Spatial Protection for Porbeagle Sharks, *Lamna nasus*, in the Northwest Atlantic
The Road to Recovery?

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Abstract

Sharks have dominated the seas as apex predators for more than 400 million years, but today they are being fished by humans at an unprecedented rate. Many of the biological characteristics of sharks make them particularly vulnerable to overfishing. Conservation of sharks is critical, not only because they are a commercially valued species that are threatened with extinction, but also because sharks are keystone species and play an important ecological role in marine ecosystems. One common mechanism being used around the world to conserve marine biodiversity is the implementation of marine protected areas (MPAs). The traditional static design of an MPA is limited in its capacity to protect mobile and migratory species that travel outside the boundaries of the MPA. However, the potential value that protected areas can have for pelagic conservation is becoming more widely discussed and explored. There is currently a lack of research on the relationship between mobile species and MPA networks internationally as well as in Nova Scotia, so studying the movements and migrations of these species can allow managers to better design connected areas which would have ecological, social, and economic benefits. This project examines a depleted population of endangered porbeagle sharks, *Lamna nasus*, off the Atlantic coast of Canada and evaluates the effectiveness of incorporating sharks into the Maritimes network of MPAs to assist in the recovery of this mobile predator in the temperate Northwest Atlantic. A spatial analysis of fisheries landings data using ArcGIS identified several potential sites of interest throughout the Maritimes region. Recommendations for future work include obtaining fisheries independent data on porbeagle movements and distribution, further studying the identified sites of interest, and studying how the changing climate may affect shark distributions.

Keywords: Porbeagle sharks, Marine Protected Areas, Connectivity, Conservation, Northwest Atlantic, Network Planning

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List of Acronyms

AOI - Area of Interest

CBD - United Nations Convention on Biological Diversity

CITES - Convention on the International Trade of Endangered Species

COSEWIC - Committee on the Status of Endangered Wildlife in Canada

DFO - Department of Fisheries and Oceans Canada

EBSA - Ecologically and Biologically Significant Area

EEZ - Exclusive Economic Zone

FAO - United Nations Food and Agriculture Organization

ICCAT - International Convention on the Conservation of Atlantic Tuna

IPOA - International Plan of Action

IUCN - International Union for the Conservation of Nature

MPA - Marine Protected Area

NAFO - North Atlantic Fisheries Organization

NPOA - National Plan of Action

RFMO - Regional Fisheries Management Organization

SARA - Species at Risk Act

TAC - Total Allowable Catch

UNCLOS - United Nations Convention on the Law of the Sea

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Chapter 1: Introduction

Healthy marine ecosystems provide countless goods and services for humans including providing food, economic opportunities, recreation, carbon sequestration, and protection from natural disasters. However, studies have shown that anthropogenic activities such as fishing, shipping, and mining are causing unprecedented changes in the environment, and will continue to do so as we rapidly consume resources for the world's growing population (Harley et al. 2006). As awareness for the importance of healthy ecosystems grows, the international community has agreed to protect its valuable natural resources, notably through the United Nations 1992 Convention on Biological Diversity, which pledged to conserve global marine ecosystems (CBD 2011).

One important mechanism being used to conserve marine biodiversity is the implementation of marine protected areas (MPAs). MPAs are defined areas of ocean that have regulations set upon them to promote conservation. MPAs have been successful in increasing species diversity, individual body size, species density, and overall biomass when compared to unprotected areas (Halpern and Warner 2002; Halpern 2003; Claudet et al. 2010). MPAs have been used for many years as a tool for conserving vulnerable marine species and critical ecosystems. They have also proven to be effective in mitigating negative effects from fishing by increasing the reproductive potential of fish species whose early life history is encompassed within the MPA (Sumaila et al. 2000). As the establishment of MPAs has grown over the years there is acknowledgement of their conservation potential, but also the understanding that they must be effectively designed, properly managed, and adequately enforced to maximize the benefits from protection (Edgar et al. 2014).

Mobile species, such as sharks, have dominated the seas as apex predators for more than 400 million years. Many species of sharks have no natural predators and have thrived at the top of the food chain since the beginning of their existence - that is, until now (Verlecar et al. 2007). Sharks are being fished by humans at an accelerated rate for their meat and for their highly valuable fins. They are also frequently caught incidentally in many commercial fisheries, causing injury and mortality (Worm et al.

2013; Dulvy et al. 2014; Oliver et al. 2015). Many of the biological characteristics of sharks, including slow growth, long lives, late age at maturity, and relatively few young, make them particularly vulnerable to overfishing (Fong and Anderson, 2002; Lack and Sant, 2011). Shark conservationists are beginning to explore the possibility of using MPAs as a tool to assist in the protection of these vulnerable and exploited species (Baum et al. 2003; Heupel and Simpfendorfer 2005, Barker and Schluessel 2005). This project examines the distribution of an endangered species of shark, the porbeagle (*Lamna nasus*), off the Atlantic coast of Canada and evaluates the effectiveness and feasibility of establishing a connected network of MPAs to assist this species in recovery.

1.1 Porbeagles in the Northwest Atlantic – A Brief History

The porbeagle shark, *Lamna nasus*, is one of the most common sharks in Atlantic Canadian waters. Porbeagles are large, fast-swimming mackerel sharks, members of the family Lamnidae. The species was fished commercially in Canada for over fifty years (1961-2013), resulting in a significant population decline (Campana et al. 2015a). Although the targeted fishery is now closed, Porbeagles in Canada are still susceptible to mortality as bycatch in fisheries for tuna, herring, and groundfish, mainly in pelagic longlines and groundfish gillnets and otter trawls (Campana et al. 2015a). Porbeagles in the Northwest Atlantic have been designated as endangered by COSEWIC, the Committee on the Status of Endangered Wildlife in Canada, and the IUCN[1], the International Union for the Conservation of Nature, although they have not been listed in Canada under the Species at Risk Act (Campana et al. 2015a; Stevens et al. 2006). Porbeagles are one of only six species of sharks that have been listed under Appendix II in the Convention on the International Trade of Endangered Species (CITES). Species listed under Appendix II have been identified as species whose trade must be controlled and closely monitored to prevent extinction (CITES, n.d.).

[1] The IUCN has assessed Porbeagles on a global scale as vulnerable, however the Northwest Atlantic subpopulation has been more heavily exploited and has been designated as endangered (Stevens et al. 2006).

1.2 Distribution and Biology

The porbeagle is a large pelagic shark that can be found throughout the North Atlantic, the South Atlantic, and the South Pacific oceans. Porbeagles are widely distributed in both inshore and offshore waters, anywhere from the surface to depths of almost 1400m (Campana et al. 2010). The majority of catch data show porbeagles in the deep basins of the Scotian shelf, or on the shelf edge (Campana et al. 2015a). They are a cold-water species, preferring temperatures around 5-15^{0} C (Campana et al. 2015a). North Atlantic populations are discrete in the east and the west, with no mixing observed between the two (Campana et al. 1999; Campana et al. 2001). Most individuals from the Northwest Atlantic population stay within Canadian and American waters, although some sharks have been tracked in international waters (Campana et al. 2010). For the purposes of this study all further information will refer to the Northwest Atlantic population unless otherwise specified.

Porbeagles are endothermic and can maintain body temperatures higher than the surrounding water. This may give them an energetic advantage over ectotherms, as they can stay at colder depths for longer (Pade et al. 2009). Porbeagles are estimated to live between 25 and 46 years and grow to average lengths of approximately 150-200 cm and weights of up to 130kg (Campana et al. 2002). They are slow growing, have low fecundity, and a late age at maturity (Campana et al. 2015a), which makes them particularly vulnerable to overfishing. Research has indicated that mating likely occurs in the summer on the Grand Banks off Southern Newfoundland, and at the entrance to the Gulf of Saint Lawrence (Campana et al. 2015a). Mature females have, on average, four pups per litter after a gestation period of nine months and give birth in late winter or spring in and around the Sargasso Sea (Campana et al. 2015a). Porbeagles are opportunistic feeders and typically eat teleosts, cephalopods, and groundfish, with some seasonal changes likely associated with changes in distribution (Joyce et al. 2002).

1.3 Fisheries and Management History

Porbeagle meat is highly valued in Europe, and its fins are highly valued in the international market (Fowler, Raymakers, and Grimm 2004). Due to this economic incentive, the porbeagle is one of only two large shark species that has been targeted by a commercial fishery in Canada, the other being spiny dogfish (Campana et al. 2015). The Northwest Atlantic porbeagle fishery began in 1961 with a fleet of Norwegian longliners. Catches increased rapidly over the next few years, and in 1964 the industry landed over 9000t (Campana et al. 2015). The fishery collapsed after only six years, landing less than 1000t in 1970 (Fowler, Raymakers, and Grimm 2004). The fishery remained, unrestricted, with landings less than 500t per year until 1989. Increased fishing effort by Faroese vessels and the introduction of Canadian vessels in 1992 raised the annual landings to around 2000t. After the introduction of the Law of the Sea convention in 1994 and the establishment of the Canadian exclusive economic zone, the fishery was almost exclusively Canadian, yet landings continued to decline annually. In 1998 a TAC of 1000t was introduced, which was lowered to 250t in 2003 (Campana et al. 2008). In 2007 the TAC was lowered again to 185t, and finally the directed fishery was closed in 2013 (Campana et al. 2015a See Figure 1 for a graphic representation of landings throughout the targeted fishery. Prior to the closure of the fishery, a mating ground off Southern Newfoundland and the Gulf of St. Lawrence had been identified as critical habitat and was closed seasonally (from September 1 to December 31) to targeted shark fishing (Davis and Worm 2013).

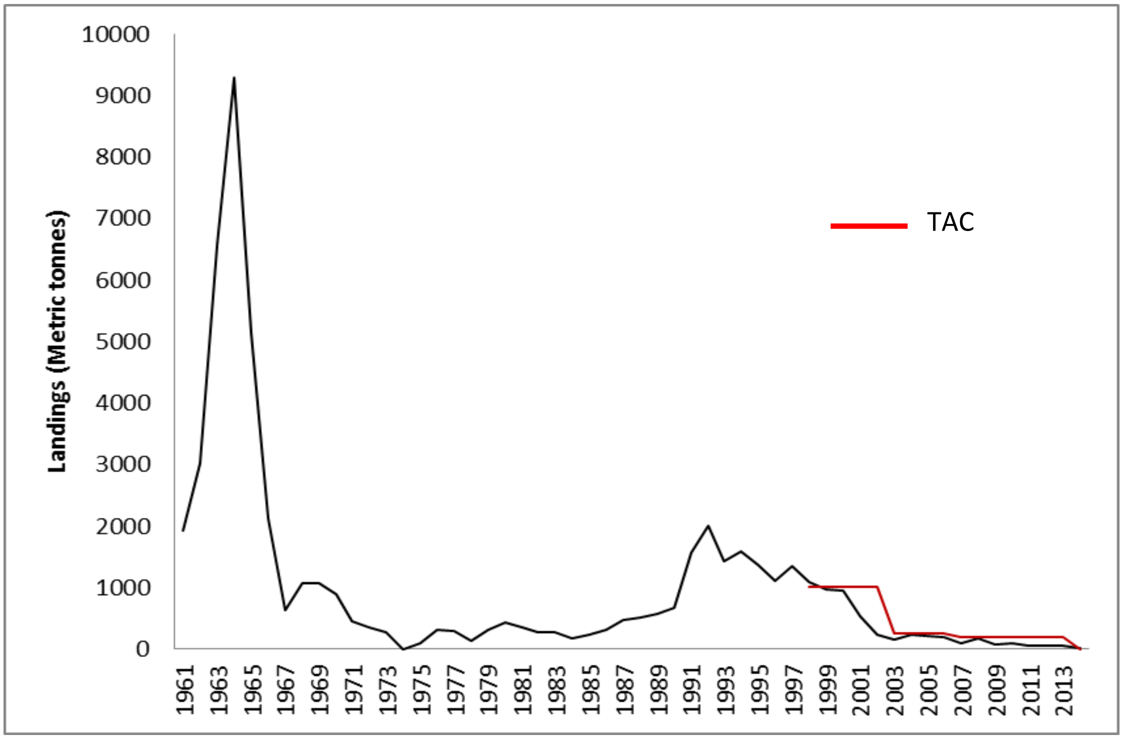

Figure 1: Recorded Porbeagle Landings in metric tonnes from NAFO Areas 4-6 between the years 1961-2013. Data Source: Campana et al. 2015a

Despite the closure of the fishery, Porbeagles are still under some fishing pressure. There is a very small recreational fishery in the Maritimes, and they are also likely targeted in international waters, although no catches are documented (Campana et al. 2015a). The greatest known non-natural mortality for Porbeagles is as incidental bycatch in pelagic longline (swordfish and tuna being the most prevalent) and groundfish fixed gear fisheries (see Figure 2). Due to their high value, porbeagles are often retained, although catches are often inadequately reported or unreported (Fowler, Raymakers and Grimm 2004). Stock assessments for the Northwest Atlantic population indicate that the stock collapsed twice during its 43-year fishing history. Age and sex structured population models estimate that the population has been reduced to only 10-20% of its pre-exploitation levels (Campana et al. 2008).

