# The use of ecosystem service valuation in environmental sensitivity analysis for ship-source oil spill preparedness and response planning in Chedabucto Bay, Nova Scotia

By

*Elise Will*

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## ABSTRACT

A recent decision was made by the Government of Canada to bring its national ship-source oil spill preparedness and response regime up to world-class standards. This signaled the movement away from an approach that uses “one size fits all” standards across every region of the country, to an approach that incorporates regional differences in geography, environment, and response capacities. The main focus of this initiative is the creation of Area Response Plans (ARPs) for four identified areas in Canada with the highest risk for ship-source oil spills. Chedabucto Bay, near Port Hawkesbury, Nova Scotia, was identified as one of these areas, and was the site of focus for this study. The main objective of this project is to provide recommendations toward the development of this ARP on the areas of highest priority for response plan development and protection. Prioritization of areas within the study site was based on the coastal habitats occurring within this region, and the values that these habitats provide in terms of ecosystem services, as well as their level of sensitivity to oil based on standard environment sensitivity indices. Ecosystem service values were determined through quantitative valuation using the benefit transfer technique, as well as through qualitative methods. Value and sensitivity were combined in an analysis in GIS to identify the locations of highest priority for focus in the current ARP development. The two main priority areas identified were the northwestern shores of Chedabucto Bay within Lennox Passage, and the areas near and within Tor Bay.

*Keywords:* ecosystem services, valuation, benefit transfer, Area Response Planning, Port Hawkesbury, Chedabucto Bay, oil spill preparedness and response, environmental sensitivity index, GIS

## ABBREVIATIONS USED

| | |
|---|---|
| ARP | Area Response Plan |
| COSEWIC | Committee on the Status of Endangered Wildlife in Canada |
| EBSA | Ecologically and Biologically Significant Area |
| ESI | Environmental Sensitivity Index |
| ESV | Ecosystem Service Valuation |
| EVRI | Environmental Valuation Resource Inventory |
| GIS | Geographic Information System |
| LEK | Local Ecological Knowledge |
| MEA | Millennium Ecosystem Assessment |
| NZ NMDB | New Zealand Non-Market Valuation Database |
| RED | Review of Externality Data |
| SARA | Species at Risk Act |
| TEEB | The Economics of Ecosystems and Biodiversity |
| TEV | Total Economic Value |

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## 1.0 INTRODUCTION

Canada has historically had a strong reliance on the coast, and this reliance is still apparent today in the way we place economic, social, and cultural value on access to the coast and its resources. We are constantly battling our need to make use of these resources with the importance of protecting them and ensuring that future generations will be able to enjoy our coasts and oceans. One activity occurring in this area that has been important to Canada's economy, and will likely continue to be important for some time, is the import and export of oil and oil products by ship. The use of our coastal spaces for the transportation of oil also involves certain risks to the environment from the potential occurrence of oil spills. Spills not only have negative impacts to human health and the health of coastal flora and fauna, but can also have serious economic and social impacts both locally and nationally.

There have been many infamous spills in the past from oil tankers around the world, and even though international safety standards and precautionary measures have greatly increased, the risk for environmental disaster still remains high (Anderson and Spears, 2012). With the degradation and depletion of our oceans' resources, and global pressures such as climate change becoming more and more apparent, it is more important than ever to ensure that everything possible is being done to prevent further damage to our increasingly fragile ecosystems.

An important defense against ship-source oil spills is to ensure that the chances of occurrence are as low as possible through the implementation and enforcement of rigorous safety standards. Many of these standards exist as regulations under the *Canada Shipping Act, 2001*, and their enforcement ensures that vessels are following proper reporting protocols, have up to date navigational and communication equipment, and meet ship design standards, among other criteria (Transport Canada, 2014a). It is impossible to eliminate the risk entirely, however, and Canada must always be prepared to respond quickly and efficiently to any environmental emergencies that may occur. Detailed planning, clearly assigned roles, and fast response could mean the difference between a minor incident and a full-blown environmental disaster.

## 1.1 Ship-Source Oil Spill Preparedness and Response in Canada

In May 2014, the Government of Canada announced plans for the implementation of new measures in order to bring Canada's Ship-source Oil Spill Preparedness and Response Regime up to world-class standards (Transport Canada, 2014b). The current regime has not been reviewed in its entirety since the mid 90's, and the need for an updated system was recognized due to a large increase in the volume of oil being shipped within Canadian waters in the last 20 years (Transport Canada, 2013). Even though the occurrence of spills within this time has remained low, large-scale incidents remain a possibility within Canada (Anderson and Spears, 2012). The only oil spill in Canadian waters that can be considered a 'large-scale' incident by international standards occurred in 1970, but the lessons learned from this event are still relevant today and can inform and provide context to the current regimes in development (Owens, 2010).

### 1.1.1 The 1970 Tanker 'Arrow' Spill

The most significant marine oil spill to ever occur in Canada was the 1970 tanker Arrow spill, which resulted in over 10,000 tonnes of oil being released into the environment (Transport Canada, 2014a). This Liberian tanker carrying 108,000 barrels of Bunker C fuel oil to Nova Scotia was grounded near the center of Chedabucto Bay where it immediately sank, spilling its cargo (Owens, 2010). It has been estimated that about one third of the oil carried on the ship reached the shore and polluted approximately 190 miles of shoreline surrounding the bay (Drapeau, 1972).

The spill was transported to both the north and south shores of the bay due to changes in prevailing winds (Owen, 2010), and this caused the oil to reach and impact many beaches, rivers, coastal ponds, and protected coves (Beson, 2001). It not only negatively impacted the health of the local flora and fauna, but also had long-lasting effects on the livelihoods and well-being of the residents of these coastal areas. Aquatic invertebrates, fish, plankton, seabirds and marine mammals were all impacted, and a large number of deaths were recorded, particularly among seabirds. The most devastating socio-economic impact of this spill was to the local fishing industry, and approximately 1000 fishermen were affected. Several types of fisheries were negatively affected, primarily the lobster fishery, which impacted the local economy (Beson, 2001).

This spill occurred at a time when there was very little pre-spill preparation and little was known about the behaviour of oil in the marine environment (Government of Canada and McTaggart-Cowan, 1970). Due to the recognition of this lack in preparation, the event was treated as a valuable learning experience, which resulted in recommendations for future response and cleanup activities. This event can serve to inform decisions being made currently in spill response planning by providing a model for the behaviour of spilled oil and a better understanding of its potential environmental and socio-economic impacts in a Canadian context (Government of Canada and McTaggart-Cowan, 1970).

### 1.1.2 Current Risk for Oil Spills in Canada

Since the Arrow spill, both the risk for and actual occurrence of ship-source spills has dramatically decreased within Canada and internationally due to greatly improved preventative measures, such as the introduction of the double-hulled tanker (Transport Canada, 2013). However, even a small spill in a sensitive area can have large impacts, and the only way to eliminate most risk is to cease the import and export of oil in Canada. This is unlikely to occur as Canada is highly dependent on international oil shipment, particularly on the Atlantic coast where approximately 82 million tonnes of petroleum products are moved in and out of 23 ports each year (Transport Canada, 2014a). Much less oil is shipped out of the West coast (between two and three millions tonnes in 2011), though this is expected to increase with the recent approval of the Northern Gateway pipeline (Moore, 2014).

In 2013, Transport Canada contracted an outside firm called GENIVAR to complete a full Canada-wide risk assessment for ship-source spills (Transport Canada, 2013). This assessment was used to inform the review occurring at that time of Canada's ship-source spill preparedness and response regime (Transport Canada, 2014a). Risk was determined using past spill statistics, vessel traffic, and oil shipment volumes to determine probability, combined with calculated environmental sensitivities for each region (GENIVAR, 2013). It was found that the level of risk for spills varies greatly across the country. Areas identified with the highest overall probability for large spills

(>10,000 $m^3$) include the marine areas near the southern portion of Vancouver, the Cabot Strait, the Gulf of St. Lawrence, and the eastern coast of Cape Breton Island. It was found that there was a much higher probability of small spills (100 to 999 $m^3$) in every region studied across the country. One of the main conclusions from this study was the need to tailor preparedness and response arrangements to suit each region due to the varied levels of risk across Canada (GENIVAR, 2013).

### 1.1.3 Area Response Planning

Since the mid 90's, Canada has had a three-part spill response regime that focuses on prevention, preparedness and response, and liability and compensation (Transport Canada, 2013). A review of this regime was conducted in November of 2013 by the Tanker Safety Expert Panel, and recommendations were made to the Government of Canada (Transport Canada, 2014a). Based on these recommendations, it was decided that comprehensive response plans would be developed for areas with the highest levels of tanker traffic within Canada. Four areas have currently been targeted for the development of tailored Area Response Plans (ARPs): the southern portion of British Columbia, the Gulf of St. Lawrence, Saint John Harbour and the Bay of Fundy, and Port Hawkesbury, Nova Scotia. The development of ARPs for these four areas is being used to refine Canada's response planning models, and in the future this approach may be implemented in other locations across Canada (Transport Canada, 2014a).

The ARP approach signals the movement away from a "one-size fits all" national safety and response regime towards an approach that takes into account regional differences in the types of vessel traffic, volume of oil movements, and environmental and socio-economic sensitivities (Transport Canada, 2013). This ensures that in the event of a spill, the local context is well understood, the organizations and departments involved have clearly defined roles and responsibilities, and spill cleanup equipment is in place and readily available (Transport Canada, 2014b).

The creation of an ARP is a complicated endeavour that involves preparation through data gathering and analysis, the design of response plans and operational protocol, and a post-spill recovery strategy (Transport Canada, 2013). Every component requires coordination between multiple federal departments, provincial and municipal governments, as well as collaboration with outside organizations, private industry, and local stakeholders. The lead agency in overseeing and developing spill preparedness and response regimes is Transport Canada, and this is done in conjunction with the Canadian Coast Guard, which has a very important, yet more operational role (Transport Canada, 2013). The role of industry is carried out through mandatory arrangements with Response Organizations, which are industry-funded and government-certified bodies with the capacity to respond to spills of up to 10,000 tonnes. The role of Environment Canada is to provide scientific, environmental, and wildlife advice and information to the lead organizations (Transport Canada, 2013). This responsibility is also partly shared with Fisheries and Oceans Canada and Natural Resources Canada, and also includes research into the behaviour of oil products in the marine environment and potential alternative response measures (Transport Canada, 2014b). Coordination with local governments, Aboriginal communities and other important stakeholders is an aim of this initiative in order to tailor each ARP to the cultural, socio-economic and environmental characteristics of each area.

As part of the preparation component of an ARP it is essential to have detailed knowledge of the environment within the response area, and to have a system in place for the collection, storage, and organization of this descriptive and spatial data. In Canada this is accomplished through the Shoreline Classification and Pre-Spill Database maintained by Environment Canada, which includes many geospatial datasets stored within a Geographic Information System (GIS) with information crucial for planning and response to environmental emergencies (Percy, LeBlanc, and Owens, 1997). This database is not publicly accessible, but has been described by Gromack and Allard (2013) to include data from a variety of sources, such as aerial photography and paper maps, and contains detailed information on shoreline material/type, potential oil behaviour along the shore, and resources at risk. This database has existed since the mid 90's and includes data from many areas across Canada (Percy, LeBlanc, and Owens, 1997), but was not developed with a focus on the four recently determined priority response areas.

## 1.2 Management Problem

The development of up-to-date and comprehensive ARPs for each of the four priority areas first requires very detailed, site-specific data collection (CBC News, 2014, October 17). The creation of coastal maps and resource inventories is a very crucial aspect in oil spill response preparation, and this involves the collection of spatial data depicting the locations of environmental, socio-economic, and cultural resources (IMO and IPIECA, 1996). The management problem stems from the need for a more overall view of the response areas through analysis of the collected spatial data in order to determine where priority areas are located for protection and response. This is an important aspect of an ARP because in the event of an environmental emergency, quick decisions must be made on how to best focus finite response resources (G. Herbert, personal communication, July, 2014). Identifying the most important coastal areas for protection necessitates the incorporation of a value system in order to prioritize one location over another. This highlights the need for a decision framework for prioritizing coastal areas that takes into account ecological, social, cultural, and economic factors.

The current ARP initiative is still in its early stages and there has not yet been detailed data collection or area prioritization within the response areas (CBC News, 2014, October 17). The purpose of this study is to develop a method for the identification of priority areas to aid in the development of ARPs. This will be accomplished through a focus on the Port Hawkesbury response area as a case study. The original boundary for this response area was determined using a 50 nautical mile radius centered on Port Hawkesbury, though this was a rough selection for the ARP pilot project and the exact boundaries may be altered in the future (G. Herbert, personal communication, July, 2014). For the purposes of this project, the boundaries were altered slightly to provide a greater focus on Chedabucto Bay, which is where the heaviest tanker traffic occurs within the response area (Simard et al., 2014) (Figure 1-1). To simplify boundary delineations, municipality and county boundaries were used for the southern and northern extents of the study site. The southern extent of the study site abuts the southern boundary of the Municipality of the District of Guysborough, and the northern boundary occurs with the northern boundary of Richmond County.

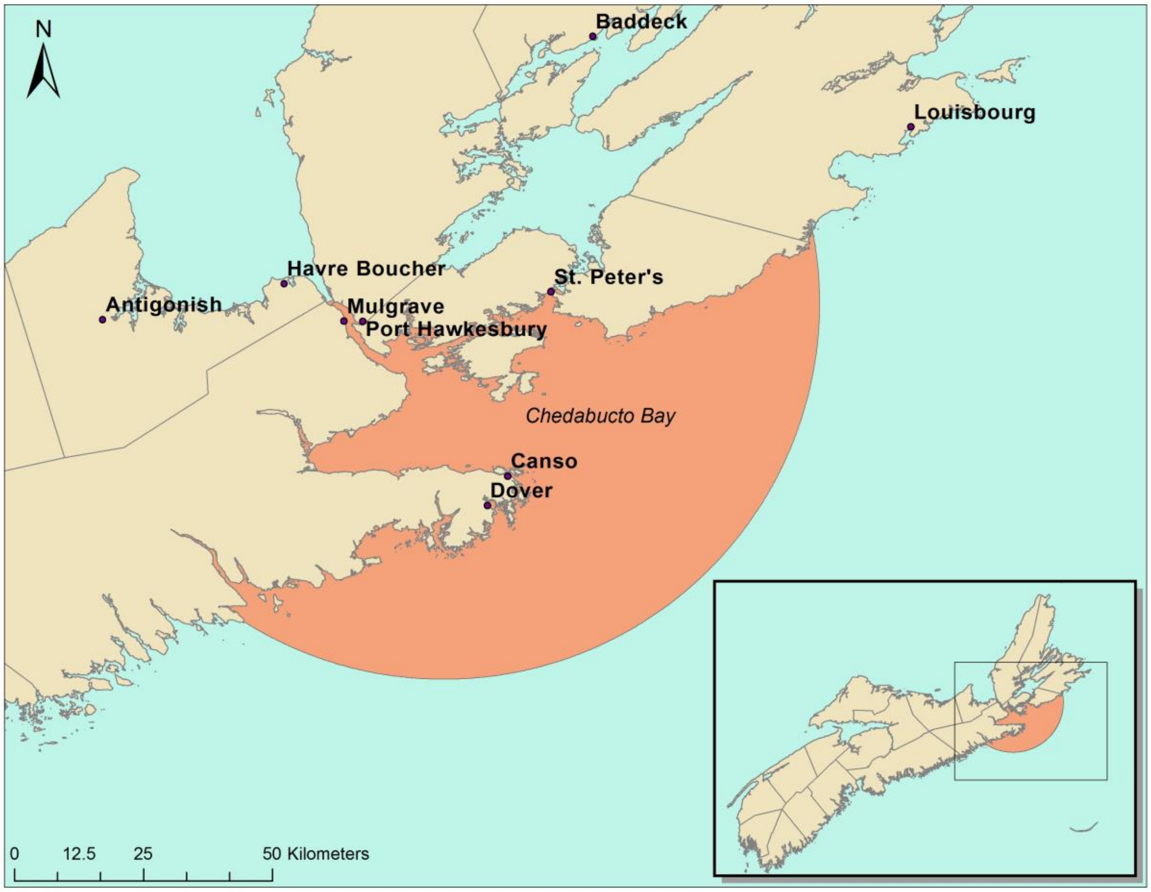


**Figure 1-1**. Depiction of the coastal and marine areas included within the study site.

Within the study site, locations of the most important coastal areas for prioritization in response planning will be identified using the approach outlined in the following section.

## 1.3 Research Approach

Priority coastal areas within the study site will be identified using two main criteria: ecosystem value and sensitivity to oil. The overall ecosystem value of coastal areas will be determined through an analysis of the ecosystem goods and services provided by coastal habitats. Ecosystems goods and services sustain human life through the benefits derived from natural ecosystem functions and processes (Daily, 1997). Making the values of ecosystems explicit, values which are not easily captured in commercial markets, is one way to recognize these values and incorporate them more easily into decision-making processes (Stahl et al., 2012).

Sensitivity to oil is also important to include in the prioritization of important coastal areas in the context of spill response planning (IMO and IPIECA, 1996). A valuable coastal resource that has very high sensitivity should not be prioritized at the same level as a similarly valuable resource with low sensitivity. The predicted oil residence time (the time that oil would remain in an environment before removal by natural processes) along with the predicted biological impacts of the oil on an environment are the main factors that determine the sensitivity of a shoreline type (Gundlach and Hayes, 1978). This concept is most often applied through the use of an environmental sensitivity index (ESI), which provides a ranked sensitivity value to different shoreline types (e.g. sandy beach, cobble beach, salt marsh) on a relative scale (IMO and IPIECA, 1996).

Both ecosystem value and sensitivity of coastal areas are important factors to include in spill response planning, but a combination of the two factors can provide a broader overview for area prioritization. The following sections will describe the concepts of ecosystem services and ESIs in more detail and provide context from the literature on their uses in environmental decision-making processes.

### 1.3.1 Ecosystem Services

The identification and description of ecosystem goods and services (hereafter referred to as "ecosystem services") produced through biodiversity and ecosystem functioning has allowed for a better understanding of exactly how these systems maintain human well-being (de Groot, 1992). Ecosystem 'goods' refer to directly useful products such as food, water and fuels, and 'services' refer to regulating and supporting functions such as climate regulation and nutrient cycling (Daily, 1997). The introduction of this concept has initiated a paradigm shift in how we perceive and value the environment and has helped to draw attention to the growing global scarcity of our natural resources (Lui et al., 2010).

The term "ecosystem services" was first introduced in 1981 in an attempt to create a more tangible link between economic and ecological systems (Liu et al., 2010). It was not until the late 1990s however that this concept became more widely recognized, mainly through the publications of Daily (1997) and Costanza et al. (1997). In the year 2000, a Web of Science search of peer-reviewed literature using the term 'ecosystem services' as part of the title, abstract or keywords returned less than 200 papers (Nunes, Kumar, and Dedeurwaerdere, 2014). By 2010 the number of papers from the same search grew to over 1200, and the number of citations of this work across multiple disciplines follows this steep upward trend (Nunes, Kumar, and Dedeurwaerdere, 2014).

The increasing popularity of the concept of ecosystem services can also be attributed to several major global initiatives that focused attention on the global decline of biodiversity and the undervaluing of natural capital. The Millennium Ecosystem Assessment (MEA) in 2005 was a large global scientific assessment that was supported by the United Nations for the purpose of evaluating the consequences of ecosystem disruption and landscape change (MEA, 2005). The MEA was integral in clarifying the links between human impacts to natural systems and how this is affecting the capacity of ecosystems to support human well-being, as well as the links between biodiversity conservation and poverty alleviation (Nunes, Kumar, and Dedeurwaerdere, 2014). The second global initiative to propagate the concept of ecosystem services was The Economics of Ecosystem Biodiversity (TEEB) report in 2010. This report focused much more on the economic value of our natural resources and showed that the full value of these resources is consistently being underestimated in policy decisions (Lui et al., 2010).

