for Bioregional Marine Protected Area Networks. DFO Can. Sci. Advis. Rep. 2012/081.

Doubleday, W. G., & Rivard, D. (1981). *Bottom trawl surveys: proceedings of a workshop held at Ottawa*, *November 12-14, 1980* (Vol. 58). Dept. of Fisheries and Oceans= Ministère des pêches et des océans.

Douvere, F. (2008). The importance of marine spatial planning in advancing ecosystem-based sea use management. *Marine policy*, 32(5), 762-771.

Dudley, N. (2008). *Guidelines for applying protected area management categories*. IUCN.

Dudley, N., & Stolton, S. (2008). Defining protected areas: an international conference in Almeria, Spain. *IUCN, Gland*.

Dudley, N., Parrish, J., Redford, K., & Stolton, S. (2010). T*he revised IUCN protected area management categories: The debate and ways forward*. Oryx, 44(4), 485-490.

Ehler, C., & Douvere, F. (2009). *Marine spatial planning, a step-by-step approach towards ecosystem-based management*. Intergovernmental Oceanographic Commission and Man and the Biosphere Programme. IOC Manual and Guides No. 53, ICAM Dossier No. 6. UNESCO.

Ervin, J., N. Sekhran, A. Dinu. S. Gidda, M. Vergeichik and J. Mee. (2010). Protected Areas for the 21st Century: Lessons from UNDP/GEF's Portfolio. New York: United Nations Development Programme and Montreal: Convention on Biological Diversity.

Evans, C., Gibbons, N., Shah, K., & Griffin, D. (2004). Virtual learning in the biological sciences: Pitfalls of simply ‘‘putting notes on the web’’. *Computers & Education*, 43, 49–61

Foley, Melissa M., Halpern, Benjamin S., Micheli, Fiorenza, Armsby, Matthew H., Caldwell, Margaret R., Crain, Caitlin M., . . . Steneck, Robert S. (2010). Guiding ecological principles for marine spatial planning. *Marine Policy, 34*(5), 955-966.

Gaines, Steven D., White, Crow, Carr, Mark H., & Palumbi, Stephen R. (2010). Designing marine reserve networks for both conservation and fisheries management. *Proceedings of the National Academy of Sciences of the United States of America, 107*(43), 18286-18293.

Game, E. T., & Grantham, H. S. (2008). *Marxan user manual: for Marxan version 1.8. 10*. Queensland, Australia: University of Queensland, St. Lucia.

Gardner Pinfold. (2014). *Economic Value of the Ocean Sector in Nova Scotia: 2007-2011*. Prepared for Nova Scotia Department of Economic and Rural Development and Tourism. 31pp.

Gaston, A. J., Bertram, D. F., Boyne, A. W., Chardine, J. W., Davoren, G., Diamond, A. W., ... & Robertson, G. J. (2009). Changes in Canadian seabird populations and ecology since 1970 in relation to changes in oceanography and food webs. *Environmental Reviews,* 17(NA), 267-286.

Gerber, L.R., J. Wielgus, and E. Sala. (2007). A Decision Framework for the Adaptive Management of an Exploited Species with Implications for Marine Reserves. Conservation Biology 21(6): 1594-1602.

Green, A., Smith, S., Lipsett-Moore, G., Groves, C., Peterson, N., Sheppard, S., . . . Bualia, L. (2009). Designing a resilient network of marine protected areas for Kimbe Bay, Papua New Guinea. *Oryx, 43*(4), 488-498.

Green, A., Fernandes, L., Almany, G., Abesamis, R., McLeod, E., Aliño, P., . . . Pressey, R. (2014). Designing Marine Reserves for Fisheries Management, Biodiversity Conservation, and Climate Change Adaptation. *Coastal Management, 42*(2), 143-159.

Government of Canada. (2011). *National Framework* for Canada‟s Network of Marine Protected Areas. Fisheries and Oceans Canada, Ottawa, On. 31 p.

Gromack, A., and Allard, K. (2013). Considerations for Marine Protected Area network planning on the Atlantic Coast of Nova Scotia with a focus on the identification of Ecologically and Biologically Significant Areas. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/066. v + 32 p.

Grorud-Colvert, K., Claudet, J., Carr, M., Caselle, J., Day, J., Friedlander, A., ... & Malone, D. (2011). 11 r NETWORKS–The assessment of marine reserve networks: guidelines for ecological evaluation. *Marine protected areas: a multidisciplinary approach*, 293.

Groves, C. (2003). *Drafting a conservation blueprint: a practitioner's guide to planning for biodiversity*. Island Press.

Halpern, B. S., & Warner, R. R. (2003). Review paper. Matching marine reserve design to reserve objectives. *Proceedings of the Royal Society of London B: Biological Sciences*, *270*(1527), 1871-1878.

Harris, Linda, Nel, Ronel, Holness, Stephen, Sink, Kerry, & Schoeman, David. (2014). Setting conservation targets for sandy beach ecosystems. *Estuarine, Coastal and Shelf Science, 150*, 45-57.