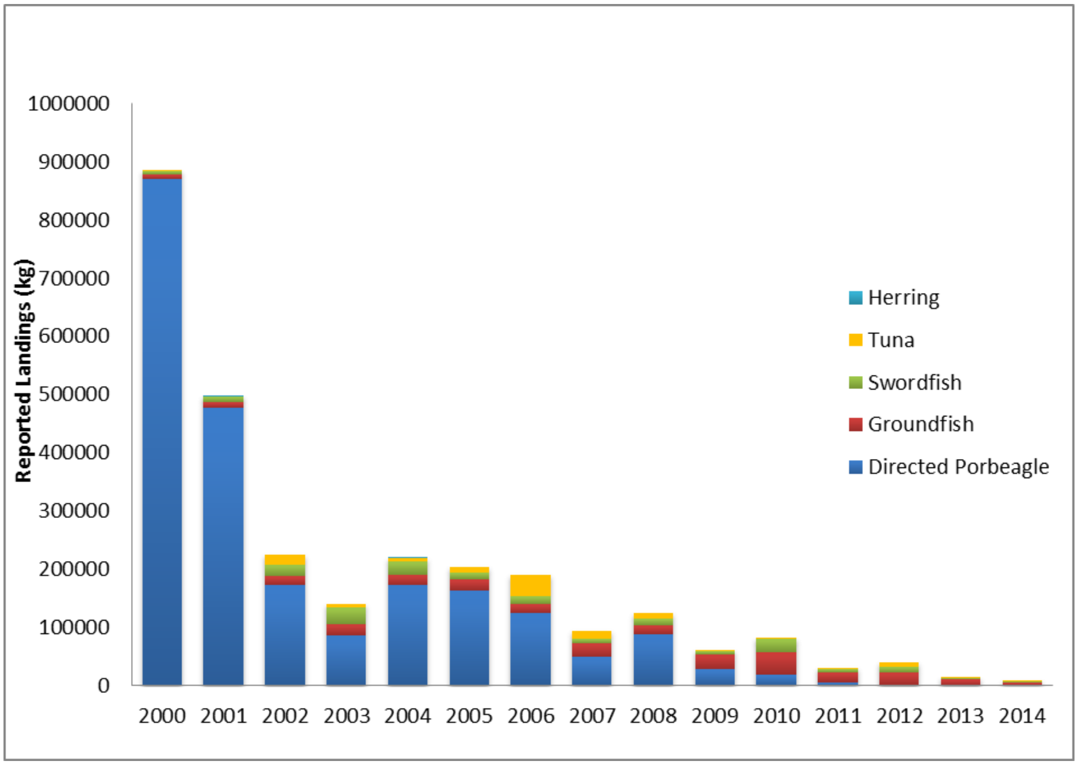

Figure 2: Reported Landings of Porbeagle in kilograms classed by fishery, both targeted and non-targeted, between 2000-2014. Data Source: Campana et al. 2015a

1.4 The Ecological Role of Apex Predators

Conservation of the porbeagle shark is critical, not only because it is a commercially valued species that is threatened with extinction due to overfishing, but also because of the ecological role that top predators maintain in marine ecosystems. Sharks are keystone species, which are defined as species whose activities and abundances determine the structure and integrity of its ecosystem (Paine 1969). Most high-level trophic predators (like sharks) exhibit top-down controls in the ecosystem, meaning that these organisms control the dynamics of the trophic levels below them, and the entire ecosystem (Baum and Worm 2009). Decreasing populations of predators can cause cascading effects throughout the ecosystem, leading to meso-predator and invertebrate predator increases (Baum and Worm 2009). For example, the removal of great sharks in the Northwest Atlantic caused increases in their elasmobranch prey (mainly rays, skates, and small sharks), which in turn preyed upon commercially valuable shellfish, decreasing their abundance. Evidence showed that over time the cascade would likely even effect seagrass, ultimately degrading benthic coastal ecosystems (Myers et al. 2007). However, because of the complexities of researching predators in the open ocean, concrete effects of decreasing predator abundances remain largely unknown (Myers et al. 2007; Baum and Worm 2009).

While concrete changes in Atlantic Canadian ecosystems resulting from declining porbeagle populations have not yet been observed, it would be unreasonable to assume that the loss of a top predator would not cause any negative effect on the ecosystem. The lack of observed effects may be due to two factors – a lack of baseline information on the ecosystem, and the relatively low population abundance of porbeagle in the Northwest Atlantic since the onset of observation (DFO 2006). The Blue shark, *Prionace glauca,* is also an abundant shark in Atlantic Canada, and it has a diet very similar to the porbeagle (Joyce et al. 2002), which could account for a lack of effects from the decline of the porbeagle population. Although Blue shark populations in the Atlantic remain relatively stable, they are the most commonly caught bycatch species in Canada (Campana et al. 2015b). If Blue shark populations begin to decline, there may be nothing filling the ecological role of top predator and the ecosystem may experience rapid change.

The management of shark fisheries in Atlantic Canada was not successful in mitigating the overexploitation of the species, which is evident in the two population collapses the species experienced during the short 50-year fishery. Growing concern for the plight of shark species has meant that conservation measures above and beyond traditional fisheries regulations may be required. MPAs are one such conservation measure that should be explored to assist in the recovery of this mobile predator in the temperate Northwest Atlantic. However, the extent to which MPAs can be effective in protecting highly mobile fish species is still up for debate. To contribute to the debate, this project will examine the distribution of porbeagle sharks off the Atlantic coast of Canada and evaluate the effectiveness and feasibility of establishing a connected network of MPAs for porbeagles. The porbeagle was chosen as the study species for this project due to its commercial value, its residency in Canadian waters, available data and information, the functional role it plays in the ecosystem, and its conservation status.

1.5 Porbeagles and the Changing Climate

Climate change is a divisive topic both on land and in the sea, but scientific experts have been providing overwhelming evidence that anthropogenic activities are causing unprecedented changes in our global ecosystems. Oceanographers and climate scientists are predicting increasing temperatures, rising sea levels, ocean acidification, and changing circulation patterns in the world's oceans (Hoegh-Guldberg and Bruno 2010; EPA 2016). These changes are expected to affect species distributions and abundances, community composition, habitat quality, and population dynamics for marine life (Cheung et al. 2009; Harley et al. 2006; Lawler 2009). These changes, and the speed at which they are occurring, can increase the vulnerability of natural and human systems, and the species therein (Hopkins et al. 2016). Many marine species are sensitive to temperature and ocean current patterns (Poloczanska et al. 2013), and a recent model predicted an average change in distribution amongst marine species of 30km per decade (Cheung et al. 2015). Porbeagles are a cold-water species, so as the ocean warms their distribution are expected to change, bringing them further north or deeper into cooler waters. This could cause complications in the future if the specific feature drawing individuals to these areas shifts with the changing ocean climate.

Chapter 2: Shark Management Tools

The concept of using spatial measures, such as an MPA, for the conservation of highly mobile fish species is relatively new. Static protected areas are just one of the many tools that marine managers can use for the conservation of sharks. Connected networks of MPAs are particularly attractive to ecologists because they not only have the potential to conserve the target species present in the area but also the ecosystem as a whole. There are, however, other tools that can be used for shark conservation that are more targeted and species-specific. In the past, shark fisheries and populations have been managed using different tools, such as fisheries regulations, national policies, and international agreements. This section explores some of these options that can be used for porbeagle conservation above and beyond marine protected areas including more traditional mechanisms for shark regulation, as well as some of the laws and policies that exist in Canada to sustainably manage shark populations.

Although it is not considered a major shark fishing nation, Canada became a leader in shark management as it was one of the first countries to develop and implement shark management in 1994, in the form of regulations on finning, the practice of removing the shark's fin from the carcass (Godin and Worm 2010). Canada has a number of national policies to manage shark populations found within its waters, and is also a signatory to a number of international agreements through United Nations conventions and Regional Fisheries Management Organisations.

2.1 International Law

As signatories to the United Nations Convention on the Law of the Sea (UNCLOS), Canada has agreed to national jurisdiction of an Exclusive Economic Zone (EEZ) extending out 200 nautical miles, and therefore jurisdiction over all organisms within that limit (UNCLOS 1982). Under UNCLOS there is an additional agreement, the Straddling Fish Stocks and Highly Migratory Fish Stocks Agreement. This agreement provides a framework for the conservation and management of fish stocks across international borders, requiring the application of the precautionary approach to recognize that changes in one part of a species' range can impact the population as a whole (DFO 2009). This agreement is particularly relevant to the management of porbeagles and other sharks found in Atlantic Canadian waters due to their wide ranges and migrations into neighbouring countries.

In 1999 the United Nations Food and Agriculture Organisation drafted an International Plan of Action for shark management (IPOA – *Sharks*) as a framework to aid nations involved in shark fishing to establish well managed, sustainable fisheries (FAO, 1999). While adherence to the plan is voluntary, the FAO urged shark fishing nations to establish a National Plan of Action (NPOA) to manage shark populations within their waters. Despite international support, the establishment and implementation of NPOAs among shark fishing nations has been slow (Fischer et al. 2013; Davis and Worm 2013). The Canadian NPOA was released in 2007 by Fisheries and Oceans to improve the management of all sharks, rays, skates, and chimaeras in Canadian waters (DFO 2007a).

2.2 National Regulations

Despite having only a minor impact on shark populations on a global scale, Canada has been fairly proactive in establishing national regulations to mitigate negative impacts from fishing on shark populations. Shark finning, a wasteful practice in which the valuable fins of the shark are cut off while the carcass is discarded, has been banned in Canada since 1994. A policy was adopted where any vessel landing fins is permitted a maximum of 5% fins relative to the weight of carcasses on board (Godin and Worm 2010). While this policy is a start for eliminating shark finning, many scientists believe that a 5% ratio in fact allows fishers to land 2-3 fins per carcass, as well as enabling mixing of species. Instead, it has been argued that Canada should adopt a fins-attached policy, where the fins must be naturally attached at the time of landing, which forces the landing of all retained sharks (Timms and Williams 2009). Additionally, despite banning the finning of sharks, Canada still allows the sale and trade of fin products (Sybersma 2015). While the porbeagle may be targeted for the value of its fins, the meat is also highly valued in Europe, so in many cases the carcass of the porbeagle is being utilized (Fowler, Raymakers, and Grimm 2004).

The first management plan for sharks in Canada, the 1995 Atlantic Pelagic Shark Integrated Fisheries Management Plan, was implemented to limit the growth of targeted fisheries by conducting stock assessments and instituting quotas for Blue sharks, Porbeagles, and Shortfin Mako sharks in the Canadian Atlantic. The management plan also limited the number of fishing licenses and put restrictions on fishing gear (Godin and Worm 2010). Following the example of the FAO, Canada established an NPOA – *sharks* in 2007. The NPOA includes objectives for improving research, improving reporting and management planning, reducing bycatch, including the Arctic in management plans, improving education and outreach in Canada and internationally, cooperating with RFMOs, and reviewing and progressing the NPOA (Davis and Worm 2013; DFO 2012a). As of 2013, Canada had successfully completed 61% of the actions outlined in the NPOA, although they have failed to establish a stakeholder advisory group or a shark assessment report to advise the management plan (Davis and Worm 2013). As part of the sustainable fisheries framework, DFO introduced the national policy for managing bycatch, which aims to ensure that fisheries are being managed in a way that reduces harm to non-target species (DFO, 2013).

2.3 Regional Fisheries Management Organisations

Canada is a member of several Regional Fisheries Management Organisations (RFMOs), of which two are involved in the management of the fisheries in the Northwest Atlantic. The Northwest Atlantic Fisheries Organisation (NAFO) is an intergovernmental body that manages and regulates fisheries within the Northwest Atlantic. NAFO requires vessels to report all shark catches, to retain all parts of the shark (except head, guts, skin), release live sharks caught as bycatch, and contribute to research for further conservation of sharks (NAFO 2015). Prior to the summer of 2016, NAFO followed the 5% fins to body weight ratio policy, however in a landmark vote in September 2016 NAFO adopted a proposal to change their policy to "fins attached", which bans the removal of fins from the carcass while at sea (Shark Advocates International, 2016).