At the national level, Canada has been slower to adopt these concepts, but recently more interest has been seen within the Government of Canada with the creation of the Measuring Ecosystem Goods and Services (MEGS) project in 2011. This federally funded project co-led by Statistics Canada and Environment Canada was created to "develop experimental ecosystem accounts with the specific objective of supporting policy needs related to the valuation of ecosystem goods and services" (Statistics Canada, 2013, p. 8). This report included some national accounting of ecosystem services and national land cover change analyses, as well as case studies to focus on changes to particular regions, such as the impacts of population increases on ecosystems in the Greater Toronto Area (Statistics Canada, 2013). This report not only provides a well of knowledge and data for decision-makers to draw from, but also reinforces the importance of understanding the full value of ecosystems and incorporating these values into decision-making processes within Canada.

### 1.3.2 Valuing Natural Capital

Just as manufactured capital has economic value, the natural systems producing ecosystem goods and services can be classified as natural capital (Costanza et al., 1997). These natural capital stocks provide direct benefits to humans, and are also ultimately the source of all manufactured capital. The direct link between natural capital and human welfare is better understood through a breakdown of the ecosystem services we receive from the natural world. A full accounting of these services was first provided by Costanza et al. (1997) through an assessment of global ecosystem services, and 17 major categories were described. This was later expanded upon by the MEA (2005), which described several additional services and grouped them into four main categories: provisioning, regulating, supporting, and cultural (Table 1-1). Provisioning services include direct, tangible resources such as food, water, and fuel. Regulating services maintain the functions of ecosystems, and supporting services mainly are necessary for the production of other ecosystem services. Cultural services include all of the non-material benefits derived by humans (MEA, 2005). The exact number of categories of ecosystem services and their classifications are not agreed upon within every sector, and slight variations of this categorization can be found throughout the literature. For example, de Groot et al. (2002) developed a framework for the assessment and valuation of ecosystem functions that includes 23 main categories of ecosystem services grouped into four classes labeled as ‘regulation functions’, ‘habitat functions’, ‘production functions’, and ‘information functions’.

**Table 1-1**. Functional categorization of global ecosystem services (adapted from: MEA, 2005).

| **Service** | **Explanation** |
|---|---|
| Provisioning | |
| Food | Food products derived from plants, animals, and microbes |
| Fresh water | Water for domestic, agricultural, and industrial use |
| Fuel | Wood, dung, and other biological materials that serve as sources of energy |
| Biochemical | Medicines and other biological material |
| Genetic material | Genes and genetic information used for animal and plant breeding and biotechnology |
| Regulating | |
| Climate regulation | Ecosystem influence on climate (e.g. carbon sequestration, emission of gases) |
| Disease regulation | Effects on prevalence of livestock and crop pests and diseases |
| Water regulation | Timing and magnitude of runoff, flooding, and aquifer recharge |
| Water purification | Retention, recovery, and removal of excess wastes |
| Pollination | Effects on distribution, abundance and effectiveness of pollinators |
| Supporting | |
| Soil formation | Sediment retention and accumulation of organic matter |
| Nutrient cycling | Storage, recycling, processing and acquisition of nutrients |
| Habitat provision | Habitat for resident or transient species |
| Cultural | |
| Spiritual and religious | Spiritual or religious values derived from ecosystem components |
| Recreation and ecotourism | Opportunities for tourism and recreational activities |
| Educational | Opportunities for formal and informal educational processes |
| Inspirational | Inspiration for art, folklore, national symbols and advertising |
| Aesthetic | Appreciation of natural features |
| Cultural heritage | Historically or culturally important landscapes or species |

The application of economic value to the services provided by natural systems is called ecosystem service valuation (ESV), and this method can serve to improve our understanding and appreciation of the direct link between ecosystem functioning and human well-being (de Groot et al., 2002). Assigning an overall monetary value to a natural feature requires the breakdown of this feature into its individual beneficial components, valuing each component, and summing all components to derive the total value. One way to accomplish this is to break down the components of a natural feature into 'use' and 'non-use' categories of ecosystem goods and services (DEFRA, 2007). This concept is depicted in Figure 1-2, which shows a Total Economic Value (TEV) framework. Direct use values include both consumptive and non-consumptive use. Examples of consumptive use are food or timber, whereas non-consumptive use could include the recreational use of a beach or the aesthetic appreciation of a forest. Indirect use values are less apparent to us but are integral to our existence, and include key life-supporting functions such as nutrient cycling and climate regulation. Option value refers to valuing goods and services that are not currently being used, but have value in their availability for future use. The three non-use values are defined through the maintenance of natural environments for either those in future generations (Bequest value), others in the current generation (Altruistic value), and simply for the knowledge of their existence (Existence value) (DEFRA, 2007).

The TEV framework is an example of one method to break down the benefits derived from natural systems in order to assign them an overall economic value. The actual valuation techniques used will vary with the type of ecosystem service being valued, the context of the study, and the resources available to the researcher (DEFRA, 2007). Generally, all use-value ecosystem services are valued using 'revealed preference' methods, which rely on individuals' preferences for marketable goods and services.

These techniques use actual market prices to determine value. The non-use ecosystem services are valued using 'stated preference' methods, which entail the use of surveys and questionnaires to determine individuals' preferences for a given change in the ecosystem service in question (DEFRA, 2007). A description of the available valuation techniques can be seen in Table 1-2, which describes various stated preference techniques (i.e., Avoided Cost, Replacement Cost, Factor Income, Travel Cost, Hedonic Pricing, and Marginal Product Estimation) and revealed preference techniques (i.e., Contingent Valuation and Group Valuation).

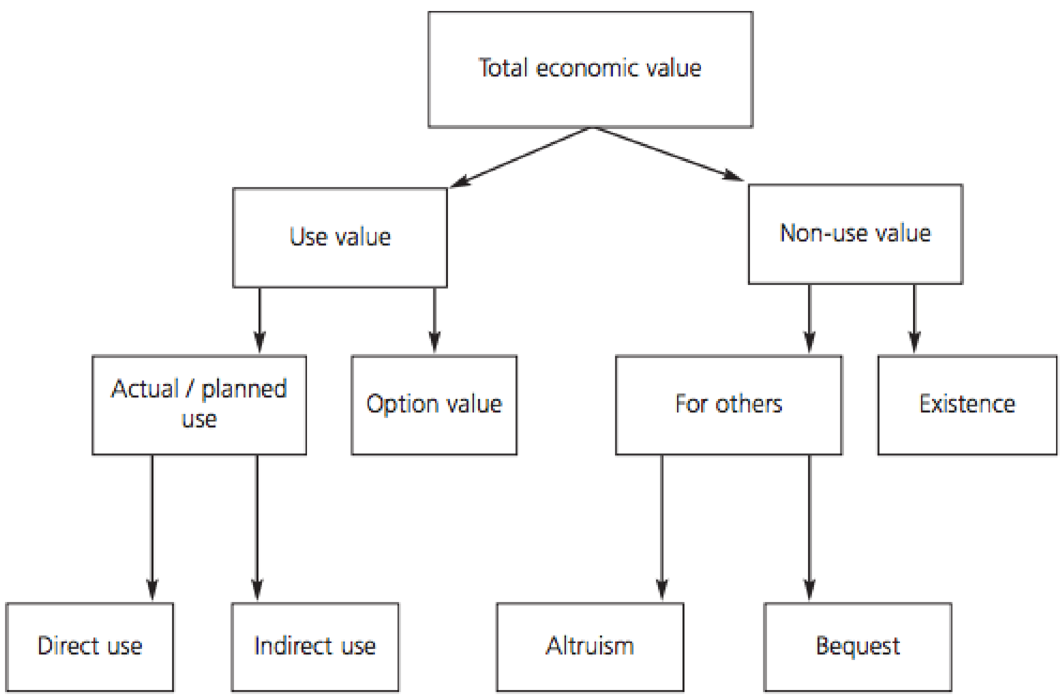


**Figure 1-2**. The Total Economic Value framework (adapted from: DEFRA, 2007).

Table 1-2. Non-market economic valuation techniques (adapted from: Costanza et al., 2006).

**Avoided Cost** (AC): services allow society to avoid costs that would have been incurred in the absence of those services; flood control provided by barrier islands avoids property damages along the coast.

**Replacement Cost** (RC): services could be replaced with man-made systems; nutrient cycling waste treatment can be replaced with costly treatment systems.

**Factor Income** (FI): services provide for the enhancement of incomes; water quality improvements increase commercial fisheries catch and incomes of fishermen.

**Travel Cost** (TC): service demand may require travel, whose costs can reflect the implied value of the service; recreation areas attract distant visitors whose value placed on that area must be at least what they were willing to pay to travel to it, including the imputed value of their time.

**Hedonic Pricing** (HP): service demand may be reflected in the prices people will pay for associated goods: For example, housing prices along the coastline tend to exceed the prices of inland homes.

**Marginal Product Estimation** (MP): Service demand is generated in a dynamic modeling environment using a production function (i.e., Cobb-Douglas) to estimate the change in the value of outputs in response to a change in material inputs.

**Contingent Valuation** (CV): service demand may be elicited by posing hypothetical scenarios that involve some valuation of alternatives; e.g., people generally state that they would be willing to pay for increased preservation of beaches and shoreline.

**Group Valuation** (GV): This approach is based on principles of deliberative democracy and the assumption that public decision making should result, not from the aggregation of separately measured individual preferences, but from *open public debate.*

It is also possible to use non-monetary valuation techniques to employ a more qualitative approach in lieu of assigning economic values (DEFRA, 2007). This can be accomplished using surveys and discussions to understand the way in which people value certain ecosystem services, and may provide insight into relative comparisons of value based on their preferences. The qualitative value of ecosystem services can also be determined based on the impacts that a change in these services would produce, using causal linkages and literature reviews (Busch et al., 2012). This type of qualitative approach can be useful to determine the relative significance of ecosystem services in order to view them in a bigger picture context, particularly when no monetary valuation data are available (Statistics Canada, 2013).

### 1.3.3 Benefit Transfer

While the most accurate and site-specific economic valuation of ecosystem services is accomplished through original valuation techniques as discussed above, this is not always possible if lack of time, money, or expertise is a factor (Loomis, 1992). To account for this issue, the concept of benefit transfer (sometimes referred to as value transfer) was developed, which involves the transfer of existing valuation data from a sample site (an area containing natural features that have been valued using ESV techniques) to the current study site (Desvousges, Johnson and Banzhaf, 1998; Loomis, 1992).

This involves the division of each resource or habitat type being valued into their associated ecosystem goods services, and a search of the literature for economic valuation studies for each of these goods and services from sample sites that are contextually similar to the study site (Troy and Wilson, 2006). The simplest and most common method for transfer is the use of mean values from the sample sites, which means that as many transferrable values as possible are found and averaged in order to increase accuracy (Bateman et al., 2011). A common representation of value is through dollar value per unit area (Woodward and Wui, 2001).

Troy and Wilson (2006) identify three major factors that must be assessed when determining if the context of the sample site is suitable for transfer to the study site. These are the biogeophysical characteristics, the human population characteristics, and the scarcity of the services being considered. The first factor relates to the features providing ecosystem services, and if these features are comparable physically so that they provide roughly the same goods and services. For example, a coral reef in Indonesia is likely not similar enough to a reef in the cold waters of the northern Atlantic to be directly compared. The human population characteristics are more difficult to compare, and these details are not always included in every valuation study. For example, if the valuation method used is Willingness to Pay (see Table 1-2, "Contingent Valuation"), the difference in the average income of those surveyed from the sample to study site is an important consideration (Troy and Wilson, 2006). Finally, if the feature being considered is extremely rare in the study site, it may be considered more valuable and therefore will likely be undervalued in a benefit transfer from a site where this feature is more common.

Several publicly accessible databases now exist that facilitate the quick access to valuation data in order to transfer values from one site to another. Environment Canada maintains the Environmental Valuation Reference Inventory (EVRI) database, which stores over 2000 international studies that include environmental valuation in an easily searchable format (Environment Canada, 2011). Other popular publicly available databases include ENVALUE out of Australia, New Zealand Non-Market Valuation Database (NZ NMDB), ValueBase Swe out of Sweden, and the Review of Externality Data (RED) out of Europe (Lantz and Slaney, 2005). Each of these databases has different organizational structures and search functions, and the choice of using one over another may depend on the purpose of the study. ValueBase Swe and NZ NMDB only contain national valuation values, whereas the other three databases have both national and international information.

The major disadvantage of the benefit transfer technique comes with the relatively few ecosystem services that have been valued globally, as well as the difficulty in finding compatible studies for transfer (Woodward and Wui, 2001). There are also questions raised about the validity of taking values derived from a local context at a particular point in time, and transferring them to another area at a later time. Criticisms have focused on the fact that market values are constantly changing as well as the availability and scarcity of particular resources, which would alter the accuracy of these values over time and reduced the validity of their transfer (Sagoff, 2011).

Despite the difficulties with this technique, it can still be very useful to provide relative comparisons of value to give context to decision making in resource management, particularly when time and resources are limited and direct valuation studies are not feasible. This approach facilitates a relatively simple valuation of resources that may otherwise be overlooked or undervalued if they are not apparent to, or in direct use by the public (Townsend et al., 2014).

### 1.3.4 Mapping Ecosystem Services

Representing ecosystem service provision in a spatially explicit format can be a powerful tool for resource managers. Mapping ecosystem services has recently become very popular, and over 60% of publications that map ecosystem service values have been published after 2007 (Schägner et al., 2013). This method has developed along with GIS technologies and was given more attention after the well-known global ecosystem service mapping study by Costanza et al. (1997).

Mapping values requires first assigning value to different ecosystem service providers, which can be done either through primary valuation or through benefit transfer. A common use of this technique is to represent how a change in land cover of a target area will result in a change in the value of the ecosystem services provided by that area (Zhao et al., 2004; Naidoo and Ricketts, 2006; Swetnam et al., 2011). This is useful for managers to visualize the impacts of a change by modeling various scenarios, which will allow for clearer understanding of the costs and benefits of a particular landscape change.

There are also larger scale projects involving mapping such as the study by Costanza et al. (2006), which set out to value the natural capital of all of New Jersey and display these values by watershed. The motivation behind this two-year study was brought on by the massive conversion of natural habitats for other purposes across the state. The ultimate goal was to make the values of these habitats more explicit in order for decision makers to better understand the costs and benefits involved with alternative land uses (Costanza et al., 2006).

The Department of Conservation in New Zealand recently came out with a large-scale study where the values of ecosystem services found within seven marine protected areas throughout the country were calculated through benefit transfer and mapped (van den Belt and Cole, 2014). Studies such as this one increase the general understanding and awareness of the values of natural resources within the country, and provide economic support for decisions to protect these valuable resources using tools such as marine protected areas.

In a review of the literature, Schagner et al. (2013) found that approximately one third of studies do not discuss the potential errors and inaccuracies of either the mapping or valuation of ecosystem service supply. Economic valuation is a subjective process that often relies on the stated preferences and values of individuals, which can show extremely large variations between different people and different locations (DEFRA, 2007). The drawbacks of these techniques are something that should be addressed, and this can be done qualitatively through a discussion of the potential sources of errors or quantitatively through estimated error margins or validity tests (Schagner et al., 2013).

### 1.3.5 Environmental Sensitivity Index Mapping

There are three general types of ESI maps made for spill response preparation, and these are biological resource maps, human-use resource maps, and shoreline classification maps (NOAA, 2002). Biological resource maps provide the locations and extents of plant and animal aggregations or the locations of habitats that support important life cycles of these species. Human-resource maps depict important coastal recreation/access sites, resource extraction sites, management areas, and sites of social or cultural importance. Shoreline classification maps depict shoreline types and their associated ESI rankings, (NOAA, 2002), and are considered the most important component of sensitivity mapping for spill response (Percy, LeBlanc, and Owens, 1997). This importance is due to the direct links from these maps to the operational response in the event of a spill. When these data are stored in GIS, predicted oil behaviour and proposed response and cleanup methods can be linked to each shoreline segment.

The three factors that determine the sensitivity of a shoreline segment are the shoreline type/material, the biological sensitivity, and the level of wave exposure (NOAA, 2002). The nine standard shoreline classification types typically used are: bedrock, man-made solid, boulder beach, pebble-cobble beach, mixed-sand-gravel beach, sand beach, sand tidal flat, mud tidal flat, and marsh. The differences between these substrates in terms of sensitivity mainly relate to the length of time that oil will reside within them. The biological sensitivity relates most heavily to tidal flats and marshes, which are complex habitats that show long-term damage from exposure to oil. The level of exposure to wave and tidal energy generally dictates the persistence of stranded oil, with high-energy areas being washed clean of oil most quickly (NOAA, 2002).

All of these factors are included within the shoreline classification ESI, which generally is represented as a one to ten ranked scale of sensitivity. The ESI that is commonly used for reference is the one produced by Gundlach and Hayes (1978) (Table 1-3). This basic ESI has been expanded upon throughout the literature in a variety of ways, and can be tailored to better represent specific locations (IMO and IPIECA, 1996).

**Table 1-3**. Vulnerability of shoreline types to oil exposure (adapted from: Gundlach and Hayes, 1978).

| Vulnerability Index | Shoreline Type | Comments |
|---|---|---|
| 1 | Exposed rocky head-lands | Wave reflection keeps most of the oil off-shore. No clean-up is necessary. |
| 2 | Eroding wave-cut platforms | Wave swept. Most oil removed by natural processes within weeks. |
| 3 | Fine-grained sand beaches | Oil doesn't penetrate into the sediment, facilitating mechanical removal if necessary. Otherwise, oil may persist several months. |
| 4 | Coarse-grained sand beaches | Oil may sink and/or be buried rapidly making clean-up difficult. Under moderate to high energy conditions, oil will be removed naturally within months from most of the beachface. |
| 5 | Exposed, compacted tidal flats | Most oil will not adhere to, nor penetrate into, the compacted tidal flat. Clean-up is usually unnecessary. |
| 6 | Mixed sand and gravel beaches | Oil may undergo rapid penetration and burial. Under moderate to low energy conditions, oil may persist for years. |
| 7 | Gravel beaches | Same as above. Clean-up should concentrate on the high-tide swash area. A solid asphalt pavement may form under heavy oil accumulations. |
| 8 | Sheltered rocky coasts | Areas of reduced wave action. Oil may persist for many years. Clean-up is not recommended unless oil concentration is very heavy. |
| 9 | Sheltered tidal flats | Areas of great biologic activity and low wave energy. Oil may persist for years. Clean-up is not recommended unless oil accumulation is very heavy. These areas should receive priority protection by using booms or oil sorbent materials. |
| 10 | Salt marshes and mangroves | Most productive of aquatic environments. Oil may persist for years. Cleaning of salt marshes by burning or cutting should be undertaken only if heavily oiled. Mangroves should not be altered. Protection of these environments by booms or sorbent material should receive first priority. |

Sensitivity information is crucial to have readily available in the event of a spill in order to determine the necessary response actions quickly and efficiently (Percy, LeBlanc, and Owens, 1997).

## 1.4 Research Questions and Study Purpose

The main research question to be answered within this study is: In the context of the Port Hawkesbury Area Response Plan development, what are the coastal areas of highest priority for protection and detailed response planning in the event of an oil spill? This study will incorporate the use of ecosystem service valuation and environmental sensitivity analyses in order to identify these areas. Recommendations will be made on the priority locations for response planning and further data collection studies in the early stages of ARP development. Conclusions made through this analysis on the merit of incorporating ecosystem service principles into spill response planning initiatives will be included in the discussion and recommendations.

The secondary purpose of this study is to characterize the environment in which this ARP development is occurring, and determine what spatial data are available that depict the physical, biological, and human-use information essential for spill response planning. Recommendations will be made on priorities for future data collection within the Port Hawkesbury ARP development based on the availability and quality of the data found.

To answer these questions, the following sub-questions will be addressed in sequence throughout this report:

1. What are the physical and biological characteristics and human-use activities located within the coastal and marine zones of the study site, and what spatial data are available depicting these features?
2. What are the main ecosystem services provided by coastal habitats within the study site?
3. What are the estimated total monetary values of these coastal habitats based on their provision of ecosystem services?
4. Which coastal habitats are most sensitive to oil and how is that sensitivity distributed throughout the study site?
5. Which coastal areas have the highest overall sensitivity when ecosystem service values and environmental sensitivity values are combined?
6. How does the inclusion of ecosystem services values impact/add to the sensitivity analysis?