Horsman, T., Shackell, Nancy, Bedford Institute of Oceanography, & Canada. Department of Fisheries Oceans. (2009). *Atlas of important habitat for key fish species of the Scotian Shelf, Canada* (Canadian technical report of fisheries and aquatic sciences; no. 2835). Ottawa]: Fisheries and Oceans Canada.

Horsman, T.L., A. Serdynska, K.C.T. Zwanenburg, and N.L. Shackell. (2011). *Report on the Marine Protected Area Network Analysis in the Maritimes Region, Canada*. Can. Tech. Rep. Fish. Aquat. Sci. 2917: xi + 188 p.

Hurrell, J. W., & Deser, C. (2010). *North Atlantic climate variability: the role of the North Atlantic Oscillation*. Journal of Marine Systems, 79(3), 231-244.

IUCN World Commission on Protected Areas (IUCN-WCPA) (2008) *Establishing Marine Protected Area Networks — Making It Happen*. Washington, D.C.: IUCN-WCPA,National Oceanic and Atmospheric Administration and The Nature Conservancy. 118 p.

Jessen, S., K. Chan, I. Côté, P. Dearden, E. De Santo, M.J. Fortin, F. Guichard, W. Haider, G. Jamieson, D.L. Kramer, A. McCrea-Strub, M. Mulrennan, W.A. Montevecchi, J. Roff , A. Salomon, J. Gardner, L. Honka, R. Menafra and A. Woodley. (2011). *Science-based Guidelines for MPAs and MPA Networks in Canada*. Vancouver, Canadian Parks and Wilderness Society. 58 p.

Jones, G. P., Srinivasan, M., & Almany, G. R. (2007). Conservation of marine biodiversity. *Oceanography*, *20*(3), 100.

Juffe-Bignoli, D., Burgess, N. D., Bingham, H., Belle, E. M. S., de Lima, M. G., Deguignet, M., ... & Eassom, A. (2014). Protected planet report 2014.*UNEP-WCMC: Cambridge, UK*.

Katsanevakis, S., Stelzenmüller, V., South, A., Sørensen, T. K., Jones, P. J., Kerr, S., ... & Ter Hofstede, R. (2011). Ecosystem-based marine spatial management: review of concepts, policies, tools, and critical issues. *Ocean & Coastal Management*, 54(11), 807-820.

King, L. H., & Fader, G. B. J. (1986). Wisconsinan glaciation of the continental shelf-southeast Atlantic Canada. *Geological Survey of Canada Bulletin*, 363, 72.

King, L.H., MacLean B. (1976) *Geology of the Scotian Shelf*. Canadian Hydrographic Service, Marine Sciences Paper 7, Geological Survey of Canada Paper, 74 –31, Department of Energy, Mines and Resources, Ottawa.

King, M. (2004). *Biodiversity considerations for marine protected area network planning in the Scotia-Fundy region of Atlantic Canada*.

King, M., Shackell, N., Greenlaw, M., Allard, K., Moors, H., and Fenton, D. (2013). *Marine Protected Area Network Planning in the Scotian Shelf Bioregion: Offshore Data Considerations*. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/064. vi + 24 p.

Klein, Chan, Kircher, Cundiff, Gardner, Hrovat, . . . Airamé. (2008). Striking a Balance between Biodiversity Conservation and Socioeconomic Viability in the Design of Marine Protected Areas. *Conservation Biology, 22*(3), 691-700.

Klein, C., Steinback, C., Scholz, A., & Possingham, H. (2008). Effectiveness of marine reserve networks in representing biodiversity and minimizing impact to fishermen: A comparison of two approaches used in California. *Conservation Letters, 1*(1), 44-51.

Locke, H., & Dearden, P. (2005*).* Rethinking protected area categories and the new paradigm. *Environmental conservation*, 32(01), 1-10.

Lockwood, D., Hastings, A., & Botsford, L. (2002). The effects of dispersal patterns on marine reserves: Does the tail wag the dog? *Theoretical Population Biology, 61*(3), 297-309.

Lopoukhine, N. (2013) *The Current State of Marine Protected Areas in Canada. A Canadian overview in a Global Context.* Wordclass Communications Consultants, Inc.

McNeely, J. A. (1990). The future of national park. *Environment: Science and Policy for Sustainable Development*, *32*(1), 16-41.

Margules, C. R., & Pressey, R. L. (2000). Systematic conservation planning. *Nature*, 405(6783), 243-253.

Margules, C., Pressey, R., & Williams, L. (2002). Representing biodiversity: Data and procedures for identifying priority areas for conservation. *Journal of Biosciences, 27*(4), 309-326.

Margules, C., Sarkar, S., & Margules, C. R. (2007). *Systematic conservation planning*. Cambridge University Press.

Martin, C. S., Carpentier, A., Vaz, S., Coppin, F., Curet, L., Dauvin, J. C., ... & Warembourg, C. (2009). The Channel habitat atlas for marine resource management (CHARM): an aid for planning and decision-making in an area under strong anthropogenic pressure. *Aquatic Living Resources*, 22(04), 499-508.

Martino, D. (2005). Unleashing the wild: Response to Locke and Deardens rethinking protected area categories. *Environmental Conservation, 32*(3), 195-196.