ICCAT, the International Commission for the Conservation of Atlantic Tunas, has also implemented regulations for the landing of sharks throughout their jurisdictional area. ICCAT requires reporting of all shark catches, adherence to the 5% fins policy, and full utilization of the shark. In addition, ICCAT has several species-specific regulations in regards to particularly threatened species, including reduced mortality in porbeagle and North Atlantic Shortfin Mako fisheries until sustainable levels of harvest can be determined (Lack and Sant 2011).

2.4 Listings under the Canadian Species at Risk Act

Canada's Species at Risk Act (SARA) was adopted in 2002 with the purpose of preventing wildlife species in Canada from disappearing. This involves both recovery efforts for species that have become extirpated in the wild, as well as prevention for species that are threatened with extinction or extirpation (Environment Canada 2016). Species that are listed as threatened or endangered under SARA are automatically protected in Canada, including both individuals and critical habitat (Mooers et al. 2010). The SARA process begins with a scientific assessment by COSEWIC and a recommendation to the Minister of Fisheries and Oceans. Following the recommendation, SARA undergoes public consultations and a socio-economic analysis of the implications of listing a species. Once the species has been listed under SARA, a recovery plan is established, critical habitat is identified, and the species is under federal protection (Mooers et al. 2010). For a schematic of the listing process, see figure 10 in the Appendix.

In 2004, following a detailed assessment, COSEWIC recommended to the Minister of Fisheries and Oceans that Porbeagles should be listed as endangered under SARA. SARA conducted a socio-economic analysis and concluded that economic losses from suspending the fishery would be too great, and that catch levels were low enough to avoid threatening the long-term survival of the species, therefore the porbeagle was not listed (DFO 2006; COSEWIC, 2014).

CITES reassessed porbeagles in 2014 and moved them from Appendix III, species who are listed at the request of a party seeking international cooperation in regulating trade, to Appendix II, which lists species that are at risk of extinction if trade is not closely controlled (i.e., they were “up-listed” in terms of their vulnerability status). This indicates a global consensus that porbeagle sharks are in need of conservation intervention to protect them from further decline. COSEWIC reassessed porbeagles in the Northwest Atlantic in 2014 and confirmed that the population is endangered. Despite being designated as endangered for over 10 years, SARA has no plans to reassess to consider adding porbeagles to the list of species at risk in Canada (Species at Risk Public Registry 2016).

SARA’s decision not to list the porbeagle shark has been criticized, with experts stating that the ecological benefit of listing the species would have far outweighed the economic implications (Rudd 2009). One of the primary reasons cited against listing the species was the financial cost to communities in Nova Scotia (DFO 2006). At the time of SARA’s decision, however, only two fishers in Nova Scotia were targeting porbeagles, and their catch equated to 25% of their annual income, and the financial benefits equalled only 2% of fisheries landings value in one community (Mooers et al. 2010). Now that the targeted fishery is closed there may be a call for reassessment, but listing the porbeagle would still incur costs to fisheries catching porbeagle incidentally as they would need to implement practices to decrease mortality, so it is not evident whether SARA’s decision would change.

2.5 Fisheries Management Tools

Once international, national, and regional management plans have been established, fisheries management tools can be used to manage fisheries and populations on a more local scale. Fishing quotas are one of the most common management strategies used to regulate commercial fisheries and protect depleted or declining populations. Quotas in Canada are set by the department of Fisheries and Oceans and are based on scientific advice including population surveys, historic catch records, and the biology of the species. The setting of a quota for porbeagle sharks, however, proved to be insufficient and ineffective at allowing the population to recover. Dwindling numbers prompted DFO to establish a Total Allowable Catch (TAC) of 1000 tonnes in 1998. Numbers continued to decrease, however, so the TAC was lowered to 250t in 2003 and then again in 2007 to 185t (Campana et al. 2015a). Setting a quota for catch limits on a highly mobile species is difficult because it is challenging to account for catches in neighbouring national waters as well as the high seas (Worm et al. 2014).

Now that the targeted fishery is closed in Canadian waters the main threat to porbeagles is incidental catches in other fisheries. Porbeagles are most frequently caught as bycatch in the groundfish fishery, although they are also regularly caught in fisheries targeting tuna, herring, and swordfish (See Figure 2). Employing fisheries observers to record bycatch species and magnitude is one way to regulate and monitor the incidental catch of porbeagles, but this is expensive and it is rare for a fishery to have 100% observer coverage. A study conducted in 2011 (Campana et al. 2011) found that observer records were available for less than 10% of the total catch in fisheries regularly catching porbeagles as bycatch. The large pelagic fishery (i.e. tuna, swordfish) had approximately 5% observer coverage since 1999, and the groundfish fishery had even less coverage (Campana et al. 2011). DFO has set a quota to limit the numbers of sharks being caught incidentally, but without observers to monitor catches there remains a degree of uncertainty over the actual amount of incidental mortality in the population. This is emphasized in a report by DFO scientists that acknowledges there is still porbeagle bycatch of "unknown magnitude" in Canadian waters (Campana et al. 2015a). Even when there is sufficient observer coverage it is critical that observers and fisheries officials are trained in the identification of shark species to ensure that the proper species is being recorded. Misidentification of shark species is a global issue, not only in the shark fin trade but also when species are being recorded in fisheries landings logs. Sharks can be misidentified due to similarities between species and the inability by the recorder to properly label the species, and also because there are often different local terms for species which can cause confusion. For example, Oceanic white tip sharks are simply called "white sharks" by some communities, while other communities call the

Great white shark, *Carcharodon carcharias*, “white sharks” (Burgess et al., 2005). Misidentifying species causes discrepancies between recorded catches and actual catches, which could result in inaccurate population estimates.

Shark finning regulations, another important fisheries management tool that can help to preserve shark species, has briefly been discussed in this section. Placing restrictions on landing fins separately from carcasses (or not landing carcasses at all) can be effective in decreasing shark mortality because they prevent fishers from discarding majority of the fish, ensuring that less is wasted. There have been some arguments that creating policies for fin-weight ratios (laws where the weight of fins must not exceed a certain percentage of the weight of shark carcass) have only been moderately successful, largely due to a lack of capacity to monitor and enforce the rules. There is also a debate surrounding the regulation because scientists believe that the weight of the fins is actually less than 5%, meaning that fishers can land 2-3 fins per carcass and remain within the allowable limit. There is also an issue with high grading, when carcasses and fins from sharks of different species or sizes are mixed, causing the weight ratio to become skewed. Monitoring and enforcement would be much easier if policy incorporated legislation stating that fins must be attached at landing, which has proven to be a much more effective measure for conservation (Timms & Williams, 2009). It is important to acknowledge that fin restrictions may not have an effect within Canadian waters because porbeagles are no longer being targeted, but RFMO regulations may help to reduce mortality on the high seas.

Another tool that can be effective in conserving sharks is a restriction on the types of hooks and gear that are used in fisheries with high incidences of shark bycatch. Incidental catch has become the biggest threat to sharks in Canadian waters since the targeted fishery was closed (Campana et al. 2015a), therefore there is an opportunity to diminish the threat by selecting gear that has a lower mortality rate associated with it. Some sharks that are caught incidentally are retained if there is commercial value in the species, but the majority of individuals are released (Campana et al. 2011). An ecological risk assessment conducted in 2015 found that porbeagles were among the most vulnerable pelagic shark species in terms of being caught incidentally in longline fisheries, both in terms of chance of being caught as well as the chance the hooking will result in mortality (Cortés et al. 2015). Limiting the soak time of the hooks, the amount of time in which the hook is in the water, can increase chances of survival (Gallagher et al. 2014). The type of hook used in fishing can also impact the survival of the species. The odds of survival for porbeagles and blue sharks can be two to five times higher when they are caught using a circle hook compared to a J-shaped hook (Neilson et al. 2011). Finally, there are technological advances that can help to reduce incidental mortality. Electromagnetics, electropositive metal alloys, and semiochemicals are all being explored as shark repellent technologies to elasmobranch mortality in fishing gear (O'Connell et al. 2014).

Education and outreach campaigns can be an extremely effective tool to garner support for conservation initiatives. There will be no effective protection for sharks unless there is a financial, social, and political desire to implement change. Sharks have been the victims of negative public opinion, with people calling them vicious predators and man-eaters, largely due to sensational, dramatic depictions and misinformation in the media (Morey 2002). When people are afraid or feel threatened by something, they are not inclined to protect it, and without public support there is no incentive for governments to implement protection. Studies have shown that people who have higher levels of knowledge about sharks are more likely to exhibit behaviour supporting conservation (O'Bryhim and Parsons 2015). Media campaigns such WildAid's culturally sensitive and celebrity driven multimedia movement aimed at educating the public on sharks and the consequences of consuming shark fin soup have been successful in reducing market demand for shark products and increasing awareness and conservation efforts (Timms and Williams 2009; O'Bryhim and Parsons 2015).

Chapter 3: Marine Protected Areas

As previously introduced, marine protected areas are becoming a widespread tool for marine conservation around the world. MPAs come in different shapes and sizes, with different regulations put in place depending on the specific features being protected in the area. While MPAs are most commonly used to protect environmental features, they can also be used to protect sites of historical or cultural value (Dudley 2008). MPAs in Canada can be established by three different governing agencies; Fisheries and Oceans Canada, Environment Canada, and Parks Canada. The specific planning mechanisms and legislation discussed throughout this paper refer primarily to MPAs established by Fisheries and Oceans using the Oceans Act.

3.1 Canada's Network of MPAs

In 2010 the Convention on Biological Diversity (CBD) proposed the Aichi targets, of which target 11 stated that, by 2020, at least 17 per cent of terrestrial and inland water areas and 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, should be protected (CBD 2011). As signatories to the CBD, Canada has a responsibility to meet this target, and the current government has pledged to establish a network of MPAs and fulfill this promise (PMO 2016). The network planning process will be conducted in a way that is representative of Canada's different bioregions and the diversity of ecosystems and organisms found within our waters (DFO 2016a), which should include considerations for Canada's many species of sharks. Socio-economic values are also evaluated throughout the network plan.

DFO's Maritimes region currently has two MPAs: Musquash Estuary in the Bay of Fundy, and the Gully, a submarine canyon on the edge of the Scotian Shelf. St Anne's Bank, a large area east of Cape Breton, has been designated as an Area of Interest (AOI) for establishment as an MPA and is currently undergoing the establishment process. Additionally, over 50 coastal sites and almost 20 offshore sites have been identified as Ecologically and Biologically Significant Areas (EBSAs) that, upon further study and review, could become candidates for future AOIs and ultimately MPAs. These EBSAs have been identified for various reasons, including areas of high biological productivity or biomass, areas of high fish and invertebrate diversity, important habitats for fishes and invertebrates, coral and sponge occurrences, Critical Habitat for species at risk, important areas for seabird functional guilds, and distinct physical conditions (King et al. 2016). The ecological data base layers for the Maritimes region EBSAs is currently lacking in information regarding Atlantic Canadian shark species. It is important that comprehensive and accurate data for porbeagle and other North Atlantic shark species in and around these EBSAs be incorporated into the network planning process. This project will act as a first step towards incorporating shark species into the network planning process.

3.2 Marine Protected Areas as a Management Tool

The traditional design of an MPA is limited in its capacity to protect mobile and migratory species that travel outside the boundaries of the MPA (Knip et al., 2012), however the potential value that MPAs can have for pelagic conservation is becoming more widely recognized (Hooker et al. 2011). Using the theory of connectivity in networks of MPAs can be effective in increasing the protection of these species, particularly by implementing multiple protected areas throughout a species' range. In order to design MPAs with specific regard for mobile species, it is crucial to first understand their movements and habitat use (Speed et al., 2016). There is currently a lack of research and understanding of the relationship between mobile species and MPA networks (Knip et al., 2012), around the world as well as in Nova Scotia, so studying their movements and migrations can allow managers to better design connected areas to ensure that these animals are protected throughout their entire spatial and temporal range.

3.3 Connectivity and Highly Migratory Species

Historically it was believed that MPAs could only effectively protect resident species whose range was confined within the boundaries of the protected area. However, recent developments in the study of connectivity and advancements in our knowledge of the movements of highly mobile species has made the concept of spatial protection for mobile species a much more feasible tool. In general terms, connectivity refers to the linkages between geographically separate areas, which occur as a result of the movement of individual larvae, juveniles, and adults, as well as organic and inorganic matter (Jessen et al. 2011). The definition of connectivity and how it relates to MPA network planning will change depending on the scale and species being studied. For example, connectivity for a sessile species such as a mussel will be very different from connectivity for a highly mobile pelagic shark like the porbeagle.