## 2.0 METHODS

The research for this study was completed in four main stages. A description of the study site was first completed to provide context to the analysis and to determine the quality and extent of the spatial data critical for ARP that exists for this region. A quantitative and qualitative valuation of the ecosystem services provided by coastal habitats occurring within the study site was then completed to determine the ranking of value of these habitats in order to inform area prioritization. The sensitivity of these habitats to oil was then determined and the distribution of these sensitivities was displayed using GIS. The software used for all map creation and spatial data analysis was

ArcGIS version 10.2. Finally, the values of the coastal habitats determined in step three were combined with sensitivities to determine the overall priority areas for protection and response planning within the study site. The following sections will describe the methods of each of these steps in detail.

## 2.1 Study Site Profile

The physical, biological, and human-use characteristics, activities and resources found within the study site were determined through a literature search of academic literature, grey literature (including technical reports and government documents), and news articles. A search was also conducted for any spatial data depicting the marine and coastal features within this area, and a list of all data layers used within this study, including their sources, can be found in Appendix A. The majority of these data were obtained from publicly available sources provided by federal, provincial, and municipal departments.

The coastal habitats to be included in the study site description and within the ecosystem service valuation (ESV) and oil sensitivity analyses were chosen from the Nova Scotia Department of Natural Resources wetlands inventory. This inventory was developed to delineate freshwater wetlands, coastal wetlands, and coastal habitats, and was created via visual interpretation of aerial photographs from the 1980s and 1990s (NSDNR, 2000). The major coastal wetlands and habitats occurring within Nova Scotia as described and mapped within this inventory include:

- Beaches
- Dunes

- Estuarine flats
- Marine flats
- Salt marshes
- Eelgrass beds
- Coastal saline ponds
- Cliff faces
- Islands
- Dykelands
- Impoundments

To create the wetlands inventory, these habitats were digitized as polygons (i.e. digital shapes representing real world features) within a GIS and were linked with descriptive data, such as the area of each polygon in hectares (NSDNR, 2000). No impoundments were found to occur within the study site and this feature was therefore excluded from any analyses. Dunes and dykelands were also excluded because it was determined that their setback from the shoreline makes them unlikely to be impacted by spilled oil. The distinction between estuarine and marine flats was due to their location within either sheltered or open ocean environments respectively (NSDNR, 2000). This distinction was determined to be unnecessary since the degree of coastal exposure for all habitats was determined manually (Section 2.3.1), and the two features were therefore merged into one layer (i.e. the grouping of geographic features in a digital environment from one data source) in ArcGIS.

Eelgrass beds were described and mapped in this wetlands inventory through their association with other features such as mud flats and salt marshes, but were not mapped as a separate feature due to a lack of information on their exact spatial extents (NSDNR, 2000). The spatial data included in this study depicting eelgrass locations were therefore taken from the Canadian Wildlife Service Maritimes Wetland Inventory (Hanson and

Calkins, 1996), and this map layer includes only point locations of eelgrass with no description of spatial extent.

## 2.2 Ecosystem Service Provision

The ecosystem value of the coastal habitats occurring within the study site was determined based on their provision of ecosystem services first through economic valuation and then through qualitative valuation. The qualitative valuation results were used in further analysis for area prioritization as described in Section 2.4

### 2.2.1 Economic Valuation

Given time and resource constraints, a full valuation study was not feasible. Instead, the ESV of coastal habitats was accomplished using the benefit transfer technique. This first involved a search of the valuation databases and academic literature for original valuation studies that included economic valuation of the coastal habitat types used in this study. All potential relevant studies were collected and then the context of each study was assessed in order to eliminate unsuitable data. The first criterion used to eliminate studies was the latitude range of the country in which the data was collected. It was assumed, as per the benefit transfer methods used by van den Belt and Cole (2014), that latitudes (in either the northern or southern hemisphere) similar to those in the location of this study site would result in relatively similar coastal and marine environments. The second criterion used was the context of the study. Priority was given to more recent studies using well-explained and practical valuation techniques. Each study used was given a confidence rating of ‘high’, ‘moderate’, or ‘low’ based on its estimated similarity to the current context of this study site.

Each value that was suitably similar for transfer was converted to the equivalent of 2014 US dollars. This rate chosen because many of the values in the literature already exist as US dollars and this was deemed suitably similar to the value of the Canadian dollar for the purpose of this study. The only values found for transfer were already in US dollars, so the US Consumer Price Index was used for conversion to 2014 values (US Bureau of Labor and Statistics, 2014).

The valuation of a natural feature involves a separate valuation of each ecosystem service provided by that feature, and therefore the TEV is a sum of all the individual services. The values to be transferred for each habitat type were first sorted into either ‘provisioning’, ‘regulating’, ‘supporting’, or ‘cultural’ service categories as defined by the MEA (2005). In cases where there was more than one value for a particular ecosystem service across multiple studies, the values were averaged. The sum of the averages of all four categories resulted in the TEV for each habitat type. The lowest and highest possible values in each category without averaging were also calculated to show the range from which the average value was derived.

### 2.2.2 Qualitative Valuation

As an alternative to economic valuation, the levels of ecosystem provision for each coastal habitat were also determined qualitatively in order to provide a relative ranking of the habitats from highest to lowest value. This was done in order to combine the values of each coastal habitat with their determined environmental sensitivity in a later analysis for area prioritization.

The ecosystem services categories included within this valuation were determined based on the MEA description of ecosystem services provided by coastal wetlands and habitats (Table 2-1). A more detailed explanation of each service can be found in Table 1-1. The relative level of provision value ('high', 'medium', 'low', or 'negligible or unknown') for each service was determined using descriptive information for each habitat. This information was found through a search of the academic and grey literature for the physical, biological, and human-use characteristics of each coastal habitat, as well as its level of rarity within Nova Scotia. Literature describing these habitats in the context of Nova Scotia or elsewhere in Atlantic Canada was used as the primary source of information. Any gaps in information were filled with the relative values assigned to these habitats by the MEA (2005b), with the exception of rocky cliffs, which was not included in the MEA assessment. Indeterminable services for this habitat were not given any value.

**Table 2-1.** The main ecosystem services provided by coastal wetlands and habitats as determined by the MEA (2005b). (Highlighted services indicate exclusion from this analysis)

| **Category** | **Service** |
|---|---|
| Provisioning | Food |
| | Fresh water |
| | Fiber, timber, fuel |
| | Biochemical products |
| | Genetic materials |
| Regulating | Climate regulation |
| | Biological regulation |
| | Hydrological regimes |
| | Pollution control and detoxification |
| | Natural hazards |
| Supporting | Biodiversity (habitat provision) |
| | Soil formation |
| | Nutrient cycling |
| Cultural | Spiritual and inspirational |

| | |
|---|---|
| | Educational |
| | Aesthetic |
| | Recreational |

Within provisioning services, 'biochemical products' and 'genetic materials' were not included due to a lack of supporting information for these services within the literature across all habitat types. The 'fresh water' category was not included due to the difficulty in distinguishing this service from the 'hydrological regimes' regulating service. Spiritual and aesthetic services were grouped into one category for the analysis due to the difficulty in determining distinct levels of values between these categories, and 'educational' services were not included due to a lack of supporting data.

To determine the relative ranking of value among the habitat types, a quantitative value was associated with the qualitative ratings. Services with 'high' value were given a score of three, 'medium' two, 'low' one, and 'negligible or unknown' zero. The scores were then summed for each habitat type. To further tailor these values to apply specifically to Nova Scotia habitats, extra value points were given to habitats considered rare within the province as described within the literature. This was done because simple economic principles predict that a decline in the abundance of an important natural feature increases its value (Costanza et al., 1997). Three extra points were given to habitats considered rare within Nova Scotia.

These summed values were then normalized into a ten-point scale in order to match the ESI scale for the final overlay analysis. This was done with a simple rescaling formula.

$$\mathbf{x'} = 1 + \frac{(x - \mathbf{A})(\mathbf{b} - \mathbf{a})}{\mathbf{B} - \mathbf{A}}$$

Where **x′** is the normalized value, **x** is the original value, **A** is the lowest value in the original dataset, **B** is the highest value in the original dataset, **a** is the lowest value of the new scale (i.e. one) and **b** is the highest value of the new scale (i.e. ten). Values had to be rounded to the closest integer in order to be incorporated into the analysis in ArcGIS.

## 2.3 Environmental Sensitivity Index Mapping

Each coastal habitat was assigned a relative sensitivity score from one to ten (one meaning low sensitivity and ten meaning high) based on the ESI created by Gundlach and Hayes (1978) for shoreline vulnerability to oil exposure (Table 1-3). Within this ESI, information on substrate particle size and the level of exposure to wave action is necessary to determine sensitivity for some shoreline types (Gundlach and Hayes, 1978). In order to assign accurate sensitivity values to the coastal habitats used in this study, the division of some habitat types into more specific categories was necessary. Once all habitat polygons were re-defined and assigned a sensitivity value, they were displayed in GIS to show these varying levels of sensitivity along the coast of the study site.

### 2.3.1 Classification of Sensitivity

The ‘beaches’ data layer includes information describing the substrate type for each polygon, with seven possible categories, including ‘clay/silt’, ‘mud’, ‘sand/mud’, ‘sand’, ‘sand/gravel/rock’, ‘cobble’, and ‘rock’, with descriptions of the range of particle size measurements for each category in the wetlands inventory documentation (NSDNR, 2000). The categories of beaches within the ESI with their associated sensitivity values include ‘fine-grained sand’ (3), ‘coarse-grained sand’ (4), ‘mixed sand and gravel’ (6), and ‘gravel’(7) (Gundlach and Hayes, 1978). The descriptions of particle size measurements for these categories from both sources were used to separate the beach habitat layer into categories matching the ESI as closely as possible. This separation was performed in ArcGIS by reclassifying the polygons from the beach layer by their substrate size attribute, and applying appropriate ESI values (‘coarse-grained sand’ ESI value = 4, ‘mixed substrate’ ESI value = 6, and ‘cobble/rock’ ESI value = 7). No beaches occurred within the study area that matched the ‘fine-grained sand’ category of the ESI.

Both the mud flat and rocky cliff layers also required reclassification in order to better align with the ESI categories. These categories have different sensitivity values depending on if they occur in a sheltered or open ocean environment (Gundlach and Hayes, 1978). Exposed locations in the ESI are described as “relatively exposed to winds, waves and currents” (Gundlach and Hayes, 1978, p. 22). The level of exposure of the coastal habitats in this study was determined through the use of exposure classification maps created by Cairns et al. (2012), which depict the intertidal and subtidal regions of Nova Scotia as either ‘sheltered’, ‘semi-exposed’, or ‘exposed’ (Figure 2-1). These classifications describe the relative level of exposure to the open ocean (Cairns et al., 2012). The mud flat and rocky cliff habitats were classified under these categories in ArcGIS by overlaying them onto the exposure layer, and determining their overlap with each exposure category through the use of both the ‘Intersection’ tool and manual selection. This resulted in three separate layers for both mud flats and for rocky cliffs. Because the ESI does not include a ‘semi-exposed’ category, the sensitivity value assigned to these habitats within this category was the median value between the ‘sheltered’ and ‘exposed’ categories. For example, ‘exposed’ mud flats have a value of 5, and ‘sheltered’ mud flats have a value of 9, therefore the ‘semi-exposed’ mud flats were assigned a value of 7. Because the median value for rocky cliffs was 4.5, this was rounded up to five in order keep all values in an integer format.

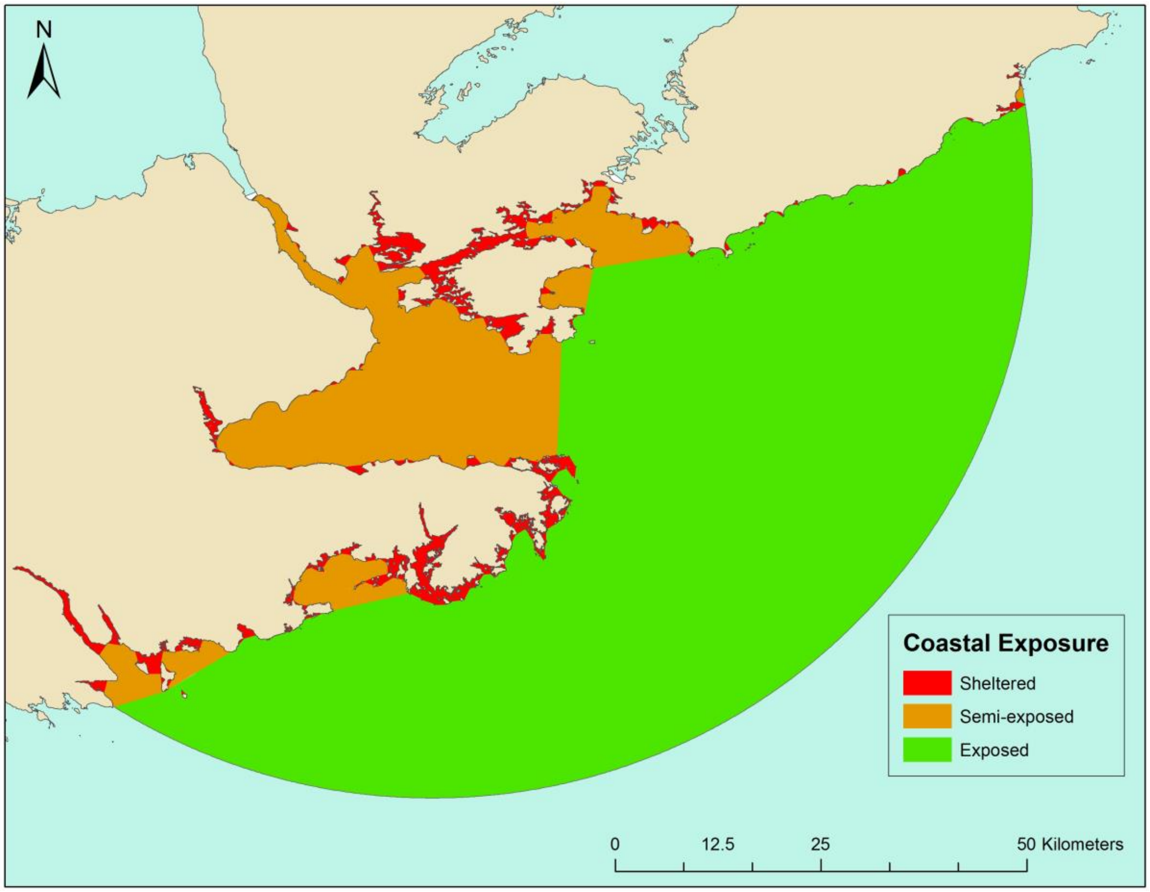


**Figure 2-1**. Coastal exposure levels within the study site. Data layers from Cairns et al. (2012).

The salt marsh layer matched the ESI category without any further classification. Coastal saline ponds and eelgrass beds were not included in the ESI by Gundlach and Hayes (1978), and typically are not included in any ESI (IMO and IPIECA, 1996). These habitats are typically not included in ESIs because their exact sensitivity to oil is difficult to determine, and often depends on the conditions of the spill and the local environment (IMO and IPIECA, 1996; Johnston and Gilliland, 2000). Coastal ponds can be heavily impacted by pollutants since they typically have very low flushing rates, but it is more difficult for oil to reach these habitats due to the restricted water input from the ocean (Johnston and Gilliland, 2000). It has also been demonstrated that eelgrass beds are impacted by large spills, but the majority of these impacts are seen in the flora and fauna living within these habitats (IMO and IPIECA, 1996; Johnston and Gilliland, 2000). Because these habitats have been shown to have sensitivity to oil in certain conditions, they have both been assigned a sensitivity value of three. This lower value was chosen as these habitats are not normally included in ESIs and there is a high degree uncertainty regarding their sensitivity.

### 2.3.2 Sensitivity Mapping

The purpose of mapping the sensitivities of these habitats is to highlight the coastal areas with the highest sensitivity to oil within the study site. In order to better visualize these areas, as well as show where there are aggregations of multiple sensitive habitats, each habitat polygon was given a 100-metre buffer in ArcGIS. This buffer increases the area of each polygon by adding a zone of equal distance around each feature. They only exception was the eelgrass layer, which only provides point locations of eelgrass beds with no spatial extents. To estimate the extents in order to create a buffer zone, kernel density data created by Allard, Hanson, and Mahoney (2014) was used (Appendix B, Table B-3). These data show an estimated relative density of eelgrass features, and eelgrass points falling in areas of low density (determined by estimation) were given a 200 metre buffer, medium density were given a 350 metre buffer, and high density were given a 500 metre buffer. If any polygons of the same habitat type overlapped after applying the buffer, these overlapping areas were removed using the 'Dissolve' tool so that their sensitivity values were not summed in the overlay.

The sum of all overlapping sensitivity values was determined through an Overlay Analysis in ArcGIS. First, all polygon layers were converted to raster (pixel-based) data using the 'Polygon to Raster' tool, with every pixel of each habitat maintaining its original sensitivity value. The overlay of each habitat was done using the 'Cell Statistics' tool, which resulted in a map showing the summed sensitivity values for all coastal areas of the study site. To highlight locations with the highest sensitivity, the areas with a total value in the top 25 percent of value categories were expanded. For example, if the highest possible total value in the overlay was 100, all areas on the map that had a total value of 75 or higher were highlighted. This was done using the 'Expand' tool in ArcGIS, which expands the pixels of a map based on your chosen criteria.

## 2.4 Value and Sensitivity Overlay

In order to show the areas within the study site with both high ecosystem value and high sensitivity, the qualitative ecosystem service values determined in Section 2.2.2 were added into the analysis. This was done by first following the same steps in creating the sensitivity overlay (Section 2.3.2), but instead of using the oil sensitivity values, the ecosystem service values (normalized to a 1:10 scale) were assigned to each buffered habitat polygon.

The resultant output was an overlay of all habitat ecosystem service values. For the final overlay, value and sensitivity were considered to be equally important and were therefore given equal weighting in the analysis. These two variables were combined by overlaying the ecosystem service value and sensitivity outputs and averaging the values. For example, if one pixel had a sensitivity value of 10 and an ecosystem service value of 10, the resultant final overlay value would remain at 10. If a pixel had a sensitivity value of 20 and an ecosystem service value of 12, the final overlay value would be 16.

### 2.5 Comparison of Approaches

In order to determine the differences between the analysis including only oil sensitivity and the analysis combining sensitivity and ecosystem service value, maps were created for both of these analyses that highlighted the areas of highest value. This was done by only displaying areas that have a value falling within the top 25 percent of value categories, as it was described in Section 2.3.2.

## 3.0 RESULTS

### 3.1 Physical and Biological Characteristics of the Study Site

The majority of the study site is located within Chedabucto Bay, the largest and deepest bay on the Atlantic coast of Nova Scotia (Davis and Browne, 1996; Gregory et al., 1993). The Chedabucto Fault cuts through the Bay of Fundy, across mainland Nova Scotia, and into Chedabucto Bay near the northern edge of the Canso peninsula (Lane and Associates Ltd, 1992). This fault creates a difference in substrates found to the north and south of this line, with more exposed bedrock and rockier coasts to the south, and sandier shorelines found to the north (Greenlaw et al., 2012). This study site can be broken down into six coastal segments based on similarities such as coastal substrate, topography, coastal habitat, and geological characteristics (described in Table 3-1). A visual representation of these segments can be seen in Figure 3-1.