Mather, C. (2013*).* From cod to shellfish and back again? The new resource geography and Newfoundland's fish economy. *Applied Geography*, 45, 402-409

McDonnell, M., Possingham, D., Ball, H., & Cousins, P. (2002). Mathematical Methods for Spatially Cohesive Reserve Design. *Environmental Modeling & Assessment, 7*(2), 107-11

McClanahan, T.R., M.J. Marnane, J.E. Cinner, and W.E. Kiene. (2006). A Comparison of Marine Protected Areas and Alternative Approaches to Coral-Reef Management. Current Biology 16: 1408-1413.

McInerney, Caitríona E., Louise Allcock, A., Johnson, Mark P., & Prodöhl, Paulo A. (2012). Ecological coherence in marine reserve network design: An empirical evaluation of sequential site selection using genetic structure. *Biological Conservation, 152*, 262-270.

McLeod, E., Salm, R., Green, A., & Almany, J. (2009). Designing marine protected area networks to address the impacts of climate change. *Frontiers in Ecology and the Environment, 7*(7), 362-370.

McInerney, Caitríona E., Louise Allcock, A., Johnson, Mark P.,Smith & Prodöhl, Paulo A. (2012). Ecological coherence in marine reserve network design: An empirical evaluation of sequential site selection using genetic structure. *Biological Conservation, 152*, 262-270.

Metcalfe, K., Roberts, T., Smith, R. J., & Harrop, S. R. (2013). Marine conservation science and governance in North–West Europe: Conservation planning and international law and policy. *Marine Policy*, *39*, 289-295.

Molloy, P., McLean, I., & Côté, I. (2009). Effects of marine reserve age on fish populations: A global meta-analysis. *Journal of Applied Ecology, 46*(4), 743-751.

Moore, J., Balmford, A., Allnutt, T., & Burgess, N. (2004). Integrating costs into conservation planning across Africa. *Biological Conservation*, *117*(3), 343-350.

Myers, R., Hutchings, J., & Barrowman, N. (1997). *Why do Fish Stocks Collapse?* The Example of Cod in Atlantic Canada*. Ecological Applications*, 7(1), 91-106.

Osmond, M., Airame, S., Caldwell, M., & Day, J. (2010). Lessons for marine conservation planning: a comparison of three marine protected area planning processes. *Ocean & Coastal Management*, *53*(2), 41-51.

Noss, R. (2003). A Checklist for Wildlands Network Designs. *Conservation Biology, 17*(5), 1270-1275.

Phillips, A. (2003). Turning ideas on their head. In: *The George Wright Forum* (Vol. 20, No. 2, pp. 8-32).

Pressey, R. L., Cabeza, M., Watts, M. E., Cowling, R. M., & Wilson, K. A. (2007). Conservation planning in a changing world. *Trends in ecology & evolution*, *22*(11), 583-592.

Richardson, E., Kaiser, M., Edwards-Jones, G., & Possingham, H. (2006). Sensitivity of Marine-Reserve Design to the Spatial Resolution of Socioeconomic Data. *Conservation Biology, 20*(4), 1191-1202.

Roberts CM, Reynolds JD, Cote IM, Hawkins JP (2006). Redesigning coral reef conservation. In: Cote IM, Reynolds JD (eds) *Coral Reef Conservation*. Cambridge University Press, Cambridge, UK, pp 515-537.

Roberts CM, Hawkins JP, Fletcher J, Hands S, Raab K, Ward S. (2010). Guidance on the size and spacing of marine protected areas in England (NECR037). Commissioned report. Sheffield, United Kingdom.

Rodrigues, A. S., Andelman, S. J., Bakarr, M. I., Boitani, L., Brooks, T. M., Cowling, R. M., ... & Yan, X. (2003). Global Gap Analysis: towards a representative network of protected areas. *Advances in applied biodiversity science*, *5*.

Roff, J. (2009). Conservation of marine biodiversity – how much is enough? *Aquatic Conservation: Marine and Freshwater Ecosystems, 19*(3), 249-251.

Roff, J., Zacharias, Mark, & Day, Jon. (2011). *Marine conservation ecology*. London ; Washington, DC: Earthscan.

Rondinini, Carlo, & Chiozza, Federica. (2010). Quantitative methods for defining percentage area targets for habitat types in conservation planning. *Biological Conservation,143*(7), 1646-1653.3

Scholz, A., Steinback, C., Kruse, S., Mertens, M., & Silverman, H. (2011). Incorporation of spatial and economic analyses of human-use data in the design of marine protected areas.*Conservation Biology : The Journal of the Society for Conservation Biology, 25*(3), 485-92.

Shackell, N. L., & Frank, K. T. (2000). Larval fish diversity on the Scotian Shelf. *Canadian Journal of Fisheries and Aquatic Sciences*, *57*(9), 1747-1760.

Smith, R., Dustan, C., Au, P., Ba`ker, D., & Dunlap, K. (1986). Distribution of cetaceans and sea-surface chlorophyll concentrations in the California Current. *Marine Biology, 91*(3), 385-402.

Smith, R., Monadjem, A., Magagula, C., & Mahlaba, T. (2010). Conservation planning and viability: Problems associated with identifying priority sites in Swaziland using species list data. *African Journal of Ecology, 48*(3), 709-717.