Mobile species such as sharks, but also sea turtles, cetaceans, and pinnipeds often have predictable habitats during different life cycles and time periods, which can enable managers to identify critical habitat for protection (Hoyt 2014). MPAs can be effective in protecting migratory species if implemented in areas important for life stages or in critical habitat areas (Hooker et al. 2011). Once these predictable habitats have been identified, researchers can begin to examine species movement between the habitats and establish connectivity patterns that can help to protect the species not only in areas of critical habitat, but also while they travel within and between sites.

3.4 Socio-Economic Benefits from MPAs

MPAs protect the natural environment and help to keep ecosystems healthy and resilient. There are, however, additional benefits from MPAs outside of environmental protection. The spillover effect, the net movement of individuals from reserves towards fished areas has been cited as an economic benefit arising from MPAs (Rowley 1994; McClanahan and Mangi 2000). The theory of the spillover effect is that it can help to strengthen fisheries outside the MPA and make up for losses that have occurred from implementation of the closed area. Spillover may occur through egg and larval drift, the trophic or reproductive migrations of adults, or movements of individuals across boundaries due to density-dependent factors (Pérez-Rustafa et al. 2008). It is difficult, however, to accurately measure and document spillover from MPAs, particularly in the early stages of implementation (Sale et al. 2005).

MPAs are effective at allowing exploited populations to recover which positively influences abundances of fish both inside and outside the reserve (Halpern 2003). This supports the theory that MPAs can in fact help to strengthen fisheries and provide an economic benefit. One study found that the size of a reserve has an influence on the level of exportation out of the area. Small reserves generally have lower abundances than large reserves, however very large reserves show less of a spillover effect. The study concluded that a connected network of medium-sized MPAs would be the most beneficial, both from a conservation point of view as well as for fisheries benefits (Pérez-Rustafa et al. 2008). This could correlate well with MPAs designed for mobile species, as there would be multiple sites established throughout the species' range that could all contribute to surrounding fisheries.

3.5 The Economics of Conservation

Society can benefit from healthy marine environments above and beyond commercial fisheries. Economic benefits from the environment can come in two forms- ecosystem goods, and ecosystem services. Goods are tangible material products resulting from ecosystem processes, while services such as the purification of water or protection from floods are intangible mechanisms that result in improvements in the condition of things of value (Brown et al. 2007).

Table 1: An estimation of the value of ecosystem services provided by the Sargasso Sea. Source: deGroot et al. 2010.

Source of Value	Mean Value (USD per hectare per year)	Sargasso Sea Value (Million USD)
Climate Regulation	30	1.3
Conservation of genetic diversity	2,539	105.4
Moderation of extreme events	6,149	255.3
Nutrient cycling	19,979	829.4
Water purification, waste management	33,966	1410.1
Habitat / nursery service	3,800	157.7
		2,759.1

Table 1 demonstrates an example of the valuation of an ecosystem service. Valuing intangible benefits such as ecosystem services is a difficult and controversial process, but it can be beneficial in at least beginning a dialogue on some of the intangible social and economic benefits that natural systems can provide. For the Sargasso Sea example by deGroot et al. in 2010, the economic value per hectare per year for various biomes in the open ocean were calculated, and then those values were multiplied by the area of the Sargasso Sea. The resulting figures estimated that the annual value of the services that the sea provides is over 2.7 billion USD. While these figures could be debated, they emphasize the need to protect these systems and services as well as the importance of assigning monetary value to services that cannot be bought or sold (Laffoley et al. 2011). Producing examples of social and economic benefits that can arise from environmental protection can help managers to garner political and public support for conservation endeavours.

3.6 Management across Borders

Normally when a highly mobile species is being considered for spatial protection measures there are a multitude of countries and governing bodies that need to coordinate and agree upon regulations for that species in order to protect it throughout its entire spatial range. Establishing MPAs across multiple jurisdictions presents multiple policy and legal considerations for which there is not a great deal of precedent (Scovazzi 2004). This lack of capacity to manage and protect species that travel across national boundaries and into areas beyond national jurisdiction is problematic and detrimental to shark conservation efforts. There is a unique opportunity, however, when considering the Northwest Atlantic population of porbeagle, since the population is limited to the jurisdiction of only two nations. While the Northeast Atlantic population would require coordination between over 10 different nations, the Northwest population only crosses between Canadian and United States waters.

Chapter 4: Exploring Areas of Interest in the Scotian Shelf Bioregion

4.1 Rationale and Methods

This project looks at how static protected areas can be used as tools for the protection of highly mobile fish species in temperate waters, using the porbeagle shark as a case study to specifically explore possible sites for inclusion in a network for protecting the Northwest Atlantic population. The vast majority of studies that have been conducted on the establishment of protected areas for shark conservation have been done in tropical areas where species typically have smaller ranges and higher site fidelity, for example due to coral reefs (Knip et al. 2012; Breen et al. 2015). This project aims to broaden the scope of MPAs for highly mobile fish species into more temperate areas, with species that have wider geographic ranges, in order to determine the most effective means for the protection of sharks in Canada.

In order to identify potential sites for porbeagle conservation for inclusion in the regional MPA network plan, a geographic analysis of shark abundance in Atlantic Canada was conducted to determine optimal sites for protection. This was done by obtaining all recorded porbeagle landings from Fisheries and Oceans Canada's Maritimes region between the years 2008-2014. These landings included both targeted catch as well as incidental landings from all commercial fisheries in the region. These landings points were overlaid with Ecologically and Biologically Significant Area (EBSA) polygons using ArcGIS. EBSA polygons were used as the foundation for the geographic analysis because these areas have already been identified as important for healthy marine ecosystems, and are potential candidates for further protection in the future. ArcGIS was used to calculate the abundance of sharks being caught within the EBSAs, which indicated hypothetical species abundance. Using these areas that have been identified as possible candidates for future MPAs and exploring whether any of these areas appear to be sites where the sharks aggregate or spend significant periods of time will be beneficial for the Maritimes network analysis.

As previously indicated, the majority of studies that have been conducted on the efficacy of MPAs for the conservation of sharks have been done on species with relatively small ranges (Knip et al. 2012). However, researchers are beginning to acknowledge the possibility of using spatial protection for the conservation of highly mobile species. Highly mobile species have wide geographic ranges, often across national boundaries and sometimes even into areas beyond national jurisdiction. This extensive range makes it unfeasible to create a protected area encompassing the species' entire habitat. Although protecting the entire geographic range of a highly mobile species is, in practical applications, impossible, it is reasonable for nations to create protected areas around critical habitat, areas of high species abundance, or areas for critical life stages. Creating multiple protected areas in places of particular importance for a highly mobile species can have a positive impact on the population. The results of the following spatial analysis can be used as a preliminary indication of potential areas of interest that could hold particular importance for porbeagle sharks.

Initial studies of the distribution of porbeagle sharks in the Northwest Atlantic showed sharks in United States waters as far south as 37°N, which is roughly the state of Virginia. A study in 2010 found that most individuals were found in Canadian waters north of 41°N (Campana et al. 2010). Another assessment several years later on the annual migrations of porbeagles throughout the Northwest Atlantic showed a fairly predictable pattern, with sharks first appearing in the southern Scotian Shelf in January-February, moving northeast along the shelf through the spring, and finally appearing south of Newfoundland and in the Gulf of St. Lawrence in the summer and early fall before returning southwest in the late fall (Campana et al. 2015a). The landings data obtained from DFO for this analysis are limited to the jurisdiction of the Maritimes region, however additional sites of interest that have been identified in scientific literature that lie outside the Maritimes region have been included in the discussion.

4.2 Spatial Analysis Results

The spatial analysis of the recorded landings of porbeagle sharks in DFO's Maritimes region between the years 2008-2014 showed several trends and interesting results. A total of 2,303 sharks were landed throughout the span of 6 years. Of these landed sharks, 1,198 were caught within the boundaries of the ecologically and biologically significant areas, meaning that 52% of all sharks were caught in sites that could potentially be developed into MPAs. Due to government privacy regulations, the specific catch locations of the sharks cannot be shown in the results, however the EBSAs with the highest landings have been identified.

Table 2: Number of Porbeagle individuals landed in each EBSA between 2008-2014. Green EBSAs are classed as offshore, while pink EBSAs are coastal sites.

EBSA	08	09	10	11	12	13	14	Total
Scotian Slope	71	46	60	24	24	21	29	275
Emerald Basin	21	31	56	47	41	12	4	212
Roseway Basin	46	29	46	40	15	7	3	186
LaHave Bank	12	14	21	30	28	7	6	118
Eastern Shelf Canyons	26	9	39	2	11	9	4	100
Browns Bank	9	8	29	20	15	7	0	88
Laurentian Channel Slope	10	12	19	10	7	3	0	61
Southwest Nova Scotia	2	10	7	6	3	6	1	35
Canadian George's Bank	3	7	20	3	2	0	0	35
Jordan Basin	2	2	8	5	12	0	0	29
Stone Fence & Laurentian environs	7	1	5	6	0	0	3	22
Scotian Gulf	1	1	8	2	0	0	0	12
Right whale conservation area	1	2	1	0	1	1	0	6
St. Anns Bank*	0	0	0	5	0	0	0	5
Emerald Sable Banks Complex	0	1	1	2	0	0	0	4
Eastern Shoal	0	0	0	1	1	1	0	3
Northeast Channel	0	1	1	0	0	0	0	2
Cabot Strait	0	2	2	0	0	1	0	2
Misaine Bank	0	1	0	0	0	0	0	1
Horse Mussel Reefs	0	0	0	0	1	0	0	1
Brier Island, Digby Neck	0	0	0	0	0	1	0	1

Table 2 shows a breakdown of the number of sharks landed in each EBSA over the study period. Several EBSAs showed fairly high catches throughout the study period, including the Scotian Shelf EBSA with 275 total individuals landed, the Emerald Basin with 212 total individuals landed, and the Roseway Basin with 186 individuals landed. Coastal EBSAs are highlighted in pink, while offshore sites are highlighted in green, and it is worth noting that all three of these EBSAs with the highest number of landings are classified as offshore sites.

Figure 3 depicts the Maritimes region EBSAs (classed as pink for coastal sites, yellow for Bay of Fundy sites, and green for offshore sites), as well as the region's two current MPAs, the Gully and Musquash Estuary, as well as St. Ann's Bank Area of Interest, soon to be designated as the region's newest MPA. The three sites with the highest landings are identified as A, the Scotian Shelf, B the Emerald Basin, and C the Roseway Basin.

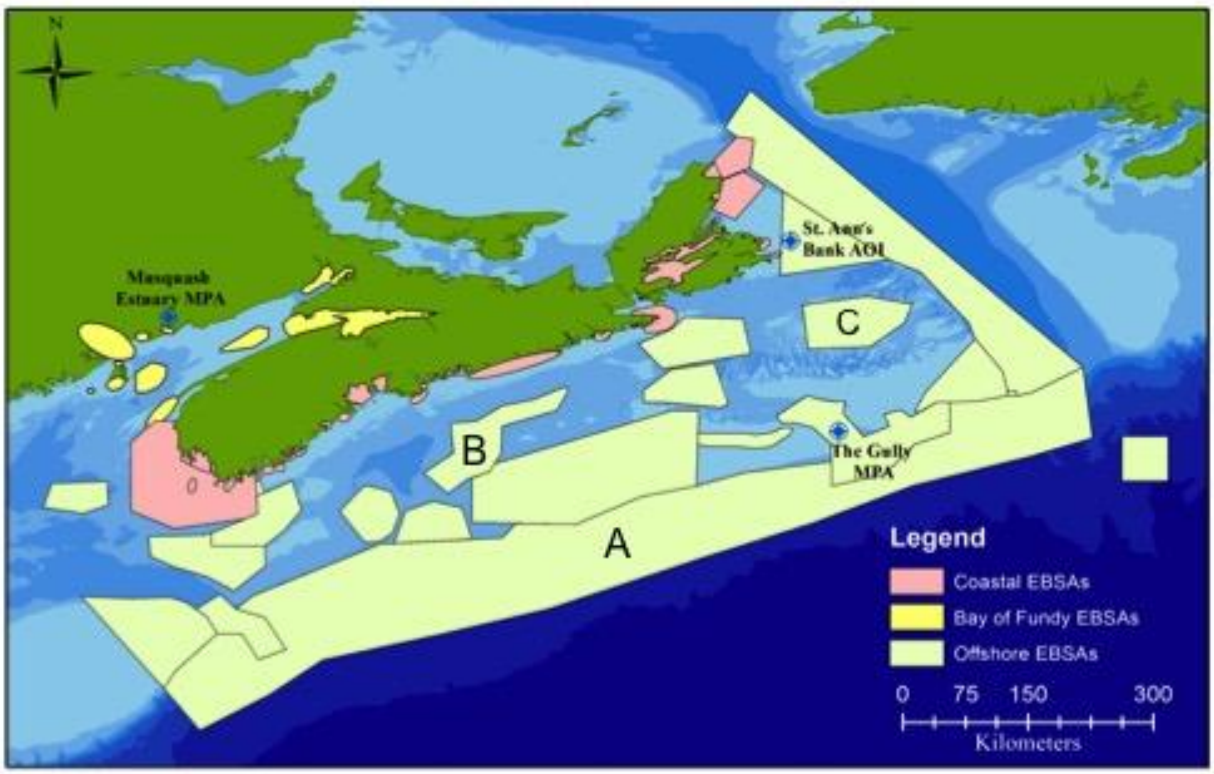

Figure 3: Maritimes Region EBSAs, current MPAs, and Area of Interest, as well as sites of high Porbeagle abundance (A,B,C)