**Table 3-1.** Descriptions of location and defining characteristics for each coastal segment within the study site (adapted from: Greenlaw et al., 2012).

| Segment | Segment Delineations | Defining Characteristics |
|---|---|---|
| 1 | Cape Mocodome (Fishermans Harbour) to Flying Point (Tor Bay) | • This area has complex inlets with some marine and estuarine flats and sandy beaches<br>• The coastal substrate is a mix of coarse substrate and sand |
| 2 | Flying Point to Glasgow Head (near town of Canso) | • This area is defined by its large headlands, with predominately boulder and bedrock substrates<br>• There are few coastal landforms apart from some small marine flats |
| 3 | Glasgow Head to Toby Point (near Guysborough Harbour) | • There are few inlets within this segment and the substrate is fairly rocky |
| 4 | Toby Point to Eddy Point (near the Straight of Canso), including the southern island shorelines from Crichton Island to Petit Nez Beach (on Isle Madame) | • Overall this segment has a simple coastline with few landforms, with some marine flats found throughout and coastal saline ponds and beaches on the more northern shores |
| 5 | Eddy Point, up into the Straight of Canso, to Point Brulee (by St. Peter's Bay), including the northern island shorelines from Crichton Island to Petit Nez Beach | • This segment of shoreline is very complex with marine flats, estuaries, coastal saline ponds, and some beaches and salt marshes<br>• There are many small islands and sheltered coastline with a wide range of substrate types, predominately coarse and sandy<br>• Shoreline is very complex with several islands, and most of this class is quite sheltered |
| 6 | Point Brulee to Barren Point (at the border of Richmond County and Cape Breton County) | • The coastline of this segment is long and straight, with some barrier beaches and coastal saline ponds<br>• The substrate is mostly bedrock, with some sandy beaches in the intertidal zone |

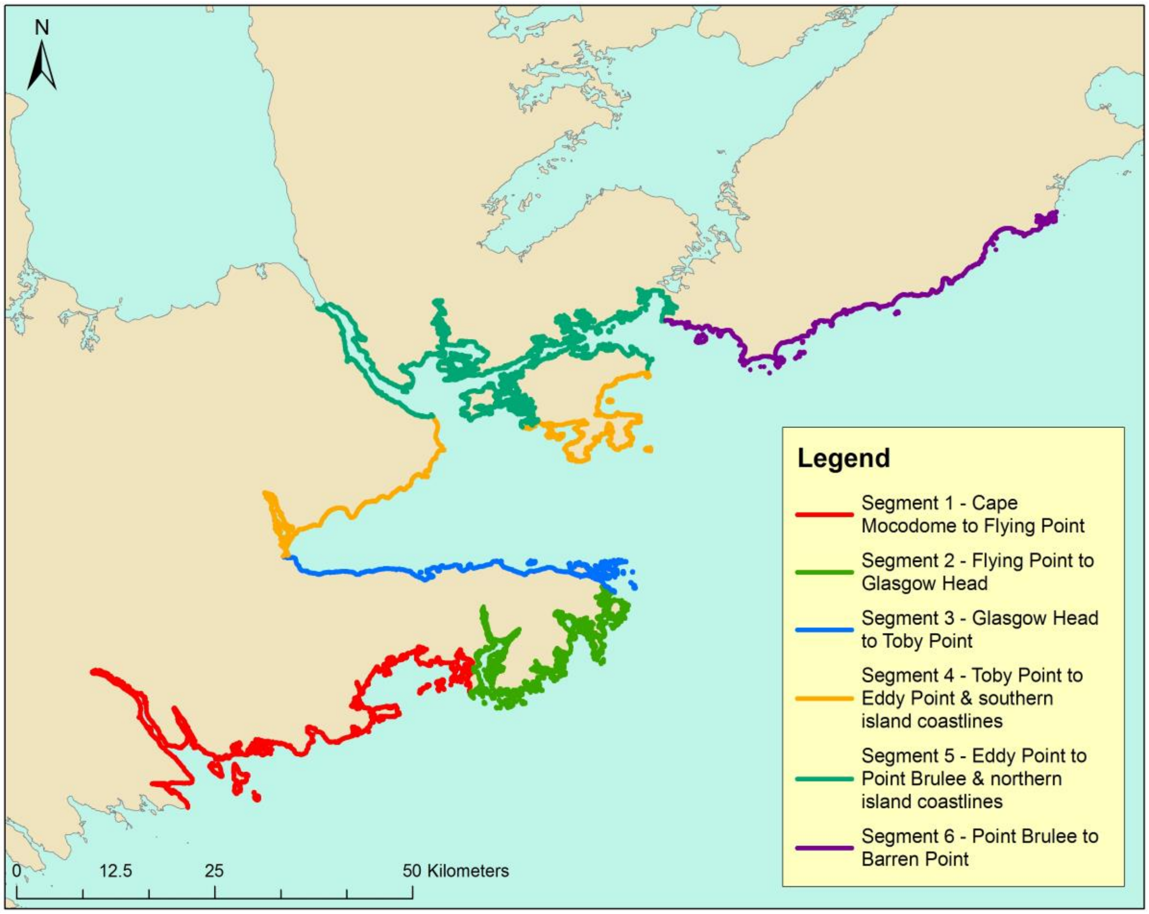


**Figure 3-1.** Depiction of six coastal segments within the study site as classified by Greenlaw et al. (2012).

### 3.1.1 Species Aggregations

Chedabucto Bay is an important location for many marine mammals, birds, fish and invertebrates species. The steep slope that occurs off the coast of the Canso Ledges creates nutrient upwelling that nurtures a high invertebrate diversity (DFO, 2006), including rare coastal aggregations of northern shrimp and snow crab (Koeller, Covey and King, 2007; Tremblay, 2006). The bay is an important spawning and overwintering area for Atlantic herring as well an area with high aggregations of bluefin tuna (Lane and Associates Ltd, 1992; COSEWIC, 2011). The locations where some of these species aggregate can be partly inferred from fisheries landings maps, which can be found in Section 3.2.

Many species of seabirds, shorebirds, and migratory waterfowl can be found within this area, particularly in the coastal barrens of the Canso Ledges and on the eastern shores of Cape Breton Island (Davis and Browne, 1996). The relative abundance and distribution of these bird species as well as their important coastal habitats has been thoroughly described in a report by Allard, Hanson and Mahoney (2014), including maps of colony locations and densities for the whole of Atlantic Canada. There are also three Important Bird Areas that occur within this study site, which are sites identified based on bird aggregation of a national or global level of significance (IBA Canada, 2014).

Several species of seals and whales can been seen within the bay at various times throughout the year, including Fin Whales which are listed under the *Species at Risk Act* (SARA) as a species of Special Concern (Lane and Associates Ltd, 1992). Other at risk species that can be found in this area, including species identified by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), include the Atlantic wolffish (SARA listed, Special Concern), thorny skate (COSEWIC listed, Special Concern), and winter skate (COSEWIC listed, Threatened), as well as potentially cusk and white hake (both Endangered under COSEWIC) (Harris 2006). No spatial data could be found that pinpoints the locations of important habitat or aggregations of these species within the study site.

### 3.1.2 Coastal Habitats

The coastal habitats that occur within the study site and were determined to be important for consideration within this study are:

- Beaches
- Mud flats
- Salt marshes
- Coastal saline ponds
- Rocky cliffs
- Eelgrass

At a small scale, these habitat polygons are not visible and it is therefore difficult to visualize their overall distribution within the study site. An example of the size and distribution of these habitats can be seen in Figure 3-2. The distribution of beaches, mud flats, salt marshes, eelgrass beds and rocky shores is more clearly depicted in kernel density maps created by Allard, Hanson, and Mahoney (2014) (Appendix B). These maps were created through the use of ‘Point Density Analysis’ tools within ArcGIS software, which roughly summarizes the abundance of each habitat by calculating the density of the feature within a fixed area (Allard, Hanson, and Mahoney, 2014). No kernel density map exist showing coastal saline ponds distribution.

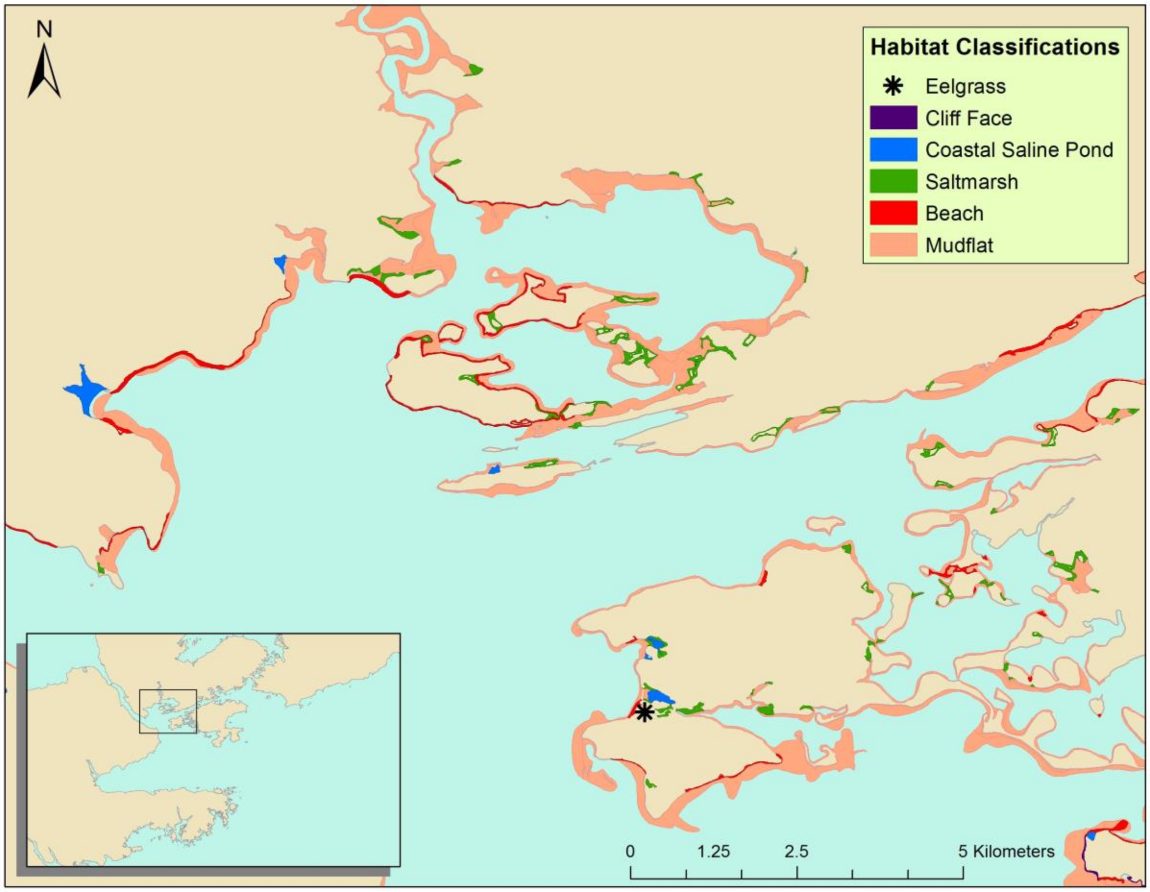

**Figure 3-2**. Representation of coastal habitats near the entrance to the Straight of Canso.

### 3.2 Human-Use Characteristics of the Study Site

There are a variety of activities occurring within the marine and coastal areas of this region that could be impacted by an oil spill, such as commercial and recreational fishing, shipping, tourism, and the day-to-day activities of those that live along the coast. Conversely, these activities are also impacting the environment, and this is depicted in a map of the Index of Human Influence within the Atlantic Provinces (Figure 3-3). This map is useful in differentiating between more "natural" and "disturbed" terrestrial areas and is based on human settlement data, access routes, landscape transformations, and power infrastructure (Woolmer et al., 2008). The extreme southern and northern portions of the study site have very low human influence whereas the northern portion of Chedabucto Bay has comparatively high human influence, as does the Canso area.

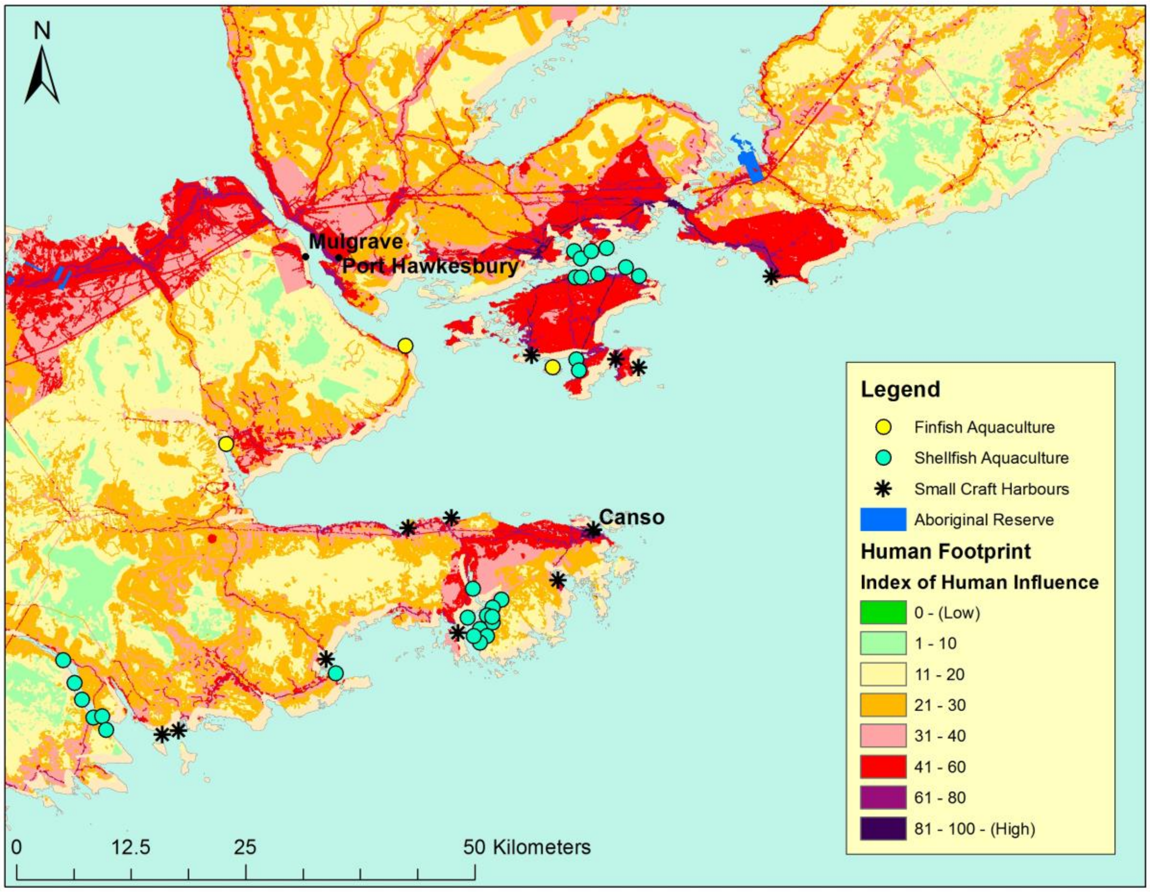


**Figure 3-3**. Level of human influence on the environment and locations of the most populous towns, aquaculture sites, and Small Craft Harbours within the study site.

The most populous coastal communities within the study site include Canso (806), Mulgrave (794), and Port Hawkesbury (3,366) (Statistics Canada, 2012). The majority of the coastal areas outside these population centers are very sparsely populated. There is only one Aboriginal reserve (Potlotek First Nation) located near the study site (Figure 3-3), but it should be assumed that coastal access throughout this area is important to Aboriginal people for a variety of reasons, including access for food/social/ceremonial fishing and hunting.

There are currently 29 active shellfish lease sites, and three active finfish site leases (Department of Fisheries and Aquaculture, 2014). The majority of these sites are aggregated in Country Harbour, Whitehead Harbour, and in the eastern portion of Lennox Passage (Figure 3-3). There are also twelve Small Craft Harbours disbursed throughout the study site, which are harbours operated and maintained by Fisheries and Oceans Canada to provide safe and accessible facilities for commercial and other fishermen (DFO, 2008).

Based on a review of the 2006-2010 fisheries composite maps from Fisheries and Oceans Canada, the four most important commercial fisheries within this area include bluefin tuna, shrimp, snow crab, and scallop (DFO, 2005) (Figure 3-3). The majority of the commercial fishing activity near the coast is occurring around the Canso peninsula, where the steep drop-off in sea floor depth creates a rich environment for many invertebrate and fish species (DFO, 2006). The offshore fishing activity appears to be disbursed throughout the study site.

Shipping is another common activity in this area, and the high densities of ship traffic flow in and out of Port Hawkesbury through the center of Chedabucto Bay (Simard et al., 2014). Plans to develop a new container port as well as an LNG terminal in the Straight of Canso are currently underway, and this will likely increase shipping activities in the future (NSE, 2014; ABN Newswire, 2014).

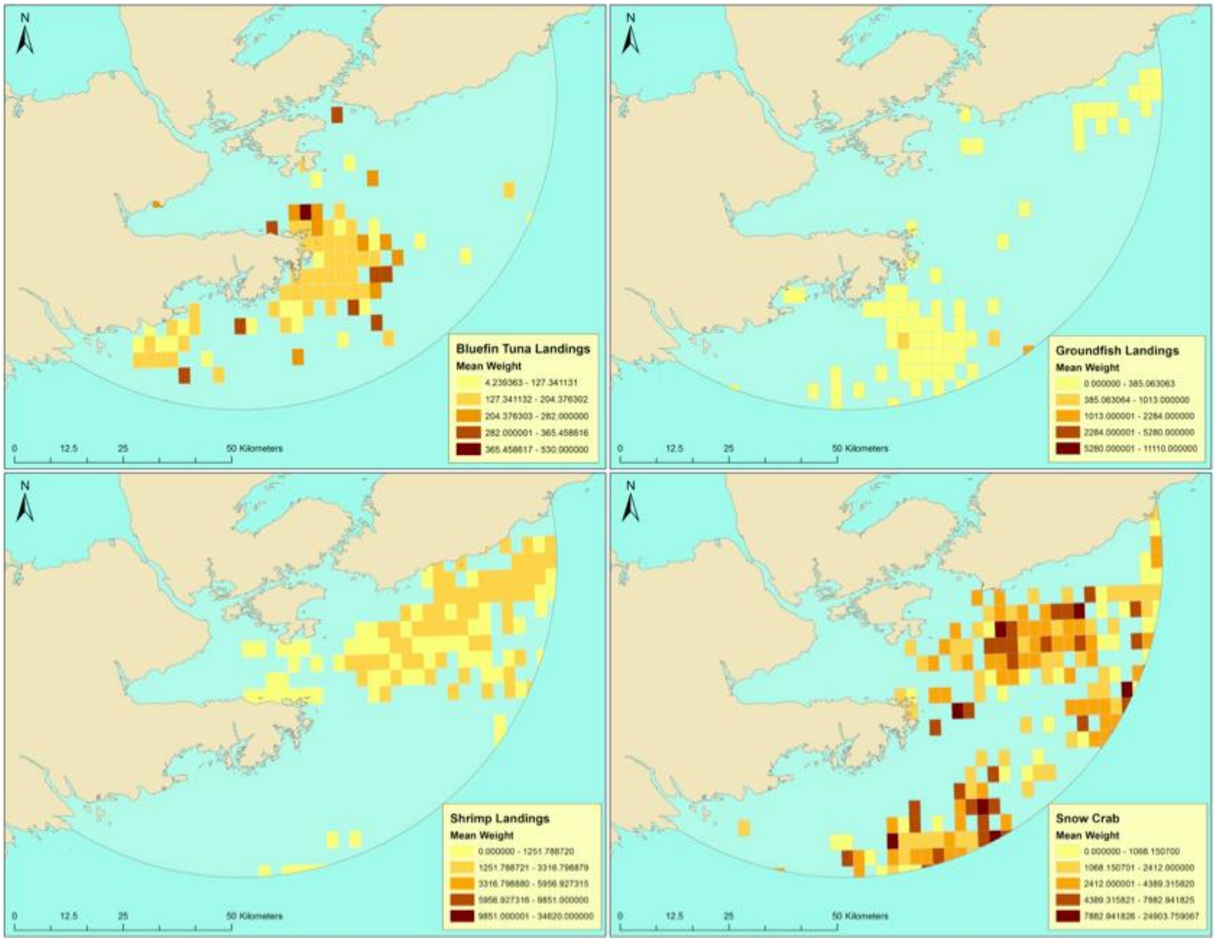


**Figure 3-4**. Distribution of bluefin tuna, groundfish, snow crab, and shrimp landings by aggregate weight within the study site, depicted in 2 by 2-minute grid cells (data from DFO, 2006-2010 fisheries composite maps).