Stewart, R. R., & Possingham, H. P. (2002). A framework for systematic marine reserve design in South Australia: a case study. In, *Inaugural World Congress on Aquatic Protected Areas, Cairns,(unpublished)*.

Stelzenmüller, V., Lee, J., South, A., Foden, J., and Rogers, S.I. (2013). Practical tools to support marine spatial planning: A review and some prototype tools. *Mar. Policy* (3), 214–227. doi: 10.1016/j.marpol.2012.05.038.

Sutcliffe Jr., W., Loucks, R., & Drinkwater, K. (1976). Coastal Circulation and Physical Oceanography of the Scotian Shelf and the Gulf of Maine. *Journal of the Fisheries Board of Canada*, 33(1), 98-115.

Svancara, L., Brannon J., R., Scott, M., Groves, C., Noss, R., & Pressey, R. (2005). Policy-driven versus Evidence-based Conservation: A Review of Political Targets and Biological Needs. *BioScience, 55*(11), 989-995.

Tear, T. H., Kareiva, P., Angermeier, P. L., Comer, P., Czech, B., Kautz, R., ... & Wilhere, G. (2005). How much is enough? The recurrent problem of setting measurable objectives in conservation. *BioScience*, *55*(10), 835-849

Thomas, H. L., Macsharry, B., Morgan, L., Kingston, N., Moffitt, R., Stanwell-Smith, D., & Wood, L. (2014). Evaluating official marine protected area coverage for Aichi Target 11: appraising the data and methods that define our progress. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *24*(S2), 8-23.p.

Underwood, Peter. (1995). *To manage quotas or manage fisheries?* The root cause of mismanagement of Canada's groundfish fishery. *Dalhousie Law Journal*, 18(1), 37-43.

Vimal, R., Rodrigues, A. S., Mathevet, R., & Thompson, J. D. (2011). The sensitivity of gap analysis to conservation targets. *Biodiversity and conservation*, *20*(3), 531-543.

Watts, M. E., Ball, I. R., Stewart, R. S., Klein, C. J., Wilson, K., Steinback, C., ... & Possingham, H. P. (2009). Marxan with Zones: software for optimal conservation based land-and sea-use zoning. *Environmental Modelling & Software*, 24(12), 1513-1521.

Westhead, M., King, M., and Herbert, G. (2012). Marine Protected Area Network Planning in the Scotian Shelf Bioregion: Context and Conservation Objectives. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/126

White, A.T, P.M. Aliño, and A.T. Meneses. (2005). *Creating and Managing Marine Protected Areas in the Philippines*. Fisheries Improved for Sustainable Harvest Project, Coastal Conservation and Education Foundation, Inc. and University of the Philippines Marine Science Institute, Cebu City, Philippines. 83 p.

Wilson, K. A., Cabeza, M., & Klein, C. J. (2009). Fundamental concepts of spatial conservation prioritization. *Spatial Conservation Prioritization: Quantitative Methods and Computational Tools. Oxford University Press, New York*, 16-27.

Yates, K., Schoeman, D., & Klein, C. (2015). Ocean zoning for conservation, fisheries and marine renewable energy: Assessing trade-offs and co-location opportunities. *Journal of Environmental Management, 152*, 201-9.

Zhang, L., Ouyang, Z. Y., Xu, W. H., Li, Z. Q., & Zhu, C. Q. (2010). Biodiversity priority areas analysis for amphibians and reptiles in the Yangtze basin based on systematic conservation planning idea. *Resources and Environment in the Yangtze Basin*, *19*(9), 1020-1028.