Researchers from DFO Maritimes have also previously identified areas of critical habitat for porbeagles in the Northwest Atlantic, notably their mating grounds and pupping grounds (Campana et al. 2015a). Porbeagles are known to mate in the fall (Jensen et al. 2002), and give birth in the late spring (Campana et al. 2010). A survey conducted in 2002 found sharks with signs of mating in the fall, including fresh mating scars, internal wounds, and spermatophores in the uterus (Jensen et al. 2002). These sharks were found in clusters on the Grand Banks, south of Newfoundland, and at the entrance to the Gulf of St. Lawrence. This indicated that mating was likely occurring in these areas during the summer. A second mating ground was identified in 2007 on Georges Bank, based on observations of similar aggregations of mature females. These additional areas of importance for porbeagle sharks are not included in the GIS analysis as these areas fall outside of the jurisdiction of DFO Maritimes.

A study published in 2010 by scientists from DFO Maritimes (Campana et al. 2010) tagged 21 sharks off eastern Canada using pop-up archival transmission tags. The tags were active between 2001 and 2008, recording depth and geolocation of the tagged individual via satellite. The study found that adult males and immature males and females remained in cool waters on the continental shelf north of latitude 38ºN, while every mature female that was tagged left the continental shelf in the winter months (December-March), swimming south into the Gulf Stream until reaching the Sargasso Sea. Depth analyses indicated the females diving underneath the flow of the Gulf Stream to maximize swimming speed and to remain in cooler waters. The fact that the southward migration was made only by mature females, along with previous studies indicating that female porbeagles are gravid after November (Jensen et al. 2002), allowed researchers to infer that the purpose of the migration was to reach a sub-tropical pupping ground in the Sargasso Sea. Mature female residency in the Sargasso Sea lasted through the late spring, coinciding with the pupping period, further solidified the evidence that female porbeagles are giving birth in the Sargasso Sea (Campana et al. 2010).

While it is critical to determine the geographic distribution of a species in order to implement spatial protection, it is also important to consider distribution on a temporal scale, particularly with a species that undergoes long migrations. A temporal analysis of shark landings in the Maritimes region showed that a high number of sites had shark residency for the majority of the year. Two EBSAs, the Eastern Shelf Canyons and the Scotian Slope had landings recorded in every month of the year (See Figure 4). Four additional EBSAs showed landings the majority of the year (9-11 months), which indicates porbeagle residency in Maritimes Region for a significant portion of the year. When looking at the region as a whole, it is clear that although the majority of landings are occurring during the summer, there are Porbeagles being landed in the Maritimes every month of the year (Figure 5).

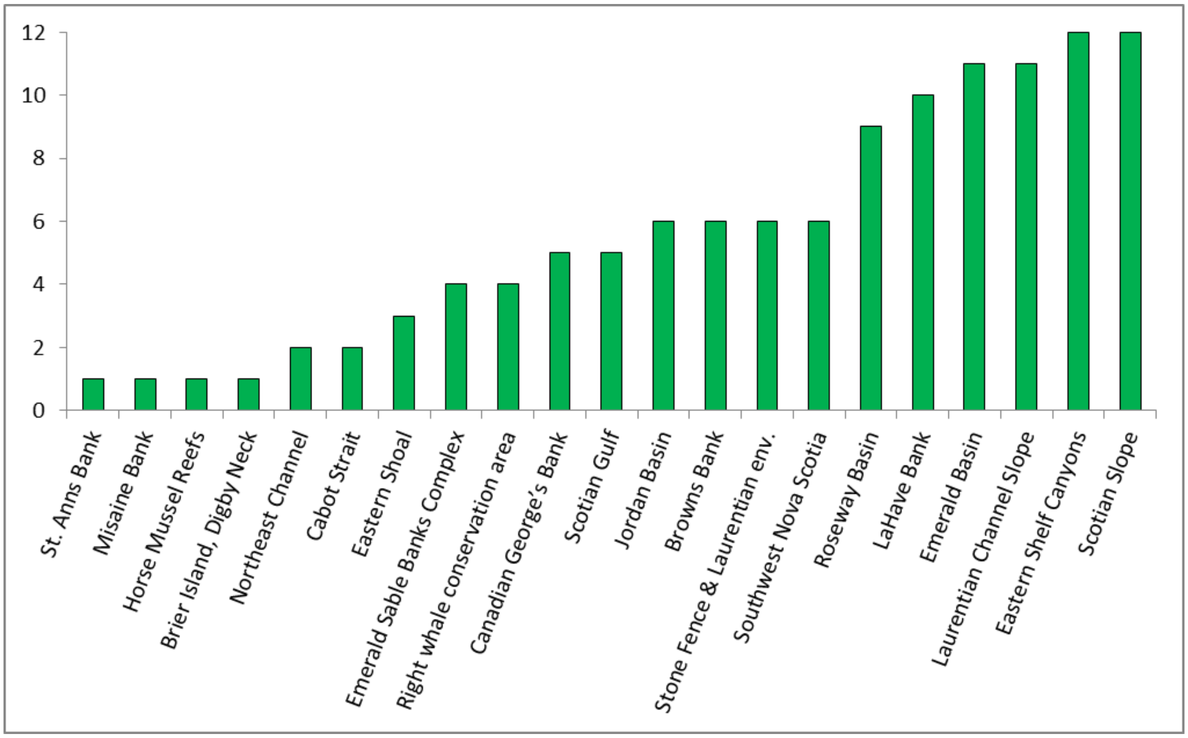

Figure 4: Maritimes Region EBSAs and the number of months with recorded landings.

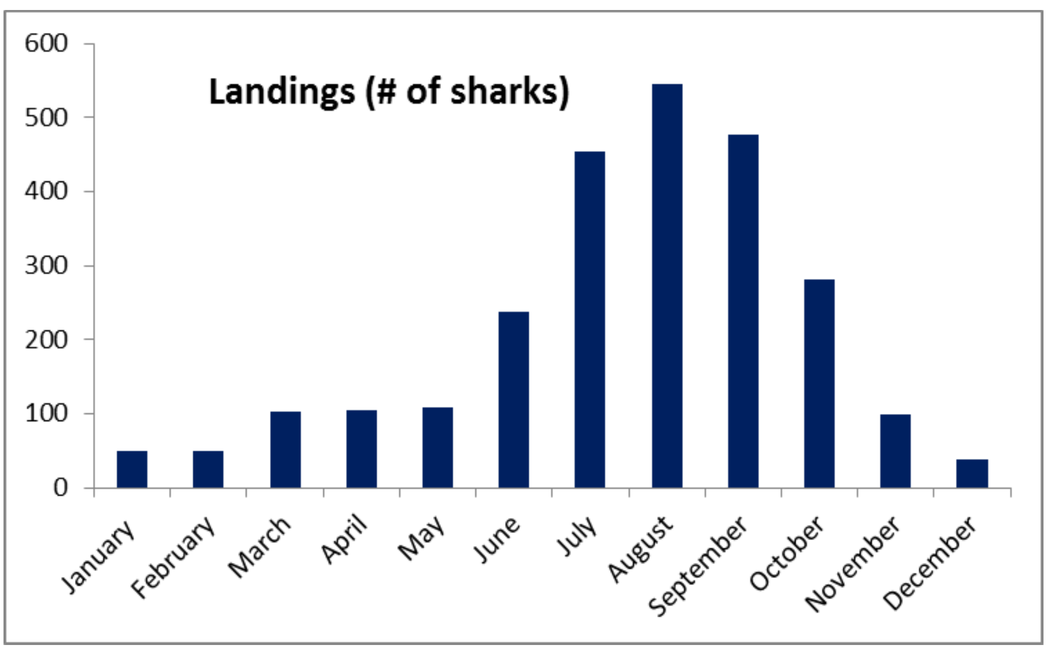

Figure 5: Number of individuals landed per month in the Maritimes Region between 2008-2014.

Porbeagles sharks in the Northwest Atlantic show clear patterns of life history stages and critical habitat, both spatially and temporally. Several important behaviours, including mating and pupping, have been identified and located throughout the region. While mature females leave the EEZ to give birth in the winter, males and juvenile sharks show residency in Maritimes Region waters throughout the entire year. This is a positive indication that permanent spatial closures in the region could be beneficial for this endangered population.

4.3 Proposed Sites of Interest for Porbeagle Sharks

4.3.1 The Sargasso Sea

Scientists have identified the Sargasso Sea as a probable pupping ground for porbeagle sharks (Campana et al. 2010). The sea is named for a genus of free-floating seaweed called *Sargassum* that provides habitat for a wide variety of species including turtles, shrimp, crab, billfish, and endangered European and American eels. There are also many species that migrate through the Sargasso Sea, including tuna, birds, cetaceans, and of course porbeagle sharks. The Sargasso Sea is unique as it is the only sea in the world not defined by land boundaries. Instead, it is defined by ocean currents within the North Atlantic subtropical gyre (NOAA, 2016; Sargasso Sea Commission 2016).

As discussed in section 4.2, mature females travel almost 2500km from Eastern Canada to the Sargasso Sea between December and March to reach the pupping ground. These females remain in the Sargasso Sea for several months until the pupping season in the late spring (Campana et al. 2010). Establishing a protected area in the Sargasso Sea would benefit not only porbeagle sharks during a vulnerable life stage, but also the multitude of other species that depend upon the area and its rich ecosystem.

Due to its location in the high seas, the Sargasso Sea encompasses an area beyond national jurisdiction. Despite its distance from any inhabited landmass, the area has experienced moderate to high impacts from human activity (Halpern et al. 2008). The sea is experiencing overfishing, shipping (and related impacts), and pollution in both the *sargassum* as well as the waters within the gyre (Laffoley et al. 2011). Establishing an MPA could help to regulate impacts from fishing and shipping if there are resources to provide sufficient monitoring and enforcement of the area.

The process to establish an MPA in an area like the Sargasso Sea that lies beyond national jurisdiction is complicated and can only occur with the participation and support of all countries surrounding the area. Currently only 0.17% of the high seas are within a protected area (Spalding et al. 2013), although there are some regional approaches and memorandums of understanding that could be used to establish protected areas on the high seas if sufficient support and political will exists (Hoyt 2014). The Sargasso Sea Commission is one such regional initiative that is working towards international protection for the Sargasso Sea (Sargasso Sea Commission 2014).

4.3.2 Grand Banks/Gulf of Saint Lawrence

The Grand Banks off the south and east coasts of Newfoundland and Labrador, as well as the mouth of the Gulf of Saint Lawrence, were first identified in 2002 by researchers studying porbeagle reproduction. The presence of females in these areas between September and November with fresh mating wounds indicated that mating had just occurred (Jensen et al. 2002).

The Grand Banks are a series of raised submarine plateaus extending for hundreds of kilometres. The mixing of the cold Labrador Current and the warm Gulf Stream in the area created one of Canada's richest fishing grounds. The area is an important spawning, nursing, and feeding ground for many different species of fish and shellfish (DFO 2012b). The Grand Banks were an extremely important area for the Atlantic cod fishery until the collapse of the population in the early 1990s due to severe overfishing. The fishery was closed in 1993 and remains closed to this day (Myers et al. 1997).

The Gulf of St. Lawrence is a semi-enclosed area that serves as the major outflow for the Great Lakes through the St. Lawrence River. Fresh water flowing from the lakes becomes saltier as it nears the Atlantic, becoming truly oceanic when it encounters strong upwelling at the head of the Laurentian channel (DFO 2014). There is a strong human presence in the area with shipping, commercial fishing, tourism and recreation, aquaculture, oil and gas exploration and scientific activity all putting pressure on the biological and physical components of the ecosystem (DFO 2007b). DFO's Gulf Region has identified several EBSAs in the estuary and Gulf of St. Lawrence (DFO 2007c), including an Area of Interest adjacent to the Saguenay-St. Lawrence Marine Park, which has been identified due to its importance to marine mammals (DFO 2016b).