### 3.2.1 Protected Areas and other Areas of Significance

This region contains numerous provincially protected terrestrial areas such as Nature Reserves, Wilderness Areas, and Provincial Parks located on or near the coast, all of which have special land-use regulations supported by legislation (NSDNR and NSE, 2013). These areas are important for inclusion in spill response planning because they tend to have higher aggregations of wildlife which would be impacted by a spill (IMO and IPIECA, 1996). These three types of protected areas are defined thus by the government of Nova Scotia:

- Wilderness areas protect nature and support wilderness recreation, hunting, sport fishing, trapping, and other uses.

- Nature reserves offer the highest level of protection for unique or rare species or features; the reserves are mostly used for education and research.

- Provincial parks and reserves protect nature and support a wide range of heritage values and opportunities for outdoor recreation, nature-based education, and tourism (NSDNR and NSE, 2013, p. 5).

The distribution of Wilderness Areas and Provincial Parks are available in downloadable map layers provided by the Nova Scotia Department of Natural Resources (Figure 3-5). There are also two small National Historic Sites within the study site: Canso Islands and St. Peter's Canal (Parks Canada, 2009a). The cultural and natural resources within these two sites are protected by Parks Canada, and both sites are popular tourist destinations (Parks Canada, 2009b and 2009c). Water supply areas near the coast that have potential for contamination from spills should also be noted, and this information was also available in GIS from the Nova Scotia Department of Natural Resources (Figure 3-5).

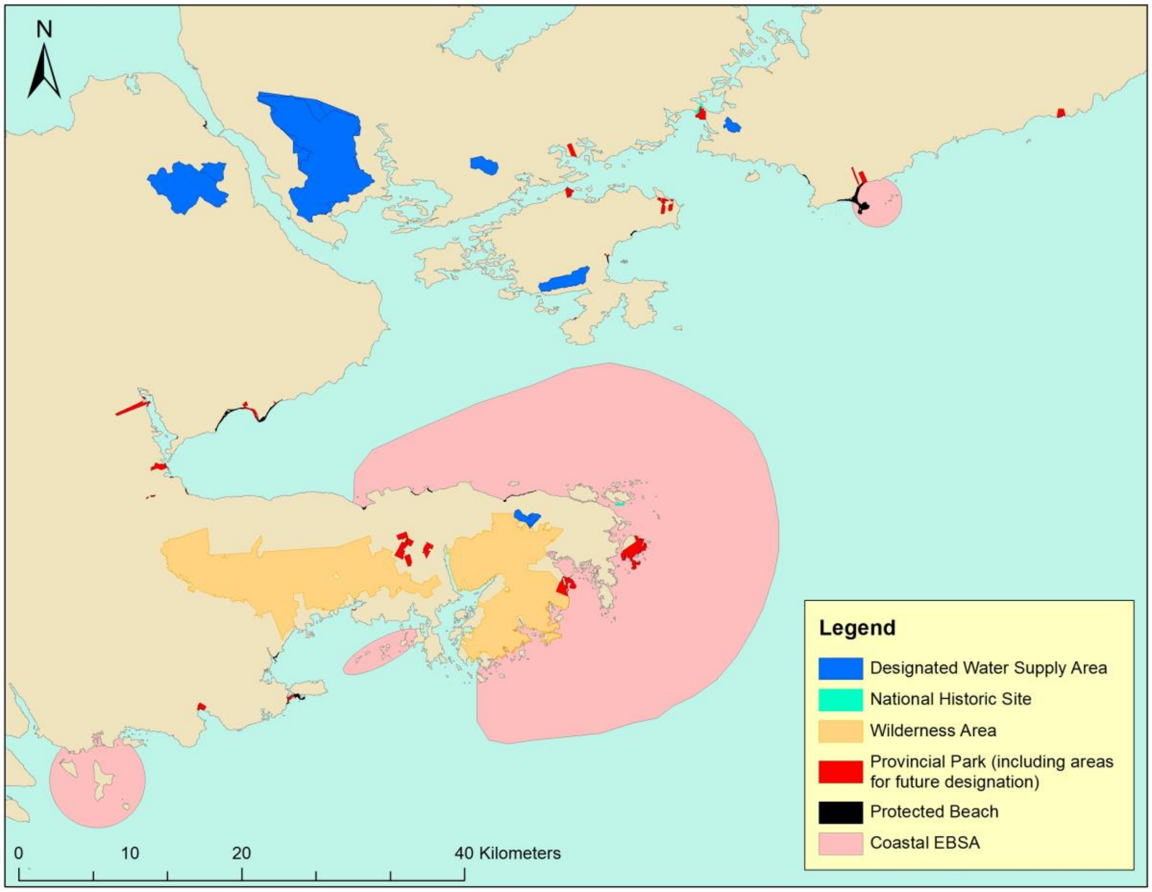


**Figure 3-5**. Protected areas and other areas of significance on or near the coast within the study site.

Fisheries and Oceans Canada have identified four Ecologically and Biologically Significant Areas (EBSAs) within this region (Hastings et al., in press). EBSAs are chosen based on high ecological importance and conservation value, and any major disturbance of these areas is expected to result in greater ecological consequences as compared to other areas. The largest EBSA covers the Canso Ledges and stretches toward the center of Chedabucto Bay, and is an important breeding and feeding area for many fish, invertebrate, marine mammal and bird species. The other three areas are quite small in comparison and include Country Harbour Islands, Sugar Harbour Islands, and

Point Michaud and Basque Islands (Figure 3-5). These three areas were primarily chosen due to significant aggregations of birds (Hastings et al., in press).

## 3.3 Ecosystem Service Provision

The values of each habitat identified in Section 3.1.2 were first valued economically using the benefit transfer technique. Due to the limited available valuation data for each habitat, these habitats were also valued based on qualitative information. The relative values of these habitats from the qualitative analysis were later included in the sensitivity and value overlay.

### 3.3.1 Economic Valuation

Only three out of the six coastal habitat types found in this study site could be included in the economic valuation due to a lack of suitable data for benefit transfer found in the literature. Beach, salt marsh, and eelgrass habitats were valued in 2014 US dollars per hectare per year (Table 3-2). For these three habitats, the total average values showed that salt marshes were the most economically valuable habitat, followed by beaches, then eelgrass. However, the range of possible values for salt marshes is three times that of its average value, which makes the comparison between habitats difficult due to high levels of uncertainty.

The studies used to determine these values can be found in Appendix C (Table C-1). This table includes the confidence ratings assigned to each study based on the determined contextual similarity to this study site. Nine out of the 20 studies used were assigned a ‘low’ confidence rating, and only five were assigned a ‘high’ confidence rating.

**Table 3-2**. Average estimates of ecosystem service values in $USD_{2014}$/ha/yr for coastal habitat types within the study site. Values were determined through benefit transfer, and rounded to the nearest dollar (range of values are provided in brackets where more than one value was found within the literature). Dash indicates where no suitable data were found.

| Coastal Habitat | Provisioning Services | Regulating Services | Supporting Services | Cultural Services | Total ($USD_{2014}$/ha/yr) |
|---|---|---|---|---|---|
| Beach | - | **57,057** (31,131 - 67,400) | - | **28,417** (20,070-36,757) | **85,474** (51,201-104,157) |
| Mud Flat | - | - | - | - | - |
| Salt Marsh | **3,506** (271-7,828) | **302, 428** (3,759-894,808) | **4** | **2073** (786-3573) | **308,011** (4,820-906,213) |
| Coastal Saline Pond | - | - | - | - | - |
| Rocky Cliff | - | - | - | - | - |
| Eelgrass | **2,090** | **32,934** | **2,510** | **-** | **37,534** |

### 3.3.2 Qualitative Valuation

Qualitative values for each of the six habitats found in the study site were determined based on descriptions from the literature. Findings for each habitat are provided below, and summarized in Table 3-3.

*Beach*

Sandy beaches (both intertidal and subtidal) provide some habitat for some commercially harvested animals such as crabs and small fish species, as well as support bird foraging and provide refuge for many invertebrate species (Centre for Coastal Resources Management, 2009; Davis and Browne, 1996). Larger particle substrate beaches, such as cobble beaches, often have very high biodiversity due to their support of rockweed, bladderwrack, and kelp species, and these beaches also provide some protection against erosion (CBCL Limited, 2009). Small amounts of storage and recycling of nutrients occur in these environments (MEA, 2005b). Some storm and flood protection is achieved through control of wave run-up, and the presence of filter-feeding animals provides some waste treatment services (Centre for Coastal Resources Management, 2009). Beaches provide many opportunities for tourism and recreation, are highly valued for their strong aesthetic appeal (CBCL Limited, 2009). Both sandy and rocky beaches are widely distributed throughout Nova Scotia.

*Mud Flat*

Mud flats are a very productive habitat with high primary productivity that supports many plant, invertebrate, fish and bird species (Centre for Coastal Resources Management, 2009). Some food species are harvested from these habitats, and they also provide important nutrient cycling services (Allard, Hanson, and Mahoney, 2014). Some soil formation is achieved through the accumulation of organic matter (MEA, 2005b). Small amounts of coastal protection from storms and erosions are achieved through sediment stabilization (Centre for Coastal Resources Management, 2009). Mud flats provide some opportunities for recreation and have high aesthetic value. This habitat is widely distributed across Nova Scotia (CBCL Limited, 2009).

*Salt Marsh*

Salt marshes have very high primary productivity and provide habitat and nursery grounds for many fish, crustacean and other species as well as bird foraging grounds (Centre for Coastal Resources Management, 2009; Davis and Browne, 1996). There is high nutrient uptake and cycling provided by these habitats, as well as wave attenuation and sediment trapping to protect against storms and erosion (Centre for Coastal Resources Management, 2009). Retention and removal of excess nutrients and toxins occurs at a high rate, and soil is formed through the accumulation of organic matter (MEA, 2005b). Salt marshes are highly productive of raw materials and important on a global scale for climate regulation (Davis and Browne, 1996). Marshes provide some opportunities for recreation as well as a high value aesthetically and spiritually (MEA, 2005b). Even though the distribution of salt marshes has been greatly reduced in recent history, they are still considered fairly prevalent throughout Nova Scotia (CBCL Limited, 2009).

*Coastal Saline Pond*

Coastal saline ponds provide refuge and provisions for some species, but tend not to have as high productivity compared to marshes due to fluctuating levels of salinity (Caraco et al., 1987). Coastal ponds are moderately important for climate regulation, waste treatment and flood protection (MEA, 2005b). Moderate opportunities for recreation exist, but there is high potential for aesthetic or spiritual appreciation (MEA, 2005b). Coastal saline ponds are among the most rare coastal habitats in Nova Scotia (CBCL Limited, 2009).

*Rocky Cliff*

Coastal cliffs support some types of vegetation and lichen (CBCL Limited, 2009), but they are primarily important habitat for bird colonies in Eastern Canada (Allard, Hanson, and Mahoney, 2014). The height of cliffs protects interior land from the effects of storms or floods (CBCL Limited, 2009). Aesthetic enjoyment can be gained from the rugged appearance of coastal cliffs as well as some potential for recreational activities. Cliffs are common throughout many areas of Nova Scotia, particularly in areas with exposed bedrock.

*Eelgrass*

Eelgrass beds have high primary productivity and provide food and habitat for many important commercial species as well as many other aquatic species (CBCL Limited, 2009). Nutrient storage and cycling are high, and some protection against storms and flooding is provided through sediment stabilization and wave attenuation. There is low potential for recreation in this submerged habitat, but knowledge of its importance and existence can contribute to spiritual well-being (MEA, 2005b). This habitat is highly threatened in Nova Scotia and is now considered rare (CBCL Limited, 2009).

**Table 3-3**. Ecosystem services provision of six coastal habitats. Relative value indicated as follows: ‘high value’ (3), ‘medium value (2)’, ‘low value’ (1), and ‘negligible or unknown value’ (0). Rare habitats scored an extra value of +3.

| **Ecosystem Service** | **Habitat Type** | | | | | |
|---|---|---|---|---|---|---|
| | Beach | Mud Flat | Salt Marsh | Coastal Saline Pond | Rocky Cliff | Eelgrass |
| **Provisioning** | | | | | | |
| Food | 2 | 2 | 3 | 1 | 0 | 3 |
| Fiber, timber, fuel | 0 | 0 | 2 | 1 | 0 | 0 |
| **Regulating** | | | | | | |
| Climate Regulation | 1 | 1 | 2 | 2 | 0 | 1 |
| Biological Regulation | 1 | 1 | 2 | 2 | 0 | 0 |
| Hydrological Regimes | 0 | 0 | 1 | 1 | 0 | 0 |
| Storm/Flood Protection | 1 | 1 | 2 | 1 | 3 | 2 |
| Pollution Control/Waste Treatment | 1 | 2 | 2 | 1 | 0 | 1 |
| **Supporting** | | | | | | |
| Habitat Provision | 3 | 3 | 3 | 2 | 2 | 3 |
| Nutrient Cycling | 1 | 3 | 3 | 2 | 0 | 2 |
| Soil Formation | 1 | 1 | 2 | 1 | 0 | 0 |
| **Cultural** | | | | | | |
| Recreation | 3 | 2 | 2 | 1 | 1 | 0 |
| Aesthetic/Inspirational Benefit | 3 | 3 | 3 | 2 | 2 | 1 |
| **Rarity score** | **0** | **0** | **0** | **3** | **0** | **3** |
| **Total** | **17** | **19** | **27** | **20** | **8** | **16** |

The quantitative values assigned to the ‘high’ (3), ‘medium’ (2), and ‘low’ (1) classifications were summed for each habitat type, with the addition of three extra points assigned to rare habitats (Table 3-4).

**Table 3-4**. Relative value of coastal habitats determined from levels of ecosystem service provision, normalized to a ten-point scale.

| Habitat | Relative ecosystem service value | Normalized score | Rounded Value |
|---|---|---|---|
| Salt marsh | 27 | 10 | 10 |
| Coastal saline pond | 20 | 6.7 | 7 |
| Mud flat | 19 | 6.2 | 6 |
| Beach | 17 | 5.3 | 5 |
| Eelgrass | 16 | 4.8 | 5 |
| Rocky cliff | 8 | 1 | 1 |

Based on this analysis, salt marshes very clearly have the highest value in terms of relative ecosystem service provision, and rocky cliffs the lowest. The other four categories only differ by four points in their total summed values. It is demonstrated by looking at the scores for beaches, mud flats, coastal saline ponds, and eelgrass in Table 3-3 that these four habitat types differ in the main types of services they provide, but the summed scores and added rarity values result in similar total values.

### 3.4 Environmental Sensitivity Index Mapping

The resulting reclassification of habitat types based on substrate type or level of exposure in order to match the ESI categories is shown in Table 3-5**.** Salt marshes have the highest sensitivity (10) and exposed rocky cliffs the lowest (1), with the rest of the habitats in a fairly even distribution across the remaining values. These ESI values were added to each habitat layer in ArcGIS in order to produce the sensitivity overlay, which is a sum of all overlapping sensitivity values. Figure 3-6 shows the results of this overlay for the entire study site, with the areas within the top 25% of values highlighted with enlarged pixels for emphasis. This maps shows that the areas with highest sensitivity are clustered in only a few locations. The strongest groupings appear to be along the southern edge of the Canso Peninsula, and the northwestern region of Chedabucto Bay. The coastlines from Dover to Port Hawkesbury, as well as from the northern extent of the study site to the entrance of Chedabucto Bay, do not show any areas with very high sensitivity. A smaller scale view of this overlay showing different sections of the study site in more detail can be found in Appendix D (Figures D-1 to D4).

**Table 3-5.** The ESI values for oil sensitivity of all coastal habitat types considered in this study. Values were assigned using a ten-point scale (10 = high sensitivity), based on the original classification by Gundlach and Hayes (1978).

| **Mapped Coastal Habitat** | **ESI Value** |
|---|---|
| Salt marsh | 10 |
| Sheltered mud flat | 9 |
| Sheltered rocky cliff | 8 |
| Semi-exposed mud flat | 7 |
| Cobble/rock beach | 7 |
| Mixed substrate beach | 6 |
| Semi-exposed rocky cliff | 5 |
| Exposed mud flat | 5 |
| Course-grained sand beach | 4 |
| Exposed rocky cliff | 1 |

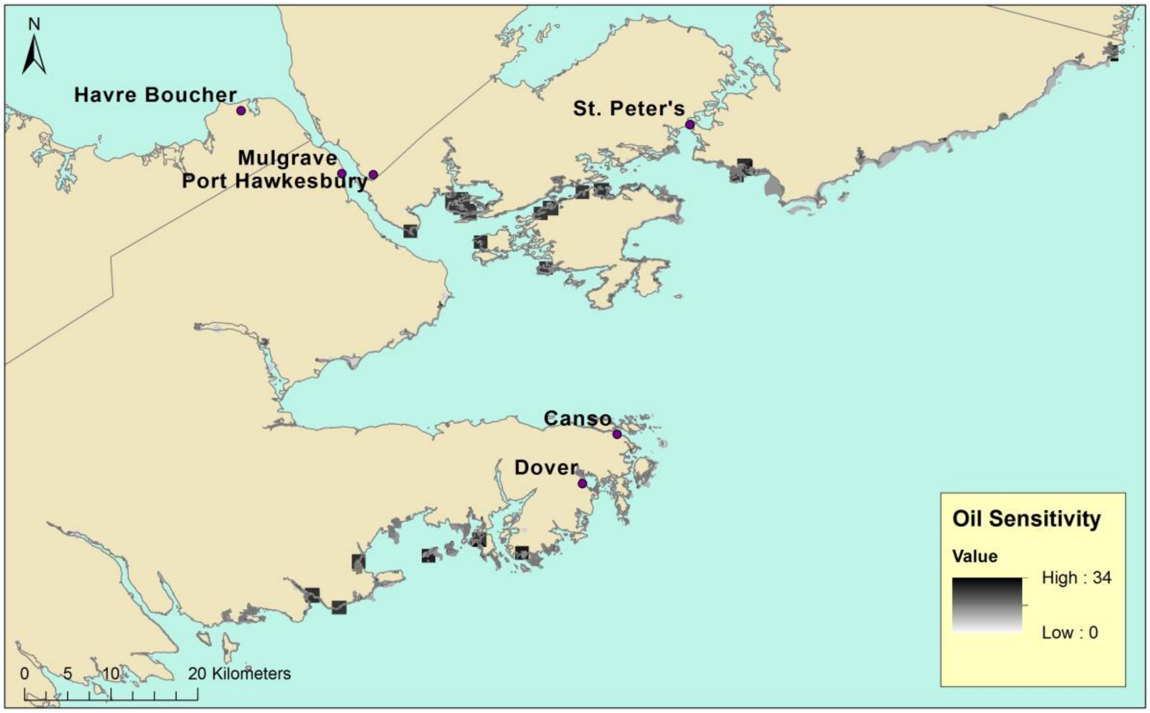


**Figure 3-6.** Relative sensitivity of coastal habitats to oil throughout the study site as determined by raster overlay analysis. Black squares indicate locations where sensitivity values fall within the top 25 percent of values.

### 3.5 Value and Sensitivity Overlay

Next, the relative value of each habitat in terms the provision of ecosystem services was incorporated into this analysis in order to determine the locations of areas within the study site with both high ecosystem value and high sensitivity. This was done through an averaging of these two characteristics for every location on the map. The output was split into two maps in order to include more detail, and areas with the highest overall score have been highlighted (Figures 3-7 and 3-8).