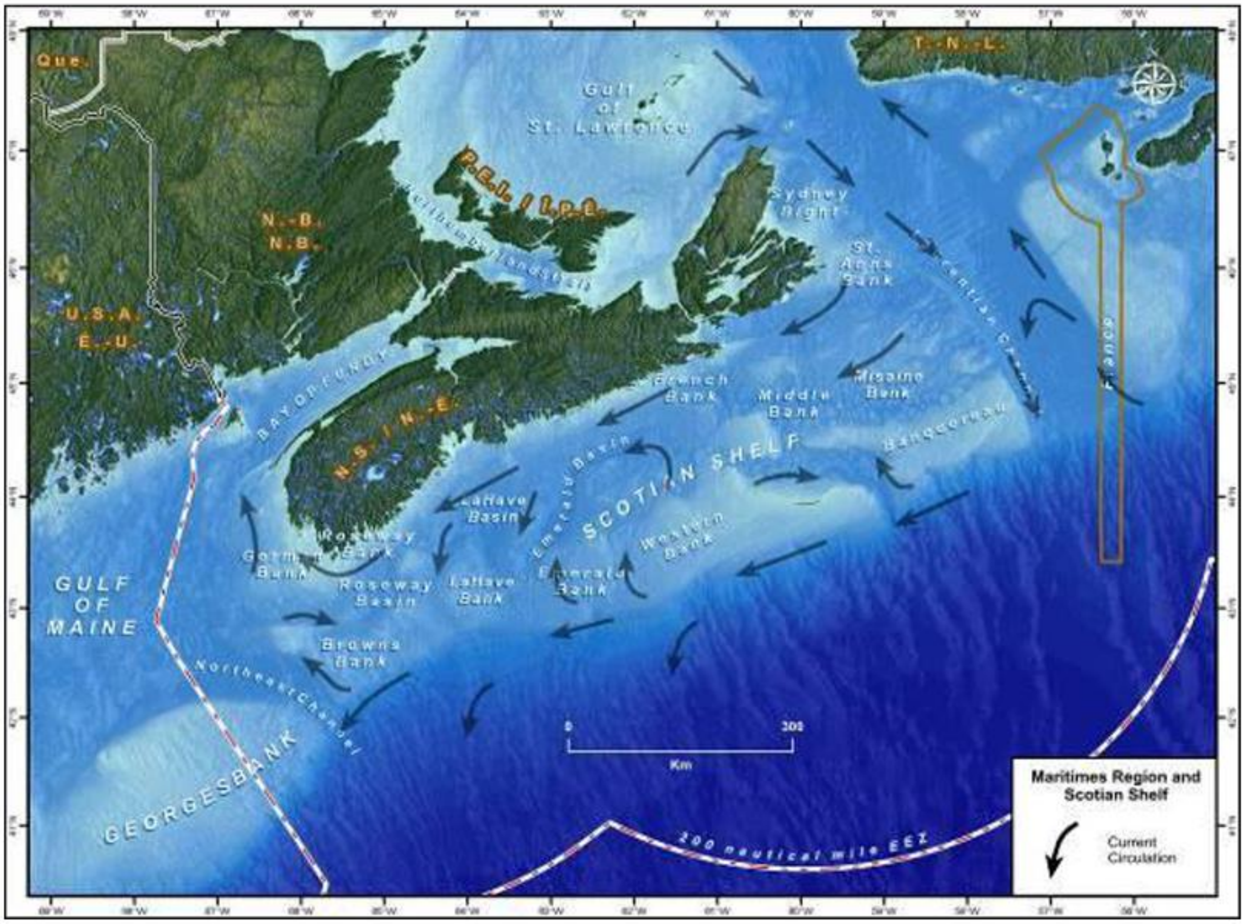
Zwanenburg, K., Canada. Department of Fisheries Oceans, & Bedford Institute of Oceanography. Ecosystem Research Division. (2006). *Implications of ecosystem dynamics for the* *integrated management of the eastern Scotian shelf* (Canadian technical report of fisheries and aquatic sciences no. 2652). Dartmouth, N.S.: Science Branch, Fisheries and Oceans Canada, Ecosystem Research Division, Bedford Institute of Oceanography.

Appendix A: Target setting methods

Traget methods (Rondinini& Chiozza, 2010)	***Description***	***Type of goal that can be achieved***	***Limitations***
Species–area relationship	Fixed percentage target across habitat types based on published literature. It states the relationship between habitat area and the number of species that an area can support. Generally, as more area is set aside for protection, the rate of increasing ecological benefits for the given species community or biome will begin to flatten, somewhere in this flattening section is where a target should be set.	Species representation	*It is not tailored to the different habitat types, it exclusively relies on generic literature and does not use any data on the distribution of biodiversity in the planning area, and therefore it can produce inaccurate estimates of the percentage target for some habitat types.*
Habitat-specific species– area relationship	Use the equation, $S= cA^z$ to fit habitat specific species accumulation curves. Habitat-specific inventory data can be used to estimate the habitat-specific value of z, hence the number of species that occur in the total area of each habitat type.	Species representation	*Sensitive to data quality and quantity. Insufficient data can lead to incorrect estimations*
Heuristic principles	Based on scientific theory. Can be adapted to a variety of specific goals. Can take into account multiple criteria.	Species representation	*A level of subjectivity in the results (qualitative and quantitative). Difficult to communicate and defend due to subjectivity.*
Spatially-explicit Population Viability Analysis (PVA) for selected species	Viability of a species in a given geographic region is often expressed as its risk of extinction or decline, expected time to extinction, or chance of recovery. PVA models attempt to predict such measures of viability based on demographic data (such as censuses, mark-recapture studies, surveys and observations of reproduction and dispersal events, presence/absence data) and habitat data. Deals explicitly with species persistence.	Species persistence	*Single species focus. Data-intensive (PVAs may need more data than some of the other methods discussed).*