The main barrier for implementing an MPA in the Gulf of St. Lawrence or on the Grand Banks is the area's socio-economic importance. Over 6400 commercial vessels pass through the Gulf every year, there are over 1800 aquaculture sites, over 40 ports exist to accommodate the vessel traffic, and the value of fisheries landings from the Gulf in 2007 was over $500 million CAD (DFO 2007b). Although the groundfish fishery is closed on the Grand Banks there are many fisheries that still remain active in the area. While the ecosystem would benefit from restrictions to extractive and harmful activities, the economic and social impact that would arise from limiting access to these places of economic and historic importance would be very high.

4.3.3 Georges Bank

Georges Bank lies at the Southwestern end of the chain of banks extending from the Grand Banks down to New England in the United States. Similarly to the Grand Banks, the Labrador Current meets the Gulf Stream causing nutrient rich waters and very productive fishing grounds on George's Bank. Shallow waters allow sunlight to reach the seafloor, creating a hospitable environment for phytoplankton, which grows three times faster on Georges Bank than any other continental shelf. These rich waters attracted fishers for centuries, eventually causing a decline in fish abundance due to overfishing (AMNH, n.d).

The suggested porbeagle mating ground on Georges Bank was identified in 2007 based on an observed aggregation of mature females who did not appear to be feeding. These aggregations were discovered in June, and due to the absence of mature males in the area researched determined that mating had yet to begin (Campana et al. 2015a). Along with the known 8-9 month gestation period (Aasen 1963), this discovery correlates with the theory that pupping occurs in the spring.

Lying on the border between Canada and the United States, Georges Bank has a history of contention between the two countries dating back to the American Revolution (AMNH, n.d). The rich fish stocks on the bank were sought after by fishers from both countries, and despite the establishment of the Hague line, the official boundary determined by the International Court of Justice, there remains tension amongst fishers in the area. A reserve in the area has been proposed in the past, suggesting that not only would it protect a valuable marine ecosystem, but also serve as a buffer for peace between American and Canadian fishers (Gulf of Maine Council, 1999).

An MPA in Georges Bank would require cooperation between the US and Canadian governments, as well as all stakeholders active in the area. Although there has been a moratorium placed on the groundfish fishery on the Grand Banks, Georges Bank remains an area of significant fishing activity which is important to the economy of surrounding communities. The Canadian portion of George's Bank has been identified as an EBSA by DFO Maritimes (King et al. 2016).

4.3.4 The Scotian Slope

The Scotian Slope is the largest EBSA identified in the Maritimes Region. Spanning over 70,000 $km^{2,}$ the Scotian Slope is defined as the area between 200m and 3000m along the edge of the Scotian Shelf. While there are several smaller EBSAs overlapping with portions of the Scotian Slope, the entire area has been identified as important. Some features, such as high primary productivity and the use of the area as a migratory corridor span the entire EBSA. Other features, such as submarine canyons, are more localized within the larger region (King et al. 2016). This EBSA had the highest number of recorded individuals caught and landed within the study period, with a total of 275 sharks over 6 years. Sharks were landed every month of the year in this EBSA, indicating that there are sharks present year-round.

4.3.5 Emerald Basin

The Emerald Basin was identified as an EBSA because of the aggregations of many different species that are commonly found in the area including invertebrates, fish, and cetaceans. Encompassing approximately 8500 km^2, the area has been identified as an important overwintering ground for both porbeagles and basking sharks. The high species richness and abundance in the area is likely due to the unique benthic communities found in the area, as well as unique temperatures and salinity causing high zooplankton biomass (King et al. 2016). The Emerald Basin had the second highest number of individuals landed within the study period, with 212 sharks. Landings were recorded in the Emerald Basin 11 months of the year, which could indicate that sharks are present in the area year-round.

4.3.6 Roseway Basin

Just over 3000 km^2 in area, the Roseway Basin EBSA is delineated based on topographic features as well as the distribution of the North Atlantic right whale that feeds, socializes, and possibly mates within the area. Persistent upwelling in the area causes high levels of surface chlorophyll year-round and high levels of biological production (King et al. 2016). The basin is separated from north to south by the Roseway Basin Moraine, which is made up of large boulders deposited by glaciers. Moraines cause higher benthic habitat heterogeneity and species richness (Kenchington 2014; King et al. 2016). A total of 186 sharks were landed in the Roseway Basin between 2008 and 2014. Sharks were recorded in the Roseway Basin 9 months out of the year, which indicates the presence of porbeagles in the area for at least a significant portion of the year.

Chapter 5: Discussion

The theory of using static spatial protection for the conservation of highly mobile species is still being developed. Although a spatial analysis of porbeagles in the Northwest Atlantic has identified several areas that could be candidates for future protection for the benefit of porbeagle sharks, there are some concerns regarding the analysis that should be addressed. The following chapter discusses some of the limitations encountered throughout the analysis, as well as some of the difficulties surrounding both spatial protection for mobile species, and shark conservation in general. Complexities regarding political processes, the changing climate, research gaps, and additional conservation tools will all be discussed.

5.1 Limitations

One of the most important limitations regarding the spatial analysis conducted for this project lies in the data source. The data that were assimilated for this analysis were obtained from Fisheries and Oceans from commercial fisheries recorded landings. This inherently indicates a bias, as observed locations where porbeagles were landed directly correlate with known fishing grounds. The main issue with using fisheries-dependent data for a distribution analysis is that an absence of recorded landings does not necessarily mean an absence of sharks; it could simply indicate an absence of fishing in that particular area. There have been shark surveys conducted by DFO in 2007 and 2009 (Campana et al. 2015a), and some tagging projects have occurred in the past, but there remains a lack of information on this endangered species.

Despite the fact that it has been well documented that many of the world's shark and ray populations are in decline and at high risk of extinction in the future (Garcia et al. 2008), there is a knowledge gap when it comes to the biology and ecology of these species. While almost a quarter of Chondrichthyes have been assessed as threatened by the IUCN, almost half of all shark and ray species have insufficient data to support an assessment (Heupel and Simpfendorfer 2010), so it is not necessarily the case that the remaining species are not threatened, rather, it could be that we simply cannot assess them. There are many uncertainties that remain in regards to the North Atlantic population of porbeagle sharks, and there is a strong ongoing need for science to help improve the conservation and management of this endangered species. Population abundance remains largely an estimate, and areas that have been identified as critical habitat, such as pupping grounds, have been inferred from observations but these life stages have not actually been witnessed by researchers.

Figure 6 is an example of one of the uncertainties that remains regarding the population. Porbeagle population dynamics in the Northwest Atlantic have been estimated using a forward projecting age- and sex-structured life history model. The model is based on catch-at-length and catch per unit effort by weight. Following the creation of the model, three additional models were created with varying levels of productivity. Model 2 is a lower productivity scenario, model 3 is an intermediate productivity scenario, and model 4 is a higher productivity scenario, with model 1 being the base model (Campana et al. 2012). Estimates from the model for the unexploited population in 1961 range from 760,620 total individuals (model 1) to 915,048 total individuals (model 2). Population fluctuations throughout the fishery are similar across all four models, but the status of the population today differs. Two of the models show modest recovery (1 and 4) while two show a stable population but no increase (2 and 3). Estimates for the population in 2009 near the end of the targeted fishery range from 198,970 individuals (model 3) to 206,956 individuals (model 1). While the discrepancies between models have decreased when considering the status of the population today, there is still a difference of several thousand individuals between estimates. In the absence of data, models are an effective tool for estimation, but management and regulations will be easier to establish and implement with more concrete information.

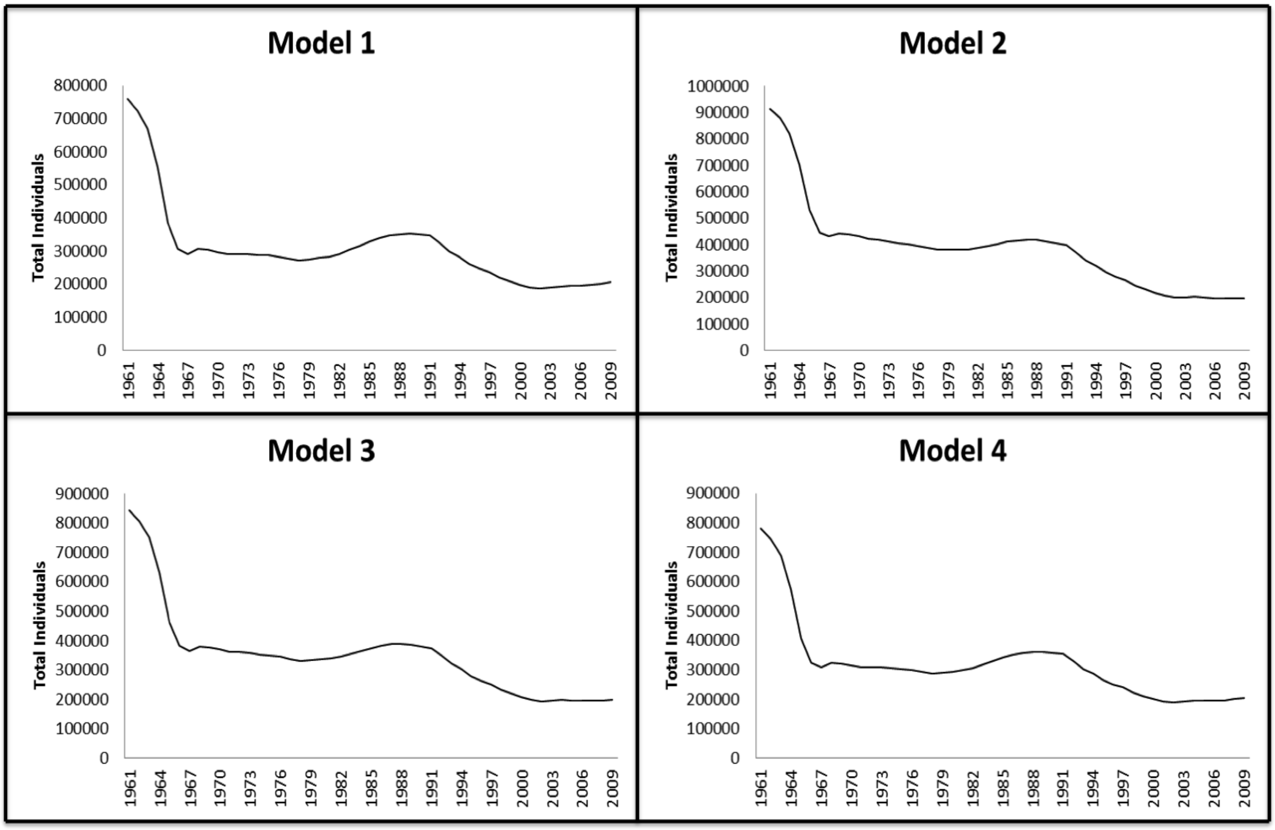

Figure 6: Estimated porbeagle population over time (total number of individuals) based on four different population models (Campana et al. 2012).

Finally, a lack of general information on designing a network of MPAs for temperate mobile species remains. Research on the efficacy of MPAs for mobile species is still quite new, and the majority of studies focus on species with small ranges and high site fidelity, which are often found in tropical areas (Breen et al. 2015). As the process for establishing a network for mobile species is much more complicated, there are far fewer studies targeting temperate species with wide ranges like the porbeagle. Without studies on the efficacy of MPAs for pelagic, temperate, wide-ranging sharks it is difficult to hypothesize the extent to which porbeagles would benefit from spatial protection.

5.2 MPA Regulations for Shark Protection

As previously outlined, the Canadian government is currently working towards the CBD goal of protecting 10% of its waters by the year 2020. Reaching this goal, however, will likely have no effect on shark populations if there aren't sufficient measures implemented within the MPAs to protect sharks. MPAs are most effective when they are designated using an ecosystem approach instead of being selected on a species-specific basis (Halpern et al. 2003), so it is important to select sites for protection that are not only important for one species, but for the ecosystem as a whole. That being said, if an MPA is established in an area important for an endangered species of shark, it is important to ensure that the shark will be adequately protected within the boundaries of the area. Many of the world's largest MPAs include critical habitat for sharks, yet they do not ban shark hunting or specifically protect the habitat of the shark in their management objectives (Hoyt, 2014).