The southern portion of the study site has fewer high aggregate value locations compared to the north, and these all aggregate within Tor Bay and New Harbour Cove. The coastal areas near Dover and Canso, including all of the small islands, appear to have large areas of moderately high aggregate value, though none occur in the top 25 percent. The coastline from Canso to Guysborough Harbour does not appear to have any high aggregate value areas. There are some areas within and near Guysborough Harbour that have moderately high aggregate values, but they are small and widely disbursed.

The northern portion of the study site has many high aggregate value areas, which are densely clustered throughout Lennox Passage to the entrance of the Straight of Canso. Particularly the northern areas of Isle Madame, Janvrin Island, and Inhabitants Bay (the small bay north of Janvrin Island) have the highest clustering. Though only the northern areas of Isle Madam are highlighted, it appears that the entire coastline of that island has relatively high aggregate values. The coastline from St. Peter's to Forchu does not have many highlighted areas, with the exception of some small, sheltered inlets near St. Peter's Island, just north of Basque Islands, and near the border of Cape Breton County.

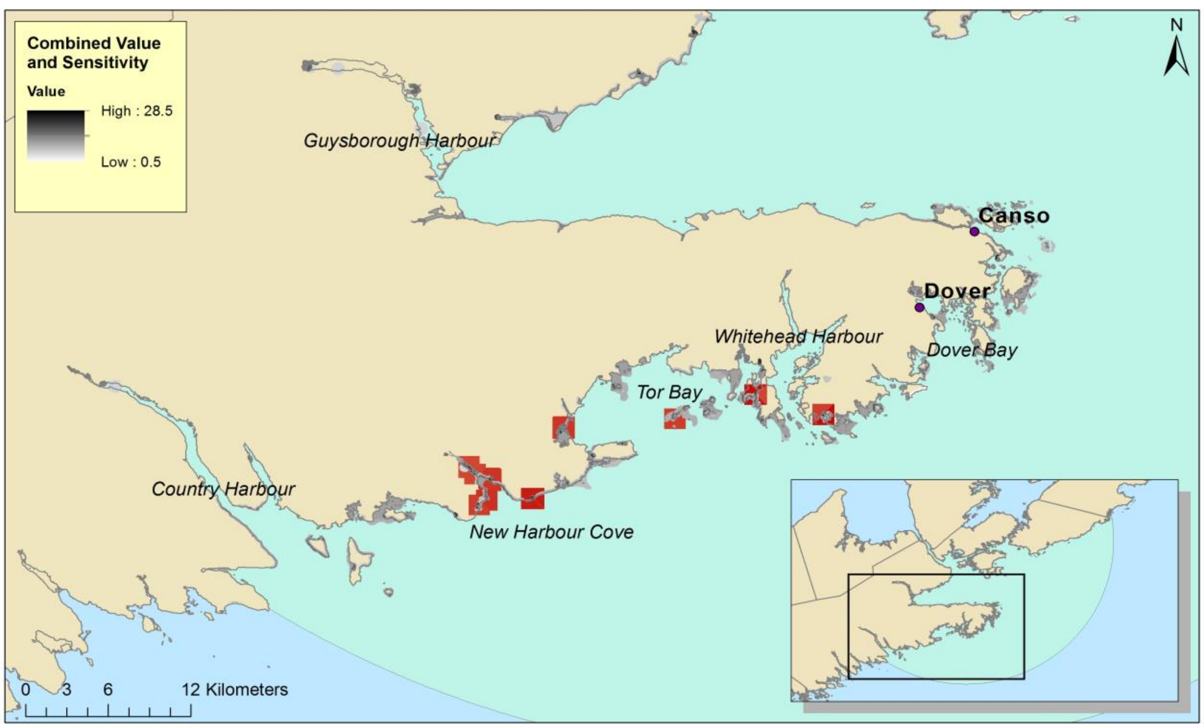


**Figure 3-7.** Southern portion of the study site showing the distribution of coastal habitats displayed by an averaging of ecosystem service value and oil sensitivity. Red squares indicate locations where aggregate values fall within the top 25 percent.

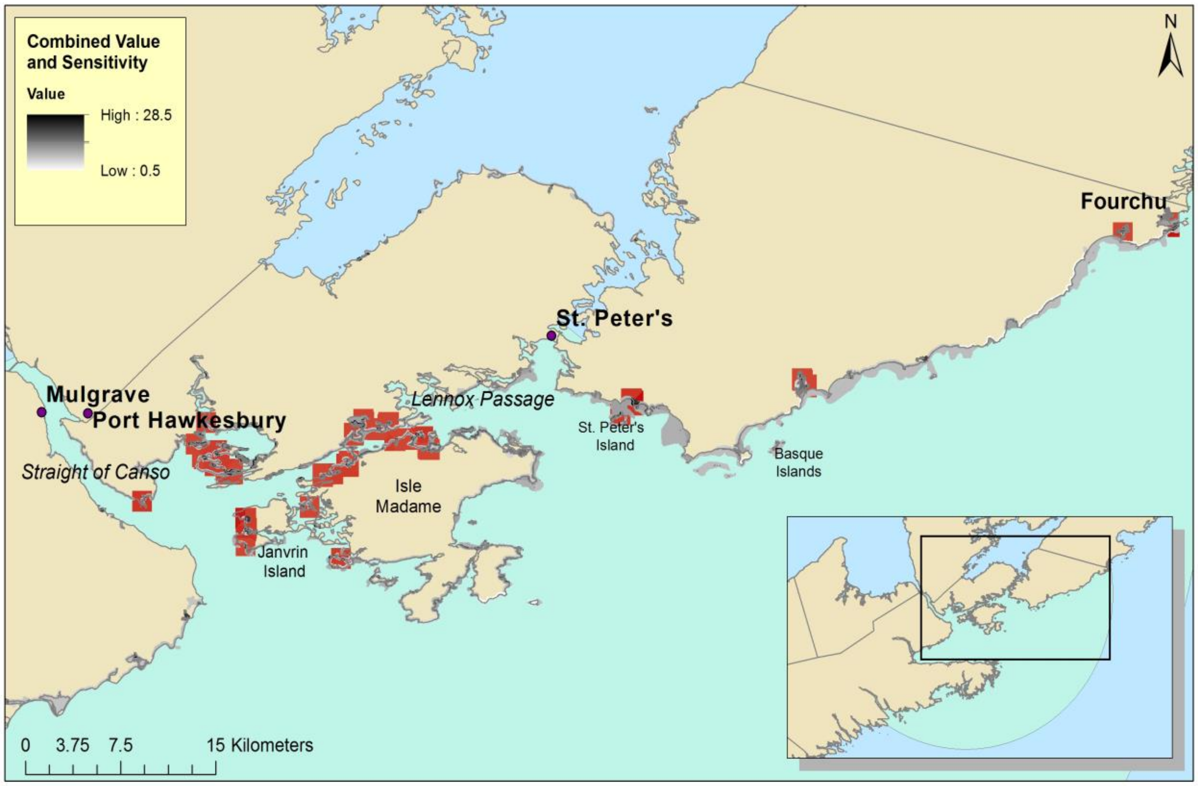


**Figure 3-8.** Northern portion of the study site showing the distribution of coastal habitats displayed by an averaging of ecosystem service value and oil sensitivity. Red squares indicate locations where aggregate values fall within the top 25 percent.

### 3.6 Comparison of Approaches

The inclusion of ecosystem service values into the sensitivity analysis produced an output with only subtle differences. The simplest method to visualize these differences was to compare the distribution of the highest value areas highlighted in each output (Figure 3-9). The overall distribution of high value areas between these two outputs is similar, with the exception of few extra locations highlighted in the combined output. The main difference was in the total number of highlighted areas with values in the top 25 percent, which was higher in the combined output. These extra areas occur mainly within

Lennox Passage and Inhabitants Bay, and a much higher density of these areas occurs within New Harbour Cove, south of the Canso Peninsula.

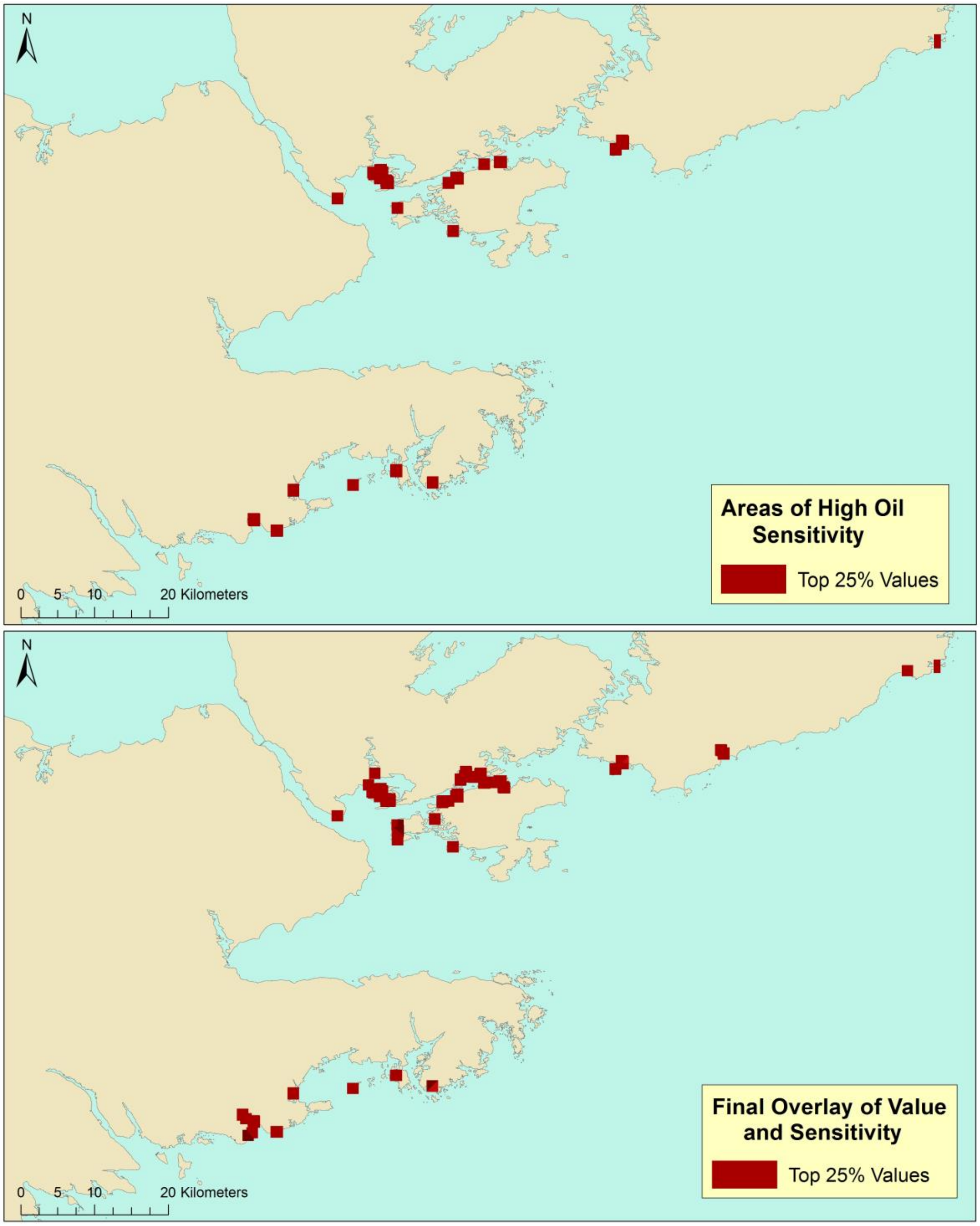


**Figure 3-9.** A comparison of the frequency and distribution of high value areas between the sensitivity analysis and the overlay including both sensitivity and ecosystem service values.

# 4.0 DISCUSSION

## 4.1 Area Prioritization

The results from both the sensitivity analysis and the analysis including ecosystem service values indicate that the coastline surrounding Isle Madame, throughout Lennox Passage, and leading up into the Straight of Canso are the areas of highest priority within the study site. The only other location within the study site with clear aggregation of value is the region south of the Canso Ledges. These two areas correspond to coastal segments two and five as characterized in Section 3.1, which were the two segments described to have complex shorelines, protected bays and inlets, islands, and mixed sediment substrates. This corresponded directly to a high density of multiple habitat types, which created many overlaps in the analyses and resulted in areas with a high summed aggregate value. Coastal segment three, which stretches from Whitehead Harbour up to Canso, also has a complex and sheltered shoreline, but it was characterized as having large headlands and boulder/bedrock substrates. This did not appear to support a diversity of coastal habitats and is likely the main reason that it was not highlighted for having high value/sensitivity. The other three coastal segments were very simple in comparison, and for the most part did not have a high diversity of coastal habitats. The main insight provided by the final overlay analysis was the location of the densest aggregations of coastal habitats. Habitats of high value and/or sensitivity that did not overlap with other habitat types did not have a high overall value in the final overlay.

The inclusion of ecosystem services into the analysis increased the number of locations with a value in the top 25 percent. This is why more areas were highlighted after these values were averaged into the output. This likely occurred because some habitats, particularly salt marshes, had both high sensitivity and high ecosystem service value, so the second overlay resulted in more areas with high aggregate values. The differences between the two analyses could only be seen when examined at a large scale. For the purpose of this study, which was primarily to determine overall priority areas for response planning and data collection, this level of detail did not add very much to the sensitivity analysis in predicting overall trends. This type of detail is more useful for detailed response operations in the event of a spill, which make use of the shoreline sensitivity information to determine response/clean up requirements along the coast. Incorporating ecosystem service values of coastal habitats into shoreline classification databases could increase the amount of information available in the event of a spill. If a coastal segment has high sensitivity value but low ecosystem service value (e.g. sheltered rocky cliffs), then protection and cleanup resources should be focused on areas of higher value.

One point that this analysis emphasized was that salt marshes are an extremely high priority resource for protection. Both the monetary and qualitative valuations showed that they have a very high value, and any disruption of this habitat would result in a large loss of ecosystem service provision. They are also the most sensitive to oil, and any areas where these habitats are known to aggregate should be considered high priority for protection. The presence of this habitat in coastal segments two and five was likely the main factor that resulted in these areas being highlighted as having high value.

The location of important human-use resources along the coast is another very important consideration when determining priority areas for protection in the event of a spill. The consideration of human-use data within the analysis was beyond the scope of this study, and would have required access to more detailed data than was currently available. However, even with a cursory look at the available data, it is clear that the two largest aggregations of shellfish aquaculture sites occur in the two of the identified priority areas within this study (Figures 3-3, 3-7 and 3-8). The presence of these resources should only increase the importance of these locations for protection and response planning.

## 4.2 Ecosystem Service Valuation

Originally, the intent was to use economic valuation results to inform the prioritization of habitats, but the benefit transfer technique provided an incomplete value assessment for the six habitats found within the study area. The main challenge was finding values that related to the specific habitat categories used in this study. Broad categories of habitat valuation were often found in the literature, such as "intertidal/lagoon/estuary". This description fits multiple habitat types and was too broad to use for transfer. Almost no studies could be found that directly valued mud flats, coastal saline ponds, or rocky cliffs. Beach valuation data was also difficult to find as valuation was often calculated on a per trip basis instead of value per year. This is due to the high recreational and aesthetic ecosystem service value of this habitat, which is best captured in valuation methods tailored to determine per trip values (Costanza et al., 2006).

It was also found that the vast majority of valuation studies are based on more tropical habitats, such as mangroves, rainforest, coral reefs etc. Very few original valuation studies exist for Canada, and available studies used transfer values from locations such as California or Florida. Many of the studies were also very outdated, occurring in the 1970s and 1980s before more updated and accurate valuation techniques existed (Kerr and Latham, 2011). These factors resulted in generally low confidence ratings of the data that was used for transfer (see Appendix C), making the exercise of limited value to the overall analysis. The usefulness of the benefit transfer technique is likely more suited to supplement original valuation studies, where gaps can be filled for certain services that are difficult to value.

The qualitative analysis had the advantage of being based on information derived from coastal habitats specifically within Nova Scotia. The exact differences in the relative levels of ecosystem service provision (i.e. high, medium, low) were sometimes difficult to determine from the descriptive data, but overall it provided a good summary of types of benefits to be derived from these habitats and the reasons that they are considered valuable. The high value of salt marshes was not surprising as coastal wetlands are rated as the most productive ecosystems in the world (Davis and Browne, 1996). Eelgrass, however, was shown not to provide as wide a range of ecosystem services as originally expected, and although this is a very valuable component of ecosystems, the submerged nature of this habitat means less direct human interaction for resource harvesting, recreation, and aesthetic appreciation.

### 4.3 Data Gaps and Limitations

The characterization of the study site highlighted the gaps in detailed spatial data that exist for this area, particularly with human-use resources and activities. Commercial fishing data, aquaculture sites, Small Craft Harbours, and protected areas are well represented, but more detailed information will be necessary for the purposes of ARP development. One Local Ecological Knowledge (LEK) study was found that provided detailed GIS information for the coastal areas within this study site, including important locations for various tourism activities, coastal infrastructure, important wildlife areas, and coastal land use. This information, however, was originally collected in the early 1990s and can no longer be considered accurate (B. Butts, 2014, November 3). This type of detailed, local information should be added to the shoreline sensitivity/value analyses to provide a comprehensive view of priority areas for ARP development.

The best available spatial habitat data that was used for the analyses came from the Nova Scotia Department of Natural Resources wetlands inventory, with the exception of the eelgrass data, which was from the Canadian Wildlife Services. However, these data layers were created from aerial photographs from the 80s and 90s and can no longer be regarded as entirely accurate; this is particularly true for the areal extents of the marine and estuarine flats (Greenlaw et al., 2012). Many factors have been impacting the coast since the time of data collection, such as changes in fishing activity, increases in/introduction of invasive species, and climate change (Bundy et al., 2014). There were also clear gaps in the extent of these data as many coastal locations throughout the study site did not have any habitat information. One of these areas was Whitehead Harbour, which is a fairly large and completely sheltered coastal area that should have aggregations of several different habitat types such as beaches, salt marshes and mud flats. Given this data gap, this area could not be considered part of prioritization exercise. The eelgrass data was difficult to use in the analysis since it was only represented in point locations. The buffers used to represent the spatial extents of this habitat were estimates that may or may not have adequately represented the real-world extents.

Though the habitat layers used in this analysis may not be completely reliable at a large scale, they are still useful in determining habitat distribution trends at the more small scale and overall view used in this study. A similar analysis that includes ecosystem service values and sensitivity values of coastal habitats can be conducted again after more detailed data collection has occurred.

## 5.0 CONCLUSIONS AND RECOMMENDATIONS

The purpose of the ARP initiative is to move away from the “one size fits all” system of oil spill preparedness and response planning to one that takes into account regional differences in risk and response capacities, as well as environmental, socio-economic, and cultural differences. This study has shown that the inclusion of ecosystem service values adds another dimension to the analysis and incorporates more holistic values into decision-making processes. Both ecosystem service values and environmental sensitivity values can be used to identify priority areas for spill response planning. However, priority areas may be more accurately identified if ecosystem service value and environmental sensitivity analyses are not combined into one analysis. Sites identified through either method may be considered separately as priorities, as both methods ultimately highlight important coastal habitats that should be protected in the event of an oil spill.

Based on the findings of this study, the following are recommendations for the next steps in ARP development for the Port Hawkesbury response area:

**1. Focus on the identified priority areas for the development of response plans and the collection of more detailed and up-to-date coastal habitat data.**

The areas of focus for response planning and data collection should be directed towards the coastline surrounding Isle Madame, throughout Lennox Passage, and leading up into the Straight of Canso, as well as within Tor Bay and New Country Harbour. These areas were shown to have the highest aggregations of both highly valuable and highly sensitive habitats, and a spill in these environments will result in the loss of ecosystem integrity and ecosystem service provision. The use of more advanced spatial data collection techniques, such as LiDAR, should be considered for these areas because wetland extents, particularly eelgrass, can be difficult to map consistently due to changing tidal and weather conditions. All attempts should be made to associated as much metadata and descriptive information as possible with all collected spatial data in order to maximize the usefulness of the data as well as facilitate data sharing between departments or organizations.