Source: *Adopted from Rondinini & Chiozza, 2010*

Appendix B: The Scotian Shelf Bioregion



***Source**: Taken from Breeze et al., 2013*

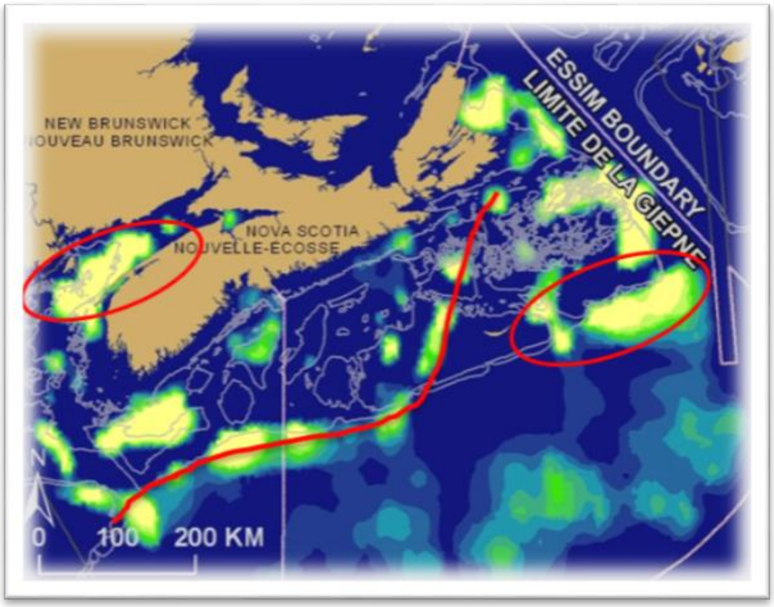
Appendix C: Conservation targets and priorities

ID	*Conservation priorities*	*Layer*	*Area (Ha)*	*% SSB*	*Target (%)*
1000	Sponge distribution (kernel)	Sponge	1,519,670	3.00	**40**
1100	Lophelia pertusa (coral) reefs	Lophelia	17,201	0.04	**100**
1200	Horse mussel reefs	Mussel	1,170	0.00	**50**
1300	Hotspots of fish species diversity	DDiversity_fish_richness_Slope	99,546	0.21	**20**
1301	Hotspots of fish species diversity	Diversity_fish_richnessInshore	1,415,744	2.98	**15**
1302	Hotspots of fish species diversity	Diversity_fish_richness4X	2,425,060	5.10	**15**
1400	Hotspots of invert species diversity	Diversity_inverts_richnessCentral	1,269,724	2.67	**15**
1401	Hotspots of invert species diversity	Diversity_inverts_richness4X	2,429,797	5.11	**15**
1600	SSIP_Haddock	SSIP_Haddock	1,883,920	3.96	**15**
1601	SSIP_Mackerel	SSIP_Mackerel	508,042	1.07	**15**
1602	SSIP_Plaice	SSIP_Plaice	2,580,036	5.42	**15**
1603	SSIP_Pollock	SSIP_Pollock	757,468	1.59	**15**
1604	SSIP_Redfish	SSIP_Redfish	4,167,448	8.76	**15**
1605	SSIP_SilverHake	SSIP_SilverHake	1,624,076	3.41	**15**
1606	SSIP_WitchFlounder	SSIP_WitchFlounder	3,543,697	7.45	**15**
1607	SSIP_yellowTailFlounder	SSIP_yellowTailFlounder	1,875,037	3.94	**15**
1608	SSIP_diversity	SSIP_diversity	6,368,078	13.38	**15**
1700	StomachDiversityInverts4VW	StomachDiversityInverts4VW	2,441,258	5.13	**10**
1701	StomachDiversityInvertsX	StomachDiversityInvertsX	1,378,492	2.90	**10**
1702	StomachDiversity_SmallFish4VW	StomachDiversity_SmallFish4VW	2,250,592	4.73	**10**
1703	StomachDiversity_SmallFish4X	StomachDiversity_SmallFish4X	1,214,565	2.55	**10**
1800	Areas of persistent high chlorophyll concentrations	chl_a_100_200m_east	2,630,900	5.53	**15**
1801	Areas of persistent high chlorophyll concentrations	chl_a_100_200m_west	903,927	1.90	**15**
1802	Areas of persistent high chlorophyll concentrations	chl_a_200m	7,199,880	15.13	**10**
1803	Areas of persistent high chlorophyll concentrations	chl_a_100_200m_central	780,008	1.64	**15**
1900	Biomass FISH	BiomassFISH7885	4,716,423	9.91	**10**
1901	Biomass FISH	BiomassFISH	5,611,121	11.79	**10**
1902	Biomass INVERTS	BiomassInverts	4,663,493	9.80	**10**
2000	Seabed	Inner Bay of Fundy	499,687	1.05	**20**
2001	Seabed	Inner Bay of Fundy - Basin	18,630	0.04	**30**
2002	Seabed	Inner Bay of Fundy - Shallow Basin	142,172	0.30	**20**
2003	Seabed	Inner Gulf of Maine Shelf	783,092	1.65	**15**
2004	Seabed	Inner Scotian Shelf	2,195,996	4.62	**10**
2005	Seabed	Laurentian Channel	2,471,238	5.19	**8**
2006	Seabed	Middle Gulf of Maine Shelf	1,407,541	2.96	**10**
2007	Seabed	Middle Gulf of Maine Shelf - Bank	12,470	0.03	**50**
2008	Seabed	Middle Gulf of Maine Shelf - Basin	433,073	0.91	**15**
2009	Seabed	Middle Gulf of Maine Shelf - Tertiary/Cretaceous	76,876	0.16	**30**
2010	Seabed	Middle Scotian Shelf	4,898,049	10.29	**5**
2011	Seabed	Middle Scotian Shelf - Bank	946,655	1.99	**10**
2012	Seabed	Middle Scotian Shelf - Basin	1,115,653	2.34	**10**
2013	Seabed	Outer Bay of Fundy	347,726	0.73	**20**
2014	Seabed	Outer Gulf of Maine Shelf	202,606	0.43	**20**