Ideally, MPAs established in critical habitat for sharks would be no-take areas where there are no extractive activities permitted. Allowing sharks, and all of the other species in the area, a respite from all forms of fishing pressure, and other anthropogenic intervention would be the most effective means to allow the population to recover (Edgar et al. 2014). If a no-take area is unfeasible, there should at the very least be management objectives aimed at the conservation of sharks and restrictions on activities with high risks, such as pelagic longlines.

5.3 The Socio-Economics of Shark Conservation

While it is expected that policy makers will have to make difficult decisions and evaluate trade-offs when assessing species for protection, it is also important to account for the social and economic benefits that arise from healthy ecosystems. The following section explores some of the ways in which porbeagles can provide economic benefits, as well as some of the social and economic benefits of MPAs in general.

As discussed earlier, the decision made by SARA not to list the porbeagle shark as endangered was based on a socio-economic analysis that determined the listing would have too great an impact on the livelihoods of Nova Scotian fishers. In fact, it has been suggested that when it comes to listing a species under SARA, economics always trumps biology. An analysis of marine species listed under SARA found that only species with zero predicted cost associated with listing were protected. Any marine fish species with an anticipated economic loss were rejected (Shultz et al. 2013). The implementation of MPAs will likely cause economic consequences if there are restrictions placed upon extractive activities that can occur throughout the area (White et al. 2013). However, the social and economic benefits that come from the conservation of fragile marine ecosystems have the potential to outweigh any losses (Sanchirico et al. 2002). The following section describes some of the economic benefits that could occur in the Maritimes from healthy porbeagle populations.

5.3.1 The Porbeagle Fishery

The targeted fishery for porbeagle was widespread and intensive due to the fact that the porbeagle shark is a highly valued commodity in the European market for its flesh, and the fins are valued in Asia for consumption as soup. An economic analysis conducted by the Sea Around Us, in partnership with the Fisheries Economics Research Unit, estimated that the value of porbeagle was $1466 USD per tonne (Divovich et al. 2015). If an average sized adult porbeagle weighs 130kg, this equates to approximately $190 per individual, keeping in mind that both the fins and flesh of the porbeagle are utilized. While it is likely that the market price fluctuated throughout the duration of the targeted fishery, the analysis conducted by Sea Around Us assumed a constant value throughout the entirety of the fishery. At the height of the targeted fishery in 1964, the estimated value of landings was $7,873,949 USD (in $2005).

Despite the biological characteristics that make elasmobranchs prone to population declines from overfishing, studies have shown that elasmobranch fisheries can be sustainable if exploitation is slow, the species is relatively fecund, and is capable of withstanding density-dependent change (Holden 1973). In fact, shark fisheries may have advantages over teleost fisheries as they generally have reliable, stable populations and are less likely to vary from year to year (Walker 1998). If the population of porbeagle sharks in the Northwest Atlantic recovers to healthy levels, it is not unreasonable to suggest that the targeted fishery could reopen. Provided that the fishery was small-scale and closely monitored, it could be sustainable and provide income to fishers in Atlantic Canada while still maintaining a healthy shark population and healthy ecosystems.

5.3.2 Non-Extractive Uses

Sharks such as porbeagles provide both ecosystem goods, in the form of food, as well as services to humans. It is much more difficult to study, describe, and quantify the ecosystem services that sharks provide, and even more difficult to place a value upon the service. Ecological economists struggle with the concept of placing value upon ecosystem services, but it is important to consider the intangible benefits that species can provide, particularly when considering the rationale behind the porbeagle not getting listed by SARA. The economic analysis claimed that protecting the species would cause too great an economic burden, however none of the benefits that healthy live sharks can provide were accounted for in the analysis.

Figure 7 shows an example of an ecosystem service that porbeagles can provide. Porbeagles feed mainly on schooling fish such as mackerel (Campana et al. 2015a). Mackerel feed on copepods, which are small crustaceans that contribute to secondary productivity and serve as a carbon sink. Some estimates say that copepods may absorb up to 2 billion tonnes of carbon per year, which is equivalent to a third of human emissions. Although figure A depicts a very simplified food web that in reality is far more complex, it demonstrates how larger numbers of predators regulate the trophic levels beneath them, allowing planktonic species to remain stable. As the right side of the figure shows, with decreased predator abundance the mackerel populations grow and consume more copepods, decreasing levels of carbon sequestration.

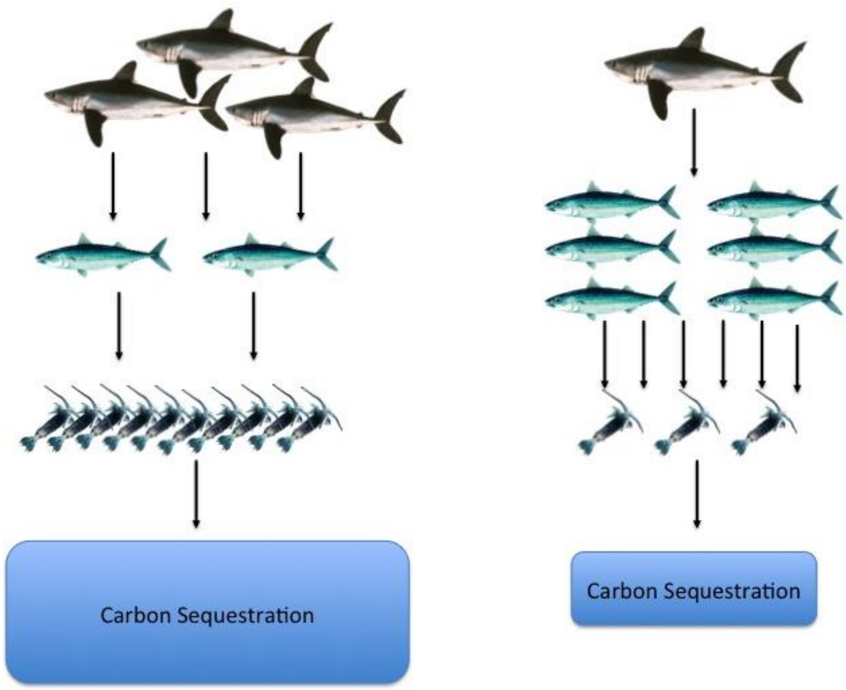

Figure 7: Graphic representation of an ecosystem service provided by porbeagles. Inspiration from Spiers et al. 2016.

Given that the targeted porbeagle fishery in Canada has been closed since 2013, and should remain closed until the population has sufficiently recovered, it is unlikely that there will be any *direct* economic benefits from establishing MPAs to conserve porbeagle sharks, at least for the foreseeable future. Instead, it is important to begin accounting for the ecosystem services that are provided by healthy ecosystems regulated by apex predators, such as carbon sequestration.

Another economic benefit that sharks can provide outside of consumptive activities lies in the potential value of tourism. Shark sanctuaries, areas where there are restrictions on hunting sharks, are beginning to be established around the world (i.e. the Bahamas, the Maldives, Palau). These sanctuaries are being established in areas where commercial shark fishing was previously a significant source of income in the country (Lack and Sant 2011). Many of these former shark-fishing nations have implemented bans and restrictions on commercial shark fisheries because they have begun to see the value in live sharks and the tourism income they can garner. Shark tourism can sometimes involve consumptive activities, like sport fishing, however the majority of activities are non-consumptive, such as catch-and-release recreational fishing, snorkelling, scuba diving, and vessel-based observing (Ward-Paige 2014). Over 250 species of sharks are "always" or "very likely" to be sighted during shark tourism in over 40 countries (including Canada) that participate in the industry (Huveneers and Robbins 2014). The value of a live shark in the tourism trade varies by species and by the country where tourism is taking place (Ward-Paige 2014), however the global shark, ray, and chimaera tourism industry is unquestionably a lucrative business. Some claim that the value of live sharks in the tourism trade could be up to half the value of landed sharks (Cisneros-Montemayor et al. 2013; Huveneers and Robbins 2014). For example, in 1992 shark tourism in the Maldives (mainly whale shark excursions) earned $2.3 million USD, while shark products were only valued at $700 000 USD (Timms & Williams 2009). It is important to note, however, that economic analyses often underestimate the consumptive value of sharks, and that the best approach to shark management is a precautionary one that promotes both tourism and sustainable fisheries (Brunnschweiler and Ward-Paige 2014).

While the majority of established shark tourism outlets operate in tropical destinations, the industry in more temperate areas is growing, and there are outlets currently operating in New Zealand, Portugal, the United Kingdom, and Canada (Huveneers and Robbins 2014). Since there is currently no targeted fishery for any species of shark in Canada, a stronger tourism industry could provide a source of income for coastal communities, and perhaps even provide a sufficient economic rationale for SARA to list the porbeagle. Protected areas could potentially help shark populations recover to a point where the species is sufficiently abundant to support a tourism industry in Nova Scotia.

5.4 Other Effective Measures for Protection

When discussing different measures that are used for shark conservation it is important to discuss shark sanctuaries, which are becoming a common tool around the world. As previously discussed, the rationale for establishing a sanctuary is sometimes attributed to the acknowledgement of the value of live sharks in the tourism industry (Lack and Sant 2011). Although the term sanctuary is sometimes interchanged with MPA, there is an important distinction between the two. Sanctuaries, sometimes called commercial fishing bans (Davidson et al. 2015), are areas where there is a fishing ban on certain shark species within a nation's waters. Shark sanctuaries may have designated boundaries, or in the case of countries like Palau or the Cook Islands, the fishing ban is applied throughout the countries' entire EEZ (Hoyt 2014). Shark sanctuaries are different from MPAs as they are generally much larger and lack the localized management and stakeholder support that is usually associated with an MPA. Blanket bans over an extensive area such as a nations' entire EEZ are difficult to monitor, and there are sometimes cases of illegal and unreported fishing within these areas (this may mean that MPAs are generally easier to enforce, have improved compliance, and provide more long-term educational and conservation benefits than a sanctuary (Hoyt 2014). The most effective management for shark conservation would be blanket protection like what is found in a sanctuary along with more localized management through the form of MPAs in areas of high use or critical habitat. This structure is, in fact, feasible for Canada. While an official shark sanctuary has not been declared, there are no targeted shark fisheries operating in Atlantic Canadian waters. Because the species has not shown significant signs of recovery despite a de facto sanctuary being in place, there is clearly a need for further regulatory measures. If MPAs are designated in the areas that have been outlined as important for porbeagles, with strong regulations for shark conservation, the species will have much better chances for recovery.

5.5 Static protection in a changing climate

Many of the areas that have been identified as important for porbeagles contain physical features that are creating a hospitable environment for phytoplankton and zooplankton, which causes an abundance of marine life that could serve as prey for porbeagle sharks. Some of these features, such as submarine canyons or plateaus, are static in nature and not expected to change even in the face of a changing climate. Others, such as upwelling or oceanic gyres, are static today but could shift with changing oceanic circulation that is predicted in the future. When establishing a network of MPAs it is important to designate areas that will be the most effective not only today, but also in the future.

A previous section in the introduction provided some specific examples of how the distribution of porbeagles could change in the context of a changing oceanic environment. Animal distributions are dictated by factors that are static in nature, such as topographic features, as well as factors that are variable, such as temperature and salinity (Schofield et al. 2013). When critical habitat is concentrated around a static topographic feature, it is easier to implement spatial protection. Although there have been several areas identified that are important for porbeagle life history stages, some of these areas lack physical characteristics anchoring the sharks to that site.

While it could be argued that the possible shift in species distributions is a reason to delay implementing protection until further information is known about future conditions, it is also important to recognize the increased pressure that a changing climate will put upon shark species. It is important to make management decisions that will be most effective not only today but also in the future. If managers wait to make decisions because of future uncertainties they risk causing more harm to a species by withholding protective measures. Mortality rates for fish are higher in habitats at the edge of their thermal tolerance, which will be detrimental for temperature-dependent species like the porbeagle. As oceans warm and porbeagle distributions shift, they also risk increased interactions with humans, loss of critical habitat, and major changes in ecosystem community structure (Cheung et al. 2015). All of these indicators suggest that porbeagles will be under more stress in the future and will be at a higher risk of mortality.

Therefore, despite uncertainties toward future distributions, a precautionary approach should be applied in the establishment of a porbeagle recovery plan. It is critical that conservation measures be implemented now to allow this population time to recover and become more resilient before more pressures are placed upon their survival.