**2. Complete a LEK study to collect information on important local socio-economic, cultural and environmental resources.**

A LEK study should be completed for this area to determine locally identified sites of importance, particularly in the areas with higher coastal populations such as Canso, the northern shores of Chedabucto Bay, and Isle Madame. Based on the typical types of data included in biological and human-use sensitivity maps for spill response planning, the following information should be included:

- Key fishery information at a local scale, such as important near-shore or shallow water fishing areas, shoreline fishing spots or net hauling areas, areas of seaweed collection, locally identified fish/invertebrate habitat or nursery areas, locations with permanent or semi-permanent fishery traps/pots
- Socio-economic information such as coastally located sites of social, cultural, or spiritual significance, important areas for swimming, kayaking, nature watching and other types of recreation, and harbours, marinas and boat ramps
- Other types of biological information that is important to include are locally identified sites of importance for bird species or marine mammals

The collection of local information should be done with representation and inclusion of Aboriginal individuals and communities, and important coastal areas for food, social and ceremonial fishing and hunting should be included as areas of high importance. All care should be taken to avoid the misuse or distribution of sensitive information derived from LEK studies.

**3. Consider the incorporation of ecosystem service principles more explicitly into decision-making processes.**

It is not always necessary to do full valuation studies in order to incorporate ecosystem services into decision-making processes. Any time tradeoffs are weighed in environmental resource decisions, the identification and recognition of the full value of natural resources will help elucidate both the potential benefits and consequences of each decision. Within ARP development, decisions made on the degree of protection or cleanup efforts to be focused in one particular area should include information on both environmental sensitivities and ecosystem service values of that area, as well as relevant human-use factors.

Based on the current scarcity of ESV data from a Canadian context, original valuation studies should be considered for projects focused at a local scale. This will not only help in determining the most beneficial long-term scenarios in tradeoff situations, but will also contribute to the pool of Canadian valuation data that can be used in future decision-making processes.

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**Appendix A: Map Data Sources**

**Table A-1.** The original source of each spatial data layer used this study, with a list of the figures in which they appear for either display or analysis.

| May Layer(s) | Use | Source |
|---|---|---|
| Nova Scotia place names | Figures 1-1, 3-3, 3-6, 3-7, 3-8 | DMIT Spatial, CanAtlas data series, obtained through Dalhousie University with permission |
| Nova Scotia county boundaries | Figures 1-1, 3-6, 3-8 | Service Nova Scotia & Municipal Relations, Nova Scotia topographic databases, obtained through Dalhousie University with permission |
| Human footprint | Figure 3-3 | Woolmer et al. (2008), data provided by Wildlife Conservation Society of Canada (available online) |
| Coastal EBSAs | Figure 3-5 | Hastings et al. (2014), obtained from Fisheries and Oceans Canada with permission |
| Small Craft Harbours | Figure 3-3 | Fisheries and Oceans Canada, obtained with permission |
| Marine aquaculture sites | Figure 3-3 | Point locations estimated based on the aquaculture site mapper tool from Nova Scotia Department of Fisheries and Aquaculture (accessible online) |
| Coastal exposure | Figure 2-1 | Cairns et al. (2012), Fisheries and Oceans Canada (available online) |
| Designated water supply areas | Figure 3-5 | *Nova Scotia Department of Natural Resources, Forestry Division; Restricted and Limited Use Land database (available online) |
| Municipal surface water supply areas | Figure 3-5 | *Nova Scotia Department of Natural Resources, Forestry Division; Restricted and Limited Use Land database (available online) |
| Provincial Parks | Figure 3-5 | *Nova Scotia Department of Natural Resources, Forestry Division; Restricted and Limited Use Land database (available online) |
| Wilderness Areas | Figure 3-5 | *Nova Scotia Department of Natural Resources, Forestry Division; Restricted and Limited Use Land database (available online) |
| Protected Beaches | Figure 3-5 | *Nova Scotia Department of Natural Resources, Forestry Division; Restricted and Limited Use Land database (available online) |

| May Layer(s) | Use | Source |
|---|---|---|
| National Historic Sites | Figure 3-5 | *Nova Scotia Department of Natural Resources, Forestry Division; Restricted and Limited Use Land database (available online) |
| Aboriginal Reserves | Figure 3-3 | *Nova Scotia Department of Natural Resources, Forestry Division; Restricted and Limited Use Land database (available online) |
| Coastal wetlands and habitats | Figures 3-2, 3-6, 3-7, 3-8, 3-9, D-1, D-2, D-3, D-4 | *Nova Scotia Department of Natural Resources wetlands inventory (2000); obtained from Fisheries and Oceans Canada with permission |
| Eelgrass points | Figure 3-2 | *CWS MWI wetlands inventory (1996); obtained from Fisheries and Oceans Canada with permission |
| Kernel density | Figures B-1, B-2, B-3, B-4, B-5 | Allard, Hanson, and Mahoney (2014); obtained from Fisheries and Oceans Canada with permission |
| Fisheries landings | Figure 3-4 | Fisheries and Oceans Canada 2006-2010 fisheries composite maps, obtained with permission |

*The organization providing the data makes no claim as to its accuracy, and the user of the data assumes all risks associated with its use

**Appendix B: Kernel Density Maps**

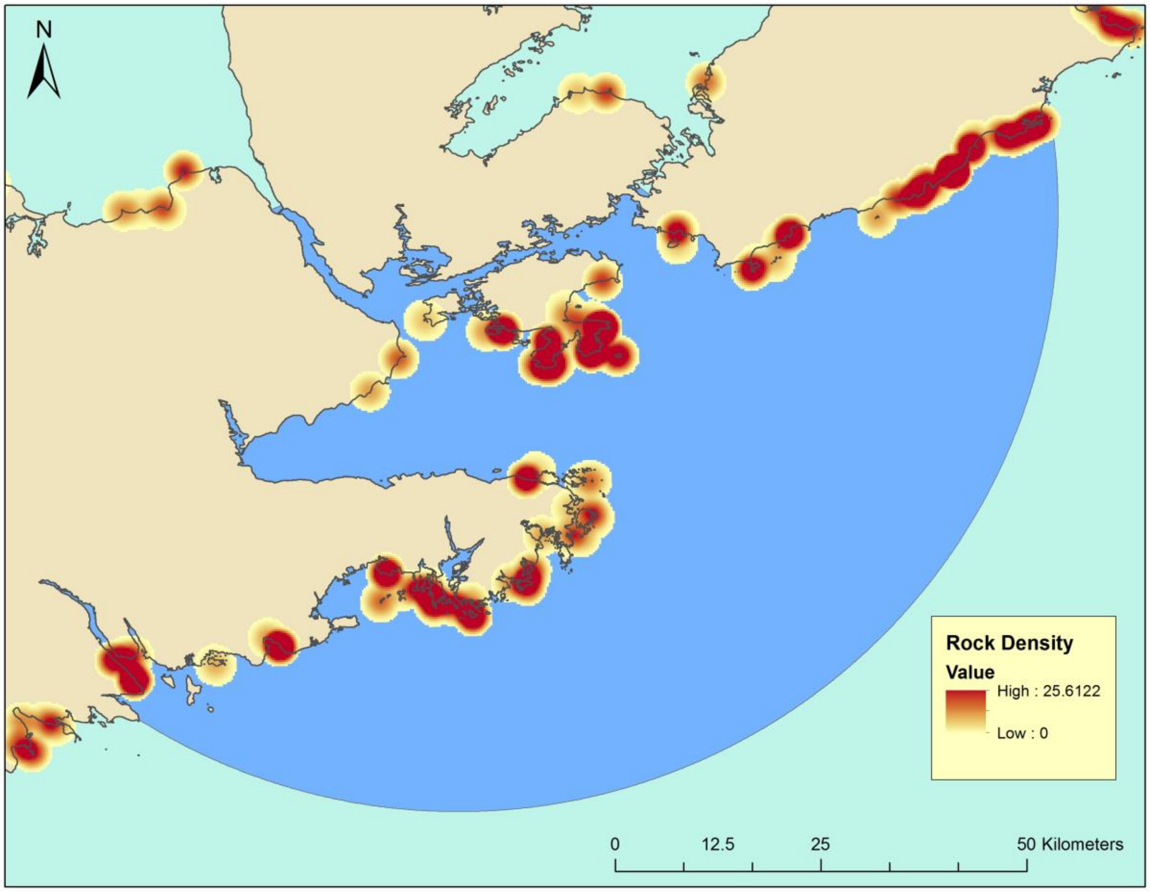


**Figure B-1**. Distribution of rocky coastline density throughout the study site using a kernel density analysis. Raster data from Allard et al. (2014).

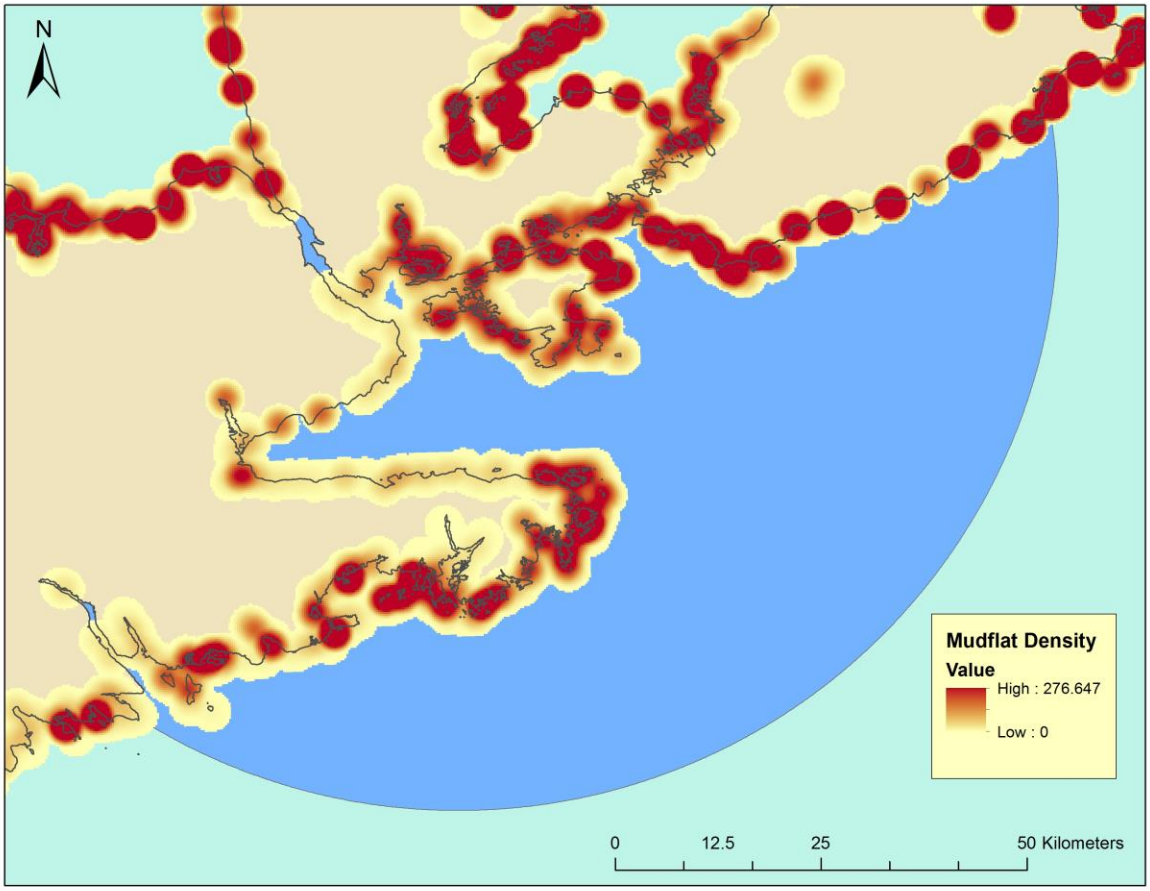

**Figure B-2.** Distribution of mud flat density throughout the study site using a kernel density analysis. Raster data from Allard et al. (2014).

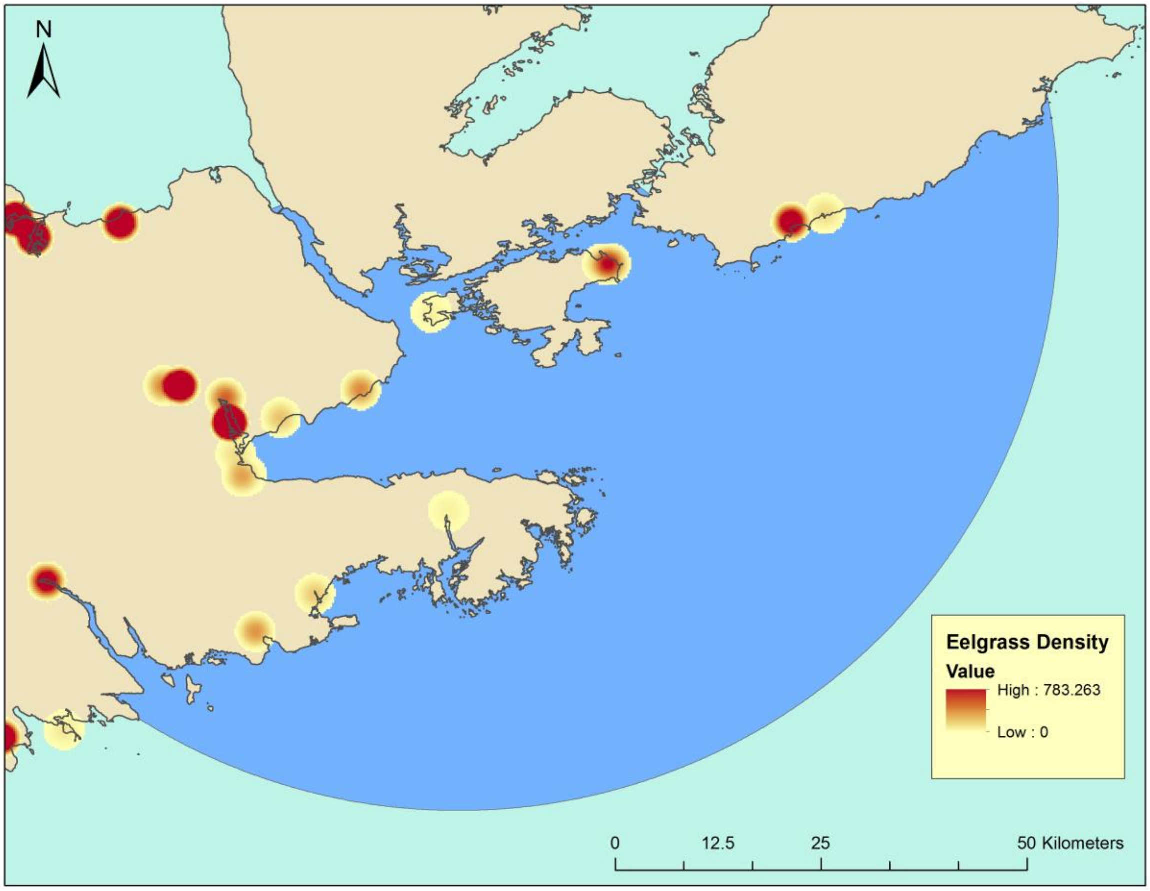


**Figure B-3.** Distribution of eelgrass density throughout the study site using a kernel density analysis. Raster data from Allard et al. (2014).

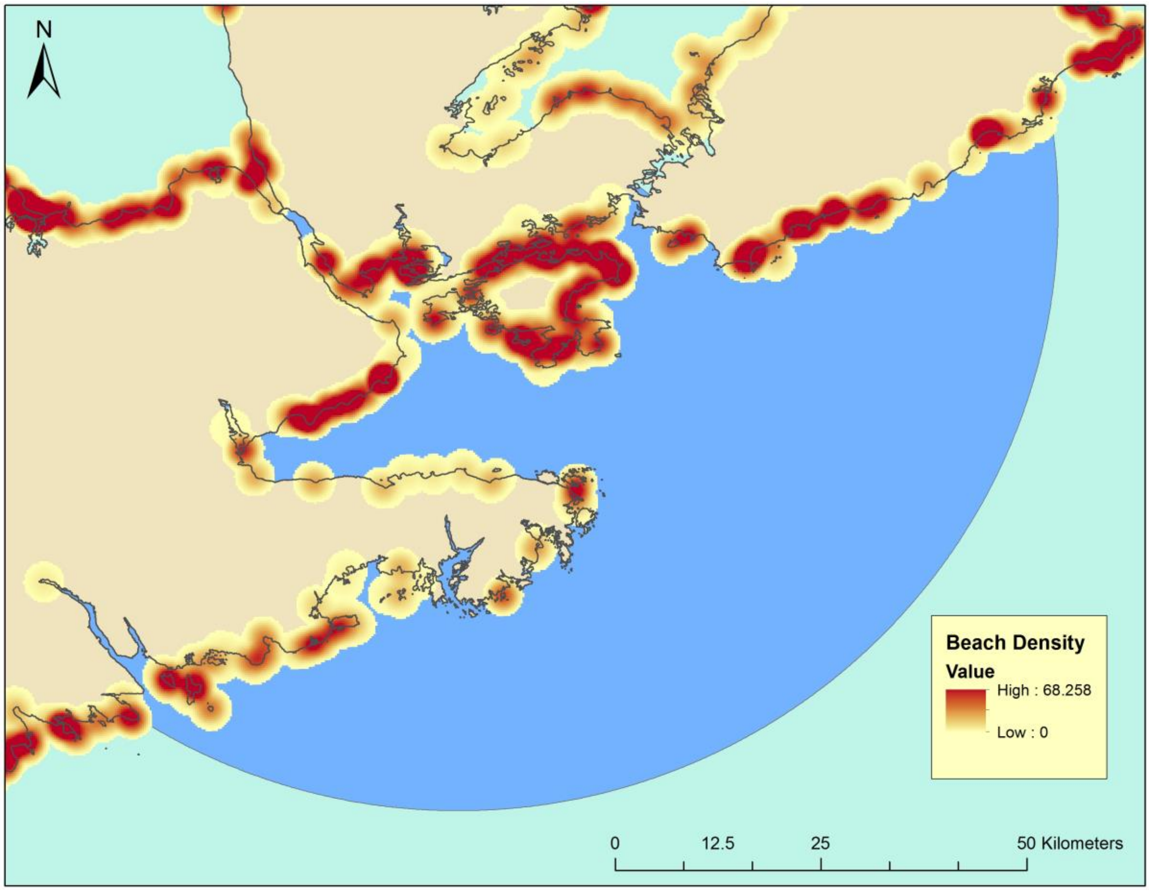


**Figure B-4.** Distribution of beach density throughout the study site using a kernel density analysis. Raster data from Allard et al. (2014).