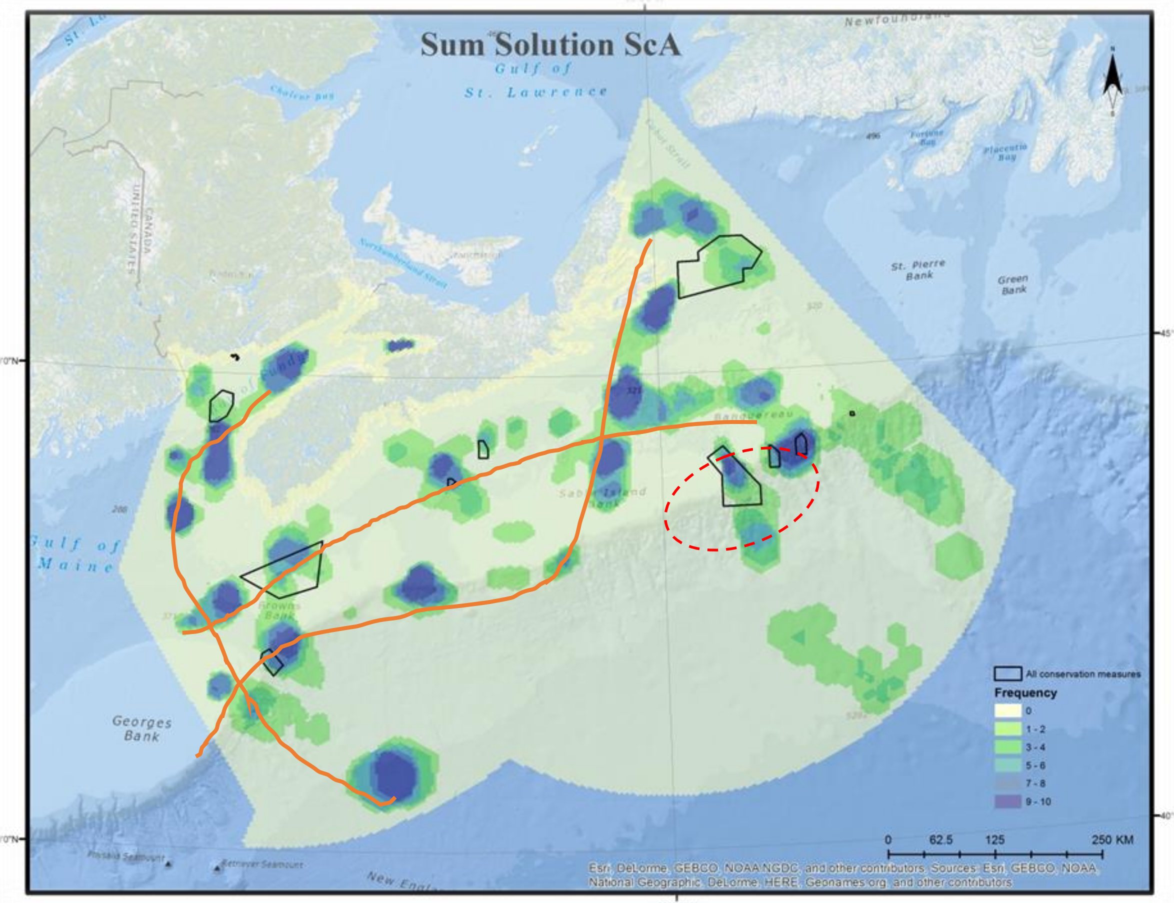
2015	Seabed	Outer Gulf of Maine Shelf - Bank	687,523	1.44	**10**
2016	Seabed	Outer Gulf of Maine Shelf - Basin	161,483	0.34	**15**
2017	Seabed	Outer Gulf of Maine Shelf - Channel	528,208	1.11	**10**
2018	Seabed	Outer Scotian Shelf	984,829	2.07	**15**
2019	Seabed	Outer Scotian Shelf - Bank	4,304,704	9.05	**7**
2020	Seabed	Outer Scotian Shelf - Saddle	529,435	1.11	**10**
2021	Seabed	Scotian Rise	8,155,362	17.14	**5**
2022	Seabed	Scotian Rise - Debris Flow	803,983	1.69	**10**
2023	Seabed	Scotian Slope East	3,567,396	7.50	**5**
2024	Seabed	Scotian Slope East - Canyon	718,618	1.51	**15**
2025	Seabed	Scotian Slope East - Gully Fan	2,105,363	4.42	**10**
2026	Seabed	Scotian Slope East - Laurentian Fan	3,078,118	6.47	**8**
2027	Seabed	Scotian Slope West	5,586,504	11.74	**5**
2028	Seabed	Scotian Slope West - Fan	1,035,790	2.18	**10**
3000	Seabirds	pursuit_diving_piscivore	4,132,283	8.68	**20**
3001	Seabirds	pursuit_diving_planktivore	4,164,853	8.75	**20**
3002	Seabirds	shallow_pursuit_generalist	4,114,023	8.65	**20**
3003	Seabirds	ship_following_generalist	4,105,513	8.63	**20**
3004	Seabirds	surface_seizing_planktivore	3,943,416	8.29	**20**
3005	Seabirds	surface_shallow_diving_coastal_piscivore	4,041,455	8.49	**20**
3006	Seabirds	surface_shallow_diving_piscivore	4,097,843	8.61	**20**
3007	Seabirds	plunge_diving_piscivore	4,153,909	8.73	**20**
3100	FISH	FishBenthivoreBenthicLarge4VW	423,303	0.89	**20**
3101	FISH	FishBenthivoreBenthicLarge4X	117,013	0.25	**20**
3102	FISH	FishBenthivoreBenthicMedium4VW	1,420,504	2.99	**20**
3103	FISH	FishBenthivoreBenthicMedium4X	1,091,048	2.29	**20**
3104	FISH	FishBenthivoreBenthicSmall4VW	423,303	0.89	**20**
3105	FISH	FishBenthivoreBenthicSmall4X	117,013	0.25	**20**
3106	FISH	FishPiscivoreBenthicLarge4VW	1,264,754	2.66	**20**
3107	FISH	FishPiscivoreBenthicLarge4X	832,552	1.75	**20**
3108	FISH	FishPiscivoreBenthicSmallMed4VW	2,201,294	4.63	**20**
3109	FISH	FishPiscivoreBenthicSmallMed4X	841,981	1.77	**20**
3110	FISH	FishPlanktivorePelagicSmallMed4VW	713,128	1.50	**20**
3111	FISH	FishPlanktivorePelagicSmallMed4X	511,035	1.07	**20**
3112	FISH	FishZoopiscivoreBenthicSmallMed4VW	1,532,689	3.22	**20**
3113	FISH	FishZoopiscivoreBenthicSmallMed4X	987,313	2.08	**20**
3114	FISH	FishZoopiscivorePelagicSmallMed4VW	76,478	0.16	**20**
3115	FISH	FishZoopiscivorePelagicSmallMed4X	2,415	0.01	**50**
3200	INVERTS	InvertebrateBenthivoreBenthicMed4VW	3,523,455	7.41	**20**
3201	INVERTS	InvertebrateBenthivoreBenthicMed4X	69,717	0.15	**20**
3202	INVERTS	InvertebrateBenthivoreBenthicSmall4VW	3,494,223	7.34	**20**
3203	INVERTS	InvertebrateBenthivoreBenthicSmall4X	2,086,967	4.39	**20**
3204	INVERTS	InvertebrateDetritivore4VW	3,236,053	6.80	**20**
3205	INVERTS	InvertebrateDetritivore4X	1,475,606	3.10	**20**