Chapter 6: Recommendations and Conclusion

A network of marine protected areas for the conservation of porbeagle sharks in Atlantic Canada could be an effective tool if implemented in advantageous areas, and if management of the protected areas was sufficient to provide a safe haven for the species to recover. Some areas that appear to hold particular significance in the life-history of the porbeagle in the Northwest Atlantic include the Sargasso Sea, the Grand Banks and the Gulf of Saint Lawrence, Georges Bank, the Scotian Slope, Emerald Basin, and Roseway Basin. In order for a network throughout some, or all, of these sites to be established, there is more research that needs to be done. Population, distribution, biology, and life history of porbeagles in the Northwest Atlantic should be further studied so that information on Atlantic Canadian sharks can be included in MPA network planning.

One of the most critical research gaps is the lack of fisheries-independent data. The information available currently is largely connected to commercial fisheries, which is biased and may not accurately represent porbeagle distribution. An independent survey to record abundance and distribution is necessary to ensure that all areas important to porbeagles are being included in the network. While this project is a first step towards including porbeagle sharks into Canada's network of MPAs, it will be critical to obtain these data to conduct a more complete distribution and abundance analysis to ensure that protected areas are being established in the areas that will be most beneficial for the species.

There should also be additional studies conducted on the effectiveness of the additional shark management tools discussed in this paper and how they can contribute to the conservation of porbeagles. Emerging fisheries technology that may reduce incidental catch rates should be explored and discussed with managers as possibilities for providing additional protection. An assessment of if and how porbeagle conservation could explicitly contribute to social and economic benefits in Nova Scotia is still needed, as it will aid managers and policy makers to justify establishing protective measures.

Another area of research that would be beneficial for progressing towards a network of MPAs for porbeagle sharks would be studies on what life history stages are the most vulnerable, and would most benefit from protection. It is unlikely that the Government of Canada will have the capacity to establish MPAs in all six of the proposed sites of interest for porbeagle sharks, therefore managers will need to prioritize which areas will have the greatest impact on the recovery of the species. This could be done by studying the different life stages found in the areas of interest, such as gravid females or neonates, and attempting to determine which individuals would benefit the most from spatial protection.

Finally, it is important to begin researching ways in which porbeagles and their distribution may be affected by the changing climate. These sharks are going to be vulnerable in warming waters, so if research can be done before their distribution begins to change and management measures can be put in place to reduce mortality they will have a much greater chance of survival.

Conclusion

Marine protected areas have been proven to be effective in allowing marine ecosystems and the species that live within them to recover from the impacts of anthropogenic activities. While the study of MPAs in the past has been focused on species with fidelity to the site of the MPA, such as fish with small ranges or benthic species, researchers have begun to evaluate the effectiveness of using spatial protection such as MPAs for the protection of highly mobile species.

An analysis of the endangered population of porbeagle sharks in the Northwest Atlantic Ocean showed that traditional fisheries management tools have been ineffective at conserving the population. A spatial analysis of their distribution, as well as a scientific literature review, found that these sharks might benefit from protection from anthropogenic pressure on Georges Bank, the Grand Banks and the mouth of the Gulf of St. Lawrence, the Sargasso Sea, the Scotian Shelf, Emerald basin, and Roseway basin. These sites were identified as either areas of importance for vulnerable life stages, or areas of high abundance.

While each site would be beneficial to the sharks if protected, they also all have barriers that would need to be overcome before being protected, such as socio-economic importance to Canadians or jurisdictional complexities.

While the areas in the proposed MPA network for porbeagle sharks may have negative socio-economic impacts to fishers, there are potential positive impacts that could arise, including the regulation of marine ecosystems that provide important services to humans such as carbon sequestration. There is also the potential to reopen the targeted fishery, or to establish non-extractive industries like shark tourism if the population recovers to healthy numbers.

Several additional shark management tools were also discussed, including fisheries regulations, outreach and education, gear restrictions, and even new technologies such as electromagnetics that function as shark deterrents. The most effective management plan for assisting in the recovery of porbeagle sharks will incorporate both spatial protection through MPAs in areas of critical habitat as well as additional tools specific to shark conservation in order to decrease mortality and protect the species throughout its entire range.

Sharks are animals that have long been considered dangerous, nuisance species that pose a threat to humans, valuable fish stocks, and even fishing gear. It is only in recent times that the value of sharks to global marine ecosystems has been revealed. Unfortunately, for the majority of shark species, this revelation comes after the population has already collapsed. The global community has a responsibility to reverse decades of overexploitation and implement policies and regulations to help these valuable species recover. Marine protected areas are one option for enabling recovery, and given the current political push to establish MPAs in Canada, every effort should be made to ensure that those selected and implemented are in areas that will be beneficial for sharks and provide them the protection that they both need and deserve.

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Appendix I

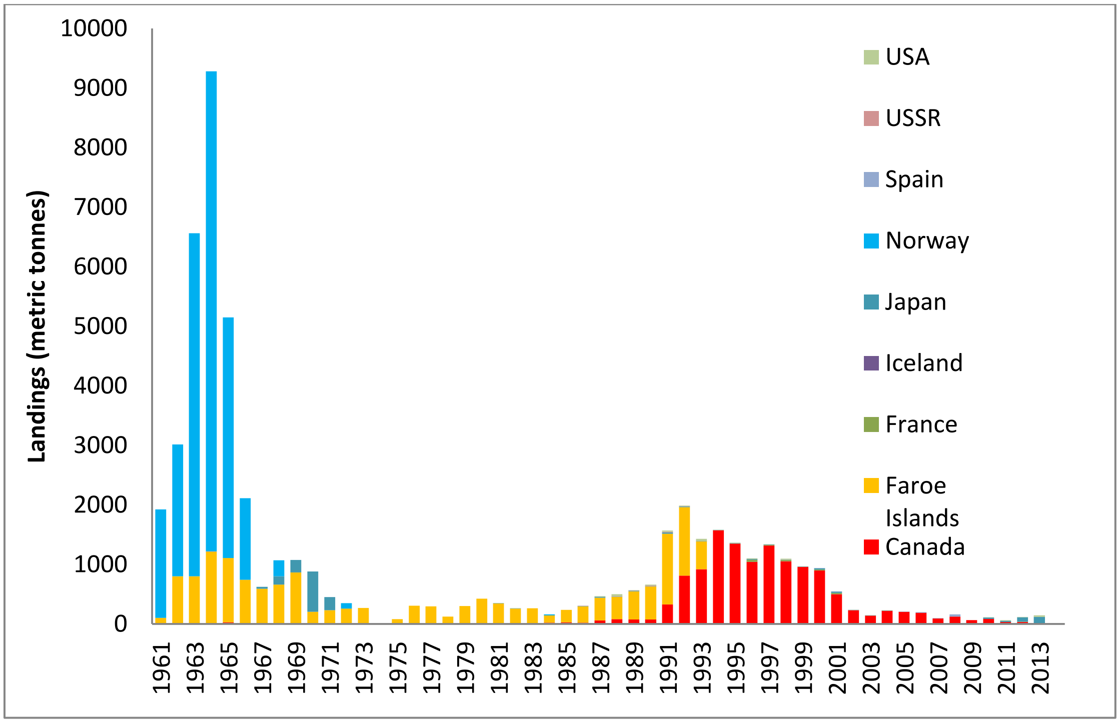

Figure 8: Porbeagle landings by country over time (Campana et al. 2015a).

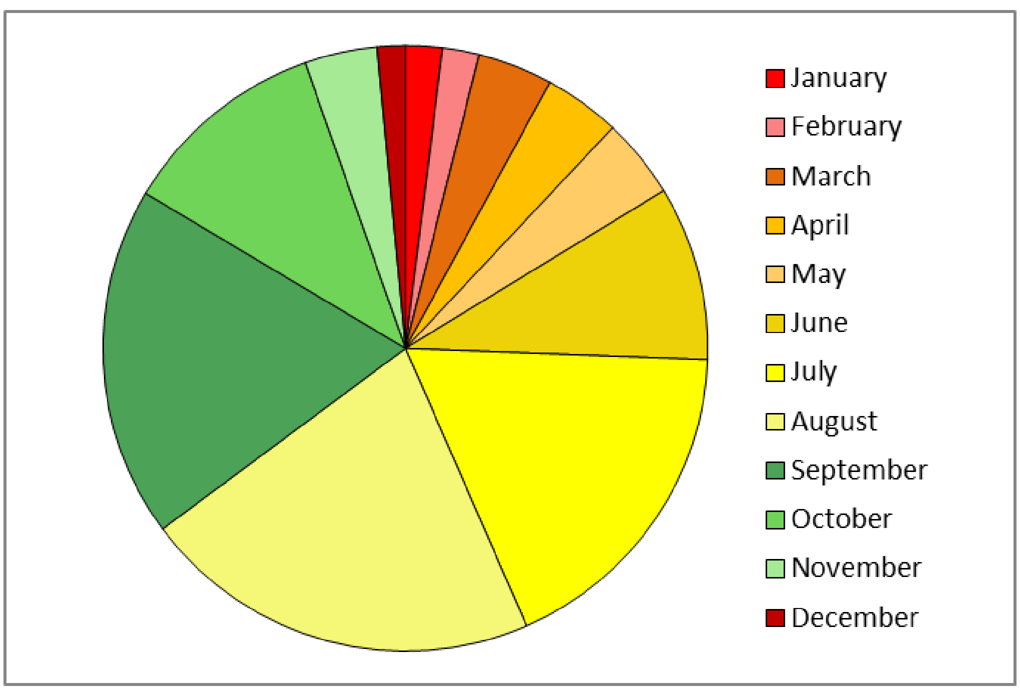

Figure 9: Total number of porbeagle individuals landed per month (2008-2014) in the Maritimes Region.

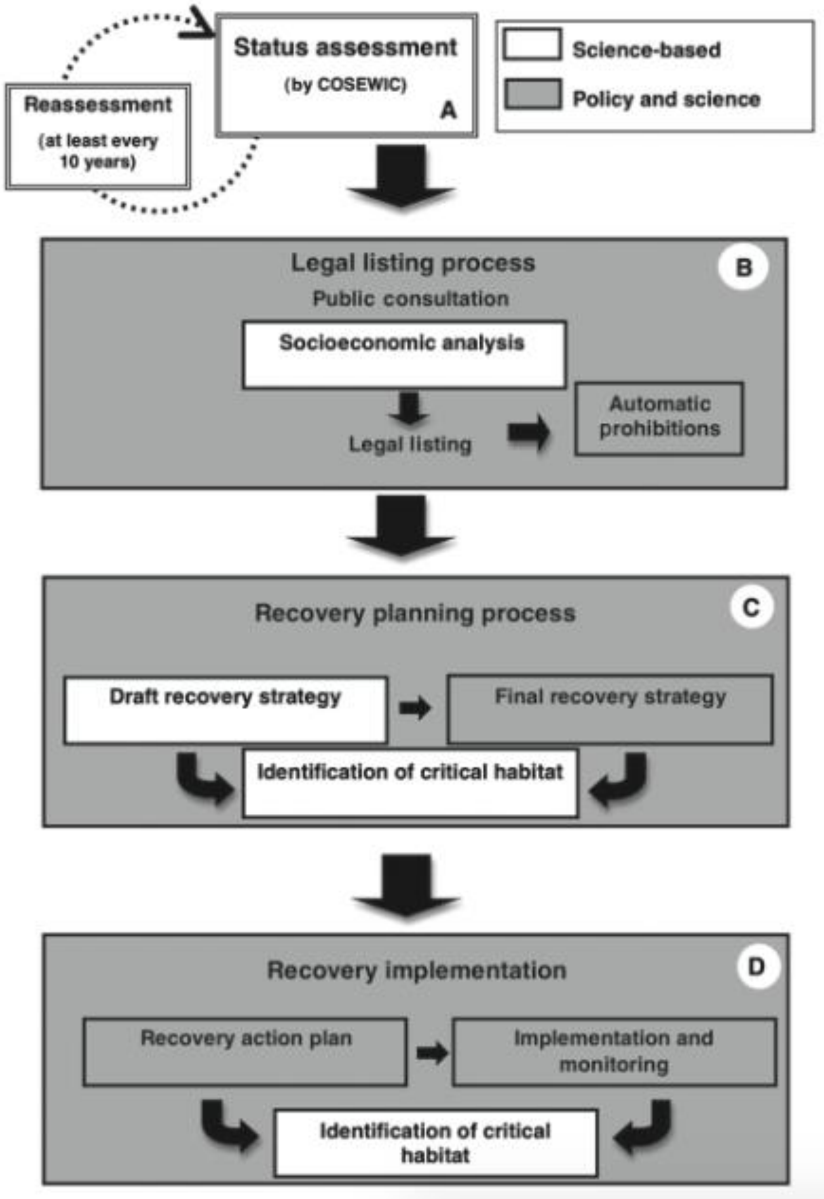

Figure 10: Schematic of the Canadian Species at Risk Act listing process. Source: Mooers et al. 2010