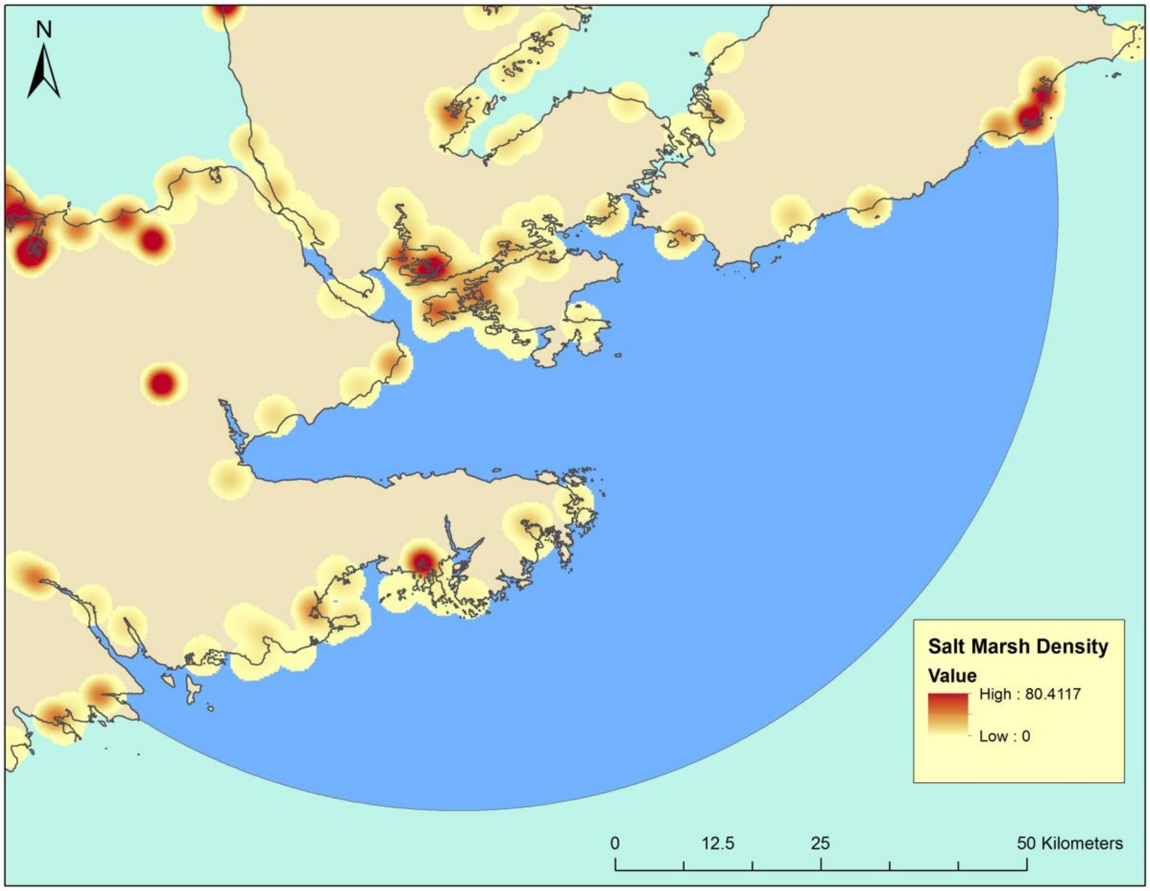

**Figure B-5**. Distribution of salt marsh density throughout the study site using a kernel density analysis. Raster data from Allard et al. (2014).

## Appendix C: Ecosystem Service Valuation Data Sources

**Table C-1**. Case studies with estimated values of ecosystem services for each coastal habitat type. Valuation method abbreviations: AC = Avoided Cost, BT = Benefit Transfer, CV = Contingent Valuation, DMP = Direct Market Pricing, FI/PF = Factor Income/ Production Function, HA = Hedonic Analysis, RC = Replacement Cost, TC = Travel Cost.

| Habitat Type | Category | Ecosystem Service | Converted Value ($USD_{2014}$/ha/year) | Valuation Method | Study Area | Reference | Confidence Rating |
|---|---|---|---|---|---|---|---|
| **Beach** | **Regulating** | Flood/storm protection | 77,375.97 | BT | Catalonia, Spain | Brenner-Guillermo, J. (2007) | High |
| | | | 36,756.66 | HA | New Jersey, US | Costanza et al. (2006) | High |
| | **Cultural** | Recreation | 36,687 | BT | Catalonia, Spain | Brenner-Guillermo, J. (2007) | Low |
| | | | 20,008.30 | HA | California, US | Costanza et al. (2006) | Low |
| | | Cultural value | 69.66 | BT | Catalonia, Spain | Brenner-Guillermo, J. (2007) | Low |
| **Salt Marsh** | **Provisioning** | Fish | 274.39 | BT | Georgia, US | Gosselink, J.G., Odum E.P., and R.M. Pope. (1974) | Low |
| | | | 214.88 | DMP | Louisiana, US | Farber, S. and R. Costanza. (1987) | Low |
| | | | 572.67 | BT | Louisiana, US | Gosselink, J.G., Odum E.P., and R.M. Pope. (1974) | Low |
| | | | 894.81 | BT | Florida, US | Gosselink, J.G., Odum E.P., and R.M. Pope. (1974) | Low |
| | | | 2,737.78 | DMP | Florida, US | Bell, F. W. (1989) | Low |
| | | Raw materials | 5,089.76 | DMP | Netherlands | de Groot, R. S. (1992) | High |

| Habitat Type | Category | Ecosystem Service | Converted Value (USD$_{2014}$/ha/year) | Valuation Method | Study Area | Reference | Confidence Rating |
|---|---|---|---|---|---|---|---|
| | | | 57.09 | DMP | Louisiana, US | Costanza, R. S. (1989) | Moderate |
| | **Regulating** | Flood protection | 608.55 | AC | Louisiana, US | Costanza, R. S. (1989) | Moderate |
| | | Water purification | 3,149.73 | BT | Delaware, US | Gosselink, J.G., Odum E.P., and R.M. Pope. (1974) | Low |
| | | | 894,808.45 | RC | US | Gosselink, J.G., Odum E.P., and R.M. Pope. (1974) | Low |
| | | | 7,634.64 | RC | Netherlands | de Groot, R. S. (1992) | High |
| | | Storm protection | 38.72 | AC | Louisiana, US | Farber, S. and R. Costanza. (1987) | Low |
| | | | 13,361.48 | RC | UK | Dugan, P. J. (1990) | Moderate |
| | **Supporting** | Nursery habitat | 3.93 | DMP | Florida, US | Lynne, G.D., Conroy, P., and Pochasta, F.J. (1981) | Low |
| | **Cultural** | Recreation | 20.79 | TC | Louisiana, US | Costanza, R. S. (1989) | Low |
| | | | 31.07 | TC | Louisiana, US | Farber, S. and R. Costanza. (1987) | Low |
| | | | 680.05 | BC | Georgia, US | Gosselink, J.G., Odum E.P., and R.M. Pope. (1974) | Low |
| | | Fishing/ Hunting | 765.28 | CV | Massachusetts, US | Gupta, T.R. and J.H. Foster. (1975) | Low |
| | | | 2,892.77 | DMP | Florida, US | Bell, F. W. (1989) | Low |
| **Eelgrass** | **Provisioning** | Fish | 2,086.58 | FI/PF | US | Hughes, Z. (2006) | Moderate |

| Habitat Type | Category | Ecosystem Service | Converted Value (USD$_{2014}$/ha/year) | Valuation Method | Study Area | Reference | Confidence Rating |
|---|---|---|---|---|---|---|---|
| | | Raw materials | 3.21 | DMP | Global | Costanza et al. (1997) | Moderate |
| | **Regulating** | Waste treatment | 1,866.20 | RC | Global | Waycott et al. (2009) | High |
| | | Carbon sequestration | 550.90 | RC | US | Hughes, Z. (2005) | High |
| | | Nutrient cycling | 30,516.79 | RC | Global | Costanza et al. (1997) | Moderate |
| | **Supporting** | Nursery habitat | 179.07 | FI/PF | Australia | McArthur, L.C. and J.W. Boland. (2001) | Moderate |
| | | Habitat | 2,330.89 | PM | Australia | Watson et al. (1993) | Moderate |

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**Appendix D: Oil Sensitivity Analysis by Coastal Segment**

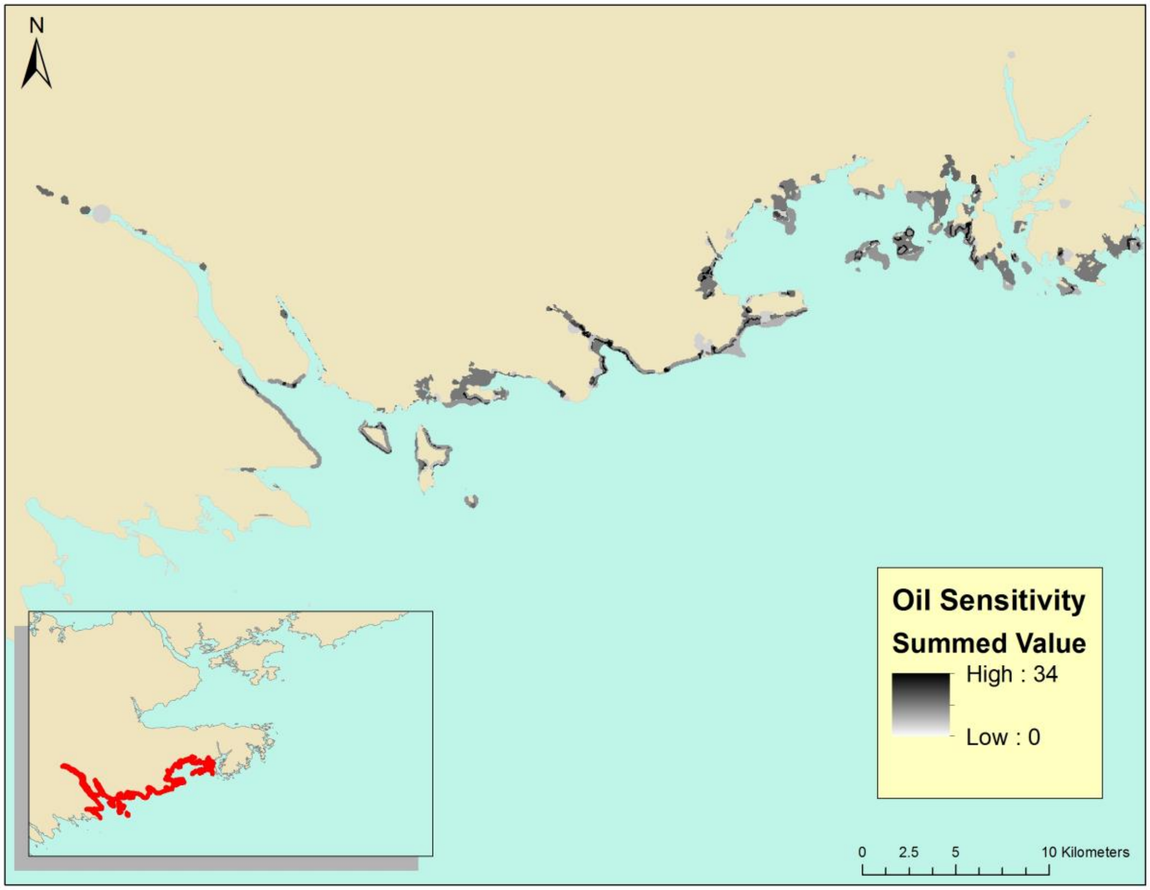


**Figure D-1.** Distribution of relative oil sensitivity values of coastal habitats within coastal segment one of the study site, from Country Harbour to Tor Bay. Based on ESI values in a summed overlay.

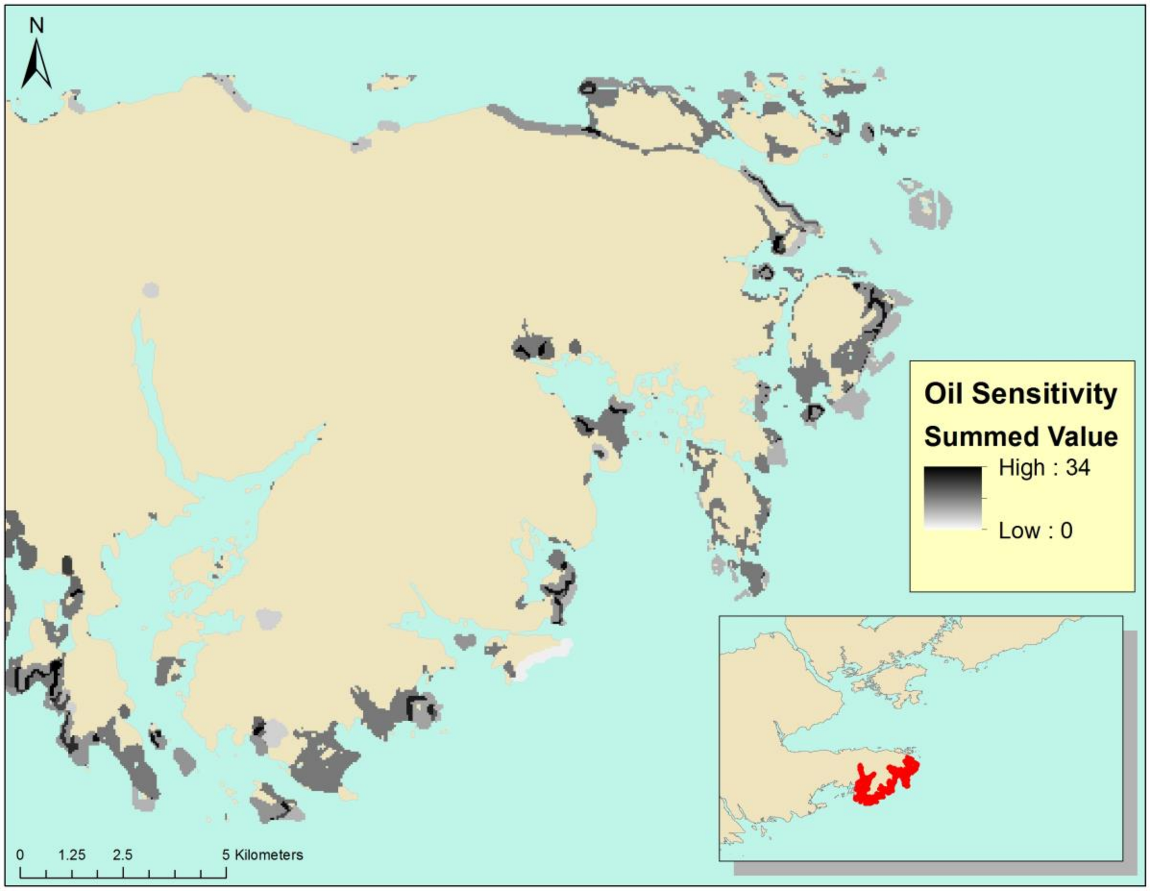


**Figure D-2.** Distribution of relative oil sensitivity values of coastal habitats within coastal segment two of the study site, from Tor Bay to Canso. Based on ESI values in a summed overlay.

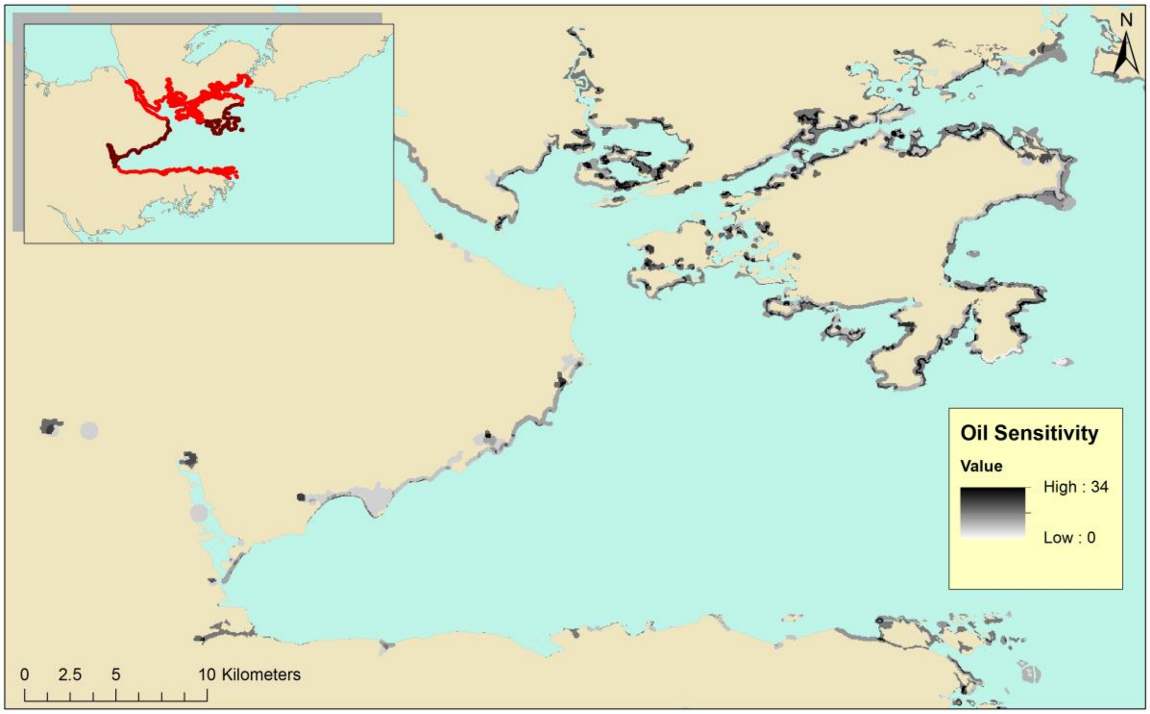

**Figure D-3.** Distribution of relative oil sensitivity values of coastal habitats within coastal segments, three, four, and five of the study site, from Canso to St. Peter's. Based on ESI values in a summed overlay.

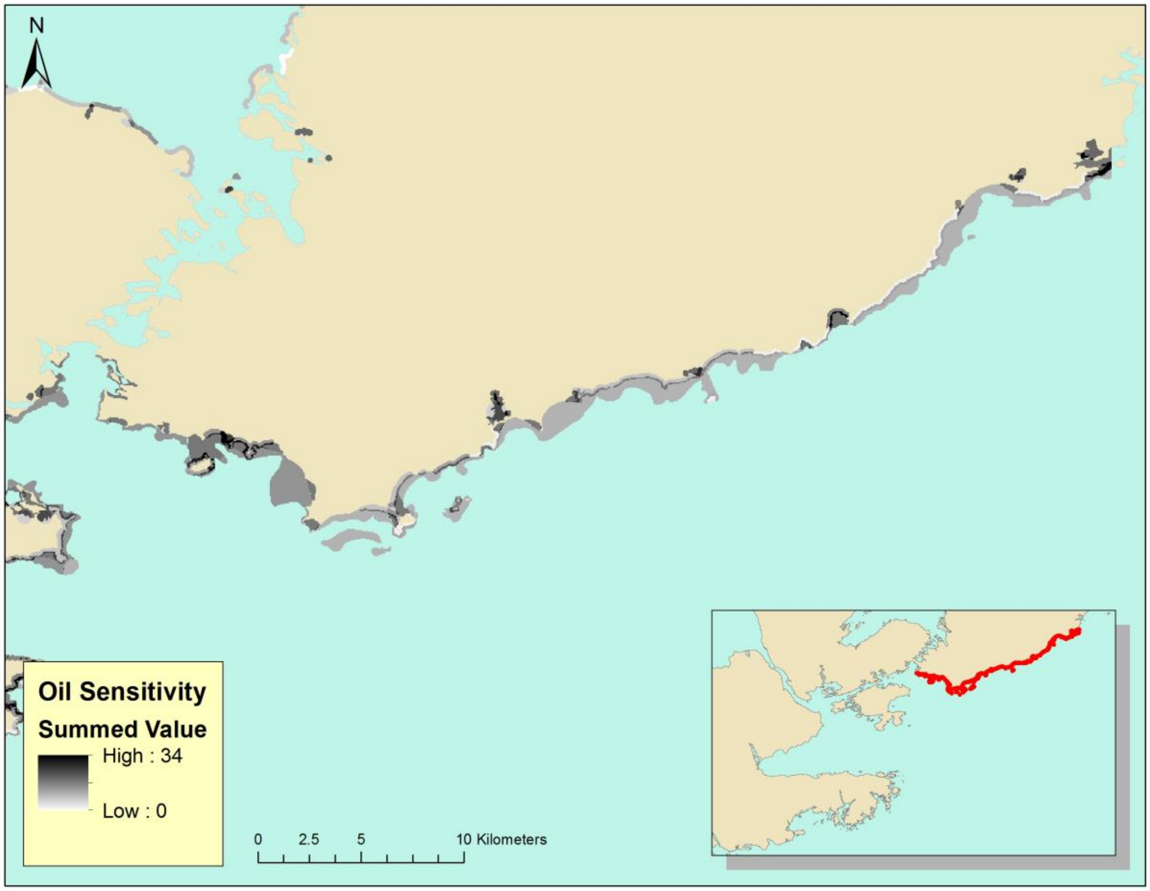

**Figure D-4.** Distribution of relative oil sensitivity values of coastal habitats within coastal segment six of the study site, from St. Peter's to Fourchu. Based on ESI values in a summed overlay.