3206	INVERTS	InvertebrateFilterfeederBenthicColonial4VW	1,228,673	2.58	**20**
3207	INVERTS	InvertebrateFilterfeederBenthicColonial4X	192,612	0.40	**20**
3208	INVERTS	InvertebrateFilterfeederBenthicNonColonial4VW	3,517,212	7.39	**20**
3209	INVERTS	InvertebrateFilterfeederBenthicNonColonial4X	2,114,869	4.44	**20**
3210	INVERTS	InvertebrateZoopiscivoreSmallMedLarge4VW	1,221,697	2.57	**20**
3211	INVERTS	InvertebrateZoopiscivoreSmallMedLarge4X	1,406,584	2.96	**20**
4000	Atlantic cod	Cod4Vn	162,134	0.34	**25**
4001	Atlantic cod	Cod4VsW	547,580	1.15	**25**
4002	Atlantic cod	Cod4X	623,090	1.31	**25**
4003	Redfish	RedFishU2	782,126	1.64	**25**
4004	Winter skate (ESS)	WinterSkate4X	170,132	0.36	**25**
4005	Winter skate (ESS)	WinterSkate4VW	64,586	0.14	**25**
4006	American plaice	American plaice4VW	1,967,483	4.13	**20**
4007	American plaice	American plaice4X	476,656	1.00	**20**
4008	Cusk	Cusk	3,575,320	7.51	**15**
4009	White hake	WhiteHake4VW	952,733	2.00	**20**
4010	White hake	WhiteHake4X	703,949	1.48	**20**
4011	Smooth skate	Smooth skate4VsW	26,442	0.06	**15**
4012	Smooth skate	Smooth skate4X	101,662	0.21	**15**
4013	Atlantic wolfish	Atlantic wolfish	387,357	0.81	**15**
4014	Thorny skate	Thorny skate4VsW	707,957	1.49	**15**
4015	Thorny skate	Thorny skate X	242,237	0.51	**15**
4016	Redfish	RedfishU3	723,010	1.52	**10**
4017	Spiny dogfish	Spiny dogfish	504,653	1.06	**10**
4100	Cetaceans Hot spots	Cetaceans Gully	685,369	1.44	**30**
4101	Cetaceans Hot spots	Cetaceans XSE	3,460,260	7.27	**20**
4200	Leatherback turtles	Leatherback_N	1,811,268	3.81	**15**
4201	Leatherback turtles	Leatherbacks_S	3,273,746	6.88	**15**

Appendix D: Pattern observed in Marxan solutions



Former Marxan output in Horsman et al., 2013



Common pattern observed across different scenarios